Workshop on
Hadronic Physics with Hadronic Beams

Summary

Winston Roberts
Simon Capstick
Joseph Comfort
Mark Manley
Mike Sadler

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Workshop Goals

- **Assess the feasibility of running a suite of experiments at the AGS, either prior to or concurrent with the RSVP suite:**

  Energy and beam line

  Detector

  Cost

- **If AGS assessment is unfavorable, examine possibilities at other facilities: JHF, GSI, JLab, etc.**

- **Develop follow-up plans.**

Physics Questions

- **What are the states of QCD?**
  E.g., baryons, mesons, glueballs, hybrids, pentaquarks,...
- **How are the states realized in nature?**
  E.g., confinement.
  - **OGE, OBE, combination,...?**
  - **Instatons?**
  - **Solitons, chiral or otherwise?**
  - **Large N_c?**
  - **Skyrme models, bag models,...?**
- **What are the couplings?**
  E.g., $^3P_0$, chiral quark; weak decays ...?

Some Baryon Spectroscopy Issues

Presentations by W. Roberts, S. Capstick, C. Bennhold

- **The numbers of states can discriminate models. E.g.,**
  - **3-quark: 30 $J^\pi = 1/2^+$ & 45 $J^\pi = 3/2^+$ states below 2 GeV.**
  - **di-quark: 5 $J^\pi = 1/2^+$ & 7 $J^\pi = 3/2^+$ states below 2 GeV.**
- **Spin-orbit puzzle in quark models.**
- **How to get the right multipole amplitudes.**
  E.g., $A_{1/2}$ and $A_{3/2}$ for $\Delta(1232)$.
- **Vertex dressing.**
- **Pion clouding?**
- **Significance and relevance of dynamically generated states.**

More Specific Issues

- **Description of $S_{11}(1530)$ state and its decays.**
- **What is the $P_{11}(1440)$ state: 3-quark, hybrid,...?**
- **"Missing" resonances? Are they really missing?**
- **Is there a new P_{13} near 1900 MeV?**
  - **Data from EM probes are currently insuffient.**
  - **But upcoming polarization data might help.**
- **The P_{11} and P_{13} partial waves are the most critical for determining the best descriptions of baryons. Also the most difficult.**
- ***Very* limited data for hyperons, often of poor quality.**
  Much improved $\pi^- p \to K^0 \Lambda$ data would be a great asset.

Pentaquarks

Currently of very active interest.

But why have only 3 quarks in the initial state?

How to produce Θ^+ with K^-:

$$\begin{aligned} K^- + p &= \bar{u}s + uud \\ &= uu\bar{u}ds \\ &= uudd\bar{s} + \bar{u}\,\bar{d}\,s\,s \\ &= uudd\bar{s} + \bar{u}\,s + \bar{d}\,s \\ &= \Theta^+ + K^- + \overline{K^0} \end{aligned}$$

A list has been made of all $\pi^\pm$ and $K^\pm$ reactions leading to $\Theta^+(1540)$, $\Xi^+(2070)$ and $\Xi^{--}(2070)$.

Threshold momenta reach upwards to ~ 6600 MeV/c.

BNL Options for Θ^+

$K^+n \rightarrow \Theta^+$ Excitation Function

- Resonant $p_K = 442$ MeV/c, in nK CM.
- Look for $\Theta^+ \rightarrow K^+n \rightarrow \pi^+\pi^0 n$
  or $\rightarrow K^0 p \rightarrow \pi^+\pi^- p$.
- Sufficient flux at C4 port.

$K^+p \rightarrow \Theta^+ + \pi^+$

- Threshold $p_K = 735$ MeV/c.
- Look for $K^+n\pi^+ \rightarrow \pi^+\pi^0 n\,\pi^+$
  or $K^0 p\pi^+ \rightarrow \pi^+\pi^- p\,\pi^+$.
- C4 Port probably OK; $p_K < 830$ MeV/c.
- Matches better to D Line.

$K^- p \rightarrow \Xi^+ + K^0 + \pi^-$

- Threshold $p_K = 1930$ MeV/c.
- Look for $\Xi^+ \rightarrow \Xi^0 \pi^+ \rightarrow \Lambda \pi^0 \rightarrow p\, \pi^- \pi^0 \pi^+$
  or $\rightarrow \Sigma^+ \overline{K}^0 \rightarrow p\, \pi^0 \pi^+ \pi^-$
  with $K^0 \rightarrow \pi^+ \pi^-$
- Near the limit of the D Line.

$K^- n \rightarrow \Xi^{--} + K^+$

- Threshold $p_K = 2860$ MeV/c.
- Look for $\Xi^{--} \rightarrow \Xi^- \pi^- \rightarrow \Lambda \pi^- \rightarrow p \pi^- \pi^-$ with $K^+ \rightarrow \pi^+ \pi^0$
- Would need a beam-line upgrade.

Relevance to EM Programs

- **Very extensive programs are being pursued with γ and (e, e') facilites: JLab, Bates, Mainz, Spring8, GRAAL,...**
- **But these programs are *not* sufficient.**
  - **The baryon spectrum cannot be determined from EM data alone! Data from hadron probes are always included.**
  - **To get from an initial state (e.g., γN) to final state (e.g., $\pi\pi N$), one must pass through intermediate states.**
  - **The coupling to the final channel is hadronic.**
  - **The unitarity of the S matrix requires that all EM and hadronic channels be coupled together in PWAs.**
  - **Although some couplings can be small, it is recognized that coupled-channel treatments are necessary.**
- **Hadronic probes not only complement EM programs, they are *necessary* for extracting the full physics, and preserving the investment.**

Need for Hadronic Beams

- **For Θ^+ excitation function, need high-statistics data in small energy steps, at rather low K^+ momentum.**
- **High-quality, *precision* $\pi^{\pm}N$ $K^{\pm}N$ data up to $\sim$ 2.5 GeV/c.**
- **Especially need kaon beams.**
  E.g., $K^-p \rightarrow K^0\Lambda$.
- **Strong need for $\pi \rightarrow \pi\pi$ data.**
- **Polarization information is also important.**

Detector Requirements

- **Large acceptance: $\sim 4\pi$**
- **General purpose: Charged particle tracking and EM calorimetry**
- **Magnetic sectrometry**
- **Good rate capabilities**
- **Flexible triggering**

A BNL Facility

Beam Line

An idea developed during the workshop.

Produce the beam parasitically from the KOPIO target.

Bend it around to area near old C6/C8 stations.

Detector

Modify the E949 detector (without compromising E949!).

LEGS detector, possibly with modifications.

Cost

Beam Line: $\sim$ \$10 M.

Detector: Small to $\sim$ \$10 M.

Operations: $\sim$ \$2 M annually.

Summary and Conclusions

- **Basic features of how non-perturbative QCD operates are not yet understood.**
- **There are many competing ideas and models, with limited experimental constraints.**
- **Baryon spectroscopy is a good place to study the issues.**
- **Pentaquarks is a particular current example.**
- **Substantial programs are being pursued at EM facilities.**
- **EM data alone are not sufficient.**
- **Hadron beam data are complementry and *necessary* to fulfill the goals of the studies.**
- **It seems possible that a program can be established at the AGS which will bring enormous benefits at modest costs.**