Muon B Flavor Tagging
A Likelihood Approach

Text for the blessed web page – CDF note 7043

The CDF Collaboration

July 29, 2004

Abstract

We describe a muon identification algorithm to be used for opposite side B flavor tagging. Track-stub matching quantities and calorimeter information are combined in a likelihood function which estimates the probability that a muon object is a real muon. The tagger performance is studied on lepton+SVT data. Using the dependence of the tagging dilution on the muon system, the likelihood function and p_T^{rel}, we obtain a combined $\epsilon D^2 = (0.698 \pm 0.042(stat.)^{+0.051}_{-0.027}(syst.))\%$.

1 Description

B flavor tagging refers to the task of determining the b or $\bar{b}$ quark content (particle-antiparticle character) of a B hadron at production. In this analysis we study opposite side muon tagging. This method looks for a muon from the semileptonic decay of the other B hadron in the event. The charge of this muon is correlated with the flavor of the B hadron: an ℓ^- comes from a $b \to c\,\ell^-\bar{\nu}X$ transition, while an ℓ^+ originates from a $\bar{b}$ quark.

The figure of merit used to compare the "tagging power" of different flavor tags is the so-called effective tagging efficiency $\varepsilon\mathcal{D}^2$, where ε is the efficiency of how often a flavor tag is applicable. The dilution $\mathcal{D}$ is defined as the number of correctly tagged events N_R minus the number of incorrectly identified events N_W divided by the sum:

$$\mathcal{D} = \frac{N_R - N_W}{N_R + N_W}. \tag{1}$$

Flavor tagging will be a key element for many B Physics analyses in Run II such as measurements of CP asymmetries and B^0 or B_s^0 oscillations.

High statistics samples of semileptonic B decays collected with the lepton-SVT trigger have been used to study opposite side muon tagging. The charge of the trigger lepton in the lepton-SVT sample provides an estimate of the B flavor on the trigger side at decay. However, the lepton-SVT data is not a pure sample of B decays. In addition to events from semileptonic B decays, it also contains semileptonic charm decays, hadrons that fake the trigger lepton and other backgrounds. A background subtraction procedure has been established in CDF note 6480 to determine the B purity of the sample. This procedure allows to study the performance that an opposite side flavor tag would achieve in a pure b sample and quantify the tagging performance in terms of dilution $\mathcal{D}$ and $\varepsilon\mathcal{D}^2$.

In this analysis we combine information from muon matching quantities and calorimeter energies into a global likelihood. This aims to identify muons without loss in efficiency from the application of cuts and attempts for a better separation between real muons and fakes. We use the track-stub matching quantities, ΔX, $\Delta\Phi$ and ΔZ along with energy depositions in the electromagnetic and hadronic calorimeters, EM and HAD, to discriminate real muons from fakes.

To study the distributions of discriminating variables for real muons, we use muons from $J/\psi \to \mu\mu$ decays. We select pions from $K_S^0 \to \pi^+\pi^-$, kaons from $D^0 \to K^-\pi^+$ and protons from $\Lambda \to p\,\pi^-$ to study the behavior of fake muons. With these samples of fake and real muons, we parametrize the distributions of discriminating variables for both muons and fakes. We treat the fitting functions as probability distribution functions (PDF). We obtain five "signal" PDF's: S_x, S_ϕ, S_z, S_{em} and S_{had} as well as five corresponding "background" PDF's: B_x, B_ϕ, B_z, B_{em} and B_{had}. The likelihood that a muon object is a real muon can be written as

$$S = S_x \cdot S_\phi \cdot S_z \cdot S_{em} \cdot S_{had} \tag{2}$$

and the likelihood that the muon object is a fake is

$$B = B_x \cdot B_\phi \cdot B_z \cdot B_{em} \cdot B_{had}. \tag{3}$$

The final likelihood estimator is constructed as:

$$\mathcal{L} = \frac{S}{S+B}. \tag{4}$$

We expect that muon objects with values of $\mathcal{L}$ close to unity are real muons while likelihood values close to zero indicate most probably fake muons.

2 Blessed Numbers

This section summarizes the numbers that have been blessed for this analysis. More information can be found in CDF note 7043.

The total tagging power, averaged over electron+SVT and muon+SVT datasets:

$$\epsilon D^2 = (0.698 \pm 0.042(stat.)^{+0.051}_{-0.027}(syst.))\%$$

The dilution as function of p_T^{rel} is parameterized in different likelihood ranges and for each muon type. The functional form of the parameterization is:

$$D(p_T^{rel}) = P_0 \cdot (1 - e^{-p_T^{rel} + P_1}). \tag{5}$$

Table 1 gives the fit parameters P_0 and P_1. It also gives the dilution for isolated muons in different likelihood bins.

		$0 \leq \mathcal{L} < 0.8$	$0.8 \leq \mathcal{L} < 0.95$	$0.95 \leq \mathcal{L} \leq 1.0$
CMU	P_0	0.05 ± 0.03	0.30 ± 0.08	0.40 ± 0.06
	P_1	0.02 ± 0.86	0.29 ± 0.19	0.07 ± 0.15
	$D^{iso}[\%]$	4.2 ± 9.0	43.6 ± 8.7	45.0 ± 5.0
CMP	P_0	0.30 ± 0.08	0.42 ± 0.08	0.47 ± 0.12
	P_1	0.03 ± 0.32	-0.10 ± 0.38	0.03 ± 0.61
	$D^{iso}[\%]$	-1.2 ± 12.6	17.0 ± 15.7	33.3 ± 54.4
CMUP	P_0	0.31 ± 0.07	0.41 ± 0.08	0.47 ± 0.04
	P_1	0.01 ± 0.35	-0.24 ± 0.52	0.06 ± 0.17
	$D^{iso}[\%]$	16.3 ± 17.6	44.4 ± 19.9	18.2 ± 8.8
CMX	P_0	0.14 ± 0.07	0.46 ± 0.08	0.43 ± 0.05
	P_1	-1.52 ± 4.46	0.22 ± 0.20	-0.16 ± 0.29
	$D^{iso}[\%]$	40.7 ± 14.1	48.9 ± 10.2	16.9 ± 10.2
BMU	P_0	0.06 ± 0.02	0.55 ± 0.09	0.37 ± 0.05
	P_1	$-29.0 \pm 3.3e+6$	0.34 ± 0.12	-0.76 ± 0.59
	$D^{iso}[\%]$	6.1 ± 4.7	39.4 ± 11.7	30.7 ± 7.3

Table 1: Fit parameters P_0 and P_1 describing the dilution as function of p_T^{rel} in different likelihood bins for each muon type. The dilution of isolated muons D^{iso} is also shown.

3 Blessed Figures

The following figures have been blessed for the likelihood muon tagger. More information can be found in CDF note 7043.

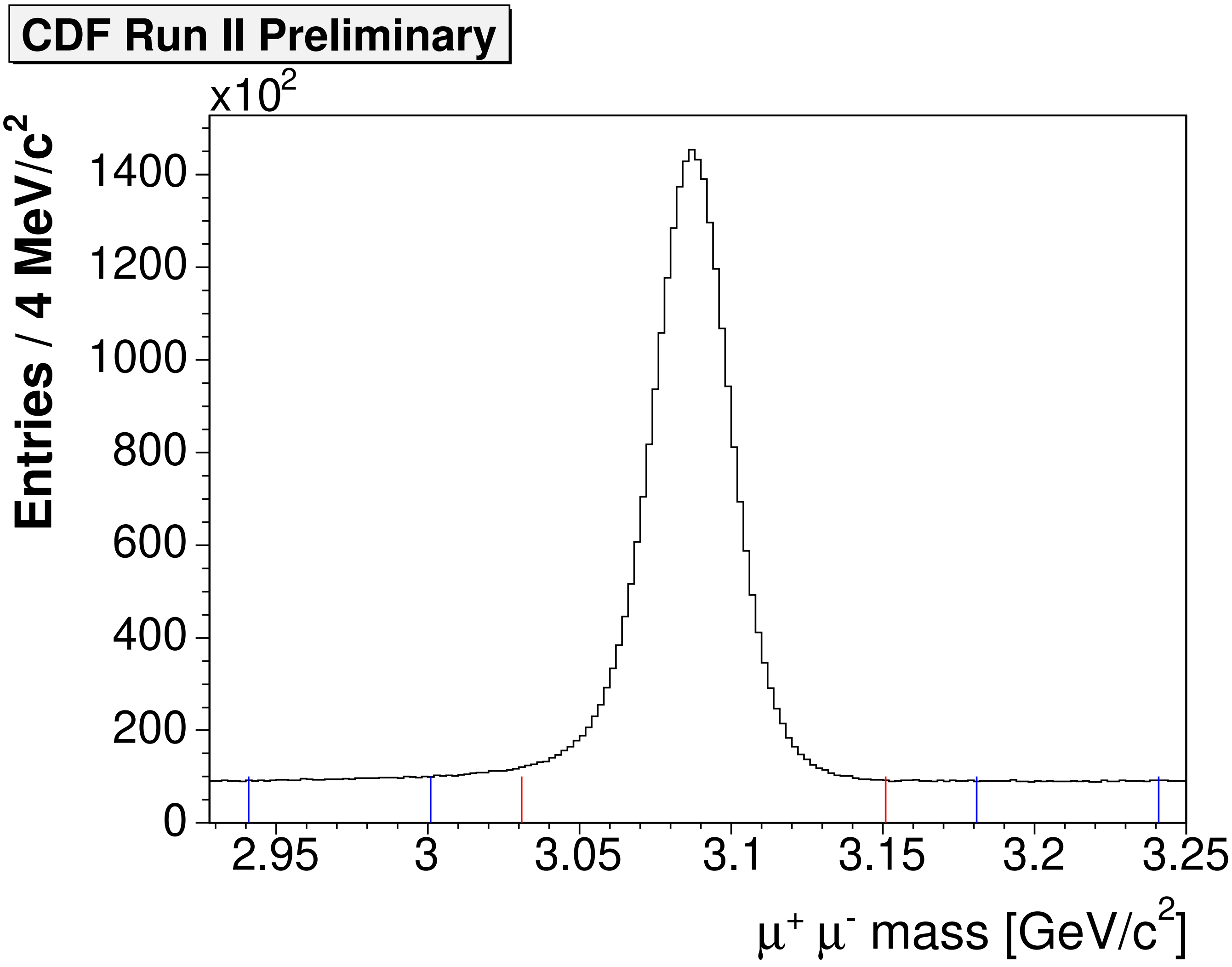

Figure 1: $J/\psi \rightarrow \mu^+\mu^-$ events used to obtain the templates for real muons. The chosen signal and sideband regions are also displayed.

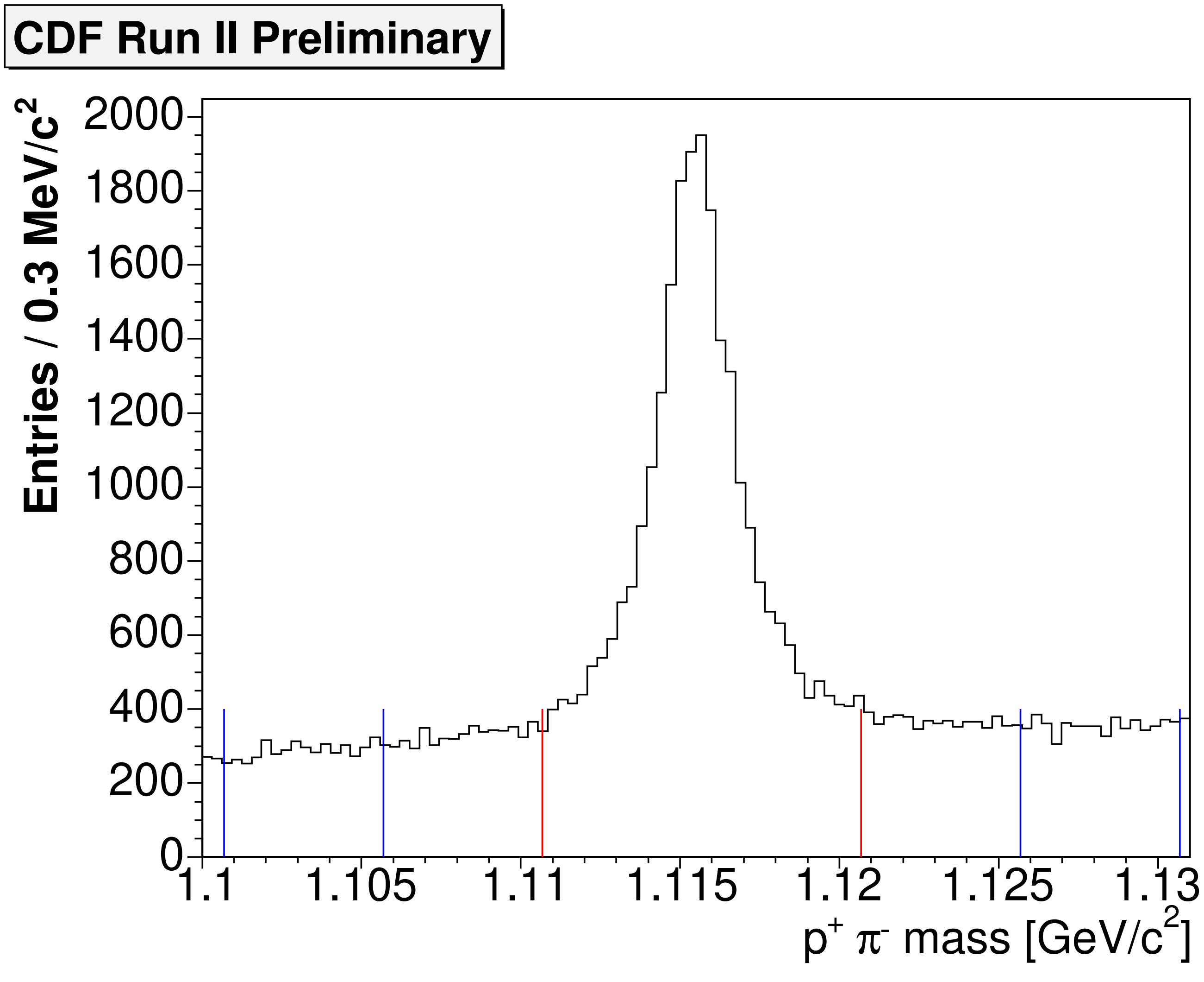

Figure 2: $\Lambda \to p^+\pi^-$ events used to obtain the templates for fake muons. The chosen signal and sideband regions are also displayed.

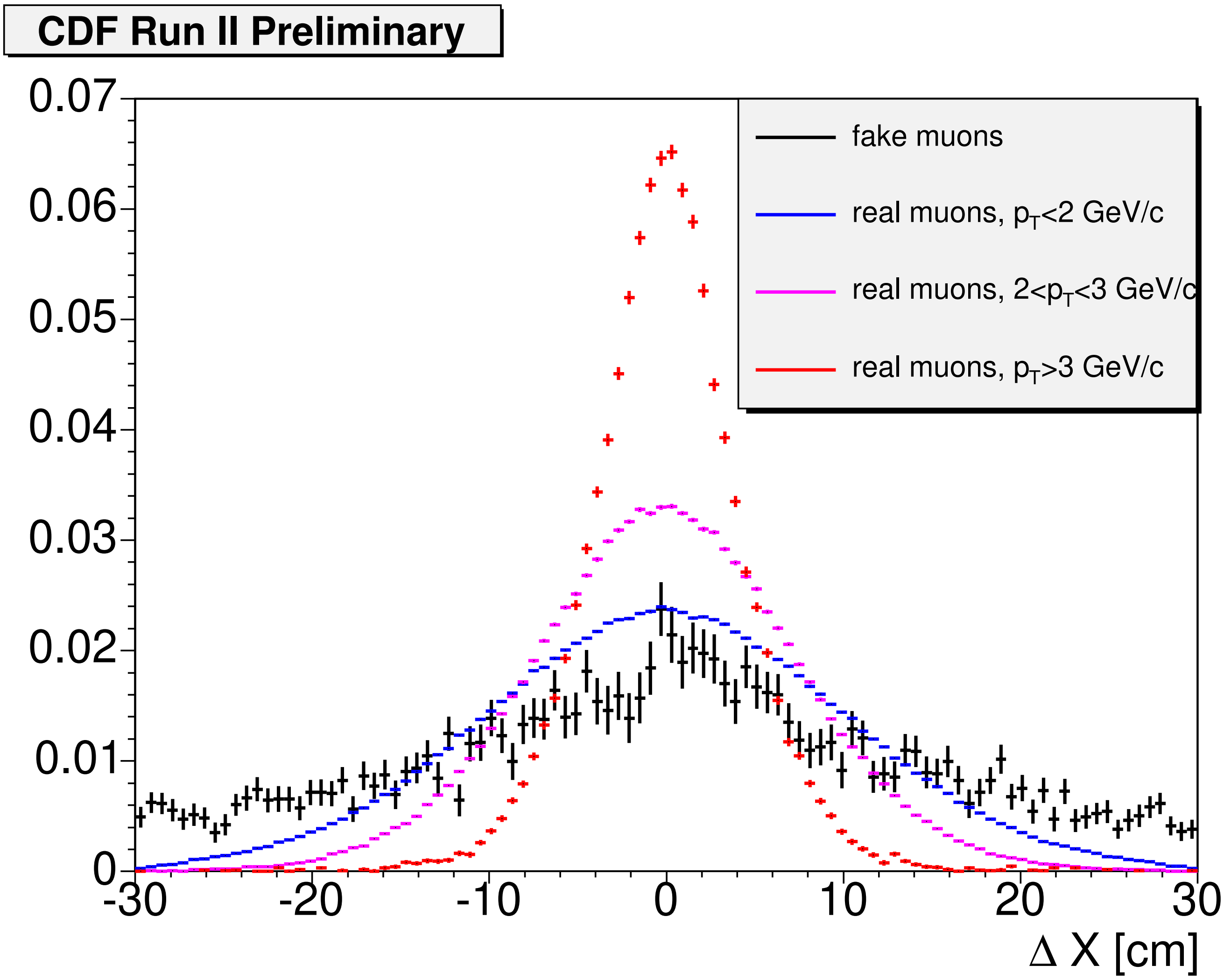

Figure 3: Transverse distance ΔX between the extrapolated track and muon stub for real muons and fakes.

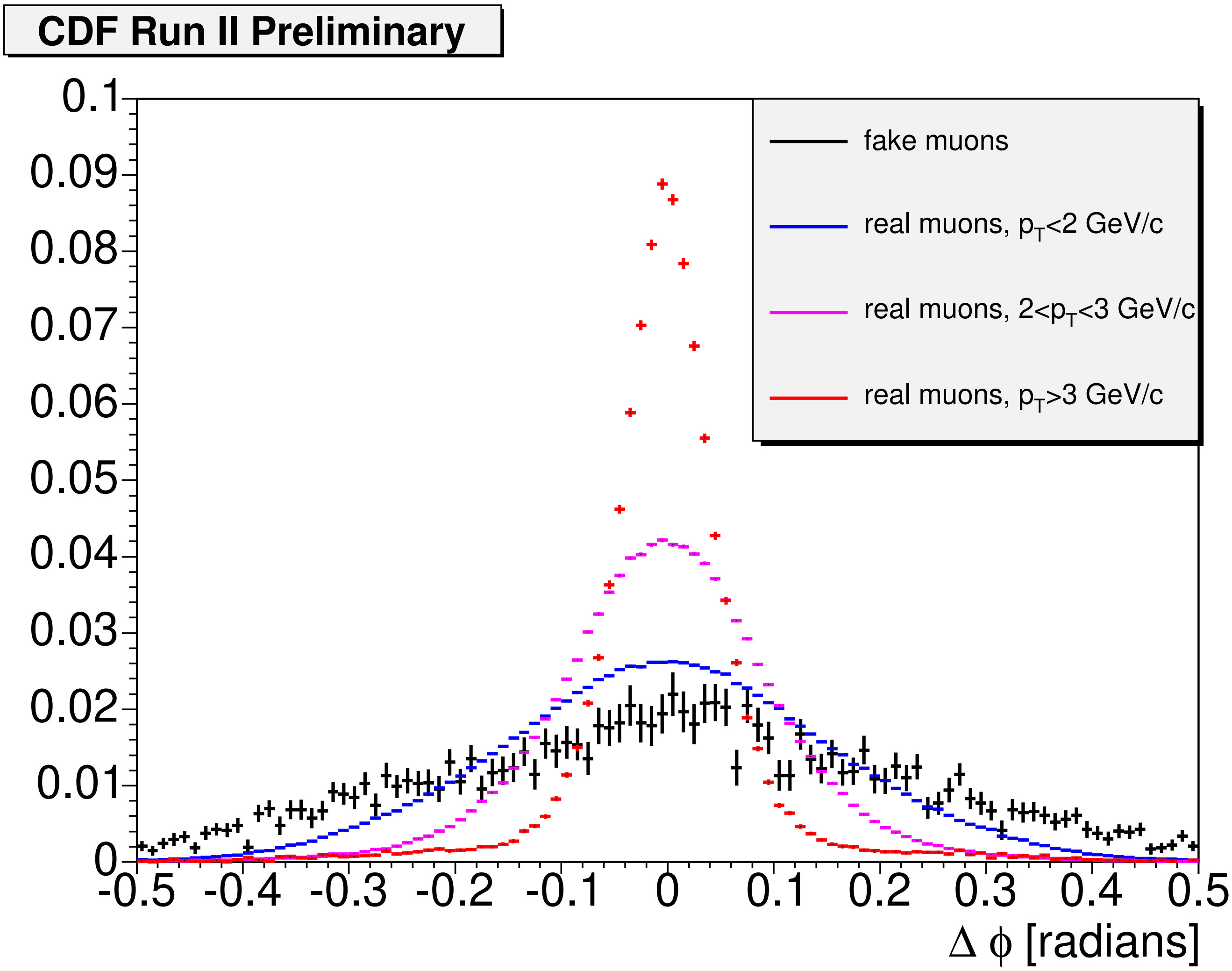

Figure 4: Transverse angle $\Delta\phi$ between the extrapolated track and muon stub for real muons and fakes.

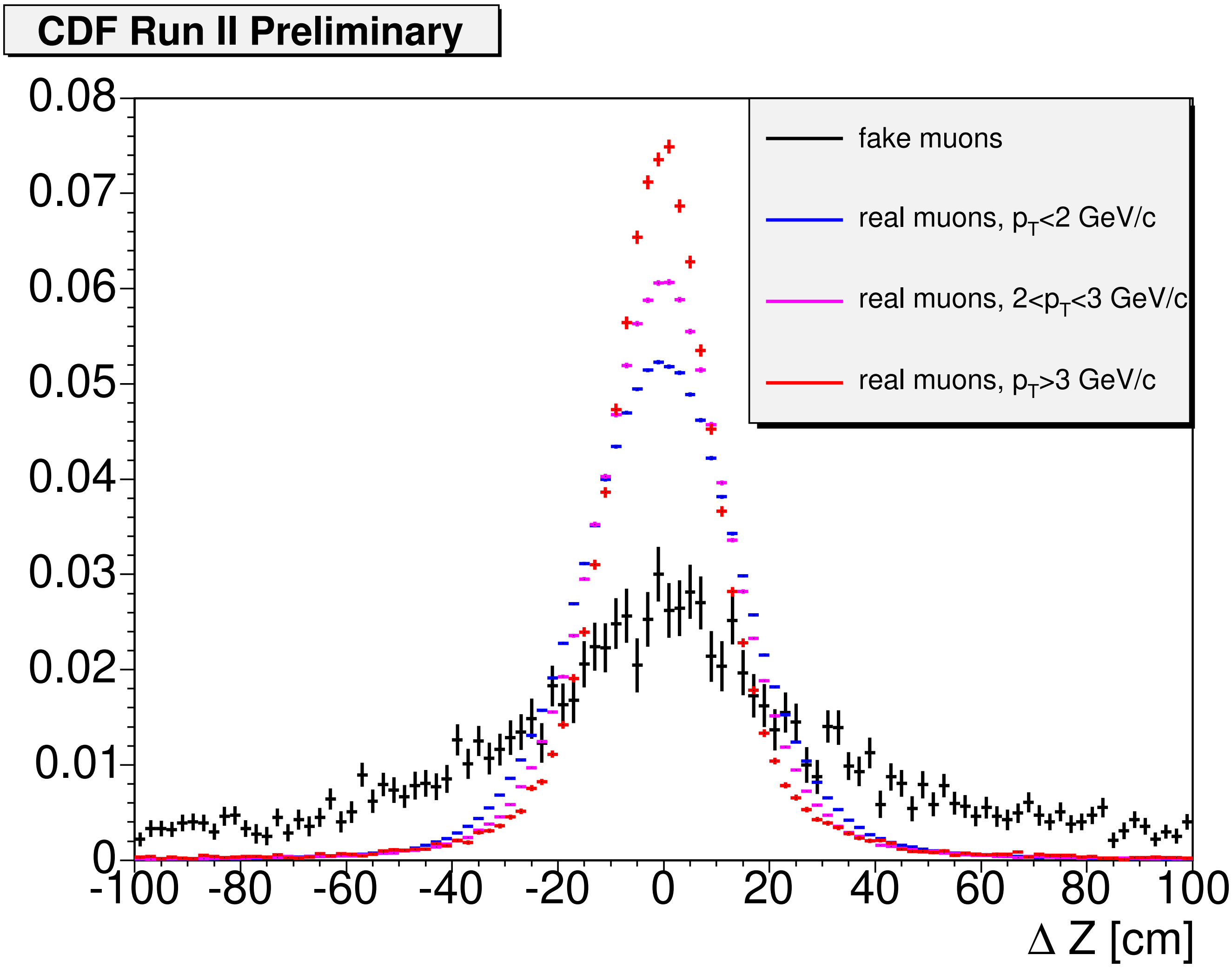

Figure 5: Longitudinal distance ΔZ between the extrapolated track and muon stub for real muons and fakes.

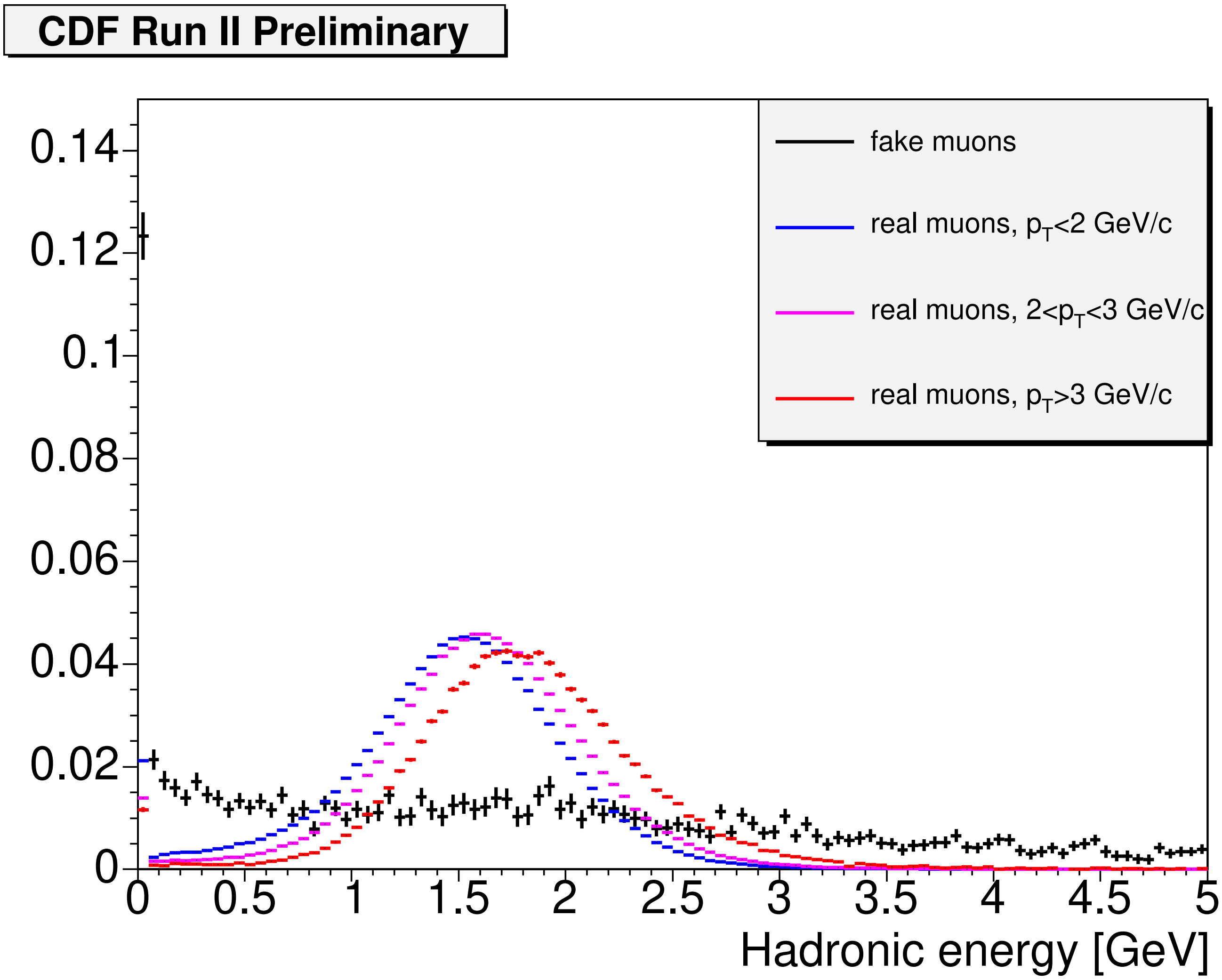

Figure 6: Hadronic energy for real muons and fakes.

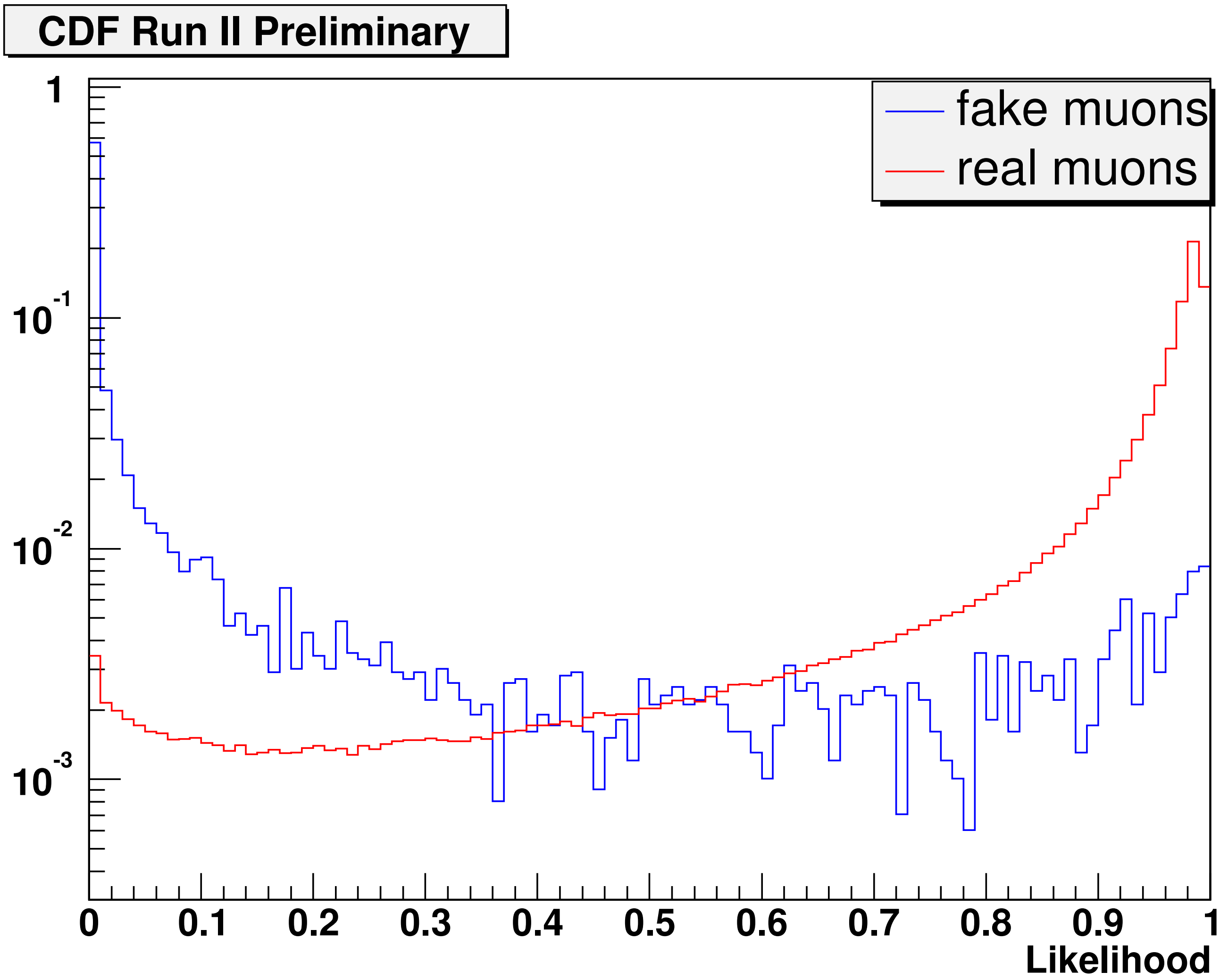

Figure 7: Likelihood distribution for real muons and fakes.

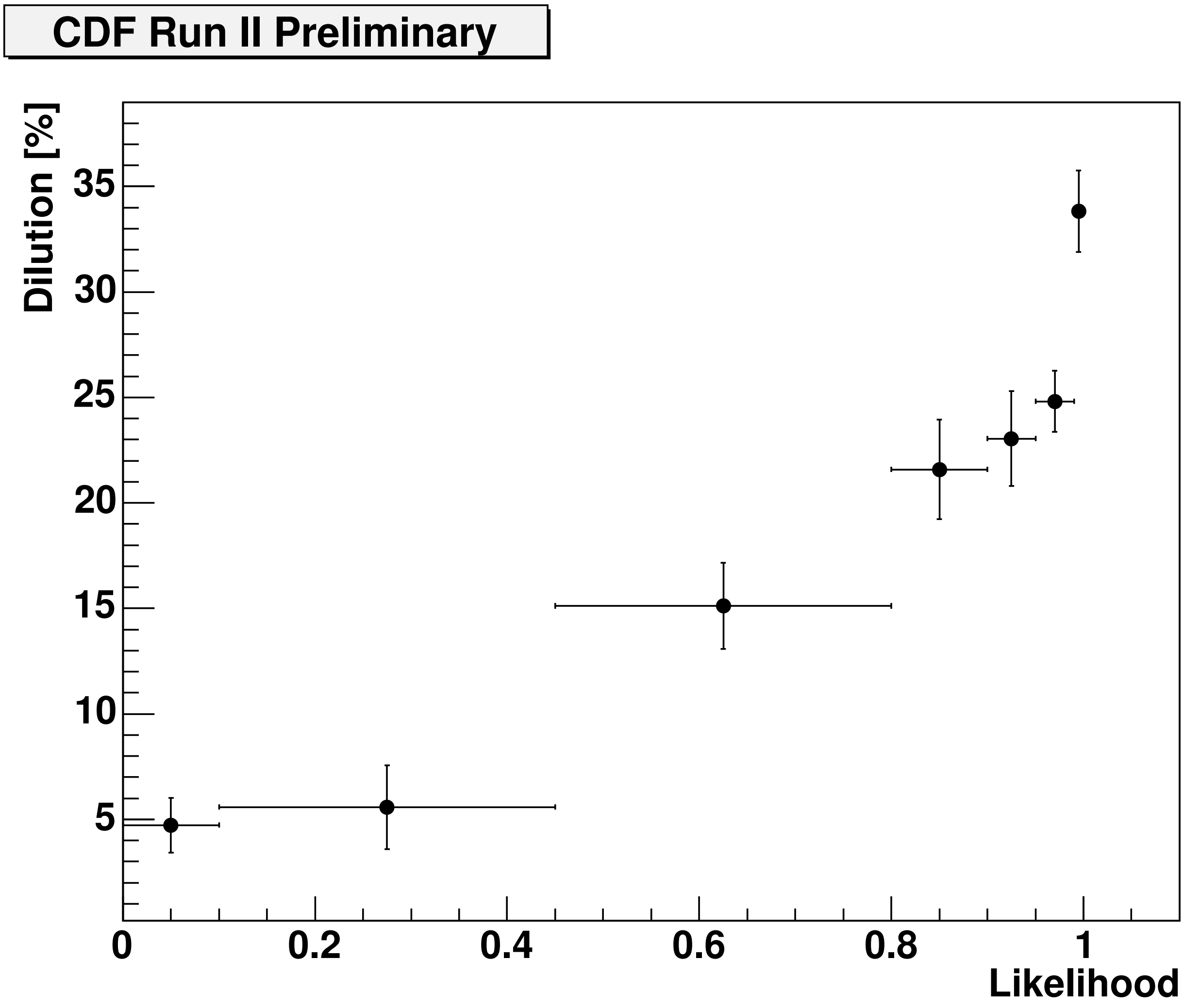

Figure 8: Dilution as function of the muon likelihood.

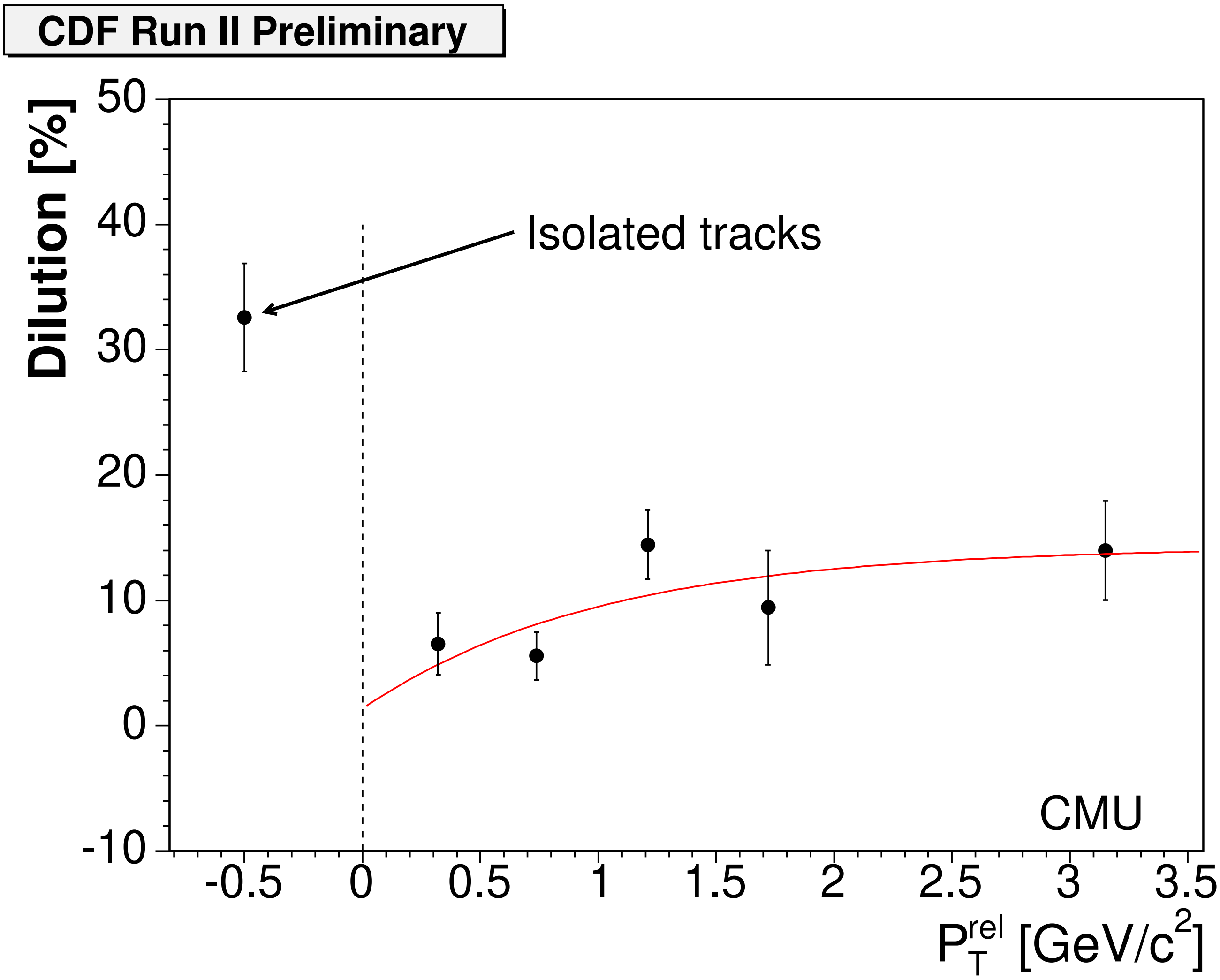

Figure 9: CMU dilution versus p_T^{rel}.

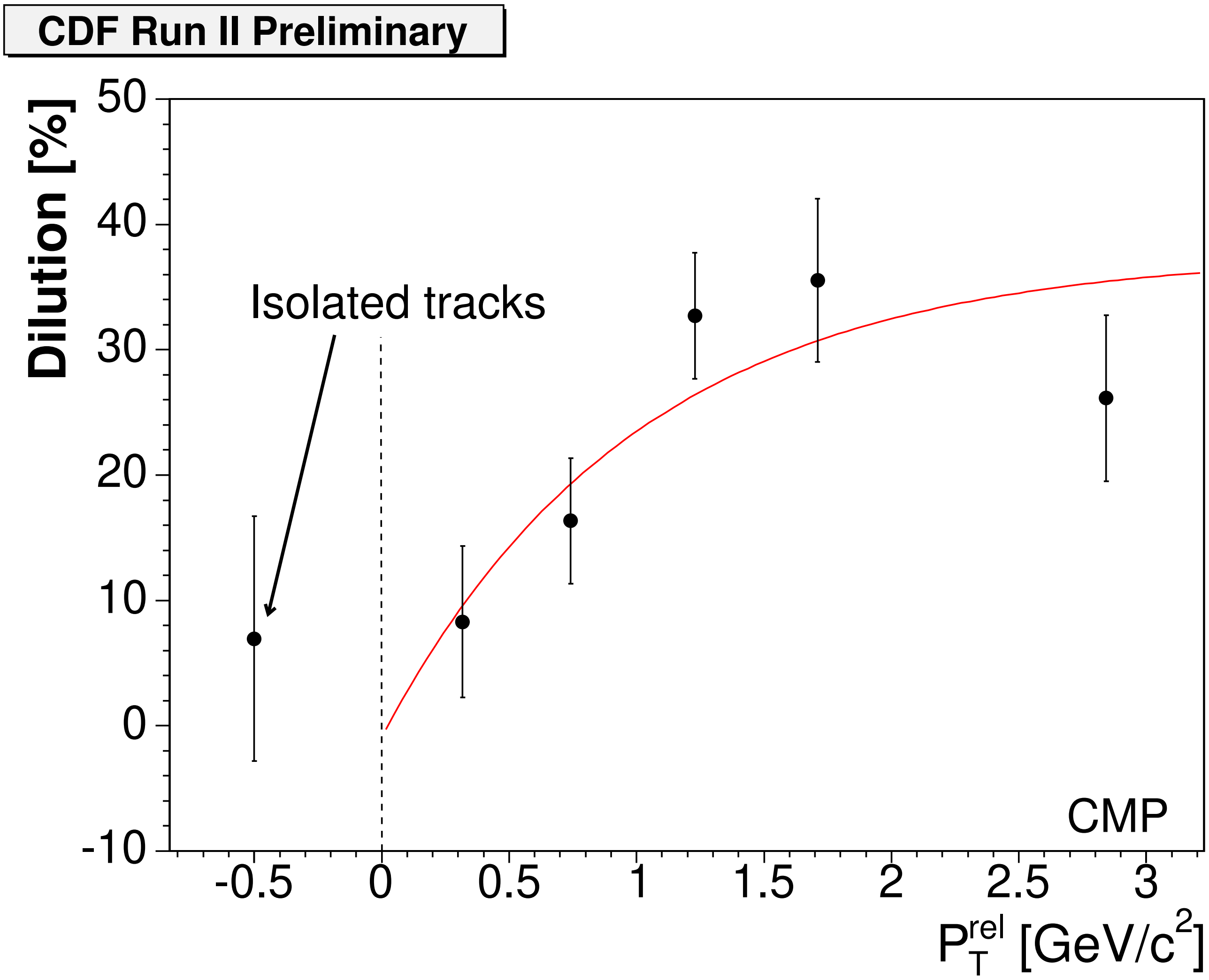

Figure 10: CMP dilution versus p_T^{rel}.

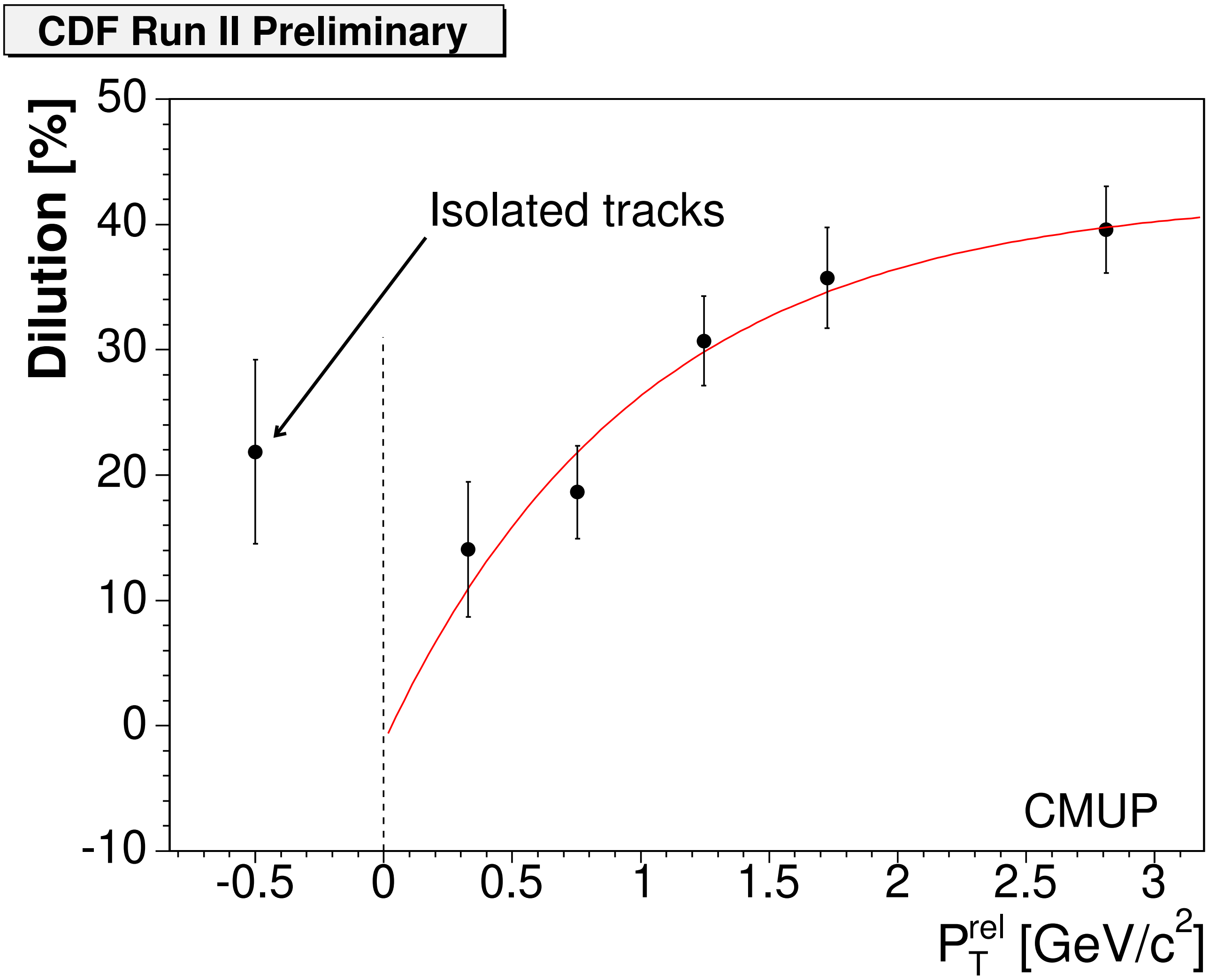

Figure 11: CMUP dilution versus p_T^{rel}.

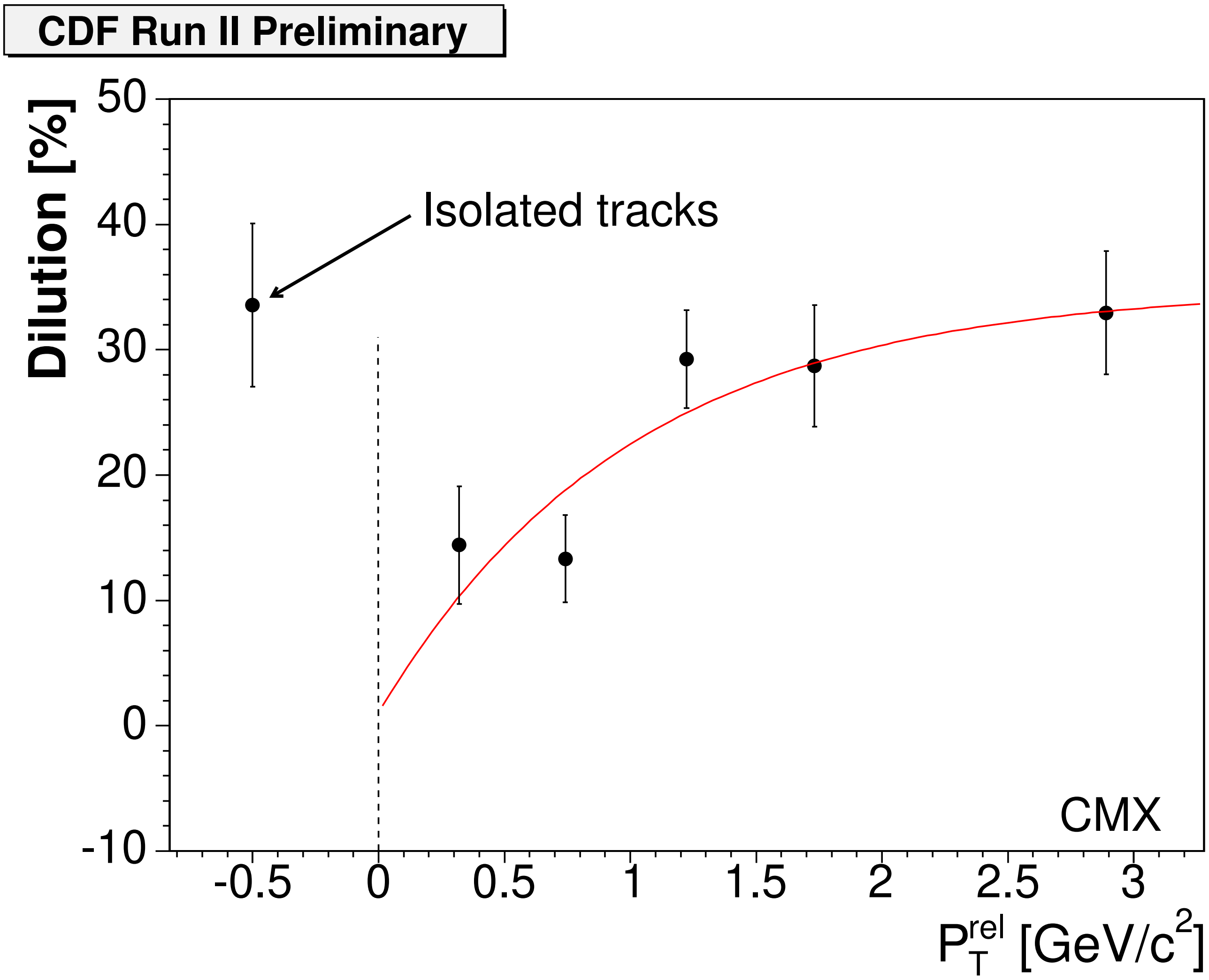

Figure 12: CMX dilution versus p_T^{rel}.

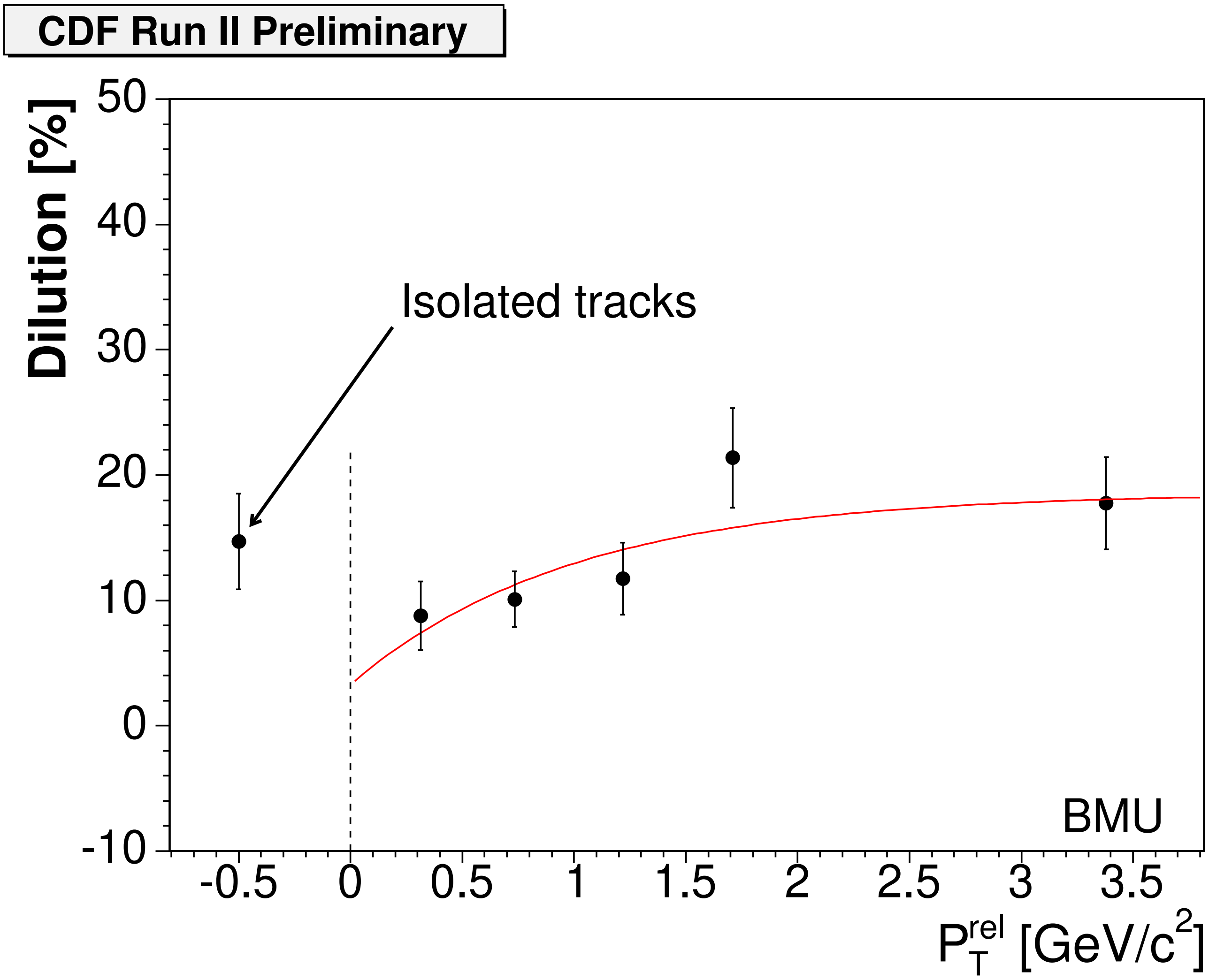

Figure 13: BMU dilution versus p_T^{rel}.