Triplet based online track finding in the PANDA-STT

M C Mertens for the PANDA collaboration
II. Physikalisches Institut, Justus-Liebig-Universität Gießen, Germany
and IKP, Forschungszentrum Jülich GmbH, Germany
Present address: ZIM, Universität Duisburg-Essen, Germany
E-mail: marius.mertens@exp2.physik.uni-giessen.de

Abstract. The PANDA-Experiment at the future FAIR facility in Darmstadt will study antiproton-proton collisions in a fixed-target setup with a phase-space cooled antiproton beam with a momentum from 1.5 to 15 GeV/c at a nominal interaction rate of \(2 \times 10^7 \text{s}^{-1}\). The data acquisition of the detectors has to run in a triggerless mode and the physics events of interest are identified by an online event filter. Tracking information is a key input for the event filter to distinguish signal events from background. A variety of tracking algorithms is foreseen to process the different track topologies. The so-called Triplet Finder, which is presented here, is a track finding algorithm based on the central straw tube tracker (STT) of PANDA. The algorithm focuses on mathematical simplicity and robustness to allow an online processing of the incoming detector hits. The algorithm and results of a proof-of-concept implementation are presented.

1. Introduction
The PANDA-Experiment will be an internal experiment in the High Energy Storage Ring (HESR) at the future Facility for Antiproton and Ion Research (FAIR) in Darmstadt. PANDA has a broad physics program in the charmonium energy region [1]. Of particular interest are channels with low production cross sections which require a high nominal interaction rate of \(2 \times 10^7 \text{s}^{-1}\) in order to be observed.

The PANDA data acquisition has to run in a continuous mode without a hardware trigger, i.e. the subdetectors continuously deliver data which is analyzed by an online event filter to identify the signal events to be stored. The main reasons for this type of operation are the high interaction rate and the fact that the topologies of signal events and hadronic background are very similar.

The online event filter uses high level information such as particle identification, momentum, invariant mass, etc. to distinguish signal events from background. Online track and event reconstruction is a key input to determine this high level information.

1.1. Charged particle tracking detectors in the target spectrometer
The PANDA apparatus consists of a target spectrometer with a 2 T solenoidal magnetic field which surrounds the interaction region and a forward spectrometer with a 2 Tm dipole field.

The main tracking detectors of PANDA’s target spectrometer are the silicon sensor based Micro-Vertex-Detector (MVD, [2]) and the large-volume Straw Tube Tracker (STT, [3]) around...
the target interaction region together with a set of Gas Electron Multiplier (GEM) disks for the charged particle tracking within the 2 T solenoidal magnetic field.

The STT is a gas based detector which consists of 4636 cylindrical drift tubes (straws) of 1 cm diameter and 140 cm length, filling an almost cylindrical volume from 16 cm up to a radius of 42 cm around the MVD. The straw tubes are glued together to closed-packed multi-layers and operated at 1 bar overpressure which provides both the wire and tube tension without the need for a massive external frame (self supporting straws). This results in a radiation length of the STT of as low as 1.2% and a weight of about 15 kg. The distance of a track to the wire is determined by the drift time, i.e. the difference of the event start time and the recorded hit time, with a maximum value of 200 ns corresponding to a hit close to the tube wall.

1.2. Online tracking
Tracking information is required to determine the high level information used by the online event filter to identify signal events. Thus it is not known in advance whether a particular track belongs to a signal or a background event and we attempt to reconstruct all tracks in a continuous manner. The interplay of different tracking algorithms is required for an optimized reconstruction of the multitude of possible event topologies. As a consequence of the high interaction rate, the hits of tracks from different events may overlap in time and have to be associated to their respective events (event building) prior to the filter decision.

There is no distinct bunch structure in the quasi-continuous beam of the HESR, but the events can be organized in so-called bursts. One burst is equivalent to the events generated by one revolution (2000 ns) of the antiprotons stored in the HESR. At the nominal PANDA interaction rate of $2 \times 10^7$ events per second, a burst comprises about 40 events. An estimated gap of 400 ns between each burst is sufficiently long (compared to the maximum drift time of 200 ns in the STT) to allow a separation into independent processing units without overlap.

PANDA’s data acquisition will comprise FPGA (Field Programmable Gate Array)-based compute nodes for online data processing (Sec. 2.2.4 in [1]) and eventually conventional PC farms utilizing GPU (Graphics Processing Unit)-computing. The burst structure also allows for a natural way of parallel processing by parallelizing the analysis of the individual bursts. This strategy of data parallelism scales very well with added nodes and does not impose any special constraints on the tracking algorithms.

2. Triplet Finder
The Triplet Finder is a track reconstruction algorithm specifically designed for the PANDA-STT to reconstruct tracks of charged particles. However, it should also be applicable to other tracking detectors of similar geometry. The design of the Triplet Finder features the following main properties:

- Dependence only on information which is initially available from the detector: Absolute hit times and straw index. This enables the algorithm to be executed as hits arrive without any additional knowledge such as drift-times or event times ($t_0$). Based on the hit time distribution the algorithm can constrain the event start time to provide a seed value for subsequent algorithms.
- Mathematical simplicity: This facilitates the implementation of the algorithm not only in software but as well on FGPAs or GPUs as may be required to process the complete hit output of the STT in real-time.
- Robustness: It should be easy to add routines which deal with faulty (e.g. dead or noisy) channels or unfortunate hit patterns in the detector in order to optimize performance under imperfect operating conditions.

It consists of three stages Triplet finding, circle calculation and hit association.
2.1. Triplet finding
The Triplet finding stage analyzes the pattern of three up to seven adjacent hit straw tubes around selected pivot straws and calculates the center-of-mass coordinates of such a pattern which is called Triplet. The location of the pivot straws has been chosen as shown in Fig. 1 (right) in order to cover a large area with a large lever arm, but other patterns with more or less pivot straws are also possible. The Triplet Finder is designed to operate on a full burst of hits which results in hits from different events being present in the buffer at the same time. Therefore, only hits with timestamps which differ by at most one maximum drift-time window (200 ns and an additional safety margin of 50 ns which is subject to optimization) can be combined to one Triplet. Due to the finite number of possible patterns the calculation of the center-of-mass on an FPGA can be implemented as a lookup table.

2.2. Circle calculation
Then the center and radius of a circle through the coordinate origin and two Triplets are calculated. It is also possible to calculate the track circle through three arbitrary points. However one of the points being the origin serves as an additional simplification and allows for quick processing of the tracks originating from the primary vertex. A later processing of the remaining hits with three arbitrary points could be a useful extension of the Triplet Finder to identify also tracks from secondary vertices, e.g. Lambda-decays. In each case the purely analytic approach of a circle calculation though three points in a plane reduces the computational complexity of the algorithm.

2.3. Hit association
The final step is the hit association which accounts all hits whose distance from the circle origin differs by at most the tube radius (5 mm plus safety margin, subject to optimization) from
the circle radius. This step also considers only hits within a compatible drift-time window for association. The total number of hits (including the Triplets) then determines whether the track candidate is considered a valid track. The threshold for the minimum number of hits is another parameter to be optimized in order to obtain the best combination of efficiency and purity.

3. Performance

A proof of concept version of the Triplet Finder has been implemented and tested within the PandaROOT framework which is based on ROOT [4]. For testing and developing the Triplet Finder the main goal of benchmarking is to optimize the reconstruction efficiency while maintaining high purity.

In order to achieve realistic results, the Triplet Finder was tested with events generated according to the Dual Parton Model (DPM, [5]) with a beam momentum of 15 GeV/c at the nominal PANDA interaction rate of \(2 \times 10^7\) events per second with a Poissonian event distribution taken into account. The DPM generator simulates elastic and inelastic, hadronic and Coulomb interactions and is used as a background generator for antiproton proton collisions. This setup ensures a realistic track distribution, event overlap and hit patterns similar to what will actually be seen by the detector.

The event overlap is also visible in Fig. 1 (right). The hit patterns which look like tracks with some missing hits are in fact early hits which actually belong to tracks from a later event. At such high rates, the overlap of events within a burst is unavoidable and therefore it must be verified that the track finding algorithm correctly processes such input.

The combination of having a continuous stream of hits and not a specific signal channel to be reconstructed but instead statistically distributed particles with very different momenta poses a challenge for the benchmark: In order to obtain realistic values for the reconstruction efficiency of the algorithm, the tracks which are reconstructable must be identified based on criteria such as momentum, number of hits, etc. so the reconstructed track ratio can be correctly normalized. Obviously, tracks with too low momentum, missing the STT, simulated secondary or tertiary electrons, remnants of nuclear reactions, etc. are all valid tracks in the simulation (Fig. 2 upper left), but should not enter the benchmark because they are neither interesting nor reconstructable at all. As an initial selection, a reconstructable track is required to meet the following criteria:

- Charged tracks in the first and second generation.
- \(p_t > 60\) MeV/c and \(\beta \gamma > 0.4\).
- Track start at most 2 cm away from coordinate origin.
- At least one STT hit.

While this still allows tracks which cannot be reconstructed due to geometric issues (e.g. just hitting a single straw) to pass, these rather loose conditions ensure that the performance is not overestimated by removing tracks which are difficult to reconstruct but will occur in a real life setup. Fig. 2 shows the momentum distribution of all simulated tracks (top left) and those which match the above criteria (top right).

From the simulated sample, 9228 tracks were considered reconstructable, of which the Triplet Finder’s raw output contained 6821 tracks. A comparison of the momentum distributions of the momentum distribution of reconstructable (Fig. 2 top right) and reconstructed (Fig. 2 lower left) tracks shows a similar shape in both cases, i.e. the efficiency distribution is flat.

Another aspect to be studied is the output quality of the Triplet Finder, i.e. how many hits have been correctly associated to the found tracks. Different combinations of hits can lead to correct tracks being found multiple times with different subsets of hits as well as fake tracks which do not correspond to an initially simulated track. With the current settings, the Triplet Finder outputs 38445 tracks of which 21137 contain more than 80 % correctly assigned hits. The deviation of the reconstructed ejection angles from the simulated ejection angles (Fig. 2,
4. Conclusion
The Triplet Finder has been designed as a track finding algorithm specifically for the PANDA-STT to identify tracks based on only the hit data with timestamps as it is generated by the detector without using further information which may require preprocessing of the data. The benchmark of its proof-of-concept implementation has shown that it is able to work under realistic operating conditions at the expected interaction rate with the resulting event overlap and delivers reasonable results. Since the development is just at its beginning, many parameters remain to be studied in order to optimize the performance of the Triplet Finder.

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