

Note on Data Analysis for Streamer Track Chambers

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Dedicated to Professor Dr. W. GENTNER on the occasion of his 60th birthday

The analysis of streamer track chamber data can be performed using parts of the available bubble chamber analysis procedures with the exception of the geometrical part. Here major modifications are required in order to fit particle tracks to unmeasured vertices and to account for non-uniform magnetic fields. A method and its test, which is suited to handle these particular problems, is described.

A new experimental tool for high-energy particle physics has been developed in recent years and its usefulness, especially for studying multiprong events in a 4π geometry, could well equal that of the bubble chamber. Some authors call it the streamer track chamber (STC). The technical details of this device, and the present status of development are given in several papers¹⁻³, where references to earlier publications on this subject can also be found.

A very short description can be given as follows. A streamer track chamber is a box-like gas-filled enclosure. Two parallel and opposite side plates are conductive and at least one transparent. One can look at it as a large open condenser or a large transmission line. A high voltage pulse (20 kV/cm, length 20 nsec, risetime ≈ 1 nsec) applied to the conducting plates makes particle trajectories between the plates visible; discharge avalanches start to grow from the centers of primary ionization in the form of rather symmetrical streamers propagating towards the conducting plates. The growth is quenched due to the shortness of the high voltage pulse to a size of a few millimeters. The recombination light lets the particle track become visible. An impressive example of streamer tracks is shown in Fig. 1⁴. The resemblance between a streamer track chamber and a fast-cycling triggerable bubble

chamber has often been noted. As for bubble chamber experiments an efficient analysis procedure for experiments with streamer track chambers is also of great importance.

In this note we want to discuss some aspects of the analysis of STC pictures, in particular those problems where methods of analysis are required different from those used in current bubble chamber analysis.

I. Can Available Bubble Chamber Programs be Used for STC Analysis?

The experimental arrangement of a STC and an analyzing magnet, which we shall have in mind in this discussion, has some similarity to a bubble chamber and is presently being considered at SLAC⁵. A large rectangular STC (200 cm \times 150 cm \times 60 cm) is set up inside the gap of a circular bending magnet; the top pole piece of the magnet will be removed. Thus, the chamber (which has transparent top and bottom plates) can be viewed by three cameras placed on top of the magnet. A sketch of the magnet is shown in Fig. 2.

As for bubble chamber data, the analysis of STC data is to be done in three major steps:

i) The geometrical reconstruction of the event from (film) coordinates, i. e. the evaluation of the

¹ G. CHARPAK, L. MASSONNET, and J. FAVIER, The Development of Spark Chamber Techniques, CERN Preprint, Geneva 19 June 1964, submitted to Prog. in Nucl. Techn. and Instr.

² A. BOYARSKI, F. BULOS, R. DIEBOLD, A. ODIAN, B. RICHTER, and F. VILLA, Development of Streamer Spark Chambers, IEEE Transactions on Nuclear Science (Purdue Conference on Instrumentation for High Energy Physics), August 1965.

³ A. BOYARSKI, F. BULOS, R. DIEBOLD, A. ODIAN, B. RICHTER, and F. VILLA, Streamer Chamber Development, 5th Intern.

Conference on High Energy Acceleration, Frascati, Italy, September 1965.

⁴ Streamer tracks in a 35 mm \times 30 cm \times 8 cm chamber of passing positrons (500 MeV) and δ rays in a magnetic field. This picture was taken at the Mark III linear accelerator, Stanford, by D. BENAKSAS, D. DRICKEY, and R. MORRISON.

⁵ Experimental proposal for a study of high energy photo-production at SLAC by I. DERADO, D. DRICKEY, D. FRIES, R. MOZLEY, A. ODIAN, F. VILLA, and D. YOUNT.





Fig. 1. Four 500 MeV positrons passing through a streamer track chamber set up in a magnetic field. One COMPTON electron.

momenta and spatial angles at the vertex of the particles.

ii) The kinematical fit of the event into the constraint of energy and momentum conservation, which implies mass assignment to the extent that the masses are unknown and a test for missing (neutral) particles.

iii) The testing of physical models by studying angular distributions, cross-sections, etc.

The STC analysis essentially differs only in (i) from bubble chamber analysis. Once momenta and angles are determined one can make use of GRIND⁶, which is a widely used CERN computer program for kinematical analysis of bubble chamber data. Similar programs are available for (iii) or have to be written in each case as the experiment requires it.

Turning now to the geometrical reconstruction, one observes a number of points where STC analysis requires a modification or fundamental changes of the available bubble chamber analysis procedures:

a) Since the light output from STC is rather poor, one has to take pictures with large camera

apertures (f number 1 or 2). This entails large lens distortions for which the film coordinates have to be corrected. Also a "depth of focus" problem arises. One can consider tilting the usually vertical camera axis to decrease the distortion, but then, amongst other problems, that of spatial reconstruction (see below) becomes more complex.

b) In a STC light rays undergo only negligible diffraction, while in a bubble chamber thick glass plates are required between the camera and the chamber. In fact, one can use conducting mylar for the conducting plates of the STC. Thus, except for lens distortions and film stretch, the ideal film coordinates are just pinhole projections of the track points in the chamber. Furthermore, due to the density of the gas, energy loss and multiple scattering are mostly negligible for the STC.

c) Due to the fact that one often wants to analyze particle tracks passing through the STC, which are then recorded again in peripheral equipment like conventional spark chamber, matrix counters, wire chamber, etc., one cannot regard the magnetic field as constant. Furthermore, the analyzing magnet itself containing the STC may be

⁶ GRIND, CERN TC Program Library, and see, for example, R. Böck, CERN Report 61-29, Geneva, 19 October 1961.

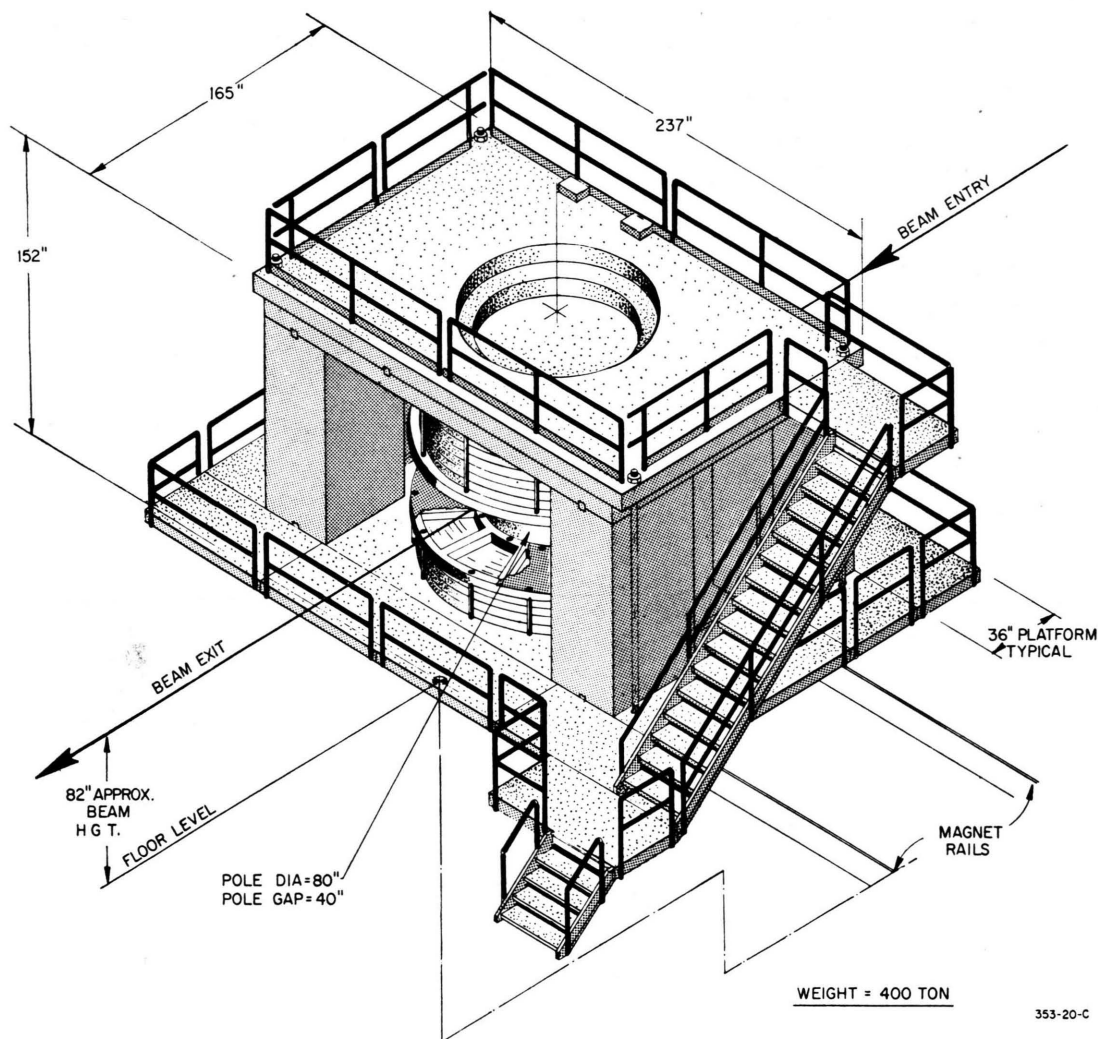


Fig. 2. Drawing of the large analyzing magnet for streamer track chamber experiments at SLAC.

a rather open construction with field non-uniformities of 30% or more. Therefore the theoretical trajectory of a particle cannot be described mathematically as a helix or polynomial of low order.

d) The vertex of a high-energy interaction is often not observed in a STC experiment since the target is either outside the chamber, or it lies in an insensitive region inside the STC (e.g. a mylar bag filled with H_2 gas). Hence one wants to optimize all observed trajectories *simultaneously*, together with an *unobserved* interaction vertex; whereas bubble chamber geometry programs usually fit one track at a time to a measured vertex. The fitting problem itself thus gets more complex in

many respects. For example, one expects large off diagonal elements in the covariance matrix.

Points (a) and (b) could be taken into account by minor modifications of some of the available bubble chamber geometry programs, at least if one does not want to tilt the camera axis. However, points (c) and (d) require essentially a different approach.

II. Reconstruction of Spatial Points and Fitting in the Film Plane

The experimental data in a STC experiment may consist of measured film coordinates (u, v) (from

two or more cameras) as well as directly measured spatial coordinates (x, y, z) of the track (from peripheral detection equipment). The analysis procedure should be adaptable to both kinds of data input.

In the conventional method a theoretical curve is being fitted to spatial track points, which are reconstructed from measurements on film. An intermediate step of this procedure is the computation of the corresponding point, that is to say, for each point measured on film I (view I) one has to compute a point on view II or view III, such that both correspond to the projection of one and the same spatial point (x, y, z) into the film planes. The standard procedure to find corresponding points by choosing the appropriate stereo system should not be described here. The main disadvantages of the method of spatial reconstruction is the fact that the reconstructed points (x, y, z) have correlated errors and are not GAUSSIAN distributed. A more sophisticated method is to fit film coordinates directly to the projection of the theoretical track onto film⁷. There one fits GAUSSIAN and uncorrelated measurements (to the extent that optical corrections of the film coordinate have a small effect on the error of the coordinates). Moreover, fitting in the film plane can, in principle, be done without any corresponding points.

In order to cope with the difficulties described in (c) and (d) of the preceding section, and in order to be able to analyze data input such as film coordinates as well as measurements of spatial points, two different STC analysis procedure for a digital computer have been developed at SLAC. The first one optimizes (reconstructs) the event (momenta, spatial angles at the vertex, and the vertex itself) from spatial coordinates (x, y, z) , which may or may not be reconstructed from measurements on film⁸; the second one being a fit in three film planes is adapted directly for an input of film measurements⁹.

In the following we describe briefly some features of the first analysis procedure and the result of a test run.

III. Geomerical Analysis for Streamer Track Chamber Data

It is assumed that the data input are measurements x, y, z . The magnetic field with all components can be computed at each point of the STC (e.g., by polynomials fitted to the measurements). The theoretical trajectory in our procedure is the solution of the differential equation describing the path of a charged particle through a magnetic field:

$$\frac{d\mathbf{u}}{ds} = 2.997 \cdot 10^{-2} \frac{1}{p} (\mathbf{u} \times \mathbf{B}); \quad (1)$$

$$\mathbf{u} = \frac{dx}{ds}, \frac{dy}{ds}, \frac{dz}{ds};$$

$$s = \text{arc length [m]};$$

$$\mathbf{B} = \text{magnetic field [kG]};$$

$$p = \text{momentum [BeV/c]}.$$

A solution is uniquely determined by a set of the following parameters α : $\mathbf{r}_0 = (x_0, y_0, z_0)$ = vertex coordinates, \mathbf{u}_0 containing the angles at the vertex, and p the momentum. These parameters are to be optimized. Since we want to fit N tracks simultaneously to the same vertex, the problem is in fact a $3N + 3$ parameter fit. The least-squares fit procedure takes the familiar form¹⁰; it has to be minimized:

$$\chi^2 = (\mathbf{m} - \mathbf{m}^*)^T \mathbf{G} (\mathbf{m} - \mathbf{m}^*),$$

where \mathbf{m} is the vector of measured quantities (coordinates), and \mathbf{m}^* are the expected quantities. $\mathbf{m}^* = \mathbf{F}(\alpha, s)$ = the numerically computed theoretical track coordinates. (T stands for "transposed".) \mathbf{G} is the weight matrix which should be the inverse of the covariance matrix of the measurement errors in the coordinate. Since the problem is non-linear in the parameters, one has to iterate starting from a first estimate of the parameters. Each iteration gives corrections $\Delta\alpha$ to the parameters by:

$$\Delta\alpha = (\mathbf{A}^T \mathbf{G} \mathbf{A})^{-1} \mathbf{A}^T \mathbf{G} \Delta\mathbf{C},$$

where $\Delta\mathbf{C} = \mathbf{m} - \mathbf{m}^*$ are the residuals in the i -th iteration, $\mathbf{A} = \partial\mathbf{F}/\partial\alpha$ is the matrix of partial derivatives in respect to the parameters.

⁷ F. T. SOLMITZ, A. D. JOHNSON, and T. B. DAY, Three View Geometry Program, Alvarez Group "Programming Note", P-117, 8 June 1965 (unpublished).

⁸ D. E. C. FRIES, Geometrical Reconstruction of High Energy Interactions in Spark Chamber Magnet Arrangements (submitted to Nucl. Instr. and Methods).

⁹ To be published.

¹⁰ See, for example, R. BÖCK, CERN Report 60-30, Geneva 15 August 1960.

The numerical solution of Eq. (1) is being computed by a third order RUNGE-KUTTA method. m^* , the theoretical coordinate entering the residuals, is obtained by a closest-distance criterium. In each integration step a distance vector \mathbf{d} between a measured point m and the track coordinate is being tested until it has passed its minimum. Then the track coordinate m^* in the actual minimum is computed.

The partial derivatives for the matrix A are obtained by introducing a variation $\delta\alpha$ into Eq. (1) and computing the partials numerically in each point m . A criterium for convergence of the iteration procedure is $\Delta\alpha^T (A^T G A) \Delta\alpha < 1$, which means that the current correction $\Delta\alpha$ lies already within the error ellipsoid defines as:

$$\Delta\chi^2 = 1$$

(provided G is the invers of the covariance matrix of the coordinates).

The method has been tested with simulated streamer tracks. Photoproduction events of the type:

$$\gamma + p \rightarrow \varphi + p \rightarrow K^+ + K^- + p$$

have been simulated assigning the input data x, y, z random GAUSSIAN errors $\Delta x, \Delta y, \Delta z$. For the photon energy there was a bremsstrahlung spectrum simulated between 3 BeV and 15 BeV. The production mechanism was assumed to be of the diffraction type. The parameters assumed for the test with simulated input correspond to measurements and design parameters of the experimental set-up mentioned in Section II:

$$\begin{aligned} \langle \Delta x \rangle = \langle \Delta y \rangle &= 0.5 \text{ mm} && \text{GAUSSIAN distributed,} \\ \langle \Delta z \rangle &= 1 \text{ mm} && \text{GAUSSIAN distributed,} \\ \text{STC dimensions} &= 200 \text{ cm} \cdot 150 \text{ cm} \cdot 60 \text{ cm} \end{aligned}$$

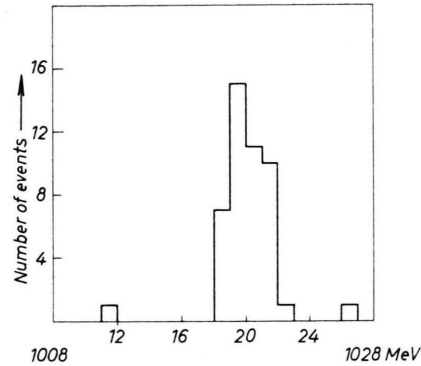


Fig. 3. Fitting of simulated events. Mass distribution of the fitted φ 's, photoproduced from a bremsstrahlung spectrum.

magnetic field $B_z = 15$ kG with 30% non-uniformity over the STC with

$$0 \leq B_r \leq 3.0 \text{ kG.}$$

target length 1 m,

invariant mass of the $\varphi = 1020$ MeV,

halfwidth = 0.

The vertex was assumed to be unobserved. The results can be shown by plotting a histogram of the invariant mass of the fitted φ 's (Fig. 3). The observed halfwidth corresponds to the experimental resolution for the mass distribution of the φ in the set-up considered.

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