Tensor gluebal search

- CERN Summer student project

Author: Rasmus Staugaard Thomsen

Supervisors: Frigyes Janos Nemes, Michael Pitt

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Analysis:

In this analysis, our focus will be on investigating the possibility of $f_J(2220)$ being a candidate for a glueball particle. One way to potentially confirm this hypothesis is by examining the relative ratios of its decay modes. This is because tensor glueball are exclusively composed of gluons and therefore do not couple to any specific quark flavors. Their decays into quark flavours are therefore expected to be symmetric. As a result, it becomes theoretically feasible to determine the branching ratios of its decay modes, assuming it is indeed a glueball. These should be:

$$\rho\rho : K^*\overline{K}^* : \omega\omega : \phi\phi = 1 : 0.84 : 0.32 : 0.11$$

Where considerations of the available phase-space have been taking into account. A comprehensive analysis would be looking at most or all of these decay modes in order to compare them at the end. This analysis will, however, mainly focus on the decays into ρ's to see how well they can be reconstructed.

All these vector mesons quickly decay into pseudoscalar mesons, pions and kaons, which are the ones showing up in the detector. Consequently, our approach will involve utilizing these pseudoscalar mesons to reconstruct the initial vector mesons. Given that our analysis primarily revolves around ρ mesons, which predominantly decay into pions, each track in the analysis will be treated as if it were a pion, effectively assigning it the pion's mass for the purpose of energy reconstruction.
The original analysis, which this analysis was based on, primarily utilized four-track events. During the project, this was the first stepping stone, whereafter higher-order tracks were later looked at.

1. Four-track:

In order to reconstruct two neutral vector mesons, then we need to ensure that there is no net-charge in the four track system. For a given neutral four track system, then there are two possible combinations to pair the tracks together two-by-two. We include them both in the following 2D-histogram:

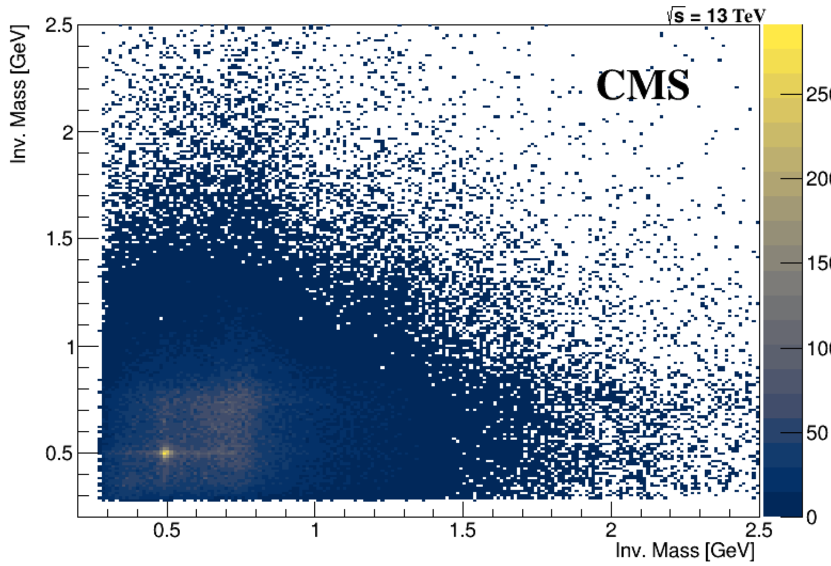

Figure 1: 2D-histogram of reconstructed invariant masses. Each event grants two entries into the histogram, since there will be two ways of constructing two pairs of neutral mother particles. Most masses fall in the region $0.5 - 1$GeV with a noticeable narrow peak at around 0.5GeV (kaon peak) and a broader peak around $0.7 - 0.8$GeV (rho peak)

This histogram can also be interpreted by looking at the X and Y-projections. This especially highlights three peaks, ~ 0.5GeV (kaon), ~ 0.73GeV (rho) and ~ 1.2GeV (phi). The fact that these show up in both projections, indicate that there is a resonant production of K, K, ρ, ρ as well as ϕ, ϕ, since the peaks are located in similar positions on the two graphs.

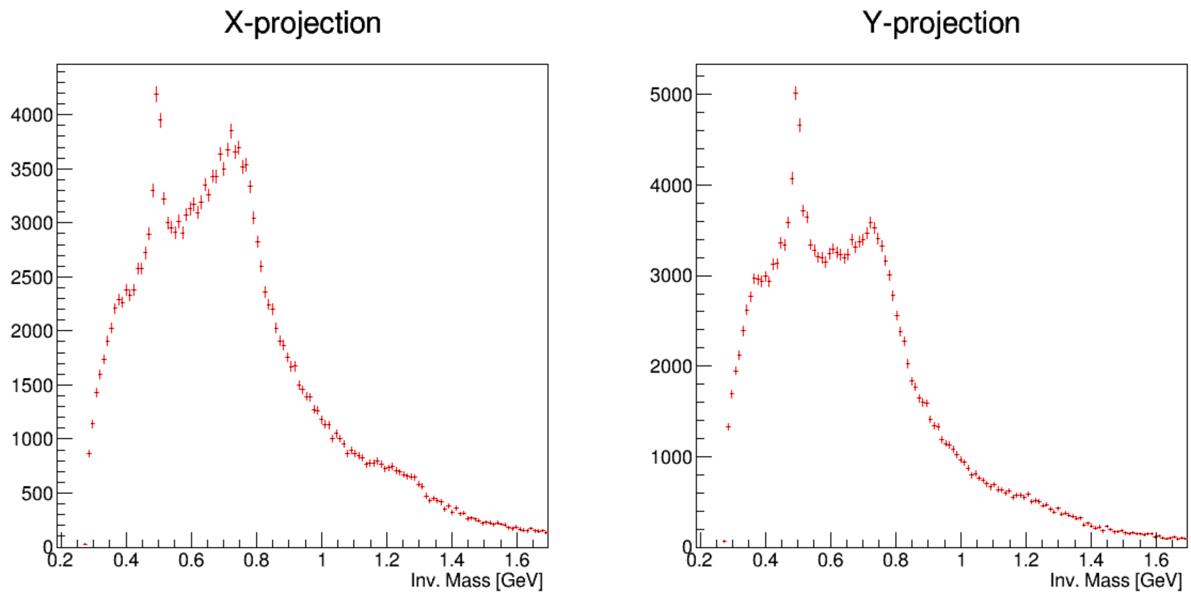

Figure 2: X and Y projections of the 2D-histogram. Both share the same attributes of a narrow peak kaon peak around 0.5GeV, broad peak around 0.7GeV. There is also a bump at around 1.2GeV in both of the histograms

We wish to separate the peaks and thereby reconstruct the true events coming from the decay mode:

$\rho\rho \rightarrow \pi^+\pi^- + \pi^+\pi^-$. One idea is to simply put in one of the two-masses given that the other two-mass is close to the mass of the rho.

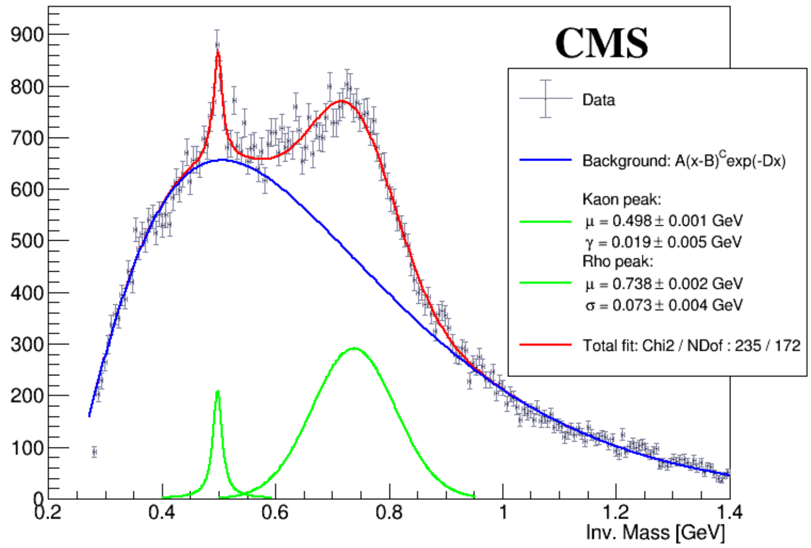

Figure 3: if the first two-mass obeys $\left|m_{\pi\pi} - m_\rho\right| < 0.15$GeV, then its corresponding partner is plotted in the histogram. This is done for both pairs. Then a fit is made of the signals. The kaon signal is fitted with a Breit-Wigner distribution ($\sigma = 5.0$). The rho peak is fitted with a Gaussian distribution ($\sigma = 30.6$)

Finally the invariant four-mass was found using constraints of the invariant two-mass:

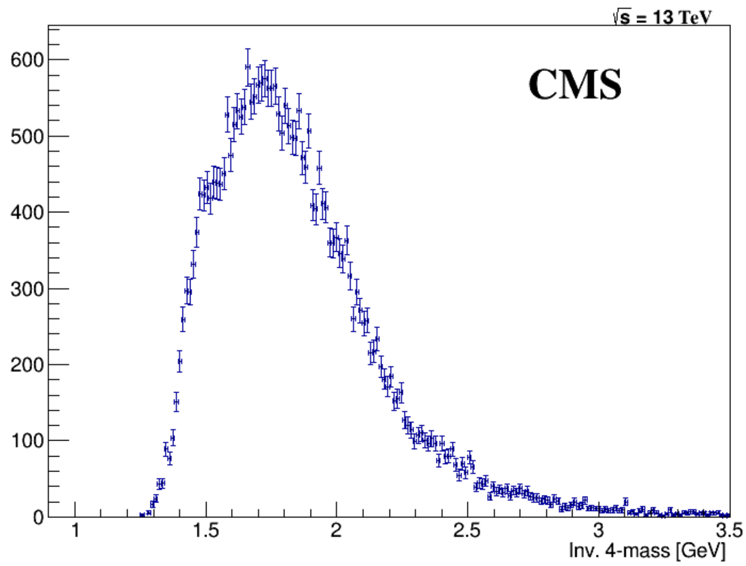

Figure 4: The four-mass of the four track given that both the two-masses obeys $\left|m_{\pi\pi} - m_\rho\right| < 0.15$GeV. This was done for both of the combinations. From this plot it is clear that any peak around 2.22GeV is hidden by the background

This leads to the analysis of higher order tracks, which will mostly concern five- and six-tracks.

2. Higher order tracks

The main way to deal with higher order tracks, in this analysis, will be to try and successfully decompose them into four-tracks. In order to successfully decompose a higher order track into a four track, we have to be careful in how we select the the four tracks. The following things should be kept in mind:

- The selected four particles must have a net-neutral charge in total
- The selected particles should be the four most likely candidates to come from a four track
- The selected particles should be related two and two within the four track
- The selected particles should not be related to any of the non-selected particles

Apart from the first one, these constraints are quite vague and have to be quantified. The way we will be quantifying whether or not tracks are related will be by using the impact parameter. Specifically for the first part the transverse impact parameter (dxy). Since we are interested in ρ's, which decay quickly, then the impact parameter should not be expected to be very large. Furthermore, we would expect that particles decaying from the same ρ to have similar impact parameter magnitudes. This means we can use this as rough estimate of which tracks ought to be paired.

The specific procedure that extracts a four-track from a higher order track is described by the flowchart 5. This flowchart describes the selection process, whereby four tracks are taken from a given higher order track and then assessed. The selection process goes through all ways to pick four elements from an n-track. The validity of these four elements to be a four-track is then assessed. The validity is based on two if-statements. The first if-statement ensures that the four elements will have net-neutral charge. The second if-statement is meant to try to prevent three-tracks being mixed up into a four track. This is because, if our four track were to consist of a three-track together with some other random track, then in many cases, this would appear as three tracks being close to each other with the final track potentially being further away from the rest. Whereas for a four track most of them should be somewhat close to each other. This is assessed by calculating all the distances between the four tracks dxys and then requiring that the sum of the three smallest distances are *not* smaller than the fourth smallest distance. In this way we secure that three of the tracks will not be substantially closer to each other than they are to the fourth track.

Finally the procedure gives us a four-track, but it does not determine how to pair the four-track up two-by-two. We used the impact parameter in the direction of the beamline (dz) to determine how to do the pairing [1]. Again we expect the dz of the two tracks decaying from a ρ particle to be similar in

[1] Dxy and a combination of dz and dxy was tried, but the best results was found just using dz

magnitude. Therefore it make sense to order them such that the difference between dz of pairs is the smallest.

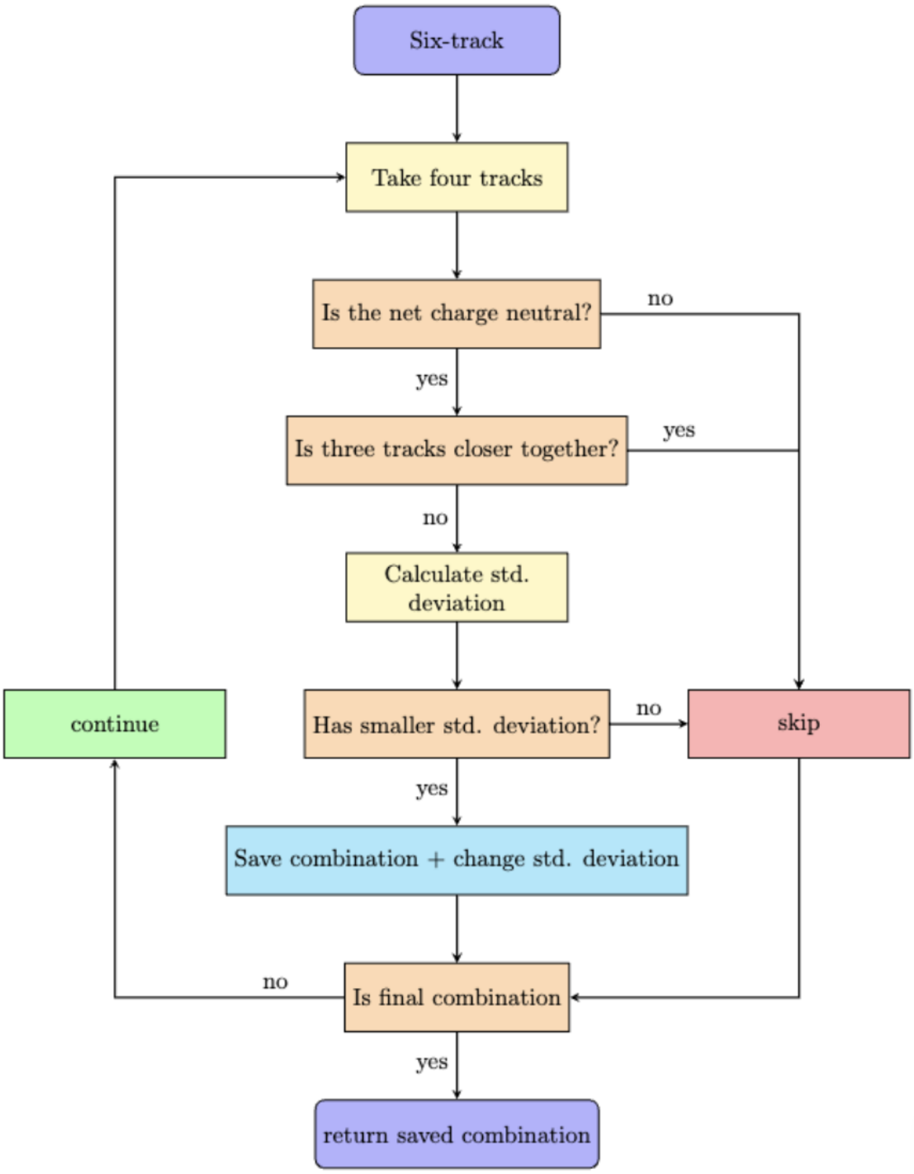

Figure 5: Flowchart of selection process

2.1 Six track

After this reduction scheme, we are left with a four-track. This still leads to the complication that there are potentially two different ways to construct two pairs of neutral particles. Following the same procedure as in the four track we find:

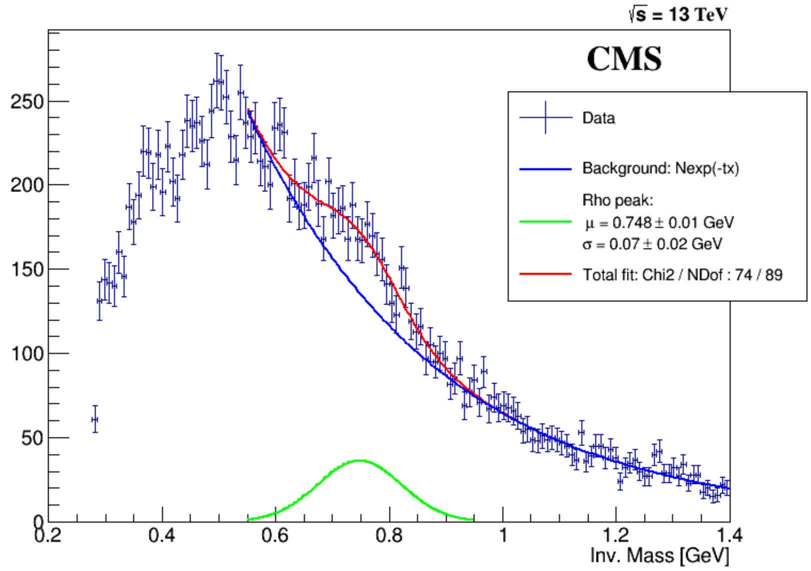

Figure 6: Fit of four-pair reduction scheme on six-track events. There is a clear bump over the exponential background, where the rho peak is expected to lie, however it is quite broad, which indicates that it still contains much background.

Choosing the combination of pairs with the lowest $\Delta|dz|$ value, aswell as making a small cut to exclude four-tracks with large differences of dxys, gives the following plot:

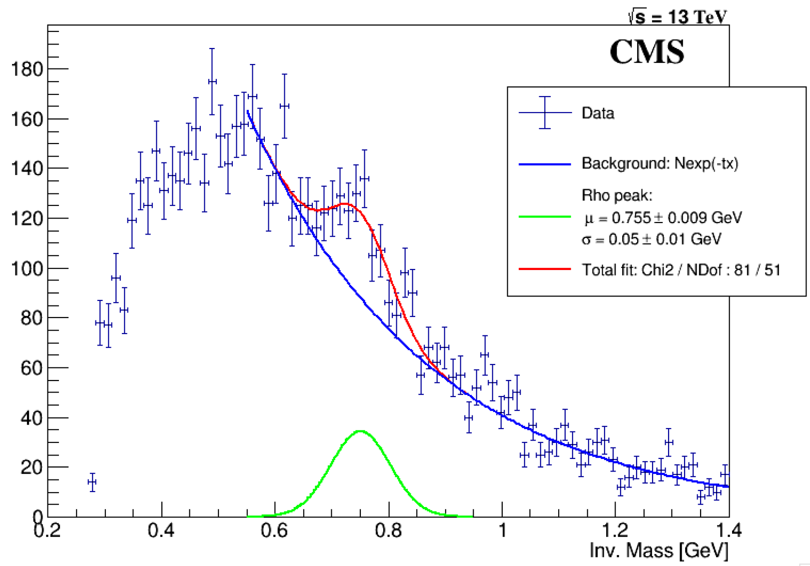

Figure 7: Plot showing the reduction of six-track into four-track and then picking the combination with lowest $\Delta|dz|$ value. The signal is now less broad and consequently includes less background

Finally, it is of interest to also look at the invariant four mass to see if any signature of $f_J(2220)$ can be seen. Requiring both two-masses to be within 0.15GeV of the rho mass gives the following plot:

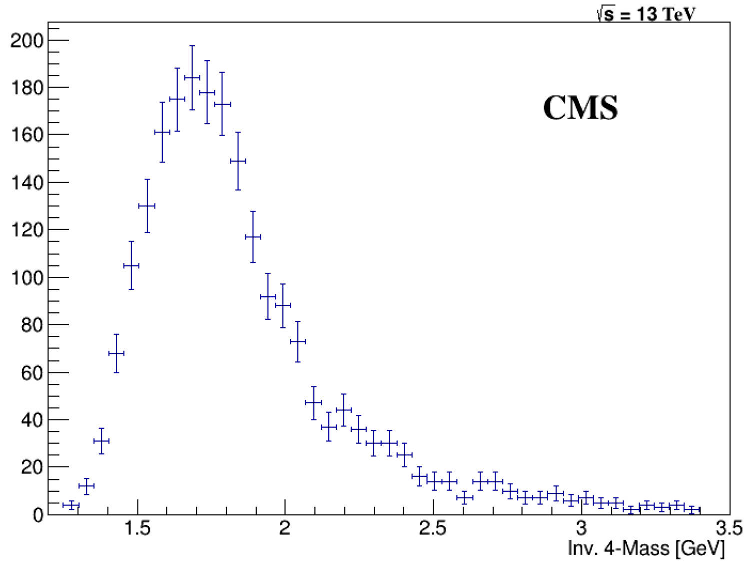

Figure 8: The 4-mass of the four chosen particles from the six-track. Interestingly a small bump can be seen near 2.2 GeV, which might indicate some four-tracks being identified as six-track in the data.

The 4-mass shows a small bump around the 2.2 GeV point. Whether this is an actual indication of some four-track events being include in the six-tracks or not, has to be evaluated by further analysis.

2.2 Five track

The story is quite similar for five-tracks. The rho peak looks somewhat less convincing, but there still seems to be a signal around the 2.22GeV in the four-mass.

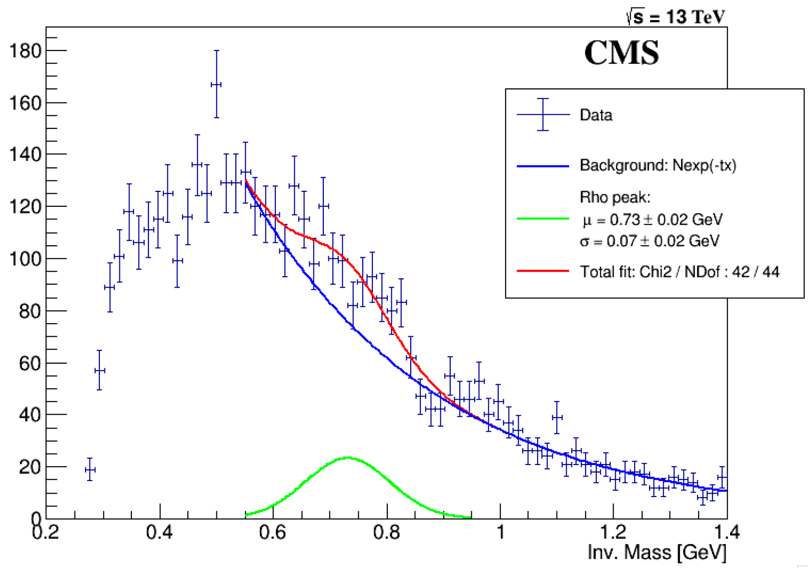

Figure 9: Two-mass of five-track after the reduction to a four-track. The rho peak is way more difficult to make out than in the six-track case. It therefore seems a little less convincing than in the six-tracks

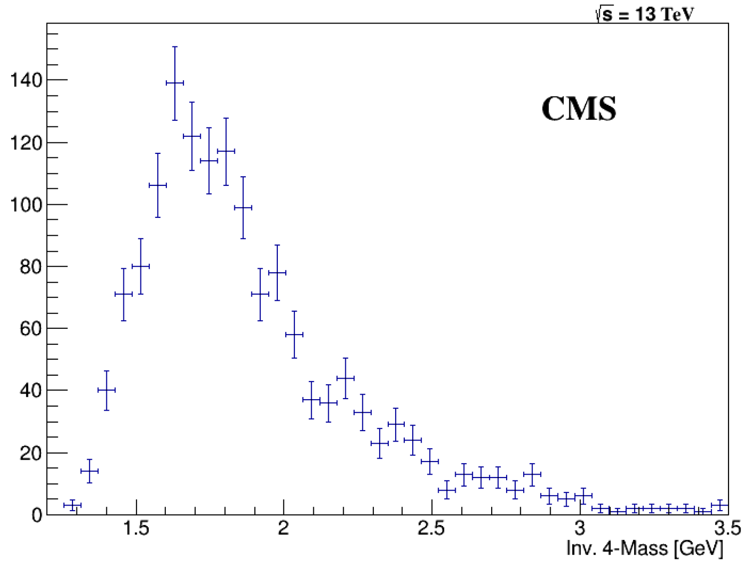

Figure 10: Four-mass of five-track after the reduction to a four-track. The signal around 2.22GeV is also visible here

The code that generates these plots can be found in the folder week5 "oldway.C" and in the folder week6 "five track.C", "six track.C".