Baryon-Antibaryon Photoproduction at GlueX

\[ \gamma p \rightarrow \{p p\} p \quad \gamma p \rightarrow \{\Lambda \bar{\Lambda}\} p \quad \gamma p \rightarrow \{p \bar{\Lambda}\} \Lambda \]

Reinhard Schumacher, Hao Li

On behalf of the GlueX Collaboration
Exploring Baryon-Baryon Photoproduction

- GlueX in Hall D at Jefferson Lab
  - Fully exclusive final states
  - Reactions: \( \bar{\gamma} p \rightarrow \{ p \bar{p} \} p \), \( \bar{\gamma} p \rightarrow \{ \Lambda \bar{\Lambda} \} p \), \( \bar{\gamma} p \rightarrow \{ p \bar{\Lambda} \} \Lambda \)
- Compare phenomenology for these channels
  - What do the data suggest?
  - Model for production mechanism
  - Cross section results
  - Beam Spin observables
Motivation:

- Pull 3 quark-anti-quark pairs out of the vacuum at once – not sufficiently studied!
- Measure ratio of strange to non-strange production: $\{ss\}$ vs. $\{uu\}$.
- Mechanism via photoproduction is poorly known*
  - We have limited theory support
  - We offer a phenomenological model

- GlueX spectrometer
- Photon beam energy: 3.7 to 11.4 GeV
- “Phase I” data set: luminosity 429.6 pb$^{-1}$
- Trigger on $\gtrsim 1$ GeV calorimetric energy deposit by ($p$, $\pi^{\pm}$, $\gamma$, ...)
- Exclusive reactions: kinematic fit to energy, momentum, creation/decay vertices, flight path significance (for hyperons)
Angular Distributions Tell the Story

Forward Proton: $\cos(\theta_{\text{CM}})$

Anti-Proton: $\cos(\theta_{\text{CM}})$

Backward Proton: $\cos(\theta_{\text{CM}})$

Invar. Mass $\{p_{fwd} \bar{p}\}$ GeV/c²

Invar. Mass $\{p_{bkwd} \bar{p}\}$ GeV/c²

$-(t - t_{\text{min}})$ of IM $\{p_{fwd} \bar{p}\}$
Angular Distributions Tell the Story

\[ \Lambda: \cos(\theta_{CM}) \]
\[ \text{Anti-Lambda: } \cos(\theta_{CM}) \]
\[ \text{Proton: } \cos(\theta_{CM}) \]

Invar. Mass \( \{\Lambda\Lambda\} \) GeV/c^2

\( -(t - t_{\text{min}}) \) of IM\( \{\Lambda\Lambda\} \) GeV^2
Elements of the Model

- Accounts for large-angle asymmetry between anti-baryons and baryons: double-Regge diagram(s)
- Match Monte Carlo simulations to all angular, momentum transfer, and mass distributions
  - Use incoherent sum of model terms fitted to data
  - New few parameters in each beam energy interval
    - 6 for hyperons (one double-Regge diagram)
    - 6+3 = 9 for protons (two double-Regge diagram needed)
- Stochastic Gradient Descent fitting algorithm
Total Cross Sections

Compare to (3-body phase space)$\times$(mass clustering):

\[ \sigma_{TOT} \sim \frac{p_{CM}q}{p_{\gamma p}S} \left| \mathcal{M}(c_m) \right|^2 \]

Note: $\Lambda\bar{\Lambda}$ & $p\bar{\Lambda}$ are equal size
Suppression of strangeness

- Strange states suppressed compared to non-strange states in photoproduction.
- We measure: \( \frac{\sigma_{\gamma p \rightarrow \{\Lambda\bar{\Lambda}\}p + \{p\bar{\Lambda}\}p}}{\sigma_{\gamma p \rightarrow p\bar{p}p}} = 0.22 \pm 0.01 \)
- Relate to quark creation probabilities (GlueX):
  \[
  \frac{P(s\bar{s})}{P(u\bar{u})} \simeq 0.22
  \]
- Compare to single-meson \( \Lambda K^+ / N\pi \) electroproduction* case (CLAS):
  \[
  P(s\bar{s})/P(d\bar{d}) = 0.21 \pm 0.03
  \]
- Consistent suppression by factor of \(~5\) relative to lightest quarks.

* M. Mestayer et al. (CLAS), Strangeness Suppression of \( q\bar{q} \) Creation Observed in Exclusive Reactions, Phys. Rev. Lett. 113, 152004 (2014), arXiv:1412.0974 [nucl-ex].
Differential cross sections $\gamma \bar{p} p \rightarrow \Lambda \bar{\Lambda}$

Theoretical predictions (Regge Approach):

- $p\bar{p}$
- $\Lambda\bar{\Lambda}$

**Theory (Regge Approach)**: $p\bar{p}$

- **Differential cross section**
  - $d\sigma/dt$ (ab GeV$^{-2}$)
  - $t$ (GeV$^2$/c$^2$)

**GlueX data: $p\bar{p}$**

**Theory (Regge Approach)**: $\Lambda\bar{\Lambda}$

- **Differential cross section**
  - $d\sigma/dt$ (ab GeV$^{-2}$)
  - $t$ (GeV$^2$/c$^2$)

**GlueX data: $\Lambda\bar{\Lambda}$**

---

Differential cross sections @\( E_\gamma = 8.75 \text{GeV} \)

- No hints of threshold “-onium states”
- Attractive interaction:
  - Baryons and anti-baryons tend to “cluster”
- Model parameterization (single Regge):
  \( d\sigma/dIM_{pp} \sim \exp[-(IM_{pp} - 2m_p)/c_m] \)
  - Each channel gets a fitted clustering parameter, \( c_m \)
- Single-Regge component: blue curves
Spin Observables

- Beam linear polarization ~35% for $8.2 < E_\gamma < 8.8$ GeV
  - Coherent bremsstrahlung off diamond radiator
- Beam Spin Asymmetry (BSA), $\Sigma$, sensitive to exchanges
  - Insensitive to experimental acceptance: $A(\phi)$

$$\phi = \tan^{-1} \frac{n_y}{n_x}$$

Proton-Antiproton Plane Beam Asymmetry

$\Sigma \approx 10.1 \pm 0.6\%$
$B S A, \Sigma, \text{ for } \{p\bar{p}\} \text{ pairs}$

- $t_{pair} = [p^{\mu}(\gamma) - p^{\mu}(p\bar{p})]^2$
  - Mild $t$-dependence seen; $\Sigma$ is small
  - Theory deals only with decay of scalar mesons to pairs – not what we see!

![Diagram of particle interactions]

**$\Sigma$ prediction of $\gamma p \rightarrow \{p\bar{p}\}p$ at 9 GeV**

Intermediate scalars:
- $f_0(1370)$, $f_0(1500)$, $f_0(1710)$

BSA, $\Sigma$, for proton alone

- $t_p = [p^\mu(\gamma) - p^\mu(p)]^2$
  - Significant negative beam asymmetry
  - Baryon & meson exchange present in double Regge picture
  - Appears that multiple reaction mechanisms interfere here
  - No theory guidance available here

$\bar{p}p \rightarrow \gamma p, Baryon$,

$\bar{p}p \rightarrow \bar{p}p, $ Meson

Interference between two mechanisms?
We examine 3 baryon-anti-baryon reactions!

Evidence for at least two exchange mechanisms:

- Single Regge
- Double Regge – with anti-baryon “in the middle”
- A Monte-Carlo based reaction model fits GlueX data well.

We see non-vanishing spin observables

- More available, e.g. for hyperons

We would welcome more theory support!
Supplemental Slides
• \textbf{\textsim{12 GeV} e^- beam} converted to:
  - 4 - 11.6 GeV photon beam
  - Linear coherent peak 8-9 GeV (\textsim{40\%})
  - Four orientations: 0°, 90°, 45°, 135°

• Solenoidal magnet
• Drift chambers
• Start counter/Time of flight
• Electromagnetic Calorimeters
GlueX Experiment in Hall D / JLab

- Physics-quality data runs in 2016, **2017, 2018, 2020**

(this talk)
Van Hove view of the Kinematics

- Use longitudinal momenta to exhibit 3-body angular correlations
- Clean separation of two $\Lambda\Lambda p$ reaction mechanisms
- Each grouping contains both single and double Regge components