Reconstructing tracks with displaced vertices with the $\overline{\text{P}}$ANDA detector at FAIR

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$\overline{\text{P}}$ANDA collaboration meeting
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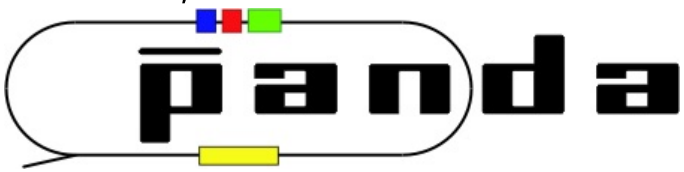
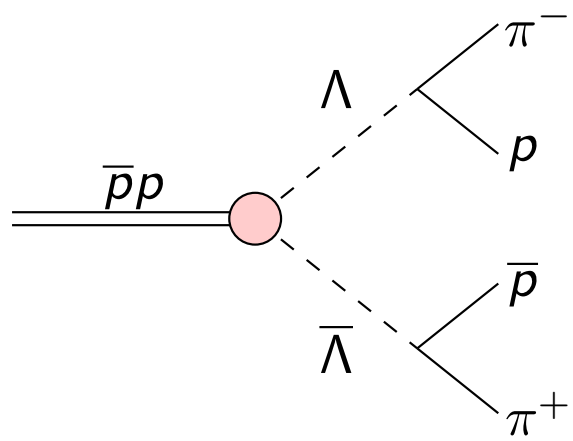


Hyperon channels in $\overline{\mathrm{P}}$ANDA

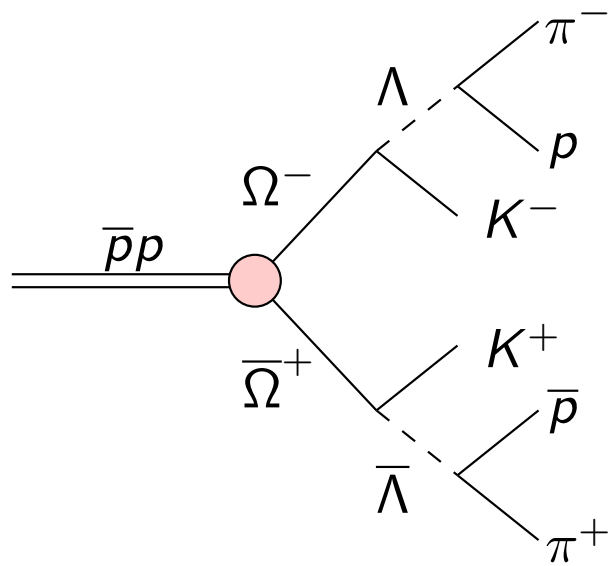
$\overline{p}p \to \overline{\Lambda}\Lambda$ process

- $\overline{\Lambda}$ produced with forward peaking distribution
- Four charged tracks from displaced vertices



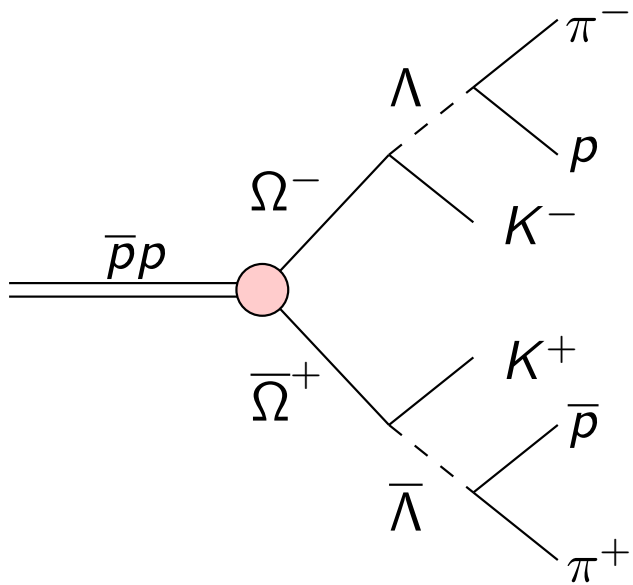
$\overline{p}p \to \overline{\Omega}^+\Omega^-$ process

- Never measured before, generated with PHSP
- Six charged tracks from displaced vertices



Pattern recognition

- Many pattern recognition and tracking algorithms for $\overline{\mathrm{P}}$ANDA under development
- Different algorithms:
  - Detectors/detector groups
  - Topologies
  - Online/offline



Hyperon decay characteristics

! Ground state hyperons decay weakly $\rightarrow$ displaced vertices

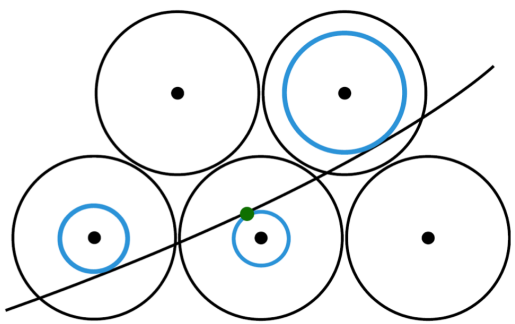
! Many hyperons decay to Λ

- $\overline{p}p \rightarrow \overline{\Omega}^+\Omega^-$: In $\sim 30\%$ of events, ≥ 1 tracks only leave hits in STT

The $\overline{\text{P}}$ANDA Straw Tube Tracker

STT specifications	
Total straws	4636
Axial layers	15-19
Stereo layers	8
Stereo angle	$\pm$ 2.9 deg

- Drift time + reference time t_0 $\rightarrow$ isochrone
- More precise position



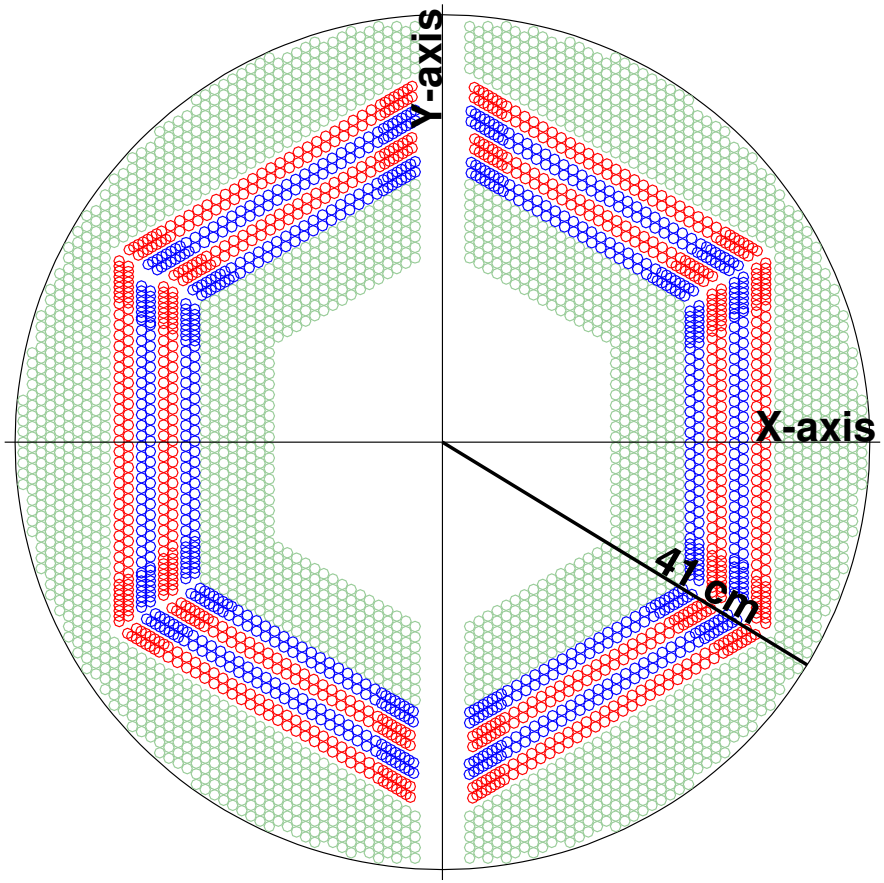


Figure: Cross sectional view of STT
Green - parallel straw
Red, blue - skewed straw

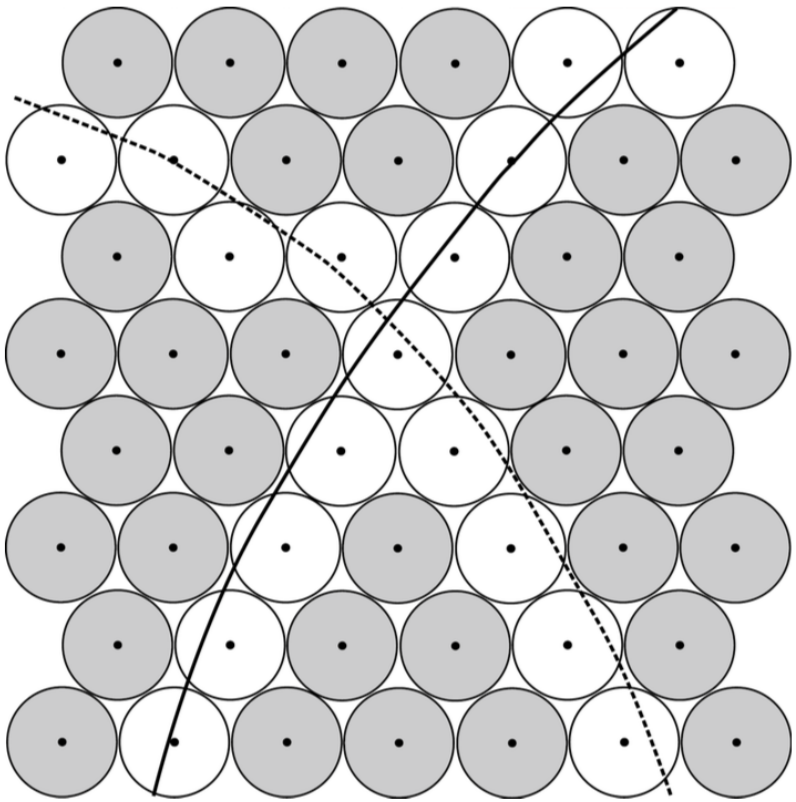
SttCellTrackFinder

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

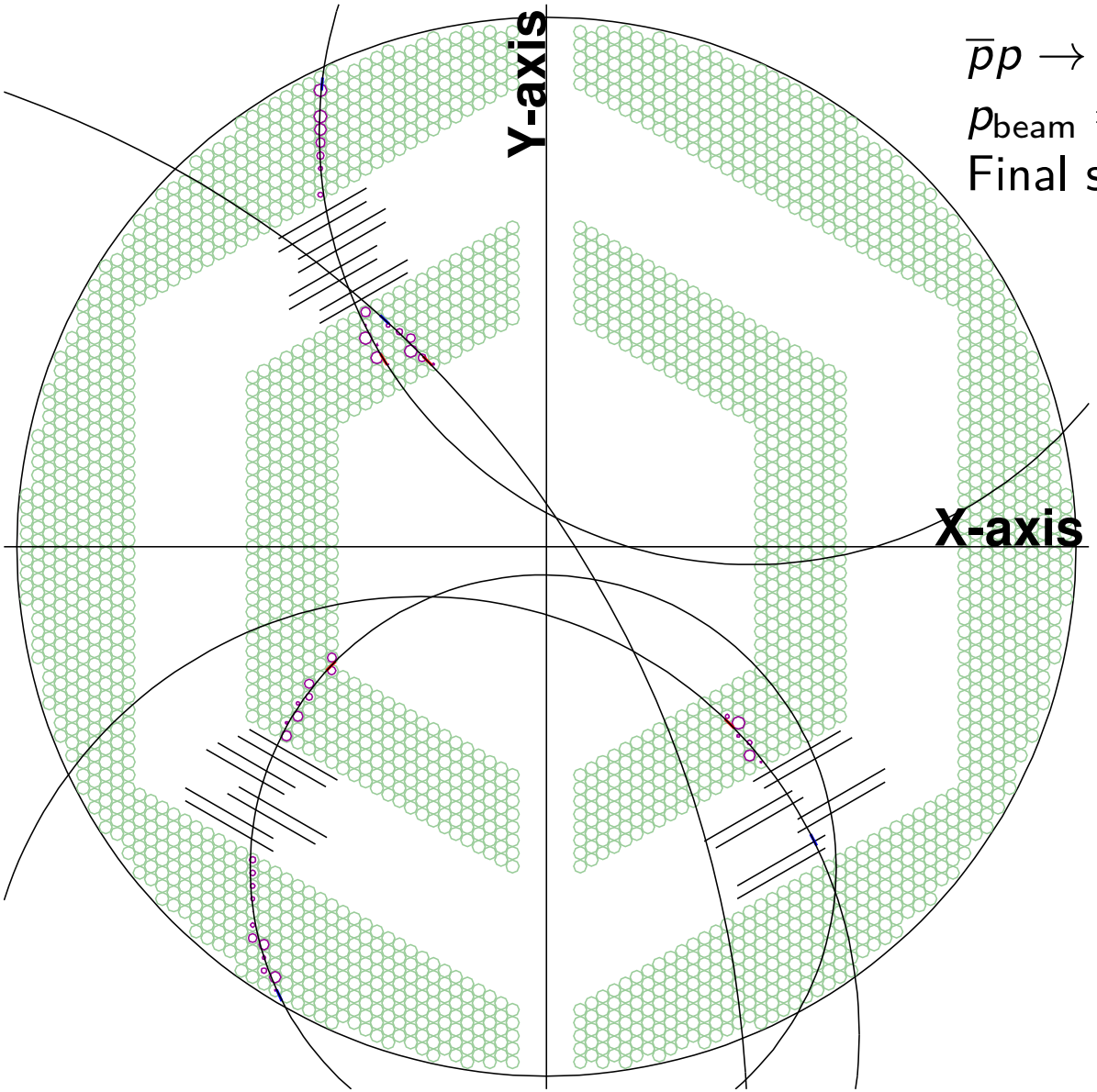
1. Cluster hits in parallel straws into tracklets
2. Combine tracklets with circle fits
3. Refined circle fit using isochrones
4. Assign skewed straw hits

Output: circle for each track in xy-plane

Must include skewed straws to reconstruct p_z

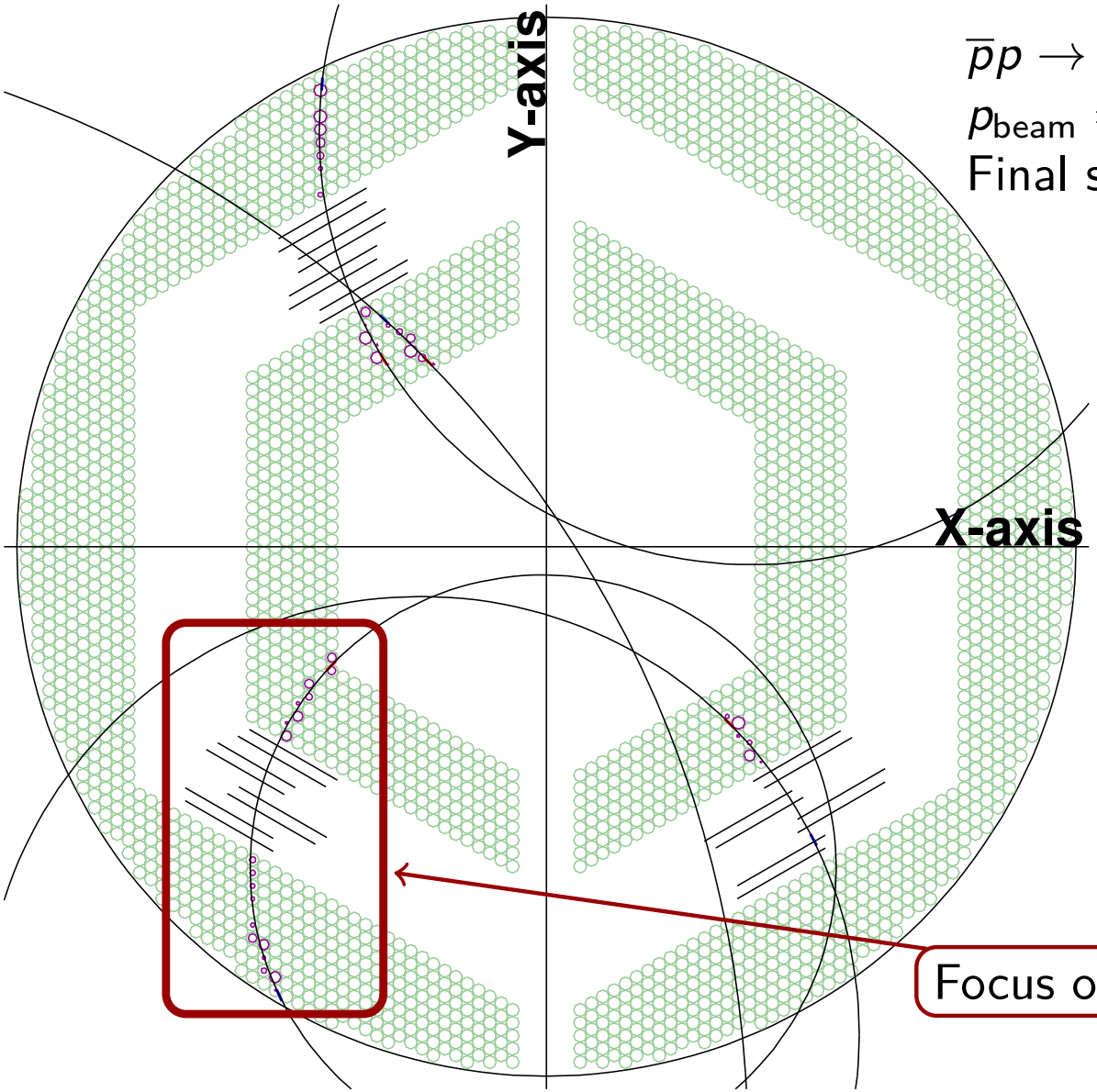


Longitudinal position from skewed straws



$\overline{p}p \rightarrow \overline{\Lambda}\Lambda$ generated at
$p_{\text{beam}} = 1.64$ GeV/c
Final state: $\overline{p}\pi^+ p\pi^-$

Longitudinal position from skewed straws



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

Longitudinal position from skewed straws

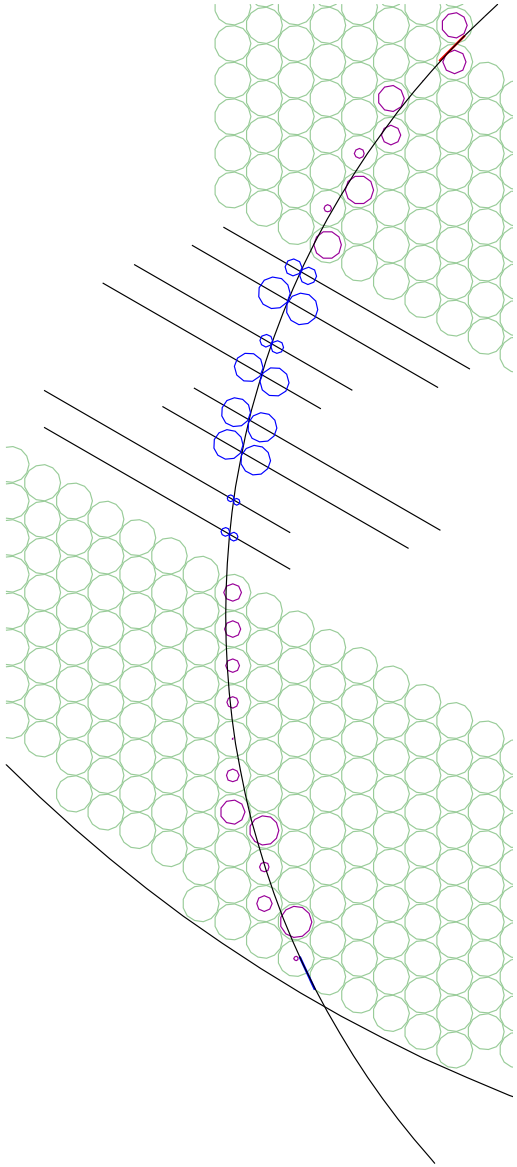
The method:

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

Ambiguity: Each straw gives two possible (z, ϕ)

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:

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

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

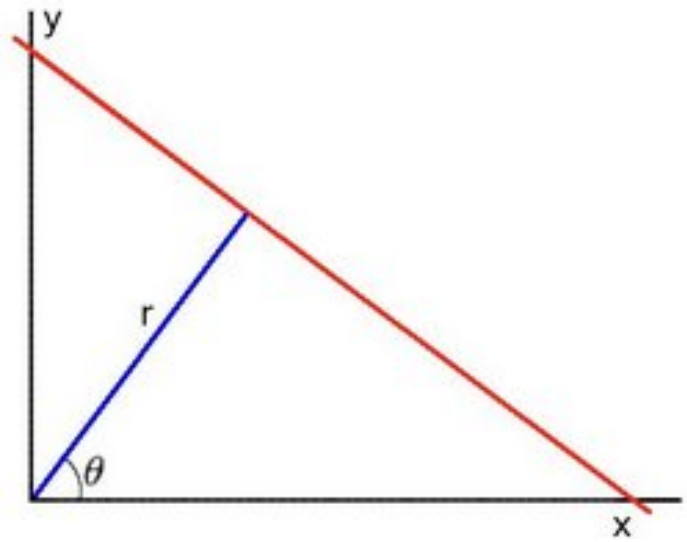
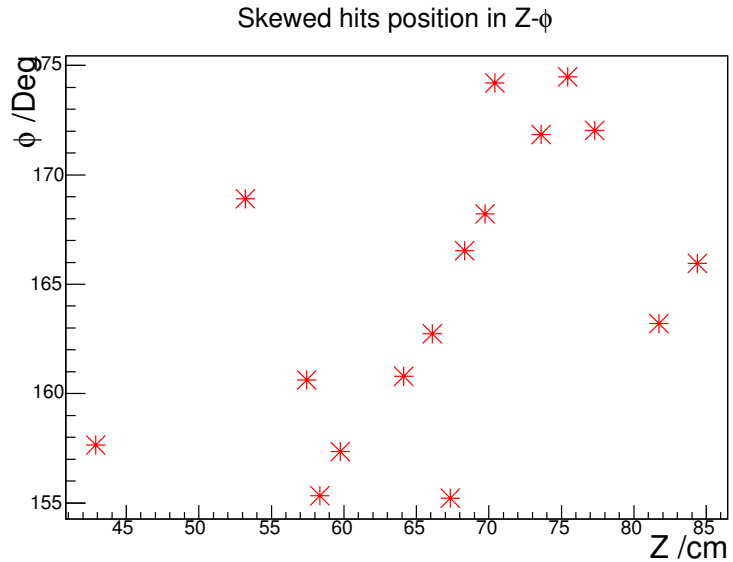


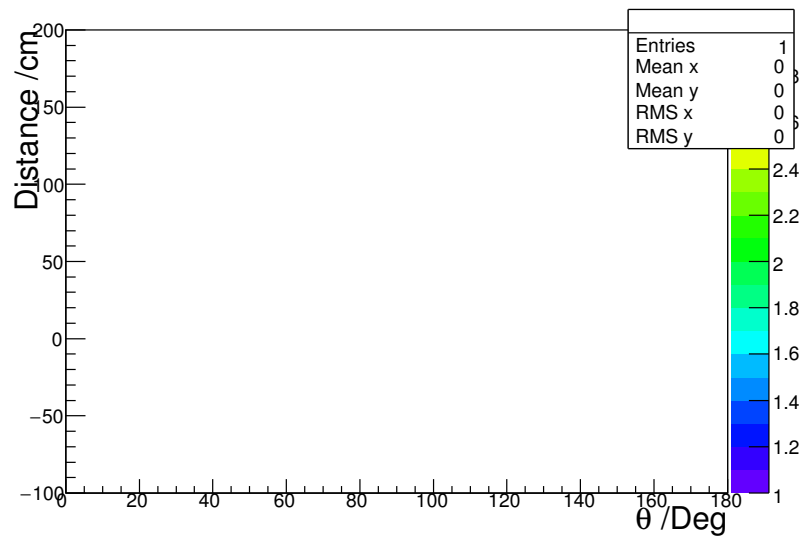
Figure: Blue line perpendicular to red line and crosses the origin

Hough transform

The method:

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

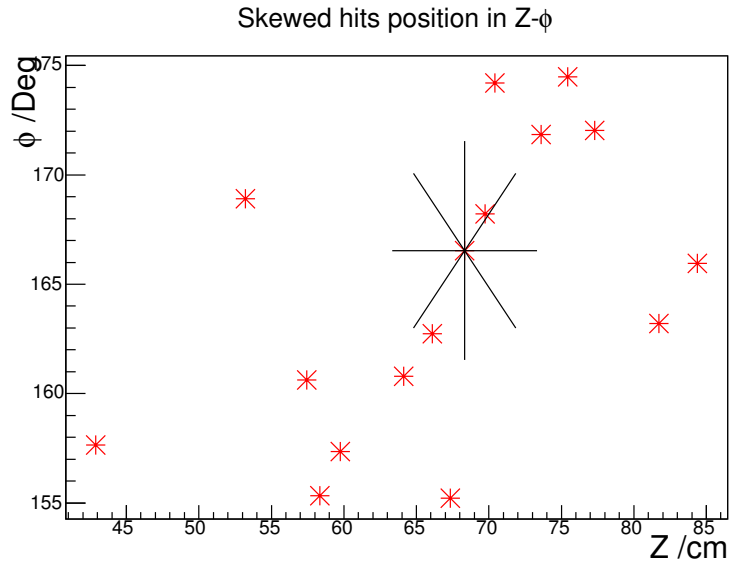


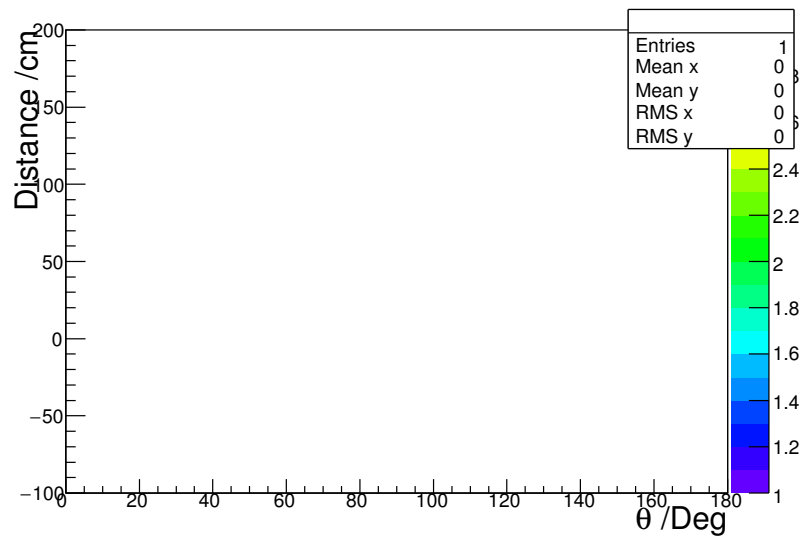


Hough transform

The method:

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

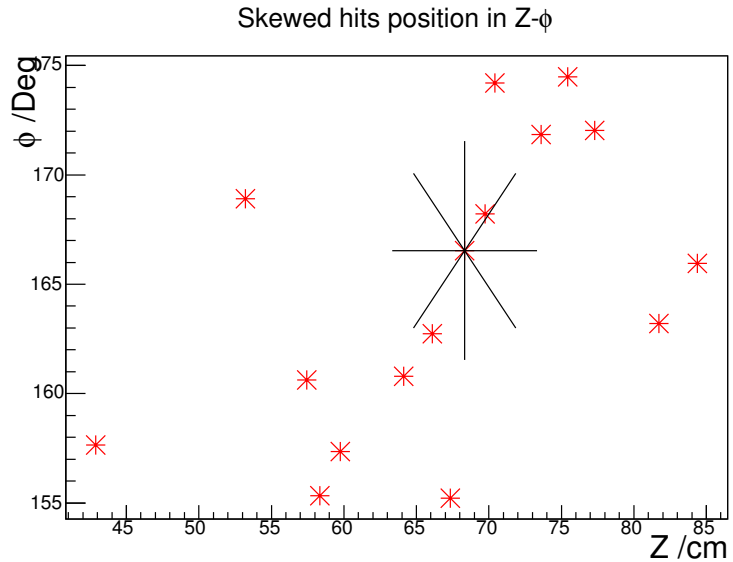


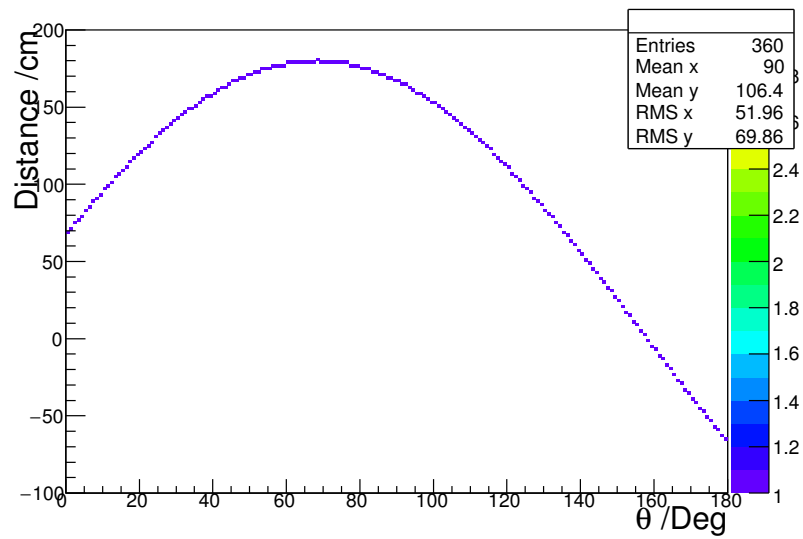


Hough transform

The method:

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

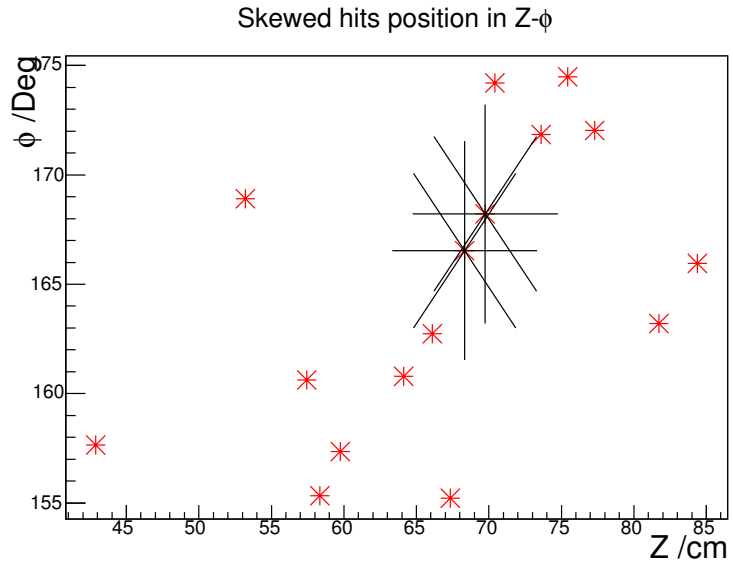


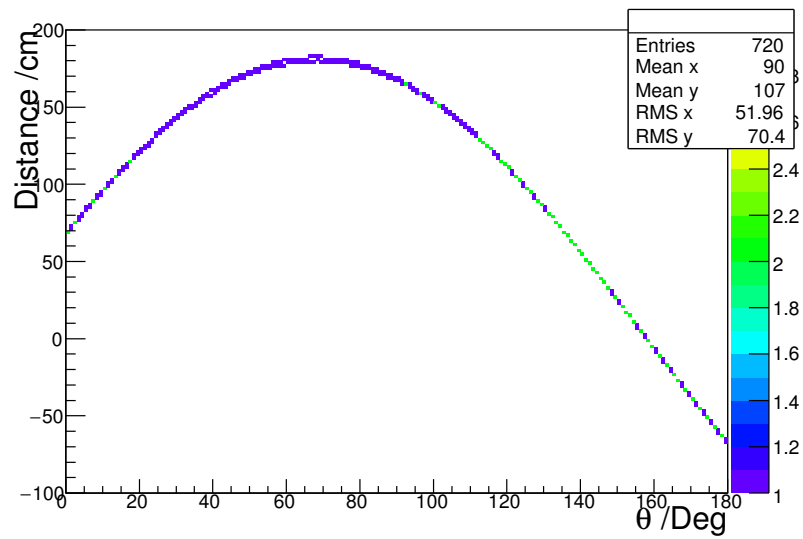


Hough transform

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





Hough transform

The method:

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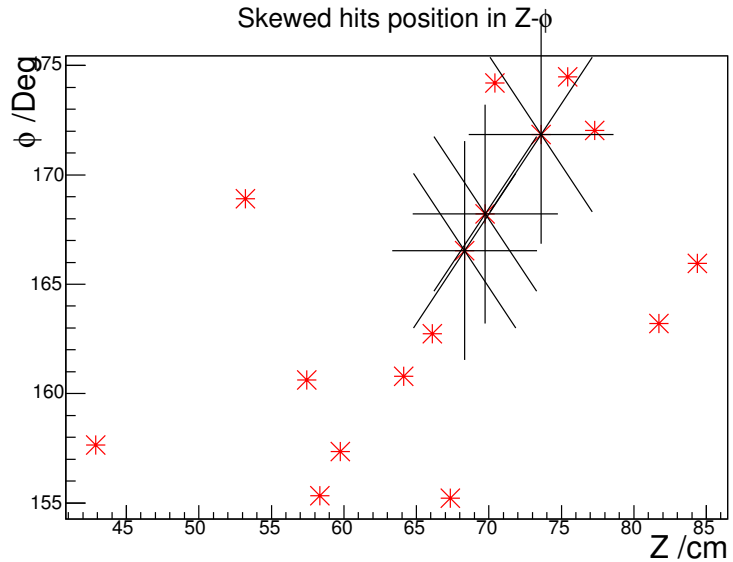
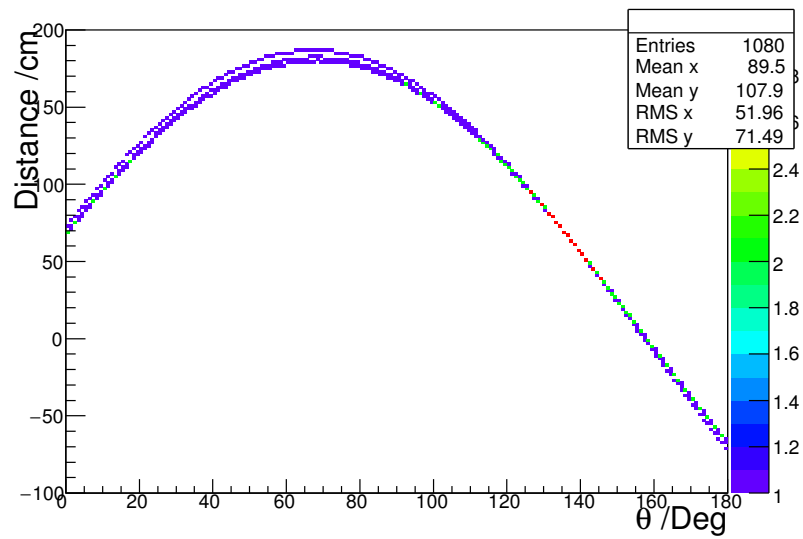


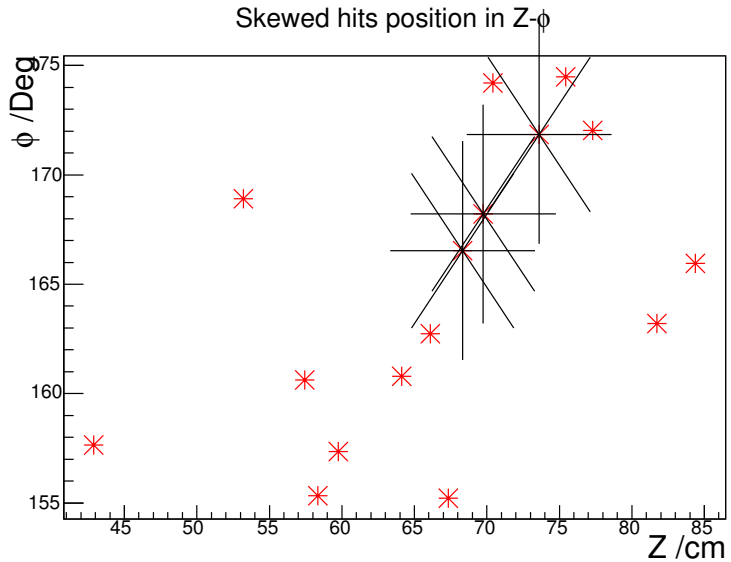


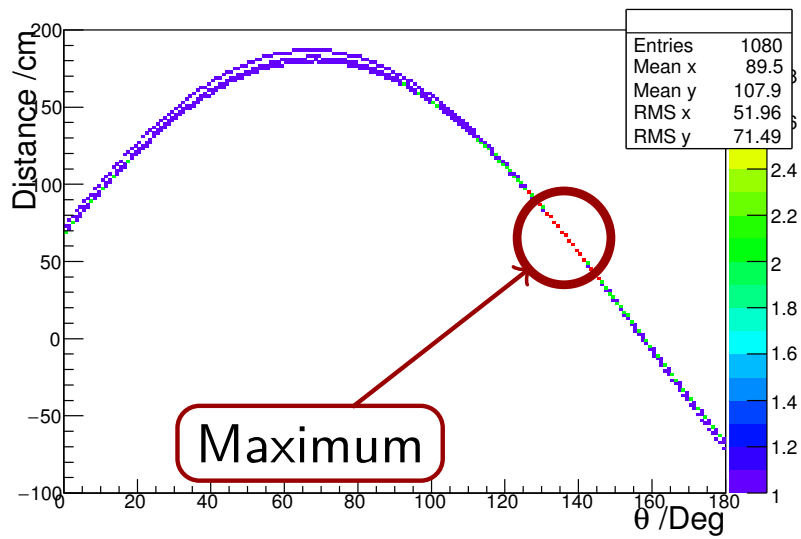
Hough transform

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

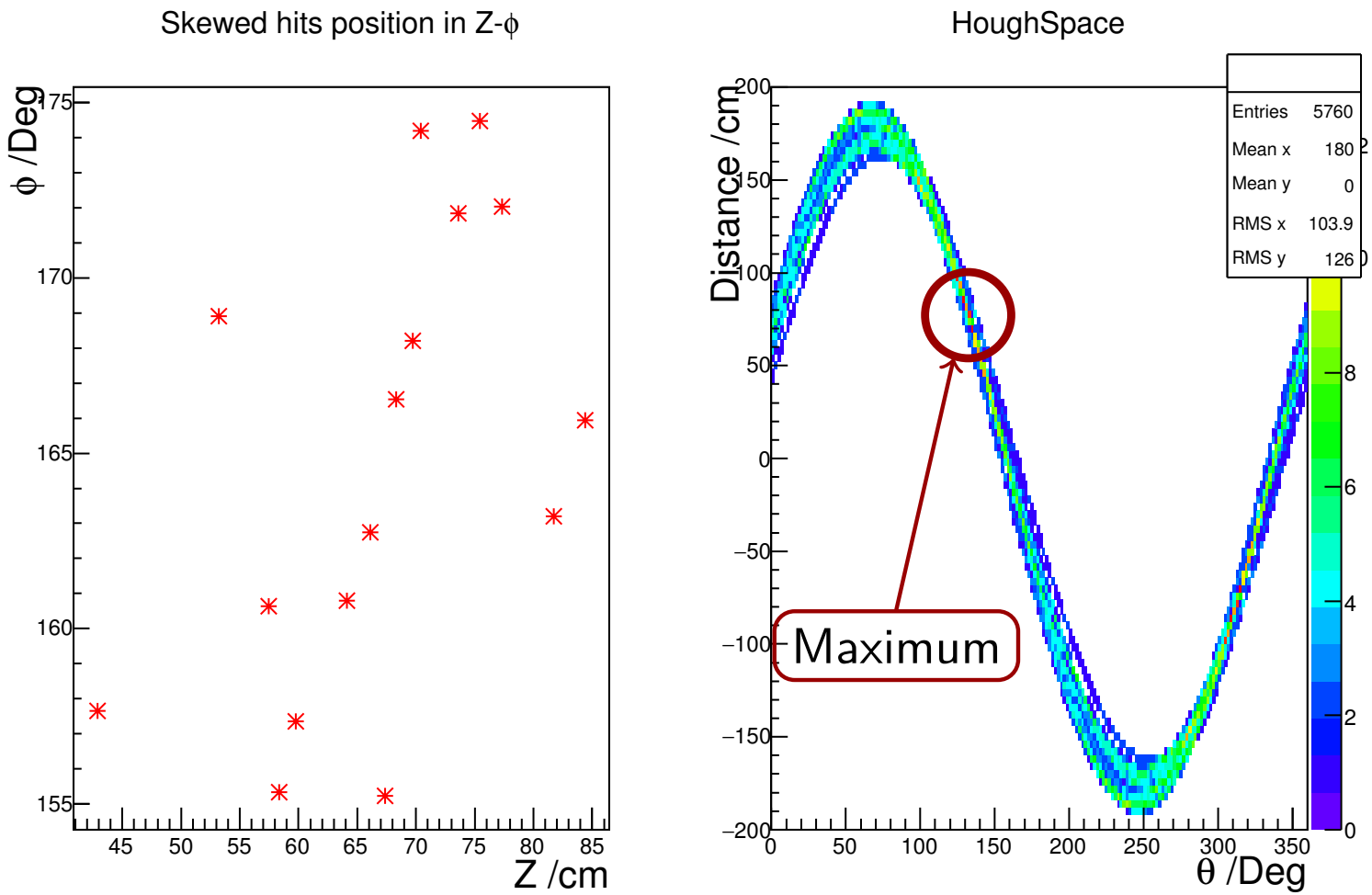


Figure: 360 lines generated for each data point in steps of 1° in θ

Extracting helix angle

The method:

1. Calculate point of closest approach (POCA) from hits to true line
2. Accept hit with smallest POCA
3. Straight line fit with selected (z, ϕ) 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
  - Helix angle $\rightarrow$ p_z and z_0
- Outlook
  - Remake the Hough transform; generate only lines that passes through all combinations of two hits
  - Optimize peak-finding procedure in accumulator space
  - Deal with events with only one or two skewed straw hits
  - Performance studies

Summary and outlook

Thank you for your attention!

Backup

Hyperon channels in $\overline{\mathrm{P}}$ANDA

Why antihyperon-hyperon production?

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

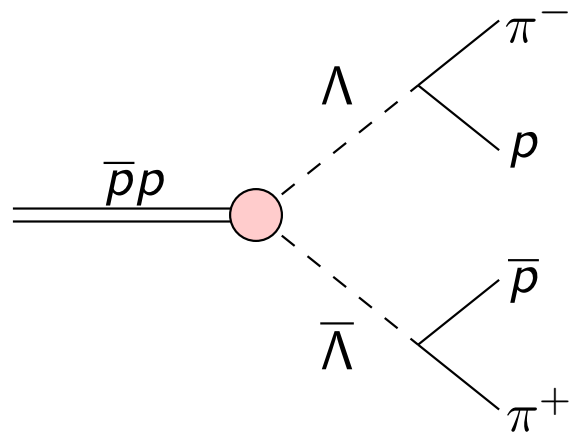


Figure: $\Lambda\overline{\Lambda}$ production channel, scarce data above $\sqrt{s} = 4$ GeV

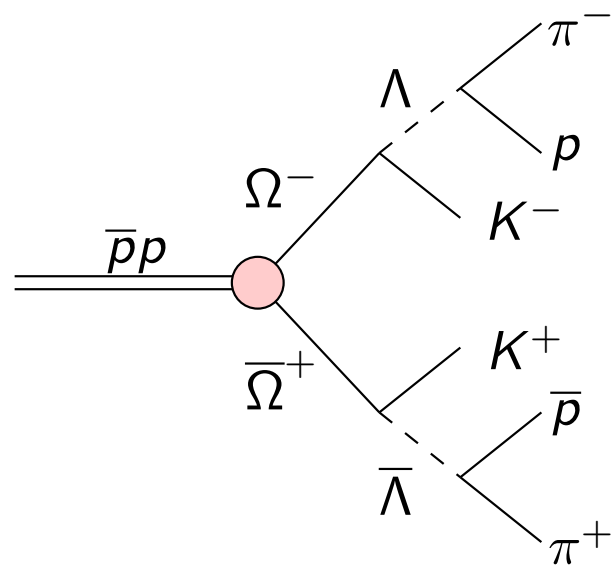
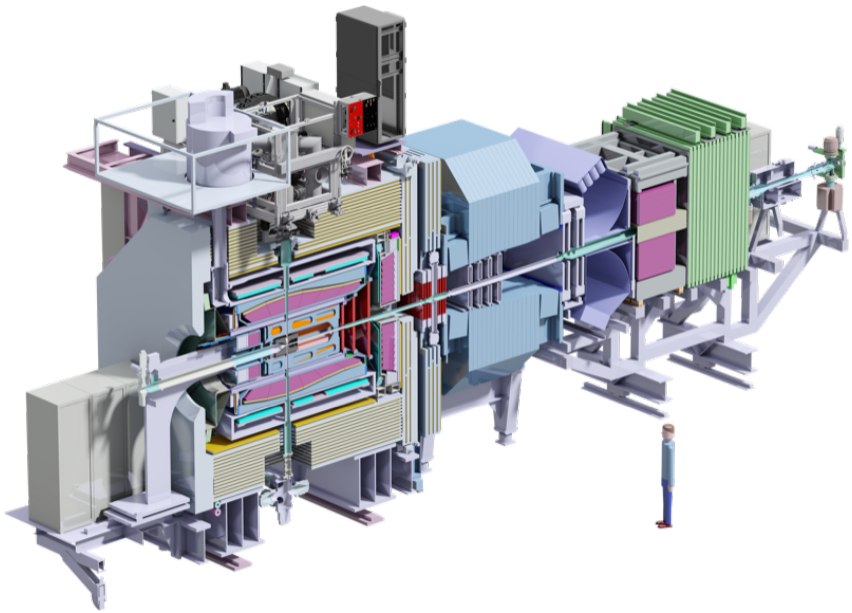


Figure: $\overline{\Omega}^+\Omega^-$ production channel, never measured

$\overline{\text{P}}$ANDA - antiProton ANnihilation at DArmstadt



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

Accessible hyperons at $\overline{\mathrm{P}}$ANDA

$$\begin{array}{lllllllll}
\bar{p}p \rightarrow & \bar{\Lambda}\Lambda, & \bar{\Sigma}^{-}\Sigma^{+}, & \bar{\Sigma}^{0}\Sigma^{0}, & \bar{\Sigma}^{-}\Sigma^{+}, & \bar{\Xi}^{0}\Xi^{0}, & \bar{\Xi}^{+}\Xi^{-}, & \bar{\Omega}^{+}\Omega^{-}, & \bar{\Lambda}_{c}^{-}\Lambda_{c}^{+} \\
\downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow \\
 & p\pi^{-} & p\pi^{0} & \Lambda\gamma & n\pi & \Lambda\pi^{0} & \Lambda\pi & \Lambda K & \Lambda\pi \\
 & 64\% & 52\% & \approx 100\% & \approx 100\% & \approx 100\% & \approx 100\% & 68\% & \approx 1\%
\end{array}$$

Momentum (GeV/c)	Reaction	σ (μb)	Efficiency (%)	Rate at $10^{31}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
1.64	$\bar{p}p \rightarrow \bar{\Lambda}\Lambda$	64	11	$29\mathrm{s}^{-1}$
4	$\bar{p}p \rightarrow \bar{\Xi}^{+}\Xi^{-}$	≈ 2	≈ 20	$1.5\mathrm{s}^{-1}$
12	$\bar{p}p \rightarrow \bar{\Omega}^{+}\Omega^{-}$	≈ 0.002	≈ 30	$\approx 4\mathrm{h}^{-1}$
12	$\bar{p}p \rightarrow \bar{\Lambda}_{c}^{-}\Lambda_{c}^{+}$	≈ 0.1	≈ 35	$\approx 2\mathrm{day}^{-1}$

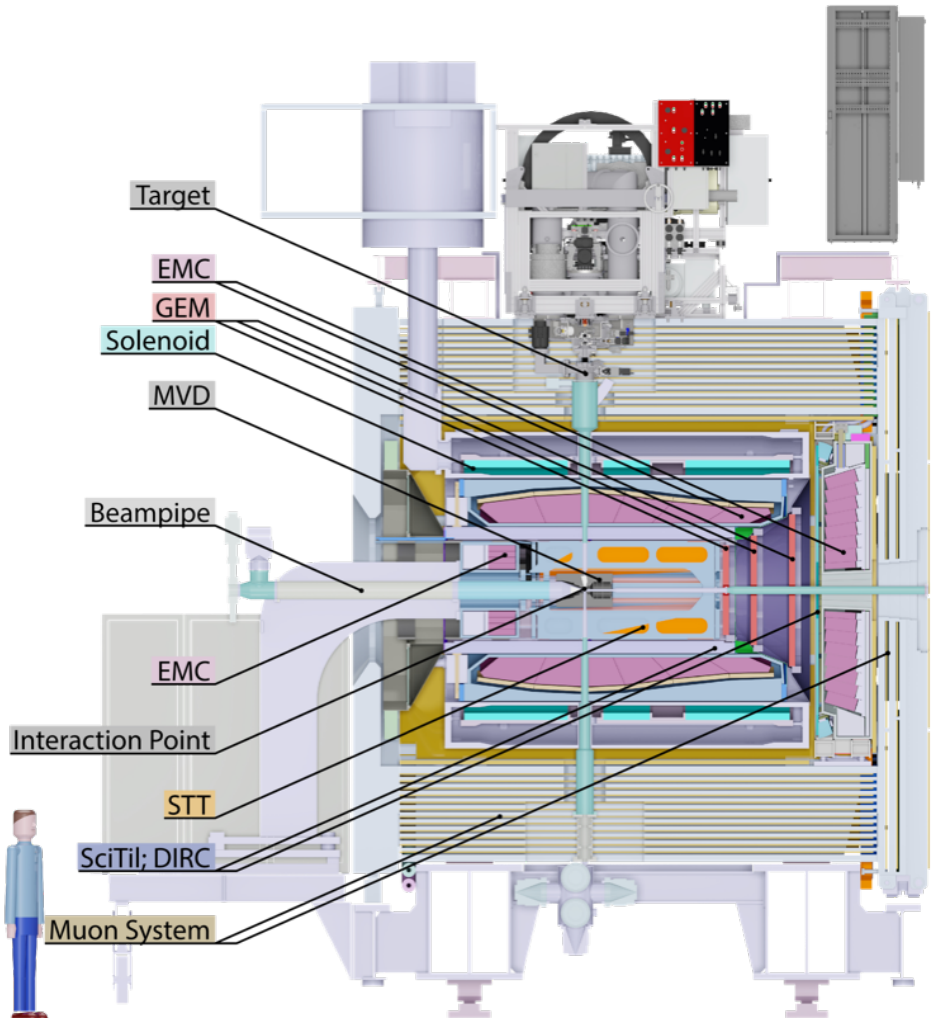
Sophie Grape, Ph. D. Thesis, Uppsala University 2009
Erik Thomé, Ph. D. Thesis, Uppsala University 2012

$\overline{\text{P}}$ANDA target spectrometer

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

Charged track reconstruction

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



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