EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN/EP 80-99
CERN/EP/EHS/PH 80-5
11 June 1980

THE BUTTERFLY DRIFT CHAMBER GEOMETRY

AN OPTIMAL FOUR-PLANE DRIFT CHAMBER FOR USE IN A HIGH TRACK MULTIPLICITY ENVIRONMENT

CERN[1]-Rutgers University, New Brunswick[2]-Université de l'Etat à Mons, Mons[3].

F. Bruyant[1], J.M. Lesceux[3], R.J. Plano[2]

1. INTRODUCTION

The spectrometers used in high energy physics experiments impose stringent restrictions on the number and placement of drift chambers due to cost limitations as well as interference with other elements of the spectrometer. For these reasons, as well as to minimize the often neglected cost of computing, it is important to design wire chambers so as to optimize their performance for track reconstruction.

The main sources of difficulty in pattern recognition by conventional drift chambers, apart from the complexity of the events, arises from the left-right ambiguity due to unsigned drift times, and from the fact that tracks can pass through the wire planes at large angles of incidence to the planes - angles which, *a priori*, are not known. Both effects are amplified by wire inefficiencies and by overlap of track signals, especially in a high track multiplicity environment.

In section 2, the basic ideas of pattern recognition in a drift chamber are reviewed. In section 3, the butterfly geometry is described and compared with the usual Y U V Y-staggered geometry.

Presented at the Wire Chamber Conference
Vienna, Austria, 27-29 February 1980

2. TRACK RECOGNITION IN MULTI-PLANE DRIFT CHAMBERS

2.1 The number of planes

A single track traversing two wire-planes with different wire orientations generates three "ghost" impacts (fig. 1). A third plane with a different wire orientation reduces the number of ghosts to one if the three wires are seen to intersect (wire node), or to zero if the wires do not intersect.

In a multi-track environment, track signals are often lost because two signals arrive too close in time. In addition, a loss of efficiency occurs when a track passes close to a field wire.

A drift chamber should therefore have three, or better, four wire planes and the construction should be such that, independent of the orientation of the track, there are no apparent wire nodes.

2.2 Tracks normal to the wire planes

Given three planes with non-parallel wire inclinations (β_1, β_2, β_3) (fig. 2), the condition that a triplet of wire co-ordinates (ρ_1, ρ_2, ρ_3) must satisfy in order to correspond to a possible impact is given by:

$$\varepsilon = |\Sigma \rho_i f_i| < \varepsilon_1 \text{ with } f_i = \sin(\beta_j - \beta_k) \equiv S_{kj}$$

The cut $\varepsilon < \varepsilon_1$ serves to connect struck wires into impacts. The standard deviations σ_ε is given by $\sigma_\varepsilon = \Sigma \sigma_{\rho i}^2 f_i^2$. The errors in the impact parameters $\sigma_{\rho i}$ include the uncertainties in time zero, the clock least count, non-linearities in electron drift time, etc. Typical values are of the order of 100 to 300 microns.

When four wire planes are used, the definition of an impact (y,z) imposes two independent conditions. These conditions can be obtained by applying the intersection condition to any two subsets of three planes each:

$$|\sum_{i=1,2,3} \rho_i f_i| < \varepsilon_1(123) \text{ and } |\sum_{i=1,2,4} \rho_i f_i| < \varepsilon_1(124)$$

or by making use of two independent subsets of two planes (1,2 and 3,4 for instance), which gives the two symmetry conditions:

$$Y_{12} = Y_{34} \rightarrow |\sum_{i=1,4} \rho_i f_{1i}| < \varepsilon_{11}$$

$$Z_{12} = Z_{34} \rightarrow |\sum_{i=1,4} \rho_i f_{2i}| < \varepsilon_{12}$$

where the f_1's and f_2's are the following simple functions of the angles β:

$$f_{11} = C_2S_{34},\ f_{12} = -\ C_1S_{34},\ f_{13} = -\ C_4S_{12},\ f_{14} = C_3S_{12}$$

$$f_{21} = S_2S_{34},\ F_{22} = -\ S_1S_{34},\ f_{23} = -\ S_4S_{12},\ f_{24} = S_3S_{12}$$

2.3 Tracks inclined to the wire planes

The intersection and symmetry conditions are, in general, not exactly valid when the tracks are not incident normally on the wire planes. In most experimental setups, where the interaction takes place in a small region with a magnetic field bending the tracks in the deflection plane, say, (Y,X), there is a strong correlation between the position of an impact on a chamber and the angle of incidence of the corresponding track. The assumption that the track comes from the centre of the fiducial region gives a first approximation to the track direction. The difference between the exact track direction and the first approximation is called the residual tilt. The residual tilt in the deflection plane for most tracks of interest is limited to a few degrees and negligible in the plane (Z,X) parallel to the average magnetic field.

Since the sense wire planes are separated by a few centimetres, the track inclination introduces distortions to the intersection condition as defined above.

The first approximation of the track direction is used to project the wire co-ordinates onto the central plane of the chamber (fig. 3):

$$\rho_i \rightarrow \rho_i' = \rho_i - T_{\rho_i} \Delta_i$$

where

Δ_i is the (signed) distance from the i^{th} wire plane to the centre of the chamber, and

T_{ρ_i} is the slope of the track in projection onto a plane perpendicular to the wire direction: $T_{\rho_i} = - S_i . T_Y + C_i . T_Z$ (T_Y and T_Z being the track slopes as given from the first approximation of the track direction).

The exact projected co-ordinate ρ_i^* can be expressed as:

$$\rho_i^* = \rho_i - T_{\rho_i}^* \Delta_i$$

or

$$\rho_i^* = \rho_i + T_Y^* S_i \Delta_i - T_Z^* C_i \Delta_i$$

where

T_Y^* and T_Z^* are the slopes of the real track.

Then,

$$\rho_i' = \rho_i^* + \delta T_Y S_i \Delta_i - \delta T_Z C_i \Delta_i$$

with

$$\delta T_Y = T_Y - T_Y^* \qquad |\delta T_Z| < \Delta T_Y$$

$$\delta T_Z = T_Z - T_Z^* \qquad |\delta T_Z| < \Delta T_Z$$

maximum residual tilts

Assuming that each original ρ_i is perfectly known, namely only the effect of the tilt is considered, the three-plane intersection condition can be written as:

$$|\sum_{i=1,3} \rho_i' f_i| < \varepsilon_2, \text{ or equivalently } |\sum_{i=1,3} \rho_i f_i + T_Y A - T_Z B| < \varepsilon_2$$

with

$$\varepsilon_2 = |\Delta T_Y \sum_{i=1,3} S_i \Delta_i f_i| + |\Delta T_Z \sum_{i=1,3} C_i \Delta_i f_i|$$

The maximum residual tilts ΔT_Y and ΔT_Z depend only upon the design of the spectrometer and there is no way to minimize them once the experimental set-up is fixed, but the terms A and B depend only upon the geometry of the chamber planes.

As observed earlier in an attempt to improve the geometry of the Fermilab Hybrid Spectrometer PWC's[(+)], the tolerance ε_2 can be minimized and pattern recognition optimized by cancelling the term A. Both A and B cannot be cancelled simultaneously but since the quantity ΔT_Z is usually small (deflection due to the radial field), ε_2 is minimized if the chamber is built in such a way that A is identical to zero.

With four planes, two symmetry conditions can be developed, giving each two coefficients A and B.

$$A_1 = \sum_{i=1,4} S_i \Delta_i f_{1i} \qquad B_1 = \sum_{i=1,4} C_i \Delta_i f_{1i}$$

$$A_2 = \sum_{i=1,4} S_i \Delta_i f_{2i} \qquad B_2 = \sum_{i=1,4} C_i \Delta_i f_{2i}$$

As shown in the next section, it is not possible to cancel all four coefficients simultaneously, but any three of them can be zeroed by suitable construction of the chamber.

3. THE BUTTERFLY GEOMETRY

3.1 The characteristics of the Butterfly geometry

The main characteristics of the Butterfly geometry correspond to a choice of β_i's and Δ_i's which cancel A_1, B_2 and A_2. This is obtained by imposing the condition that the quantities $\frac{\Delta_i S_i}{C_i}$ $(= \Delta_i T_i)$ have the same value $\underline{\alpha}$ for all planes.

With such a configuration the first of the two symmetry conditions is exactly satisfied (as $A_1 = B_1 = 0$). The second condition is nearly satisfied ($B_2 \neq 0$, factorizes the small term ΔT_Z). Therefore, the wire pattern corresponding to a given impact is (quasi) invariant, i.e. is not modified by the perspective.

(+) Wire chambers: Tilted tracks and Dalitz condition
F.B. March 31, 1976 - unpublished.

Employing the natural spacing of four sense wire planes ($\Delta_1 = 3\ \Delta_2 = -\ 3\ \Delta_3 = -\ \Delta_4$) the relation between the tangents of the angles β have to be:

$$\frac{T_2}{T_1} = 3,\ \frac{T_3}{T_1} = -\ 3,\ \frac{T_4}{T_1} = -\ 1$$

with any value of β_1.

The wire patterns corresponding to real impacts being nearly tilt invariant as seen above, nodes of sense wires can be avoided even when seen from a large angle perspective, provided (1) there is no node in normal projection and (2), the pattern of wires reproduces itself without deformation throughout the chamber. The first condition can be achieved by a proper staggering of the planes, and the second by taking wire spacings equal in projection along the frame side for all planes.

These details of construction complete the definition of the Butterfly geometry, as displayed in fig. 4.

Another important advantage of the Butterfly drift chambers is that they do behave well even in the presence of a misfiring in anyone plane. Their construction characteristics are such that for <u>any</u> subset of three planes the (most important) coefficient A is zero.

3.2 The indetermination of the solution

The impossibility to cancel the four coefficients A_1, B_1, A_2, B_2 is due to the linear relations between the four ρ-co-ordinates and the four track parameters Y^*, Z^*, T^*_Y, T^*_Z :

$$\begin{pmatrix} \rho_1 \\ \rho_2 \\ \rho_3 \\ \rho_4 \end{pmatrix} = \underbrace{\begin{pmatrix} -\ S_1 & C_1 & -\ S_1\ \Delta_1 & C_1\ \Delta_1 \\ -\ S_2 & C_2 & -\ S_2\ \Delta_2 & C_2\ \Delta_2 \\ -\ S_3 & C_3 & -\ S_3\ \Delta_3 & C_3\ \Delta_3 \\ -\ S_4 & C_4 & -\ S_4\ \Delta_4 & C_4\ \Delta_4 \end{pmatrix}}_{M} \begin{pmatrix} Y^* \\ Z^* \\ T^*_Y \\ T^*_Z \end{pmatrix}$$

Indeed, the condition $\sum_{i=1,4} \rho_i^* f_{1i} = 0$ imposes

$$- Y^* \Sigma S_i f_{1i} + Z^* \Sigma C_i f_{1i} = 0 \text{ for all } Y^*, Z^*, \text{ i.e.}$$

$$\Sigma S_i f_{1i} = 0 \text{ and } \Sigma C_i f_{1i} = 0$$

and cancelling A_1 and B_1 leads to

$$\Sigma S_i \Delta_i f_{1i} = 0 \text{ and } \Sigma C_i \Delta_i f_{1i} = 0$$

The two relations cause the determinant of M to be zero. The first consequence is that it is impossible to find an independent second set of coefficients f_i satisfying these relations showing that A_2 and B_2 cannot be cancelled simultaneously with A_1 and B_1. The second consequence is that only three of the four parameters Y^*, Z^*, T_Y^* and T_Z^* can be determined: the fact that all $\Delta_i T_i$'s are equal (to α) causes the second and third columns of the matrix M to be proportional and the only three independent variables are Y^*, T_Z^* and $(Z^* - \alpha T_Y^*)$.

This indetermination has no consequence in our context of application, as Y^* is the essential variable (co-ordinate in the deflection plane). Z^* is known to the extent that T_Y^* is known (1st approximation) and can be readjusted later through the relation

$$\Delta Z = \alpha \Delta T_Y$$

3.3 Comparison of the Butterfly geometry with YUVY*

Simulation studies have been made to compare the performance of the Butterfly and YUVY* drift chamber geometries, taking into account realistic errors for the individual plane co-ordinates and multi-track losses.

The results quoted here apply to a 4 x 2 m^2 drift chamber located in the EHS(++) spectrometer 5 metres downstream to the bubble chamber, with the following basic parameters:

(++) EHS: European Hybrid Spectrometer, CERN/SPSC, P42, Add.

- Wire spacing : ~ 48 mm
- Wire inclinations: $106^{o}.67$, $95^{o}.70$, $84^{o}.30$, $73^{o}.33$ for the Butterfly
  90^{o}, 107^{o}, 73^{o}, 90^{o} for the YUVY*
- Sense wire plane separation : ~ 40 mm

3.3.1 Single track tests

The reconstruction is performed from the co-ordinates in all four planes, then from the co-ordinates in each subset of three planes (because of the symmetries only two of the four subsets have to be considered). This gives an exact image of the chamber behaviour under normal conditions and when one co-ordinate is lost.

The results, based on 36000 impacts, are summarized in Table 1.

Table 1

	4-plane	3-plane (1)	3-plane (2)	σ_Y	σ_Z
Butterfly	8	13	12	80	(360) theoretical limit
YUVY*	17	242	125	80	380
	Ambiguity rate in %			Reconstruction precision in μ	

3.3.2 Multitrack tests (+++)

The results for 1000 four-impact configurations and for 300 ten-impact configurations are displayed in Table 2, with detail of the numbers of "quadruplets" lost, and of external ambiguities (multiplets reconstructed from signals belonging to different impacts).

(+++) This part of the work has been done with the collaboration of Ian Matthews, Birmingham University, summer student 1977.

Table 2

Number of 4-plane impacts

	Lost	Ext. Amb.	Lost	Ext. Amb.
Butterfly	111	36	191	76
YUVY*	108	268	218	674
	for 1000 x 4 impacts		for 300 x 10 impacts	

Of course the loss of "quadruplets" generates "triplets" which are known to behave poorly in the YUVY* configurations.

FIGURE CAPTIONS

Fig. 1 Left-right ambiguities generating ghosts.

Fig. 2 β-ρ co-ordinate system.

Fig. 3 Projected wire co-ordinate.

Fig. 4 Butterfly geometry.

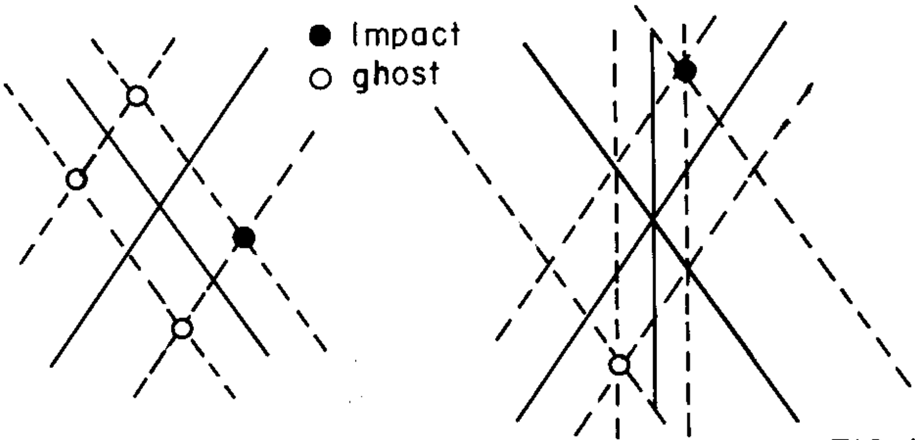

FIG. 1

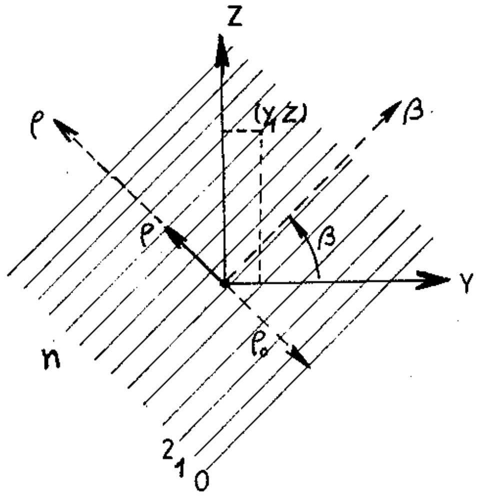

FIG. 2

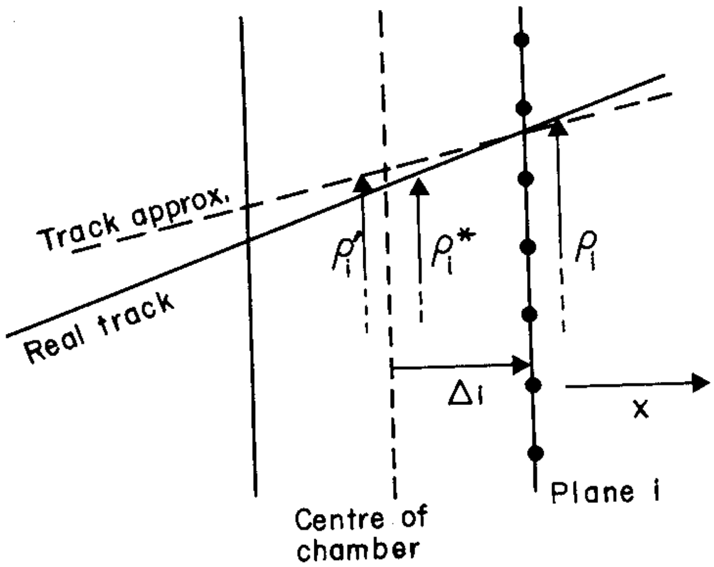

FIG. 3

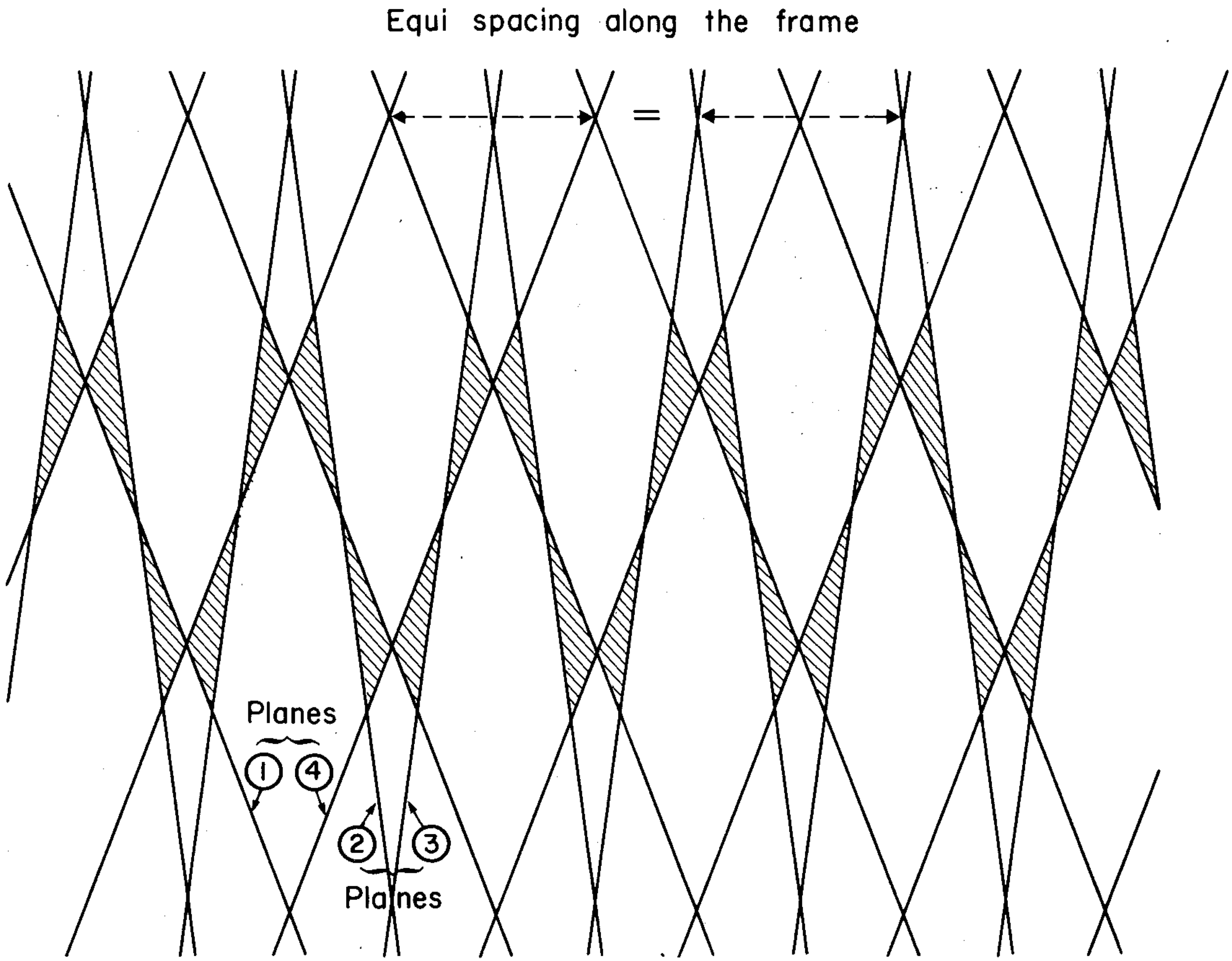

FIG. 4