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Particle Interactions in the LHCb detector

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Abstract

The dependence of physics tracks selection and the track fit performance on the material in the detector is discussed.

1 Introduction

The amount of material in the LHCb detector has been growing since the time of the Technical Proposal. Latest estimates indicate that material budget of the tracking stations has increased from the 1.6% X_0 per station assumed at that time to around 3% now. In this note the effect on the number of physics quality tracks per event and momentum resolution for minimum ionizing particles is discussed. The effect on electrons will be discussed in a future note.

This note also does not address the effect on pattern recognition performance of increasing the material budget. It can always be argued that any deterioration in pattern recognition performance can be recovered by improvements in the algorithm used. This is not the case for the losses described in this note.

To study the performance for different radiation thickness' of tracking stations samples of 1000 $B_d \rightarrow \pi^+\pi^-$ events were generated with SICBMC version v233r1 with values of $1, 2, 4$ and 8% X_0 per station. This version of SICBMC corresponds to the all Aluminium beam-pipe ('version 4.1'), the design of the Velo dating from the Technical Proposal and the layout of the tracking system containing eleven stations described in Table 1.

Station	z/cm	Layout
T1	100.0	XUVXYY
T2	217.0	YYXUVX
T3	330.0	XUVX
T4	480.0	XUVX
T5	620.0	XUVX
T6	700.0	XUVX
T7	790.0	XUVX
T8	840.0	XUVX
T9	890.0	XUVX
T10	940.0	XUVXYY
T11	1160.0	YYXX

Table 1: Tracking system layout.

2 Number of physics tracks per event

An important number to compare for the different samples is the number of physics tracks per event. A track is defined to be of good physics quality if:

- Particle type is not an electron.
- Momenta at production vertex > 1 GeV.
- Production vertex inside the Velo.
- Track makes it to at least T7 (Start of track seeding region).

These criteria only make use of information coming from GEANT.

Fig. 1 shows the average number of tracks per event versus the % X_0 per station. It can be seen that the number of physics tracks falls off as the amount of material is increased. In Fig. 2 the momentum spectra of selected tracks for the cases of 1% X_0 and 8% X_0 per station are compared. It can clearly be seen that that the loss of tracks occurs for all momenta. To understand this effect samples of 400 events were generated switching on and off the GEANT cards [1]:

- MULS (multiple scattering).
- LOSS ($\frac{dE}{dx}$ energy loss).
- HADR (hadronic interactions).

All other GEANT physics processes were turned off for each run. The results are summarized in Table 2. From these numbers it is clear that the losses are due to tracks undergoing hadronic interactions in the detector. Compared to to the situation where there is no material in the detector there is a $\sim$ 18% loss in tracks when turning on all the detector material and assuming 2% X_0 per tracking station. If this is increased to 8% X_0 the loss increases to around 30%. A simple calculation gives that $\lambda_I \approx \frac{1}{3} X_0$ for the outer tracker [2]. A radiation thickness of 2% X_0 per tracking station would then correspond to a total of $\sim$ 10% λ_I in the tracking system alone. Assuming a similar relationship holds for the Velo and RICH1 the GEANT results look consistent with what is expected.

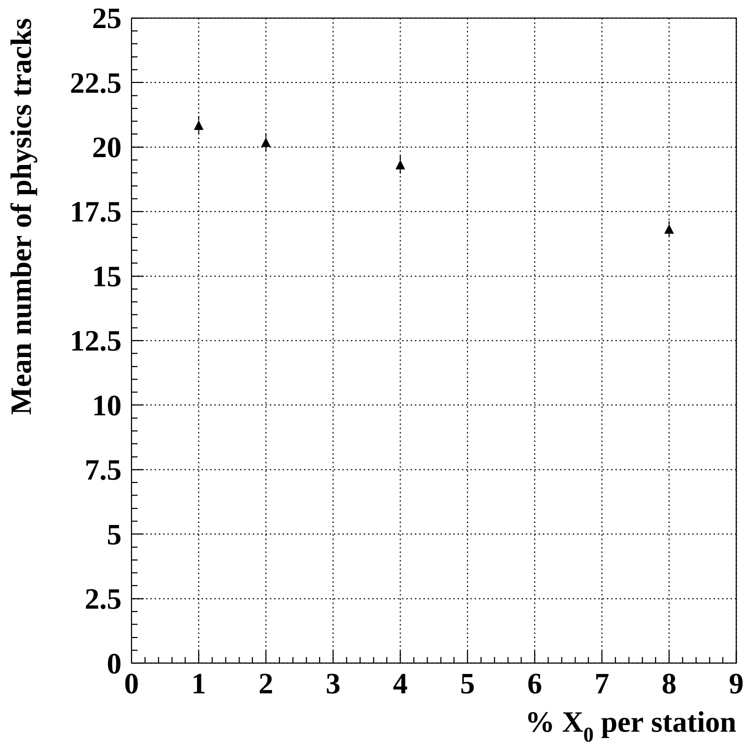

Figure 1: Average number of physics tracks per event versus % X_0 in a tracking station.

% X_0 per station	MULS	LOSS	HADR	number of tracks
—	off	off	off	24.15 ± 0.65
2	on	off	off	22.91 ± 0.60
8	on	off	off	22.81 ± 0.61
2	on	on	off	23.32 ± 0.6
8	on	on	off	22.79 ± 0.62
2	on	on	on	19.72 ± 0.49
8	on	on	on	16.69 ± 0.49
2	off	off	on	19.26 ± 0.49
8	off	off	on	17.60 ± 0.49

Table 2: Effect of changing GEANT Flags.

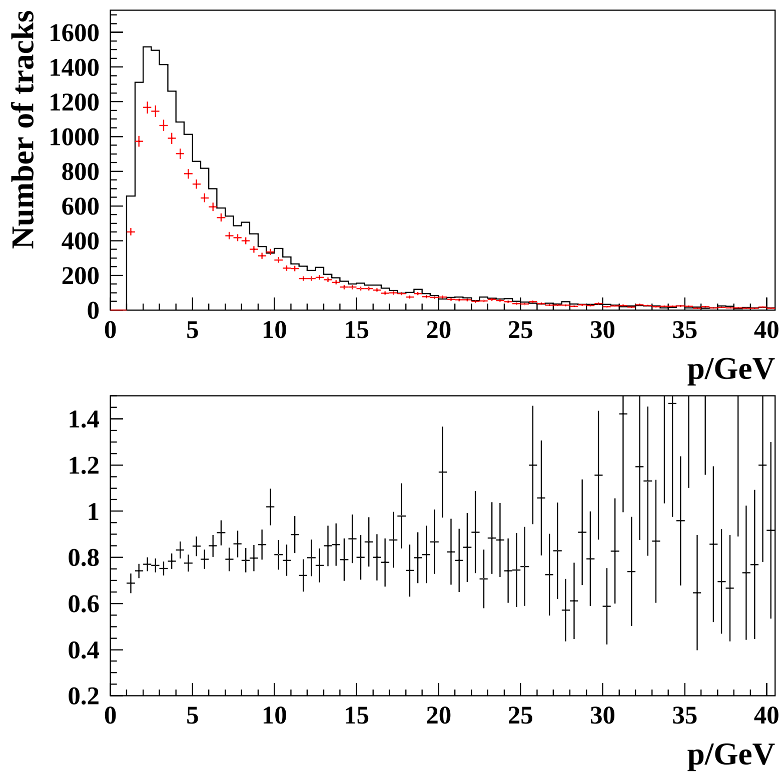

Figure 2: Momentum spectra comparison for physics tracks. The top plot shows the spectra for 1% X_0 per station(solid line) and 8% X_0 per station (dotted line) The bottom plot is the result of dividing the two.

3 Momentum Resolution

The other quantity of interest is the momentum resolution as a function of the X_0 per station. For each of the data samples with the full simulation the tracks selected using the above criteria are fitted up to station T1 and the momentum resolution $\frac{\delta p}{p}$ determined using the procedure described in [3]. Fig 3 shows the resulting plot of $\frac{\delta p}{p}$ as a function of the X_0 in the tracking stations. Since the error on the multiple scattering is roughly proportional to $\sqrt{X_0}$ it is expected that the form:

$$\frac{\delta p}{p} = A + B \times \sqrt{X_0} \tag{1}$$

should fit the distribution. As can be seen this is indeed the case.

At the time of the Technical Proposal with a radiation thickness of 1.6%

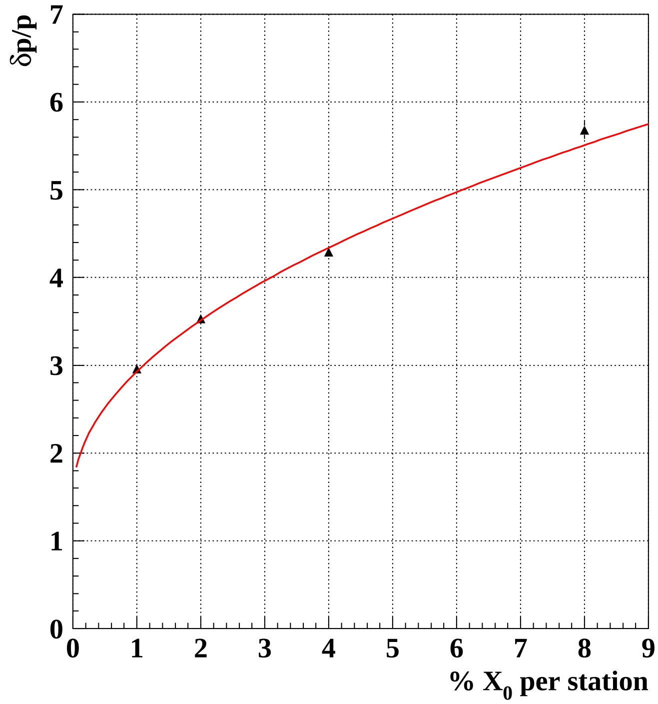

Figure 3: Momentum resolution as a function of the material budget in the tracking system. The solid line is the result of the fit described in the text.

X_0 per station the momentum resolution was around 3.3×10^{-3}. With the current value of 3.0% X_0 a resolution of around 4×10^{-3} is expected — a deterioration in performance of 18%.

4 Conclusions

Increasing the material budget in the tracking stations has been shown to lead to a noticeable loss in the number of reconstructible physics tracks. This loss is due to the increased number of hadronic interactions in the detector. It should also be noted that due to the different interaction cross-sections of K^+ (and π^+) with matter compared to K^- (and π^-) these losses can potentially cause fake CP asymmetries in the detector. This should be investigated further in the future.

The effect of increasing the material budget on the momentum resolution has also been investigated. It has been shown that there has been an 18% deterioration in performance since the time of the Technical Proposal.

Both the losses will be partially recovered if as seems likely the Y measuring planes of T1, T2 and T10 and the current station T4 are removed from the setup. For example,the momentum resolution should improve to around $3.7 \times 10^{-3} - 3.8 \times 10^{-3}$. On the other hand the increased material budget in the new design of the Velo will lead to a deterioration in performance.

References

[1] GEANT Detector Description and Simulation Tool. CERN Program Long Writeup W5013, 1994.

[2] B. Koene. Private communication.

[3] M. Merk *et al.* Performance of the LHCb OO Track Fitting Software. *LHCB-note*, (86), 2000.