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# **Tracking in DIRAC using only downstream detectors**

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# 1 Introduction

The aim of the study is to evaluate  $\pi^+\pi^-$  data using only the drift chambers on the opposite side of the magnet than the target ('downstream' tracking). The motivation for this is to be found in inefficiencies and other systematic effects introduced by the usual ('full') tracking, that makes use also of detectors upstream of the magnet (Ionization hodoscope, Scintillation fiber detectors and MSGCs). We expect to become independent of systematics introduced by the upstream detectors and to retain many more events, due to the independence of inefficiencies. The drawback, however is a somewhat worse reconstruction quality for  $Q_L$  and, due to the immense multiple scattering in the up-stream detectors, a significantly worse quality for the transverse components of  $Q$ . Complete independence on the up-stream detectors can, however, not be achieved as they were partly involved in the trigger (IH, SFD).

## 2 The 'downstream' tracking procedure

Tracking for the DIRAC set-up starts at the downstream end of the track and then proceeds back toward the target. The first step is a first order determination of the momentum  $p$  of the track by extrapolating a roughly determined track in the drift chambers back to the beam spot at the target by straight lines and a magnet deflection algorithm that transforms entry coordinates and slopes into exit coordinates and slopes. Using this momentum a new straight-line fit is made with the DC informations and the multiple scattering in the DCs in order to come out with a better upstream track that now is again extrapolated to the target and provides the final momentum estimate. This procedure fixes the x-coordinate at the target to zero. We point out that the procedure can not take into account any deflection of the track due to multiple scattering e.g. in the Al-window or in the up-stream detectors ('extrapolation method').

In y-direction the extrapolation is done analogously and provides a y-coordinate for each track at the target ( $y_T$ ). A vertex fit is then applied by the constraint that both tracks pass through the same point which is the middle of the y-coordinates of the two tracks ( $y_{vertex}$ ).

Reconstructing events by 'full' and 'downstream' tracking shows that 'downstream' tracking finds only about 50% of the events that were found with 'full' tracking. These events could be recovered by releasing all cuts concerning track quality at the target in 'downstream' tracking. This results in accepting tracks with very large  $y_T$  and track pairs with very large vertex positions  $y_{vertex}$ .

Assuming the tracks to come from the beam spot, we may take the beam spot as a vertical constraint for a vertex, i.e.  $y_T = 0$ . This should result in a more realistic single track. Conse-

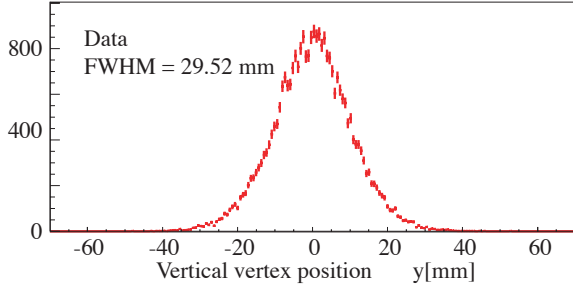


Figure 1: *Distribution of two-track vertices in the target plane in y-direction from ‘down-stream’ tracking’ for events, that were also reconstructed with ‘full’ tracking. Ni-2001 data.*

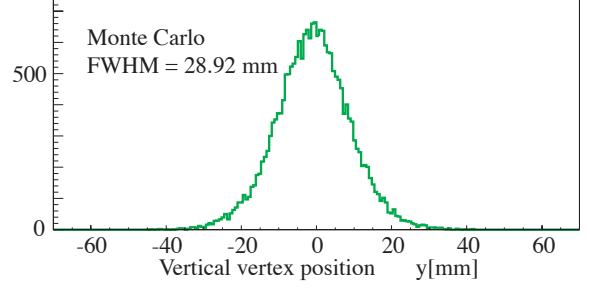


Figure 2: *Distribution of two-track vertices in the target plane in y-direction from ‘down-stream’ tracking’ for events, that were also reconstructed with ‘full’ tracking. Ni-2001 Monte Carlo CC background.*

quently we obtain the slope of the track at the target  $\Phi_y$  by interpolating between  $y_T = 0$  and the vertical coordinate at the Al-window  $y_{Al}$  (interpolation method)<sup>1</sup>:

$$\Phi_y = y_{Al}/L_{track} \quad (1)$$

where  $L_{track}$  is the length of the track in its horizontal projection between the target and the Al-window. By doing so we neglect the vertical deflection of the track by the magnetic field<sup>2</sup>. Using the momentum component in z-direction  $p_z$  as obtained by the extrapolation method (accuracy of a few permille), we obtain  $p_y = \Phi_y p_z$ .

For the  $Q_y$  determination the interpolation method leads to a somewhat worse resolution but behaves much better as shown in section 5.

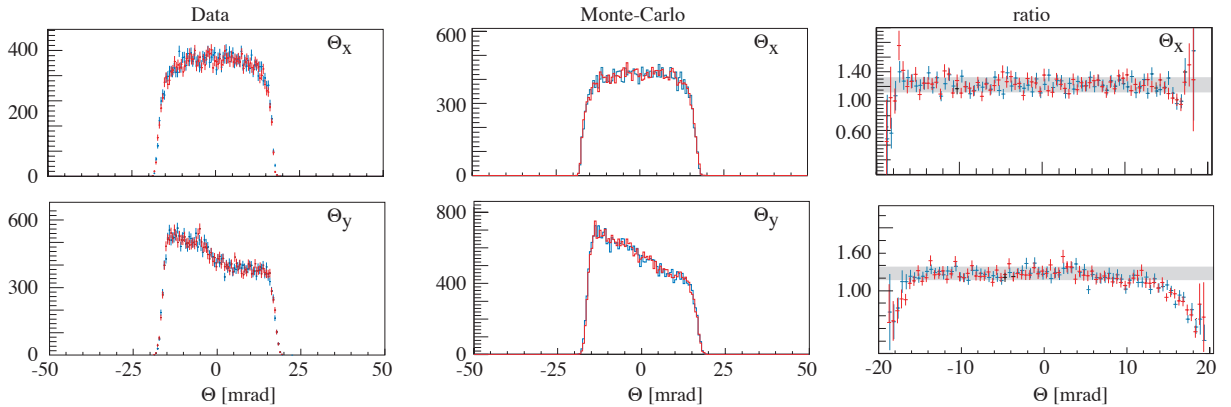


Figure 3: *Reconstructed track inclinations in x - and y - direction for positive and negative charge from experiment and Monte-Carlo CC-background, as well as the ratio of both. Ni-2001 prompt data. Only events that were reconstructed also with ‘full’ tracking*

<sup>1</sup> See also DIRAC Note 02-04

<sup>2</sup> see DIRAC Note 07-08

### 3 Quality of reconstruction

In this section 3 we use the extrapolation method and events that were reconstructed with both, 'downstream' and 'full' tracking.

#### 3.1 Quality of geometrical reconstruction

Figs. 1 and 2 show the vertical vertex coordinate at the target from data and Monte Carlo simulation, respectively. Only events were used that were also reconstructed with 'full' tracking. The spread is the result of multiple scattering in the downstream Al-window of the magnet vacuum, and of the upstream detectors. The Monte-Carlo simulation using DIRAC GEANT with new multiple scattering is about  $2 \pm 2\%$  narrower than data. The Monte-Carlo thus reproduces the experiment with satisfactory accuracy.

Fig. 3 shows the inclination angles  $\theta_x, \theta_y$  of the individual tracks at the target plane and compares them with Monte-Carlo (CC background) for prompt events. For the x-direction the ratio of the two shows perfect agreement (1 percent level) between data and Monte-Carlo, except at the very edges of the distributions. For y, the situation is more complex. Data and Monte-Carlo seem to follow the same slope, but with a step around zero. A similar feature is observed also for 'full' tracking. Although the difference is of the order of 20%, the influence on  $Q_y$  is negligible (fraction of a percent).

We conclude that the geometrical reconstruction relevant for  $Q$  determinations is well described by Monte-Carlo.

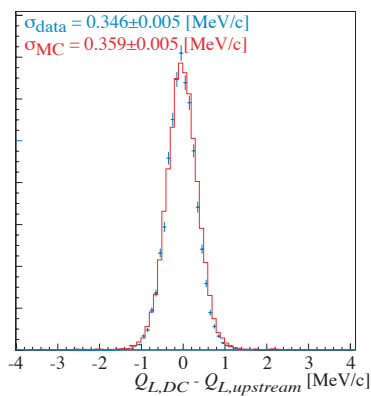


Figure 4: *Difference of  $Q_L$  reconstructed with upstream and downstream tracking. Ni-2001 data prompt (solid blue) and Monte-Carlo CC-background (red hatched).*

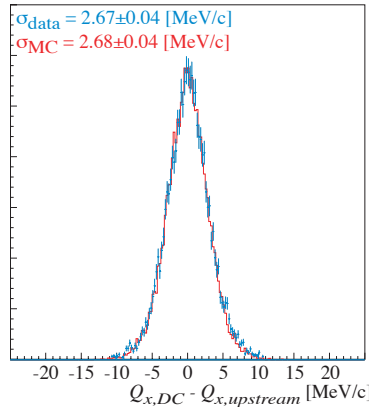


Figure 5: *Same as Figure 4, but for  $Q_x$ .*

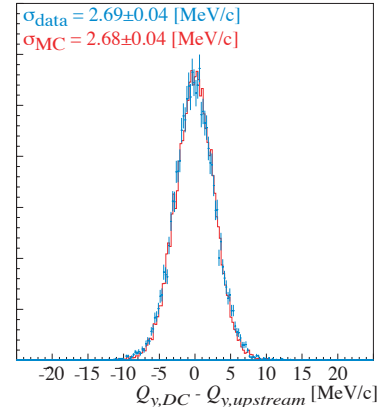


Figure 6: *Same as Figure 4, but for  $Q_y$ .*

#### 3.2 Quality of 'downstream' tracking

The quality of 'downstream' tracking was checked by using measured data, that were reconstructed with both, 'downstream' tracking and tracking using up-stream detectors ('full' track-

ing). Comparing the two procedures for the same events allows a quantitative characterization of the method. Figures 4, 5, 6 show the results for prompt events. For comparison we also show the Monte-Carlo simulation of prompt CC background. Table 1 summarizes the results. Since the distributions are not purely gaussian but have some tails, the  $\sigma$ s of Table 1 were obtained from the FWHM of the distributions. Comparing the results for prompt and simulated events of Table 1 we observe identical reconstruction performance for the three  $Q$ -components within the errors (percent). 'Downstream' tracking worsens the  $Q_L$  reconstruction slightly by an additional 0.34 MeV/c as compared to the 0.5 MeV/c for 'full' tracking. Reconstruction in the transverse plane is significantly worse than for 'full' tracking (2.67 MeV/c and 2.69 MeV/c instead of 0.5 MeV/c for  $Q_x$  and  $Q_y$ , respectively), reflecting the strong multiple scattering in the up-stream detectors. We observe that reconstruction for  $Q_x$  and  $Q_y$  yields the same widths.

The shapes of experimental and simulated distributions show very satisfactory agreement.

We may use the IH detectors for confirming that a track has correctly passed the collimator in front of the magnet by asking a signal in either of the four IH slabs predicted by the track parameters or their adjacent neighbours, using the vertex fit or the method outlined in formula 1. Neither of the two methods have an influence on the resolution but both lead to losses of around 10%.

We have also tested accidental data and found perfect agreement with prompt data.

### 3.3 Monte Carlo simulation

The same studies as done for data have been done for Monte-Carlo Coulomb (CC) background. The results are shown in Figs 4, 5, 6, and summarized in Table 1. Comparing with data we observe that MC reproduces the experimental data well. The deviations from experiment are for  $Q_L$   $-3\pm 2\%$ , for  $Q_x$   $-0.4\pm 2.6\%$ , and  $0.4\pm 2.6\%$  for  $Q_y$ . We conclude, that Monte-Carlo reproduces data on the percent level.

Studies with ionization hodoscopes and accidentals yielded same results as data.

Table 1: Widths of distributions obtained by comparing 'downstream' tracking with 'full' tracking for events that were reconstructed by both methods (see Figs 4, 5, 6). Ni-2001 data, prompt, and Monte-Carlo simulated CC background.

|                    | $\sigma_{Q_L}$ [MeV/c] | $\sigma_{Q_x}$ [MeV/c] | $\sigma_{Q_y}$ [MeV/c] |
|--------------------|------------------------|------------------------|------------------------|
| prompt events      | $0.346\pm 0.005$       | $2.67\pm 0.05$         | $2.69\pm 0.05$         |
| simulated events   | $0.359\pm 0.005$       | $2.68\pm 0.05$         | $2.68\pm 0.05$         |
| <i>differences</i> | $-0.013\pm 0.007$      | $-0.01\pm 0.07$        | $0.01\pm 0.07$         |

## 4 Absolute characterization of 'downstream' reconstruction quality.

In order to characterize absolutely the reconstruction quality of 'downstream' tracking (extrapolation and interpolation methods) we compare Monte-Carlo simulated data from atomic pairs, from CC background and accidentals event by event with generated data just after the target.

The results on reconstruction quality are shown in Figs 7,8,9 and in Table 2. Quality is identical for atoms and CC background, indicating independence of  $Q$ .

For the extrapolation method the resolution for atoms in  $Q_L$  is found to be 0.55 MeV/c, for  $Q_x$  to be 2.86 MeV/c and for  $Q_y$  to be 2.62 MeV/c. The somewhat worse resolution in  $Q_x$  (additional sigma of 1.2 MeV/c) might be caused by multiple scattering in the Al-window at the magnet exit, which, in y-direction, is partially eliminated by the vertex fit.

The interpolation method for accidentals shows somewhat worse resolution for  $Q_L$  than for CC-background and atoms (additional 0.27 MeV/c), possibly due to the accidental nature of the events, and significantly worse resolution for  $Q_y$  (additional 1.43 MeV/c), due to the neglect of vertical magnetic deflection.

Table 2: Comparison of 'downstream' -reconstructed  $Q$ s with  $Q$ s generated and determined at the exit of the target for Monte Carlo simulated CC background, atoms (extrapolation method) and accidentals (interpolation method) for Ni-2001

|                               | $\sigma_{Q_L}$ [MeV/c] | $\sigma_{Q_x}$ [MeV/c] | $\sigma_{Q_y}$ [MeV/c] |
|-------------------------------|------------------------|------------------------|------------------------|
| atoms (extrapolation)         | $0.550 \pm 0.001$      | $2.864 \pm 0.006$      | $2.619 \pm 0.005$      |
| CC background (extrapolation) | $0.554 \pm 0.001$      | $2.887 \pm 0.004$      | $2.619 \pm 0.005$      |
| accidentals (extrapolation)   |                        |                        | $2.684 \pm 0.013$      |
| accidentals (interpolation)   | $0.616 \pm 0.002$      |                        | $3.040 \pm 0.018$      |

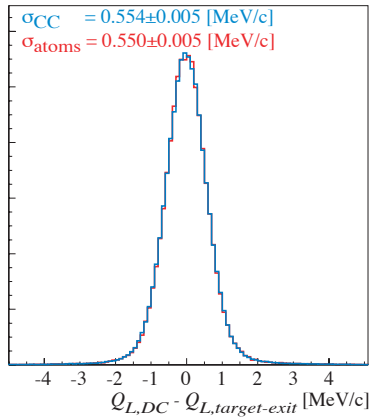


Figure 7: Difference of 'downstream'-reconstructed (extrapolation method)  $Q_L$  with  $Q_L$  generated and determined just after the target. Ni-2001 Monte-Carlo atoms and CC-background.

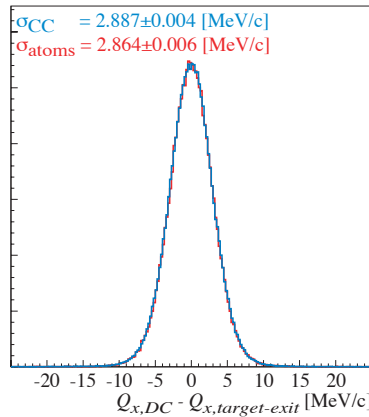


Figure 8: Analogous to Figure 4, but for  $Q_x$ . Extrapolation and interpolation methods provide the same results.

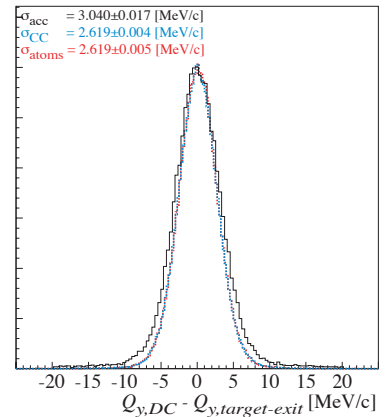


Figure 9: Analogous to Figure 4, but for  $Q_y$ , and additionally accidentals. (dashed for extrapolation method, solid for interpolation method).

## 5 Comparison of Monte Carlo with data.

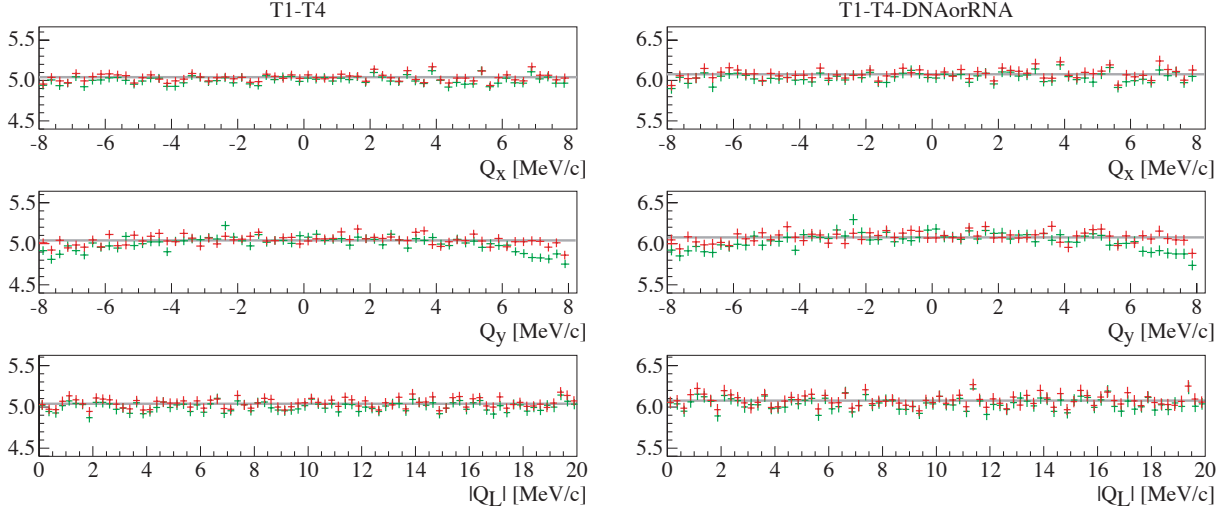


Figure 10: Ratio data over Monte Carlo for T1-T4 trigger (left) and T1-T4-DNAorRNA trigger (right), no vertex cut, for Ni2001 accidental data. Green: extrapolation, red: interpolation method. Solid lines indicate the constant fit results.

Monte Carlo events have been generated with a cut  $Q_T^{Generated} \leq 30 \text{ MeV}/c$ , and  $Q_L^{Generated} \leq 30 \text{ MeV}/c$  for accidental events, atoms and all prompt background. Reconstruction was done using 'downstream' tracking without any constraint on track quality. The trigger was simulated (T1-T4 and T1-T4-DNAorRNA) where adequate. The generator used pair momentum distributions that were optimized for  $Q_x, Q_y \leq 8 \text{ MeV}/c$ .

For the extrapolation method the vertical vertex position distribution for prompt data and Monte Carlo are found to be identical to those from Figs 1 and 2.

Accidental data were used with cuts at  $Q_x, Q_y \leq 8 \text{ MeV}/c$  to check the Monte Carlo reproducibility for  $Q_x, Q_y, Q_L$ . Fig 10 shows the result for T1-T4 and T1-T4-DNAorRNA trigger data. No vertex cut was applied for the extrapolation method. While for  $Q_x$  and  $Q_L$  the extrapolation and interpolation methods result in identical and perfectly uniform distributions,  $Q_y$  clearly is deviating from uniformity above  $|Q_y| = 4 \text{ MeV}/c$ . The interpolation method removes this deficiency completely.

The  $Q$ -distributions show the same features for T1-T4 and T1-T4-DNAorRNA trigger data.

We conclude that unbiased reconstruction needs the interpolation method. The extrapolation method could even better match the requirements, if it was properly extrapolating the track in vertical direction onto  $y_T = 0$  (vertex fit with vertex position at  $y_T = 0$ ). This would most certainly reconstruct the resolution in  $Q_y$  to a sigma of  $2.7 \text{ MeV}/c$ . The present ARIANE version does, unfortunately, not offer such a vertical vertex fit.