TAG 2 Tracking Report

Outline

- Mission & Strategy
- Requirements for the different tracking detectors
- Design Choices
- Milestones

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in der Helmholtz-Gemeinschaft

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Mission of the tracking TAG

- Subject
  - Define requirements for tracking detectors
  - Develop criteria for design choices
- Deliverables
  - Adjustment of detector parameters
  - Roadmap to TDR: deliverables and milestones
- Tracking detectors are:
  - The micro vertex detector – MVD.
  - Central tracker – CT which will be either a TPC or STT.
  - Forward tracker – FT which will be GEM & MDC or Straws.
  - Muon detectors are not regarded as tracking detectors.

Strategy

- We recognised that a definition of all requirements is not possible within our timeframe.
  - Physics driven requirements demands a lot of simulations which are not available yet.
  - Define the central issues and questions which have to be answered by the simulation for each tracking detector individually.
  - Define the key parameters of the detector and the according figure of merit to judge on them.
  - In order to do so we defined a bunch of benchmark channels for the tracking in PANDA
- Identification the important design choices
  - Define criteria and procedure
- Proposal of a reasonable timeframe of sub-detectors TDRs

Benchmark channels

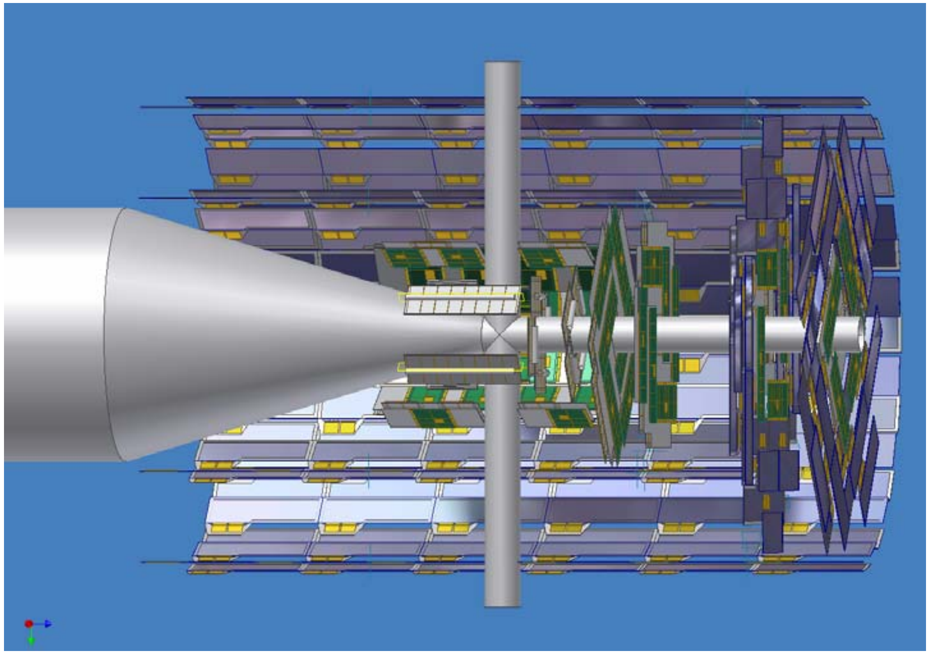
Channel	Final state	Related to
$\bar{p}p \rightarrow (n)\pi^+\pi^-$	$(n)\pi^+\pi^-$	CT
$\bar{p}p \rightarrow \psi(3770) \rightarrow D^+D^-$	2K 4π	MVD,CT
$\bar{p}p \rightarrow \psi(4040) \rightarrow D^{*+}D^{*-}$	2K 4π	MVD,CT
$\bar{p}p \rightarrow \bar{\Lambda}\Lambda$	$p\pi^{-}\bar{p}\pi^{+-}$	MVD,CT,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

Benchmark channels

- $\bar{p}p \rightarrow D^{*+}D^{*-}$ and $\bar{p}p \rightarrow D^{+}D^{-}$ with 2K 4π final state
  - Secondary vertex tagging capability
  - special consideration of the slow π coming from the D* decays.
  - important for MVD but also for CT/FT → K, π tracking and momentum measurement.
- $\bar{p}p \rightarrow \bar{\Lambda}\Lambda \rightarrow \bar{p}p\ 2\pi$, $\bar{p}p \rightarrow \bar{\Xi}\Xi \rightarrow \bar{p}p\ 4\pi$
  - Λ reconstruction, partly only with CT (~15%) → tests vertexing capabilities of CT/FT.
  - consider channel to incorporate also cascade decays outside MVD
- $\bar{p}A \rightarrow J/\Psi X \rightarrow 2l\ X$
  - high p_T lepton tracks in multi-track environment → CT/FT important for momentum measurement and tracking.
- $\bar{p}p \rightarrow \eta_c \rightarrow \Phi\Phi$ with 4K final state, $\bar{p}p \rightarrow (n)\pi^+\pi^-$
  - PID studies and V^0 reconstruction with CT
- $\bar{p}p \rightarrow \bar{p}p$ elastic scattering
  - important for FT, background studies for CT and MVD.

This doesn't mean that only these channels should be considered but for detector optimization work we don't need full physical picture

MVD Design: Rev 14b



~540 modules in 4 barrel & 6 disk layers

- Geometry:
  - pixel barrels at R= 27; 50 mm
  - strip barrels at R= 75; 125 mm
  - 2 single sided pixel disks at Z= 20; 40 mm
  - 4 double sided mixed disks at Z =60; 85; 145; 185 mm
  - closest distance to beam-pipe: 2 mm (disks)
  - overall length: 40 cm
- 140 pixel modules
  - 0.15 m^2 active silicon
  - ~6.5 Mio readout channels
- 400 strip modules
  - 0.5 m^2 active silicon
  - ~70,000 readout channels
- 2 kW power dissipation inside the MVD

MVD : Figures of Merit

- Spatial resolution of track points σ_s in rφ and z vs. p_T and θ.
  - For all charged particles, esp. low momentum π from D*-decays.
- Vertex reconstruction resolution σ_v in x, y and z vs p_T and θ.
  - for primary vertices and secondary vertices coming from D/D* decays as well as hyperon decays inside MVD volume.
- Relative resolution Δp/p of charged particle momenta vs p_T and θ.
  - to be judged with the overall momentum resolution coming from the entire tracking system, the impact of the MVD might be small in some cases
- Relative mass resolution Δm/ m of reconstructed D*- and D-mesons vs p_T and θ.
  - to be judged with the overall mass resolution coming from the entire tracking system, the impact of the MVD might be small in some cases.

Technical requirements for MVD: pixel

- spatial resolution in r-phi ➔ < 100µm (for momentum measurement)
- spatial resolution in z ➔ < 100µm (especially for D-tagging)
- time resolution ➔ < 50ns (for separation of ‘DC’-beam 10^7 events/s)
- triggerless readout ➔ count rate up to 10 MHz (peak) (average) per chip.
- low material ➔ < 1.2 % per layer (for low momentum particle tracking)
- modest radiation hardness ➔ $\sim 3 \times 10^{14}$ n_{eq} / cm^2
- moderate occupancy ➔ up to 16 kHz (peak) and 350 Hz (average) for $50 \times 400 \mu m^2$
- amplitude measurement ➔ dE/dx for particle identification, resolution ~10% for particles well below 1 GeV

Technical requirements for MVD: strip

- spatial resolution in r-phi ➔ < 100µm (for momentum measurement), to be confirmed by simulations.
- spatial resolution in z ➔ < 100µm, to be confirmed
- time resolution ➔ at least < 50ns (for separation of ‘DC’-beam 10^7 events/s); better < 2ns (for DAQ event de-convolution and ToF)
- triggerless readout ➔ up to 8 MHz per chip
- occupancy ➔ 10 kHz
- low material ➔ < 1% per layer (for low momentum particle tracking)
- modest radiation hardness ➔ $\sim 10^{14}\ n_{eq} / cm^2$
- amplitude measurement ➔ dE/dx for particle identification, resolution ~10% for particles well below 1 GeV

MVD Simulations: defining FE electronics

- Data loads (strip and pixel part)
  - rates & rate distributions – peak rates, average rates
  - energy deposit - global and locally, peak and average → define dynamic range

Channels: background p̄p & p̄A

  - time structure and ordering (strip and pixel part)
  - latency distributions
  - beam fluctuations on various timescales
  - overlapping of events

Channels: background p̄p & p̄A

Note: these simulations need input/interactions with dedicated electronics simulations!

MVD Simulations: geometry optimization (1)

- variation of pixel size and shapes
  - [50x400 μm²]; 100x100 μm²; 50x200 μm²; 200x50 μm²
  - different relative orientations of layers

- strip optimization
  - modules size and shape

    rectangular vs wedge for the disks
  - pitch sizes

- positions of forward disks and barrels → 'strangeness layout' vs. 'charm layout'
  - number and position of disks
  - position of additional disks downstream
  - layout of disks – only pixel, mixture of strips and pixel
  - barrel layer radii

MVD Simulations: geometry optimization (2)

- variation of sensor thickness (strips and pixels)
  - 200 µm - 100 µm

- sensor sizes and shapes (to optimize material)
  - size and dead zone ratio (for pixel)
  - arrangement options: overlap layout vs straight layout (for pixel and strip)

- structural support, services (cables, cooling,…)
  - different inhomogeneous distributions
  - identify areas to put things

- other layout option
  - effect of target pipe hole
  - constant radius vs. constant angle for beam pipe

MVD Simulations: optimization of performance goals

- optimize $D^{*+}D^{*-}$ (D^+D^-) resolving power
  - input needed: efficiency / purity requirements to be settled!
  - limited amount of variation, strategy:

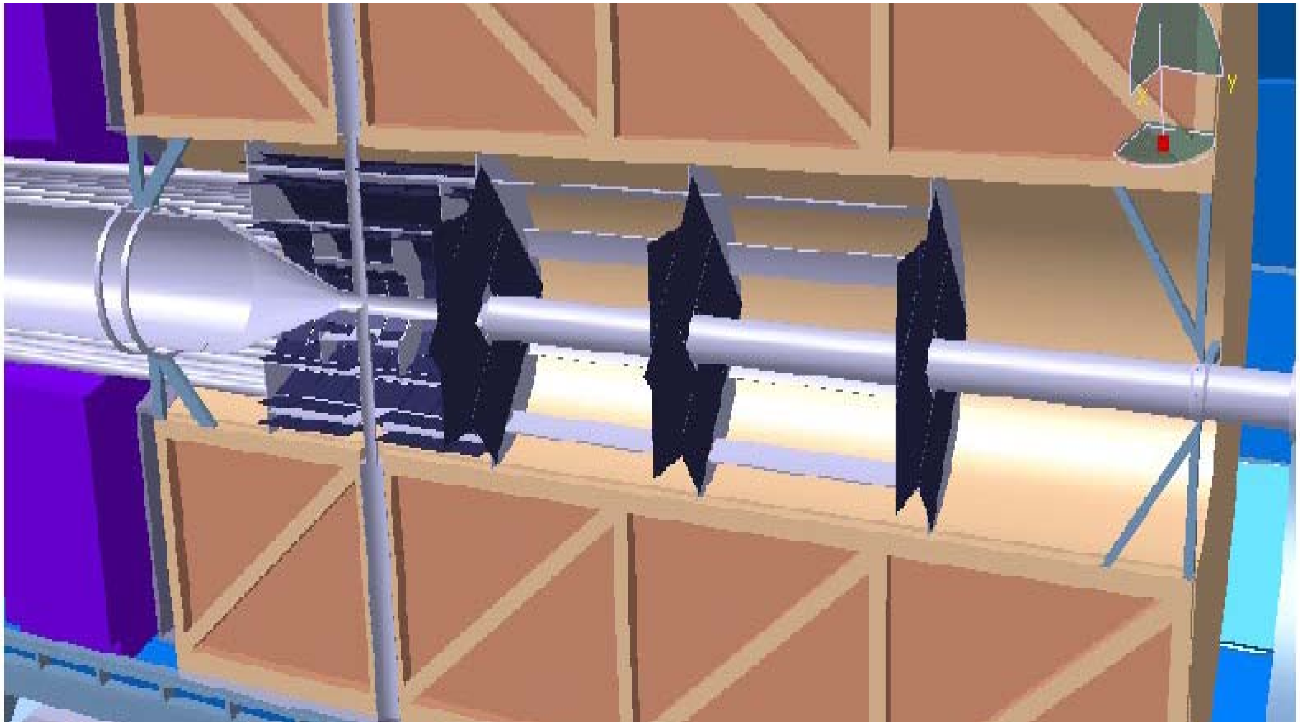
    → key parameters to be defined after basic geometry optimization!

    → keep a number of constraints that are already "established"

    → respect boundary conditions!

    → optimize $D^{*+}D^{*-}$ (D^+D^-), then check performance with background

Additional two forward disks



- 2 additional silicon disks at roughly Z = 800 and Z = 1100, 30mm < r < 150mm, similar to the last two MVD disks but only silicon strips (so far)

Central Tracker

- Two different options are considered for the central tracking device of PANDA up to now:
  - Time projection chamber (TPC)
  - Straw tube tracker (STT)

- We decided to treat the two options in an integrated process:
  - Use the same figures of merits and benchmark channels to allow a fair comparison between the two options
  - the individual properties and problems of each option will be reflected by special requirements and open issues

CT: Figures of Merit

1. Point resolution versus polar angle 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 =2.68 cm) and hyperons (c = 7.89 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. 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;

CT: Straw Tube Tracker

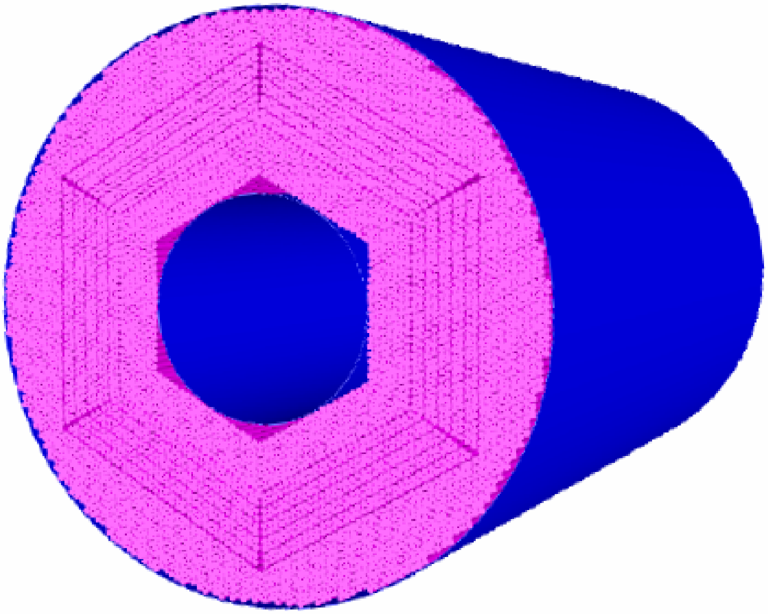
5340 straws in 21-27 layers

- Al-mylar film tube: 10.0 × 0.03 × 1500mm (Ø×d×L)
- R_{in}/R_{out}: 160 / 415- 420 mm, V = 610L
- Self-supporting straw layers at Δp ~ 1bar
- Straw pitch: 10.1mm
- 15kg straw weight
- Ar/CO_2, p ~ 2 bar

- Axial layers:
  $\sigma_{r\varphi}$ ~ 150µm, $A_\omega \times \varepsilon$ ~ 98%

- Skewed layers:
  σ_z ~ 2.9 mm, $A_\omega \times \varepsilon$ ~ 90-95%

- Radiation length:
  X/X_0 ~ 1.0-1.3 %



→ σ_{pt} / p_t ~ 1.2 %

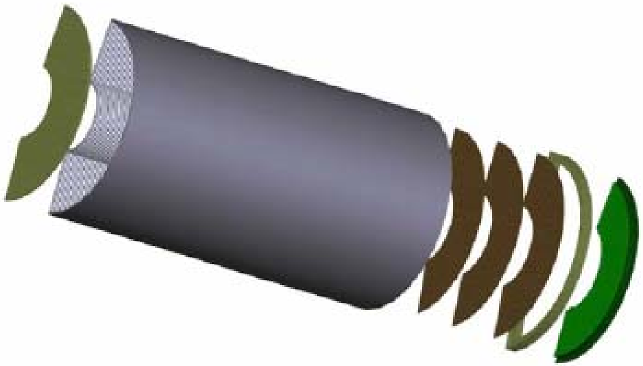
Paola Gianotti
LNF

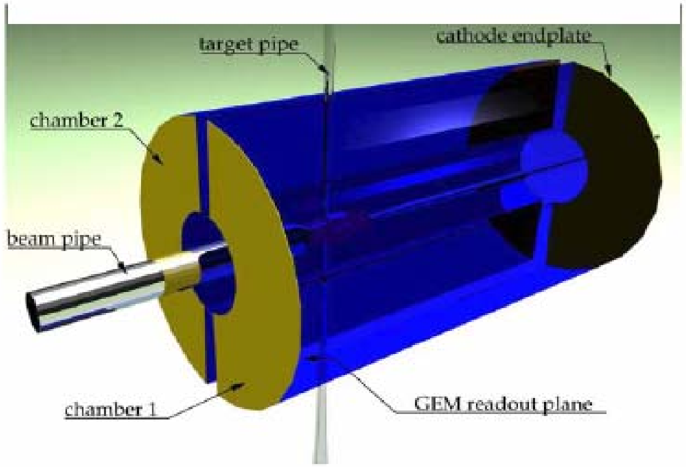
STT: technical requirements

- Aging resistance
  - elastic p̄p scattering produces high flux $\theta = 90°$
- Geometry number of tubes and their arrangement
  - Background simulations p̄p and p̄A
- High particle rates and pile up issues due interaction rate 2×10^7 s^{-1}
  - Occupancy, gas mixture and tube diameter
- Material budget and arrangement of services
- Reconstructions of z-coordinate for tracks and vertices
  - Location of skewed layers

CT: Time Projection Chamber

Parameter	Value
Length (cm)	150 (z=-40...110)
Inner radius (cm)	15
Outer radius (cm)	42
Drift field (V/cm)	400
Gas	Ne/CO_2 (90/10)
Electron drift velocity (cm/μs)	2.8
Pad size	~ 2 mm x 2 mm
Channels	~ 100.000





TPC Simulations

B. Ketzer

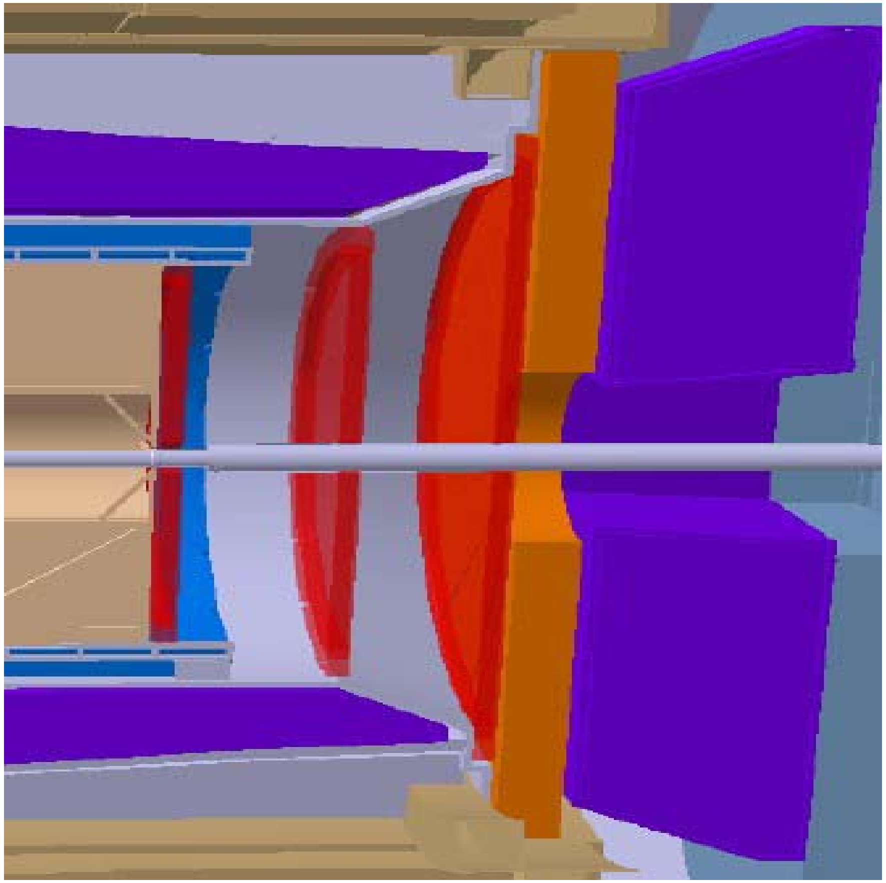
TPC: technical requirements

- exact pad geometry and size for TPC readout
  - will be determined from simulations of the physics channels taking into account the expected noise performance of the readout electronics.
- readout electronics parameter
  - shaping time, sampling rate, dynamic range and buffer depth
  - expected occupancies by the background of $\bar{p}p$ and $\bar{p}A$ annihilations.
- Realistic simulations of the distorting effect of space charge
  - ions in the drift volume, combined with a non-homogeneous magnetic field of the solenoid
  - study possible corrections
- 1000 events will be superimposed inside the TPC volume
  - maximum drift time of electrons of about 54 μs
  - study tracks deconvolution and matching of the information given by other detectors.

Forward Tracking: Target Spectrometer

New baseline design:

- Large area GEM detectors
  - Patched or large area GEM foils
  - R/O plane adapted to occupancy
  - R/O with silicon strip frontend
- Performance improvements:
  - High rate capability
  - Better resolution
  - Three tracking stations
  - Thin detectors



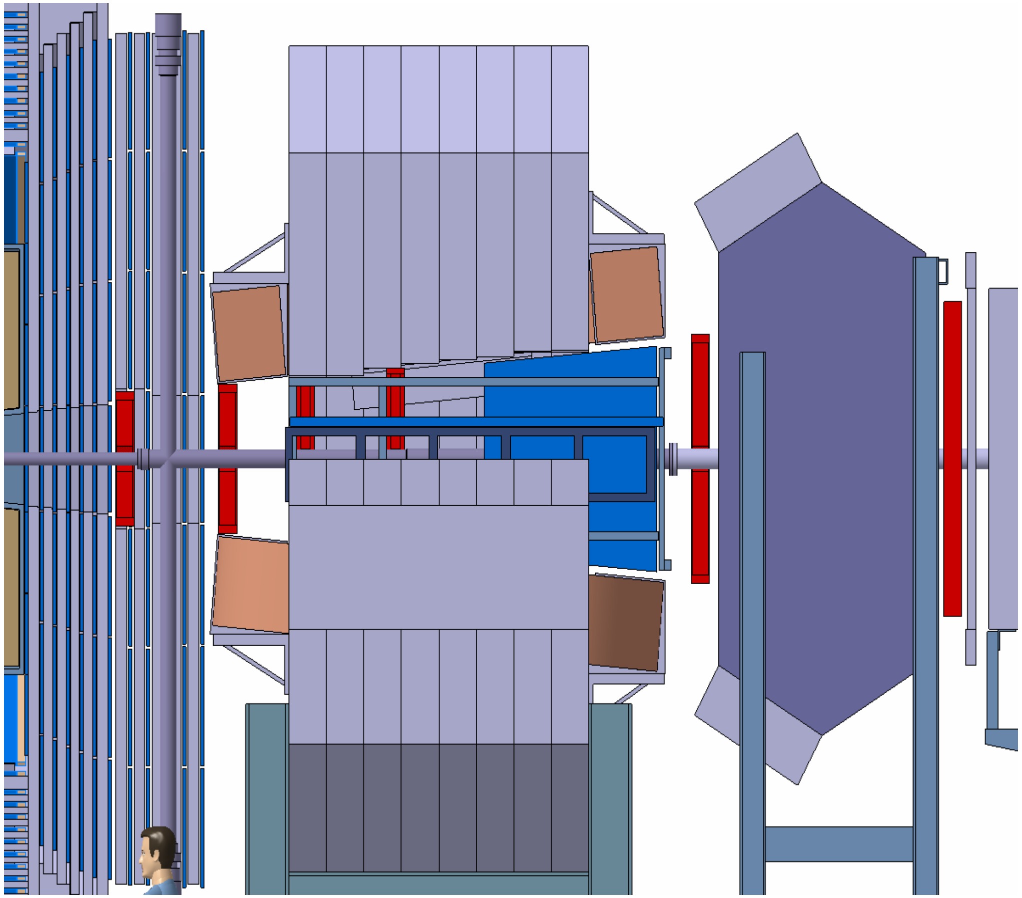
Target Spectrometer Forward Tracking

- Figures of Merit:
  - p/p(p,θ,z,r) - relative momentum resolution as a function of particle momentum p, scattering angle and the vertex coordinates z and r.

- Additional technical requirements:
  - Angular range: ~2° - 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.

Forward Spectrometer Tracking

- Layout of tracking stations:
- Stations are before and behind the dipole
- 2 further stations inside the dipole magnet gap
- Two options are considered:
  - Planar drift chambers with square drift cells
  - Straw tube chambers with 1 cm tubes

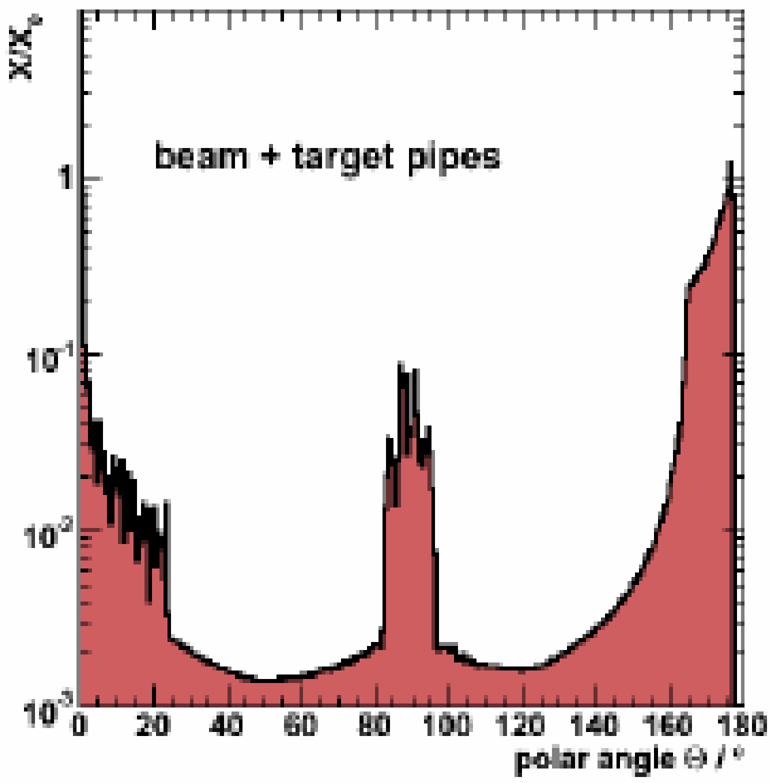


Forward Spectrometer Tracking

- Figures of Merit:
  - p/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.
- Additional technical requirements:
  - Angular acceptance: ±10° horizontally and ±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.

Additional aspects

- current beam-target pipe design is not well suited for the tracking detectors esp. for the forward direction
  - → need a better concept here
- Interaction rate is not clear due to pile up (pellets) and beam fluctuations issues
  - → need defined numbers here to allow detectors group to settle their requirements for electronics etc.
- Reliable radiation load maps also for regions slightly outside the detector acceptance are missing
- The length of the CT is fixed to 150 cm but a shortening is still under discussion
  - → need a decision soon



Design Choices

Identification of the important design choices:

- for the Forward spectrometer tracker:
  - Drift Chambers (MDC)
  - Straws for the FT

- for the Central Tracker
  - Time Projection Chamber
  - Straw Tube Tracker

Design choice criteria

Global Tracking performance of the entire PANDA tracking system

- Mass resolution, total efficiency and purity as well as the uniformity of the efficiency and purity distribution for:
  - J/Φ in different production and decay channels.
  - D*D* states in different production and decay channels.
  - ΛΛ states in different decay channels.

- Additional technical criteria
  - technical feasibility of the concept
  - feasibility of the production
  - complexity and costs during operation and maintenance

Design Choices for FT

Two different design options are considered:

- MDC with cathode foils (Dubna design)
- Straw Tube Design

Main criteria are:

- High rate behaviour
- Aging rate - test of prototypes with radioactive sources
- Reliability - checked in a long term (~0.5 year) test
- Material budget

Procedure will include prototype tests with accelerators beams during 2007, source tests and long term tests

- Decision between straws and MDC in 2009
- Final design decision by mid of 2009 after all tests finished

Design choice criteria for the CT

- For the STT
  - Show that the self supporting concept is able to keep the total amount of material 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
  - Show that the resolution of the z-coordinate of the decay vertices is sufficient.
- For the TPC
  - 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.

Design choice procedure

- We prefer a decision upon ourselves if possible
- If a formal decision procedure is needed a two staged process is proposed:
  - Report about the mentioned design choice criteria of each option has to be prepared → refereed by an internal group and a decision could be taken by CB
  - Design review by an external expert group of the different option on basis of the reports → give recommendation and CB decides on the outcome.

Milestones

1. Final Draft of this document concerning tracking requirements: March 2008.

2. Definition of work-packages for each sub-detector R&D: March 2008.

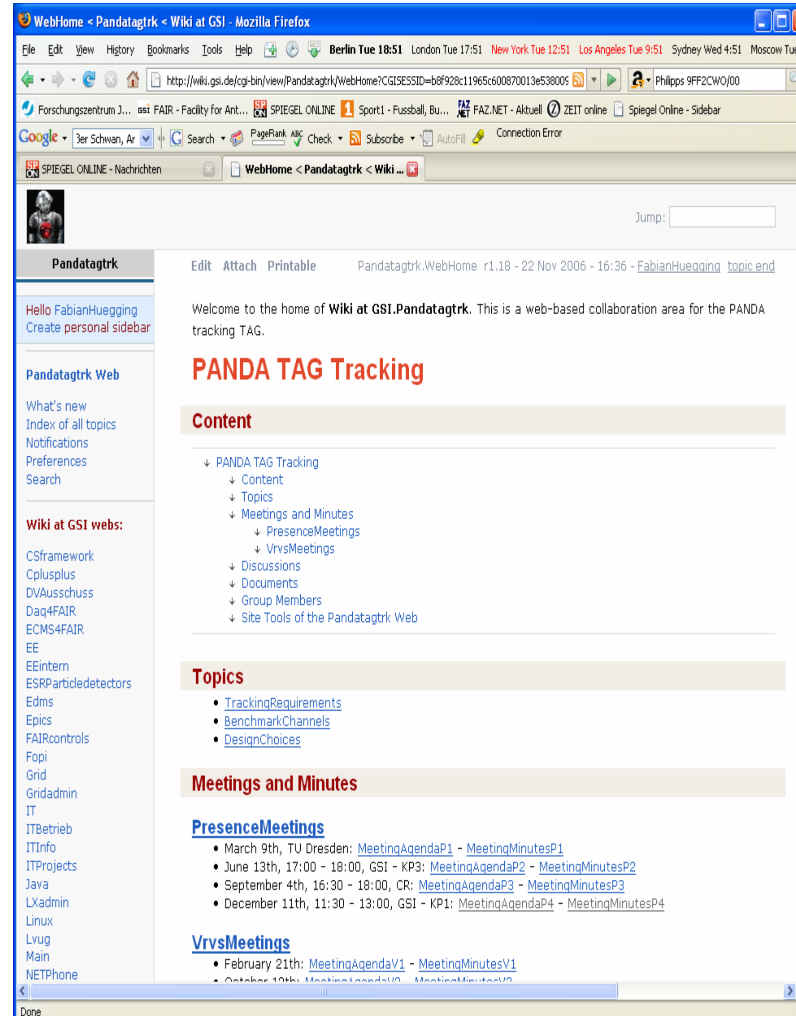
3. Decision upon the FT design: mid of 2009

4. Decision upon the CT design: end of 2009

Communications of results

- Results of the TAG are posted on the Wiki page of the TAG
  - http://panda-wiki.gsi.de/cgi-bin/view/Tagtrk/
  - meeting agendas & minutes
  - additional information about the tracking detectors
  - Visible for all with a PANDA Wiki account
- Final Draft of the concluding document is posted here

→ still open for comments



Status & next steps

- Definition of benchmark channels Done
- Discussions on requirements and simulation questions for each sub-detector
  - MVD Done
  - MDC Done
  - STT Jan/Feb 2007
  - TPC Jan/Feb 2007
- Design choices, definition of criteria and procedure.
  - MDC design1, MDC design2 or Straws Done
  - TPC – STT Jan/Feb 2007
- Towards a TDR started - Mar 2007