PANDA Technical Assessment Group: Tracking

Final Draft 1.1

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Contents

1 Introduction

This document is a report dealing with the effort made by the PANDA Technical Assessment Group (TAG) tracking. The 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. The TAG consists of the following members:

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Significant contributions from other members of the PANDA collaboration have been integrated as well.

2 Requirements for the tracking detectors

The requirements for the charged particle tracking of the PANDA detector will be derived from the important physics channels. To reduce the complexity related to this decision we defined a small subset of channels which are regarded as the important for the tracking properties of PANDA and will therefore serve as the tracking benchmark channels in the future.

The requirements for each tracking component inside PANDA are discussed individually to accommodate the specific technology of each detector part. The scope of this document is however not to define the technology specific requirements, but rather the physics requirements arising from the benchmark channels. This discussion shall be concentrated on physics issues which has to be expressed in terms of figures of merit. Of course they have to be defined for each subdetector in the first place. Now the quoted performance values in Appendix 5 are based on experience and educated assumptions about the needs within PANDA and the possibilities of the different detector types.

Channel	Final state	Related to detector
$\bar{p}p \to (n)\pi^+\pi^-$	$(n)\pi^+\pi^-$	CT
$\bar{p}p \to \psi(3770) \to D^+D^-$	$2K\,4\pi$	MVD, CT
$\bar{p}p \to \psi(4040) \to D^{*+}D^{*-}$	$2K\,4\pi$	MVD, CT
$\bar{p}p \to \bar{\Lambda}\Lambda$	$p\pi^-\bar{p}\pi^+$	MVD, CT, FT
$\bar{p}p \to \bar{\Xi}\Xi$	$p\bar{p}4\pi$	MVD, CT, FT
$\bar{p}p \to \eta_c \to \phi\phi$	4K	CT
$\bar{p}A \to J/\Psi X$	$2lX$	MVD, CT
$\bar{p}p \to \bar{p}p$	$\bar{p}p$	MVD, CT, FT

Table 1: Benchmark channels to evaluate the performance of the different tracking detectors.

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 regard also more complex processes and requirements in the optimization work.

To reflect this approach this document consists for each sub-detector a dedicated chapter concerning their questionnaire to the simulation in order to derive requirements and optimize the detector layout, see chapters 2.2, 2.3 and 2.4. Finally the overall tracking requirements for PANDA are discussed, especially the topic of a combined tracking system to which all tracking components contribute is addressed, 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 physics goals of PANDA. In the TPR a lot of benchmark channels are given and optimization of the tracking detectors with respect to all of them seems not very practical. To streamline the discussion and the needed simulation work we decided to choose a smaller subset of channels which can be regarded as 'tracking benchmark channels'. This means that the definition of tracking requirements and optimization of the detectors should be done primarily with respect to these channels.

The channels reflect the main applications of the 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 emphasis is given to the secondary vertex capabilities for hadrons with c- and s-quark content. All tracking benchmark channels are listed in Table 1.

The importance of these channels for the different detectors is not always the same and will be discussed in detail within the following dedicated sub-detector chapters. However, roughly spoken the channels are needed for:

- The channels $\bar{p}p \rightarrow D^{*+}D^{*-}$ and D^+D^- define mainly the requirements for secondary vertex finding capabilities of the MVD for vertices displaced by several hundred μm. A good tracking of all involved charged particles is necessary and especially the slow pions from D^*-decays are demanding.
- The channel $\bar{p}p \rightarrow \bar{\Lambda}\Lambda$ has to be distinguished from the K^0 production, i.e. $\bar{p}p \rightarrow K^0_S K^\pm \pi^\mp$ with $K^0_S \rightarrow \pi^+\pi^-$. In this sense the channel is similar to the previous channel regarding the tracking, however on the scale of about 10 cm. But the reconstruction of the Λ decay vertices also relies on the outer tracking detectors. In addition the channel $\bar{p}p \rightarrow \bar{\Xi}\Xi$ shall be considered to introduce a two stage decay cascade with two relative long life particles decaying outside the MVD volume.
- $\bar{p}A \rightarrow J/\Psi X$ serve as a benchmark channel for high p_T charged tracks in a multi-track environment.
- The elastic $\bar{p}p$-scattering serves as benchmark for tracking and momentum measurement in particular for the forward tracking detectors as well as background process for the CT because it produces a high particle flux close to $\Theta = 90°$.
- The channel $\bar{p}p \rightarrow \eta_c \rightarrow \phi\phi$ is dedicated for the PID studies with the Central Tracker whereas the $\bar{p}p$-annihilation to pions serves correspondingly as background channel.

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)

The current layout of the innermost tracking component of PANDA, the micro vertex detector (MVD), incorporates 4 barrel layers and six disk layers. Altogether roughly 400 double sided strip modules and 140 hybrid pixel modules cover an active area of about 1 m^2 with 10^7 readout channels. Two more disk stations further downstream are foreseen to improve vertex tagging of hyperons and other particles with strangeness as well as to assist the tracking of particles in the forward

spatial resolution for track points versus p_T and Θ	σ_s in rφ, σ_s in z
resolution for vertex reconstruction versus p_T and Θ	σ_v in x, y and z
relative resolution for charged particle momenta vs. p_T and Θ	Δp/p
relative mass resolution of reconstructed D^* and D	Δm/m

Table 2: Basic figures of merit for the MVD, the momentum and mass resolution can only be derived with the entire PANDA tracking system.

region. These disks will be only equipped with double sided strip detectors. More details concerning the design and the layout can be found elsewhere [1, 2, 3]. The main task of the MVD is a high resolution tracking for charged particles and the vertex reconstruction of primary and secondary vertices. Especially for the open charm physics an excellent reconstruction of D-meson decay vertices in all three spatial dimensions is mandatory. This task defines the figures of merit which are collected in Table 2.

The requirements of the MVD for these figures of merit will primary be derived from the $\bar{p}p \rightarrow D^{*+}D^{*-}$ benchmark channel which allows a determination of the crucial secondary vertex detection for the short lived D-mesons together with tracking of low momentum pions coming from the D^*-decays. A first estimation of the expected performance in terms of the figures of merit, divided into the pixel and strip part of the MVD, based on experience and educated guesswork at least, is given in Appendix 5, Table 4, second column and third column, respectively.

Apart from the requirements directly connected with the physics performance of the MVD many requirements exist which can't be expressed easily in terms of figures of merit. They are mostly given by the environmental and operational conditions of the MVD and can therefore be derived from background process simulations or they are given by the needs from the outer detector components. With this in mind the requirements can be expressed much more solid although changes are still possible depending on the input from background simulations and other detector components constraints. These requirements are:

- Radiation tolerance up to $3 \cdot 10^{14}$ n$_{eq}$cm^{-2} for the innermost pixel layers and up to 10^{14} n$_{eq}$cm^{-2} for the strip layers.
- Material budget less than 1.2% of a radiation length per pixel layer and less than 1% per strip layer including all support structures and services.

- Single channel occupancy up to some kHz for pixel sizes of $50 \cdot 400$ or $100 \cdot 100$ μm^2 resp. and up to some 10 kHz for single strips.
- Total count rates per FE chip of about 10 MHz for the pixel part and 8 MHz for the strip part.
- Time resolution σ_t must at least be better than 50 ns to separate the single events; an improved resolution of about 2 ns is desirable for further event deconvolution in later DAQ stages.
- $\frac{dE}{dx}$-resolution in the order of ten percent is desirable for the reconstruction of low momentum particles, especially kaons, pions and protons well below 1 GeV momentum.

The determination of the MVD requirements and the optimization of the MVD layout requires extensive simulation studies and can be divided into three stages. The first stage contains detailed simulations which define the needs for the readout electronic chain. Peak and average data rates together with rate distributions at all stages of the readout architecture have to be investigated, e.g. rates and distributions at FE, module and several multi-module levels. The time structure of events needs to be considered, latency distributions at different readout levels are needed to investigate the influence of overlapping events and event rate fluctuations. Finally, the energy deposition and its distribution has to be evaluated to define the required dynamic range for the FE-electronics of the MVD. For all these simulations full background processes of the $\bar{p}p$ and $\bar{p}A$ reactions for different nuclei are needed.

The second stage deals with geometrical optimization of the MVD layout, in particular a broad variety of possible layout options:

- Variation of pixel sizes and shape, e.g. $50 \cdot 400$ μm^2 or $50 \cdot 200$ μm^2 or $100 \cdot 100$ μm^2.
- Strip pitches between 50 and 200 μm and strip crossing angles between 1° and 90°.
- Different pixel and strip module sizes and shapes, e.g. wedge strip modules for disks, rectangular modules for barrels etc.
- Variation of active sensor thickness between 200 and 100 μm silicon and different sensor sizes to optimize the ratio between dead and active areas.
- Arrangement options of modules on the local supports, e.g. overlap of modules versus straight module placement.

- Local support and services options.

For all the geometrical aspects the $\bar{p}p \to D^+D^-$ and $\bar{p}p \to D^{*+}D^{*-}$ resp. are the important benchmark channels. The corresponding figures of merit are the single track, vertex and momentum resolutions. For the later aspects like module arrangement and local support and services options the overall material budget drives the optimization process because the amount and distributions of material of the MVD has severe consequences for the outer detector components and must be minimized.

Of special interest concerning the layout of the MVD is the question whether the detector should be optimized for charm meson tagging or strange particles (hyperon) detection. Since the decay lengths of strange particles are of the order of cm the arrangement of barrels and disks in the forward part may contradict the D-meson layout which favors layers as close as possible to the interaction point. To balance this two cases the $\bar{p}p \to \bar{\Lambda}\Lambda$ benchmark channel must be considered concerning the secondary vertex resolution and the momentum resolution of the particles from hyperon decays.

All these simulation studies optimizing the geometry of the MVD can't be done without a re-consideration of the impact of the proposed layout changes to the points discussed under the first simulation stage. Therefore an iterative process is needed which keeps the readout electronic requirements under control during this optimization. The result of this process should be the identification of a limited set of key design parameters together with their range which respects the electronic and material constraints. These key parameters will go to a final optimization stage which considers not only the bare figures of merit but also environmental challenges in terms of background processes. The benchmark channel is again the $\bar{p}p \to D^+D^-$ and $\bar{p}p \to D^{*+}D^{*-}$ resp. signal process now hidden in the background faking such $\bar{D}D$-events. Apart from the vertex and track resolutions key issue is the efficiency and purity for the D- and D*-meson identification which has to be optimized.

2.3 Central Tracker

The main task of the Central Tracker is the efficient reconstruction of charged particle trajectories with high resolution and almost full solid angle coverage. In addition to the precise determination of the momenta of charged particles, the capability to reconstruct decay vertices of longer-lived neutral particles, e.g. hyperons, is also required. The identification of different particle species by their specific energy loss is an additional task, to which the Central Tracker is expected to contribute. In order to minimize multiple Coulomb scattering and secondary interactions, especially photon conversion, in the detector material the total material budget of the Central Tracker should not exceed a few percent of a radiation length X_0. Technically the target pipe, which intersects the beam pipe perpendicularly, divides the volume of the Central Tracker into two halves. This will be reflected in the design of the Central Tracker by the need of two half barrel detectors which might result in an acceptance hole in the region of the target pipe parallel to the z-axis.

2.3.1 Figures of Merit

The performance of the Central Tracker will be evaluated by several Figures of Merit, which are defined as follows:

1. Point resolution versus polar angle θ in the laboratory system and transverse momentum p_{T} for single tracks;
2. Momentum resolution vs θ and p_{T} for single tracks;
3. Reconstruction efficiency vs θ and p_{T} for single tracks;
4. Vertex resolution for decay vertices of neutral particles (V^0), e.g. K^0_{S} ($c\tau = 2.68\,\mathrm{cm}$) and Λ hyperons ($c\tau = 7.89\,\mathrm{cm}$);
5. Mass resolution for V^0;
6. Reconstruction efficiency for V^0.
7. Reconstruction efficiency and purity including pile-up and realistic background conditions for single tracks and V^0.
8. $\frac{dE}{dx}$-resolution and particle identification separation power vs. particle momentum p and vs. the polar angle Θ.
9. Material budget distributions in terms of radiation length X_0 and hadronic interaction length λ_{I} vs θ and p_{T};

2.3.2 Benchmark Channels

In order to assess the performance of the Central Tracker in terms of the figures of merit defined above, a list of benchmark channels is suggested in an attempt to cover the full range of physics tasks for this detector, see Table 1. The connection of the benchmark channel to the figure of merit is given in Table 3.

As background for these channels $\bar{p}p$ and $\bar{p}A$ annihilation and elastic $\bar{p}p$ scattering, which produces a high flux of slow protons close to a polar angle in the laboratory frame of $\theta = 90^{\circ}$, should be taken into account.

Channel	Related to FoM
$\bar{p}p \to (n)\pi^+\pi^-$	1,2,3,7
$\bar{p}p \to \psi(3770) \to D^+D^-$	1,2,3,7,8
$\bar{p}p \to \psi(4040) \to D^{*+}D^{*-}$	1,2,3,7,8
$\bar{p}p \to \bar{\Lambda}\Lambda$	4,5,6,7,8
$\bar{p}p \to \eta_c \to \phi\phi$	1,2,3,8

Table 3: Benchmark channels and related figures of merit of the Central Tracker.

As a first preliminary result, the phase space of decay products of many different reactions, including the above channels, has been scanned to get an estimate of the required two track resolution. It was found that the angle between charged tracks is larger than $5°$ in most cases, except for hyperon decays. For tracks originating in the target, an angle of $5°$ translates into a minimum distance between tracks in the Central Tracker of $\sim 1\,\mathrm{cm}$.

2.3.3 Straw Tube Tracker (STT)

Apart from the requirements directly connected with the physics channels, additional constraints have to be considered. Those are due to the environmental conditions of the STT and can be derived by analyzing background processes. The elastic scattering $\bar{p}p \to \bar{p}p$ produces a high flux of protons close to $\Theta = 90°$, and can be used to evaluate the charge density on components of the detector. This will impose the limits of ageing resistance for the materials which would be used to construct the STT.

From the simulations of background reactions of $\bar{p}p$ and $\bar{p}A$ annihilations one would like to get the best detector characteristics in terms of geometry, number of tubes, and their arrangement. The HESR will be a high luminosity machine (up to 2 $\times 10^7$ annihilations/s), therefore the STT must be able to withstand high particle rates, and the parameters of the detector have to be optimized in order to avoid suffering from pile-up problems. The simulations will have to check the mean occupancy of the single detector channels; if necessary, the parameters like the tube diameter or the composition of the gas mixtures could be adopted. Other checks will be performed to determine the influence of the material budget on the overall resolution, and the best arrangement for the services needed by the detector, i.e. support structure, electronics housing, gas distribution and so on.

At present, the layout of the PANDA STT foresees an array of planar straw double-layers, which are arranged to fit at best the hollow cylindrical area assigned. Each double-layer consists of closely packed staggered layers of tubes, glued together on a reference plate with precise positioning. In detail, we foresee:

- 4 axial double-layers for the inner zone;

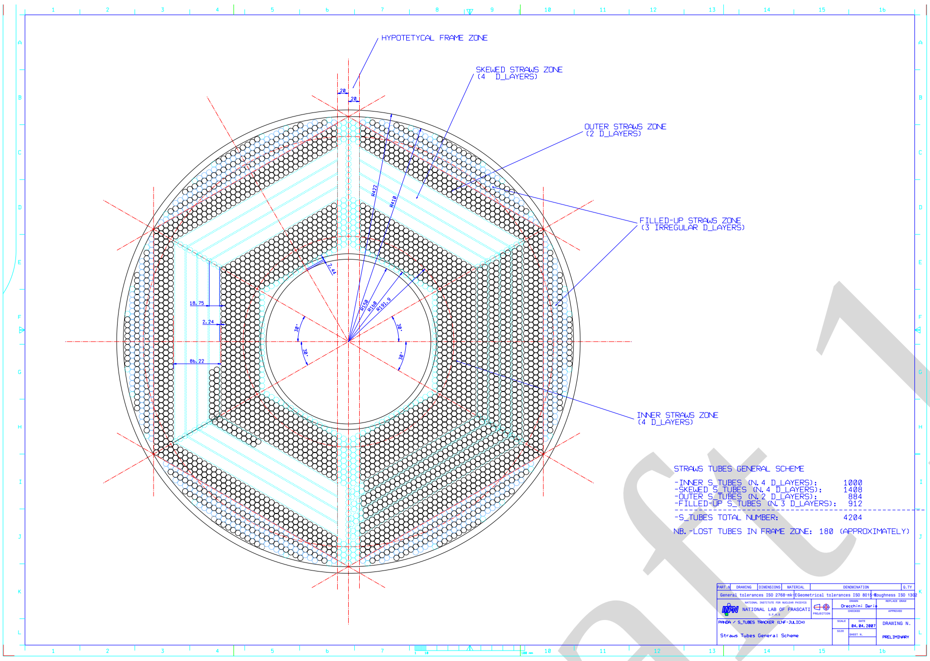

Figure 1: A possible layout for the STT. Details in the text.

- 4 skewed double-layers for the intermediate zone;
- 2 axial double-layers for the outer zone.

Eventually, the remaining outer region can be filled with other smaller axial double-layers. A detail of this layout can be seen in Figure 1.

Here, all straw tubes have a diameter of 10 mm, and the axial ones have a length of 1500 mm. The cathodes are made of overlapping Mylar films with an aluminum deposit of 0.03 μm on both sides. The overall cathode thickness is 30 μm. The anodes are W/Re gold-plated wires with a diameter of 20 μm. We intend to use a double component gas mixture (90% Ar + 10% CO_2) with an overpressure of about 700 $\sim$ 1000 mbar. This will give more mechanical stability to the double layers, helping to obtain good spatial resolution, too.

The skewed double-layers are foreseen to allow a precise reconstruction of the z coordinate of the tracks. Nevertheless, the bigger the skew angle, the more difficulties arise for the mechanics and the technical problems for the STT construction increases. The simulations have to determine the minimum skew angle which allows to reach the expected performance as given in Table 4. From the simulations we also expect the determination of the best location for the skewed double-layers, and the number of shorter tubes needed in each module as well.

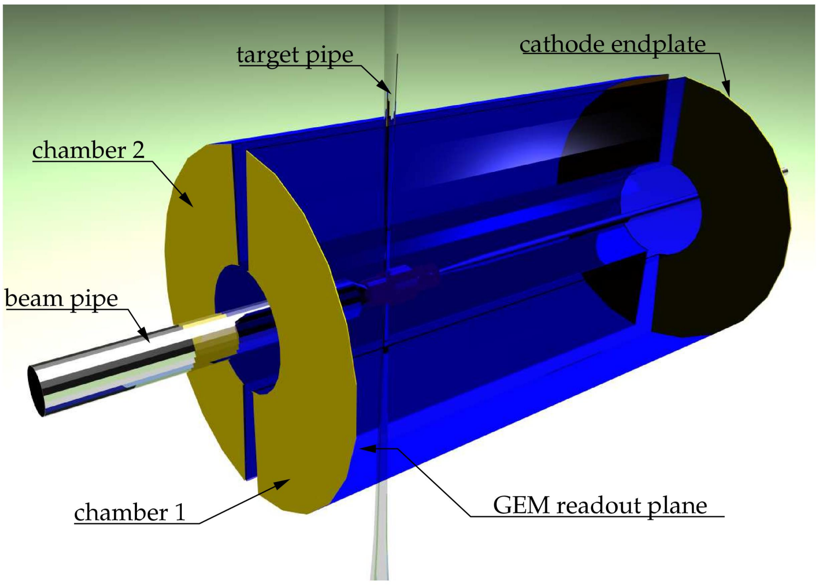

Figure 2: 3-D view of the PANDA TPC.

2.3.4 Time Projection Chamber (TPC)

Figure 2 shows a 3-D sketch of the TPC layout. Because of the target pipe the cylindrical chamber, consisting of drift volume and the readout end cap at its upstream end, is split in two half cylinders. The total length of the vessel is $1500\,\mathrm{mm}$, its inner and outer radius $150\,\mathrm{mm}$ and $420\,\mathrm{mm}$, respectively. The baseline gas mixture is Ne/CO_2 (90/10) with an electron drift velocity of $28\,\mathrm{mm}/\mu\mathrm{s}$ at the foreseen drift field of $400\,\mathrm{V}/\mathrm{cm}$. With a lower limit for the pad area of $4\,\mathrm{mm}^2$, the total number of readout channels will be up to 100000.

The high interaction rate of up to $2 \cdot 10^7\,\mathrm{s}^{-1}$ envisaged for PANDA and the continuous nature of the $\bar{p}$ beam at the HESR makes the operation of a TPC very challenging. This imposes a number of items to be addressed specifically for the TPC in order to ensure that this detector will be able to fulfill the physics requirements:

- The exact pad geometry and size will be determined from simulations of the physics channels mentioned above by considering the figures of merit 1, 2, 4, 5, also taking into account the expected noise performance of the readout electronics.
- The parameters of the readout electronics, like shaping time, sampling rate, dynamic range and buffer depth have to be determined by considering the expected occupancies on each readout channel induced by the background of $\bar{p}p$ and $\bar{p}A$ annihilations.

- Realistic simulations of the distorting effect of space charge caused by ions in the drift volume, combined with a non-homogeneous magnetic field of the solenoid need to be carried out and possible corrections to be applied need to be studied. The relevant FoM here are 1 and 2.

- Due to the maximum drift time of electrons of about $54\,\mu s$ tracks from about 1000 events will be superimposed inside the TPC volume at any given instant in time. These tracks will have to be deconvoluted and matched to the information given by other detectors. The relevant FoM here is 7.

2.4 Forward Tracking Detectors

The tracking detectors for the forward region of PANDA can be divided into two parts. Tracks emitted at angles smaller than the acceptance of the Central Tracker will be covered by the forward tracker located inside the target spectrometer and therefore inside the solenoid magnet. For tracks at very low angles only visible in the forward spectrometer dedicated tracking stations are foreseen before and behind the dipole magnet. Because the requirements for these detectors are slightly different the discussion about them is given individually. Furthermore the detector technology for the forward tracker is not fixed yet. So the forward spectrometer tracker will either be a planar drift chamber or a straw tube detector whereas the forward tracker inside the target spectrometer will be a GEM detector.

2.4.1 Forward Tracker inside the target spectrometer

The Forward Tracker is foreseen for the measurement of trajectories of charged particles emitted at angles below 22°. The current layout of this tracker consists of three stations of GEM detectors placed in the space between the STT and the forward endcap. Each station contains a triple stack of GEM foils. Either a large area foil or patched foils will be used. The granularity of the read-out plane will be adapted to the expected occupancy and so it will vary with the distance from the beam-axis.

The momenta of particles emitted in the forward direction will be determined by tracing their trajectories in the magnetic field of the TS solenoid using combined hits from the GEM detectors, MVD and STT. The basic figure of merit characterizing performance of the forward tracking system is the momentum resolution as a function of particle momentum, scattering angle and the vertex position given by the z and r coordinate.

The momentum measurement for particles emitted directly from the target can be studied using the elastic $\bar{p}p$ scattering for various beam momenta. In turn the $\bar{p}p \rightarrow \bar{\Lambda}\Lambda$ reaction can be used for studies of the momentum reconstruction for particles emitted from displaced vertices and in particular for those laying outside the MVD volume.

The requirements for the Forward Tracker can be summarized as follows:

- Angular range: $\sim 2^\circ$ - 22°.
- Material budget in the active area: <0.5% X_0 (for one GEM station).
- Position resolution: < 0.1 mm (for one GEM station).
- Counting rate: up to 20 kHz per cm^2 and s.
- Resistance against aging effects, to be demonstrated by a stable operation at design luminosity for the whole lifetime of 10 years with a maximum track efficiency degradation of 2% per layer.
- Double track resolution of about 10 mm which has to checked again with the expected pile-up event rate (see also section 2.6) and an angular double track resolution of 5° which is regarded to be no problem at all.

The figures of merit for the Forward Tracker are defined as follows:

- $\Delta p/p(p,\Theta,z,r)$ - relative momentum resolution as a function of particle momentum p, scattering angle Θ and the vertex coordinates z and r.

2.4.2 Forward spectrometer tracker

For measuring momenta of charged particles emitted at small angles and passing through the gap of the FS dipole magnet, two pairs of drift detectors - one installed before the magnet and the other after the magnet - will be used. Additionally, for tracing of low energy particles being bent inside the dipole magnet gap towards the magnet yoke, another pair of drift detectors will be installed inside the gap.

As drift detectors we plan to use either planar drift chambers with square drift cells with a width of about 1 cm or straw tubes with a diameter of about 1 cm arranged one near the other in detection planes. Each drift detector consists of three double-layers: one with vertical wires and two with wires inclined with respect to the vertical direction. This configuration of detection planes allows for a three-dimensional reconstruction of multi-track events and contains some redundancy needed in the case if one or two detection planes do not react to particles due to a failure or due to lack of efficiency. The proposed inclination angles for the wires of roughly +30° and -30° are of course a subject which have to be optimized during the design phase.

The basic geometrical parameters of the drift detectors system including the dimensions of the rectangular active areas of the detectors, the inclination angle of the sense wires and the positions of the individual detectors should be optimized using simulations of the tracking system and calculating the basic figures of merit including the momentum resolution and geometrical acceptance as specified below. In the simulations the reaction $\bar{p}p \rightarrow \bar{\Lambda}\Lambda$ can be used as a benchmark channel allowing, in particular, for studies of the momentum reconstruction for particles coming from displaced vertices and for reconstruction of tracks of low momentum particles. Consequently the figures of merit for the FS tracking detectors are:

- Δp/p(p,Θ) - relative momentum resolution as a function of particle momentum p and scattering angle Θ measured with respect to a vertical plane oriented along the beam direction at the target point.
- A(p,Θ) - geometrical acceptance.

The basic requirements concerning the FS tracking detectors are collected in the list below. The most critical requirements concern the high occupancies expected in the high luminosity mode and the resulting high rate of aging. The high rate behavior and the rate of aging of the drift chambers (or straws) shall be studied experimentally and shall be taken as one of the basic criteria for taking the final choice between the drift chambers and the straws. In turn, the influence of the magnetic field on the detector performance will be studied using the GARFIELD simulation package. Therefore the operating conditions in terms of the magnetic fields are:

- Maximum magnetic field at the positions of detectors inside the dipole magnet: B_y = 1 T.
- Non-uniformities of the magnetic field inside the dipole magnet per wire length: $\Delta B_y \sim 0.3$ T, $\Delta B_z \sim 0.3$ T.
- Maximum stray magnetic field expected at the positions of detectors outside the dipole gap: $\Delta B_y \sim 0.3$ T, $\Delta B_z \sim 0.3$ T

The requirements for the FS tracking detectors are listed here:

- Angular acceptance: $\pm 10°$ horizontally and $\pm 5°$ vertically.
- Material budget in the active area of single detector: < 0.3% X_0.
- Single wire occupancy: up to 0.4 MHz.
- Counting rate: up to 8 kHz per cm^2.

- Negligible aging for collected charges of 0.1 C for 1 cm wire per year; estimation for gas amplification of $5 \cdot 10^4$, beam-target interaction rate of $2 \cdot 10^7$ s^{-1}, accumulation time of about 1 year and ionization produced by reaction products originating from $\bar{p}p$ interaction at the beam momentum of 15 GeV/c.

2.5 Overall tracking performance

It is clear that the demanding goals of the PANDA tracking system can only be reached if the information from the different sub-systems is combined appropriately. This task is assigned to the tracking software group which is currently developing code within the pandaRoot framework. Main issues are the pattern recognition, track following and track fitting for all kinds of tracks and track pieces.

Currently different approaches are discussed; among them are for instance a track finding and fitting for each sub-component individually followed by an overall track fitting. But also other solutions like a more integrated approach using all hits from all tracking detectors at once are investigated. This situation is complicated because the options for the main tracking devices, the Central Tracker - TPC or STT - are quite different in terms of providing the hits. For the TPC up to 1000 events (or ~ 3000 tracks) are superimposed inside the drift volume. Every track is sampled 50-100 times, which greatly simplifies pattern recognition. In the STT signals from tracks within the drift time of 300-400 ns will be superimposed ($\sim 6-8$ tracks). The number of hits per track depends on the track angle and can be up to 30. The possibility of separating these tracks if they hit the same tube is not a priory given but can be included with special readout electronics allowing a sufficient double pulse resolution.

However, this work is still ongoing and the results will of course influence the requirements of the tracking detectors. Eventually the full simulation of the tracking benchmark channels will contain the complete track reconstruction of the entire PANDA tracking system and therefore can be used for deducing the final requirements for each tracking component. This is especially true for any kind of efficiency and purity studies taking into account the full background processes. The computing group is asked to ensure a realistic simulation and digitization of each sub-system, especially in terms of pile-up modelling and track reconstruction algorithms. Apart from that it is possible that a direct impact from one tracking component on another can be stated in an earlier stage. For instance the necessity of a number of hits in the MVD serving as a track seed for the TPC or the restriction and relaxation of the material budget in some acceptance areas.

2.6 Additional aspects

During the work of our group some aspects arose which really do not fit into the scope of our tasks. But they are influencing the PANDA tracking performance and therefore have to be mentioned here. In particular there are two topics of more general concern to be explained in the following.

Firstly the issue of tracks penetrating the beam and target pipe under very shallow angles have to be addressed. For instance particles penetrating the beam pipe under a angle below 1° see 50 times more material than particles with Θ angles near 90°. Due to the increased multiple scattering especially for low momentum particles these tracks can become more or less useless for high resolution tracking and vertexing. Because of the potentially high number of such tracks depending on target material and beam momentum they can also cause a severe occupancy problem for the forward tracking detectors. We propose therefore a careful study of this effect. Eventually this has to be reflected in the beam pipe design to optimize not only the needs of the tracking detectors but also other aspects like pumping issues, complexity of the beam pipe design and so on. However, since this is not only a tracking problem this requires input and work from other members of the collaboration as well. Finally, the same might be true for tracks penetrating the target pipe under shallow angles. Although the number of such particles will be small at least we have to check together with the target groups if this effect is influencing the performance of the MVD and the CT.

Secondly the problems of the beam and luminosity fluctuations have to be taken into account. The main source of luminosity fluctuations is the non uniformity of the pellet stream which can yield 2 or 3 times higher peak luminosity if more than one pellet is in the beam simultaneously. Of course, the usage of a cluster jet target might allow to bypass this particular problem. Furthermore also differences between beam fills of the HESR can cause luminosity fluctuations. Therefore more detailed studies of the time structure of the luminosity on different time scales (from hours down to the ns range) are required. This information is especially necessary for the MVD and FT as well as for most of the readout stages to get realistic requirements for the occupancy and the data transfer load. We propose therefore a combined effort of the involved tracking detector groups with experts of the beam and target groups to ensure that reliable requirements can be defined.

Finally we need reliable simulations of the radiation dose expected in certain regions of the detector, where some of the front-end electronics will be located. This is obvious for the MVD, but also for the CT in the backward region this may be an issue, if one wants to put FPGAs close to the inner radius, which usually are not radiation tolerant (SEV).

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.
    - TPC using GEM readout.
2. Forward Spectrometer Tracker: MDC or Straw Tubes.
    - MDC using ”Dubna design”.
    - Straw Tube Design

Some of these different design options might 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 up to the ”TDR” stage.

There are of course many more choices to be taken, e.g. the different mechanical design options for the 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

The criteria given here are mostly connected to the already mentioned ’important design choices’, i.e. the Central Tracker and forward tracker decision. First the criteria to be applied for all decisions are presented, afterwards the more specific criteria for each decision are discussed.

Surely the design choice criteria must be driven by the physics performance of the eligible detector option which must be shown by simulation and prototype performance results. Therefore a set of central figures of merit have been defined for each subsystem (see sections 2.2, 2.3, 2.4) which allows to characterize the performance issues of the detector options. However, to evaluate the global tracking performance within a design choice here are figures of merit which shall be used to compare different detector options in terms of the full PANDA tracking performance:

- Mass resolution, total efficiency and purity as well as the uniformity of the efficiency and purity distribution for reconstructed J/Ψ in different production and decay channels.
- Mass resolution, total efficiency and purity as well as the uniformity of the efficiency and purity distribution for reconstructed D^*D^* states in different production and decay channels.
- Mass resolution, total efficiency and purity as well as the uniformity of the efficiency and purity distribution for reconstructed $\bar{\Lambda}\Lambda$ states in different production and decay channels.

Apart from these central criteria there are a set of additional criteria dealing with feasibility, production and maintenance of the detector. Although the impact of the criteria has to be adjusted for each decision individually the relative weighting of the following criteria is generally lower.

- Technical feasibility of the concept:
  - Readout concept and data handling issues.
  - Mechanical issues and interaction with beam- and target-pipe (if appropriate).
  - Capability to cope with expected rates.
  - Time resolution and trigger issues.
  - Influence on other detector components.
- Feasibility of the production:
  - Person power.
  - Available infrastructure.
  - Costs and financing issues.
- Complexity and costs during operation and maintenance.

3.1.1 Criteria for the Central Tracker decision

The most difficult decision will concern the Central Tracker because two quite different approaches are pursued. To streamline the decision process specific issues are listed below for each option which must be addressed in addition to the criteria mentioned in the CT section (see section 2.3) and the last section before a positive decision can take place. With this in mind the listed issues can be regarded as a weighting of the general design choice criteria.

1. For the Straw Tube Tracker:
   - Show that the self supporting concept is able to keep the total amount of material (including global support structures) around 1% of a radiation length.
   - Show the tolerance of the single straws against the expected aging effects.
   - Demonstrate that the single point resolution is sufficient, i.e. below 150 μm in $r\varphi$ for the 1.5 m long self-supported straws.
   - Show that the resolution of the z-coordinate of the decay vertices is sufficient.
2. For the Time Projection Chamber:
   - Show that the required single track and momentum resolution is possible even for forward tracks where the deposited charge has to drift through the entire TPC including the deteriorated field region in the forward area.
   - Demonstrate the capability to handle the 1,000 superimposed events per TPC 'picture'.
   - Show the feasibility of coping with the expected space charge coming from positively charged ions at Panda like interaction rates including the expected luminosity fluctuations.

3.2 Roadmap towards a decision

Since the design decision probably won't be taken before the end of 2009 fot the Central Tracker, it is too early to define a detailed procedure right now. Rather results from the simulation effort and prototyping need to be considered first. However, one solution could be an external review process which might be executed as follows:

1. For each design choice a report covering the important items of the defined criteria shall be prepared 3-6 months before the decision has to be 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 can 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 2008 or early 2009 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. Much of the given information can of course go into 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 current tight FAIR/PANDA schedule the sub-detector TDRs should be finished by mid/end of 2010.

For 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 2009 so the natural time to take the design decisions will be 2009. For the case of the FT the decision between the Straw Tube and MDC approach could be taken during 2008 leaving only the final MDC layout decision (if MDC are chosen) for 2009.

However, the scope of this document is not the planing for the 'official' paperwork 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: March 2008.
2. Definition of work-packages for each sub-detector R&D: March 2008.
3. Decision upon the FT design: end of 2008
4. Decision upon the CT design: end of 2009

References

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5 Appendix

	MVD		CT		FT
Estimated perf. for	Pixel	Strips	STT, skewed	TPC	MDC/ST
spatial resolution σ_s for track points	rφ = 40 μm z = 40 μm	rφ = 40 μm z = 100 μm	rφ = 150 μm z = 1-2 mm	rφ = $100 - 200$ μm z = 0.2-1 mm	x, y = 0.2-0.3 mm z = 1 mm
resolution σ_v for vertex reconstruction	$\sigma_x = 100$ μm $\sigma_y = 100$ μm $\sigma_z = 100$ μm	$\sigma_x = 100$ μm $\sigma_y = 100$ μm $\sigma_z = 200$ μm	$\sigma_x \sim 1\,\mathrm{mm}$ $\sigma_y \sim 1\,\mathrm{mm}$ $\sigma_z \sim 3-5\,\mathrm{mm}$	$\sigma_x \sim 1\,\mathrm{mm}$ $\sigma_y \sim 1\,\mathrm{mm}$ $\sigma_z \sim 1\,\mathrm{mm}$	- - -
time resolution σ_t	20 ns	2 ns	?	?	?
relative resolution Δp/p for particle momenta	2%	2%	1.5%	1.2-1.5% (m.i.p.)	1%
relative resolution ΔE/E for energy deposit	7-15%	7-15%	?	6-7%	-
material budget X/X_0 for tracks with 90° incident angle	1.2% per layer incl. support & supplies	1% per layer incl. support & supplies	1% (active volume)	1.7% (barrel region)	0.01% (active area)

Table 4: Realistically estimated performance of the different detector options for the tracking system of PANDA based on state-of-the art detector technology and educated guesswork. This does not necessarily mean that the performance is sufficient for the PANDA physics goals.