Studies of ATLAS Very Forward Detectors

DESY Summer Student Program 2007
report

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14$^{\text{th}}$ of September 2007

1 Introduction to Atlas Very Forward Detectors

The Atlas experiment at the LHC will measure collisions of two 7000 GeV protons. The aim of the Very Forward Detectors (VFDs) is to detect intact protons scattered at small angles, which would make possible to have some events with measured all particles in the final state.

Protons travel the distance between the interaction point and the detector in the beamline, i.e. in the magnetic field. The curvature of the proton that interacted will be different that the one that did not. For some range of energy, at the detector region, the proton is still inside the beamline, but far enough from the beam itself to be detected.

There are plans to install a few different very forward detectors in the distance of 200 – 500 meters from the interaction region. The detectors are to be placed in the roman pots to be able to move the detector close (few millimeters) to the beam, when it is stable enough.

The physics motivation of such detectors is to investigate diffractive events which would lead to better understanding of QCD. The large distance from the interaction point cause a good mass resolution for some events, for example a double pomeron Higgs production, so VFDs can be also be used for research on a new physics.

1.1 Roman pots at 220 m

As said before, there are a few projects of forward detectors for the Atlas experiment. I was mainly analyzing behavior of detectors "at 220 m". This project contains 4 detectors (2 from each side) located at 216 m and 224 m from the interaction point.

Detectors will measure the horizontal (x) and vertical (y) position (z is the coordinate along the beamline) of protons at each plane with resolution of 10 μm.

Below I introduce symbols and assumptions I will use. Incoming protons have their four-momenta respectively:

$$P_{01} = (p_0, 0, 0, -p_0) \qquad P_{02} = (p_0, 0, 0, p_0) \tag{1}$$

where $p_0 = 7000$ GeV is the beam energy. After the interaction, if proton remains intact, it has four-momentum:

$$P = (p, p_x, p_y, p_z) \tag{2}$$

where $p = \sqrt{p_x^2 + p_y^2 + p_z^2}$. To describe proton after interaction I will use another, equivalent variables ξ, p_T (transversal momentum) and φ defined as:

$$\xi = \frac{\Delta p}{p_0} = \frac{p_0 - p}{p_0} \tag{3}$$

$$p_T = \sqrt{p_x^2 + p_y^2} \tag{4}$$

$$\varphi \;-\; \text{angle between } x \text{ axis and the } \vec{p}_T = (p_x, p_y) \text{ vector} \tag{5}$$

1.2 My research

All my work was done with use of the FPTrack – program written by Peter Bussey (Department of Physics and Astronomy, University of Glasgow) with my tiny modifications. FPTrack computes proton transport through the beamline using the LHC Optics files. I used the "LHC Optics Version V6.500 Collision" for 7000 GeV protons.

2 Beam profiles

Using beam characteristics at the ATLAS interaction region I generated a set of particle momenta that was used as an input to FPTrack to see how beams look like at the detectors planes. I used: $\sigma(x_0) = \sigma(y_0) = 16.6$ μm, $\sigma(\theta_x) = \sigma(\theta_y) = 30.2$ μrad, $\sigma(E) = 0.77$ GeV.

The beam profiles that I managed to obtain are included in figure 1, their parameters – in table 1.

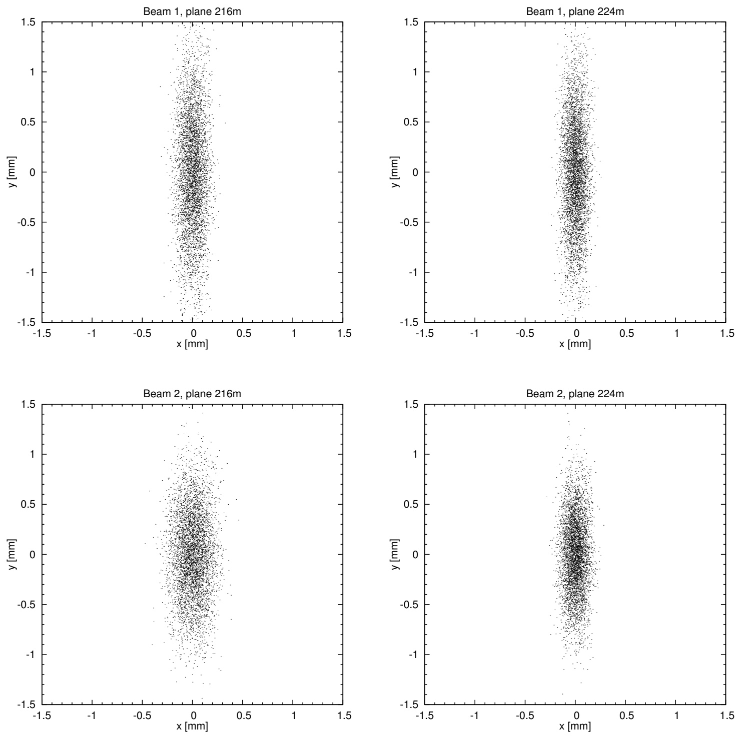


Figure 1: Beam profiles at ”220 m” planes

Beam	Plane	$\sigma(x)$	$\sigma(y)$
1	216 m	84 μm	547 μm
1	224 m	72 μm	508 μm
2	216 m	117 μm	407 μm
2	224 m	77 μm	368 μm

Table 1: Beam profiles parameters

3 Protons behavior

I studied how the hits left by the protons in the detectors depend on its kinematics. I generated another set of momenta corresponding to $\xi = 0, 0.02, 0.04, 0.06, 0.08, 0.10, 0.12, 0.14$. For each ξ I used one proton with $t = 0$ and $\varphi = 0$ and a set of protons with $t = -0.05$ GeV^2 and $\varphi \in [0; 2\pi)$ with step $2\pi/16$. I present the results in figure 2.

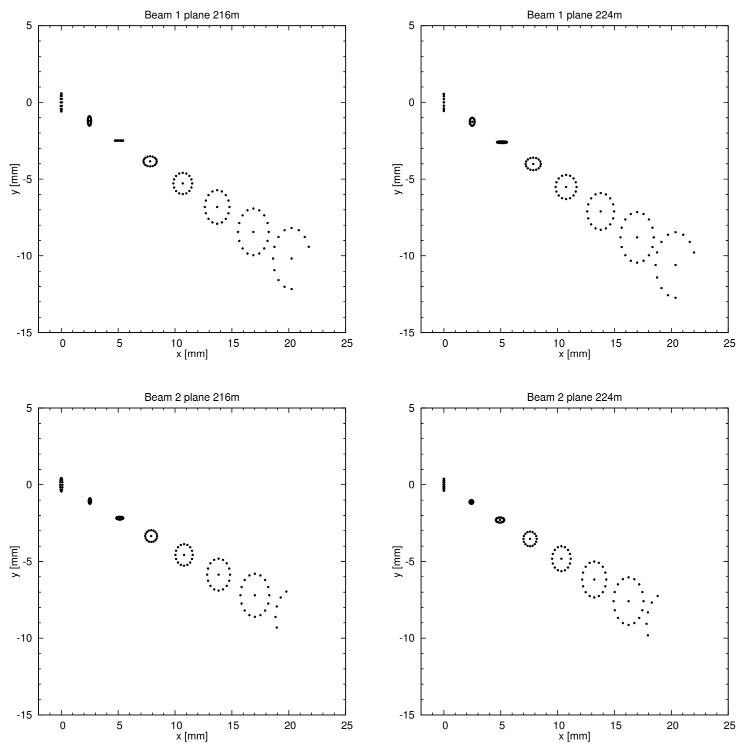


Figure 2: Hits of protons of different ξ, t and φ

It was interesting to find out which protons can be seen at the forward detectors. In order to study this I created a plot of acceptance as a function of ξ and t. In this case acceptance is understood as a ratio of particles with given ξ and t observed in the beamline at 220 m (small differences between 216 and 224 m are not important here) to the number of particles produced in the interaction point (with the same ξ and t). In figure 3 I include the plot of acceptance.

As we cannot build a detector that is able to measure particles in the

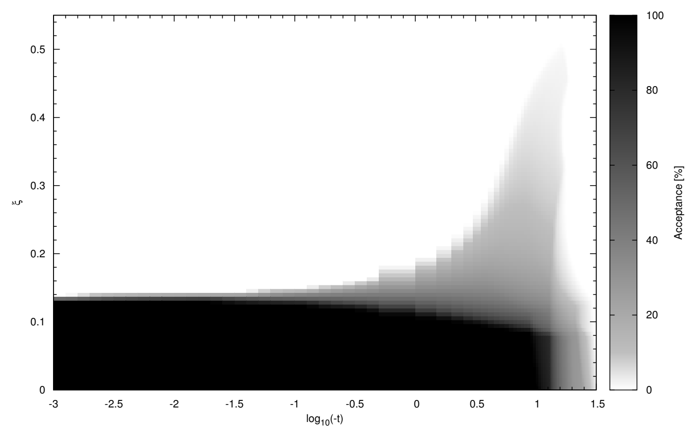


Figure 3: Acceptance at 220 m for beam 2

center of the beampipe (where the main beam is located) I checked what is the acceptance for a detector, that can measure only particles, with $|x| > 2$ mm and $|y| > 2$ mm. I present appropriate plot in figure 4.

The plots in figures 3 and 4 were created using uniform particle distribution in (ξ, t, φ) space. I created plot similar to the one in figure 4, but in order to investigate the real physics events I installed Pythia event generator and modyfied the output in such a way, that it was readible for FPTrack. Selecting process 93 from Pythia (single diffraction) I repeted the study of acceptance at 220 m. The results ars shown in figure 5.

4 Position in detectors as function of kinematic variables

Computing the positions of protons at the detectors planes using FPTrack is rather time consuming and doesn't give any easy way of event reconstruction. That is why I investigated the possibility of describing the position in the detector as a function of kinematics at the interaction point. In

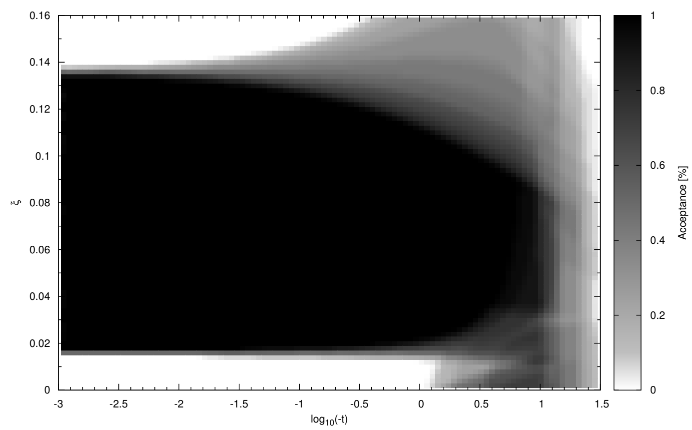


Figure 4: Acceptance at 220 m for beam 2 for a detector measuring only $|x| > 2$ mm and $|y| > 2$ mm

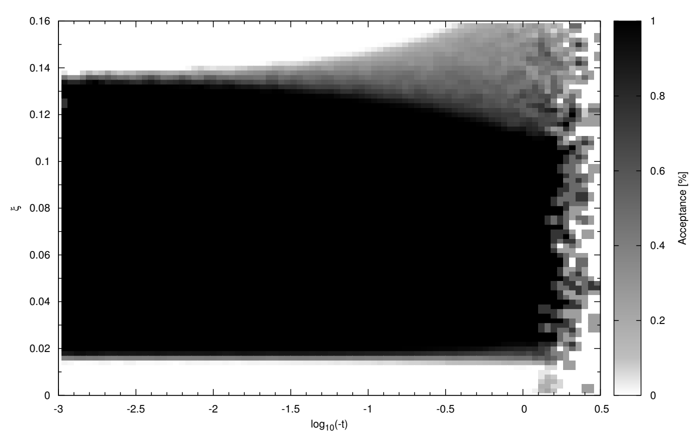


Figure 5: Acceptance at 220 m for beam 2 for a detector measuring only $|x| > 2$ mm and $|y| > 2$ mm. Particles generated with Pythia process 93 (single diffraction)

this part i will use following variables:

$$E = E_{loss} = \Delta p = p_0 - p = \xi p_0 \tag{6}$$

$$x_0' = \frac{p_x}{p_z} \tag{7}$$

$$x0 \; - \; \text{position of the interaction point} \tag{8}$$

As can be seen in figure 2 x coordinate od protons is more sensitive to changes of E_{loss} (or ξ) then the y coordinate. That is why I focused on the x-position. In this section everything is done for beam 2 and plane 220 m. In plots I used the most convenient units, whereas all the coefficients are computed for E_{loss} in GeV and everything else in SI units.

4.1 Dependence on E_{loss}

As a first step I checked the dependence of the x-position on the E_{loss} (for $x_0' = 0$ and $x_0 = 0$). The results are shown in figure 6 where I also present a fitted cubic polynomial defined in equation (9). Figure 7 contains a plot of dependence of the difference between real (FPTrack) value of x and $x(E_{loss})$. The degree of the polynomial is the smallest one that gave errors in figure 7 below 10 μm (which is the detector resolution). Values of the coefficients of the fitted polynomial can be found in table 2.

$$x(E_{loss}) = c_3 E_{loss}^3 + c_2 E_{loss}^2 + c_1 E_{loss}^1 + c_0 \tag{9}$$

Coefficient	Value	Error
c_0	$-7.5849 \cdot 10^{-07}$	$3.407 \cdot 10^{-08}$
c_1	$1.72336 \cdot 10^{-05}$	$3.104 \cdot 10^{-10}$
c_2	$2.63245 \cdot 10^{-09}$	$7.588 \cdot 10^{-13}$
c_3	$5.01785 \cdot 10^{-13}$	$5.245 \cdot 10^{-16}$

Table 2: $x(E_{loss})$ fit coefficients (see eq. (9))

4.2 Dependence on x-slope

Like in the previous analysis I checked (for few different E_{loss}) how the x position depends on the x_0'. In this case a linear function was good enough

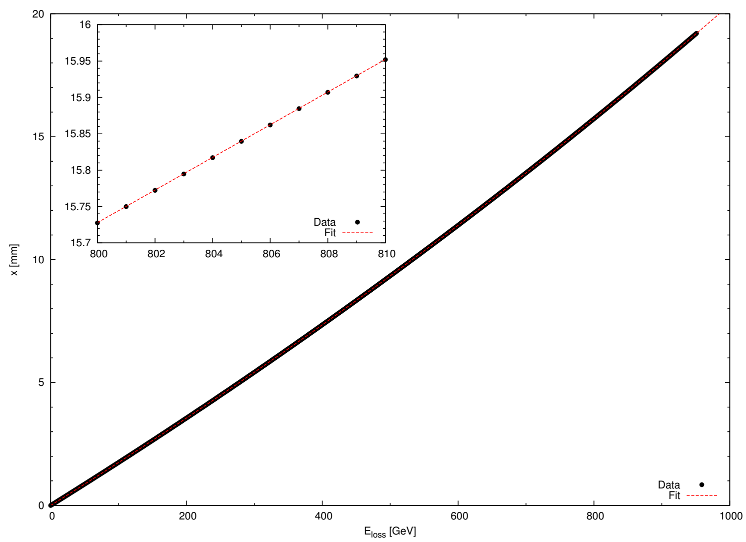


Figure 6: Dependence of x on E_{loss}

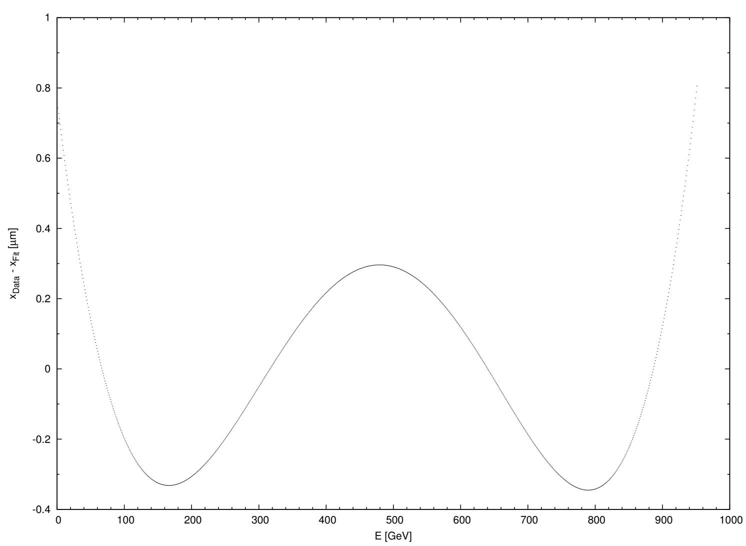


Figure 7: Fit error (difference between real (FPTrack) x and $x(E_{loss})$ from fit)

to fit the data. The plotted points and fitted lines are presented in figure 8, while differences between the FPTrack position and the fit are shown in figure 9.

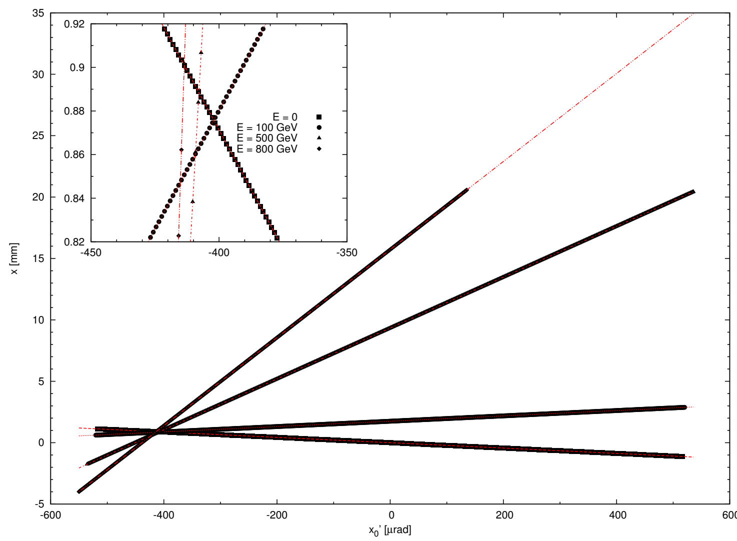


Figure 8: Dependence of x on x'_0 for few different energies

Knowing that the linear function is a good approximation, the next question is how its coefficients change with changing energy. This question was partially answered in the previous section, where $x(E_{loss})$ was found for $x'_0 = 0$, so:

$$x(x'_0, E_{loss}) = A(E_{loss})x'_0 + x(E_{loss}) \tag{10}$$

To parametrize $A(E_{loss})$ I wrote a script that generates a number of sets of plots like the one in figure 8 for different energies and for each of them it computes the linear regression slope coefficient. In figure 10 I present these coefficients as a function of E_{loss}. I fitted the distribution with a quadratic polynomial:

$$A(E_{loss}) = a_2 E^2_{loss} + a_1 E^1_{loss} + a_0 \tag{11}$$

Values of the coefficients of the fitted polynomial can be found in table 3, and error of the fit in figure 11.

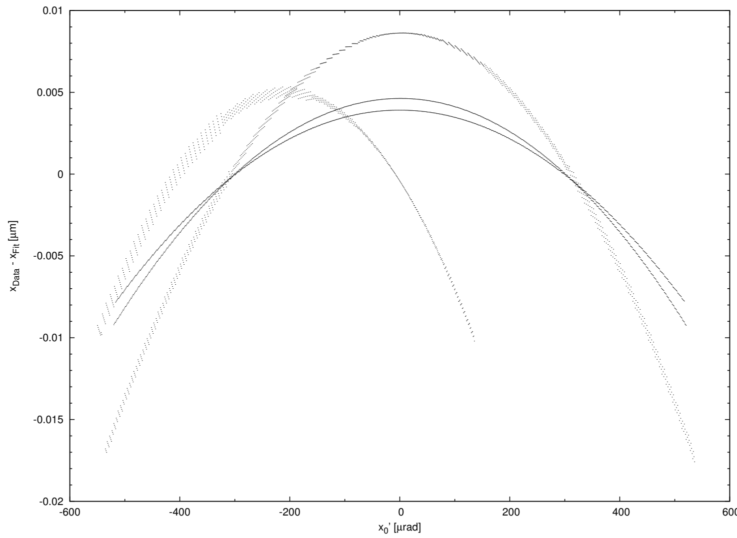


Figure 9: Fit error (difference between real (FPTrack) x and $x(x_0')$ from fit)

Coefficient	Value	Error
$a0$	-2.17214	0.0001551
$a1$	0.0428596	$7.171 \cdot 10^{-7}$
$a2$	$5.8288 \cdot 10^{-6}$	$6.95 \cdot 10^{-10}$

Table 3: $A(E_{loss})$ fit coefficients (see eq. (11))

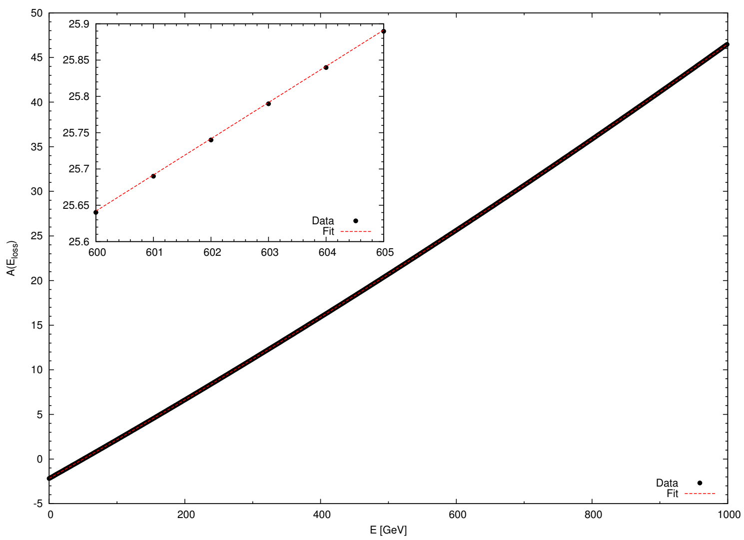
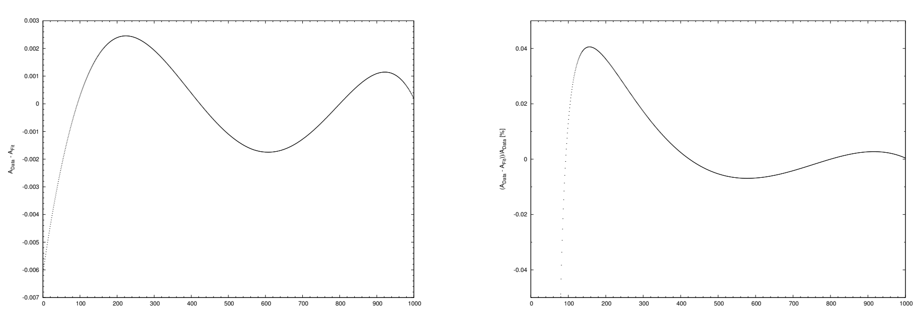


Figure 10: Slope coefficients of linear regressions for $x(x_0')$ plot as a function of E_{loss}



(a) Absolute error

(b) Relative error

Figure 11: Fit error for $A(E_{loss})$

4.3 Dependence on x_0

The last variable to check is x_0. In figures 12 and 13 are presented plots of the dependence for fixed E_{loss} and x'_0 and error of the linear fit. As can be seen in figure 13 linear fit works fine for this data, so we can write:

$$x(x_0, x'_0, E_{loss}) = B(x'_0, E_{loss})x_0 + A(E_{loss})x'_0 + x(E_{loss}) \tag{12}$$

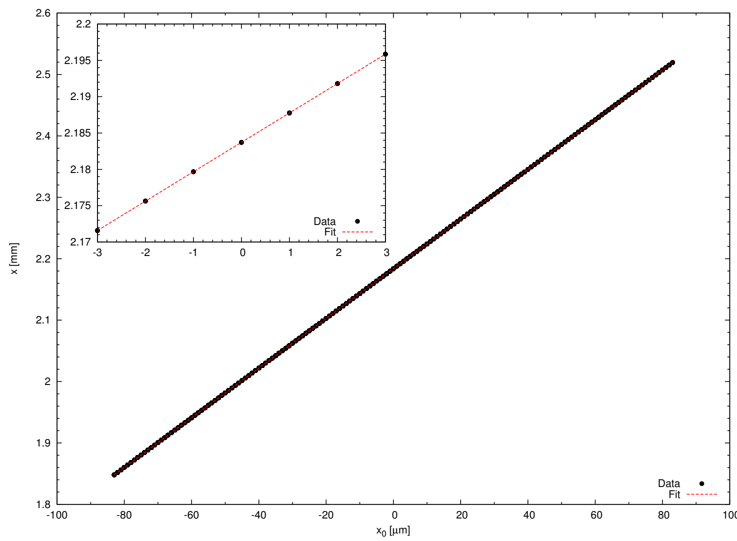


Figure 12: Dependence of x on x_0 for $E_{loss} = 100$ GeV, $x'_0 = 200$ μrad

Now the task is to find $B(x'_0, E_{loss})$. In figures 14(a) and 14(b) I present dependence of B on x'_0 for fixed $E_{loss} = 0$ and dependence of B on E_{loss} for fixed $x'_0 = 0$, respectively. Due to the fact that B changes only slightly with x'_0 I will treat it as a function of E_{loss} only. For fitting I take a quadratic polynomial as in the equation (13), the coefficients from fitting are included in table 4.

$$B(x'_0, E_{loss}) = B(E_{loss}) = b_2 E^2_{loss} + b_1 E^1_{loss} + b_0 \tag{13}$$

4.4 Fit result

Summarising, we have a following parametrization:

$$x(x_0, x'_0, E_{loss}) = B(E_{loss})x_0 + A(E_{loss})x'_0 + x(E_{loss}) \tag{14}$$

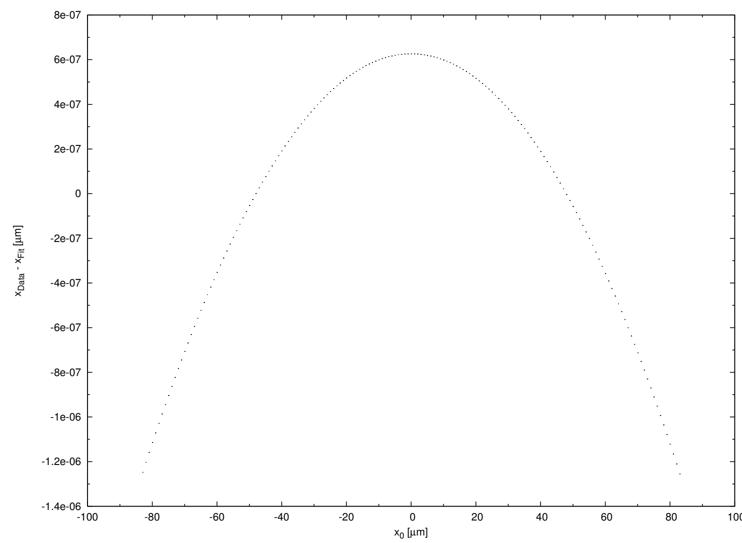
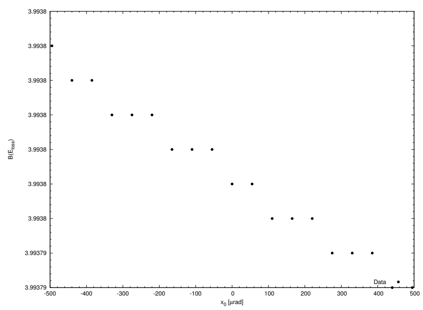


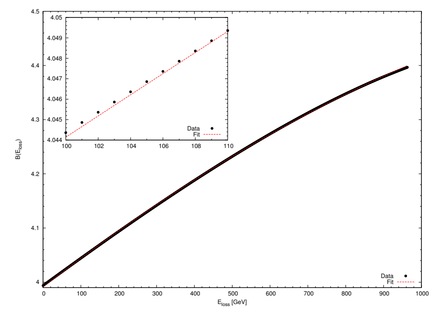
Figure 13: Fit error (difference between real (FPTrack) x and $x(x_0)$ from fit)

Coefficient	Value	Error
$b0$	3.991	0.000112
$b1$	0.000543821	$5.372 \cdot 10^{-7}$
$b2$	$-1.23759 \cdot 10^{-7}$	$5.401 \cdot 10^{-10}$

Table 4: $B(E_{loss})$ fit coefficients (see eq. (11))

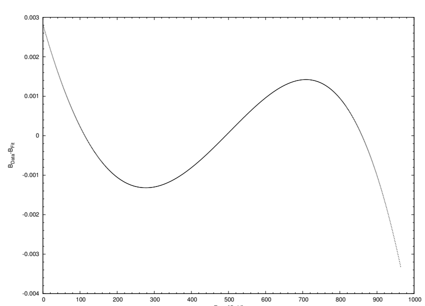


(a) Fixed E_{loss}

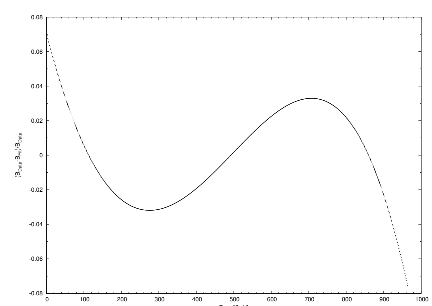


(b) Fixed x_0'

Figure 14: Dependence of B on x_0' and E_{loss}



(a) Absolute error



(b) Relative error

Figure 15: Fit error for $B(E_{loss})$

with $B(E_{loss})$, $A(E_{loss})$ and $x(E_{loss})$ given by the equations (13), (11) and (9), respectively.

To check how good the overall fit is I created another set of points with E_{loss}, x'_0 and x_0 covering the whole range of theirs values, that are seen at the detector plane. For each particle the difference between FPTrack x and $x(x_0, x'_0, E_{loss})$ from fit was computed. The results projected into a (E_{loss}, x) plane are presented in figure 16, where the detector resolution level is also shown.

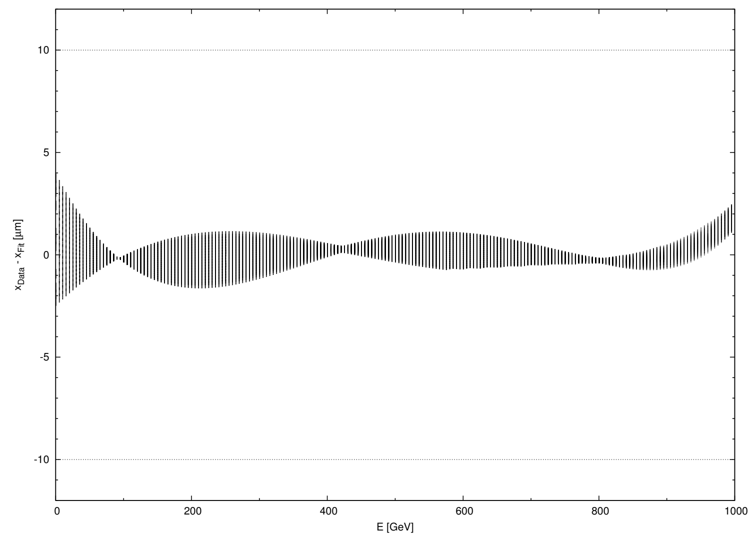


Figure 16: Overall fit error

As one can see, the precision of posiotion reconstruction provided by the proposed parametrisation is better then the detector resolution, so the formula can be used for faster simulation and event reconstruction of particles in the VFDx.