# Update on Spin Observable Measurements in $\overline{Y}Y$ Reactions

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GSI

# Outline

- Recap on Spin observables
  - Accessible observables
  - Analysis methods
- $\overline{\Lambda}\Lambda$ @ 1.642 GeV/c
  - Acceptance functions
  - Reconstructed Polarisation
- $\overline{\Xi}\Xi$ @ 4.6 GeV/c
  - Acceptance functions
  - Reconstructed Polarisation
- Outlook

# Spin observables in $\bar{p}p \to \overline{Y}Y$

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 $\chi_{0000}$, polarisation $\chi_{00\mu0} = P_{\bar{i}}$, $\chi_{000\nu} = P_i$ and the spin correlations $\chi_{00\mu\nu} = C_{ij}$ are accessible.

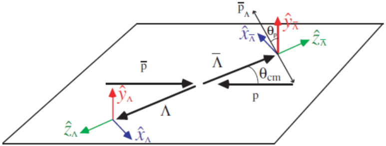
## Polarisation

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

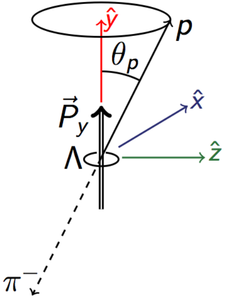
## Spin correlation

- 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

# Spin observables in $\bar{p}p \rightarrow \overline{Y}Y$




$$\hat{z} = \frac{\vec{p}_\Lambda}{|\vec{p}_\Lambda|}, \hat{y} = \frac{\vec{p}_i \times \vec{p}_f}{|\vec{p}_i \times \vec{p}_f|}, \hat{x} = \hat{y} \times \hat{z}$$




## Polarisation

Proton angular distribution:

$$I(\theta_p) \propto \frac{1}{4\pi}(1 + \alpha P_y \cos\theta_p)$$

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

## Spin correlation

Nucleon angular distribution:

$$I(\theta_i, \theta_j) \propto \frac{1}{16\pi^2}(1+ \overline{\alpha}\alpha \sum_{i,j} C_{ij} \cos\theta_i \cos\theta_j)$$

# Reconstructing the Spin Observables

Spin observables can be extracted using Method of Moments:

$$\langle \cos\theta_y \rangle = \langle k_y \rangle = \int_{-1}^{1}\int_{-1}^{1} I(k_y, k_{\overline{y}}) \times k_y \, dk_y \, dk_{\overline{y}}$$

Polarisation and Spin Correlation is given by:

$$P_y = \frac{3}{\alpha}\langle k_y \rangle = \frac{3}{\alpha}\frac{\sum_{m=1}^{N} k_{y,m}}{N}$$

$$C_{ij} = \frac{9}{\overline{\alpha}\alpha}\langle \overline{k}_i k_j \rangle = \frac{9}{\alpha\overline{\alpha}}\frac{\sum_{m=1}^{N} \overline{k}_{i,m} k_{j,m}}{N}$$

Erik Thomé, Elisabetta Perotti, Uppsala University

# Reconstructing the Spin Observables

If $\cos\theta_y$ is symmetric around 0 i.e.

$$A_y(\cos\theta_y) = A_y(-\cos\theta_y)$$

$$A_{\overline{y}}(\cos\theta_{\overline{y}}) = A_{\overline{y}}(-\cos\theta_{\overline{y}}),$$

the spin observables are obtainable without acceptance correction:

$$P = \frac{1}{\alpha}\frac{\langle k_y \rangle}{\langle k_y^2 \rangle}$$

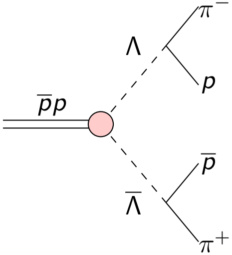
$$C_{yy} = \frac{1}{\alpha\overline{\alpha}}\frac{\langle \overline{k}_y k_y \rangle}{\langle \overline{k}_y^2 \rangle \langle k_y^2 \rangle}$$

$$C_{ij} = \frac{1}{\alpha\overline{\alpha}}\frac{\langle \overline{k}_i k_j \rangle - \langle \overline{k}_i \rangle \langle k_j \rangle}{\langle \overline{k}_i^2 \rangle \langle k_j^2 \rangle}, i, j = x, z$$

# Simulation study of $\overline{p}p \rightarrow \overline{\Lambda}\Lambda$

# Simulation parameters

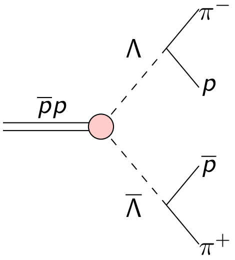
- $\sim 10^6$ $\overline{p}p \to \overline{\Lambda}\Lambda$ events
- Forward-peaking distribution
- Antiproton beam $p_{\overline{p}} = 1.642$ GeV/c
- Full $\overline{\text{P}}$ANDA Detector setup
- Ideal Pattern Recognition
- Ideal Particle Identification



# Event reconstruction

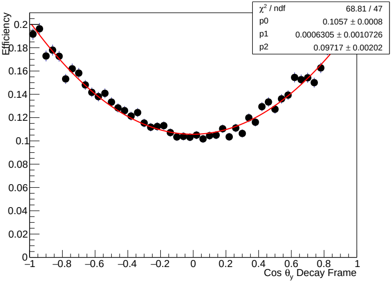
Event selection:

- Combine $p\pi^-$, $\overline{p}\pi^+$
- Select $|m_\Lambda - M(p\pi^-)| < 0.3$ GeV
- Vertex & Mass fit
  Select combination based on $\chi^2$
- Reject candidate if $P(\mathrm{Vtx}) < 0.001$
- Tree fit

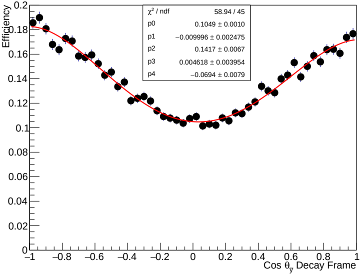


# Symmetry in $\cos\theta_y$

$\cos\theta_y$




$\cos\theta_{\overline{y}}$



# Generating Spin Observables sample

How to generate $\overline{p}p \rightarrow \overline{\Lambda}\Lambda$ sample:

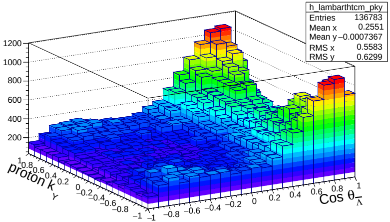
- Simulate $\Lambda \rightarrow p\pi^-$ with flat phase space
- Use input polarisation
$$P_y = \sin\theta_\Lambda$$
- Evaluate
$$w_m = \frac{1}{4\pi}(1 + \alpha P_y k_{y,m}),$$
assign as weight to each event

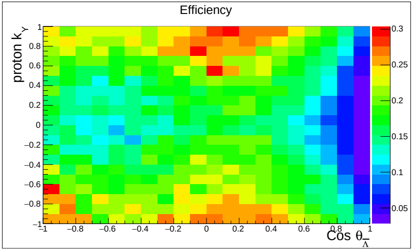
Polarisation is reconstructed according to

$$P_y = \frac{3}{\alpha}\frac{\sum_m w_m k_{y,m}}{\sum_m w_m}$$

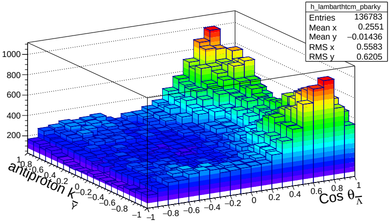
# Acceptance functions

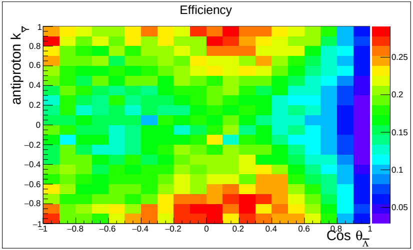
$\cos\theta_y$




$\cos\theta_{\overline{y}}$

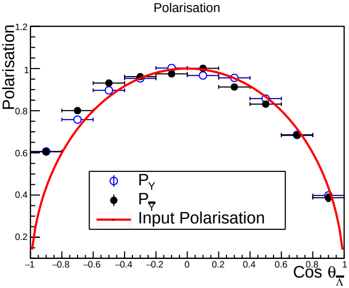


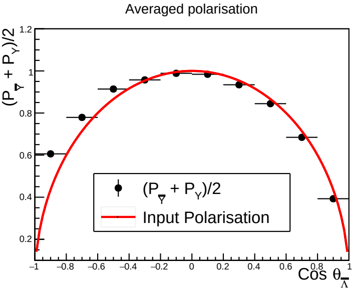



# Polarisation

Correcting for acceptance, the Polarisation is given by

$$P_y = \frac{3}{\alpha}\langle k_y \rangle = \frac{3}{\alpha}\frac{\sum_{m=1}^{N}\frac{w_m k_{y,m}}{A(k_{y,m})}}{\sum_{m=1}^{N}\frac{w_m}{A(k_{y,m})}}$$



# Polarisation without acceptance

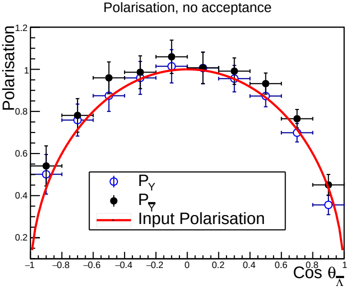
Polarisation is reconstructed according to

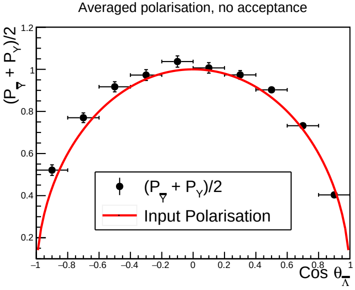
$$P_y = \frac{1}{\alpha}\frac{\langle k_y \rangle}{\langle k_y^2 \rangle} = \frac{1}{\alpha}\frac{\frac{\sum_m w_m k_{y,m}}{\sum_m w_m}}{\frac{\sum_m w_m k_{y,m}^2}{\sum_m w_m}}$$

Error of each expectation value given by

$$\sigma^2(\langle X \rangle) = \frac{1}{N-1}\left(\frac{\sum_m w_m X_m^2}{\sum_m w_m} - \left(\frac{\sum_m w_m X_m}{\sum_m w_m}\right)^2\right)$$

# Polarisation without acceptance



# Simulation study of $\overline{p}p \to \overline{\Xi}\Xi$

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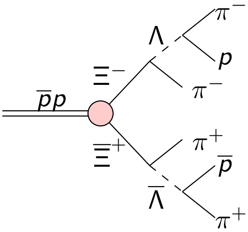

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- Reject candidate if
  $P(\mathrm{Vtx}(\mathrm{p}, \pi^-)) < 0.001$
- Combine $\Lambda\pi^-$
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  Select combination based on $\chi^2$
- Reject candidate if
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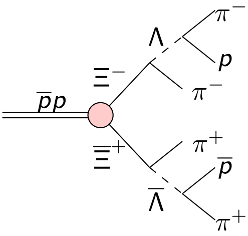
- Tree fit



# Symmetry in $\cos\theta_y$

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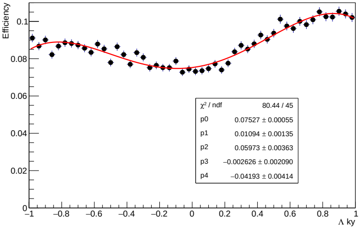
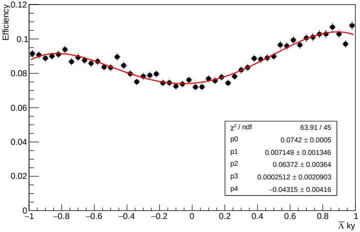
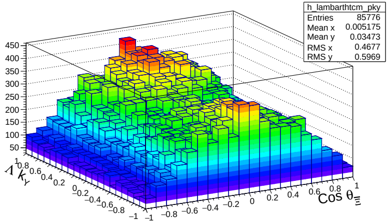


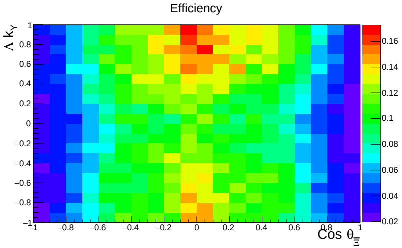

$\cos\theta_{\overline{y}}$



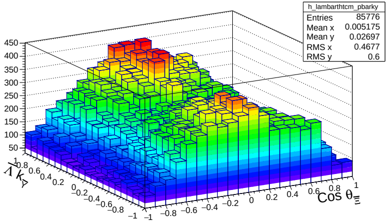
# Acceptance functions

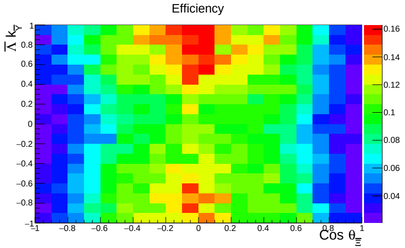
$\cos\theta_y$



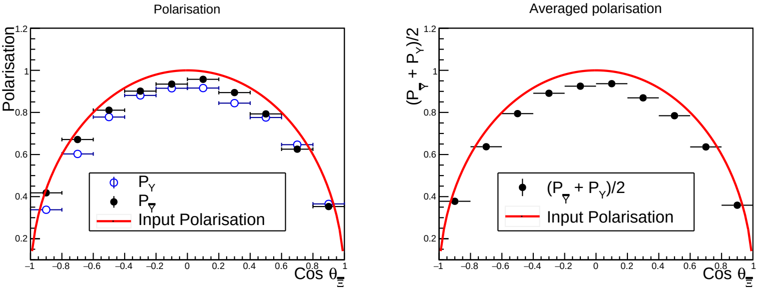




$\cos\theta_{\overline{y}}$



# Polarisation



# Outlook

- Reconstruct Spin correlation
- Performance check of analysis tools:
  - Update to Feb17 release
  - DecayTreeFitter as alternative
- Realistic PID
- Background studies
- Efficiency studies of $\overline{p}p \to \overline{\Omega}\Omega$

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- Reconstruct Spin correlation
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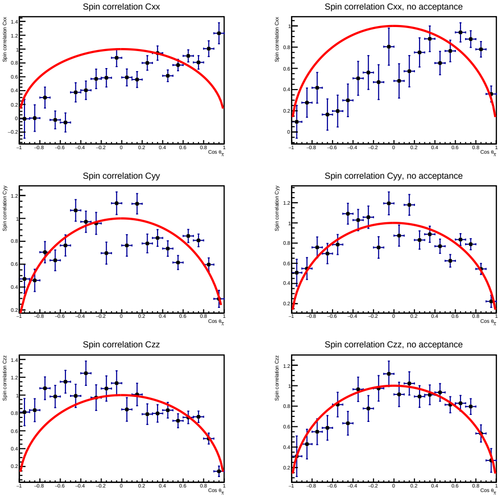
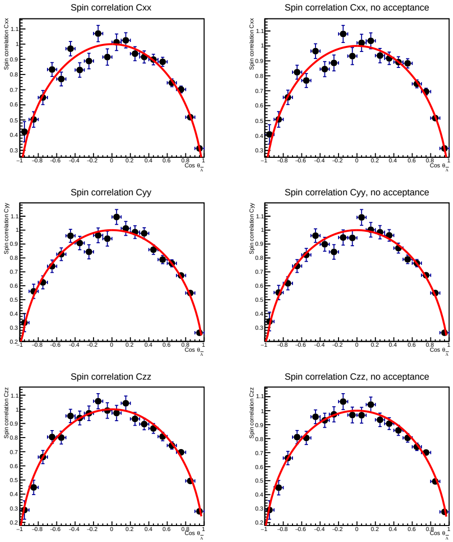
## Thank you for your attention!

# Backup

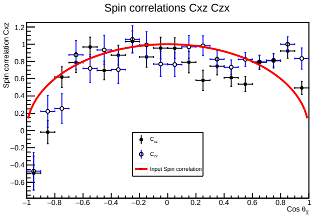
# Spin Correlation Cii

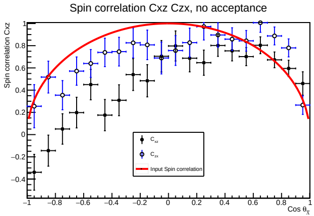


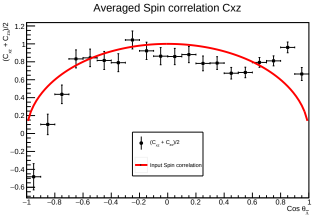
# Spin Correlation Cii - Monte Carlo truth

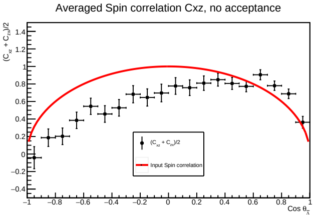


# Spin Correlation Cij

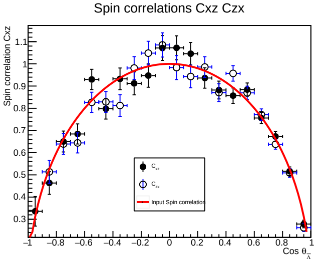


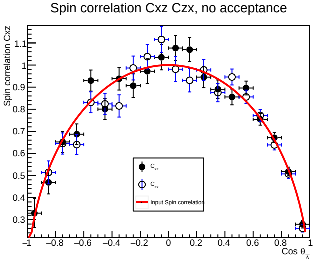



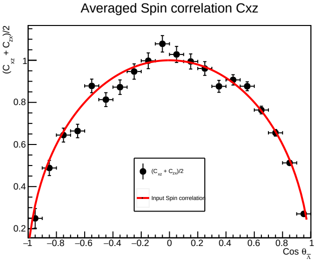



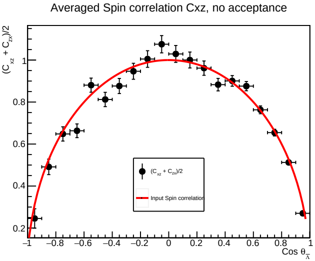



# Spin Correlation Cij - Monte Carlo truth



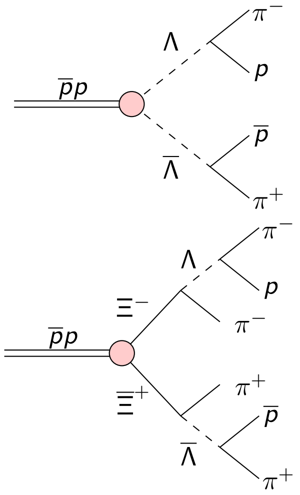



# Hyperon channels accessible with $\overline{\text{P}}$ANDA

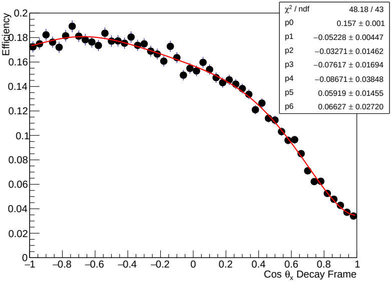
Why antihyperon-hyperon production?

- $\bar{p}p \rightarrow \bar{\Lambda}\Lambda$
  - Measured before @ LEAR
  - Comparison of polarisation & spin correlation
- $\bar{p}p \rightarrow \bar{\Xi}^{+}\Xi^{-}$
  - Scarce data
  - Potential to measure @ 7.0 GeV/c
- $\text{BR}(\Lambda \rightarrow p\pi^{-}) = 64\%$
- $\text{BR}(\Xi^{-} \rightarrow \Lambda\pi) \approx 100\ \%$

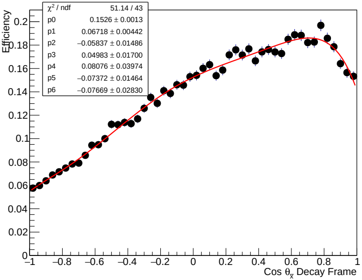


# Acceptance Functions

$\cos\theta_x$

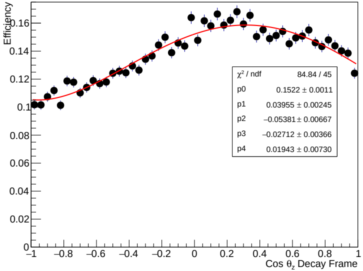



$\cos\theta_{\overline{x}}$

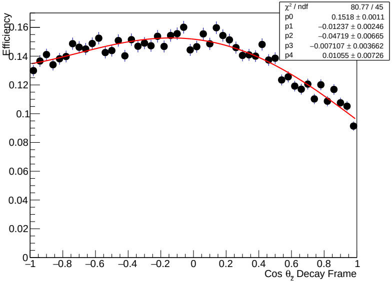


# Acceptance Functions

$\cos\theta_z$




$\cos\theta_{\overline{z}}$



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

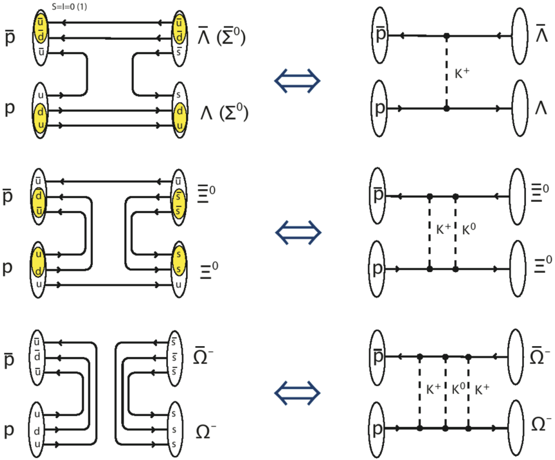



Figure: $\overline{p}p \to \overline{Y}Y$ in quark-gluon picture (left) and in Hadron picture (right).

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

| **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

# Accessible hyperons at $\overline{\text{P}}$ANDA

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