Update on the Polarization Observables Extraction in Double-Pion Production from g9a
Outline

• Introduction

• Analysis
  - Identification of the Double-Pion Reaction
  - Bound Nucleon Background
  - Asymmetry from Target Polarization Flip
  - Polarization Observables: $P_z P_z^s P_z^c$
  - Further Study on Observables
  - Comparison with Circularly Polarized data

• Conclusion and Future
Intro - Reaction

Research interest -- second resonance region

Three main independent reaction channels

Three main channels

\[ \gamma p \rightarrow \begin{pmatrix} p \rho \\ \Delta^{++} \pi^- \\ \Delta^0 \pi^+ \end{pmatrix} \rightarrow p \pi^+ \pi^- \]
To extract observables, free protons in butanol are longitudinally polarized (positive and negative).

- Carbon target is necessary for extraction of unpolarized background.
- Photon beam is linearly polarized.
Intro - Reaction Plane

- **Scattering plane** - by incident photon and recoiling proton
- **π+π- plane** - by two π mesons

**CMS Frame (Side view):**

- $\phi$ - Azimuthal angle (between scattering and $\pi+\pi-$ plane)
- $\theta$ - Polar angle (between $\pi+$ vector and $z'$ axis)
- $\theta_{CM}$ - CM Polar angle (between $E_\gamma$ and recoiling proton)
Reaction Reconstruction

Particle ID:

- Time-difference cut (assumed and calculated time) for proton and pion meson
- Photon selection (1ns time difference cut)

Channel ID:

- Reconstruct the reaction channel by detected particles and incident photon
- 4 topologies with various missing mass distributions
- Cut on missing mass to make channel ID

1: None missing
2: Proton missing
3: π⁺ missing
4: π⁻ missing

All Units: (GeV²/c⁴)

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\[ \gamma p \rightarrow p\pi^- (\pi^+) \]
(Channel Interested)

\[ \gamma n \rightarrow p\pi^- \]
(Background)

- Neutron reaction in butanol target
- Larger mass of neutron caused the MM peak shifted to left
- Background peak is removed by cut on the 2D histogram
- 97% of the events from proton passed the cut
- The other 3 topologies have \( \pi^+ \) detected. Thus only in the topology 3, events off the neutron can enter the missing mass distribution.
**Bound Nucleon Background**

- **Scale Factor:**
  The ratio of bound-proton yields between butanol and carbon targets.

- **Procedure:**
  Fit butanol missing mass distribution with scaled carbon and gaussian peak, where scale factor is the fit parameter.

- **Free Proton:**
  Subtract the scaled carbon distribution from that of butanol.

- **Problem:**
  Low statistics of carbon target influenced the fit quality in some kinematic bins.

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Asymmetry from Target Polarization Flip

Yields: $Y^+$ and $Y^-$ from positively and negatively polarized target cannot be applied for asymmetry calculation directly, **NORMALIZATION** is necessary!

Definition of asymmetry:

$$Asy = \frac{I^+ - I^-}{I^+ + I^-}$$

Normalized yield with target positively polarized

$$I^+ = I_0 \left\{ (1 + \Lambda^+ \cdot P_z) + \delta^+ [\sin 2\beta(I_s + \Lambda^+ \cdot P_z^s) + \cos 2\beta(I_c + \Lambda^+ \cdot P_z^c)] \right\}$$

Normalized yield with target negatively polarized

$$I^- = I_0 \left\{ (1 - \Lambda^- \cdot P_z) + \delta^- [\sin 2\beta(I_s - \Lambda^- \cdot P_z^s) + \cos 2\beta(I_c - \Lambda^- \cdot P_z^c)] \right\}$$

Flux can be represented by event yields from unpolarized targets

- Carbon asymmetry
- From different runs
- After normalization
- Constant fit

Check the Normalization quality

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Asymmetry from Target Polarization Flip

After the normalization, make the subtraction:

\[ \Delta I = I_0 (\Lambda^+ + \Lambda^-) P_z \]
\[ + I_0 (\delta^+ \Lambda^+ + \delta^- \Lambda^-) (\sin 2\beta \cdot P^s_z + \cos 2\beta \cdot P^c_z) \]
\[ + I_0 (\delta^+ - \delta^-) (\sin 2\beta \cdot I^s + \cos 2\beta \cdot I^c) \]

- The Blue term contains two other observables
- Blue term could appear if beam polarizations are unequal for target positively and negatively polarized
- Right plot: check the equality
- Equality ranges from 0.986 – 1.014

How can we extract the observables?

\[ \frac{\Delta I}{2I_0} = \Lambda_z (P_z) + \delta (\sin 2\beta \cdot P^s_z + \cos 2\beta \cdot P^c_z) \]

Asymmetry

Polarization Observables
Asymmetry calculated:
\[ \frac{\Delta I}{2I_0} = \frac{N^+_B - N^-_B}{N^+_B + N^-_B - S.F \cdot N_C} \]

- \( N^+_B \) -- Yields from positively polarized, butanol target
- \( N^-_B \) -- Yields from negatively polarized, butanol target
- \( N_C \) -- Yields from carbon target
- \( S.F \) -- Scale Factor

1.56 < \( W \) < 1.62 (GeV)

- Bin: \( W(17) \) and \( \phi(8) \)
- Entries: 1000 - 35000 for each kinematic bin
- \( \chi^2 \): Close to 1

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Fit the observables by Fourier series
Amplitudes of observables decrease as W increases

\[ P_z = a \cdot \sin(\phi) + b \cdot \sin(2\phi) + c \cdot \sin(3\phi) \]
Observable: $P_z^s$

$P_z^s = a \cdot \cos(\phi) + b \cdot \cos(2\phi) + c \cdot \cos(3\phi)$

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## Observable: $P_z^c$

$P_z^c = a \cdot \sin(\phi) + b \cdot \sin(2\phi) + c \cdot \sin(3\phi)$
Observables - Further Study

Asymmetry of a certain kinematic bin:
W: 1.69 GeV
\( \phi \): 247 deg.

Bin on the 3rd variable -- Invariant mass of p\( \pi^+ \)
(1st - W, 2nd - \( \phi \) angle)

- In one W bin
- In one azimuthal angle bin
- Bin the Invariant Mass (6 bins, 1.1-2.4 GeV)
- Clear distinct asymmetries and observables for third level kinematic bins

Asymmetries of sub-kinematic bins with various Invariant mass of p\( \pi^+ \)

\begin{align*}
1.2 \text{ GeV}^2 & \quad 1.5 \text{ GeV}^2 & \quad 1.7 \text{ GeV}^2 & \quad 1.9 \text{ GeV}^2 \\
2.1 \text{ GeV}^2 & \quad 2.3 \text{ GeV}^2 & \quad & \\
\end{align*}

\( \text{Chi2/ndf: 1.36} \)
\( \text{Entries: 17,000} \)
Observables - Further Study

**Observable-Sensibility on IM_{p\pi^+} peak cut**
- In one W bin (1.74 GeV)
- In one Invariant Mass bin of p\pi^+ (1.4-1.6 GeV)
- Bin the Azimuthal angle

**What we can find?**
- Much larger amplitudes for all the 3 polarization observables
Comparison of the Pz

Yuqing (South Carolina): Linearly-Polarized beam of g9a

Sungkyun (Florida State): Circularly-Polarized beam of g9a

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Conclusion & Future

Conclusion:

- Asymmetries are calculated by using normalized data.
- Observables have symmetric behavior for azimuthal angle bin.
- In addition to W and Phi bins, further kinematic bins showed more different asymmetries and observables.
- Yuqing vs. Sungkyun -- Qualitatively comparable observable Pz.

Future:

- Systematic uncertainty analysis.