PANDA Technical Assement Group: Tracking

Draft 2.0

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Contents

1 Introduction

This document is a working document dealing with the effort made by the PANDA Technical Assessment Group (TAG) tracking. Main scope of this TAG is the definition of requirements for the tracking detectors and the procedure needed to come to a final concept and layout of the PANDA tracking system. Apart from the author members of the TAG are:

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- S. Neubert
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Of course contributions from other members of the PANDA collaboration is welcome too.

Since this is a working document it reflects the current status of the work and will be updated regularly after discussions among the TAG team until it reaches its final version. Therefore comments and remarks are included to highlight where more work is needed or inaccuracies and mistakes are given.

2 Requirements for the tracking detectors

Requirements for the tracking of the PANDA detector should be derived from the important physic channels. To ensure an easy access to the required information we defined a small set of channels which are regarded as the most important concerning the tracking properties of PANDA and will therefore serve as tracking benchmark channels in future, see section chapter 2.1.

The requirements for each tracking component inside PANDA are discussed individually to accommodate the specific technology of each detector part. Scope of this document is not to define such requirements but to specify in detail the performance questions on the basis of the detector technology which have to be addressed by the simulation of the benchmark physics channels. This discussion shall be concentrated in terms of figures of merit which of course have to be defined for each sub-detector in the first place. Now given values are based on experience and educated assumptions about the needs within PANDA and the possibilities of the different detectors types.

The simulation work needed to derive the final requirements can be divided into a two stage process. In the first stage basic figures of merit for each sub-component are used to optimize the detector design and layout. In a second stage the entire PANDA tracking system is considered to incorporate also more complex processes and requirements in the optimization work.

To reflect this approach one can find in this document for each sub-detector a dedicated chapter concerning their questionnaire to the simulation in order to derive requirements and optimize the detector layout, see chapter 2.2, 2.3 and 2.4. Finally the overall tracking requirements for PANDA are summarized in terms of most important figures of merit like track-, vertex- and momentum-resolutions taking into account a combined tracking system to which all tracking components contribute, see chapter 2.5.

2.1 Benchmark channels for tracking

It is clear that the requirements for the PANDA tracking system must be driven by the physic goals of PANDA. In the TP a lot of benchmark channels are given and optimization of the tracking detectors with respect to all of them seems not very suitable. To streamline the discussion and the needed simulation work on this topic we decided to choose a smaller subset of channels which can be regarded as 'tracking benchmark channels'. This means definition of tracking requirements and optimization of detectors should be done with respect to these channels in the first place.

The channels reflect the main applications of tracking detectors inside PANDA like high precision track measurement and subsequently high precision momentum measurement for charged particles in an energy region from 100 Mev up to 15 GeV. Furthermore special emphasize is given to the secondary vertex capabilities for c- and s-quark particles. In particular the tracking benchmark channels are:

- $\bar{p}p \rightarrow D^{*+}D^{*-}$ with $D^{*\pm} \rightarrow D^0\pi^\pm$ and $D^0 \rightarrow K^-\pi^+$, $D^0 \rightarrow K^-\pi^+\pi^-\pi^+$ or $D^0 \rightarrow \bar{K}^0\pi^+\pi^-$; all single sided. This channel sets mainly the requirements for secondary vertex finding capabilities of the MVD in the case of close displaced vertices in the range of several hundreds of μm. A good tracking of all involved charged particles is necessary and especially the slow pions from D^*-decays are demanding.

spatial resolution σ_s for track points	rφ z
resolution σ_v for vertex reconstruction	x y z = 100 μm
time resolution σ_t	
relative resolution Δp/p for charged particle momenta	

Table 1: Basic figures of merit for the MVD.

- $\bar{p}p \to \bar{\Lambda}\Lambda \to p\pi^-\bar{p}\pi^+$ which has to be distinguished from the K^0 production, i.e. $\bar{p}p \to K_S^0 K^\pm \pi^\mp$ with $K_S^0 \to \pi^+\pi^-$. In this sense the channel is similar to the previous channel regarding the tracking but the reconstruction of the Λ decay vertices also relies on the outer tracking detectors. In addition the channel $\bar{p}p \to \bar{\Xi}\Xi \to \bar{\Lambda}\pi\Lambda\pi$ can be considered to introduce a two stage decay cascade with two relative long life particles decaying inside the central tracker.
- $\bar{p}A \to J/\Psi X$ with $J/\Psi \to \mu^+\mu^-$ or $J/\Psi \to e^+e^-$ serve as a benchmark channel for high p_T charged tracks in a multi-track environment.
- Finally the elastic $\bar{p}p$-scattering $\bar{p}p \to \bar{p}p$ could serve as benchmark in particular for the forward tracking detectors.

  We believe that these channels are the most relevant for the tracking properties of PANDA but of course we encourage a careful verification of the deduced requirements with other channels once the optimization of the tracking system layout has been done.

2.2 Micro Vertex Detector (MVD)

Here now more work/input is needed for each sub-system. I will prepare a draft for the MVD as soon as possible, meanwhile the content here is not more than skeleton of things to come.

Main physical requirements for the pixel and strip detectors inside the Micro Vertex Detector will be derived from the $\bar{p}p \to D^{*+}D^{*-}$ benchmark channel. The basic figures of merit can be found in table 1; further important requirements for the MVD are connected with:

- Radiation tolerance up to $3 \cdot 10^{14}$ n$_{eq}$cm^{-2} for the innermost layers.

spatial resolution σ_s for track points	rφ z
resolution for σ_v secondary vertex reconstruction	x y z
time resolution σ_t	
relative resolution Δp/p for charged particle momenta	

Table 2: Basic figures of merit for the Central Tracker.

- Material budget less than 4% of a radiation length for the entire MVD including all support structures and services.
- Readout capable to cope with a triggerless readout architecture at an average annihilation rate of 10^7 per second and a peak rate up to $3 \cdot 10^7$.
- $\frac{dE}{dx}$-resolution in the order of a few percent (?) for a dynamic range from 1 to 20 (?) m.i.p. energy.
- ...

Furthermore one can find a first estimation of the expected performance for the MVD pixel and strip part based on experience in table 4, second column and third column respectively. This 'educated guess' should serve as starting point for implementation into the fast simulation. More detailed information like momentum and acceptance dependencies of the resolutions will come as soon as they are available.

2.3 Central Tracker

Input needed. Should be coordinated by the sub-detector representative. First of all How should this section look like?

The main figures of merit for the central tracking devices are listed in 2. Apart from them more requirements are:

- Material budget less than 1% of a radiation length including all support structures and services.
- Resistance against ageing effects of the order 0.1-1 C per cm and year.
- High rate capability ...

spatial resolution σ_s for track points	rφ z
resolution σ_v for vertex reconstruction	x y z = ?
time resolution σ_t	
relative resolution Δp/p for charged particle momenta	

Table 3: Basic figures of merit for the Forward Tracker.

- ...

A first approximation of the expected performance for the different proposed options can be found in table 4, column 4-6.

2.3.1 Straw Tube Tracker (STT), tilted tubes

This and the following subsections can be used for special remarks to the different options under discussion, if needed!

2.3.2 Straw Tube Tracker (STT), straight tubes

2.3.3 Time Projection Chamber (TPC)

2.4 Forward Tracker

Input needed. Should be coordinated by the sub-detector representative.

The main physical requirements for the Forward Tracker are given in table 3; more requirements are:

- High rate capability up to $3 \cdot 10^4$ per cm and second.
- Operation in a non-uniform magnetic field with variation up to 0.3 T
- ...

A first approximation of the expected performance for the different proposed options can be found in table 4, column 8 and 9.

2.4.1 Mini Drift Chambers (MDC)

2.4.2 Straw Tubes (ST)

2.5 Overall tracking performance

We have agree soon what shall come here.

3 Design choices

There are several design choices which have to be taken in the next years BUT it is agreed that the most important ones are connected with global Central Tracker and Forward Tracker design, in particular:

1. Central Tracker: Straw Tube Tracker (STT) or Time Projection chamber (TPC).
    - Skewed STT design.
    - STT design using harge division and/or time difference techniques.
    - TPC using TUM design.
2. Forward Tracker: MDC or Straw Tubes.
    - High-rate MDC design (i.e. ”PSI design”).
    - MDC using ”Dubna design”.
    - Straw Tube Design

Some of these different design option might be vanish before the time for decision will come. However, for both sub-detectors, CT and FT, at least two completely different approaches are proposed so it is very likely that two options will be developed until a ”TDR” stage.

There are of course many more choices to be taken, e.g. the different mechanical design options for STT, the number of layers needed for the forward spectrometer or the choice of the Pixel FE-chip. Many of them deal with the particular design of the sub-detector and are therefore not as controversial as others. Rather such decisions will evolve naturally during the R&D phase and may not need any formal procedure. However, all chosen options must at least demonstrate that the required criteria coming from physics or from technical aspects are fulfilled.

3.1 Criteria for design choices

We have to indicate the most important criteria for each choice, or this list can evolve to separated lists for each decision.

The criteria given here are mostly connected to the already mentioned 'important design choices'. Of course they can also serve as input for other design choices even if no formal procedure takes place.

1. Sufficient performance to reach the requirements driven by the physics goals of PANDA, in particular:
   - Space and vertex resolutions.
   - Capability to cope with expected rates.
   - Efficiency and multiplicity issues.
   - Time resolution and trigger issues
2. Technical feasibility of the concept:
   - It has to be demonstrated by a test beam of a prototype (can be scaled down).
   - Readout concept.
   - Data handling issues.
   - Particle identification possibilities (if appropriate).
   - Mechanical issues.
   - Interaction with beam-pipe (if appropriate).
3. Feasibility of the production:
   - Person power.
   - Available infrastructure.
   - Financing issues.
4. Influence on other detector components.
5. Complexity and costs during the operation and maintenance.

3.2 Roadmap towards a decision

Not discussed at all up to now! Please comment!

Since not all of the required criteria can be fulfilled on the same time scale or with the same effort a two step procedure is proposed if we have to decide between elaborated design options.

1. For each design choice a report covering items 1., 3.b, 4., and 5 shall be prepared 6-12 months before the decision have to taken. Afterwards it will be refereed by an internal group and a decision may be taken by the CB if appropriate.

2. After a further evaluation period which should not exceed the time scale for the sub-detector TDR a final report covering all criteria for each choice will be prepared and presented to a group of internal and/or external experts (Design Review). The reviewers are asked to formulate a recommendation to the CB for a final decision.

As already pointed out not all design choices or design options need to go through the whole process but the criteria should be valid for all decisions. For each 'design choice decision' the described process shall be adjusted accordingly.

4 Milestones to a PANDA TR

The current schedule to prepare a Technical Review of the PANDA detector (TR) until end of 2007 or early 2008 might clash with the time needed to take all necessary design choices. Therefore different options might be presented in the TR although an already taken decision is desirable. However, this TR is an intermediate step towards the individual sub-detector Technical Design Reports (TDR) which will come roughly a year later. It is an important milestone for the PANDA project and a definitive time frame for the open design choices must be given in this TR. Apart from a more detailed technical description of detector components the implementation of the production must be covered too. This includes productions milestones as well as feasibility and financing of the production. Many of the given information can of course go to the different TDRs as well to avoid duplication of the work. But in contrast to the TR the TDRs shall be as close as possible to the detector as it will be built. In order to cope with the tight FAIR/PANDA schedule the sub-detector TDRs should by finished by mid/end of 2009.

The the moment it seems feasible that both sub-detectors groups, CT and FT, could finish their R&D phase for the different design options by end of 2008 so the natural time to take the design decisions could be Dec. 2008. For the case of the FT the decision between the Straw Tube and MDC approach could be taken by end of 2007 leaving only the final MDC layout decision (if MDC are chosen) for 2008.

However, the scope of this document is not the planing for the 'official' paper-work but the definition and planing of the needed tracking detector work including open R&D questions. Therefore the proposed milestones could be:

1. Final Draft of this document concerning tracking requirements: January 2007
2. Fix time frames for design choices: December 2006.
3. Definition of work-packages for sub-detector R&D: March 2007.
4. Detailed outline of the sub-detector chapters of the TR: October 2007.
5. Decision between Straw Tubes and MDC for the FT: December 2007
6. Decision upon the CT design: December 2008

5 Appendix

	MVD		CT			FT	
Requirement for	Pixel	Strips	STT, tilted	STT, straight	TPC	MDC	ST
spatial resolution σ_s for track points	rφ = 40 μm z = 40 μm	rφ = 40 μm z = 100 μm	rφ = ? z = ?	rφ = ? z = ?	rφ = ? z = ?	rφ = ? z = ?	rφ = ? z = ?
resolution σ_v for vertex reconstruction	x = 100 μm y = 100 μm z = 100 μm	x = 100 μm y = 100 μm z ¿ 1 mm	x = ? y = ? z = ?	x = ? y = ? z = ?	x = ? y = ? z = ?	x = ? y = ? z = ?	x = ? y = ? z = ?
time resolution σ_t	20 ns	2 ns	?	?	?	?	?
relative resolution Δp/p for charged particle momenta	1%	1%	?	?	?	?	?

Table 4: Expected performance of the different detector options for the tracking system of PANDA.