Longitudinal Phasespace Analysis

A technique to apply kinematic cuts to enhance different reaction mechanisms

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LONGITUDINAL PHASE-SPACE PLOTS
OF MULTIPARTICLE HADRON COLLISIONS
AT HIGH ENERGY

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At high Energy (>8GeV)
transverse momenta small
Reduce dimensionality of
reaction to N-2

ANALYSIS OF γp REACTIONS IN THE LPS FRAMEWORK
AT $E_\gamma = 6-18$ GeV *

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**Van Hove Plots (Longitudinal)**

Beam Fragmentation $\gamma$

Target Fragmentation $p$

**Example 3-3.8GeV $\gamma p \rightarrow K^+ K^- p$**

CLAS g11 dataset

$\text{CM}$

$P \leftrightarrow K^+$

$K^- \rightarrow p$ $K^+$

$K^+ \rightarrow P$

Van Hove Plots (Longitudinal)

Beam Fragmentation $\gamma$

Target Fragmentation $p$

**Target Fragmentation** $p$

$p \leftrightarrow K^+$

$K^- \rightarrow p$ $K^+$

$K^+ \rightarrow p$

$K^- \leftrightarrow p$

$K^+$

$K^-$

$\omega$

$K^+$

$K^-$

$\gamma$

$P$

$P_{\text{lab}} = 3.4 \text{ GeV}$

$\omega$

$p_{K^+L} = \sqrt{\frac{2}{3}} q \sin \omega,$

$p_{K^-L} = \sqrt{\frac{2}{3}} q \sin \left( \frac{2}{3} \pi + \omega \right),$  

$p_{PL} = \sqrt{\frac{2}{3}} q \sin \left( \frac{4}{3} \pi + \omega \right).$
Example $\gamma p \rightarrow K^+K^-p$ at around 3-3.8GeV
Now acceptance corrected

Divide out phase space distribution
Larger Mass 2K mesons will have lower CM momenta. Decay products can decay back into different sector.

Phase Space Plots:

Acceptance for increasing meson mass

Correlation of $\cos\theta_{GJ}$ and $\omega$ for $M_{K^+K^-}=1.1$ and $M_{K^+K^-}=1.6$

For $K^+K^-$ forward from decay of meson

K- back from decay

$M(2K) = 1-1.2$ OK, but...

$M(2K) > 1.2$ has limited $\theta_{hel}$

Also if $-t > 0$ can decay in different sector.
Threshold enhancement in pK-, phase space corrected

Projection Y of binx=[23,32] [x=1.384..1.604]

Sensitive to pK- scattering length
van Hove Plot for $\gamma p \rightarrow \pi^+\pi^-p$

CLAS g11 dataset
Select all 4 topologies for $\pi^+\pi^-p$ final state
These results are Background subtracted and acceptance corrected

Photoproduction of $\pi^+\pi^-$ meson pairs on the proton

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Event Reconstruction: sWeights


Given discriminatory PDF for signal and background, calculates weight:

\[ s \mathcal{P}_n(y_e) = \frac{\sum_{j=1}^{N_s} V_{nj} f_j(y_e)}{\sum_{k=1}^{N_s} N_k f_k(y_e)} \]

- \( N_s \) = Number of species
- \( f_k \) = PDF for species \( k \)
- \( N_k \) = Yield for species \( k \)
- \( V \) = covariance matrix

Part of RooStats (used here)
Can include multiple signal and background species

Can fit multidimensional discriminatory PDF

Only as good as fit model...

Can use directly in likelihood fits
Signal shapes are not always well described by parameteric functions
⇒ Simulated PDFs
systematic uncertainty in shape accounted for via morphing with additional nuisance parameters
i.e Profile Likelihood
Construct new RooFit PDF
Supply simulated events
Sequential 1D histograms
Smoothed and interpolated
Adding greater additional smearing with morphing parameter $\alpha$
Additional offset parameter (Also RooFit HistFactory...)
Sweight Event Selection: $\pi^+\pi^-p$

g11 dataset, detect $\pi^+$ and $p$
Model from simulated $\pi^+\pi^-p$ and $\pi^+\pi^-\pi^0p$ events

RooFit Extended Maximum likelihood fit

- Just Phase Space

RooStats sWeight calculation
⇒ Disentangle distributions

For Cross section

For amp analysis

Note 2 fits required. First fixes alpha and off.
Second, only Yields free => Covariance matrix
More sWeights

Perform multiple fits to find best parameters
Can do binned chi2 for speed
Can limit range and merge background for sWeight Fit

Fit 1

Fit 2

Fit3 Winner!

sWeight Fit
Shrink Range => less BG to subtract

Merge 3pi and pi0
Some Analysis details

Fiducial Cut as analysis note (more or less)

Background Subtraction Done
- Shown previously
- Sweights Method

Acceptance Correction Done for p pi+
Weighted MC function of Eg, t and Omega (Van Hove)
Two Pion Masses

All Events.
Background Subtracted
Acceptance Corrected
Phase Space divided out
Two Pion Masses in LPS Sectors

Split into LP Sector

Baryon/Meson Masses: $M(\pi^+\pi^-) \lor M(\pi^-\rho)$

Named particles are travelling forward

$\pi^+\pi^-$

$\pi^+\rho$

$\pi^-\rho$

$\pi^+$

$\pi^-$

$\rho$
No Background Subtraction

Split into LP Sector

Baryon/Meson Masses: $M(\pi^+\pi^-) \lor M(\pi^-p)$

Named particles are travelling forward

\[ M(\pi^+\pi^-) \lor M(\pi^-p) \]

\[ \pi^+\pi^- \]

\[ \pi^+p \]

\[ \pi^-p \]

\[ \pi^+ \]

\[ \pi^- \]

\[ p \]
Two Pion Masses in LPS Sectors

Split into LP Sector
Baryon/Meson Masses: $M(\pi^+\pi^-) \, v \, M(\pi^+p)$
Named particles are travelling forward

\[ M(\pi^+\pi^-) \, v \, M(p\pi^+) \]

\[ M(\pi^+\pi^-) \, v \, M(p\pi^+) \]

\[ M(\pi^+\pi^-) \, v \, M(p\pi^+) \]

\[ M(\pi^+\pi^-) \, v \, M(p\pi^+) \]

\[ M(\pi^+\pi^-) \, v \, M(p\pi^+) \]

\[ M(\pi^+\pi^-) \, v \, M(p\pi^+) \]
Two Pion Masses in LPS Sectors

Split into LP Sector

Baryon/Meson Masses: \( M(\pi^- p) \) vs \( M(\pi^+ p) \)

Named particles are travelling forward

\begin{align*}
\pi^+ \pi^- & \quad \pi^+ \rho & \quad \pi^- \rho \\
\pi^+ & \quad \pi^- & \quad \rho
\end{align*}
Restrictions on Longitudinal Phase Space

At low reaction $s$
Affected by $t$ dependence
And mass dependence

$\rho$ restricted to $\omega$ where
both $\pi$ go forward or back
All $\rho$ contained $100<\omega<200$
Low $t$ van Hove $120<\omega<180$

All $f_2$ contained $90<\omega<210$
Now our cut is defined as the corresponding value of omega for $\pi^-(\pi^+)$ decaying backwards along z axis in meson rest frame.

⇒ Do not lose any meson decays (acceptance)
⇒ Throw away everything else

Wider cut as $M$ increases
Now our cut is defined as the corresponding value of omega for $\pi^-(\pi^+)$ decaying backwards along z axis in meson rest frame.

This is a function of $W$, $M(\pi^-\pi^+)$, $M(\pi^-)$, $M(\pi^+)$ i.e rest frame breakup momentum.

Problem: resolution effects are an issue, need to widen the cuts to compensate.
Investigated Longitudinal Phase Space as a means for enhancing different reaction mechanisms
Publication in process

Found to be effective means of separating meson and baryon production, with some limitations at JLAB energy

Currently investigating more specific method: Isobar Phase Space
WORK IN PROGRESS....
Equivalent to Longitudinal Phase Space plots