Why do we need hadronic beams?

Talk prepared with D. Mark Manley (Kent St.)

- K^+ beam and true pentaquarks
- Missing and new baryon states
  - Physics motivation (recap)
  - Where to look; partial waves, final states
  - How to find them: multi-channel unitary analysis
- Required new hadronic beam data
  - Example: have we found a missing P_{13} resonance? How a π beam would help
- Conclusions

Need for a K^+ beam

- Do S=+1 pentaquark baryons exist?
  - High statistics experiment with:
    - Beam down to low energies (Θ^+ ~110 MeV above threshold)
    - Narrow beam energy range (narrow Θ^+ state)
  - Would allow partial-wave analysis
    - Crucial to find the J^P of the Θ^+
    - If we find a ($J^P=3/2^+$) spin-orbit partner nearby:
      - It is orbitally excited
      - Would confirm several popular models

Missing and new resonances

- Symmetric (qqq) potential models:
  - Agree on **number** of excited states of a given character
  - Disagree on their **place** in spectrum, especially at higher energy ($s^{\frac{1}{2}}$>1.8 GeV)
  - many positive (and doubly-excited negative) parity states **not** seen in analyses of data: "missing" (new) resonances
- PDG states established in analyses of $\pi N \to \pi N$ & $\overline{K}N \to \overline{K}N$
  - States which couple weakly to these channels will be "missing"

Why should we try to find new states?

- Identify relevant degrees of freedom in low-energy QCD:
  - Three confined constituent quarks?...
    - Interacting via one-gluon exchange?
    - Via exchange of pseudo-Goldstone bosons?
    - Via instanton-induced interactions?
  - Can confinement be modeled by flux tubes?
    - Where are lightest hybrid baryon states?
- Do pentaquark baryons exist?
    - Non-exotic partners of Θ^+ ?
      - Mix with conventional qqq excitations...

Where would we like to find new states?

What are the crucial partial waves?

- Denoted by $L_{2I,2J}$
  - L = relative angular momentum of final state baryon and (usually pseudoscalar) meson
  - I(J) = their total isospin(spin); parity = $(-1)^{L+1}$

- Non-strange baryon states:
- P_{11}: this is where I=1/2 ($J^P=1/2^+$) partners of (isoscalar) Θ^+ pentaquark would be
  - Also one of the most difficult to analyze, complicated dynamics
  - One light "missing" conventional qqq state
- P_{13}: lightest hybrid S=0 baryons predicted to be in P_{11} and P_{13} (bag and flux-tube models)
  - Three light "missing" conventional qqq states

Finding new states...

- Strangeness -1 baryon states:
  - Current state of knowledge of Σ and Λ resonances *much* poorer than N* and Δ* states
  - New K beam experiments have potential to discover exciting new physics:
    - The Σ states with $J^P=1/2^+$ ($P_{I=1,1}$) will contain S=-1 isovector partners of Θ^+
    - S_{01} $\Lambda(1405)$ ($J^P=1/2^-$) and D_{03} $\Lambda(1520)$ ($J^P=3/2^-$) are spin-orbit partners
      - Predicted degenerate in OGE constituent quark models
      - Are split by flavor-dependent OBE interactions
      - $\Lambda(1405)$ may contain substantial baryon-meson components (just below threshold for decay to $\bar{K}N$)

Finding new states...

- S=-1 states...
  - Can we find strange partners of interesting N* and Δ* states?
    - Can test flavor symmetry, may lead to a new understanding of non-strange states
    - Understand role of strange quark in baryon structure
- S=-2 (Ξ states)
  - Almost nothing is known about excited states
  - EM production experiments $\gamma N \Rightarrow K^+K^+\Xi$ are not easy
    - J. Price
  - K^- beam would allow simultaneous study of $K^-N \Rightarrow K^+\Xi$

How to find missing resonances

- N* program@JLAB
  - Excite new states using a different (EM) probe: photon (electron) on proton
  - Analyze data in final states other than πN and $\bar{K}N$
  - Promising reactions:
    - Isospin selective (I=1/2 N resonances) $\gamma N \rightarrow K\Lambda, \quad \gamma N \rightarrow \eta N$
    - Mesons are $J^P=0^-$, use same formalism for partial-wave analysis as in pion photoprod'n

How to find missing resonances…

- E.g. $\gamma N \Rightarrow K \Lambda$
  - Tantalizing evidence for new D_{13} ($N^*3/2^-$) state at 1900 MeV in SAPHIR data (C. Bennhold et al.)
    - Cross section exceeds expectations from known resonances in that region
- To positively identify a missing resonance:
  - Need more than position and width of peak in σ
  - Need quantum numbers, decay properties
    - Photo-decay amplitude
    - Strong decay amplitudes

How to find missing resonances…

- Cannot get both EM and strong amplitudes from $\gamma N \Rightarrow N^* \Rightarrow K\Lambda$ experiment!
  - Proportional to $(A_{N^* \Rightarrow \gamma N})^* A_{N^* \Rightarrow K\Lambda}$
  - Suppose have partial-wave analysis of this reaction
    - At **most** could provide M and Γ for resonances
      - Assumes: non-overlapping states, no complicated non-resonant/resonance interference

Multi-channel unitary analysis

- If same state observed in:
  - Pion photoproduction $\gamma N \Rightarrow N^* \Rightarrow \pi N$
    - Proportional to $(A_{N^* \Rightarrow \gamma N})^* A_{N^* \Rightarrow \pi N}$
  - Pion elastic scattering $\pi N \Rightarrow N^* \Rightarrow \pi N$
    - Proportional to $|A_{N^* \Rightarrow \pi N}|^2$
  - Simultaneous unitary analysis of all three channels could yield $A_{N^* \Rightarrow K\Lambda}$ and $A_{N^* \Rightarrow \pi N}$ and $A_{N^* \Rightarrow \gamma N}$
- Crucial additional information: $\pi N \Rightarrow N^* \Rightarrow K \Lambda$

Analysis of N* data

Masses, widths, decay branches, photocouplings, EM form factors

from

Simultaneous unitary description of partial wave amplitudes in many (all open) channels; multipoles in γ N (e^- N)

from

partial-wave analysis of scattering data

$$\pi N,\ \gamma N \to X$$

Required new hadronic beam data

- Pion photoproduction $\gamma N \Rightarrow \pi N$
  - High-quality data from JLab and other modern EM production facilities, lately with beam polarization
- Pion elastic scattering $\pi N \Rightarrow \pi N$
  - Data set needs improvement, especially above π production threshold
- Data for $\pi N \Rightarrow K \Lambda$ in poor shape
  - Only energy-dependent PWA available
    - Assume a certain energy dependence, introduces bias
    - Amplitudes may not be unique
- Need high-quality, high-statistics $\pi N \Rightarrow K \Lambda$ data
  - Differential cross section
  - target polarization observables

Required new hadronic beam data…

- Another example: reaction γ N ⇨ η N
  - important for S_{11} (possibly P_{11}) and other partial waves, also isospin selective (no Δ^* states)
  - Have new data from more than one lab
- Analysis requires π N ⇨ η N partial-wave amplitudes
  - Data set does not allow energy-independent partial-wave analysis (noisy, no physics output)
  - Improved data set will have significant impact

Required new hadronic beam data…

- Vector meson final states: e.g. $\gamma N \Rightarrow \omega N$
  - Important source of information on missing resonances
    - Isospin selective (no Δ^* states)
    - Requires many more partial-wave amplitudes (ω spin 1) and so high-quality data for several observables
  - Data has been taken at EM production labs
    - Analyses require models (Oh, Titov and Lee; Penner and Mosel)
- Almost nothing is known about $\pi N \Rightarrow \omega N$
  - A few data just above threshold
  - No unique partial wave analysis possible because of lack of data

Have we found a missing P_{13} resonance?

- PDG lists one clear resonance, and a 2* state N(1900)
  - N(1720) 4*, listed with **large** ρN coupling (70-85%)
- Coupled-channel analyses:
  - agree on small π N branching fraction
  - Disagree on amount of π π N which is ρ N, or π Δ
- This issue crucial because of new $\pi^+\pi^-$ electroproduction data from CLAS (M. Ripani, e.g. N*2004 mtg.) and new kaon production data
  - Find P_{13} or P_{33} state at 1.75 GeV, **small** ρN branch
  - Either PDG wrong about N(1720), or new state!
- Can this be resolved?

A missing P_{13} resonance…?

- Need new measurements of $\pi N \Rightarrow \pi \pi N$ with:
  - 4π detectors
  - Charged and neutral particle detection
- 1984 isobar analysis (Manley, PRD**30**, 904)
  - Only 240K events for entire analysis
  - Orders of magnitude more data would result from modern experiment
- Partial-wave amplitudes could be dramatically improved
  - Modern detectors + computers + analysis techniques
  - Channels $\pi \Delta$ and ρN expected to be an important source of information about missing resonances
    - Need hadronic production data!

Other channels with hadronic beams?

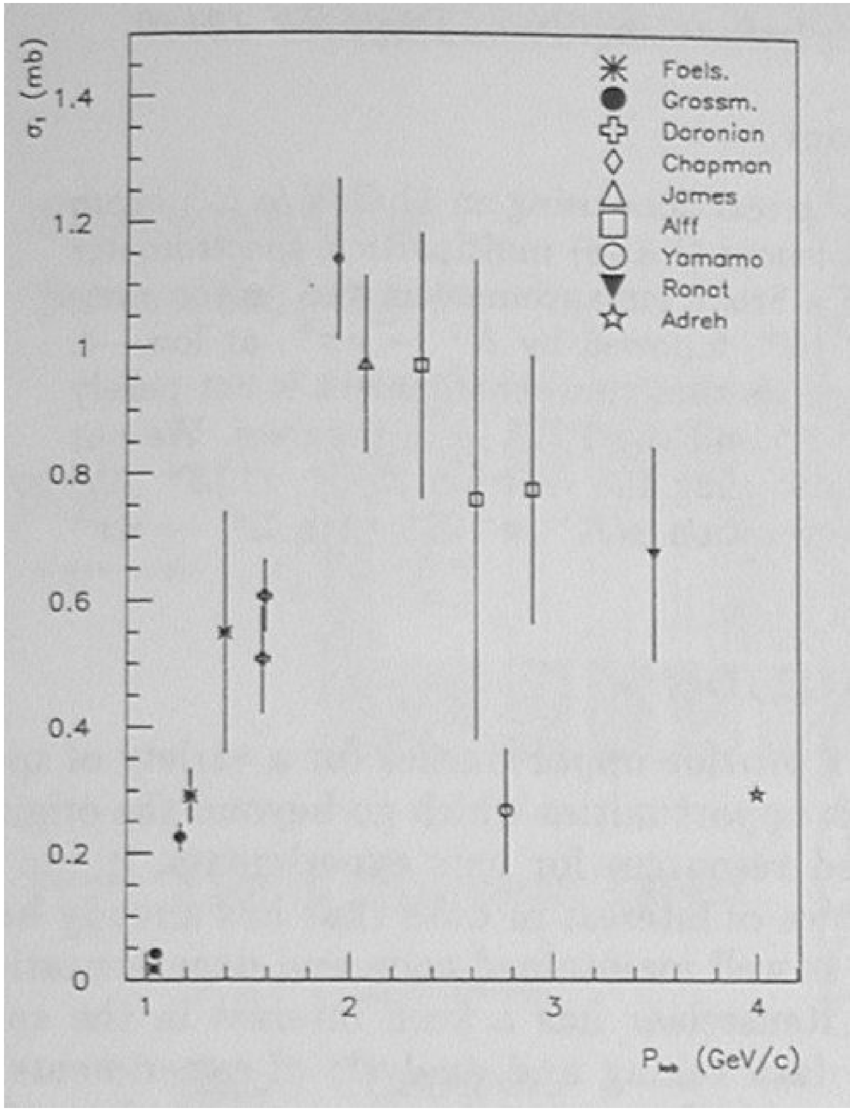
- With modern detectors and a π beam:
  - Interesting reaction $\pi N \Rightarrow \eta \pi N$
    - Includes isospin-selective (I=3/2, Δ^* states) reaction $\pi N \Rightarrow \eta \Delta(1232)$: (Nefkens)
    - Also contains $\pi N \Rightarrow \pi S_{11}(1535)$
  - These channels can and should also be studied in γN, data sets complementary
    - Nefkens: $\eta \Delta(1232)$, Crystal Barrel@Bonn; R. Gothe, U. Thoma: $\pi S_{11}(1535)$
    - High potential for discovering positive parity (missing) and doubly-excited negative-parity states ~1900-2000 MeV

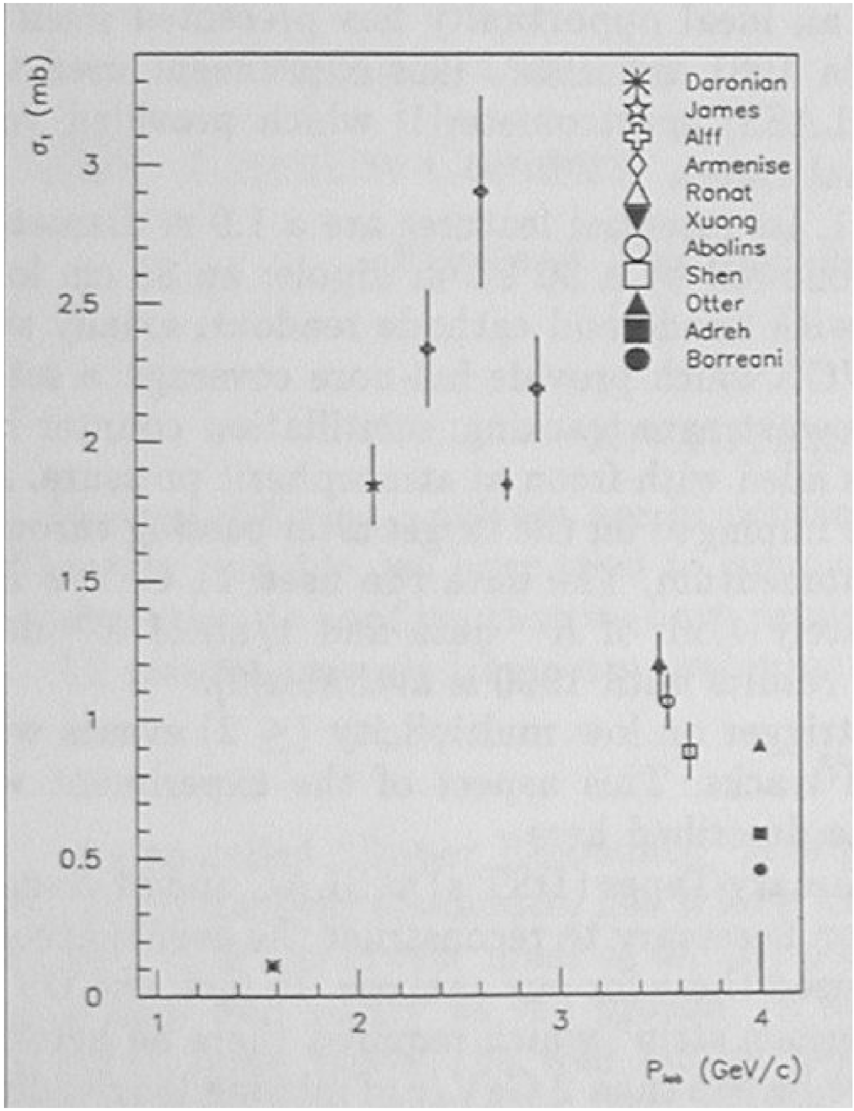
Conclusions

- To meet baryon physics goals we require:
  - Precise data in **new** channels: **underway!**
    - You could get lucky and find an isolated missing resonance near a new channel's threshold
      - But multiplicity of resonances high at these masses
      - It helps to have a high channel threshold, ~1700-1800 MeV and to be isospin selective ($\Delta\eta$, $N\omega$)
    - More likely that adding a new resonance has consequences in several channels, convincing evidence will come from simultaneous fit
  - **Polarization** experiments: beam, target, recoil:
    - E.g. all three possible, and planned, in $\vec{\gamma}\vec{N} \rightarrow \Lambda K$

Conclusions…

- Hadron beams!
  - Hadron-beam information complementary to that of photoproduction
  - Simultaneous unitary analysis of data from γN and πN **required** to find new N^*, Δ^* states
  - Kaon-beam experiments **could** map out spectrum of a persistent Θ^+ and its partners
    - **Would** make enormous improvement in our understanding of Σ, Λ and Ξ resonances





$\pi^+ p \Rightarrow \pi^+ p \eta$ $\pi^+ p \Rightarrow \pi^+ p \omega$

From B. Nefkens, πN Newsletter (1997)