The Central Straw Tube Tracker In The PANDA Experiment

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Outline: PANDA - Straw Tube Tracker

- PANDA physics
- Central Straw Tube Tracker (STT)
  - Minimal material budget
  - High-rate tracking and PID
  - Online event reconstruction (→ next talk)
- Test systems and results
- Simulation studies
- Summary
The PANDA Physics Program

PANDA investigates $\bar{p}p$ and $\bar{p}A$ annihilation in the charm quark mass regime

- Hadron spectroscopy ($m$, $\Gamma$, $J^{PC}$, $BR$)
  - Charmonium states
  - Open charm mesons (D-mesons)
  - Exotic states (glueballs, hybrids, multi-quarks)
  - Strange and charmed baryons
- Hadrons in nuclear medium
  - $J/\psi$ – absorption, D meson mass shift
  - Hypernuclei ($\Xi^{-}AZ$, $\Lambda\Lambda AZ$), YY-interaction
- Structure of the nucleon
  - Electromagnetic formfactors
  - Generalized Distribution Amplitudes
  - Transverse nucleon spin (full PWA)

PANDA Physics Performance Report

arXiv:0903.3905 (216pp)
The PANDA Detector System In HESR → Talk by D. Calvo

- Central Tracker
- GEM Detectors
- Mini Drift Chambers
- Shashlyk Calorimeter
- Muon Range System
- TOF Wall
- Forward spectrometer, 2Tm dipole magnet
- 13m
- Target spectrometer, 2T solenoid
- Barrel TOF
- Solenoid
- Beampipe
- Dipole
- Barrel DIRC
- EM Calorimeter
- Muon Detection
- RICH
- Bank D IRC
- Micro Vertex Detector
- Targetspectrometer
- 2Tm dipole magnet
- DLL
- Tm dipole magnet

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Tracking At PANDA

- Variety of event topologies, all particle species involved
  - particle multiplicities up to 6 and higher, on average ~150 tracks / 2µs
  - broad momentum range ~ 100 MeV/c - 8 GeV/c
  - displaced vertices $O(100\mu m) - O(10 cm)$
- $4\pi$ solid angle coverage (PWA)
- High momentum & spatial resolution: $\sigma_p/p \sim 1-2\%$, vtx $\sim 50 \mu m$
- Particle identification: $p/K/\pi < 1$ GeV/c (exclusively)
- Readout of (quasi-) continuous data stream
  - fast online track & event reconstruction, w/o $t_0$, evt. deconv.
  - flexible software triggering, specific reactions $\rightarrow$ data storage

$\rightarrow$ Tracking system: MVD (vertex) + Central Tracker (large-vol) + GEMs (forwd)
Central Straw Tube Tracker (STT)

- 4636 straw tubes in 2 separated semi-barrels
- 23-27 radial layers in 6 hexagonal sectors
  - 15-19 axial layers (green) in beam direction
  - 4 stereo double-layers: ±3° skew angle (blue/red)
- Volume: $R_{in} / R_{outr} = 150 / 418$ mm, $L \sim 1650$ mm
  - Inner / outer protection skins (~ 1mm Rohacell/CF)
- Ar/CO$_2$ (10%), 2 bar, ~ 200ns drift time (2 T field)
- Time & amplitude readout
  - $\sigma_{r\phi} \sim 150$ μm, $\sigma_z \sim 2$-3 mm (isochrone)
  - $\sigma(dE/dx) < 10\%$ for PID ($p/K/\pi < 1$ GeV/c)
- $\sigma_p/p \sim 1$-2% at B=2 Tesla (STT + MVD)
- $X/X_0 \sim 1.25\%$ ($\sim 2/3$ tube wall + $1/3$ gas)

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Straw Tubes

Material budget at lowest limit (2.5 g per assembled straw)
- thinnest Al-mylar film, d=27µm, Ø=10mm, L=1400mm
- thin-wall endcaps (ABS), wire fixation (crimp pins), radiation-hard
- self-supporting modules of pressurized straws (Δp=1bar)
  - close-packed (~20 µm gaps) and glued to planar multi-layers
  - replacement of single straws in module possible (glue dots)
- strong stretching (230kg wires, 3.2tons tubes)*, but no reinforcement needed
Self-Supporting Straw Modules

.. technique first developed for COSY-STT (planar double-layers, in vacuum!)

.. upgraded for PANDA-STT (barrel geometry with 3d stereo-layers, quad-layers)

3kg Pb brick on 27µm Mylar

Pressurized, close-packed straw layers show a strong rigidity ..
STT Mechanical Prototype

Full hexagon sector, overpressure 1 bar

Even more confidence in the self-supporting straw modules through the years..

.. 3×3kg! 😊
Mechanical Frame Structure

- CABLE ROUTING TRAY SUPPORT STRUCTURE (CRFP)
- ELECTRONICS CARDS
- ELECTRONICS CARDS PROTECTION SKIN (Kevlar)
- CABLES ROUTING TRAY (Aluminum)
- ELECTRONICS PATCH PANELS (Aluminum)
- MAIN GAS PIPES (Rilsan)

Sketch of frontend part

- INFN Frascati
- Jun-13, 2013

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Final Assembly Scheme

- Central frame structure to support all central components
  - beam pipe + MVD + STT semi-barrels
- Rail system for insertion into the PANDA target spectrometer

INFN Frascati + Torino
STT Readout

2 Concepts to measure drift time + signal amplitude (for dE/dx)

- **Amplitude sampling: LE-Time + Q**
  - Amplifier-shaper boards frontend at detector
  - Pulse sampling by FADC (240 MHz), pulse analysis and readout by FPGA

- **Amplitude by time-over-threshold*: LE-Time + ToT(Q)**
  - Ampl.-Shaper-Discr. (ASIC-chip) frontend at detector
  - Time Readout Boards (TRB), TDC in FPGA

- **Requirements**
  - ~ 2fC sensitivity (thresh. ~ 1.2×10^4 e^-)
  - ~ 1ns time resolution, ~ 200ns drift time range for Ar/CO_2(10%) at 2 T field
  - < 10% dE/dx resolution for PID
  - Hit rates: ~ 800 kHz/straw (max), ~ 400 kHz (avg.) at full luminosity

- FEE must be radiation-hard, low power consumption, minimum space

*ToT used for PID at ATLAS-TRT & HADES-MDC

Design by AGH Krakov (CMOS 0.35µm)
Test Systems

- STT semi-barrel (1:1) for assembly techniques
- Mechanical central frame structure on rail system

- STT detector in COSY-TOF experiment
  - “Global“ test system for PANDA-STT (straw technique)
  - Spatial resolution: $\sigma \sim 140\mu\text{m}$ (2700 straws)
  - Operated (4 yr) in evacuated time-of-flight barrel (25m$^3$)
  - Leakage on permeation level (molecular flow thru mylar)

- Straw setups for in-beam tests (p/d-beam)
  - Aging tests done, charge loads $\sim 1.2$ C/cm ($\sim 5$yrs PANDA)
  - High-rate readout tests ongoing, 1-2 MHz/straw
  - Beam momentum 0.6 - 3 GeV/c (dE/dx range $\sim 3\times$ mips)
FADC Energy-Loss Measurements

- dE/dx resolutions measured in beam with FADC
  - $\sigma_{dE/dx} = 7.0\% - 9.3\%$ (0.6, 1.0, 2.9 GeV/c protons)
  - 30% truncation factor (Landau-tail)
  - < 19 straw hits per track $\rightarrow$ 25 layers at PANDA-STT
- $\sigma_{dE/dx} \sim 7.0\%$ feasible with PANDA-STT
- $\sigma \sim 150\mu m$ spatial resolution measured
- High-rate FPGA analysis & readout ongoing

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Time-Over-Threshold Method

- ASIC testversion with analog out, first in-beam test 2012
  - gain (3-24mV/fC), peak time (20/40ns), ion tail cancell., BL stability, ..
- Next ASIC version in production: 100 chips × 8 ch, few param. optimisations
- Calibration of ToT ↔ dE/dx with $^{55}$Fe-source (simple) and beam protons
  - need >4 different beam momenta to get ToT ↔ dE/dx relation and resolution

$^{55}$Fe-signals, 220(110)e⁻/200µm, pulse integral + ToT measuremt

Charge (pC) vs ToT(ns)

Beam on straws, TRB readout

Pulse integral

ToT (25mV)

ToT (50mV)

dQ/Q resolution ~ 10%

50mV threshold

25mV threshold

55Fe signals, 220(110)e⁻/200µm, pulse integral + ToT measurement
Simulation Studies

- Single track simulation (MVD+STT+GEM, B=2T)
  - Momentum resolution 1-2% for $\theta < 140^\circ$
  - Test of tracking system with benchmark channels
    - $\bar{p}p \rightarrow \pi^+\pi^-\pi^+\pi^-$
    - $\bar{p}p \rightarrow \eta_c \rightarrow \phi\phi \rightarrow K^+ K^- K^+ K^-$
    - $\bar{p}p \rightarrow \Psi(3770) \rightarrow D^+D^- \rightarrow K^-\pi^+\pi^+K^+\pi^-\pi^-$
  - vertex resolutions and reconstructed mass of D-mesons

D-meson reconstruction numbers

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Acceptance</td>
<td>24.5%</td>
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<tr>
<td>Total Reconstructed</td>
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<td>Vertex Resolution (xy)</td>
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<td>Vertex Resolution (z)</td>
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<tr>
<td>Mass Resolution</td>
<td>13.1 MeV</td>
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Summary

- The PANDA-STT provides a complete measurement of charged particles: space, momentum, pid, (time)
- Test measurements and benchmark channel simulations confirm the required performance
- Technical design report of the STT was approved in 2012
- Funding process will be completed soon (Germany, Italy, Poland, Romania)
- Straw mass production during 2013-2016 (> 50% spares)
- Electronic readout optimisation in parallel, beam test times at COSY
- Commissioning of the detector setup with beam in 2016/2017 at COSY
- Shipping to FAIR and installation in PANDA 2017