CB-Note 118

Version 1.33/00

LEAR Crystal Barrel Experiment, PS197
Global Tracking Particle Bank Structure

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Contents

1 Introduction

This memo describes the Global Tracking Particle Banks in Crystal Barrel software. These are the banks it is anticipated will be used for analysis of events after the reconstruction pass through the data has been completed. The LATEST version is described in this memo, the section titled '**HISTORY**' should be read to follow any changes in time to the software. This is necessary, users should check the version number in the events they use and see what features have subsequently changed (this is particularly true if you use DST's created in 1990).

Some jargon is used in this memo and is explained as followed: A track is an object found in the JDC by LOCATER, a PED (Karlsruhe definition: Particle Energy Deposition) is a signal in the Barrel (reconstructed by BCTRAK), a matched-PED is a PED which has been associated with a track, and an un-matched PED is a PED which was not associated with any track. A particle is defined as any track or un-matched PED.

Anyone who uses PI0FND (otherwise known as PHYSAC) should read Appendix II.

2 History

The first released version of the software was simply called version 2, and was used in March 1990. Since then the version numbering system has changed drastically. The current version is version 1.33/00 (13300) and includes the following corrections and updates:

Version 1.0/05 (June 1990) contained:

- The pointers JTTKS to the TTKS sub-banks can be defined in two ways (see Section 9). However previously the banks were lifted in such a fashion that if you called the particles 1 to N in one scheme for obtaining JTTKS, then you would find them in the reverse order in the other definition of JTTKS. This obviously has great potential for confusion. It has been changed so that now the numbering scheme is independent of the method of defining the pointer and also agrees with the particle number (word 1) saved in the sub-bank.

- Previously the TBTK bank had a similar problem numbering the PEDs and their pointers. The result was that for charged tracks in TTKS sub-banks, the matched PEDs were correctly identified but some of their properties incorrectly filled into the sub-bank (words +11,12,33,34,35,39,40 and 41 are affected, remember this is only in the charged track TTKS sub-banks of version 2). This has now been corrected. The method now is to always identify PED I in the TBTK sub-bank as that given by pointer LQ(LTBTK-IQ(LTBTK-2)-I).

- A new dummy subroutine (GTDEDX) is called once per event. This is after the banks (if any) are lifted. The intention is that this will eventually interface to the de/dx analysis.

- The new method of finding the version number has been implemented. This uses as the version number the pam version multiplied by 10000 plus the update number.

Version 1.1/00 (July 1990) contained:

- The dE/dx code of C.Strassburger (CB Memo 137) has been added to routine GTDEDX and words 26 to 30 in TTKS sub-banks are now filled.

- TTKS particle sub-bank word +11 changes. It was (number of PEDs in the same cluster as this un-matched PED) *plus* 100 times the crystal type, 1 to 13, of the central crystal in the un-matched PED. It is now (number of PEDs in the same cluster as this un-matched PED) *plus* 100 times the compound index of the central crystal in the un-matched PED. Nb. The crystal compound index is defined as: $\phi + (\theta - 1) \times 60$.

Version 1.1/01 (July 11^{th} 1990) contained:

- Old (extra) dummy call to GTDEDX removed (has no effect).

Version 1.1/02 (July 17^{th} 1990) contained:

- Uses updated dE/dx formula.

Version 1.1/03 (August 21^{st} 1990) contained:

- TTKS sub-bank word +26 $\rightarrow$ +30 changed from probabilities to χ^2 for the dE/dx.
- TTKS sub-bank words +44 and +45 are now filled correctly. Previously for charged tracks they were incorrect and should be ignored.

Version 1.1/04 (Sept. 24^{th} 1990) contained:

- Changes in the TCVP bank necessitated some change in the method of calculating some TTKS sub-bank words. NB. The definition of all TTKS words is unchanged.

Version 1.20/00 (Oct. 8^{th} 1990) contained:

- **MAJOR CHANGE**. 4 extra words have been added into the TTKS sub-banks. These are at +36, +37, +38 and +39. All words previously at +36 $\rightarrow$ +47 are now at +40 $\rightarrow$ +51. The new words are for un-matched PEDs and are the energy and u,v,w directional cosines (in that order) of the parent cluster. Note that in the remainder of this History Section the pointers to values in TTKS sub-banks use the previous numbering convention.

Version 1.20/01 (Oct. 25^{th} 1990) contained:

- A bug in the lifting of the TTKS banks was found and corrected.

Version 1.20/02 (Oct. 31^{st} 1990) contained:

- **MAJOR CHANGE**. The Global Tracking vertex banks are now filled. These are banks TVTX and sub-banks TVTV. They are simply copies of the LOCATER vertex banks TCVX and TCVT. The advantage is that the copies are in the Global Tracking Zebra division, so the vertex information will still exist even if the LOCATER Zebra division is dropped on a DST or mini-DST.

Version 1.20/03 (Nov. 9^{th}, 1990) contained:

- A bug in lifting vertex banks was found and removed. Too much space was being reserevd in zebra (no effect for users).

Version 1.20/04 (Feb. 4^{th}, 1991) contained:

- Word +36 in the TTKS sub-banks was only filled for matched PEDs, this was a mistake and it is now filled for un-merged PEDs as well.

Version 1.20/05 (Late Feb. 1991) contained:

- Unused +PAM lines in the cmz file were removed.

Version 1.20/06 (March 10^{th} 1991) contained:

- The constants for the dE/dx routine are now read from the data base.
- Word +10 in the TTKS sub-bank has been extended, its value is now: old value plus 1000000$\times$(layer containing last hit on a track)

- In routine GTBANK the call to the CERNLIB function PROB has been adjusted. It is now only called if the χ^2 is greater than 0.000001, previously it was called if χ^2 greater than 0.0 and this caused an underflow error on about 1 in 2000 events processed.

Version 1.21/00 (July 22^{nd} 1991) contained:

- **MAJOR CHANGE**. The Global Tracking vertex banks now have a new sub-bank appended to them. This is called TVVP, and is a copy of the LOCATER vertex fit TCVP sub-bank. It contains the vertex fit constrained momentum etc for tracks fit to the vertex. Note that the TTKS sub-banks now always contain charged track momentum etc as given by the LOCATER helix fit.

Version 1.21/01 (Sept 1991) contained:

- Remove several debug statements accidentally left on.

Version 1.21/02 (Oct 11^{th} 1991) never released.
Version 1.21/03 (Oct 16^{th} 1991) contained:

- TTKS sub-bank word 10 is changed. What used to be *number of hit layers* is now the *total number of hits (JDC plus PWC) on a track*. In addition the number of PWC hits on the track is added as 100000000×(number of PWC hits on a track) to the previous contents.

Version 1.21/10 (Mar 18^{th} 1993) contained: split-off recognition (Dolby-C/Smart/neural networks) adds 7 new words at the end of the TTKS bank (two words each) with the following meaning:

- integer : Dolby-C : -2 for below threshold, -1 for charged, 0 for good gamma, > 0 for split-off (value indicates parent TTKS id).
- integer : Dolby-C : TTKS id of parent for split-off, 0 for non-split-off
- integer : SMART : return code
- integer : SMART : pointer to parent
- real : neural net : split-off probability
- integer : neural net : pointer to parent
- integer : BCTRAK (bits 1..16) and LOCATER (bits 17..32) user flags

Version 1.30/02 (Jul 2^{nd} 1994): This version is following the locater release 1/90.

- Logging errors on non-error condition has been disabled in gtbank.
- Implement /GTGLUE/ factors in GTBANK.
- Use GTVERS to print out version.
- Use TCRSLT to get helix information, as it is always corrected for /GTGLUE/.
- New deck gtvers(lun,ivers) to return current version number of global tracking.
- New deck gtdump(lun,pointer,qbad) to print the ttks banks.

Version 1.31/00 (Jul 13^{th} 1994): no changes

Version 1.32/00 (Jul 20^{th} 1994): no changes

Version 1.33/00 (Jan 23^{rd} 1995)

- split-off recognition packages DOLBY-C, SMART, TAXI2 and single Xtal flagging are now available in the official code. Options for neural network BRAIN have been installed, too, but not the code itself. Common block modified: /GTFLAG/ New common blocks: /GTSOST/ (allow to store the splitoff info in the TTKS bank), /GTSOCO/ (split-off statistics), /GTTAXI/ (TAXI internal variables)
- All splitoff handling is called from the new subroutine GTSOFF, which tests first if the corresponding logical is set and is written to the TTKS banks if the storing logicals are true. Flags are then set in TTKS word 3, if the PED is found to be a split-off. Further info is stored in words 52..57, see the global tracking manual for details. IEHDCB(12) holds the number of good gammas, if any of the split-off routines is turned on.
- new patch GT_TAXI to keep the TAXI code in a seperate directory.
- example kumac file to build a library on the dec-station: //gtrack/gtkumac/kumac_dec
- replace the track probability in TTKS word 13 by the χ^2/degree of freedom. A cut on probability is very dangerous, but a cut on χ^2 may be quite useful to select good quality tracks

Version 1.33/01 (Feb 9^{th} 1995)

- repair small bugs which were distributed with the last release. (initialize dolby-C properly, crystal index in tarond, ..)

Version 1.33/02 (Feb 13^{th} 1995)

- NO WAY of getting the correct version if the CMZ sequence VERSQQ is hardwired in the code! That must have been introduced at version 1.31/00 I removed the content of the sequence by the CMZ sequence call. (GTBANK,GTVERS)
- Inserted the printing of all splitoff recognition packages which have been selected (GTVERS)

Version 1.33/03 (Mar 3^{rd} 1995)

- TTKS word 53 was not filled correctly for TAXI (TAXSTO)

3 How to use

The code for Global Tracking is contained in the cmz file GTRACK. Updates are distributed via cmz update files. When using Crystal Barrel software, control of Global Tracking is via an FFREAD card GLOB. This should be included in the INPUT file for the job. The default (in the absence of the GLOB card) is to do everything involved with Global Tracking, both the matching of tracks and PEDs and, if no banks exist already, to lift the resulting particle banks. If you include the GLOB card you **must** include the options 'TRAK' and 'MTCH' otherwise no matching will ocur nor will any banks be lifted. To turn off the Global Tracking altogether you should include the GLOB card followed only by 'NONE' (similar to LOCATER and BCTRAK control cards). At the start of the job a message is printed giving the date of the creation of the version of Global Tracking used. At the end of the job a list of statistics particular to Global Tracking is printed.

Note that due to a Crystal Barrel convention, when reconstructing events the order (assuming they are requested) is: CRYSTALS, JDC then GLOBAL TRACKING. If at any stage an error code is produced processing of that event is immediately terminated. So if BCTRAK or LOCATER hits a problem GLOBAL TRACKING is not called. Thus you can find events on processed tapes that do not contain the GLOBAL TRACKING banks. When doing analysis you must therefore always check an event for the presence of the GLOBAL TRACKING banks.

4 Philosophy

The method of matching tracks to PEDs is described in Appendix I. After matching, a 'particle' is a charged track or an un-matched PED. Information on all particles plus vertices found in an event is saved in a series of ZEBRA banks. The banks are stored in a structure where there is an overall header bank (**HTRK**), an overall particle header bank (**TTKS**) and individual **TTKS** sub-banks for each separate particle. There is also a vertex header bank (**TVTX**) followed by sub-banks (**TVTV**) particular to each vertex found. The vertex information is copied from LOCATER (if there is no vertex found or if LOCATER has not been run a LOCATER vertex bank is created with the vertex at the origin, so **EVERY EVENT** processed by Global Tracking **CONTAINS A VERTEX**). All stored information has units of **cm., MeV** and **radians**. This is the standard CB convention.

The various header banks give information about the overall properties of an event (e.g how many particles/un-matched PEDs/charged tracks/vertices there are in the event) and the TTKS and TVTV sub-banks information on an individual particle or vertex. The contents of each bank are described in the remaining sections of this memo. However first a note of caution. The TTKS sub-banks contain particle information on un-matched PEDs (showers) and the charged tracks. For PEDs the information is obtained from the TBTK banks filled by BCTRAK. For charged tracks the information concerning momentum etc is that given in the LOCATER helix fit (TCTR) bank. If a good vertex has been found LOCATER will carry out a vertex constrained fit to the attached charged tracks, and the results of this fit (with potentially superior momentum resolution) are saved in the TVVP bank (which is a sub-bank of the Global Tracking vertex banks, and is a copy of the LOCATER TCVP vertex fit sub-bank).

Since separate TTKS sub-banks only exist for tracks and un-matched PEDs, it appears at first glance that no information on the matched PEDs in an event appears in the Global Tracking banks. However this is not correct. Some words in the TTKS sub-banks are only defined for tracks and some for un-matched PEDs, and not for both. In such cases the word is present but empty if the particle is of the wrong type. The exception to this rule is that in a sub-bank for a track the words unique to un-matched PEDs are in fact filled; they are filled with the appropriate values calculated for the matched PED associated with that track.

5 HTRK Bank

Offset	TYPE	*Quantity*
+1	INTEGER	*Version number*
+2	INTEGER	*The number of vertices in the TCVT sub-banks*
+3	INTEGER	*The number of particles in the TTKS sub-banks*

Table 1: Data stored in the **HTRK** bank

This bank can be read in the usual way by using the pointer plus the offset to each word. A pointer is the bank name preceded by an L, e.g. LHTRK, and all pointers to Global Tracking header banks are available in CB common block CBLINK.

- Word 1, VERSION. The bank structure may change with time, so a version number will always be saved. This formed from the PAM version and update numbers. The PAM number is multiplied by 10000 and added to the update number. So for example, PAM 1.1/3 becomes version 11003
- Word 2 This is the number of vertices in the TCVT sub-banks.

- Word 3 This is the number of particles (charged tracks plus unmatched PEDs) in the TTKS sub-banks.

6 TVTX Header Bank

This bank can be read using the pointer LTVTX. There is only one (integer) word in this bank, it is the number of vertices (n) in the event. There is also a pointer to each vertex sub-bank (TVTV). These are saved in locations LQ(LTVTX-i), i = 1 to n. If LOCATER did not find a vertex, a default vertex at the origin is created by the Global Tracking (with TVTV error code 1000).

7 TVTV Sub-banks

These are copies of the TCVT (LOCATER) vertex sub-banks. To read the bank for the I^{th} vertex the user can use the pointer to the bank in the fashion shown below

```
JTVTV = LQ(LTVTX-I)
IF (JTVTV .NE. 0) THEN
  .
  . quantity = Q(JTVTV+...)
  .
END IF
```

The contents of the bank are as shown and described below.

Offset	TYPE	*Quantity*
+1	INTEGER	*Number of charged tracks*
+2	INTEGER	*Number of un-matched PEDs*
+3	INTEGER	*Error code*
+4	INTEGER	N_{DF}
+5	REAL	$x[cm]$
+6	REAL	$y[cm]$
+7	REAL	$z[cm]$
+8	REAL	C_x
⋮	⋮	⋮
+14	REAL	χ^2

Table 2: Data in the **TCVT** sub-bank

- Word 1 is the number of charged tracks fit to this vertex.
- Word 2 is the number of un-matched PEDs at this vertex. All un-matched PEDs are assumed to come from the main (first) vertex.
- Word 3 is an error code returned from the TCVRTX routine for this vertex. It has the following meanings:

  0 Normal convergence occurred.

  100 Only one track fit to this vertex.

  300 The iterative routine converged with a too large χ^2.

400 The χ^2 started to diverge for this track.

500 The routine did not converge in the allowed number of iterations.

600 The number of tracks to fit was out of range.

700 The routine tried to invert a singular matrix.

1000 The vertex is the default vertex lifted by GLOBAL TRACKING (x=y=z=0.0)

- Word 4 N_{DF} is the number of degrees of freedom from the fit.
- Word 5 is the x coordinate of the fit vertex, [cm].
- Word 6 is the y coordinate of the fit vertex, [cm].
- Word 7 is the z coordinate of the fit vertex, [cm].
- Words 8-13, C_x contain the 6 unique elements of the 3 by 3 symmetric covariance matrix for $\vec{x}$. They are stored as follows:

$$\begin{pmatrix} +8 & * & * \\ +9 & +10 & * \\ +11 & +12 & +13 \end{pmatrix} = \begin{pmatrix} \sigma_{xx} & \sigma_{xy} & \sigma_{xz} \\ \sigma_{xy} & \sigma_{yy} & \sigma_{yz} \\ \sigma_{xz} & \sigma_{yz} & \sigma_{zz} \end{pmatrix}$$

- Word 14 is the resulting χ^2 of the fit with N_{DF} degrees of freedom.

7.0.1 TVVP

The **TVVP** data bank contains fit momentum information for all tracks coming from the corresponding vertex. The **TVVP** bank is a subbank under the **TVTV** data bank descrbing the vertex. To read the bank for the I^{th} vertex the user can use the pointer to the bank in the fashion shown below

```
JTVTV = LQ(LTVTX-I)
IF (JTVTV .NE. 0) THEN
  JTVVP = LQ(JTVTV-1)
    IF (JTVVP.GT.0) THEN
  .   quantity = Q(JTVVP+...)
  . END IF
END IF
```

The bank contains the following information for every track. The length of each block is given by the parameter LENVP obtained using +CDE,TRKPRM..

- *Track number* is the track number from the **TCTR** data bank.
- *Quality word* is the track length in hits plus one hundred times the first layer of the track plus ten thousand times the error code from the helix fit.
- *Charge* is the electric charge of this particle. It is possible for this to be different from the charge in the **TCTR** bank, as the vertex fit is allowed to change the charge of a track.
- p_x is the improved x–component of momentum.
- p_y is the improved y–component of momentum.
- p_z is the improved z–component of momentum.

Offset	TYPE	*Quantity*
+1	INTEGER	*Track Number in* **TCTR**
+2	INTEGER	*Quality Word*
+3	REAL	Charge of particle.
+4	REAL	p_x *[MeV/c]*
+5	REAL	p_y *[MeV/c]*
+6	REAL	p_z *[MeV/c]*
+7	REAL	*E [MeV]*
+8	REAL	$\sigma^2[px]$ *[Mev/c]*^{2}
+9	REAL	$\sigma[p_{xy}]$ *[Mev/c]*^{2}
+10	REAL	$\sigma^2[p_y]$ *[Mev/c]*^{2}
+11	REAL	$\sigma[p_{xz}]$ *[Mev/c]*^{2}
+12	REAL	$\sigma[p_{yz}]$ *[Mev/c]*^{2}
+13	REAL	$\sigma^2[p_z]$ *[Mev/c]*^{2}
⋮	⋮	⋮

Table 3: The data stored in the subbank of the **TVTV** data bank, (the **TVVP** bank). The above information is repeated for every track.

- E is the energy under the assumption the particle is a pion.
- The remaining six terms are the unique elements of the three by three covariance matrix for the momentum.

$$\begin{pmatrix} +8 & * & * \\ +9 & +10 & * \\ +11 & +12 & +13 \end{pmatrix} = \begin{pmatrix} \sigma_{xx} & \sigma_{xy} & \sigma_{xz} \\ \sigma_{xy} & \sigma_{yy} & \sigma_{yz} \\ \sigma_{xz} & \sigma_{yz} & \sigma_{zz} \end{pmatrix}$$

8 TTKS Header Bank

The bank pointer is LTTKS.

Offset	TYPE	*Quantity*
+1	INTEGER	*The number of particles*
+2	INTEGER	*The number of charged particles*
+3	INTEGER	*The number of un-matched PEDs*

Table 4: Data stored in the **TTKS** header bank

- Word 1 This is the total number of particles in the event, and hence the number of TTKS sub-banks (word 1 = word 2 + word 3).
- Word 2 This is the number of charged tracks in the event.
- Word 3 This is the number of un-matched PEDs in the event.

9 TTKS Sub-bank

To read these banks use the JTKS pointers defined in the fashion shown below

```
   JTTKS = LQ(LTTKS-1)
10 IF (JTTKS .NE. 0) THEN
     .
     . (this code is executed for every PARTICLE)
     . e.g quantity = Q(JTTKS+...)
     .
     JTTKS = LQ(JTTKS)
     GOTO 10
   END IF
```

Or you can directly obtain the pointer to the i^{th} PARTICLE from:

```
JTTKS = LQ(LTTKS-IQ(LTTKS-2)-I)
```

One note of caution, some words refer to PEDs, others charged tracks. The words which refer uniquely to PEDs are filled, even if the particle to which the bank as a whole refers to is a charged track. In such cases words numbers 11, 12, 33, 34, 35, 36, 37, 38, 39, 43, 44 and 45 are filled with the appropriate values calculated for the matched PED (if any).

Word by word the bank is:

- Word 1 This is the i^{th} particle in the event.
- Word 2 This indicates if the data comes from Crystals (0), the JDC (1), or PI0FND (2).
- Word 3 This will/may eventually contain the GEANT id of the particle type most favoured by our analysis. However, this word is negative, if the PED has been found to be a splitoff. In that case the bit pattern gives the type of splitoff: Bits 1-4 are set if the splitoff information comes from DOLBY-C, SMART, BRAIN, or TAXI, respectively. If PI0FND has been used this word = 7 for a π^o or 17 for an η.
- Word 4 Charge
- Word 5 Number of points used in dE/dx.
- Word 6 If this is a charged track this is it's id in the TCTR bank.
- Word 7 The PED id in the TBTK bank. If this particle is a charged track this is the TBTK id of the PED it is matched to (if any).
- Word 8 The vertex in the TVTX bank that the particle starts at.
- Word 9 The vertex (if any) at which the particle decays. This is not yet defined for any particle.
- Word 10 Charged track quality word. This allows a user to make a quick assessment of the worth of this track. It is a compound word and consists of: the number of hits on a track (JDC plus PWC) *plus* 100×(first JDC layer hit) hit *plus* 10000 times the track fit error code (obtained from LOCATER) *plus* 1000000×(JDC layer containing last hit on the track) *plus* 100000000×(number of PWC hits).
- Word 11 Shower quality word. This allows a user to make a quick assessment of the worth of a PED. It is a compound word and consists of: the number of PEDs in the same cluster as this one, *plus* 100 times the compound index of the central crystal in the PED. Nb. compound index = $(\theta - 1) \times 60 + \phi$.

- Word 12 More PED information. It is the number of the cluster *plus* 100 times the number of crystals in the cluster. The word is negitive if in the cluster there is a PED matched to a charged track.
- Word 13 This **was** the probability from LOCATER for a charged tracks reconstruction. Since version 1.33/00 we write the χ^2 per degree of freedom. This may help very much when selecting for good tracks. The number of degrees of freedom used is $(3 \times \sharp of JDChits) - 5$
  For NEUTRAL DATA this word is the energy of the central crystal of the PED.
- Word 14 Momentum (P).
- Word 15 Energy. For un-matched PEDs this is the TBTK energy, and for charged tracks this is calculated as if the track were a pion.
- Word 16 Px. For un-matched PEDs Px, Py and Pz assume the particle comes from the origin. For charged tracks these quantities are calculated at their vertex of origin.
- Word 17 Py.
- Word 18 Pz.
- Word 19 Error on P.
- Word 20 Error on the energy.
- Word 21 Error on Px.
- Word 22 Error on Py.
- Word 23 Error on Pz.
- Word 24 The value of dE/dx.
- Word 25 The error on dE/dx.
- Words 26 to 30 The χ^2 from the dE/dx for a particle to be either an electron, muon, pion, kaon or proton respectively. To obtain a probability remember that the number of degrees of freedom is 1. The algorithm used in the dE/dx is described by C.Strassburger in CB Memo 137.
- Word 31 Only filled if the particle is a charged track matched to a PED. It is the cosine of the angle used in matching. The angle is defined as the angle between two vectors; each starts at the origin, one points to the PED, the other to the charged tracks intersection point on the crystal face. If not filled the default value is -1000.
- Word 32 Filled for all particles. For charged tracks it is the cosine of the angle to the closest **unmatched** PED. For un-matched PEDs it is the cosine of the angle to the closest charged track.
- Word 33 For un-matched PEDs this is E1/E9 and gives information on shower shape.
- Word 34 Second moment of PED.
- Word 35 Showermass of parent cluster.
- Word 36 The energy of the parent cluster.
- Word 37 The u directional cosine of the parent cluster.

- Word 38 The v directional cosine of the parent cluster.
- Word 39 The w directional cosine of the parent cluster.

The remaining words in the bank are those needed for input to the kinematic fit. The quantities are the measured quantities in the form with the most gaussian-like errors.

- Word 40 ψ direction for charged tracks at their origin.
- Word 41 1/Pxy for charged tracks.
- Word 42 Tan(λ) for charged tracks. Opening angle of track. Note that we use λ to avoid infinities when taking the tangent.
- Word 43 ϕ angle for PEDs
- Word 44 θ angle for PEDs
- Word 45 The square root of E for PEDs.
- Words 46 to 51 This is the covariant error matrix in lower triangular form for the three quantities per particle needed by the fit. For charged tracks these three quantities are words 40, 41 and 42, and for un-matched PEDs are words 43, 44 and 45.
- Words 52 to 57 (from version 1.21/10 on) :
  - Dolby-C : -2 for below threshold, -1 for charged, 0 for good gamma, > 0 for split-off (value indicates parent TTKS id).
  - TAXI : for charged tracks it's the Number of associated unmatched PEDs in the TAXI-Cluster; for neutral tracks it's the TTKS id of the parent matched PED, or 0 for non-split-off.
  - SMART : return code
  - SMART : pointer to parent PED
  - neural net (BRAIN) : split-off probability
  - neural net (BRAIN) : pointer to parent PED
- Word 58 (from version 1.21/10 on) : BCTRAK (bits 1..16) and LOCATER (bits 17..32) user flags

10 APPENDIX I: MATCHING

The method of matching is in essence simple: Charged tracks are projected to the face of the crystals and if a PED occurs at the same place a match is made. The tracks are those in the TCTR (helix fit) bank and the PEDs those in the TBTK bank. I only use tracks with: at least 3 hits, a TCTR error code less than 30 and a non-zero track curvature. These cuts select 91.9% of TCTR tracks (all numbers in this appendix were obtained from a sample of minimum bias trigger data taken in Dec. 1989). The tracks are projected using the LOCATER subroutine TCBARL. I then form the (x,y,z) 3-vector from the origin to the point of intersection, and a 3-vector of the directional cosines of the PED (which are calculated assuming the PED comes from the origin). The normalized scalar product of these two vectors is found and yields the cosine of the track to PED opening angle. For each track this is found for every PED, and the largest cosine (if greater than 0.98) flags the matching PED. The distribution of cosines is shown in figure 1 for events in run 1376. The choice of the cut at 0.98 is made to maximize the number of matches at the same time as minimizing the number of false matches. False matches occur because genuine electro-magnetic showers can coincide with a projected tracks intersection with the crystals. By studying the distribution of the cosines in the region well away from matching and extrapolating the behaviour to the region cosine > 0.90, I predict that a maximum of 77.1% of all TCTR tracks can possibly be correctly matched by this method. For the chosen cut of 0.98 I measure that 70.6% of TCTR tracks are matched, of which 65.1% are correct matches whilst 5.5% are falsely matched. Expressing these figures as percentages of all TBTK PEDs, I find 25.5% are correctly matched, and 2.1% are falsely matched. In a separate study of collinear events ($p\overline{p} \to \pi^+\pi^-$), I find that for events which are clearly of this type 98% of TCTR tracks are matched.

A variety of other parameters in the events were studied to try and improve upon the efficiency of the matching. These included; PED energy, the number of crystals in a PED, track momentum/PED energy, the direction of a track in the crystals and more. None provided a clear separation between hadronic and other PEDs so were unable to improve the matching criteria. Several however did show differences between matched and un-matched PEDs and for example I show the PED energy for matched and un-matched PEDs in figure 2. A nice min-I peak at the expected energy is apparant for the matched PEDs with only traces of such a signal for the un-matched. In figure 3a) are all unmatched PED:PED invariant masses from a sample of 450 events in run 1376. In figure 3b) I plot the similar distribution where at least one of the PEDs was matched to a track, and the π^0 peak vanishes as expected.

11 APPENDIX II: PI0FND

The description of PI0FND (also known as PHYSAC) is given in CB-Memo 133 (author P.Schmidt). The code finds π^o's for the user by looping over the un-matched PEDs in the TTKS sub-banks. (Note: It can also be used for η finding, so in the following read π^o or η whenever π^o appears). Information on each of the π^o's found is stored in an extra TTKS sub-bank appended onto the existing TTKS bank structure. The contents of these extra banks is as defined in table 5 (this is for version 2.0). Running PI0FND also results in other changes to the banks. The HTRK header bank changes: Word (pointer + 3) is now the total number of TTKS sub-banks (i.e. the number of tracks plus the number of un-matched PEDs plus the number of π^o's). An extra word is included in this bank at pointer + 4, and is the version number of the PI0FND code. The TTKS header bank also changes, word (pointer + 1) is now the total number of TTKS sub-banks, (i.e. tracks + un-matched PEDs + π^o's), and extra words are added such that (pointer + 4) is the number of merged π^o's, and word (pointer + 5) is the number of π^0's seen in 2 separated PEDs.

After running PI0FND a user should beware of double counting the un-matched PEDs in the TTKS sub-banks that have also been used to make a π^o.

Offset	TYPE	*Quantity*
+1	INTEGER	*Particle number*
+2	INTEGER	*= 0 if BC data, = 1 if JDC data, = 2 if PI0FND*
+3	INTEGER	*Geant Particle id, if a choice is made* **NOT YET FILLED**
+4	INTEGER	*Charge, -1, 0, +1*
+5	INTEGER	*♯ of dE/dx hits*
+6	INTEGER	*Id. of track entry in TCTR bank*
+7	INTEGER	*Id. of PED entry in TBTK bank*
+8	INTEGER	*Id. of particles vertex of origin*
+9	INTEGER	*Id. of particles decay vertex* **NOT YET FILLED**
+10	INTEGER	*Charged track reconstruction quality word*
+11	INTEGER	*PED reconstruction quality word*
+12	INTEGER	*More data on the PED*
+13	REAL	*Chi2 per degree of freedom for charged tracks*
+13	REAL	*central crystal energy for neutral peds*
+14	REAL	*Momentum, P.*
+15	REAL	*Energy (all charged tracks are assumed to be pions)*
+16	REAL	*Px.*
+17	REAL	*Py.*
+18	REAL	*Pz.*
+19	REAL	ΔP
+20	REAL	ΔE
+21	REAL	ΔPx
+22	REAL	ΔPy
+23	REAL	ΔPz
+24	REAL	*dE/dx.*
+25	REAL	$\Delta dE/dx$
+26	REAL	$\chi^2(e^{\pm})$ *from dE/dx*
+27	REAL	$\chi^2(\mu^{\pm})$ *from dE/dx*
+28	REAL	$\chi^2(\pi^{\pm})$ *from dE/dx*
+29	REAL	$\chi^2(K^{\pm})$ *from dE/dx*
+30	REAL	$\chi^2(\mathbf{p})$ *from dE/dx*
+31	REAL	*Cosine of angle between track and its matched PED(if any)*
+32	REAL	*Cosine(angle) between closest track and* **unmatched** *PED*
+33	REAL	*E1/E9 for PEDs*
+34	REAL	*Second moment of PED*
+35	REAL	*PED showermass*
+36	REAL	*Energy of parent cluster*
+37	REAL	*u directional cosine of cluster*
+38	REAL	*v directional cosine of cluster*
+39	REAL	*w directional cosine of cluster*
+40	REAL	ψ *direction angle of charged track*
+41	REAL	*1/Pxy for charged tracks*
+42	REAL	$tan(\lambda)$*, tangent of opening angle of particle*
+43	REAL	ϕ *angle in XY plane for PEDs*
+44	REAL	θ *angle for PEDs*
+45	REAL	$\sqrt{E}$ *for PEDs*
+46	REAL	*Covariant error matrix in lower triangular form. For this particle three*
+..	REAL	*quantities needed for the kinematic fit, i.e. errors for words*
+51	REAL	*40,41 and 42 if JDC and words 43,44,45 if crystal data*
+52	INTEGER	
+..	REAL	
+58	INTEGER	

Table 5: Data stored in the **TTKS** sub-bank

Offset	TYPE	*Quantity*
+1	INTEGER	*Number of particle*
+2	INTEGER	$= 2$ *if PI0FND reconstr. particle*
+3	INTEGER	*Part. id* $\pi^0 = 7, \eta = 17$
+4	INTEGER	*not filled*
+7	INTEGER	....
+8	INTEGER	*orig. vertex, not yet defined*
+9	INTEGER	2 PED π^0: γ *index* $= \gamma_1 \cdot 1000 + \gamma_2$
		merged π^0: - *cluster id (negativ)*
+10	....	*not filled*
+11	INTEGER	merged π^0: *cluster id*
+12	INTEGER	merged π^0: *see TTKS manual*
+13	...	...
+14	REAL	*Momentum, P of* π^0
+15	REAL	*Energy of* π^0
+16	REAL	Px *of* π^0
+17	REAL	Py *of* π^0
+18	REAL	Pz *of* π^0
+..	...	*words 19 - 23 errors*
+..	...	*words 24 - 30 are not filled for* π^0
+31	REAL	2 PED π^0: *opening angle*
+35	REAL	*reconstructed* π^0*mass*
		for GTRACK version less 1.20/00
		remaining words are at offset - 4
+..	...	*words 36 - 42 are not filled for* π^0
+43	REAL	Φ *angle in XY plane for* π^0
+44	REAL	Θ *angle for* π^0
+45	REAL	$\sqrt{E}$ *of* π^0
+..	...	*words 46 - 51 covariance matrix*

Table 6: Data in the PI0FND created **TTKS** sub-bank