Comments on tracking at high luminosity

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Abstract

We discuss the effects of luminosity on CFT tracking. These include combinatorics, track reconstruction time, VLPC gain, electronics, fake rate, efficiency, and the reconstruction of Ks.

1 Combinatorics *vs* luminosity

The occupancy ϵ_i of the Central Fiber Tracker (CFT) layer i is observed to depend linearly on the instantaneous luminosity L, *i.e.* $\epsilon_i \propto (a_i + b_i L)$.[1] Table 1 shows occupancies extrapolated from measurements up to $74 \cdot 10^{30} \text{cm}^{-2}\text{s}^{-1}$.[1] The number of fake tracks is proportional to $\propto p_{Tmin}^{-1} \cdot \prod_{i=1}^{i=N} \epsilon_i$, where $N \approx 20$ is the number of required hits (16 in the CFT plus 4 in the SMT) and p_{Tmin} is the minimum p_T at which tracking is done.[2] We conclude that at some luminosity $L \approx a_i/b_i$ the number of fake tracks (and the processing time per event) will grow like $\propto L^{20}$ and a "brick wall" will be reached. For the CFT it is observed that $a_i/b_i = 91 \cdot 10^{30}\text{cm}^{-2}\text{s}^{-1}$, independent of i.[1] The luminosity up to which bench mark tracking performance can be achieved was calculated to be $\approx 100 \cdot 10^{30}\text{cm}^{-2}\text{s}^{-1}$.[3]

2 Reconstruction time *vs* luminosity

Figure 1 (provided to us by Michael Diesburg and Suyong Choi) shows the "total execution time of d0reco *vs* the initial luminosity of the run. Each point in this plot is for a single run. The times are averaged over all the files in the run. The execution time plotted is normalized to what would be expected if the job were running on a 1GHz PIII processor." The "non-tracking part takes roughly a constant 3 seconds per event." Note that the d0reco time per event for tracking has increased from 8 seconds at low luminosity to 80

Luminosity	layer 1	layer 8
0	0.12	0.06
80E30	0.22	0.11
100E30	0.25	0.13
200E30	0.38	0.19
300E30	0.50	0.26

Table 1: Occupancies of the Central Fiber Tracker for jet triggers JT_45TT, JT_95TT or JT_125TT, as a function of luminosity [$cm^{-2}s^{-1}$]. Axial layers have same occupancy as stereo layers. Note that these occupancies are after a cut of 20 adc counts are applied off-line.

seconds at $\approx 65 \cdot 10^{30} cm^{-2}s^{-1}$. [1] So it appears that the "brick wall" is indeed reached at $\approx 100 \cdot 10^{30} cm^{-2}s^{-1}$.

3 VLPC gain *vs* luminosity

The gain of the Visible Light Photon Counters (VLPC's) decreases with increasing rate.[4] The effect of this decrease in gain can be observed in Figure 2. Note that the average number of hits per track, for events with a single reconstructed vertex, drops with increasing luminosity!

4 Electronics *vs* luminosity

The effects of increasing luminosity on the present electronics (AFE I and VLPC) have been discussed in [5], [6] and [7]. The CFT uses several lengths of clear fibers. For axial layers the length is 11.2m for $0.63 < \phi < 1.89$, 10.4m for $1.89 < \phi < 3.14$, 8.1m for $3.14 < \phi < 4.40$, 7.8m for $4.40 < \phi < 5.66$, and 9.6m for $5.66 < \phi < 0.63$. The clear fibers of stereo layers are somewhat longer. Note in Figures 3 and 4 that the efficiencies follow the clear fiber lengths, indicating that the light yield is critical.

Histograms of ϕ of tracks with 16 CFT hits are shown in Figure 5. They vary wildly with ϕ. Again, the lowest efficiency corresponds to the sector with longer clear fiber. It is observed that some sectors have higher efficiency than others due to variations of the characteristics of the electronic modules. The

[1] Taking into account that during a high luminosity run the luminosity drops by $\approx 10 \cdot 10^{30} cm^{-2}s^{-1}$.

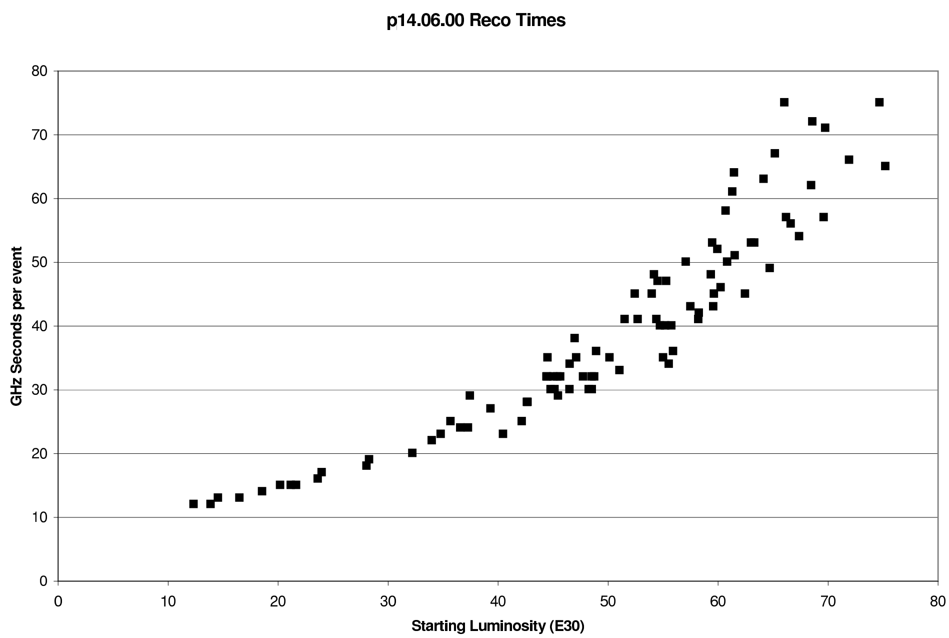

Figure 1: Execution time of d0reco (averaged over the events in a run) *vs* the initial luminosity of the run. The non-tracking part takes roughly a constant 3 seconds per event. 1GHz PIII processor.

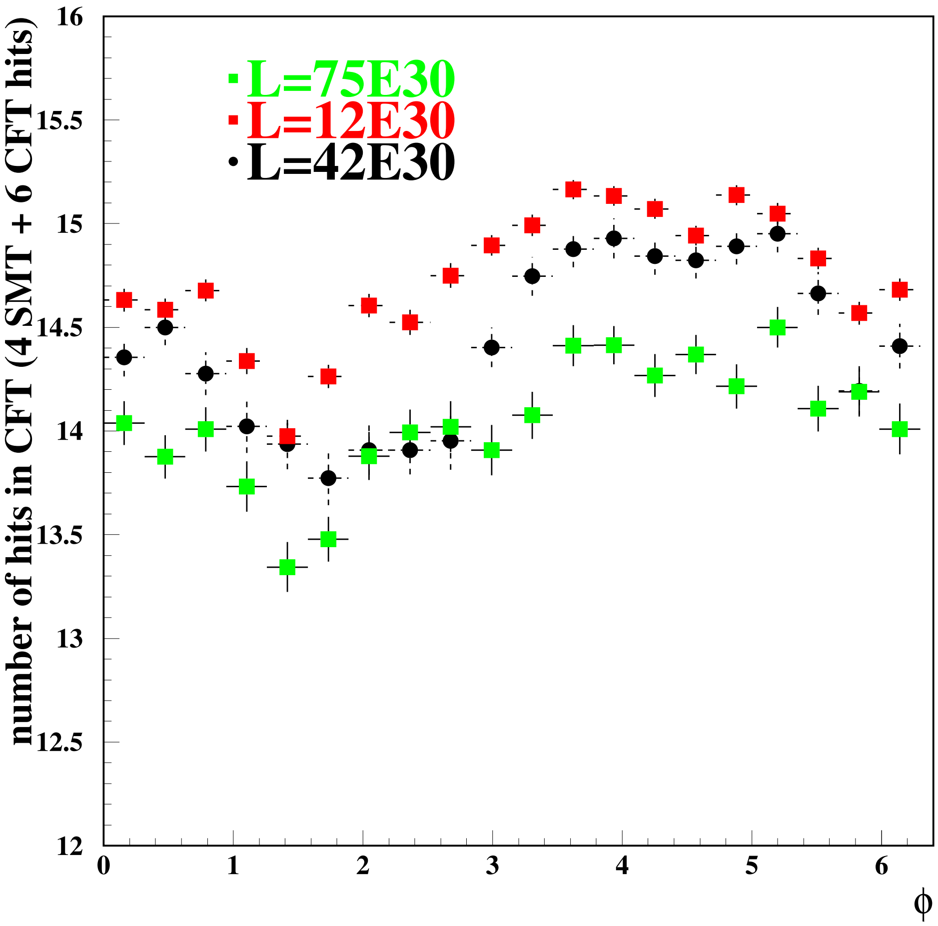

Figure 2: Average number of CFT hits per track as a function of ϕ at three different luminosities. To reject fake tracks we required at least 4 SMT hits and 6 CFT hits. Exactly 1 reconstructed vertex is required. All triggers. $|\eta| < 0.5$.

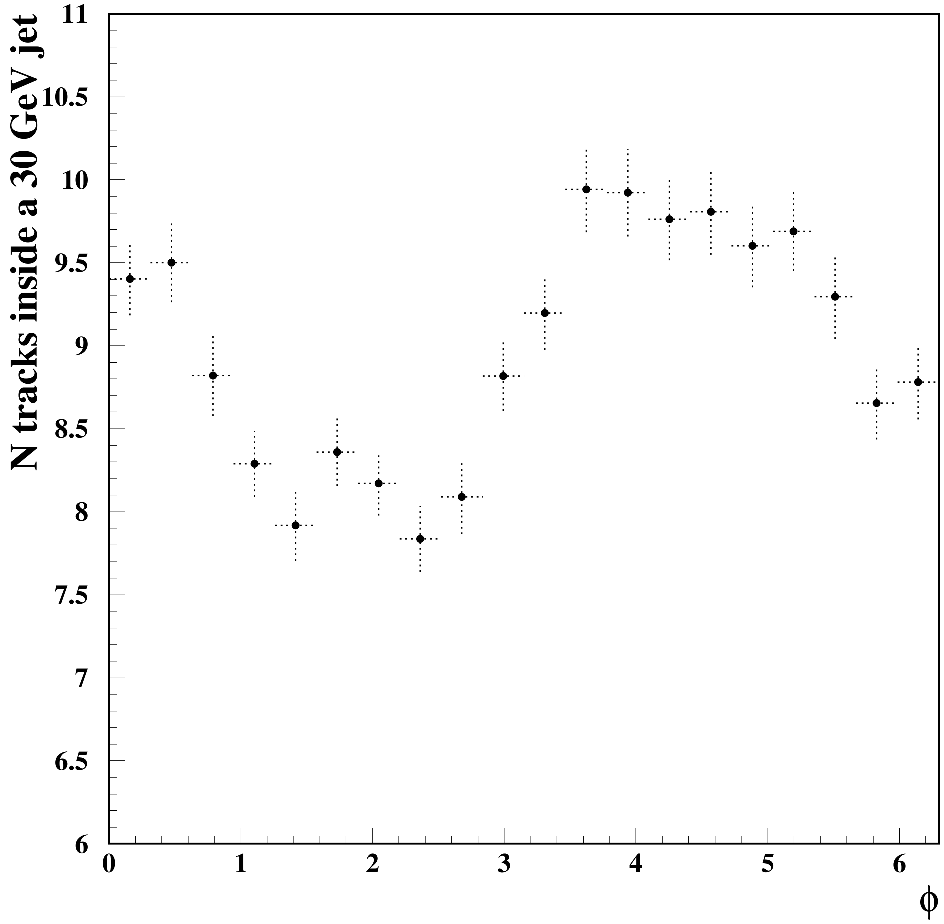

Figure 3: Average number of tracks in jets (in a $\sqrt{\Delta\eta^2 + \Delta\phi^2} = 0.5$ cone) as a function of ϕ. The jets are required to have energy between 25 and 30GeV/c^2, have at least 2 tracks, and have $|\eta| < 0.5$. The tracks are required to have at least 4 SMT and 6 CFT hits. The events are required to have exactly 1 reconstructed vertex.

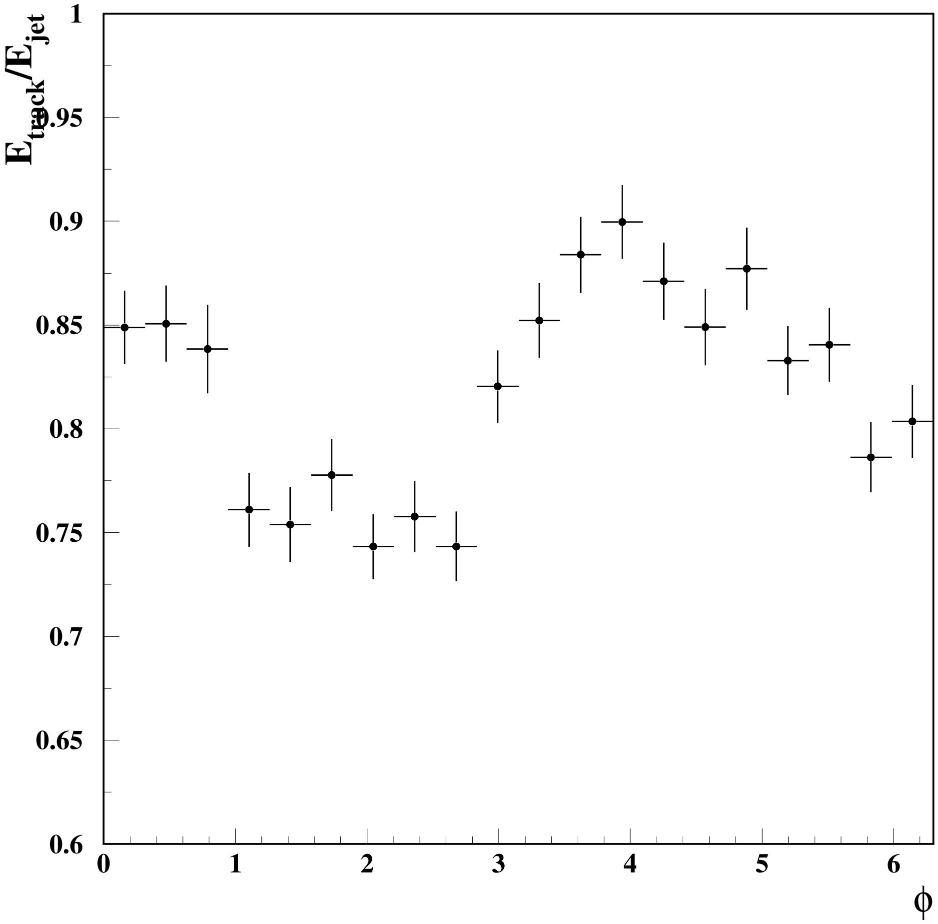

Figure 4: Fraction of energy of jet in reconstructed tracks. Same selection as Figure 3.

modulation in ϕ is much smaller when only 15 CFT hits are required on track.

Tracks with larger $|\eta|$ have larger light yield because the oblique tracks traverse more scintillating fiber. The reduction of the average number of hits per track at small $|\eta|$, where the light yield is lower, is shown in Figure 6. So the light yield at small $|\eta|$ is critical, requiring a difficult compromise between offline threshold and occupancy.

Events with more vertexes have, on average, larger occupancy. Larger occupancy means that more discriminators fire. It is known that the firing of discriminators shifts the pedestals of the adc channels. [2] Due to these shifts, some adc channels drop below threshold causing an inefficiency. In Figure 7 we observe the drop in the average number of hits per track that occurs in events with more reconstructed vertexes.

5 Fake rate *vs* luminosity

The occupancy and fake track rate increase with increasing number of vertexes. As more CFT hits are required, the smaller is the number of track candidates due to efficiency and fake track rate. This is shown in Figure 8. To be able to separate the two effects we require ≥ 4 SMT hits and obtain Figure 9. The fake track rate for ≥ 12 CFT hits is immediately apparent by comparing these two figures (and even from Figure 8 alone). The ratio of the number of tracks with ≥ 16 CFT hits over the number of tracks with ≥ 15 CFT hits is shown in Figure 10. This ratio should be constant if there are no fake tracks. This is approximately the case when ≥ 4 SMT hits are required: see top points in Figure 10. Note that the efficiency of the 16'th hit is ≈ 0.56. From Figures 10 we obtain the fake track rate when ≥ 15 CFT hits are required, see Figure 11. At high luminosity there is a difficult compromise between efficiency and fake rate.

6 Tracking efficiency

We choose events with a very tight local muon pair (each muon candidate with ≥ 3 PDT hits in layer A, ≥ 5 PDT hits in layers BC, scintillator time stamp within 5ns of t_0, local track fit with good χ^2). Then we obtain

[2] Typically, a Multi Chip Module (MCM) on AFE I firing discriminators at an occupancy of 30% shifts the pedestals of SIFT-chip 1 by -1 photo-electron (pe), SIFT-chip 2 by -0.5pe, SIFT-chip 3 by +1pe, and SIFT-chip 4 by +4pe. This shift should be compared with the light yield of a track traversing perpendicularly the center of a fiber: $\approx$ 8pe. These shifts are not observed in stereo modules that have no firing discriminators.[7]

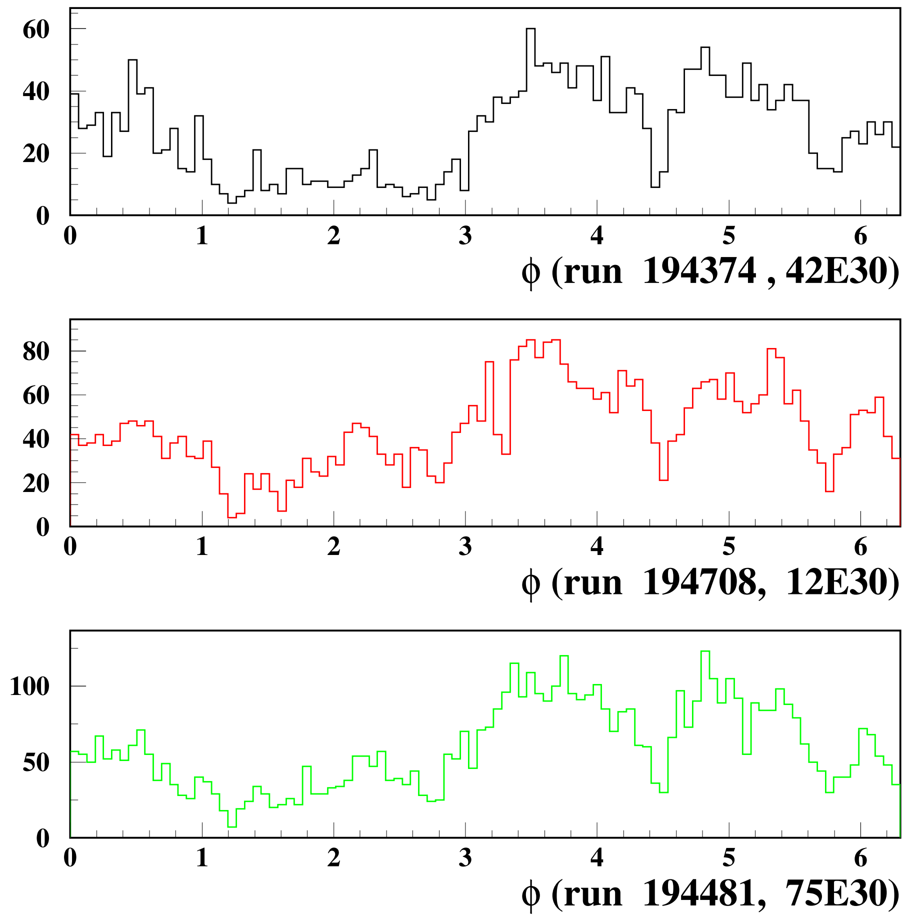

Figure 5: Histogram of the number of tracks per bin of ϕ. Tracks are required to have 16 CFT hits, $p_T > 1$GeV/c, $|\eta| < 0.5$ and at least one SMT hit, All triggers. Three runs.

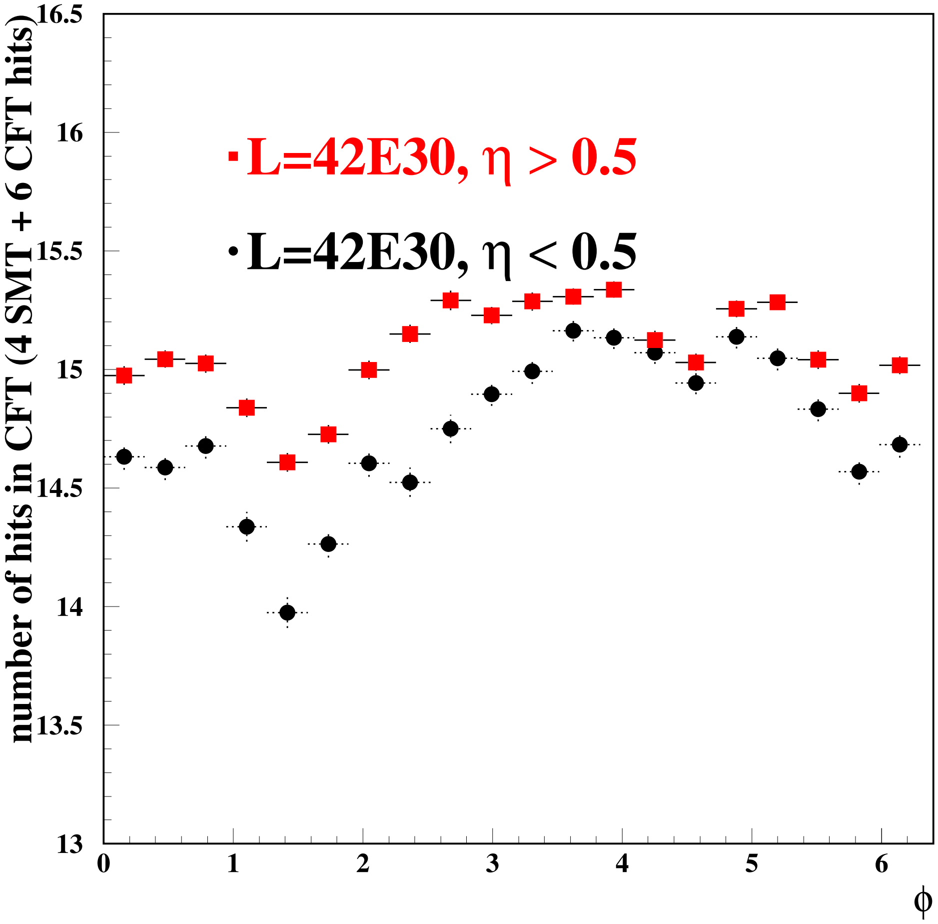

Figure 6: Average number of hits per track in the CFT, at a given luminosity, for events with 1 vertex, as a function of ϕ. To reject fake tracks we required at least 4 SMT hits and 6 CFT hits. All triggers. Circles: $|\eta| < 0.5$. Squares: $|\eta| > 0.5$.

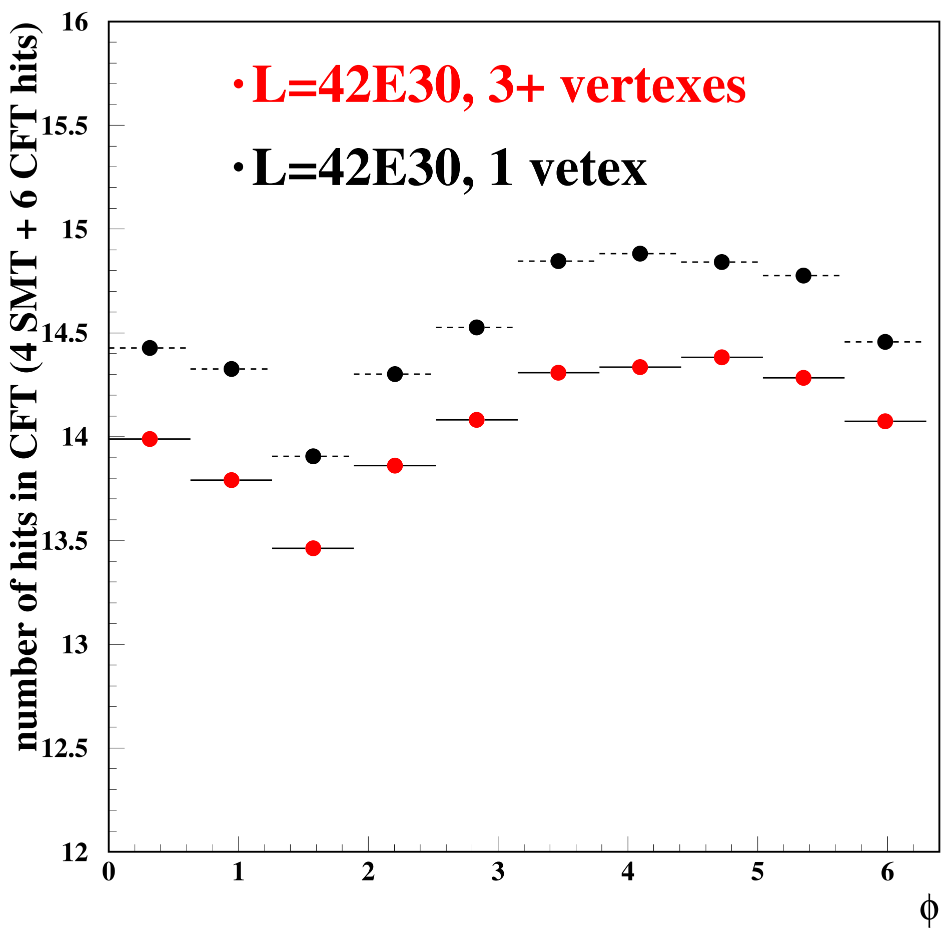

Figure 7: Average number of hits per track in the CFT as a function of ϕ, at a given luminosity, for events with 1 or ≥ 3 vertexes. To reject fake tracks we required at least 4 SMT hits and 6 CFT hits. All triggers. $|\eta| < 0.5$.

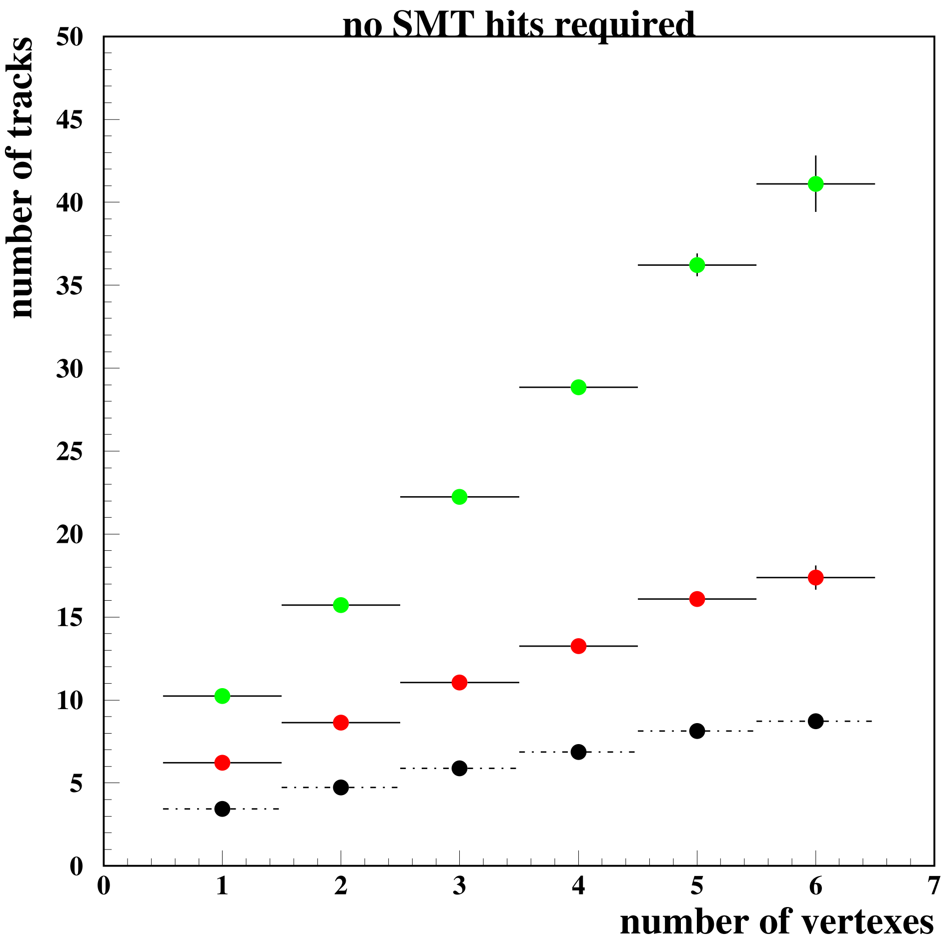

Figure 8: Number of track candidates with ≥ 12, ≥ 15 or ≥ 16 CFT hits as a function of the number of reconstructed vertexes. $|\eta| < 0.5$. All triggers. Any number of SMT hits.

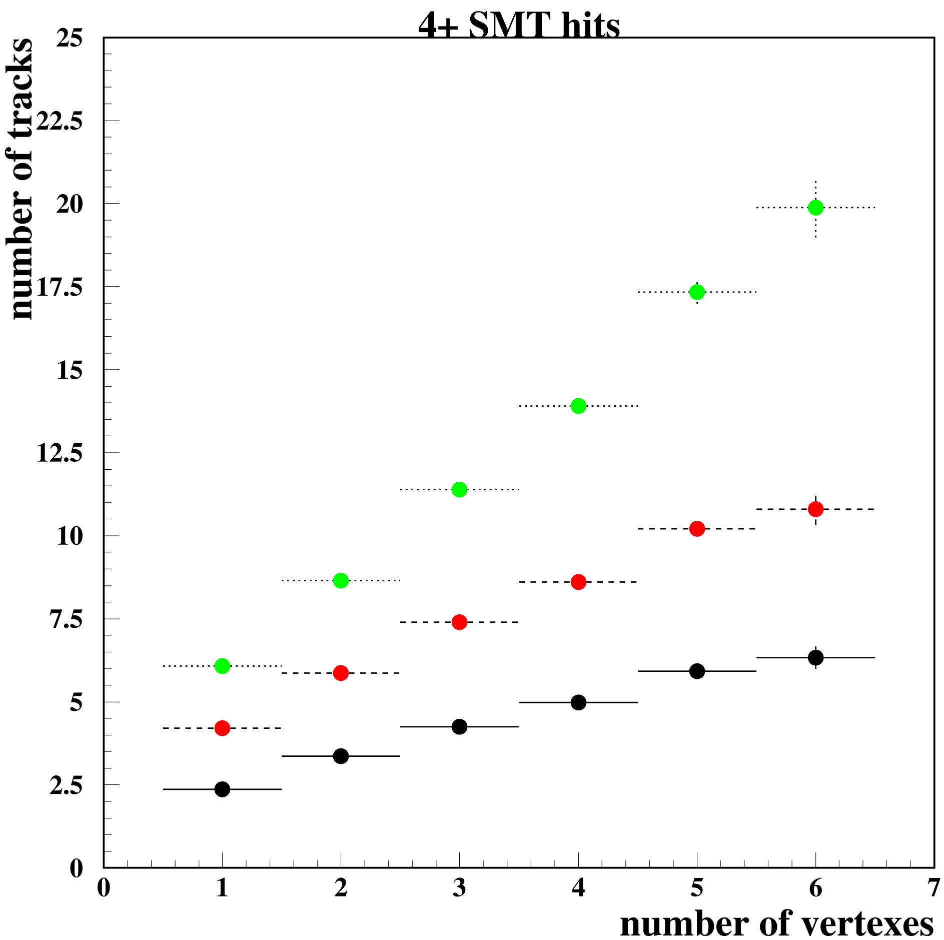

Figure 9: Number of tracks with ≥ 12, ≥ 15 or ≥ 16 CFT hits as a function of the number of reconstructed vertexes. ≥ 4 SMT hits are required to reduce the number of fake tracks. $|\eta| < 0.5$. All triggers.

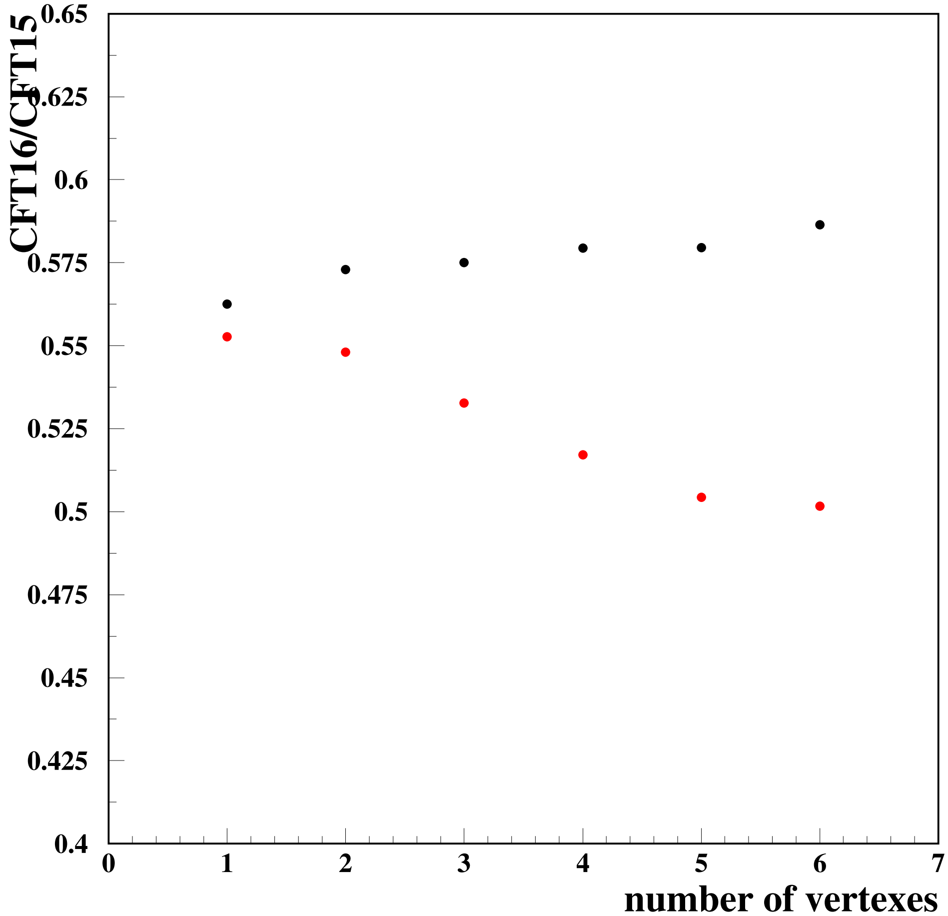

Figure 10: Ratio of the number of tracks with ≥ 16 CFT hits over the number of tracks with ≥ 15 CFT hits. Upper points: ≥ 4 SMT hits are required on track. Lower points: no requirement placed on the SMT. $|\eta| < 0.5$. All triggers.

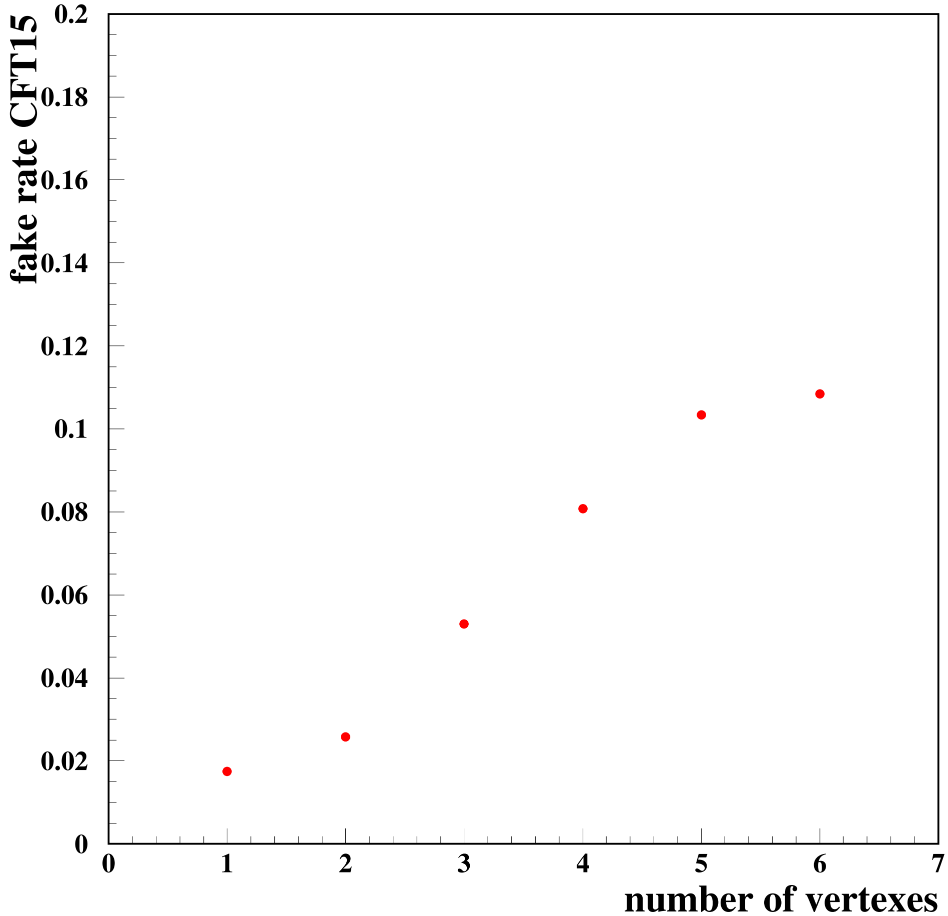

Figure 11: Fraction of tracks that are fake when ≥ 15 CFT hits are required, as a function of the number of reconstructed vertexes in the event. $|\eta| < 0.5$. All triggers.

CFT hits	“efficiency” at 11.6E30	“efficiency” at 70.0E30
≥ 0	0.96	0.94
≥ 12	0.94	0.89
≥ 13	0.94	0.86
≥ 14	0.90	0.78
≥ 15	0.67	0.61
≥ 16	0.34	0.28

Table 2: Fraction of gold plated muons having a matching track candidate with the indicated number of CFT hits. $|\eta| < 0.5$. $p_T > 4.0$GeV/c. The luminosity is $11.6 \cdot 10^{30}\text{cm}^{-2}\text{s}^{-1}$ or $70.7 \cdot 10^{30}\text{cm}^{-2}\text{s}^{-1}$.

a histogram of the number of CFT hits of the matching tracks for a low luminosity run and a high luminosity run, see Figure 12. The results are shown in Table 2. Note in Figure 12 the effect of luminosity on the VLPC gain: the histogram peaks at 15 CFT hits at high luminosity. The fraction of track candidates with sign opposite to the muon is 0.024 (0.050) at $11.6 \cdot 10^{30}\text{cm}^{-2}\text{s}^{-1}$ ($70.7 \cdot 10^{30}\text{cm}^{-2}\text{s}^{-1}$).

7 Ks *vs* luminosity

In Figures 13 and 14 we show the number of Ks found in events with two gold plated muons at two luminosities. The number of Ks per dimuon at $11.6 \cdot 10^{30}\text{cm}^{-2}\text{s}^{-1}$ ($70.7 \cdot 10^{30}\text{cm}^{-2}\text{s}^{-1}$) is 0.119 (0.106) when no cuts are applied to the tracks, and 0.042 ± 0.015 (0.046 ± 0.009) when tracks are required to have ≥ 3 SMT hits and ≥ 15 CFT hits. So, we see no significant drop in the efficiency to reconstruct Ks's between these two luminosities.

References

[1] David Lam, Agenda Server → Detector → Fiber Tracker → July 13 → CFT Occupancy, (2004)

[2] “Documentation for the Find_Jpsi_Ks software that searches tracks and track pairs using the Fiber Tracker”, B. Hoeneisen, DØ note 3842 (2001)

[3] “Time-of-flight measurement in the Central Fiber Tracker”, J. Estrada, C. Garcia, B. Hoeneisen and P. Rubinov, DØ note 4202 (2003)

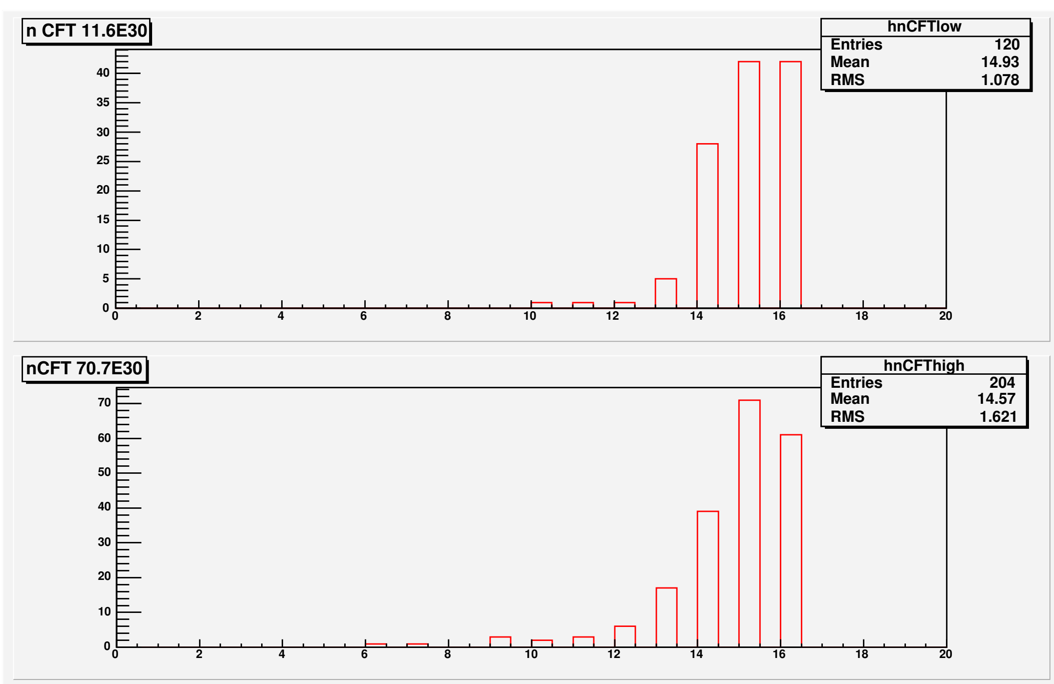

Figure 12: Distributions of CFT hits for track candidates matching gold plated muons in dimuon events. Top panel: $11.6 \cdot 10^{30}\text{cm}^{-2}\text{s}^{-1}$, 125 muons. Bottom panel: $70.7 \cdot 10^{30}\text{cm}^{-2}\text{s}^{-1}$, 218 muons. $|\eta| < 0.5$. $p_T > 4.0\text{GeV/c}$.

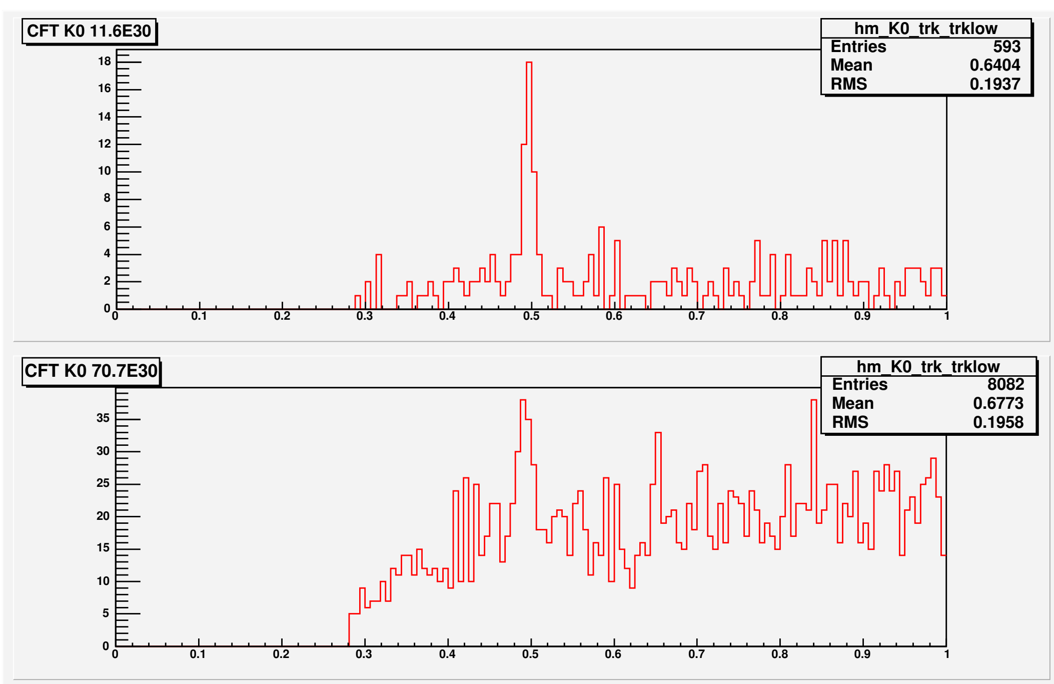

Figure 13: Invariant mass of two displaced tracks showing Ks peak. No cut on the track. Events with two gold plated muons. Top panel: $11.6 \cdot 10^{30}\text{cm}^{-2}\text{s}^{-1}$. Integrated luminosity proportional to 336 dimuons. Bottom panel: $70.7 \cdot 10^{30}\text{cm}^{-2}\text{s}^{-1}$. Integrated luminosity proportional to 592 dimuons. $|\eta| < 0.5$. $p_T > 4.0$GeV/c.

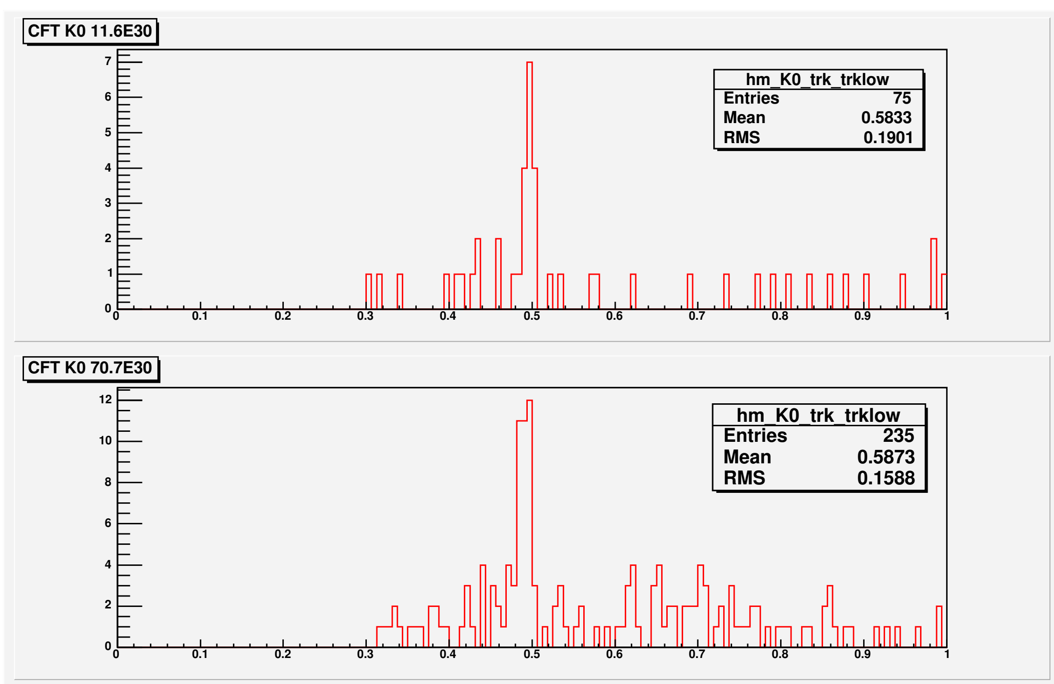

Figure 14: Invariant mass of two displaced tracks showing Ks peak. Tracks are required to have $\geq$ 3 SMT hits and $\geq$ 15 CFT hits. Events with two gold plated muons. Top panel: $11.6 \cdot 10^{30}\text{cm}^{-2}\text{s}^{-1}$. Integrated luminosity proportional to 336 dimuons. Bottom panel: $70.7 \cdot 10^{30}\text{cm}^{-2}\text{s}^{-1}$. Integrated luminosity proportional to 592 dimuons. $|\eta| < 0.5$. $p_T > 4.0$GeV/c.

[4] "Understanding the dark current and rate effects of Visible Light Photon Counters", J. Estrada, C. Garcia, B. Hoeneisen, D. Lincoln, P. Rubinov, (2003)

[5] "System tests of the new electronics for the Central Fiber Tracker and Preshower detectors", J. Estrada, C. Garcia, B. Hoeneisen and P. Rubinov, DØ note 4233 (2003)

[6] "Saturation of the SVX Chip", P. Hasiakos and J. Estrada, DØ note 4495 (2004)

[7] "Problems with the AFE operation at high rates", A. Bross, J. Estrada, P. Hasiakos, and P. Rubinov, DØ note 4500 (2004)