Event Reconstruction in the PandaRoot framework

Stefano Spataro for the PANDA collaboration

Dipartimento di Fisica Generale, Universitá di Torino and INFN, Italy

E-mail: stefano.spataro@to.infn.it

Abstract. The PANDA experiment will study the collisions of beams of anti-protons, with momenta ranging from 2-15 GeV/c, with fixed proton and nuclear targets in the charm energy range, and will be built at the FAIR facility. In preparation for the experiment, the PandaRoot software framework is under development for detector simulation, reconstruction and data analysis, running on an Alien2-based grid. The basic features are handled by the FairRoot framework, based on ROOT and Virtual Monte Carlo, while the PANDA detector specifics and reconstruction code are implemented inside PandaRoot. The realization of Technical Design Reports for the tracking detectors has pushed the finalization of the tracking reconstruction code, which is complete for the Target Spectrometer, and of the analysis tools. Particle Identification algorithms are currently implemented using Bayesian approach and compared to Multivariate Analysis methods. Moreover, the PANDA data acquisition foresees a triggerless operation in which events are not defined by a hardware 1st level trigger decision, but all the signals are stored with time stamps requiring a deconvolution by the software. This has led to a redesign of the software from an event basis to a time-ordered structure. In this contribution, the reconstruction capabilities of the Panda spectrometer will be reported, focusing on the performances of the tracking system and the results for the analysis of physics benchmark channels, as well as the new (and challenging) concept of time-based simulation and its implementation.

1. Introduction

The PANDA[1] experiment is one of the main projects of the future Facility for Antiproton and Ion Research (FAIR), which is currently under construction at GSI laboratory in Darmstadt (Germany). As internal experiment of the High Energy Storage Ring (HESR), it will study antiproton-proton annihilations and antiproton collisions against nuclear targets, covering a center-of-mass energy range from 2.3 GeV to 5.5 GeV. In this energy region a very accurate spectroscopy will be performed, expecially in the charm quark sector where also new exotic states (glueballs, hybrids, multiquark states) can be searched for. By studying the non pertubative regime it will be possible to improve our understanding of QCD and hadron structure, exploring the nature of the strong interaction. Moreover, the broad physics program foresees also the study of hadrons once produced in nuclear medium, the measurement of single and double hypernuclei production, the study of nucleon structure using electromagnetic processes, electroweak physics and many other topics. In order to face the very high event rate (around $2 \cdot 10^7$ Hz) a triggerless data acquisition is foreseen.

In preparation for the PANDA experiment, the *PandaRoot* software framework is under development and it is currently used for detector studies and the analysis of benchmark channels. In this paper features and results from event reconstruction within *PandaRoot* will be discussed; first a general overview of the framework will be described, then the current software

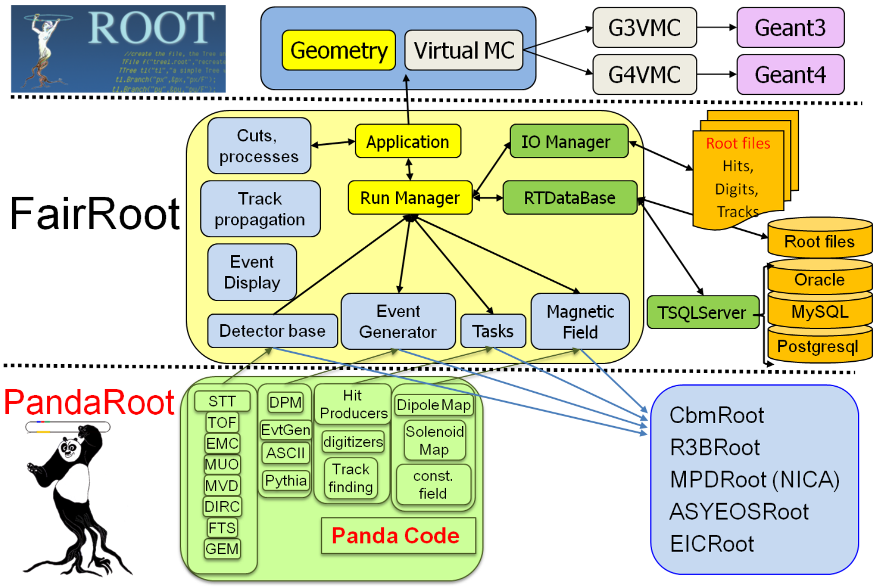

Figure 1. Code design of the FairRoot and PandaRoot frameworks.

implementations, mainly focusing on tracking, particle identification and analysis of physics channels. The concept of time based simulation and its implementations in the framework will be presented, necessary to deal with the PANDA data stream based on a triggerless data acquisition. Finally conclusions will be drawn.

2. The *PandaRoot* framework

PandaRoot is the offline software for the PANDA detector simulation and event reconstruction. It is implemented inside the FairRoot[2] framework, which is used by all the big FAIR experiments and it is developed by the GSI-IT (see Figure 1).
The FairRoot framework handles the basic features, such as the interfaces with simulation, geometry handling, parameter database and the I/O. It is based on the ROOT[3] package, with a dynamic data structure using trees and folders; the Virtual MonteCarlo[4] is used for detector simulation, which allows to use different transport models, such as Geant3 and Geant4, with the same geometry and detector code. Many ROOT applications are implemented and currently used, such as the EVE Event Display, the TMVA package for particle identification, PROOF and recently also the TSQLServer interface to database. The PANDA detector specifics and the reconstruction code are developed inside PandaRoot. The code is maintained under many different Linux distributions and also on MacOS X, so that the user/developer can install the software in his laptop or computing farm without strict restrictions on the operative system. In order to maintain the compatibility on different platforms, nightly builds are sent and the results can be checked on a public webpage, so that possible bugs or incompatibility can be quickly found and fixed. The software run also on an Alien2 based grid, namely PandaGrid[5], which was used successfully for the analysis of benchmark channels of the central tracking system, for the realization of the Technical Design Reports.
As a first simulation step, events can be produced by several event generators according to the physics case, such as Evtgen, DPM, Pythia, UrQMD or also by generators developed within the collaboration for specifics physics cases (i.e. for electromagnetic form factors, Drell-Yan, HyperNuclei, etc.). Particles are then propagated through the spectrometer with the Virtual MonteCarlo interface, and detector responses are simulated by digitizers. Charged tracks are

combined by combining hits from different tracking detectors, which are extrapolated to PID detectors to form the charged candidates for the particle identification selection. Clusters in the electromagnetic calorimeter which are not correlated to charged tracks are supposed to be neutrals, such as photons or π°, and will form the neutral candidates. Different independent algorithms assign to each candidate a pid probability value, and this information is sent to the analysis for particle selection. Finally kinematic and vertex fitters can be run to improve the quality of the analysis results.

3. Tracking

The momentum values and the vertex coordinates of each charged particle are reconstructed by merging the information from all the tracking detectors present in the spectrometer. PANDA is a fixed target experiment and can be divided in two parts: a region surrounding the target where a solenoidal 2T magnetic field is present, namely the Target Spetrometer (TS), and a forward region where charged particles are deflected by a dipole field with 1T maximum intensity, the Forward Spectrometer (FS). In the target spectrometer tracking is performed by a high precision silicon based Micro Vertex Detector (MVD) surrounding the interaction point, a Straw Tube Tracker (STT) arranged in a cylindrical volume around the beam axis, and Gas Electron Multiplier (GEM) stations for forward angle tracks in the target spectrometer. The Forward Tracking System (FTS) in the forward spectrometer consists on six planes of Straw Tube detector placed before, in the middle and after the dipole magnetic field region; at this low polar angle region the FTS information is correlated also with the MVD and GEM detector signals to improve the tracking performance.

The tracking code in the TS is complete, and it was used to evaluate the STT and MVD performances in the respective Technical Design Reports[6, 7]. Pattern recognition consists on three different steps. First, signals from MVD and STT are matched separately with an assumption of constant field: local track finding in MVD uses the projection of the hits to a Riemann sphere[8] and it fits a plane through them; local STT track finding uses a conformal space transformation and adds hits by a road technique, starting from the external ones and fitting them by a helix. In a second step, tracklets from MVD and STT are matched together, adding also hits which were not associated in the previous step and cleaning the sample from spurious (fake) tracks. As a third step, in the angular region where particles can cross both MVD/STT and the GEM detectors, tracks are extrapolated from the last point of the central

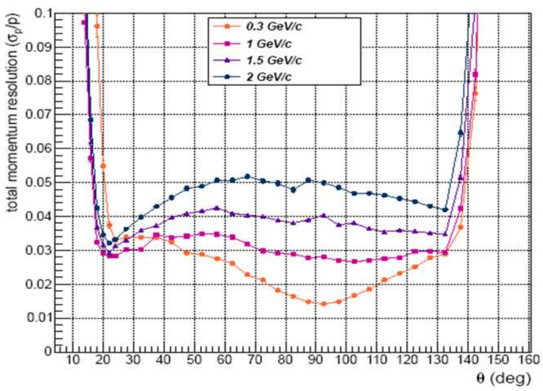

Figure 2. Momentum resolution as a function of polar angle for STT stand-alone.

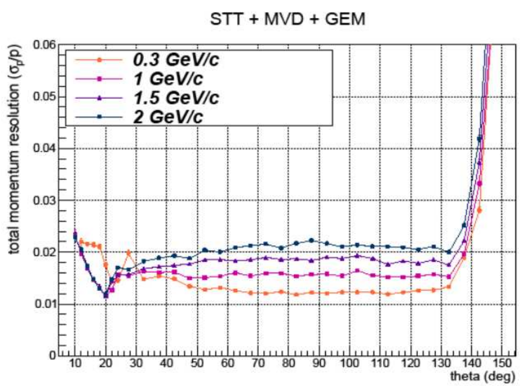

Figure 3. Momentum resolution as a function of polar angle for muons with STT+MVD+GEM tracking.

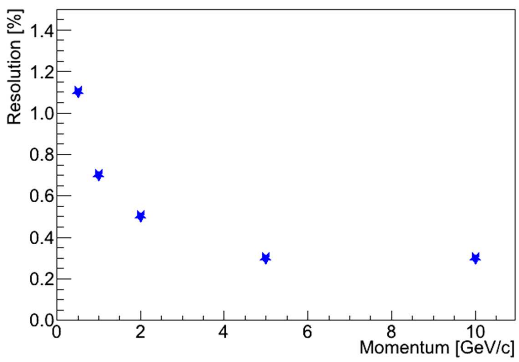

Figure 4. Momentum resolution for muons with FTS+MVD+GEM tracking in the Forward Spectrometer.

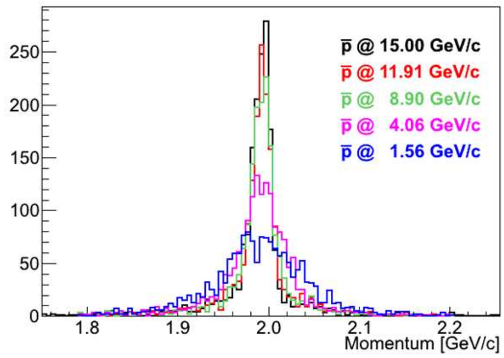

Figure 5. Momentum distributions for muons at 2 GeV/c in the FS, for different momentum values of the anti-proton beam.

tracker on each plane of the GEM detector and close hits are associated.
For a high resolution momentum reconstruction: a) signals of different detectors must be matched, each one with a different data structure and error calculation; b) magnetic field unhomogeneities must be considered, in particular in the transient region between the solenoid and the dipole magnets; c) proper energy loss inside different materials must be calculated. In PandaRoot global tracking is achieved employing the Kalman Filter technique, by using the GENFIT package[9] developed within the PANDA collaboration, and using GEANE[10] as track follower to propagate track parameters and error covariance matrices from a detector plane to another.
Figure 2 shows the momentum resolution distribution for muons as a function of the polar angle, for the STT stand-alone tracking. Figure 3 shows the same distribution for the global MVD+STT+GEM tracking.
Pattern recognition for the forward tracker is still under study and several options are currently under evaluation. For the moment, in PandaRoot it is possible to use an ideal pattern recognition algorithm which adds hits from MVD + GEM + FTS using the MonteCarlo information, and give a gaussian smeared seed to the Kalman Filter. Figure 4 shows the momentum resolution obtained in such a way for muons, as a function of the particle momentum and with the maximum dipole magnetic field. PANDA is an internal experiment of the HESR, and its dipole is one of the magnetic elements of the storage ring. Therefore, the beam of antiprotons circulating inside the PANDA beam pipe feels the effect of the dipole field; this means that, according to the beam momentum, the dipole field needs to be scaled so that the antiprotons can continue to circulate inside the storage ring. Therefore, tracking performances are depending on the momentum of the anti-proton beam, as shown in figure 5 for 2 GeV/c muons.

4. Particle Identification

All the found charged tracks are extrapolated into the PID detectors by using GEANE, and the point of closest approach (PCA) is calculated. For each PID detector, the closest hit (inside a correlation window) to the extrapolated PCA is associated to the track, and charged candidates are filled with the track parameters variables adding the information relevant for particle identification, i.e. dE/dx, cherenkov angle, energy deposit in EMC, etc. The EMC clusters which are not correlated to charged tracks are considered as neutral candidates.
Currently several PID algorithms run on each candidate and probability density functions are

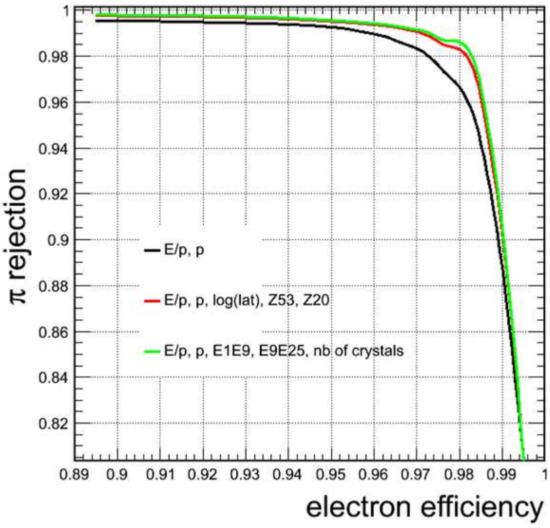

Figure 6. Multi Variate Analysis with EMC: ROC curve showing electron/pion separation.

calculated for each detector independently; all the PDFs with each stable particle hypothesis (e, μ, π, K, p) are then associated to each candidate, and at the analysis stage the user can choose which kind of algorithm to use and to merge (using Bayes' theorem) to obtain a global PID probability, where he can select his favorite particle list. In this way maximum flexibility is guaranteed, important in this phase of developments where algorithms and selection criteria need to be evaluated and optimized.

In order to improve the particle identification performance, multi variate algorithms based on the TMVA[11] ROOT package are implemented and under study, dealing with a large number of parameters. The current implementation allows to use the basic TMVA functionalities, such as preprocessing and evauation tools, to run different classifiers, to select variables and load weight files in a simple way. One application is the electron identification and the suppression of the pionic background, by using the shower shape parameters from the electromagnetic calorimeter. In figure 6 the obtained ROC curve is showed, i.e. background rejection versus the signal efficiency, using a Multi Linear Perceptron neural network with two hidden layers; results with different training variables are shown, with the standard E/p (cluster energy divided by the track momentum) and adding different shower shape parameters.

Different classifiers are currently under evaluation, and studies on muon identification using the information from the Muon detector have just started.

5. Analysis

The Rho[12] package has been included inside PandaRoot as analysis framework; the user has the possibility to fill candidate lists according to his PID selections and kinematic constraints, combine them for the physics analysis, and retrieve the MonteCarlo truth for studies. Different kinematic and vertex fitters[7] have been implemented, and were used in the analysis of benchmark channels for the central tracker TDRs. An example to test the reconstruction chain can be the channel $\bar{p}p \rightarrow \Psi(3770) \rightarrow D^+D^- \rightarrow$, where $D^\pm \rightarrow K^\mp\pi^\pm\pi^\pm$. This decay has six tracks in the output channel, and secondary vertices with a short decay length ($c\tau = 311.8$ μm for the charged D mesons). Figure 7 shows the mass distributions of the reconstructed D mesons after the vertex fit, while figure 8 shows the vertex coordinate distributions. We obtain a D mass resolution in the order of 16 MeV/c^2, and a vertex resolution in the order of 55μm for X and Y coordinates, of 104μm for Z coordinate.

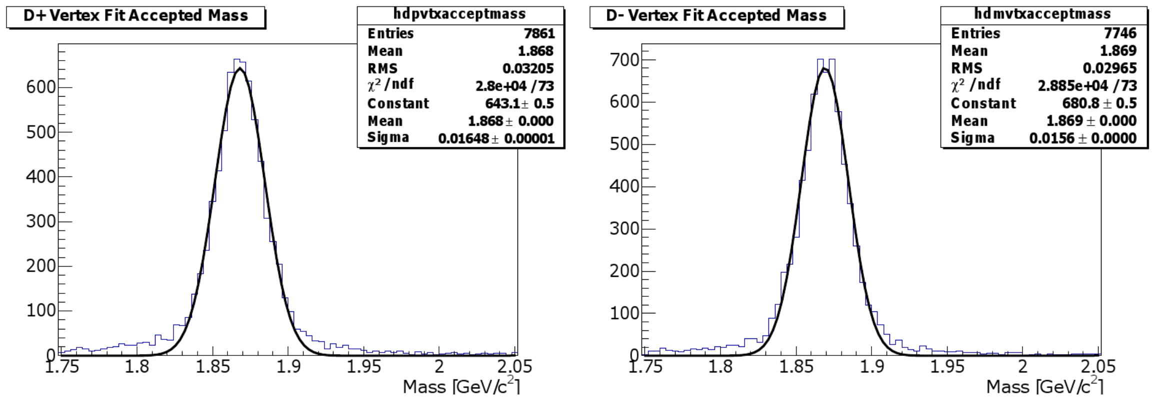

Figure 7. Mass resolution of the reconstructed D mesons after the vertex fit.

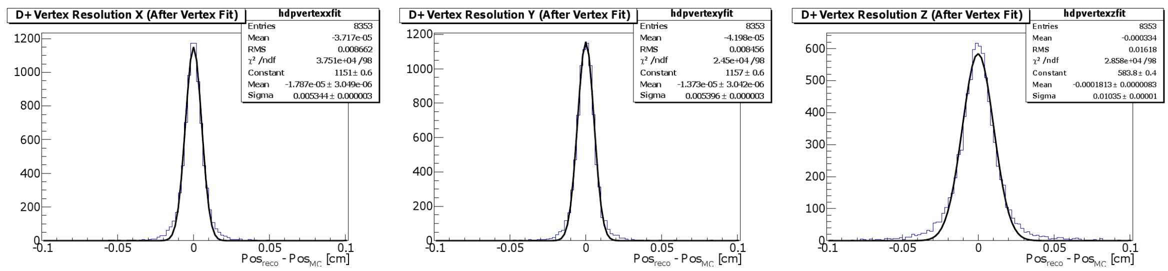

Figure 8. Spatial resolution of the reconstructed D^{+} decay vertex.

6. Time based simulation

In PANDA the many different research topics require various sophisticated event selection criteria, where different detectors might contribute. In order to achieve high flexibility and selectivity and to deal with the high event rate ($\leq 2 \times 10^{7}$ evt/s), in the data acquisition no common hardware trigger is foreseen but all the detectors are self triggering: they preprocess the data streaming only the relevant information in the so called *compute nodes* for event selection. This means that the event is not defined by the DAQ, but all the signals are marked by time stamps provided by a distributed high quality clock, and are continuously streamed for further processing.

The order of signals reaching the DAQ does not follow explicitely the event order, but in particular for slow detectors (i.e. STT, where the acquisition time depends on the time when the particle hits the tube, on the drift time of the electronic charge into the wire, and on the integration time from ADCs) signals from different detectors can be mixed (see figure 9) and the event time needs to be deconvoluted by the software.

The FairRoot software structure was redesigned from an event basis to a time ordered simulation, in order to reproduce such randomized order, and we started to implement the propagation of time stamps at the digitization level for several detectors, as well as algorithms to reconstruct the event time. At present the user can chose if to run the standard event-based simulation or the new time-based simulation. The next step is to redesign reconstruction algorithms, in order to handle the additional time information and do the event building. This is a quite important and challenging project, which will affect both *offline* and *online* reconstruction.

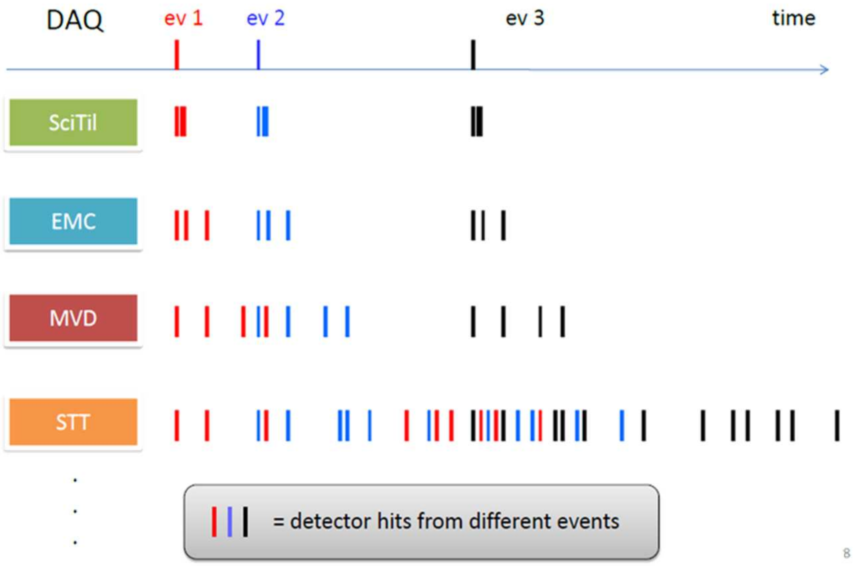

Figure 9. In the triggerless PANDA data acquisition, the order of signals reaching the DAQ does not follow strictly the event order, signals from different events are mixed and the event time needs to be deconvoluted by the software.

7. Conclusions

PandaRoot is the framework for the PANDA full simulation, reconstruction and analysis. Tracking in the Target Spectrometer is complete and the Technical Design Reports for MVD and STT detectors are now finalized, showing the reconstruction performances for benchmark channels; the general structure for forward tracking is implemented but still pattern recognition algorithms are in the developing phase.
Particle identification information is present for almost all the detectors, and new studies using Multi Variate Analysis methods are ongoing to improve the PID performances, in particular for electromagnetic channels (i.e. identification of eletrons and muons) which are overcome by strong interactions and the pion background needs to be heavily suppressed.
For the analysis the user can select in a flexible way the PID selection criteria, and kinematic and vertex fitters are working nicely; massive data production for TDRs' analyses has run successfully on Pandagrid, our Alien2 based GRID.
A new challenge comes to simulate the triggerless PANDA data acquisition system; the software structure was redesigned from an event basis to a time ordered simulation, and now reconstruction algorithms need to handle the additional time information for the event building. The basic infrastructre is present in the framework and the detectors implementation are work in progress, finalized in the next months.

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