Reconstructing tracks with displaced vertices with the $\bar{\text{PANDA}}$ detector at FAIR

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Hyperon channels in PANDA

Why antihyperon-hyperon production?

- Hyperons produced at scales where QCD is poorly understood
- \( CP \) violation - needed to describe matter in the universe
- Never-before measured hyperon states
- Measure properties e.g. spin of hyperons

See M. Papenbrock and D. Bettoni talk

Figure: \( \bar{\Lambda}\Lambda \) production channel, scarce data above \( \sqrt{s} = 4 \text{ GeV} \)

Figure: \( \bar{\Omega}^+\Omega^- \) production channel, never measured
PANDA - antiProton ANnihilation at DArmstadt

- Target- and forward spectrometer provide a near $4\pi$ coverage
- $\bar{p}$ beam momentum of 1.5 - 15 GeV/c
- Unpolarized beam and target
- High resolution measurement and PID
- HESR provides $\mathcal{L} \sim 10^{31}\text{cm}^{-2}\text{s}^{-1}$

See D. Bettoni talk
PANDA target spectrometer

Detect particles with $\theta \geq 10^\circ$, $0 \leq \phi < 360^\circ$

Charged track reconstruction

- Micro Vertex Detector (MVD)
- Straw Tube Tracker (STT)
- Gas Electron Multiplier (GEM)
- Scintillator Tile Hodoscope (SciTil)
Pattern recognition

- Many pattern recognition and tracking algorithms for PANDA under development

- Different algorithms:
  - Detectors/detector groups
  - Topologies
  - Online/offline

Hyperon decay characteristics

- Ground state hyperons decay weakly $\rightarrow$ displaced vertices
- Many hyperons decay to $\Lambda$
- $\bar{p}p \rightarrow \Omega^+ \Omega^-$: In $\sim 30\%$ of events, $\geq 1$ tracks only leave hits in STT
The PANDA Straw Tube Tracker

<table>
<thead>
<tr>
<th>STT specifications</th>
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</thead>
<tbody>
<tr>
<td>Total straws</td>
</tr>
<tr>
<td>Axial layers</td>
</tr>
<tr>
<td>Stereo layers</td>
</tr>
<tr>
<td>Stereo angle</td>
</tr>
<tr>
<td>Spatial resolution (xy)</td>
</tr>
<tr>
<td>Spatial resolution (z)</td>
</tr>
</tbody>
</table>

- Drift time + reference time \( t_0 \) → isochrone
- More precise position

Figure: Cross sectional view of STT
Green - parallel straw
Red, blue - skewed straw
SttCellTrackFinder

Track reconstruction algorithm using only STT.
(J. Schumann, Forschungszentrum Jülich)

1. Cluster hits in parallel straws into tracklets
2. Combine tracklets with circle fits
3. Refined circle fit using isochrones
4. Assign skewed straw hits

Output: circle for each track in \( xy \)-plane

Must include skewed straws to reconstruct \( p_z \)
Longitudinal position from skewed straws

\[ \bar{p}p \rightarrow \Lambda\bar{\Lambda} \] generated at
\[ p_{\text{beam}} = 1.64 \text{ GeV}/c \]
Final state: \( \bar{p}p\pi^+\pi^- \)
Longitudinal position from skewed straws

\( \bar{p}p \to \Lambda \bar{\Lambda} \) generated at
\( p_{\text{beam}} = 1.64 \ \text{GeV}/c \)
Final state: \( \bar{p}p\pi^+\pi^- \)

Focus on this track!
Longitudinal position from skewed straws

The method:

1. Extract isochrone radius in skewed straw
2. Center of isochrone gives $z$-position
3. Generate all possible isochrone positions
4. Calculate $(z, \phi)$

Ambiguity: Each straw gives two possible $(z, \phi)$

Solution

Use Hough transform to reject fake positions
Hough transform

Find geometric shapes in images. Invented for automated bubble chamber analysis in 1962.

- Helix trajectory $\rightarrow$ straight line in $z - \phi$ space
- Line parameters in $xy$-plane, slope $k$ and intercept $m$
  $$y(x) = kx + m$$

Problem: The intercept parameter $m$ unbound.

Hesse normal form:

$$r = x \cos \theta + y \sin \theta$$

$$y = \left(-\frac{\cos \theta}{\sin \theta}\right)x + \left(\frac{r}{\sin \theta}\right)$$
Hough transform

The method:

1. Isochrone centers in $z - \phi$ space
Hough transform

The method:

1. Isochrone centers in $z - \phi$ space
2. Generate set of all lines
Hough transform

The method:

1. Isochrone centers in $z - \phi$ space
2. Generate set of all lines
3. Parameters $\rightarrow$ accumulator space
Hough transform

The method:

1. Isochrone centers in $z - \phi$ space
2. Generate set of all lines
3. Parameters $\rightarrow$ accumulator space
4. Repeat for all points

![Skewed hits position in Z-\(\phi\)](image)
Hough transform

The method:

1. Isochrone centers in $z - \phi$ space
2. Generate set of all lines
3. Parameters $\rightarrow$ accumulator space
4. Repeat for all points
Hough transform

The method:

1. Isochrone centers in $z - \phi$ space
2. Generate set of all lines
3. Parameters $\rightarrow$ accumulator space
4. Repeat for all points
5. Voting procedure $\rightarrow$ true line

True line found in maximum!
**Hough transform: our track**

**Skewed hits position in Z-\(\phi\)**

![Skewed hits position in Z-\(\phi\)](image)

**HoughSpace**

![HoughSpace](image)

**Figure:** 360 lines generated for each data point in steps of 1° in \(\theta\)
Straight line fit

The method:

1. Calculate point of closest approach (POCA) from hits to true line
2. Reject hit with largest POCA
3. Straight line fit with selected \((z, \phi)\) coordinates

Finish

The slope of the fitted line yields the helix angle. \(z_0\) and \(p_z\) can now be extracted!
Summary and outlook

- The SttCellTrackFinder will be extended to reconstruct $p_z$ with skewed straws
  - Move isochrones to track
  - Hough transform to reject fake hits
  - Use line fit to extract helix angle

Outlook

- Remake the Hough transform; generate only lines that pass through all combinations of two hits
- Optimize peak-finding procedure in accumulator space
- Deal with events with only one or two skewed straw hits
Summary and outlook

Thank you for your attention!
Backup
### Accessible hyperons at PANDA

The table below summarizes the momentum, reaction, cross section, efficiency, and rate for various hyperon processes at PANDA.

<table>
<thead>
<tr>
<th>Momentum (GeV/c)</th>
<th>Reaction</th>
<th>$\sigma$ (µb)</th>
<th>Efficiency (%)</th>
<th>Rate at $10^{31}$cm$^{-2}$s$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.64</td>
<td>$p\bar{p} \to \Lambda\Lambda$</td>
<td>64</td>
<td>11</td>
<td>29s$^{-1}$</td>
</tr>
<tr>
<td>4</td>
<td>$p\bar{p} \to \Xi^+\Xi^-$</td>
<td>$\approx$ 2</td>
<td>$\approx$ 20</td>
<td>1.5s$^{-1}$</td>
</tr>
<tr>
<td>12</td>
<td>$p\bar{p} \to \Omega^+\Omega^-$</td>
<td>$\approx$ 0.002</td>
<td>$\approx$ 30</td>
<td>$\approx$ 4h$^{-1}$</td>
</tr>
<tr>
<td>12</td>
<td>$p\bar{p} \to \Lambda_c^-\Lambda_c^+$</td>
<td>$\approx$ 0.1</td>
<td>$\approx$ 35</td>
<td>$\approx$ 2day$^{-1}$</td>
</tr>
</tbody>
</table>

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Sophie Grape, Ph. D. Thesis, Uppsala University 2009  
Erik Thomé, Ph. D. Thesis, Uppsala University 2012
Pattern recognition

Solenoid $\vec{B}$-field in beam direction $\rightarrow$ helix trajectory.

- Assume no energy loss
- Reconstruct charged track helix
- Realistic track with Kalman filter