Extracting longitudinal position and momentum with the skewed straws

Walter Ikegami Andersson

Uppsala University
on behalf of the $\overline{\text{P}}$ANDA collaboration

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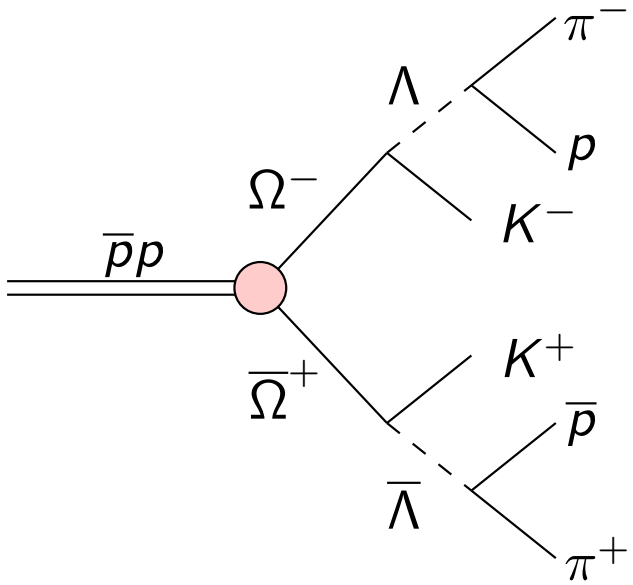
Detecting hyperons with $\overline{\text{P}}$ANDA

A track finder to detect hyperons:

- Ground state hyperons decay weakly $\rightarrow$ displaced vertices
- Many excited hyperons decay into Λ



$\overline{p}p \rightarrow \overline{\Omega}^+\Omega^-$ characteristics

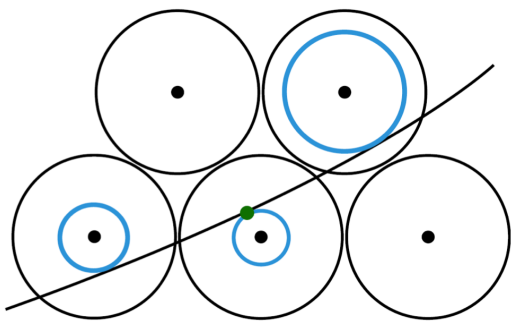
- 6 charged tracks from 4 displaced vertices
- Tracks from displaced vertex can miss MVD

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

Isochrone radius

Radial distance from track to wire



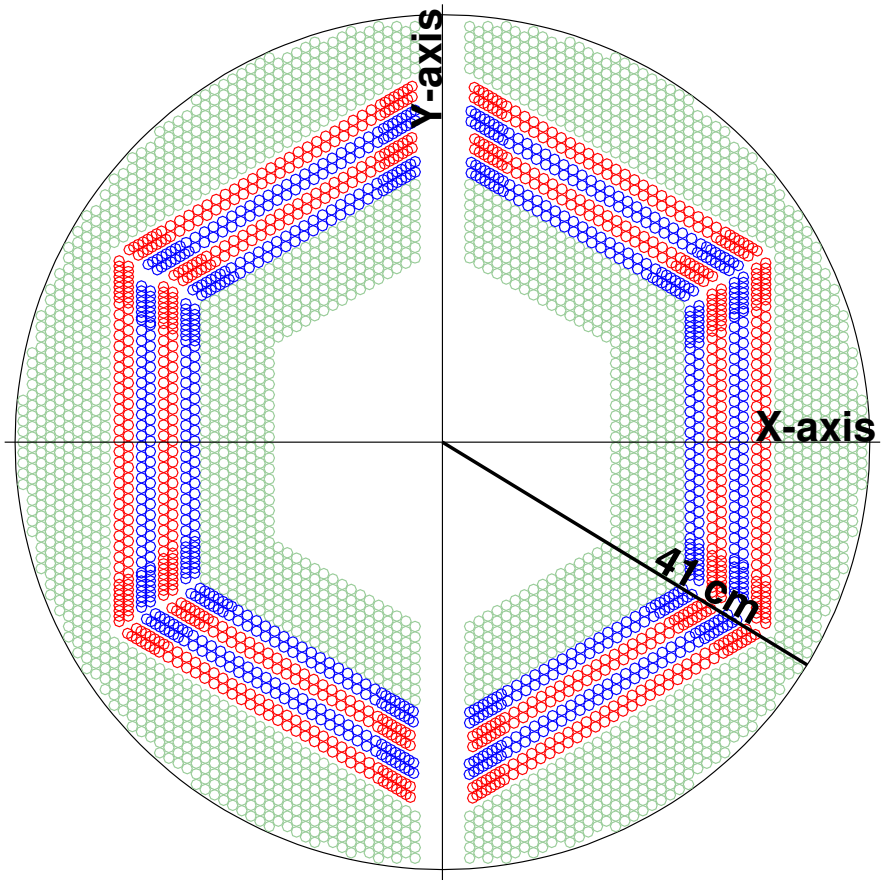


Figure: Cross sectional view of STT
Green - parallel straw
Red, blue - skewed straw

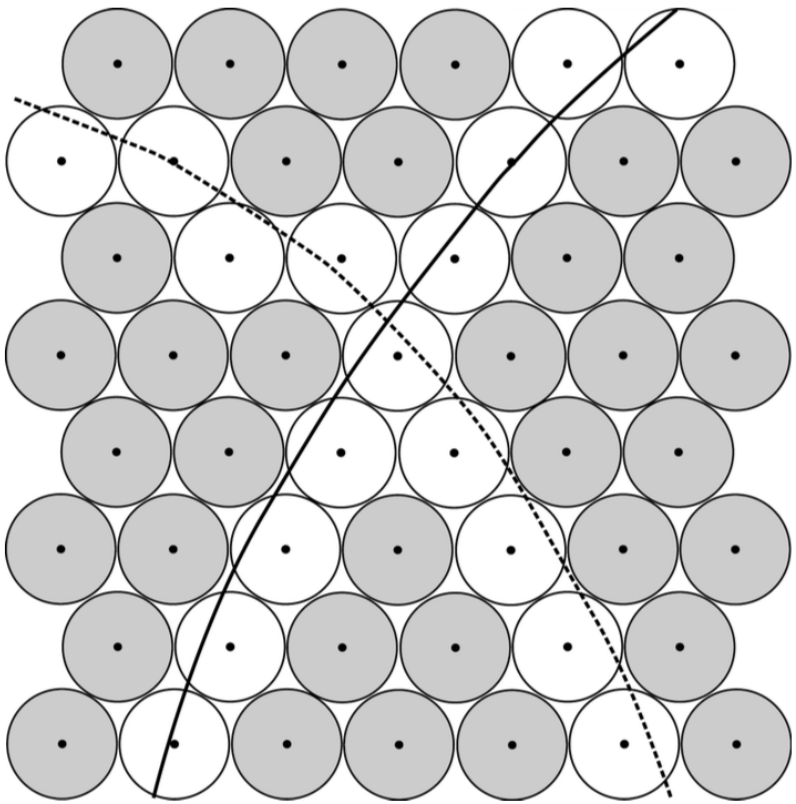
SttCellTrackFinder

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

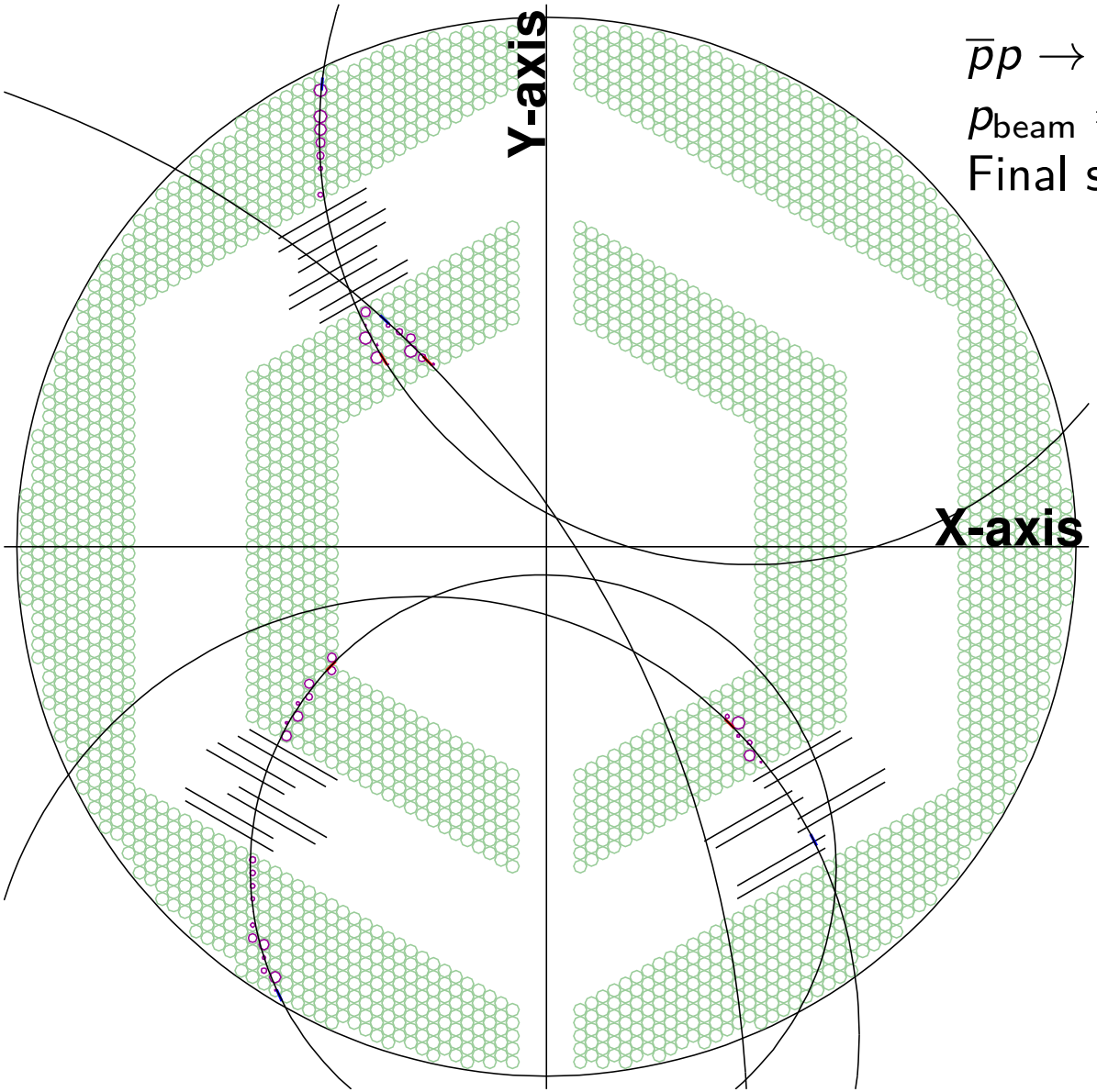
1. Cluster hits in parallel straws into tracklets (neighboring relations)
2. Refined circle fit using isochrones
3. Assign skewed straw hits to track

Output: circle for each track in xy-plane

Must include skewed straws to reconstruct p_z

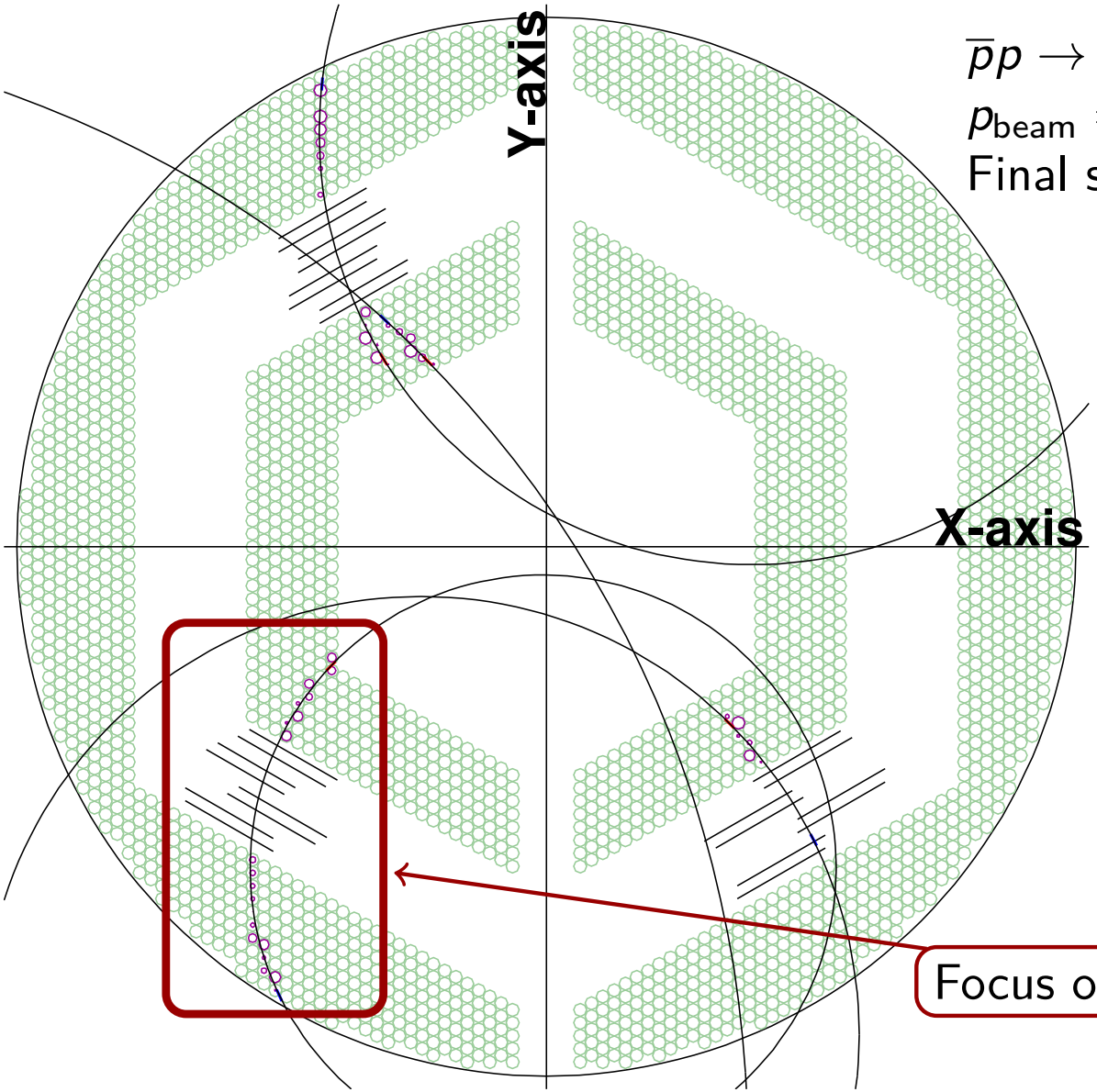


Longitudinal position from skewed straws



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

Longitudinal position from skewed straws



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

Longitudinal position from skewed straws

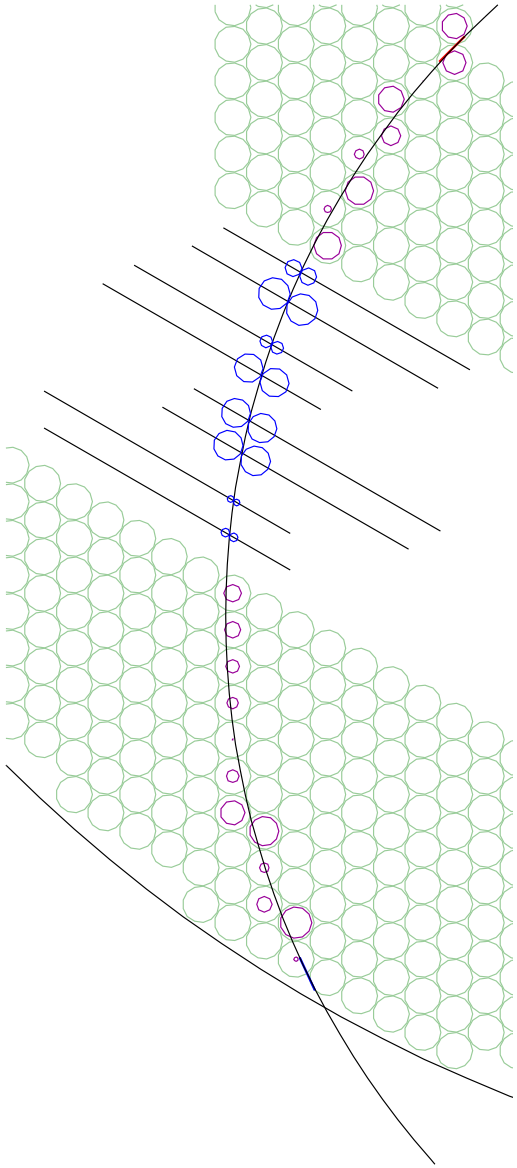
The method:

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)

Solve ambiguity

Use Hough transform or combinatoric method to reject fake positions



Method 1: Hough transform

Find geometric shapes in images.

- 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

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

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

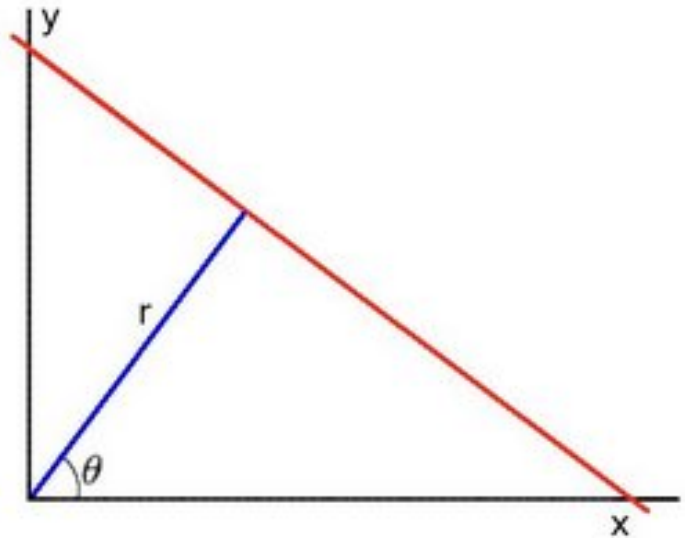
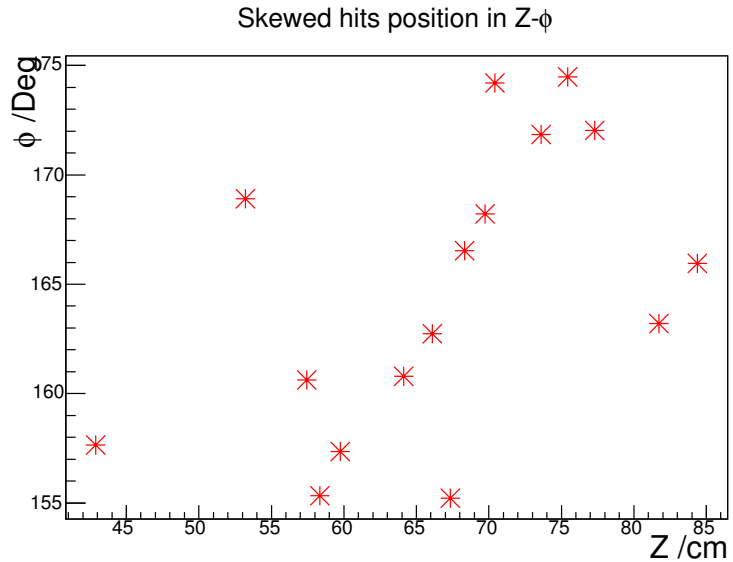


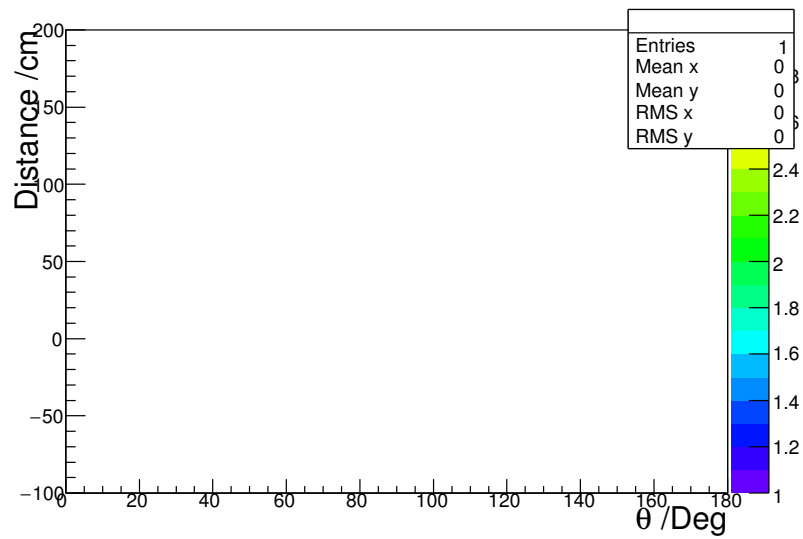
Figure: Blue line perpendicular to red line and crosses the origin

Method 1: Hough transform

The method:

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

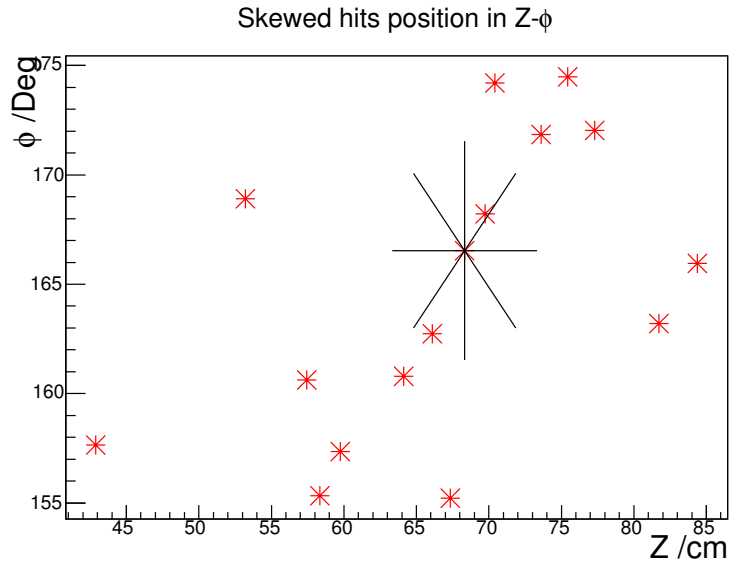


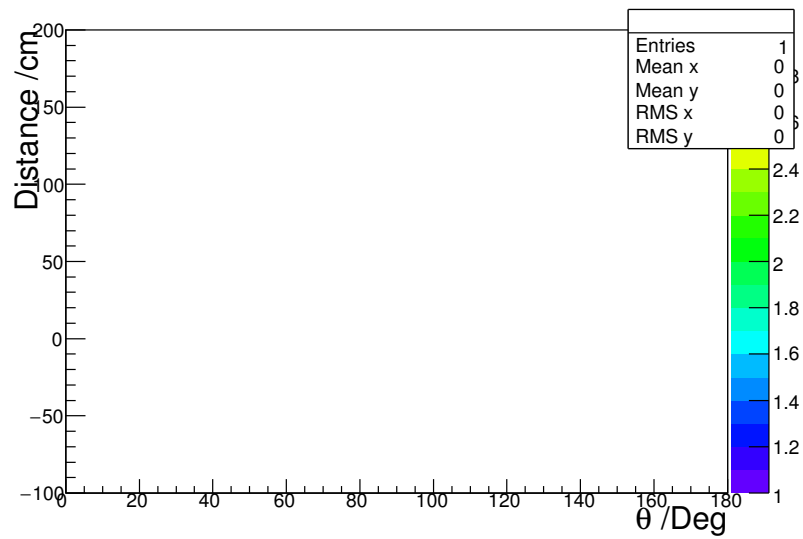


Method 1: Hough transform

The method:

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





Method 1: Hough transform

The method:

1. Isochrone centers in $z - \phi$ space
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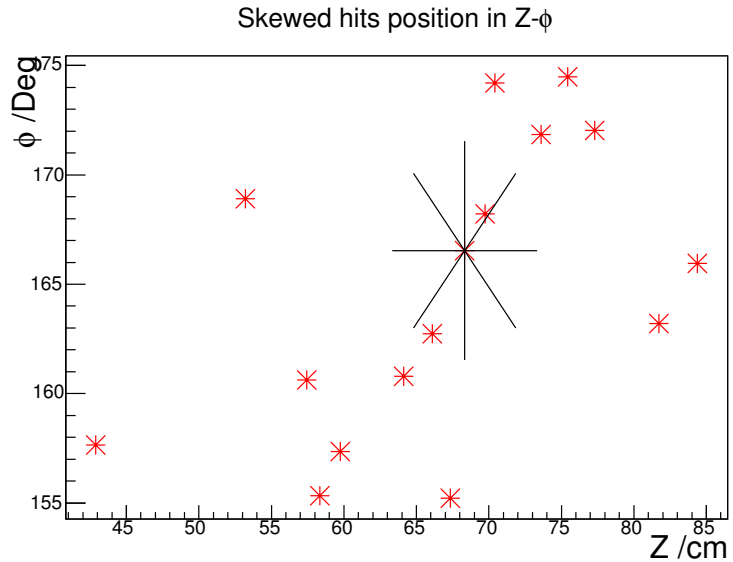
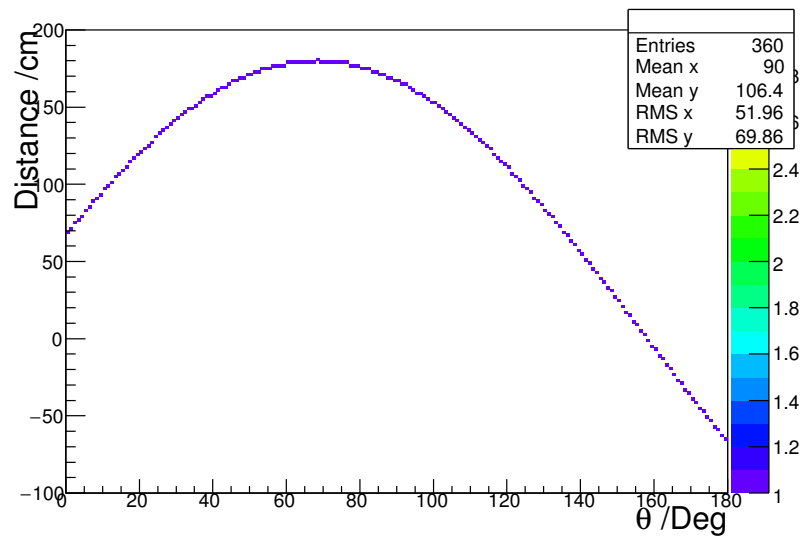
3. Parameters $\rightarrow$ accumulator space





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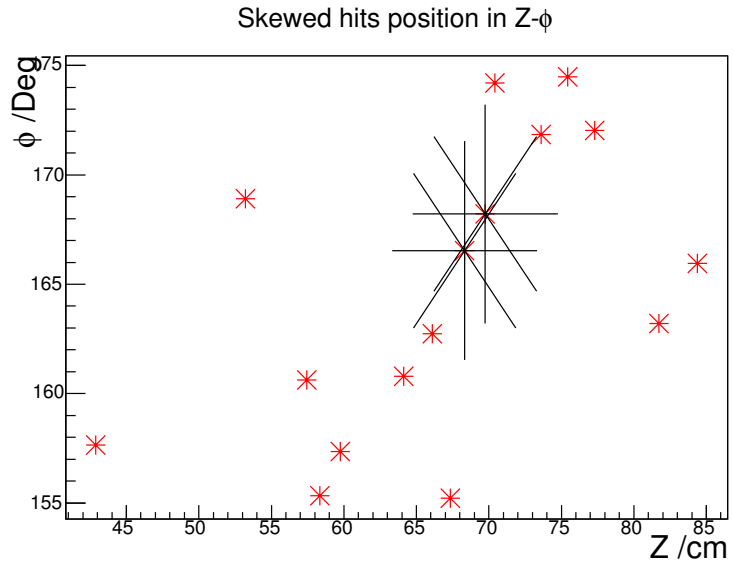
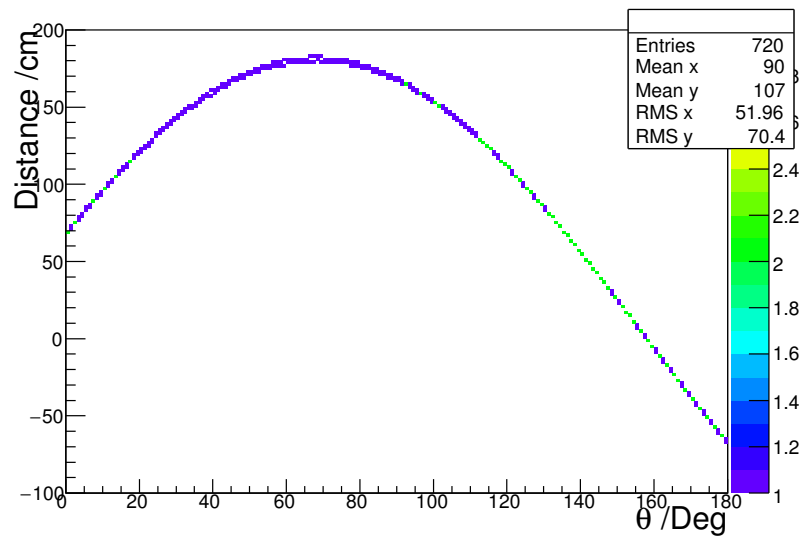
The method:

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





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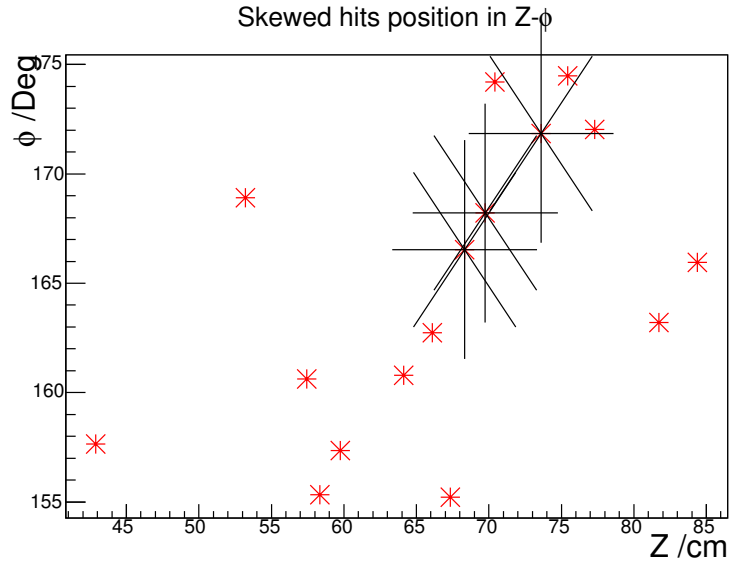
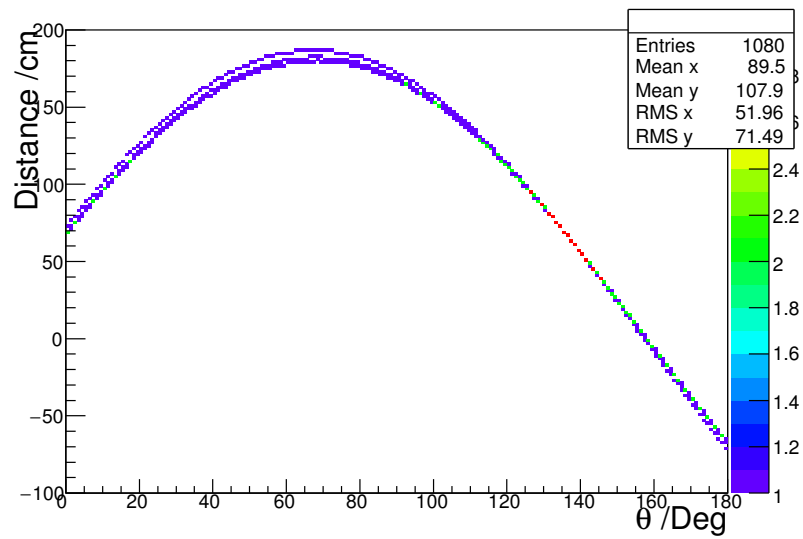


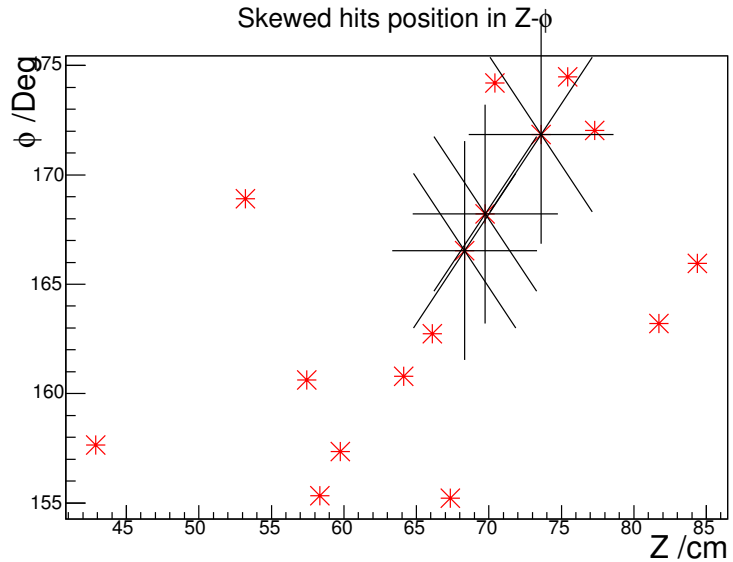


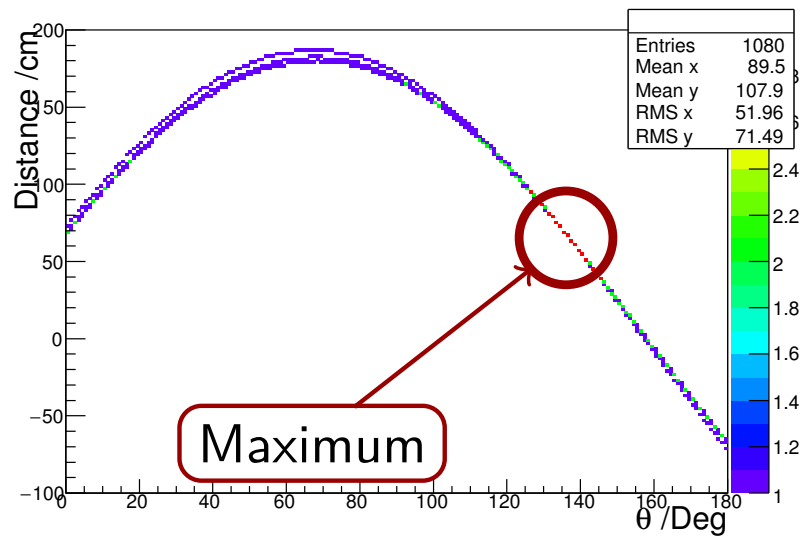
Method 1: Hough transform

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!





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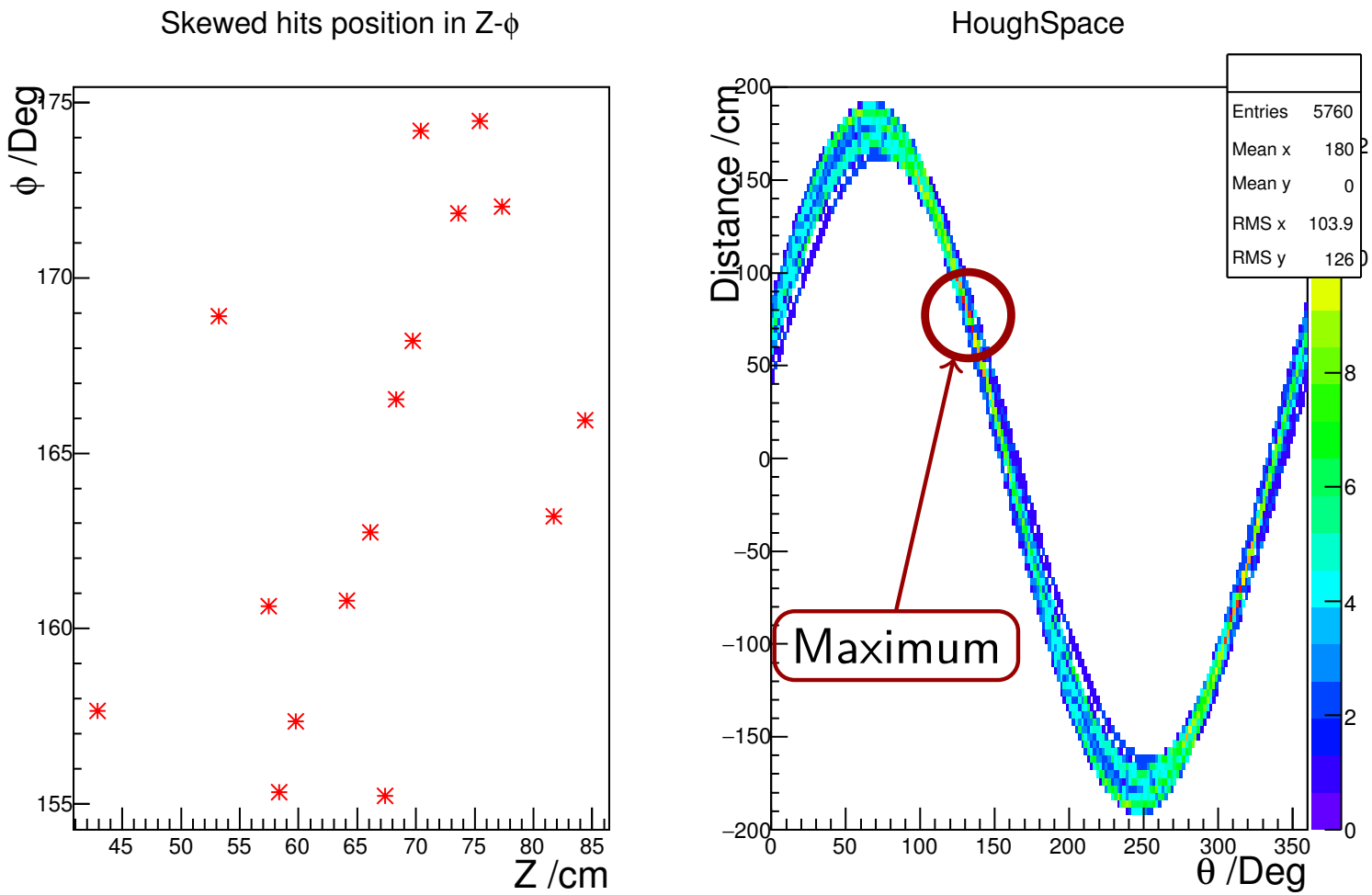


Figure: 360 lines generated for each data point in steps of 1° in θ

Method 1: 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

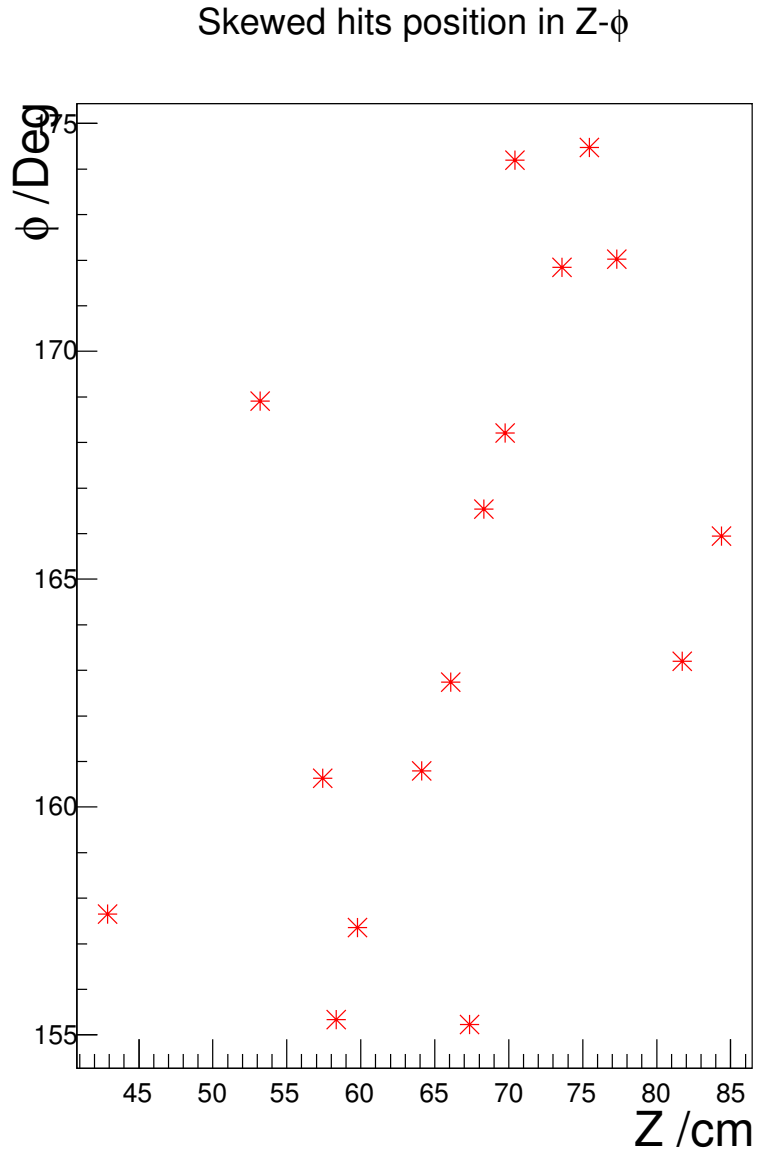
Finish

The slope of the fitted line yields the helix angle. z_0 and p_z can now be extracted!

- z-position assigned to all skewed hits
- Extrapolate helix to first and last parallel hit $\rightarrow$ new FairTrackParP

Method 2: Combinatorics

The method:



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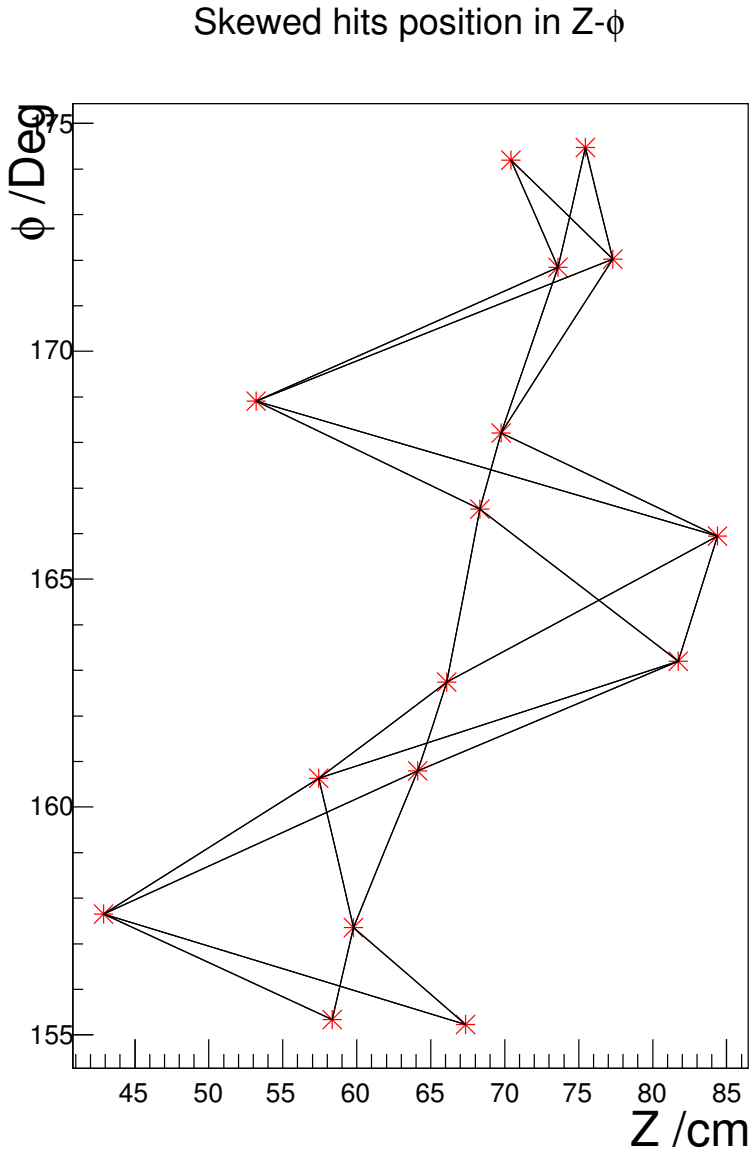
The method:

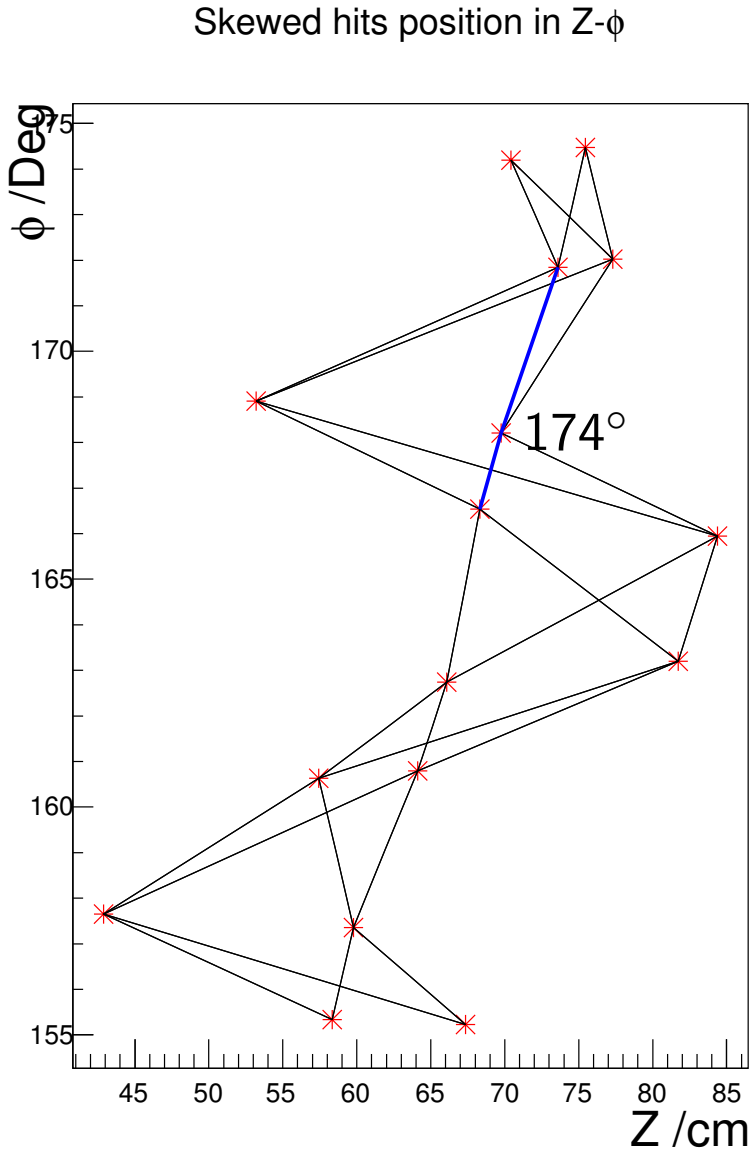
1. Calculate all lines between (z, ϕ) points in neighboring skewed straws



Method 2: Combinatorics

The method:

1. Calculate all lines between (z, ϕ) points in neighboring skewed straws
2. Calculate angle between all possible neighboring lines



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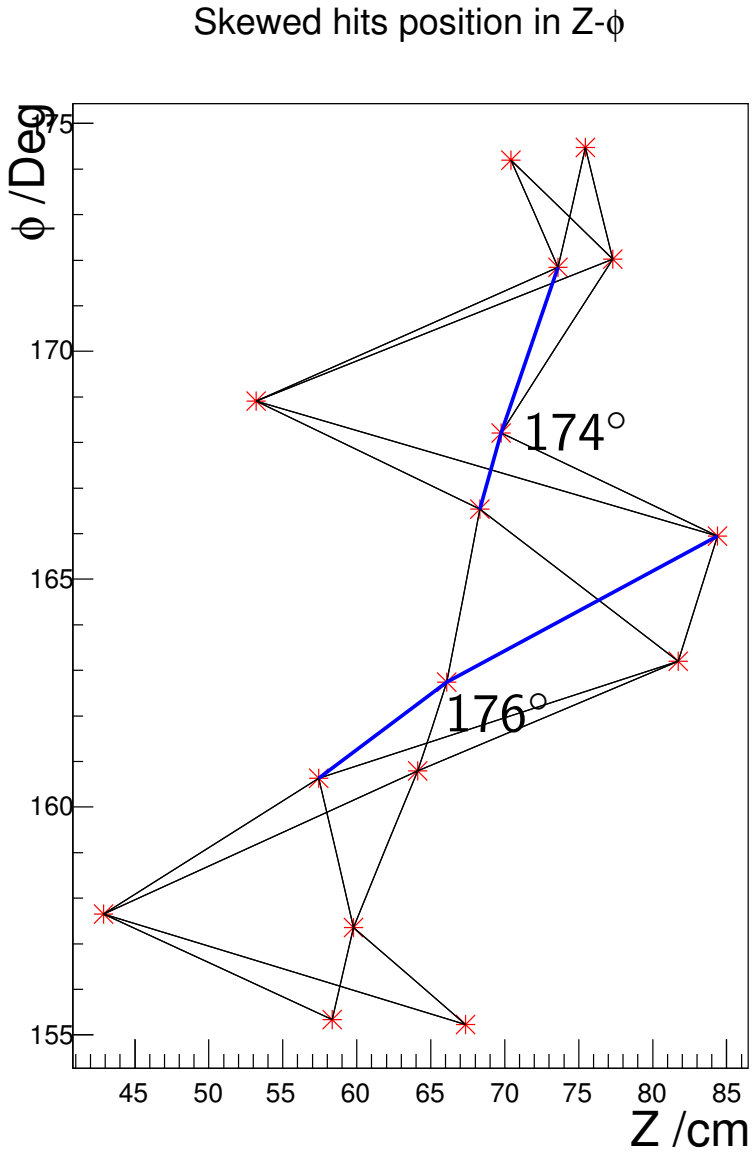

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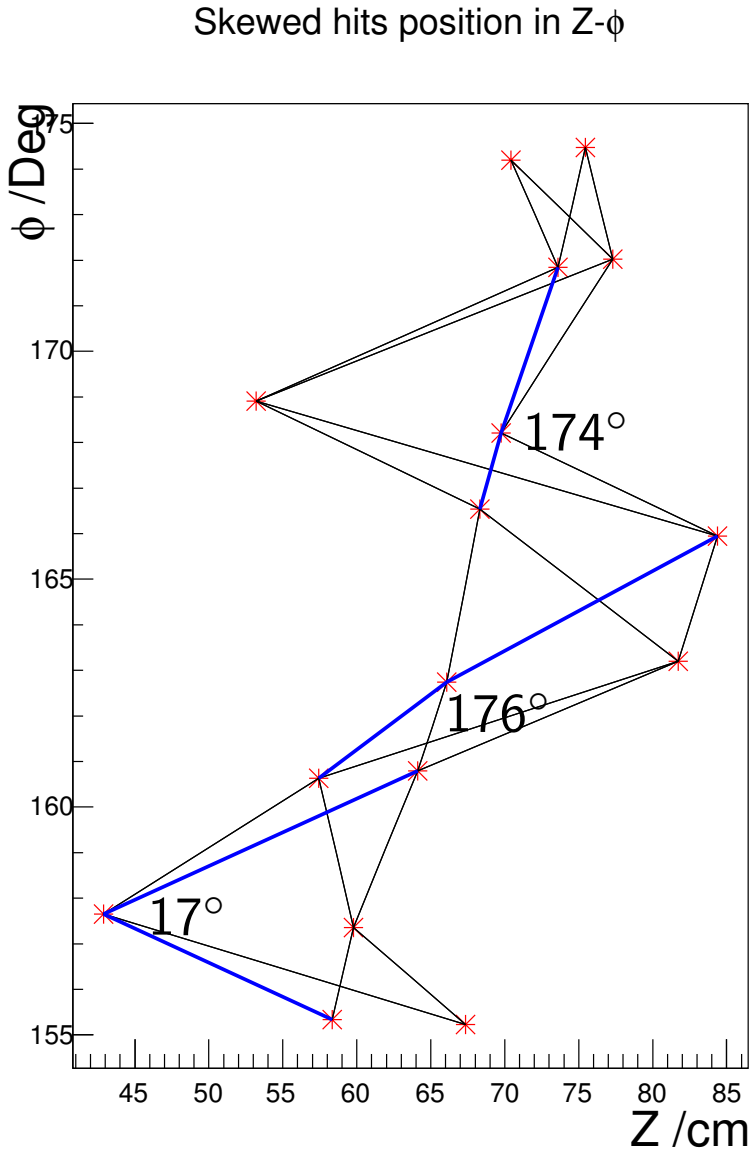
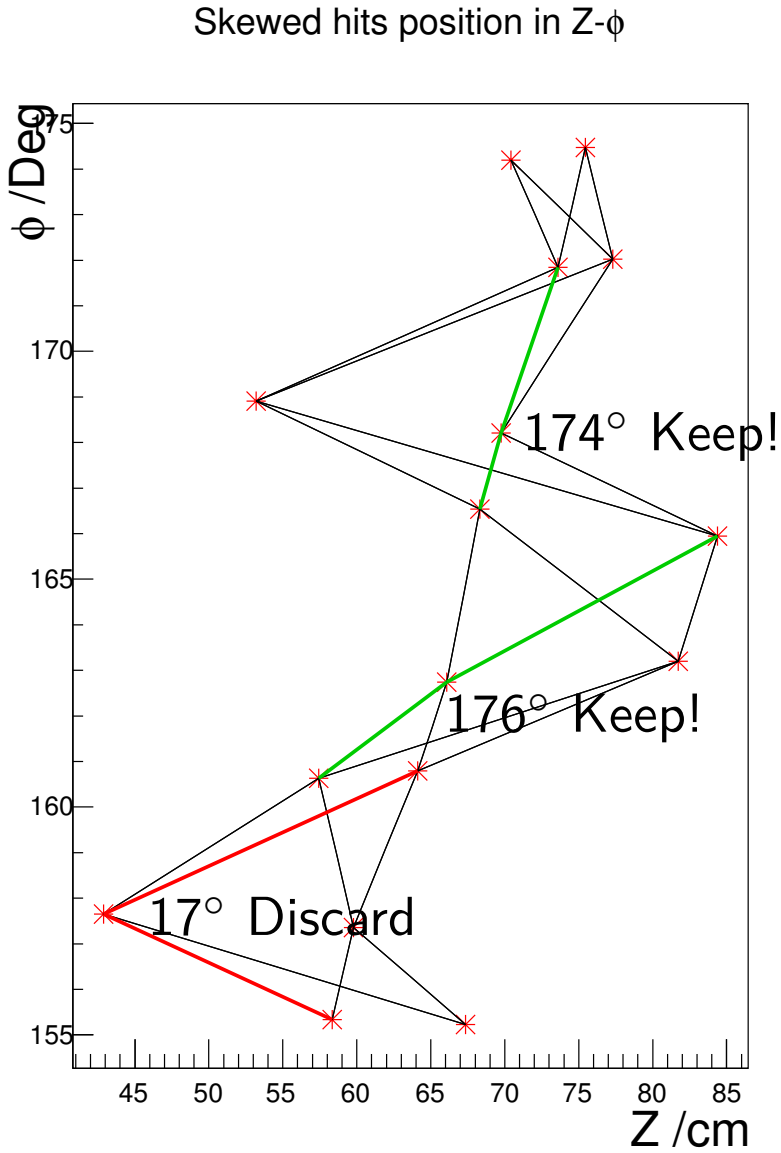


Method 2: Combinatorics

The method:

1. Calculate all lines between (z, ϕ) points in neighboring skewed straws
2. Calculate angle between all possible neighboring lines
3. Ignore paths where $\theta < 160°$ $\rightarrow$ reduces number of combinations



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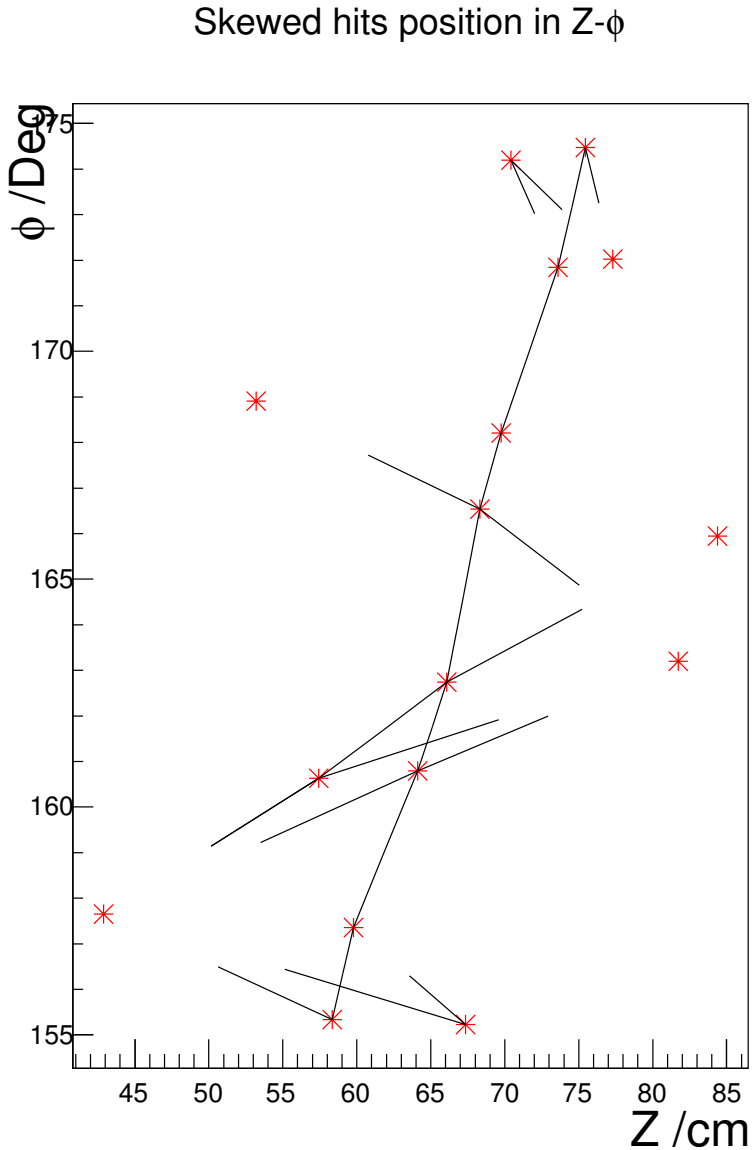

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The method:

1. Calculate all lines between (z, ϕ) points in neighboring skewed straws
2. Calculate angle between all possible neighboring lines
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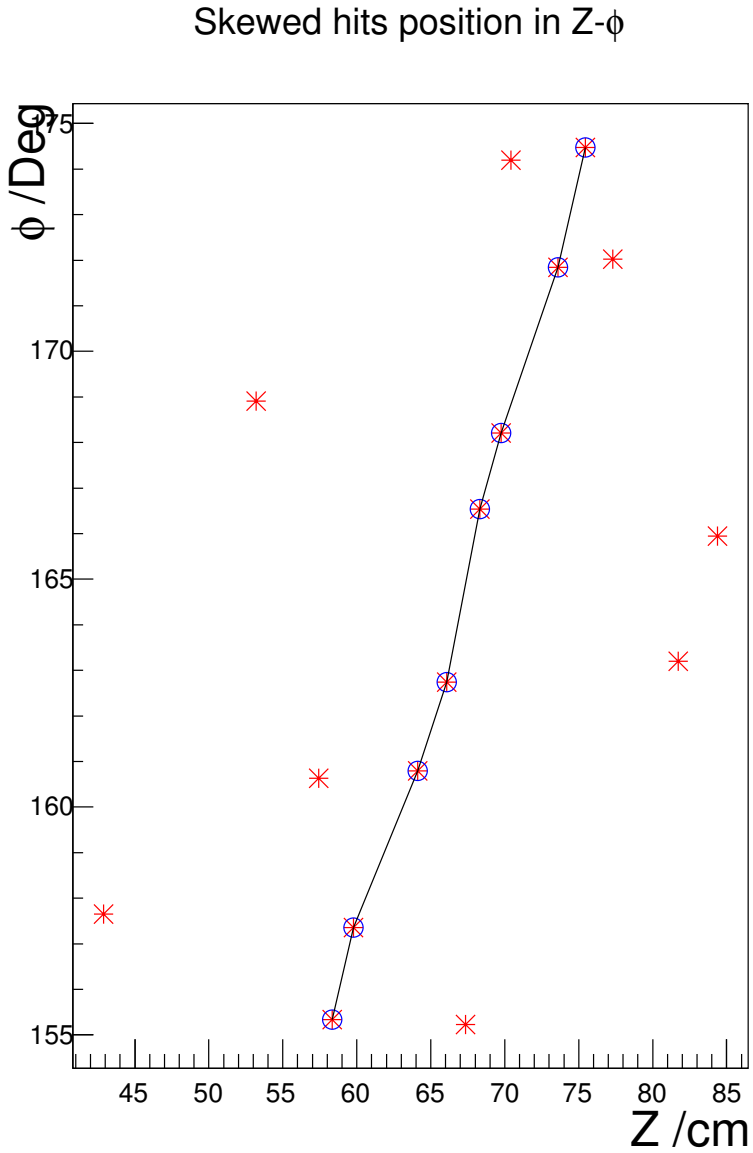
4. Choose path with $\min(\sum \theta_i - 180°)$

Hits in final path chosen as true hits



Code structure

- PndSttSkewStrawPzFinderTask.cxx
  - PndTrack - Standard $\overline{\text{P}}$ANDA track object
  - PndTrackCand - PndSttHits belonging to track
  - PndRiemannTrack - Riemann circle parameters to track
- PndSttSkewStrawPzFinder.cxx
  - MoveSkewedHitstoCircle
    - Calculates all possible (z, ϕ) in skewed straw
  - HoughTrueIsoFinder
    - Fills accumulator space, find maximum, rejects fake hits with POCA
  - LineCombiIsoFinder
    - Generates lines, calculates angles, find best path
  - PzLineFitExtract
    - Simple line fit to true (z, ϕ) hits and extracts helix angle
- PndSttSkewStrawPzFinderAnaTask.cxx
  - Task for analysing and drawing output

Summary and outlook

- Hyperons pose a challenge due to displaced vertices
- General class developed to extract longitudinal information from skewed straws
  - Input: Circle parameter of helix, list of hits
  - Output: Helix angle, modified FairTrackParP
- SttCellTrackFinder now reconstructs complete track helices
- Benchmarking SttCellTrackFinder
  - How does PndRecoKalmanTask deal with SttHits?
  - Standard ways of Quality assurance?

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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

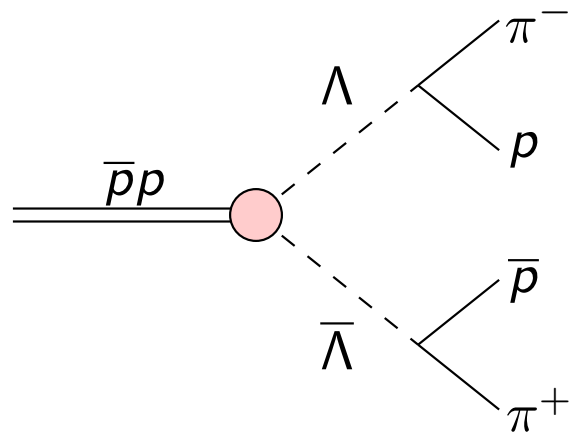


Figure: $\Lambda\overline{\Lambda}$ production channel, scarce data above $\sqrt{s} = 4$ GeV

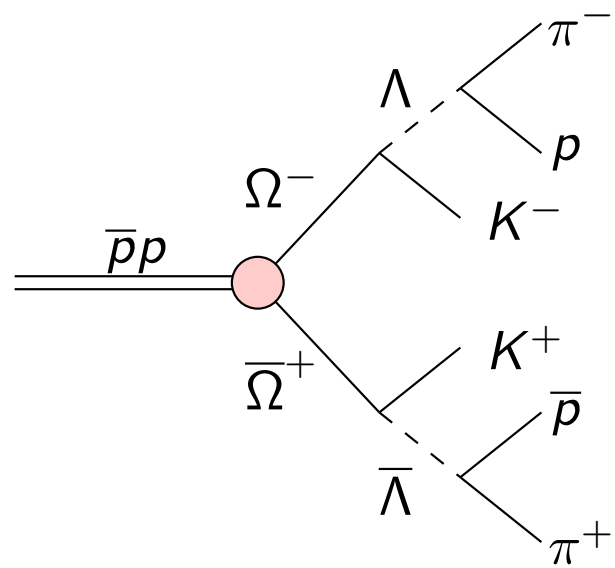


Figure: $\overline{\Omega}^+\Omega^-$ production channel, never measured

Hyperon production $\overline{p}p \to \overline{Y}Y$

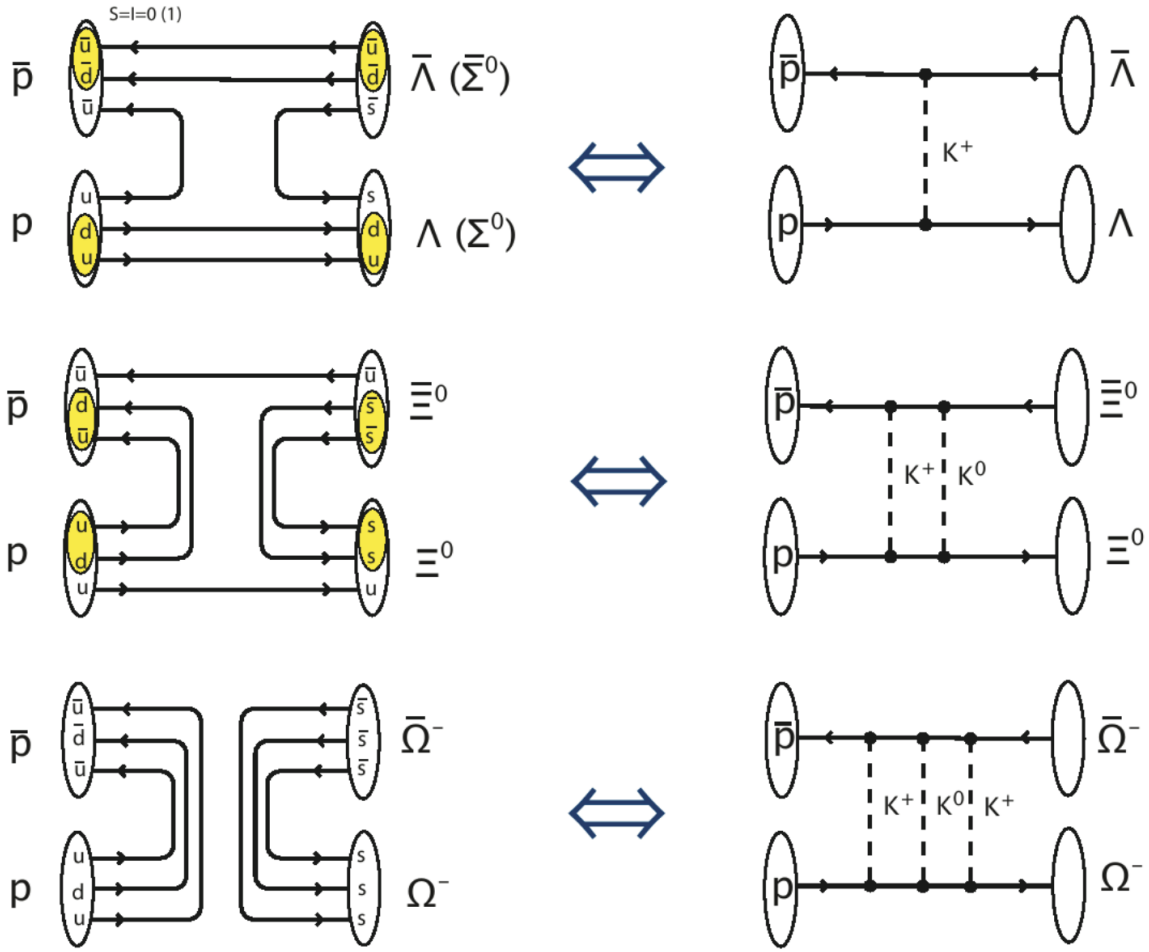


Figure: $\overline{p}p \to \overline{Y}Y$ in quark-gluon picture (left) and in Hadron picture (right).

Hyperons: Spin observables in $\overline{p}p \to \overline{Y}Y$

Spin observables can be used to test theoretical model. Angular distribution related to

$$I \propto \sum_{\mu,\nu=0}^{3} \sum_{k,l=0}^{3} \overline{\alpha}\alpha\chi_{kl\mu\nu} P_k^B P_l^T \overline{k}_\mu k_\nu$$

With unpolarised beam and unpolarised target, differential cross section χ_{0000}, polarisation $\chi_{00\mu 0} = P_{\overline{i}}$, $\chi_{000\nu} = P_i$ and the spin correlations $\chi_{00\mu\nu} = C_{ij}$ are accessible.

Polarisation

- 3 polarisation parameters for spin-$\frac{1}{2}$ hyperons: P_x, P_y, P_z
- $P_x = P_z = 0$ due to strong production
- $P_y = P_{\overline{y}}$ due to rotational invariance

Spin correlation

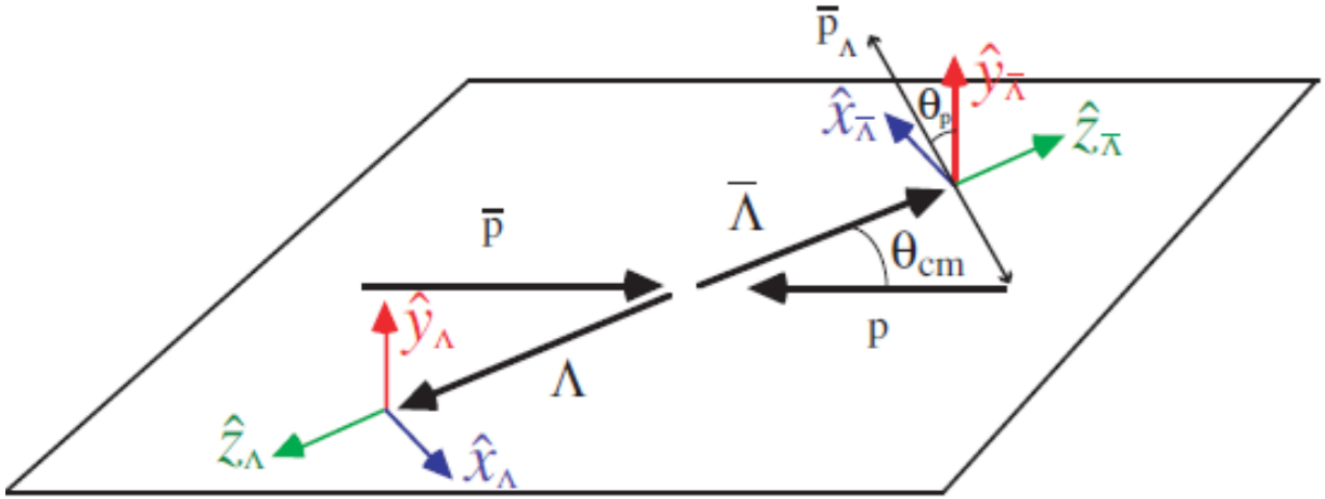
- 9 spin correlation parameters for spin-$\frac{1}{2}$ hyperons: $C_{i,j}$
- $C_{xy} = C_{yx} = C_{yz} = C_{zy} = 0$ due to strong production
- $C_{xz} = C_{zx}$ due to rotational invariance

Hyperons: Spin observables in $\overline{p}p \to \overline{Y}Y$

Polarised Particle	None	Beam	Target	Both
None	I_{0000}	A_{i000}	A_{0j00}	A_{ij00}
Scattered	$P_{00\mu 0}$	$D_{i0\mu 0}$	$K_{0j\mu 0}$	$M_{ij\mu 0}$
Recoil	$P_{000\nu}$	$K_{i00\nu}$	$D_{0j0\nu}$	$N_{ij0\nu}$
Both	$C_{00\mu\nu}$	$C_{i0\mu\nu}$	$C_{0j\mu\nu}$	$C_{C_{ij\mu\nu}}$

- In $\overline{p}p \to \overline{Y}Y$ there are 256 spin variables in total

Hyperons: Spin observables in $\overline{p}p \to \overline{Y}Y$



Polarisation

Proton angular distribution:

$$I(\theta_p) = \frac{1}{4\pi}(1 + \alpha P_Y \cos\theta_p)$$

$\overline{\alpha}, \alpha$ - decay asymmetry parameter

Spin correlation

Nucleon angular distribution:

$$I(\theta_i, \theta_j) = \frac{1}{16\pi^2}(1+$$

$$\overline{\alpha}\alpha \sum_{i,j} C_{ij} \cos\theta_i \cos\theta_j)$$

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

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