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Summary of the updates in the DELPHI forward tracking to include the VFT

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Abstract

In this note a brief summary of the new forward tracking in DELANA is given. Ideas and strategies used to include the new Very Forward Tracker in the existing DELPHI code are described. The new tracking code also uses to the full extent the major DELPHI upgrades, the longer Vertex Detector, the longer Inner Detector jet chamber and the Straw tubes. The performance and first results are described. Finally remaining problems in the charged tracking and possible solutions are discussed.

1 Introduction

Hermeticity and charged tracking capabilities over nearly the full polar angle range are of immense importance for the LEP 2 physics program. Thanks to the enormous effort of the DELPHI collaboration major detector upgrades were done in the years 1995 till 1997 to improve the situation in the forward region (below 40° in θ). With the LEP 1 setup of the detector the tracking was limited by the amount of material in front of the forward tracking detectors, while at the same time the barrel tracking detectors drop out of the tracking. After the upgrade the much longer Vertex Detector (VD) and Inner Detector (ID) jet chamber cover polar angles down to 22° and 15°, respectively. The old ID trigger layer was replaced by 5 layers of Straw tubes giving a much more precise $R\Phi$ measurement from the timing to the wires. The VD is extended over the region between 25° and 11° by the new Very Forward Tracker (VFT), which has 2 layers of pixel detectors and 2 layers of mini strips with readout in both projections in each endcap.

Major changes in the DELPHI tracking code in DELANA [1] were made to benefit from these upgrades and to improve the efficiency to detect charged particles at small θ. At the same time it was essential to preserve the excellent b tagging performance of the code for the barrel part.

In this note no basic introduction to the DELANA analysis structure is given. The reader will find more detailed information in reference [1] or [2]. The reader will also find a detailed description of the detector layout of 1994 in [2]. Only a very short summary of the structure will be given in the next section. Only the changes to the reconstruction strategy used for LEP 1 are discussed in the following.

2 The structure of the DELANA used for LEP 1

The DELANA pattern recognition for charged tracks was structured in 3 stages. At the beginning of the 1st stage the local pattern recognition of detectors was creating track elements (TE) using the measurement of the individual detectors only. Then the barrel and forward track search algorithms were run to find the track candidates . After the final fit of all tracks the ambiguity processor was called to resolve tracks of the event. At 2nd stage the detectors used the extrapolations of the found tracks to find additional TEs and to improve the 1st stage results. After an additional iteration of the searches the 3rd stage ID+VD only tracking was recovering additional tracks using only the ID and the VD. Also here tracks using only the ID and the Outer Detector (OD) in regions of the TPC cracks are lifted. One should notice that the 1st stage knows only about the VD $R\Phi$ measurements. The z information is added only at 2nd stage and therefore does not contribute to the track finding.

3 Updates to the detector codes

Here the most relevant changes to the detector pattern recognition codes and new detector codes are described.

3.1 Updates to the VD 2nd stage code

No major update for the 2nd stage VD z association package was needed to include the additional z information from the last plaquettes of the inner layer. In order to account for the now much longer outer layer and the new z readout of the inner layer the cuts in the pre-association routine [3] were changed to scale with $1/\sin\theta$ of the tracks to open the δz cuts at small θ. Only a cleanup of the code [4] to refit the ambiguities and to solve them using the full ambiguity processor has been done. It is now in a separate package called FITVDZ.

3.2 The new VFT pattern recognition

A new pattern recognition program [5] was written for the VFT. Unlike the barrel VD the VFT is working as a ordinary tracking detector. For all hits, track elements are created after the final noise suppression using hot pixel maps and signal over noise cuts for the mini strips. In overcrowded shower situations a module is masked completely. A standalone pattern recognition is used to find combinations of 2 or more points in different layers from tracks pointing to the primary vertex. Here the relative angle of 4° for the two mini strip layers is useful to reduce the number of fake combinations for those multipoint TEs. The VFT also provides service routines for the forward track search which are discussed in section 4.

Furthermore the material of the VFT, its support structure and the readout electronics was implemented into the fit database [6]. The complex structure including the tilted plaquettes was approximated using small cylinders and planes.

3.3 The Straw Detector in the tracking

In 1995 the new Inner Detector has replaced the old detector. This new detector consists of a much longer jet chamber and of 5 layers of straw tubes giving a precise $R\Phi$ measurement from the timing to the wires. To use this timing information, a new pattern recognition program [7] was written on the basis of the Outer Detector analysis program [8]. This was possible since both detectors are of a very similar geometry.

The pattern recognition of the Straw Detector is complicated by the stereo angle of the two outermost Straw layers w.r.t. the other 3 layers. This introduces a strong correlation of $R\Phi$ and ϕ to the reconstructed z. On the other hand, the resolution of 15 cm in z is sufficient to calculate z dependent transformations needed to transform the local measurement into the DELPHI reference frame. Therefore it was possible to move this part of the reconstruction into the 1st stage and to use the measurements in the track finding.

Since the local pattern recognition is not using a real helix fit, it was necessary to estimate the error matrix by hand in order to match the experimental resolution. It was assumed that the error per measurement is 80 μm and that there is an additional uncertainty of 200 μm for the wire position. In addition the correlations for $R\Phi$ vs z and ϕ vs z of 0.03/15 and 0.024/15 cm^{-1}, respectively, has to be taken into account. The pull distributions for the 97 real data are shown in figure 1. These distributions are obtained from the measured track element in the Straws and the average of the forward and backward Kalman filter extrapolation on the Straw Detector measurement surface.

Also shown is the correlation plot for $dR\Phi$ vs dz. These plots are obtained using all tracks above 0.5 GeV in hadronic events.

3.4 The changes to the ID pattern recognition

An important part of the new tracking is the 2nd stage pattern recognition for the ID jet chamber [9]. Now all detectors apart from the TPC have a 2nd stage pattern recognition using track extrapolations to improve their 1st stage results. For the ID the track extrapolations are used to improve the 1st stage track elements, if additional track points can be added. Furthermore new track elements are created in case the 1st stage pattern was inefficient for this track. A special tuning for very short forward track elements with less than 8 wires was done. This significantly improves the efficiency below 18° in θ. At the moment, the possibility to estimate θ from the radius of the last measured point and the length of the detector is not used.

Furthermore the solution of the left/right ambiguities in the jet chamber previously made using the old trigger layer readout with no timing information has been dropped. Due to the very limited precision in $R\Phi$ of 1 cm per cell, the efficiency to solve the ambiguity in hadronic jets was very poor and also gave a high rate of wrong decisions. Therefore the solution has been moved to the event ambiguity processor to use the full track information by simply dropping this part of the code. Also the old trigger layer TEs have been replaced by the new Straw information.

3.5 Dropping the FCA-FCB combined pattern recognition

The idea of the old combined pattern recognition of FCA and FCB was to perform at 2nd stage a search for track elements in the chambers using extrapolations of measurements in the other chamber. This is needed to improve the poor track efficiency for FCA+FCB only tracks. Especially the low redundancy of the 6 planes of FCA leads to large inefficiencies or large rates of fake measurements without the use of external predictions. Therefore all 1st stage FCA track elements, which are not associated to tracks, were extrapolated using infinite momentum to FCB. These extrapolations were then used like ordinary tracks to search for additional track elements in FCB. Afterwards all unassociated track elements in FCB (including the newly found) were extrapolated to FCA using the beam spot to estimate the momentum. Again FCA was using the extrapolations like ordinary tracks to perform a search. It should be stressed here that FCA, unlike all other detectors in DELPHI, is dropping all results from the 1st stage pattern recognition apart from those which are used already in tracks. Therefore only the result of the FCA 2nd stage and the associated hits from the 1st stage are used later on and also written to the DST.

This algorithm was rather successful for reconstruction of isolated tracks at very low θ. It was mainly used to improve the $\mu^+\mu^-$ efficiency at LEP 1. With the new tracking the aim is to reconstruct also hadronic jets with good efficiency and reliability. In such a situation the combined FCA-FCB pattern recognition fails. Good quality tracks are found at 1st stage using the VFT and the other detectors. But any track showering in the material before FCA or FCB creates many hits in those chambers. Because of the low redundancy of FCA any hit in FCB generates fake track elements in FCA and leads to a corresponding fake track (up to 40 candidates per event). Therefore this algorithm was dropped sacrificing a bit of efficiency for low quality FCA+FCB tracks.

4 The new forward track search

The new forward track search is based on the LEP 1 version [10]. The principle difference of the forward region compared to the barrel part above 36° is the strong θ dependence of the number of tracking detectors and their resolution. This is illustrated in figure 2 for all detectors apart from the FCA,RIF and FCB, which cover (more or less) the full θ range shown. Therefore many search algorithms are needed starting with the measurements of different detectors to be efficient over the full range.

There are now 10 different searches implemented in the forward track search. The old searches, which were also present in the LEP 1 version, are starting at TPC, FCB and FCA, respectively. There are two new searches starting at the VFT. The first one is using the VFT multipoint TEs, which are created by the VFT standalone pattern recognition, to look outwards for hits in the other detectors. The second search is based on the jet chamber TEs to pick up VFT hits in $R\Phi$ roads. These ID and VFT combinations are fitted and used as a seed to find the track. There are 3 searches to extend the barrel track searches to the full polar angle coverage of the longer barrel VD. These searches start from TPC+VD, TPC+ID and ID+VD combinations below 40° found by the barrel track search [11] and add in these track candidates the missing forward detectors. Finally a recovery pass is done which uses all track candidates found by the 8 searches mentioned above. This search tries to recover hits in detectors missing in the track candidates using the improved estimate of the track parameters after fitting. There is also a special search algorithm which works only on barrel track candidates above 40° in θ. It works as a fix for the barrel track searches to include the Straw measurements from 1st stage into the barrel track candidates. The search working on the result of the combined FCA and FCB pattern recognition is inactive as discussed in section 3.5.

For practical reasons a generalized search engine is needed to cope with 10 different search algorithms working on the results of 9 tracking detectors. Furthermore cpu time and memory usage must be limited. Therefore a search engine was written to work on a generalized type of track element. These are either reconstructed TEs from the 9 tracking detectors (VFT,VD,ID,STW,TPC,FCA,RIF,FCB,OD) or detector combinations found by any type of reconstruction algorithm before, like the ID+VFT, TPC+VD, TPC+ID or ID+VD combinations used by the different searches. Also the combinations (STRINGs) found by the forward searches and the results of the BARREL searches are treated as track elements in the search engine. Based on generalized track elements any search is realized by extrapolating a PIVOT track element to all tracking detectors. For each detector one track element can be associated to build up a track.

To reduce the number of possible combinations the search procedure works in steps. First the pivot track element is extrapolated to all detectors. From the list of TEs measured by a detector only those TEs are selected which are close to the extrapolation. The selection is done using simple geometrical cuts. For the VFT, FCB and FCA search the extrapolation of the pivot track element is improved forcing the extrapolation through the beam spot position in $R\Phi$. Starting from the lists of candidate TEs selected, the tracks are then built up. Care has to be taken not to split the long tracks into several small pieces. Therefore the algorithm starts to look for all possible combinations including the maximum number of detectors. Combinations using all but one detector are only considered if none of the full combinations is accepted by the subsequent filters. Combinations without two or more detectors are possibly considered only if all previous combinations fail. The first filter uses improved extrapolations based on a polar inversion to estimate the track parameters. Tighter cuts w.r.t. the improved extrapolations are used to veto fake combinations. No polar inversion is needed for the TPC+VD, TPC+ID and the TPC pivot since the track estimate is already well defined by the TPC itself. After this filter the generalized track elements and also the VFT multipoint TEs are split into the original TE measurements. The final filter is the Kalman filter of the track fit. A track candidate is created if the combination is accepted by the χ^2 cut in the fit. The outlayer removal of the fit is used to reject up to two TEs having unacceptably large χ^2 to the fitted track. The result of this procedure is a set of ambiguous track candidates based on the pivot track element.

pivot	beam spot	polar inv.	unused only	VFT	VD	ID	STW	TPC	FCA	RIF	FCB	OD
IDVFT	-	x	-	-	-	-	x	x	x	x	x	-
TPCVD	-	-	-	x	-	-	x	-	x	x	x	-
TPCID	-	-	-	x	-	-	x	-	x	x	x	-
IDVD	-	x	-	x	-	-	x	x	x	x	x	-
TPC	-	-	x	x	x	x	x	-	x	x	x	-
VFT	x	x	x	-	x	x	x	x	x	x	x	-
FCB	x	x	x	x	x	x	x	x	x	x	-	-
FCA	x	x	x	x	x	x	x	x	-	x	x	-
STRING	-	-	-	x	x	x	x	x	x	x	x	-
BARREL	-	-	-	-	-	x	x	-	-	-	-	x

Table 1: The different searches based on different pivot track elements in order of execution. Shown are algorithms used to perform the search and the detectors considered to form combinations. See text for details.

In order to save CPU time the searches based on long PIVOT track elements are run first. For all searches a bookkeeping of TEs used in accepted track candidates is done. This allows to skip those TEs as a starting point for the following searches like the TPC, VFT, FCB and FCA. The ordering of the searches is given in table 1. Combinations found twice, or being subsets of longer track combinations, are removed from the list of track candidates and are not seen by the following processors.

The VD and the VFT are non standard detectors. The VD does not have a standalone pattern recognition and is not able to create TEs without predictions from track candidates. Furthermore the information is provided in the form of up to 12 TEs having $R\Phi$ or z information only. The VFT has a standalone pattern recognition and is providing TEs based on multiple hits from one track. But multiple tracks hitting one mini strip module create ambiguous solutions based on the crossing points of n strips in both projections. Furthermore the efficiency of the standalone pattern recognition is limited. Hence both detectors do not fit into the search strategy discussed above and need some special treatment. After the searches are run all track candidates are extrapolated to the VD, except those found by the TPCVD and IDVD searches, which already contain the VD points found by the barrel search. For each of the extrapolated track candidates the VD association routine [3] is called to provide all possible combinations of VD hit associations. For each combination of VD hits a new ambiguous track candidate is created adding the hits into the original track. After this all track candidates are extrapolated to the VFT and the VFT association routine is called [5]. In contrast to the VD, the VFT routine has to associate only missing hits. These are either not picked up by a multipoint TE associated to the track or are missed since only one hit out of many was found by the general search engine in cases where the VFT pattern recognition was inefficient. Again new ambiguous track candidates are created. Overlaps of VD and VFT are naturally taken into account by adding missing hits into the tracks. In addition, for tracks with a single VD or VFT hit, a substring of the track excluding the VD/VFT point is created before calling the VD/VFT routine in order not to bias tracks by one fake point close to the overlap.

soft. module	pivot	software package
101	ID+VD combined	barrel search
102	TPC+VD combined	barrel search
103	TPC	barrel search
51	TPC below 40 deg.	forward search
52	VFT multipoints	forward search
53	FCB	forward search
54	FCA	forward search
55	ID+VFT combined	forward search
56	TPC+VD below 40 deg.	forward search
57	ID+VD below 40 deg.	forward search
58	TPC+ID below 40 deg.	forward search
59	2nd pass TE recovery	forward search
60	FCA+FCB(not running)	forward search
61	TPC only recovery or	delana steerings
	straw fix for barrel	forward search
2xx	TE outlayer(s) in fit	track fit
3xx	modified at 2nd stage	delana steerings
1xxx-9xxx	ID+VD(OD) only track	ID+VD only
1xxxx-nxxxx	modified track	ambiguity processor

Table 2: Software module identifier of tracks created in DELANA. The 'x' digits are preserved by the processors later in the chain.

In a final pass all track candidates (STRINGs) are extrapolated to those detectors which do not contribute to the track yet. The idea of this search is to pick up TEs missed using the improved extrapolation based on all information available after the original search. Finally the search to include the Straws into the barrel tracks is carried out. For each track the search used to find the candidate is flagged in the software module identifier. A complete list of identifiers is given in table 2 for all processors in DELANA.

In the process of finding the track candidates many track combinations are tried which contain only very little tracking information and have therefore a high risk of being a fake combination. Furthermore many short track candidates would create a high risk of splitting good tracks in the ambiguity process (see next section). Hence lists of bad combinations of TEs are used to veto those candidates in an early stage of the process. In

bad detectors	bad single	bad TPCfrw.
TPC only	VD+ID	TPCfrw.
VD+FCA	VD+TPC	VD+TPCfrw.
VD+RIF	VD+ID+FCA	ID+TPCfrw.
VD+FCB	VD+ID+RIF	TPCfrw.+FCA
ID+FCA	VD+ID+FCB	TPCfrw.+RIF
ID+RIF	VD+FCA+RIF	TPCfrw.+FCB
ID+FCB	VD+RIF+FCB	VD+TPCfrw.+FCA
VD+RIF	VD+FCA+FCB*	VD+TPCfrw.+RIF
FCA+RIF		VD+TPCfrw.+FCB
RIF+FCB		

* becomes FCA+FCB.

Table 3: Lists of bad detector combinations used to veto track candidates with poor tracking information or high risk of being fake. See text for details.

table 3 the bad combinations are given. 'Bad detector' combinations are vetoed directly in the general search engine. The category of 'bad single' combinations is rejected after the VD and the VFT association has finished. Here all candidates are rejected if they only contain one VD/VFT hit and only either the ID jet TE or the Straw TE. A special list 'bad TPCfrw.' was introduced for the forward TPC TEs. Those TEs are created below 25° in θ and contain only the information of up to 3 pad rows and some wire hits. The combinations given in the table are vetoed like the 'bad single' combinations. They are rejected provided that they do not contain more than one VD hit or both ID jet and Straw TE.

The ID+VFT combinations are a special case for the forward track reconstruction. In the forward search they are treated like normal tracks, but they are a problem for the ambiguity processor, because they have the potential risk that they are a subsample of a long forward track. Therefore the ambiguity solution does not work on this type of tracks and they are processed afterwards in the ID+VD only tracking like the ordinary ID+VD only tracks.

5 Changes to the ambiguity processor

A big problem for the forward tracking is the high risk of splitting one long track into 2 or more short substrings. Here the forward region is fundamentally different from the barrel region. In the barrel a track is created on the basis of the TPC track element. For those tracks the ambiguity processor [12] has to resolve the association of the VD points and of the ID and OD track elements to those TPC tracks. In the forward the ambiguity processor also decides about the track multiplicity on the basis of the possible combination of track elements from many detectors.

There are now two mechanisms to reduce the probability to create split and fake tracks. First there is the list to suppress track combinations with poor quality and high risk of being a fake. Such a list was already used for LEP 1 and is now extended to reflect the new detector setup. The list is essentially a copy of what is used also in the forward track search given in table 3.

Second a new protection is introduced at the level of substring creation. A substring is created in the process of solving an ambiguity between two tracks. To assign a track element to one track, it has to be removed from all other track candidates. Therefore for a given track the association list has to be reduced by the removed TE and the track candidate needs to be fitted if possible. The problem in this procedure arises if a long track and e.g. a FCA+FCB track share the FCA track element. Removal of the FCA from the long track results in two tracks, while one kills the FCA+FCB track when removing the FCA from it. Hence the solution with two tracks is favoured without any protection, because it also contains more TEs.

In practice this is not exactly what one likes to have. That way one removes track elements from long and very precise tracks creating low quality tracks with low internal constraints and high risk of being fakes. Furthermore a single track element can be rejected from a long track because of scattering, problems in the detector measurements or inefficiencies in the track search. In this case the rejected track element will almost certainly fit to only a part of the full set of TEs of the track. The result is that the track is split into two overlaying tracks in the process of the ambiguity solution.

To avoid this problem a change of the logic for creating the substrings was introduced. If a track element is assigned to track A and needs to be removed from another track candidate B, a substring of track B is only created if also track A is still a good track candidate without the shared track element. I.e., in the example discussed above it is not possible to remove the FCA track element from the long track to put it into the FCA+FCB track, because the FCA+FCB track without the FCA TE is not a valid track. Hence one can either take the long track with FCA or the FCA+FCB track and thus the long track survives. The risk of splitting tracks is considerably reduced.

6 Updates in the ID+VD only track reconstruction

The old ID+VD only track search [13] which was used for LEP I was largely rewritten. This was necessary to include the creation of ID+VFT tracks into this search. Furthermore inconsistencies in the treatment of hadronic showers and TPC single pad points lead to inefficiencies and the z readout of the VD inner layer was not included in the original search. The overall strategy to tag the correct z and θ for each of the 1st stage $R\Phi$ ID+VD track candidates was not changed.

At the beginning of the ID+VD search all strings from the 1st stage track searches are scanned for combinations of the type ID+VD or ID+VFT or ID+OD. Track elements are removed from the scan list if they are used in valid tracks. These track candidates are then associated to the hadronic showers or scattered tracks reconstructed after interaction with the material in front of the TPC. The track candidate can be associated in $R\phi$ either to a hadronic shower tagged by the shower finder at 1st stage [14] or to one or more secondary tracks. If this is not successful a 2nd step is done scanning all TPC single pad track elements close to the inner wall of the TPC. A first θ estimate is then defined by the direction from the primary vertex to the hadronic interaction. Here VFT points or z measurements in the Straws are taken into account. This θ information is then used to define a range to look for VD z hits.

All z hits in VD plaquettes crossed by the track are considered for association. Combinations of hits in two layers are accepted if the z impact to the primary vertex is smaller than 1 cm. Multiple solutions are resolved using the estimated θ mentioned above. In the forward region 3 VD layer combinations are created joining solutions using 2 layer combinations which are close in θ. In case no multiple layer solution is found single layer associations are considered.

Finally the tracks are fitted allowing for outlayers. Tracks with insufficient z information are completed using a hadronic shower or the primary vertex as additional fake track elements. Possible ambiguities are solved using the ambiguity processor. For each created track the software module identifier is set to reflect its quality. This coding is not changed with respect to the LEP1 code. A VFT track element is counting like one VD $R\Phi$ and one VD z track element. A summary of the software module identifiers is given in table 4. Note that the z of the primary vertex is used in the track fit in case the z information is insufficient without this additional constraint. Tracks with $9xxx$ are in general of very poor quality and are rejected for data of all years after 1993 when the VD has z readout.

soft. module identifier	VD z layers or VFT hits	hadronic interaction or ID/Straw TE with z	z of primary vertex used
1xxx	1	yes	no
2xxx	2	yes	no
3xxx	0	yes	yes
4xxx	1	no	yes
5xxx	2	no	no
6xxx	ID-OD like		if needed
7xxx	like 3xxx, but only 2 $R\Phi$ hits		yes
8xxx	like 4xxx, but only 2 $R\Phi$ hits		yes
9xxx	theta only from $R\Phi$ plaquette center		yes

Table 4: Software module identifier of tracks created by the ID+VD only tracking. See table 2 for definition of the last three digits. No difference is made between VD and VFT hits.

The new ID+VD only search is moved from the 3rd stage to the middle of the 2nd stage. The idea is to improve these tracks using the usual method of 2nd stage local pattern recognition of the detectors. Therefore it was necessary to split the old 2nd stage into two parts. The VD and the OD 2nd stage has to be done before the ID+VD only. The VD z hits have to be associated to normal tracks not to confuse the solution of the ID+VD tracks. The OD should not be associated to ID+VD tracks which are usually tracks stopping before the TPC. The ID+VD tracking is then called before the ID and the Straw 2nd stage is done to improve those tracks. An attempt was made to call the FCA and FCB 2nd stage using ID+VD/VFT track extrapolations. This was not successful due to the limited resolution of the extrapolated track and therefore the forward chambers are processed before the ID+VD only search.

7 Performance of the new tracking code

The Monte Carlo is used to study the performance of the track reconstruction. Based on the Monte Carlo truth the pattern recognition of all tracking detectors assign a label (the track number) to the reconstructed track element. For minor reconstruction problems (overlapping tracks or noise) of the detectors the label is negative, while background has zero label. The track is assigned its label on the basis of the labels from all contributing detectors. Again good quality tracks get a positive label, tracks with contributions from noise or hits from other tracks get negative labels and fake tracks get label zero.

This information is used to determine the performance of the track search. To unfold the detector efficiencies from the track finding efficiency, only combinations of at least two detectors or the TPC contributing to a track measurement are considered. Combinations of VD/VFT and ID/STW only measurements are also excluded and a p_t cut of 0.5 GeV is applied to remove low momentum secondary interaction tracks. A set of 1806 $Z^0 \to c\bar{c}$ events with a thrust axis below 40° is used to determine the numbers. All numbers are compared to the results using the DELANA 97 D tracking code.

In table 5, a summary of the tracks found below 40° is given. The number of detector combinations (i.e., the detection efficiency in the forward region) has increased due to the addition of the VFT and Straws to the tracking. This results in an increase in the number of good reconstructed tracks using the new tracking. Also the rate of tracks with negative or zero label and the number of split tracks has been reduced.

	new tracking	DELANA 97 D
number of events	1806	1806
detector combinations	35 119	31 864
good tracks found	30 515	27 884
positive label	26 632	22 518
negative label	3 883	5 366
label zero	535	835
split tracks	349	993
not found	4 604	3 980

Table 5: Reconstructed tracks below 40° using the DELANA 97 D and the new tracking. Note that the number of detector combinations is different in both cases.

The composition of tracks which are not found by the tracking code is given in table 6. Bad combinations rejected using the lists from table 3 in the track search and ambiguity processor contribute significantly to the number of lost tracks. The lost TPC(+STW) tracks are those with no tracking information apart from a very short TPC track element below 30 cm in length in DELANA 97 D. In the new tracking 235 tracks are moved from TPC only to the TPC+STW because of an additional Straw TE. A significant increase in the number of lost tracks can be found for ID+VD/VFT and FCA+FCB(+RIF) combinations. The increase of lost ID+VD/VFT tracks in the new tracking is due the ID+VFT combinations. The overall efficiency for ID+VD and ID+VFT tracks is limited by misassociation of TEs to other tracks before the ID+VD only track reconstruction. Furthermore ID+VD/VFT tracks with insufficient z information are rejected from the search. More FCA+FCB(+RIF) combinations are lost in the new tracking due to the changes in the ambiguity solution and due to removal of the FCA+FCB combined pattern recognition. At the same time the number of fake tracks was reduced as can be seen from table 7. For all other detector combinations the total number of lost tracks is about constant.

	new tracking	DELANA 97 D
not found	4604	3980
bad detectors	1240	680
bad single	140	412
bad TPCfrw.	259	663
short TPC(+STW)	622	670
ID+VD/VFT	934	349
FCA+FCB(+RIF)	703	526
other good tracks	706	654

Table 6: Number of track combinations not reconstructed. See text for details.

Tracks without a label are classified into 6 different types in table 7. First there are fake ID+VD or ID+VFT tracks, then there are tracks including the TPC. The TPC only tracks without label are due to problems in the TPC pattern recognition. The other tracks include special forward TPC track elements or a forward tracking detector but no TPC information at all. One has to notice that a large fraction of fake tracks in DELANA 97 D is of the type FCA+FCB(+RIF). Problems in FCA+FCB combined pattern recognition in shower situations account for many of these tracks.

	new tracking	DELANA 97 D
label zero	535	835
IDVD/VFT	8	9
TPC only	47	50
with TPC	159	117
with TPCfrw.	51	59
FCA+FCB+(+RIF)	136	463
FCH+barrel	134	137

Table 7: Tracks with no label. See text for the definition of the classes.

The efficiency to reconstruct a track originating from the primary vertex is shown in table 8. A clear gain in the number of reconstructed primary tracks is found for the new tracking. In figure 3 the efficiency to reconstruct a primary track in the simulation using the new tracking is shown with and without the VFT. Also the gain of good tracks in the 97 real data using the new tracking compared to the DELANA 97 D result is show. In both cases a clear gain is visible in the region from 22° to 14° in θ. Below 14° the ID drops out of the tracking and the material increases dramatically. Here the new algorithms are not sufficient to reliably reconstruct the tracks.

	new tracking	DELANA 97 D
number of events	1806	1806
generated tracks	28 892	28 892
tracks found	23 303	20 667
positive label	20 992	16 657
negative label	2 311	4 010

Table 8: Reconstructed primary tracks below 40° using the DELANA 97 D and the new tracking.

Apart from the track finding efficiency, the efficiency and purity to associate a track element from the different detectors to a found track is a good measure of the performance. Here the efficiency of the detector itself is not considered since it is normalized to the number of found track elements which should be associated to a track. The rates are given in table 9. Note that lost or fake tracks are not taken into account and therefore the track finding efficiency is not considered below. Therefore these numbers reflect the quality of the association of the detectors to the tracks.

detector	new tracking		DELANA 97 D	
	efficiency	purity	efficiency	purity
VFT	93.0 %	95.1 %	-	-
VD	97.6 %	97.6 %	92.2 %	97.1 %
ID	96.9 %	98.4 %	87.8 %	97.3 %
Straws	91.3 %	97.1 %	-	-
TPC	99.1 %	98.1 %	98.3 %	98.1 %
FCA	97.4 %	84.5 %	95.0 %	83.0 %
RIF[1]	95.1 %	92.0 %	82.9 %	92.1 %
FCB	94.5 %	91.0 %	92.5 %	92.8 %
TPCfrw.	95.6 %	93.6 %	91.5 %	87.4 %

[1] The RIF numbers are estimates. The RIF does not have any simulation information for the measured tracks. Hence only an approximation is used to label the TEs. All track elements without a label are not considered for this detector.

Table 9: Efficiency and purity to associate a TE to a found track.

A comparison of two simulated events reconstructed using the old and the new DELANA is shown in figure 4. Only the central part of the detector is displayed. The three layers of the VD are displayed close to the beam pipe in the center. The ID and the Straws are surrounding the VD. The inner edge of the TPC is also shown.

8 Discussion of major problems left over

In this section some of the major problems left over in the DELPHI charged tracking are discussed:

- For the Straw TEs large tails in ϕ due to wrong solutions in solving the internal ambiguities are visible in dimuon events. This is the same problem known for the OD, where it is even more severe due to the loss of hits in dead regions. The linking efficiency of the OD is clearly affected by this problem and drops by 20 % if one does not work with artificially scaled errors.

- Due to the lack of manpower for development of the barrel track search, a fix was used to include the Straw TEs at 1st stage into the barrel tracks. All barrel track candidates are read in by the forward search and the Straws are then added using the general association engine implemented in this search. In order to fully benefit from the Straw measurement it would be necessary to modify the barrel searches directly. This would imply implementation of a new detector in the 3 more or less independent search packages used for the barrel search.

- The efficiency of the ID + OD pattern recognition is not sufficient to recover the track losses in the region close to the TPC boundaries in $R\Phi$ or near $\theta = 90°$. These regions account for most of the track losses in the central detector. Here it would be possible to improve the TPC information, which is badly treated at the moment. The charge mirroring effects at the boundary is not corrected and also not introduced in the simulation. Therefore the errors of the 2 last pads in each TPC pad row are inflated creating problems in the association of the hits in other detectors to those TPC TEs. Furthermore the TPC efficiency drops out for tracks which are of sufficiently high momentum to be straight enough not to leave the boundary region. Here a new pattern providing only the measured information ($R\Phi, z, \theta$, no ϕ and $1/p_t$) and a more efficient ID+OD tracking would help in recovering those tracks.

- In 1338 cases in 1806 events, a track combination including a VFT was not found. These inefficiencies are either due to track combinations rejected by the bad combination lists or because of misassociation of track elements to other tracks. These tracks could partially be recovered using only the VFT multipoint information. An attempt to open up the cuts of the 2nd stage searches for tracks at small θ was creating too many fake combinations. Therefore this strategy was not implemented in the final code, but dedicated searches at 2nd stage might improve the result.

- The present track finding strategies are insufficient at very small angles below 14° in θ where essentially the VFT and the forward chambers are left alone and the material is dominating. VFT multipoint track elements, which are not used in tracks nor excluded by other VFT track elements in tracks, can be used together with the primary vertex to increase the hermeticity for the charged tracking. The VFT multipoints TEs are written to a special DST bank.

- The shower reconstruction at the beginning of the 1st stage is only done for the TPC track elements in the barrel. There is a need to include the forward, especially the region after the TPC endcap into the vertex search. This will avoid to create fake tracks and bad associations in such situations. Furthermore secondary tracks could be recovered for a better reconstruction of the charged energy. Also the rate of fake associations of calorimeters to shower tracks could be reduced.

9 Conclusion

After the end of the '97 data taking the VFT and the Straw detectors have been fully integrated in the DELPHI tracking code. First tests show that about 0.7 track per event are recovered in the forward region corresponding to a gain in energy of 1.0 GeV. The gain is concentrated in the θ range above 14° where the ID jet chamber is still present. Simulation studies show that for all detectors, including the VFT, the efficiency and purity to associate the TE to a track is around 95 %. The present track finding strategies are insufficient at polar angles below 14°.

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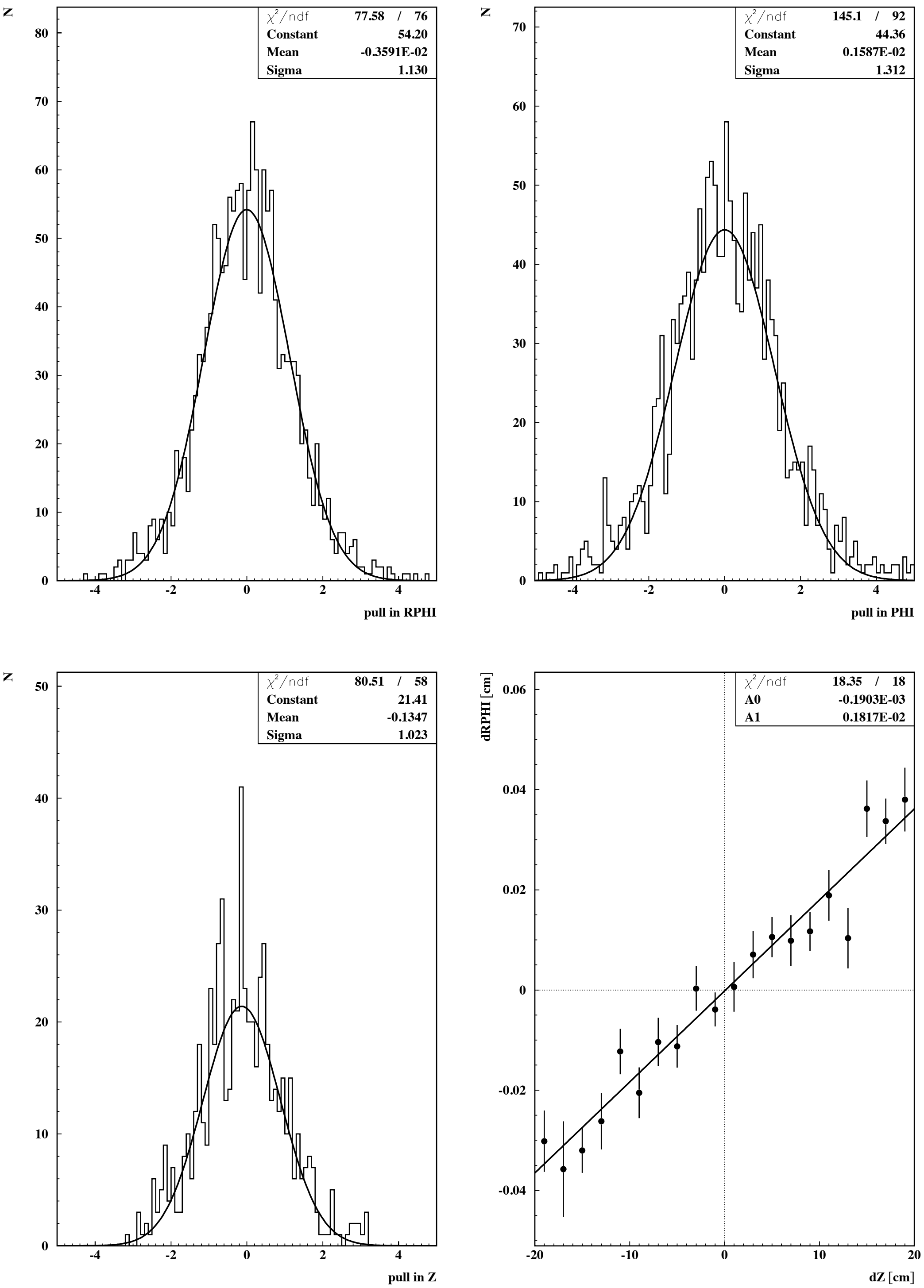


Figure 1: Pull distributions for the Straw track elements w.r.t. the measured track for the 97 data. Also shown is the dependence of $dR\Phi$ on dz.

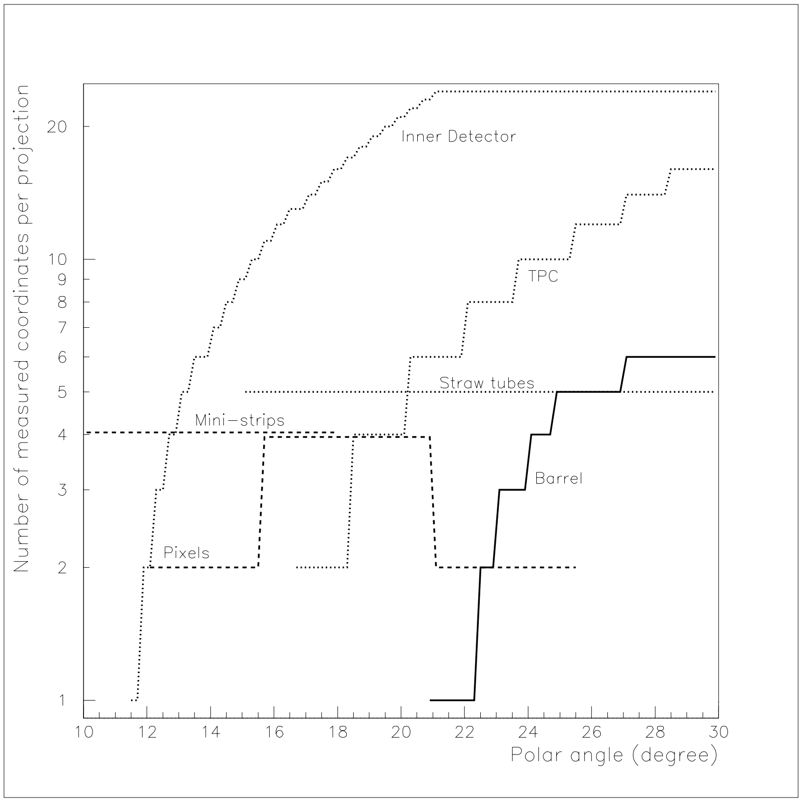
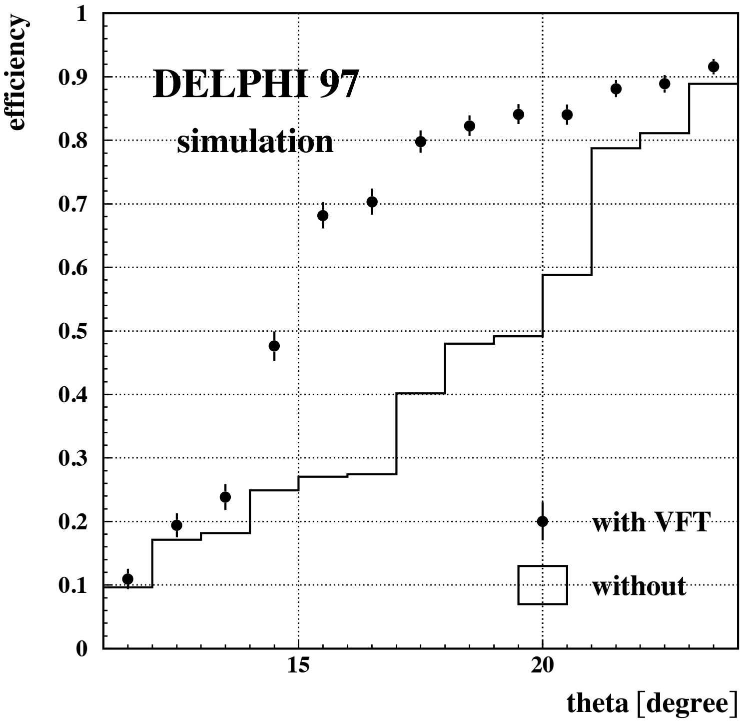


Figure 2: The coverage of the central detectors in the forward region as a function of θ. Shown is the number of $R\Phi$ measured points plus the number of z measured points. The FCA, RIF and FCB are not shown for simplicity.



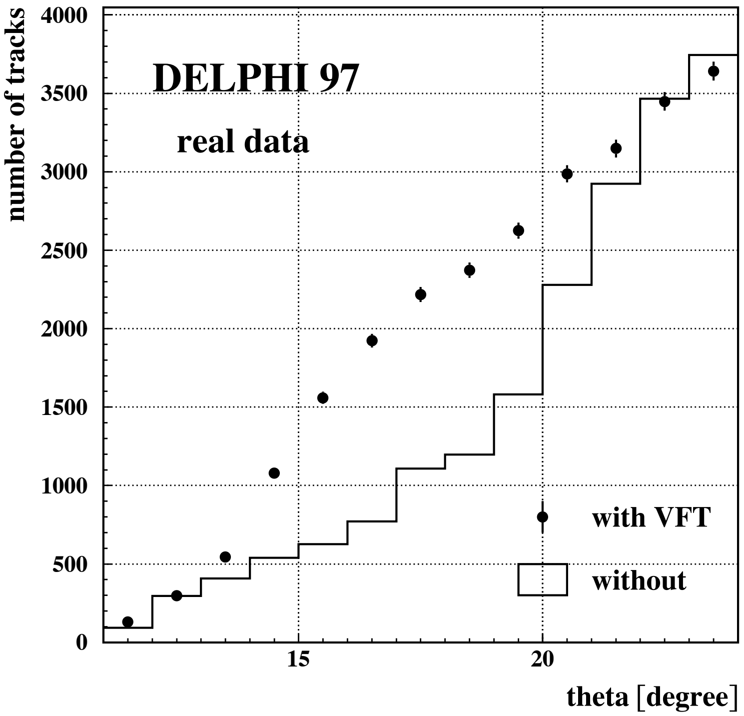


Figure 3: Efficiency for primary tracks in simulation using the new tracking with and without the VFT (upper plot). The number of good tracks as a function of θ in real data 97 using the new tracking with the VFT and the DELANA 97 D (lower plot).

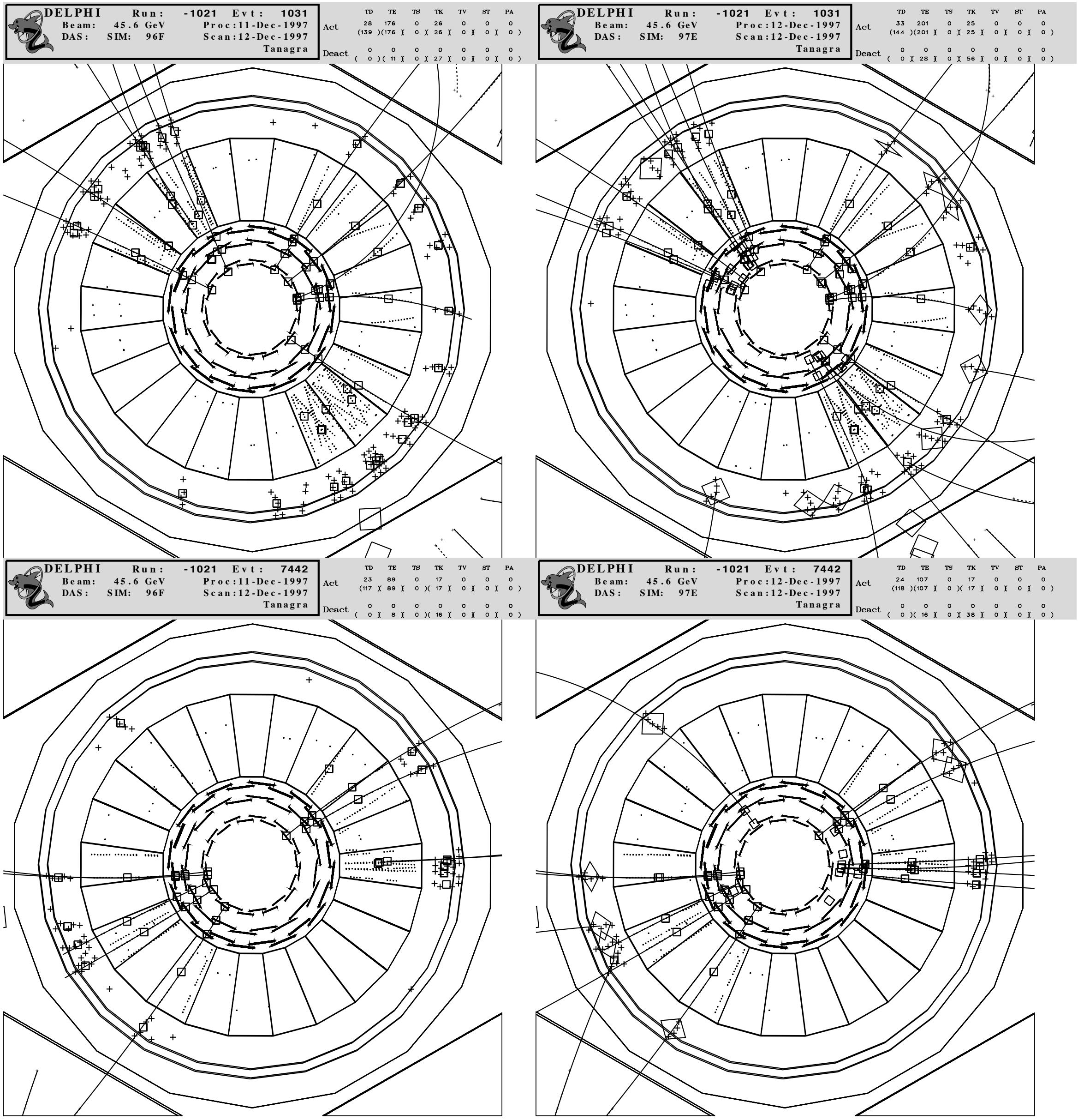


Figure 4: Event pictures of 2 simulated events. Shown is the central region of the VD/VFT/ID/STRAWs and the TPC. Left column is the result using the DELANA 97 D, right column the result using the new tracking.