IFR Reconstruction Summary

Document submitted to the BaBar Reconstruction Review, 12-13 April 1996

Luca Lista (INFN Napoli) and Maria Grazia Pia (INFN Genova)

1 Detector overview

The IFR is the outermost BaBar detector. It consists of a series of planar RPC layers alternated to the 18 iron plates of the magnet flux return and of four cylindrical layers placed between the electromagnetic calorimeter and the magnet coil. Half of the total number of layers will be equipped with read-out in orthogonal coordinates, the other half with one coordinate read-out only. The read-out is digital, with variable strip pitch depending on layer radius and coordinate view, for a total of $\sim$ 42000 channels. TDCs will provide a time measurement for groups of strips. The optimization of the layout of single or double view strip read-out and of TDCs is in progress.

RPC spatial resolution is expected to be of the order of 7 mm, time resolution of the order of 2 ns. Single gap RPC efficiency is 97%.

RPC's are very low noise detectors, with single rate of the order of 1 KHz/m^2, translating into approximately just 20 spurious hits per event in the whole detector. This characteristics, together with the low multiplicity of physical tracks expected in the IFR, results in a clean detector response and in an easier pattern recognition.

While the hardware technology (RPC) is very well known and proven, the design of the detector as a whole is highly non-traditional for a muon system, usually structured to detect and identify muons as fully penetrating tracks. The fine IFR iron segmentation allows the detection of muons down to 500 MeV/c (i.e. of tracks penetrating just a few cm of iron) and their discrimination from pions [2] on the basis of their different pattern of interaction with material, that in the low energy range covered by the IFR is rather complex. The same IFR features make possible the detection and identification of neutral hadrons - namely of K^0_Ls. The detector design has been motivated by the gain in tagging efficiency achievable [1] and the opening of physics channels - such as $J\psi K_L^0$ [3-4-5].

The IFR reconstruction software has to cope with the complexity deriving from detector design; at the same time it is expected to fully exploit the physics capabilities open by the detector.

2 Roles and requirements

The primary goals of the IFR, that determined the detector design, are:

- μ/π discrimination
- detection of neutral hadrons, and in particular K_L^0 identification and reconstruction

Studies [1-5] proved that the current detector design together with appropriate software algorithms can satisfy these requirements.

In addition to these primary goals, the IFR can play an important role in other fields, such as

- determination of t_0,
- identification of cosmics.

These issues would profit of the good time resolution and simple pattern recognition intrinsic of the IFR. However, as the optimization of the hardware configuration concerning these items (namely the TDC layout) is still in progress, the related software requirements and goals cannot be completely specified yet.

The IFR can also provide useful information to other systems - it may act, for instance as a tail catcher for the calorimeter; however combined studies across systems have not been performed yet, but realistically they will take place in a near future. Requirements concerning the use of IFR information across systems are expected to result from detector or physics studies; the IFR software design will be kept flexible enough to accomodate the desired communication across systems.

The requirements of high quality, stability and accurate knowledge of IFR performance will be fulfilled by monitoring at online and offline level.

3 Inputs

Primary input to IFR reconstruction is represented by the digitized hit pattern generated in the detector, consisting of **hit strip identifiers** and **TDC** associated to a group of strips. This may come either from real data or from Monte Carlo simulation.

At the present time the actual data digitization format as coming from DAQ is not defined yet and the only input data derive from Monte Carlo generated hits. A module generating a digitized pattern from Monte Carlo hits provides the current interface to reconstruction.

Complementary input specific to IFR reconstruction is stored in **geometry and calibration databases**, as described in the 'Geometry and calibration' chapter.

IFR reconstruction requires input from **charged track reconstruction** and **calorimeter reconstruction**.

Tracking represents a key input to IFR pattern recognition and provides essential information to μ/π identification algorithms. This requires swimming tracks from inner detectors to IFR entrance and in the IFR through material and non-uniform magnetic field. A fairly accurate track extrapolation - compatible with the RPC resolution of the order of approximately 7 mm - is required by μ/π discrimination, as the transverse spread and IFR hit pattern with respect to expected track extrapolation represents a discriminant variable between muons and hadronic showers. The input required from tracking includes:

- impact point, direction and error matrix at IFR layers,
- momentum,
- energy loss in material traversed before the IFR,
- vertex coordinates.

Calorimeter reconstruction plays a role equivalent to tracking for neutral particles in IFR pattern recognition: IFR clusters not belonging to charged tracks are associated to calorimeter clusters. The input required consists in calorimeter clusters energy deposition and pattern and associated neutral track direction with error matrix.

Discrimination between direct and cascade muons required by B tagging needs the full topological and kinematical information from the event.

4 Geometry and calibrations

The information relative to the IFR **geometry** in the database will include:

- RPC geometrical and material parameters,
- flux return geometry and material description,

- cabling and correspondence between electronics channels and detector components,
- magnetic field map in the IFR,
- RPC positioning with respect to the iron reference system.

These parameters will be used to reconstruct hit positions and to swim tracks through the IFR. They are supposed to be very stable; changes can occur only in the rare case of a RPC module replacement.

Alignment will be performed in two steps:

1. RPC alignment internal to the IFR, by means of cosmic rays; with a typical RPC spatial resolution of 7 mm, internal alignment can achieve a few mm precision, that is appropriate for the scope of IFR reconstruction;
2. alignment with respect to the rest of the BaBar detectors.

The **calibration** database will contain the following information:

- dead RPC modules,
- dead and hot electronics channels,
- efficiency of each RPC module,
- cluster size distribution of each RPC module,
- TDC offsets,
- plateau curve (efficiency as a function of high voltage) for each RPC module,
- temperature and pressure and relative high voltage settings.

The occurrence of discontinuous events, such as the failure of a RPC or electronics module is expected to be signaled by the online system.

Dead and hot channels will be detected by online and offline monitoring.

Efficiency and cluster size distributions will be derived from cosmics and dimuon calibration events. As their monitoring requires tracking and IFR pattern recognition, they will be handled by offline reconstruction.

TDC offset calibration requires special data taking procedures; it is expected to take place every few days.

Verification of the stability of the plateau curve is expected to be performed every few months as a special data taking procedure.

Temparature and pressure will be continuously monitored and HV settings automatically adjusted to keep the efficiency constant. The verification of this control as well as accounting for any effects due to HV adjustments will be responsibility of online and offline detector monitoring.

The IFR requires a complementary calibration, defined as 'physics calibration'. In fact the IFR output in terms of μ/π identification does not depend uniquely on the hardware (RPC) response itself, but on the different pattern of muon and pion interactions with material, as well as on how this pattern appears in the detector. Models in the low energy range of BaBar are highly unreliable; therefore the information for physics calibration will be derived from IFR test beam data to be taken in 1997-1998. These physics calibration parameters will be included in the calibration database; however it is too premature to define their content and structure.

5 Outputs

The IFR μ/π discrimination will produce as an output a probability for a track to be a muon or a pion; this - as well as all the discriminant variables involved in the probability calculation - will be provided as an input to the common Particle Identification.

The output of the neutral hadron reconstruction will provide the identification of a neutral hadron as such and its direction. The neutral hadron reconstruction studies performed up to now in the IFR leave still open the issue whether a better determination of neutral track direction parameters is provided by the calorimeter, the IFR or a combination of both in the case when the particle interacts in the calorimeter before reaching the IFR. Clarification of this problem can come only from combined calorimeter-IFR detector and physics studies; however, as ultimately it will be driven by physics requirements, IFR reconstruction will be designed to leave the possibility open to any of the alternatives listed above.

The momentum of low energy neutral hadrons may be derived from the time measurements; however this hypothesis needs further studies.

It has been suggested that it might be possible to perform such a fine pattern recognition in the IFR that K_L^0 decay vertex and decay products are reconstructed; such a hypothesis will be subject to further investigation, even if the coarse granularity and the material interactions in the IFR make it quite difficult.

Neutral hadron identification - that is discrimination of K_L^0, neutrons and antineutrons - looks closely intertwined with physics analysis; therefore it is not evident whether the IFR can give a positive hadron identification by itself or the particle identification is demanded to the more global issue of testing physical hypotheses.

Clarification of this aspect - and consequent reconstruction and analysis design - will be derived by further detector and physics studies.

A t_0 measurement will be provided for all the events having at least a minimal significant number of hits in the IFR (estimated to be of the order of 90% of the total). Details are in the t_0 paper.

A fast and effective identification of cosmics can be provided by the IFR reconstruction independently of other detectors. This can be useful for fast cosmics rejection as well as for cosmics selection for calibration and monitoring purposes.

6 Interfaces

μ/π identification will be integrated in the common **particle identification**.

IFR neutral hadron reconstruction will be part of the common **neutral particle reconstruction** and **particle identification**.

IFR contribution to t_0 determination will be integrated in **tracking**.

Cosmics identification in the IFR will be integrated in the common **event selection**.

For consistency checks and possible requirements imposed by evaluation of systematics on physics measurements, procedures to achieve the primary IFR goals not only as part of global procedures, but also as independently as possible from other systems, will be developed too.

7 Monitoring

Offline monitoring will be complementary to online monitoring.

Hardware monitoring will be based on the experience with the L3 RPC muon system. The strict requirements of stability and quality imposed on that system by being part of the L3 trigger ensure that the monitoring developed in that environment is reliable.

Detector performance monitoring will check the behaviour and stability of various distributions:

- strips occupation,
- TDC performance,
- RPC efficiency,
- RPC hit multiplicity and cluster size,

- spatial resolution,
- time of flight distribution as a function of angle,
- compatibility of IFR t_0 with t_0 calculated by drift chamber and DIRC.

Events required for monitoring are cosmics and dimuons. Rates of the order of 2 Hz look adequate to collect sufficient statistics. Random triggers will be preferable for strips occupation monitoring.

The performance of IFR software will be subject to monitoring too to ensure stability, consistency and adequacy of implemented algorithms.

8 Structure

The reconstruction flow is sketched in figure 1.

The choice of the IFR pattern recognition strategy requires some investigation to determine the most efficiency and accurate way to associate hits to the charged or neutral tracks they belong to. Preliminary studies as well as experience in other detectors suggest that starting pattern recognition from the extrapolation of existing charged tracks and calorimetr clusters may be preferable to reconstructing tracks in the IFR independently and linking them later to tracks and clusters provided by other systems. However, even if the former approach will be verified as more efficient, the latter cannot be completely ignored, as the IFR will have to perform - at least partially - an independent pattern recognition for neutral hadrons not interecting in inner detectors.

Therefore it was decided to pursue both strategies in parallel and to select the best performing one after comparing their results. For practical reasons it was decided to start with the independent pattern recognition first, as it requires IFR information only and does not depend on input from other systems, still in a preliminary evolution phase. Whatever the final strategy is, the present work will have a necessary application in the neutral hadron reconstruction anyway.

It is expected that the current implementation will be subject to evolution, resulting from evaluation of its performance on detector and physics studies as well as from input and requirements from other systems. The design is kept as flexible as possible to accomodate future evolution without any major reconfiguration of existing developments.

The current implementation of reconstruction in the IFR is structured mainly into two parts. A reconstruction involving IFR data only is carried on first; later information from the other detectors are taken into account to complete and improve the previous step of IFR standalone reconstruction. For Monte Carlo data a digitization step reproduces detector output that undergoes full reconstruction.

8.1 Digitization

At a very first stage a digitization procedure for Monte Carlo data starts from the `GEANT` hits and simulates the detector response. Hit coordinate information are decoupled into the two orthogonal readout views and a discretization procedure is used to generate the hit strip pattern; the strip pattern is generated reproducing the correct average strip multiplicity as a function of the distance of the `GEANT` hit with respect to the center of the hit strip along the coordinate measured by the strips.

Data from L3 RPC tests are presently used to tune the procedure; a more detailed simulation will arise from tests on the actual BaBar RPCs. The module `IfrGHitToStrip` generates the strips pattern from the `GEANT` hits.

TDC time response has to be generated taking into account the strip propagation delay and the smearing due to the intrinsic RPC time resolution.

8.2 Reconstruction in the IFR

Reconstruction in the IFR first performs a clustering of adjacent hit strips in each readout view of the RPC layers. In some cases clusters with a number of strips much larger than the average multiplicity can be due to two tracks very close to each other in one readout projection, but well separated in the other view. For those cases, which should be very rare due to the low IFR occupancy, time information will be used to split the cluster and provide the right assignment to the correspondent tracks. This step is provided by the module `IfrStripToLayer`.

Pattern recognition is first performed in the two orthogonal readout views; the 2D clusters are then paired in the two views to make 3D clusters, resolving the possible ambiguities with the help of timing information and with the extrapolation of charged tracks from the Drift Chamber to the IFR. At present the 2D pattern recognition is done in a simplified way and is responsibility of the module `IfrMake2DClusters`.

Special cases of 3D clusters are due to tracks that leave hits in two adjacent sectors - for instance, both in the barrel and in one endcap. Merging the barrel and endcap part of such clusters is foreseen.

8.3 Contributions from other detectors

Good track extrapolation from central detectors is important to match Drift Chamber charged tracks with IFR track segments or clusters. Clusters not associated with charged tracks are considered as belonging to neutral hadron candidates.

Information on energy loss in the Drift Chamber and DIRC response can contribute to μ/π separation especially in the low momentum region.

For K_L^0 identification and reconstruction the information from the calorimeter is of extreme importance for the fraction of neutral hadrons interacting in the CsI before reaching the IFR.

9 Key classes

Two main cathegories of classes are designed, one for detector structure description and the other for detector output data.

The detector classes provide geometry information and refer to each other by mean of pointers. Coordinate transformations from global to local reference frames and vice versa are provided.

The following if a brief description of detector classes.

- `IfrDetector` represents the whole IFR; it contains references to its parts that are described in the following classes; it provides pointers to the belonging sectors.

- `IfrSector` represents each of the six barrel sextants and two endcaps and (to be implemented) the inner RPC layers. The endcap sectors are going to be further subdivided in the forthcoming developement (i.e. into left and right sides). A local reference system for each layer with x and y axes parallel to the RPC layers and the z outgoing for each sector is provided.

- `IfrLayer` represents a sensitive RPC layer; geometrical information as the distance with respect to the interaction point are provided. A layer can have one or two readout views.

- `IfrView` provides geometry information (strip pitch, etc.) and defines a local reference frame with x perpendicular to the strips, z perpendicular to the RPC layer and outgoing and y such to form a right-handed reference. It provides a method to discretize the local x coordinate into a strip number, that is used in the digitization module.

IFR detector response data are represented by the following classes.

- `IfrAbsDigi` is an abstract class from which both single strips (`IfrDigiStrip`) and clusters of adjacent strips (`IfrDigLayerCluster`) are derived. It provides utilities to handle position infornmation and convert those to 2D points. The 2D pattern recognition module is written in terms of `IfrAbsDigi` methods in such a way to easily run pattern recognition both on clusters of adjacent strips and on single non clusterized strips.

- `IfrStripCode` represents the hardware code of one strip. Data read from the raw data stream are going to be incapsulated in such objects. Services to convert `IfrStripCode` into `IfrDigStrip` are provided.

- `IfrDigStrip` is derived from `IfrAbsDigi` and represents one single strip hit. It has links to the View, Layer, Sector (and Detector) it belongs to. An order relation between two strips is defined in such a way that strips can be sorted. Adjacency of two strips is provided as an operator of the class.

- `IfrDigLayerCluster` is a cluster of adjacent strips in the same readout view. It is derived from `IfrAbsDigi`. `IfrDigLayerCluster` is constructed from `IfrDigStrip` by the module `IfrStripToLayer`. it contains information on the strips it is made of, its size and local position (center of gravity).

- `Ifr2DCluster` is a cluster of `IfrDigLayerClusters` (or, compiling with a particular option, of `IfrDigStrips`) which belong to the same sector and are on the same readout side. `Ifr2DClusters` are produced by the module `IfrMake2DClusters`.

- `Ifr3DCluster` (yet to be implemented) represents a 3D cluster which contains information from both the readout projections. Room for 3D clusters coming from a track split between two adjacent sectors is foreseen.

Timing data classes are still under design, as well as interfaces with the other detectors.

10 Status and schedule

The current implementation provides a minimal functionality for standalone IFR reconstruction from strip hit patterns. Implementation of the complementary part related to TDC hit patterns is foreseen in the near future. Further progress both in pattern recognition and implementation of a preliminary μ/π discrimination requires the availability of tracks (and swimming).

Preliminary implementation of IFR charged pattern recognition is planned by end of summer 1996 (subject to the development of swimming). It is planned to be followed by preliminary muon/pion discrimination implementation by Fall 1996. Neutral pattern recognition and preliminary implementation of K_L^0 reconstruction and identification is planned by end 1996. This schedule is driven by the requirement of having a preliminary but functional implementation of the primary IFR tasks available for the optimization of the IFR strip read-out, expected to be completed by the time of IFR installation. A working implementation of the whole chain is planned by summer 1997.

Detector and physics studies will proceed in parallel to the software developments: not only they represent the goal of reconstruction developments, but also the guidance.

Design evaluations and improvements are expected to come as a result of the application of the existing software to detector and physics studies.

11 Organization and manpower

The IFR software management organization is shown in figure 2; it is inspired by the requirement of coordination among the various areas of IFR software (reconstruction, simulation, online, trigger, detector optimization studies, physics studies).

The development of IFR software involves various groups spread across Italy and the US.

- INFN and University of Bari
- INFN and University of Genova
- Laboratori Nazionali dell'INFN di Frascati
- INFN and University of Napoli
- LLNL
- Prairie View A&M University

Communication is highly desired, but not easy across two continents. Phone conferences with the participation of members of the IFR group and of the reconstruction and simulation coordinators are going to take place regularly. IFR software meetings or sessions are scheduled regularly. The Hypernews discussion system on WWW is used for exchange of information.

Close communication with the software coordination group and with the tracking group has been and will be kept.

Full integration into the common reconstruction framework is considered an essential priority and a guideline of all IFR specific software developments.

Several people expressed their interest to contribute to IFR software development, in general to both reconstruction and simulation. The current availability of software dedicated manpower is limited by the constraints of the hardware schedule - requiring the installation of the IFR in its final configuration at SLAC in summer 1997, one year earlier than the other BaBar detectors - that drives most of the IFR group manpower into the construction effort. Moreover a large fraction of the IFR group is still in the process of acquiring sufficient familiarity with Object Oriented techniques and c++ to be able to effectively contribute to software development. However the manpower available to software is expected to increase in the next few months, when the hardware activity will have gone through its major startup effort taking place just now. The active participation of all the people that have expressed their intention to contribute and the introduction of the new students and post-docs foreseen within the next few months represents adequate manpower to achieve the goals of IFR reconstruction.

The software development of the IFR group takes place on DEC-OSF and HP-UX platforms; available cpu and storage are adequate for the present requirements. The acquisition of Object Oriented design tools (Rational Rose) is in progress.

References

[1] M.G. Pia, B tagging with muons, BaBar Note 192

[2] L. Lista and S. Mele, Study of the iron segmentation optimization of the I.F.R. detector for π/μ discrimination, BaBar Note 194

[3] R. Baldini-Ferroli, R. de Sangro, A. Palano and A. Zallo, A Study of CP violation in $B^0 \to J/\psi K_L^0$ using a highly segmented IFR, BaBar Note 198

[4] D.M. Wright, K_L^0 identification in $B^0 \to J/\psi K_L^0$ decays, BaBar Note 201

[5] R. Baldini-Ferroli, R. de Sangro, A. Palano and A. Zallo, Further study of $B^0 \to J/\psi K_L^0$, BaBar Note 223

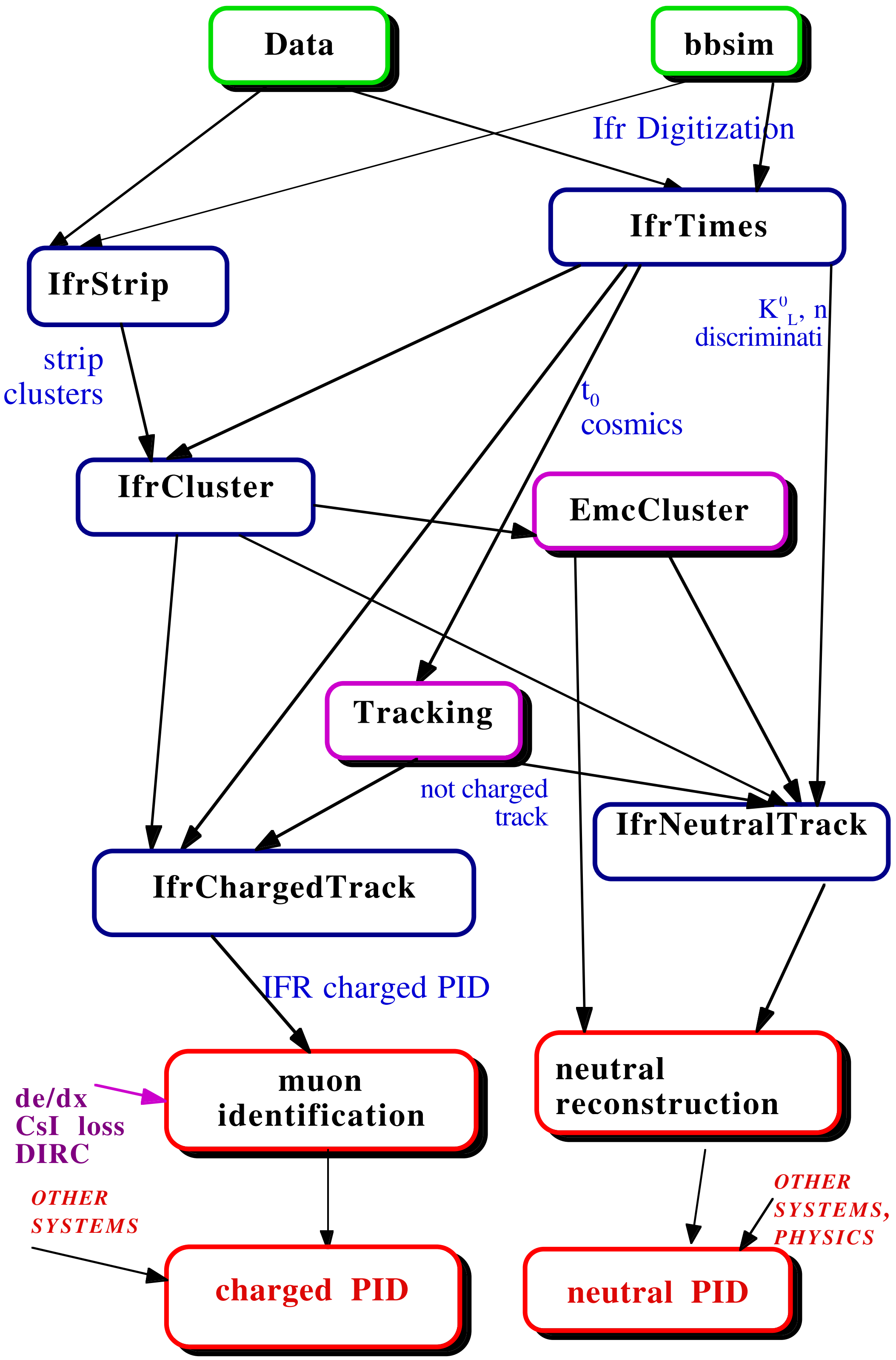

Figure 1: IFR reconstruction flow

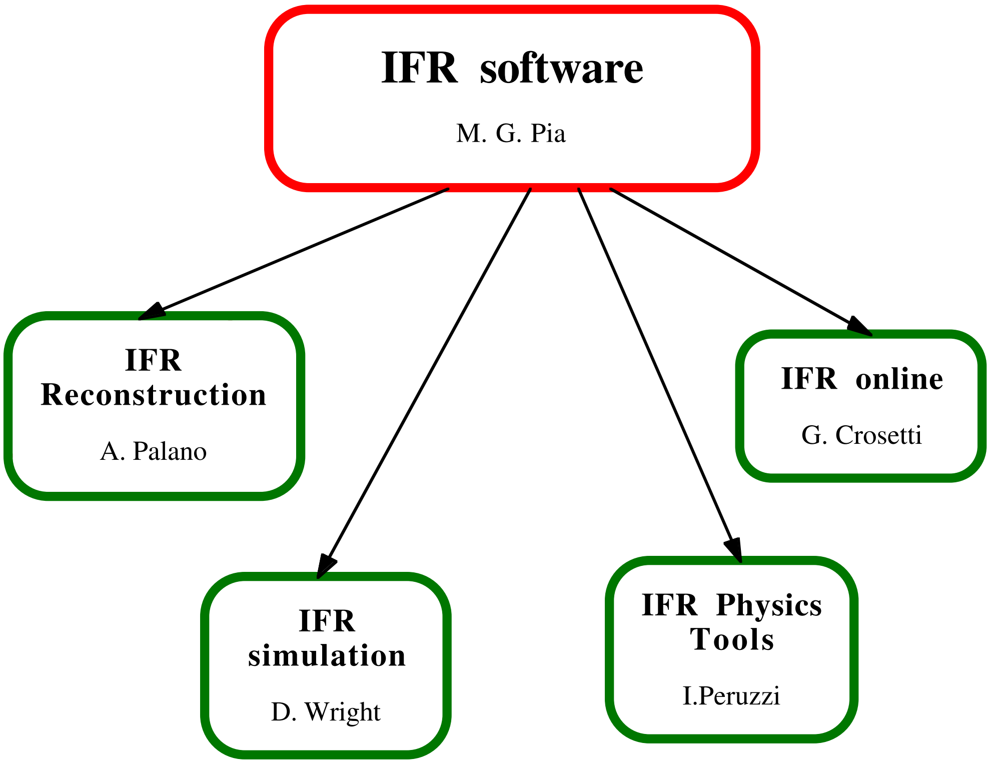

Figure 2: IFR software organization