Detector Identification in the FPD System

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Abstract

This note describes the identification method of optical fiber detectors that is included in the algorithm code that is being used for reconstructing track trajectories in the Forward Proton Detector System. The (X_t,Y_t) track position at each Roman pot station is converted into a detector (fiber) number by using standard FPD's numbering and definitions, availables at the FPD home page. Only the proton arm quadrupole pots P1 and P2 will be considered in this memo.

1 Introduction

The Forward Proton Detector (FPD)[1] is conceived to measure diffracted particles ocurring in $p+\overline{p}$ events at Fermilab. Designed to be a subsystem of the DØ detector, it consists of a series of six castles (or pot stations) forming eight quadrupoles and one dipole spectrometers. Inside each Roman pot, optical fibers detectors will register hits left by particles diffracted in the spectrometers. From these light-output signals, X_t and Y_t (transverse positions) should be determined with great accuracy [1], allowing for a very good determination[2] of the phase space physical parameters at the Interaction Point (IP), located at the center of the DØ detector.

Since the conversion from fiber number to phase space physical parameters is of utermost importance in studying diffractive events, a reliable method to identify fiber ribbons light output with track coordinates X_t and Y_t needs to be created.

In Section 2, we present the method by which the trajectory of the diffracted particle is converted into detector numbers inside each Roman pot. An example is given in Section 3 and final conclusions are made in section 4.

2 Detector Identification

In the FPD system, there are 4 Roman pots in each quadrupole pot station (or castle). With respect to the beam direction, there are two horizontals, named Outward and Inward and two verticals, named Up and Down Roman pots, accordingly to Mike Martens' note *Coordinate System and Naming Conventions for the FPD Roman Pots*[3]. Each Roman pot will be equipped with 112 detectors disposed in 6 different planes: u and u′, v and v′, and x and x′. Each detector is composed of a ribbon formed by 4 ($0.8\ x\ 0.8\ mm^2$) scintillating fibers, as described in reference[1]. There are 20 detectors in each plane, with a gap of 0.27 mm betwen them, excepted for planes x and x′, with 16 detectors each. Primed planes are shifted by 0.54 mm with respect to the unprimed ones. The u-plane faces the beam incoming direction in all pot station, and has fibers detectors making 45° with respect to the bottom of the Roman pot, while the v-plane has its fibers making 135° and facing the outgoing beam direction. The x-plane is between u- and v-planes, with fibers in perpendicular direction with the bottom of the Roman Pot.

2.1 Horizontal Pots

The (horizontal) Outward and Inward pots will be located closer to both extremities of the electrostatic separator. The Outward Roman pot sits at x-positive values, while the Inward Roman pot sits at x-negative values, with respect to a coordinate system defined in *Coordinate System and Naming Conventions for the FPD Roman Pots*[3]. Their $8\sigma_x$ locations at both quadrupole stations are given at table 1.

2.1.1 u and u′ Planes

A sketch showing detector geometries and coordinate systems is given in figure 1 for u-detectors at horizontal Roman pots. X,Y refer to a coordinate system centered at the beam closed orbit[3], while X^O,Y^O and X^I,Y^I refer to coordinate systems that are fixed on the frame of u-plane detectors of pots Outward and Inward, respectively. A scattered proton that leaves a track P(X_t,Y_t) in the outward u-plane, for instance, has the following coordinates at the X^O,Y^O reference system:

$$Y^u = Y_{half} - Y_t, \tag{1}$$

$$X^u = X_t - X_{out}. \tag{2}$$

In the equations above, $X_{out} = 8\sigma_x$ is the horizontal pot positionning[1] with respect to the fixed reference system X,Y and Y_{half} is the detector frame half-width, the frame being a square with sides of 17.39 mm (see fig.1). In these new coordinate system, each detector N_i (from 1 to 20) can be defined by a straight line 0.8 mm wide, and whose intercept N_i^O on the Y^O axis lies inside a range given by

$$\Delta N_i^{inf} = (2.64 + (N_i - 1) \times \frac{0.27 + 0.80}{\cos(45°)})\ mm, \tag{3}$$

$$\Delta N_i^{sup} = (\Delta N_i^{inf} + \frac{0.8}{\cos(45°)})\ mm. \tag{4}$$

A threshold of 2.64 mm is taken into account in equations above in order to include the small dead area at each corner of the detector frame, which is indicated by the shaded triangles in figures 1 to 3. A diffracted particle that leaves a track $P(X_t, Y_t)$ in this Roman pot will excite a detector ribbon whose number (from 1 to 20) can be easely identified by comparing the track Y_0^u-intercept

$$Y_0^u = Y^u + X^u. \tag{5}$$

with equations 3 - 4, by a searching routine called by the track algorithm code described in reference[2].

Table 1 shows the 8σ Roman pots positions for both quadrupole pots on the proton arm. The proton closed orbit positions were taken into account in the determination of these values.

u$'$-planes are shifted down and to the left by 0.54mm with respect to the u-planes in all pot stations. In this case, the same equations above can be used to identify detector numbers at these planes, except that one has to take into account the smaller value of 1.876mm of the corner of the dead area of these planes.

2.1.2 v and v$'$ Planes

For v-detectors, it is more convenient to flip the direction of the Y^O axis, as it is shown in fig.2. In this case, the equations relating the X_t,Y_t coordinates to the X^v,Y^v are:

$$Y^v = Y_{half} + Y_t \tag{6}$$

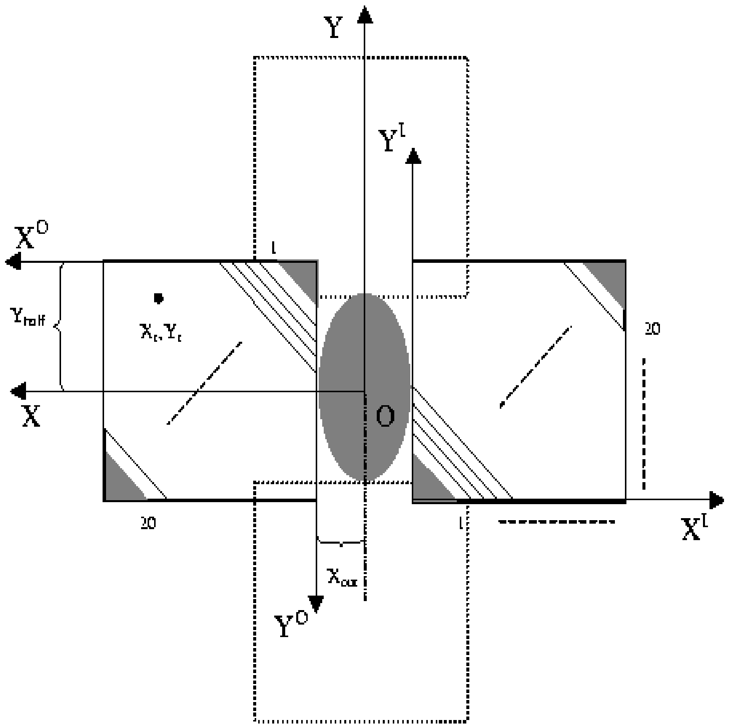

Figure 1: Sketch showing detector numbering and locations for u-plane detectors of a Roman pot. The Z axis is pointing into the plane of the page. X^I, Y^I and X^O, Y^O are the reference sistems that are fixed in detector frames at pots Inward and Outward, respectively (see text). X_{out} is the $8\sigma_x$ horizontal pot positionning, and Y_{half} is the detector-frame half-width. A track is represented by the track coordinates X_t and Y_t. Dashed squares are representing locations of vertical pots Up and Down, which are 152 mm behind horizontal pots. The shaded isosceles triangles are representing the dead area at each detector frame. It has equal sides of 2.64mm at low-left corners, and 1.876mm sides at up-right cornes. For u′ detectors, these numbers are swapped on these planes.

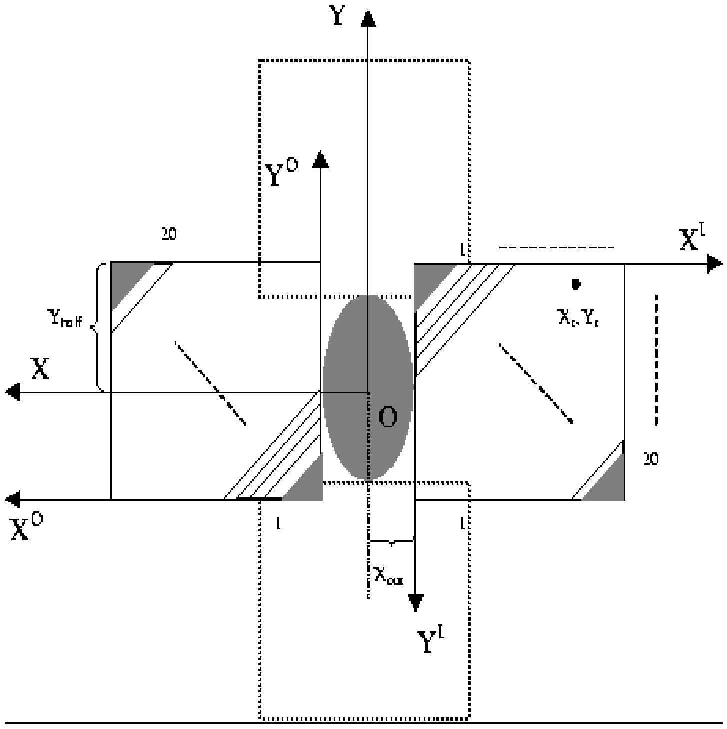

Figure 2: Same as figure 1 caption for v-plane detectors.

Table 1: Roman pots 8σ distances (in milimeters) for quadrupole pots at the proton arm. These values were obtained from Mike Martens calculations[4], where the position of the beam closed orbit were taken into account (see ref.[3]).

Roman Pot	Pot1 (mm)	Pot2 (mm)
Outward ($8\sigma_x$)	8.158	6.266
Inward ($8\sigma_x$)	- 8.158	- 6.447
Up ($8\sigma_y$)	14.570	12.189
Down ($8\sigma_y$)	- 14.570	- 12.229

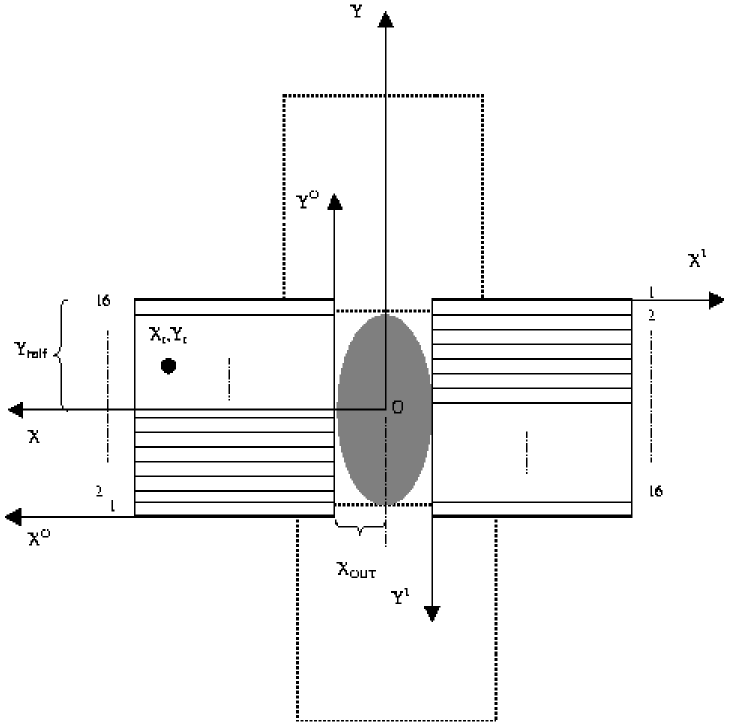

Figure 3: Same as figure 1 caption for x-plane detectors.

$$X^v = X_t - X_{out}, \tag{7}$$

These new coordinates allow for the determination of the intercept Y_o^v by using the same equation (5), but using 1.876mm as the corner of the dead area. The searching routine identifyes the detector hit (from 1 to 20) in this plane by the same procedure as it was outlined in section 2.1.1 above. v′ detectors are also shifted 0.54mm up and to the right with respect to v detectors, restoring the 2.64mm of equation (5) to be used in this plane.

2.1.3 x and x′ Planes

As shown in fig. 3, the same reference system used to identify v and v′ detectors can be used to identify x and x′ hit detectors (from 1 to 16) by scattered particles. In this case, the hit fiber can be easely identified by requiring that the value of Y^x, given by equation (6), has to be within the values given by the two following relations:

$$\Delta N_i^{x_{inf}} = (N_i - 1) \times (0.8 + 0.27)\ mm. \tag{8}$$

$$\Delta N_i^{x_{sup}} = \Delta N_i^{x_{inf}} + 0.8\ mm. \tag{9}$$

To identy x′ detectors, which are shifted by 0.54mm to the right of the x plane, the value of $Y^{x'}$, given by equation (6), has to be within the values given by the relation:

$$\Delta N_i^{x_{inf}} = 0,54mm + (N_i - 1) \times (0.8 + 0.27)\ mm, \tag{10}$$

and equation (9).

2.2 Vertical Planes

Vertical pots (Up and Down) at the same station should have an orientation such that the u-plane will be the closest to the interaction point. This is obtained by just rotating counter-clockwise (Roman pot UP) and clockwise (Roman pot Down) both planes and fixed frame reference system by 90 degrees. The reference system fixed on the detector frame on the vertical pots are always chosen in such a way as to preserve an intercept determination as given by equation (5).

3 A Testing Example

In order to test our detector id code, a complete calculation was performed using the steps outlined in reference[2]. We start with a probe particle at the IP region, defined such that $Z = Y = X = 0$. This probe particle corresponds to a diffracted proton with $\Delta P/P = -0.03$, which corresponds to a momentum fraction $x_p = 0.97$, and $t = 1.0$ GeV^2. This probe particle follows a trajectory that is completely determined, untill it reachs Pot1 and Pot2 locations. At these points, our searching routine is launched to identify the set of ribons (detectors) that are excited by the probing proton with (X_1,Y_1) and (X_2,Y_2) coordinates at these pot locations. The results obtained with such a procedure is given bellow. For a given $\Delta P/P$, t and ϕ, the track coordinates (XO,YO) and slopes (XOS,YOS) are converted by the searching routine to new coordinates at the detector-frame reference system. The first step is to verify that these new coordinates lie inside each frame detector size, thus identifying in which pot (Up, Down, Outward, Inward) the diffracted particle is. Then, from equation 5, a search is performed to identify such a value with the corresponding detector intercept, as given by equations 3 and 4.

$$***** *\Delta P/P = -0.030 ******$$
$$****** t = 1.0 GeV^2, \theta = 1.0153 mrad *****$$

ϕ = 0.0 rad, XO = 0.000 mm, XOS = 0.0000 mrad, YO = 19.288 mm, YOS = -0.3904 mrad

pot1 = Up
u = 8, u$'$ = 8
x = 9, x$'$ = 8
v = 8, v$'$ = 8

ϕ = 0.0 rad, XO = -0.112 mm, XOS = -0.0184 mrad, YO = 15.584 mm, YOS = -0.4010 mrad

pot2 = Up
u = 7, u$'$ = 7
x = 9, x$'$ = 8
v = 0, v$'$ = 7

ϕ = 1.571 rad, XO = 10.179 mm, XOS = -0.3719 mrad, YO = 0.0 mm, YOS = 0.0 mrad

pot1 = Outward
u = 6, u′ = 0
x = 9, x′ = 8
v = 0, v′ = 6

ϕ = 1.571 rad, XO = 6.674 mm, XOS = -0.3903 mrad, YO = -0.019 mm, YOS = -0.0106 mrad

pot2 = Outward
u = 5, u′ = 0
x = 9, x′ = 8
v = 0, v′ = 5

ϕ = 3.142 rad, XO = 0.0 mm, XOS = 0.0 mrad, YO = -19.288 mm, YOS = 0.3904 mrad

pot1 = Downward
u = 8, u′ = 8
x = 9, x′ = 8
v = 8, v′ = 8

ϕ = 3.142 rad, XO = -0.112 mm, XOS = -0.0184 mrad, YO = -15.626 mm, YOS = 0.3798 mrad

pot2 = Downward
u = 7, u′ = 0
x = 9, x′ = 8
v = 7, v′ = 7

ϕ = 4.712 rad, XO = -10.179 mm, XOS = 0.3719 mrad, YO = 0.0 mm, YOS = 0.0 mrad

pot1 = Inward
u = 6, u′ = 0
x = 9, x′ = 8

v = 0, v′ = 6

ϕ = 4.712 rad, XO = -6.892 mm, XOS = 0.3535 mrad, YO = -0.019 mm, YOS = -0.0106 mrad

pot2 = Inward
u = 5, u′ = 0
x = 9, x′ = 8
v = 0, v′ = 5

As it can be seen from the results above, the same set of detectors is found at equivalents Roman pots located on Pot1 and Pot2 castle, when ϕ varies by π, indicating the correctness of a such method.

4 Conclusions

This note discusses the method that is presently used by the searching routine to obtain detector identification in the FPD. The method is based in a transformation performed in the track position coordinates from the reference system centered at the beam closed orbit to a reference system that is fixed on the detector frame, for each detector plane. This transformation gives a track slope determination in this reference system that is compared to each projected detector width on the Y-axis, which allows unambiguously detector identification at each Roman Pot of the FPD system.

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References

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[3] M. Martens, Coordinate System and Naming Conventions for the FPD Roman Pots, A memo notice, FPD Web Page.

[4] M. Martens, private communication.