Baryon spectroscopy with $(\pi,2\pi)$ reactions at J-PARC E45

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1. Physics motivation
2. J-PARC E45
3. Detector status
5. Summary
Studies of baryon resonances in ($\pi$,2$\pi$) reactions for

- Precise measurements of baryon resonance properties
  - Many resonances have not been established experimentally
  - $\pi\pi N$ has strong coupling to high mass resonances
  - Not enough ($\pi$,2$\pi$) experimental data since 1970’s
- Deeper understanding of non-perturbative QCD
- Search for new baryon states
  - e.g. hybrid baryons (qqqqg)
Baryon mass: Exp vs QM (PDG)

Orders of mass levels are different

Missing baryons
Quark model does not describe well $N^*$ mass levels.

Most of the $N^*$s so far were measured from

$$\pi N \rightarrow \pi N \ , \ \gamma N \rightarrow \pi N$$

PDG 2014
Partial wave (LSJ) amplitude of a $b$ reaction:

Reaction channels:

Transition potentials: coupled-channels effect

Dynamical coupled-channels model (ANL-Osaka)

Kamano’s talk (Apr 14)

Physical $N^*$s will be a “mixture” of the two pictures:

Physical $N^*$s will be a “mixture” of the two pictures:

$$|N^*\rangle = |MB\rangle$$

$$|N^*\rangle = |qqq\rangle + |m.c.\rangle$$

Transition potentials:

$$V_{a,b} = V_{a,b} + \sum_{N^*} \frac{\Gamma^+_{N^*,a} \Gamma_{N^*,b}}{E - M_{N^*}}$$

exchange potentials of ground state mesons and baryons

bare $N^*$ states)
Importance of $N\pi\pi$ Decay

World’s $\pi N \rightarrow \pi \pi N$ data

Only 240K bubble chamber data in 1970’s

\[ \pi^+ p \rightarrow \pi^+ \pi^0 n \]

\[ \pi^- p \rightarrow \pi^+ \pi^- n \]

\[ \pi^- p \rightarrow \pi^- \pi^0 p \]

\[ \pi^+ p \rightarrow \pi^+ \pi^0 p \]

\[ \pi^- p \rightarrow \pi^- \pi^0 n \]

\[ \pi\pi N \text{ center of mass energy} \]

H. Kamano et al.,
Recent Lattice QCD calculations

J. Dudek et al., PRD85 (2012) 054016

Hybrid baryons (qqgqg)

\[ m_\pi = 396 \text{ MeV} \]
Bird's eye photo in January of 2008

**Neutrino Beams**

**T2K experiment**

**Hadron Exp. Facility**

**Materials and Life Experimental Facility**

**3 GeV Synchrotron**

**400 MeV LINAC**

**J-PARC (MW proton synchrotron)**

**Neutrino Beams**

**(T2K experiment)**

**MR Synchrotron (30 GeV)**

**Hadron Exp. Facility**
Hadron Experimental Facility

Hypernuclei

Strange
ness

ΛΛ, Ξ Hypernuclei

Λ, Σ Hypernuclei

Hypernuclei

K meson

Implantation of Kaon and the nuclear shrinkage

Why are bound quarks heavier?

Quark

Free quarks

Bound quarks

Vector meson in nucleus

Kaonic nucleus

J-PARC HI WS, K. Ozawa

10^{14}/cycle p beams
10^{8}/cycle π beams
10^{6}/cycle K beams

(2017) cycle ~ 6s
Measure ($\pi,2\pi$) in large acceptance TPC in dipole magnetic field

$\pi p \rightarrow \pi^+ \pi^0 n$, $\pi^0 \pi p$

$\pi^+ p \rightarrow \pi^0 \pi^+ p$, $\pi^+ \pi^+ n$

$\pi N \rightarrow K Y$ (2-body reaction)

$\pi p \rightarrow K^0 \Lambda$,

$\pi^+ p \rightarrow K^+ \Sigma^+ (I=3/2, \Delta^*)$

$\pi^+$ beam on liquid-H target
(p= 0.73 – 2.0 GeV/c
W=1.5-2.15 GeV)

2 charged particles + 1 neutral particle
→ missing mass technique

LH target

Superconducting Helmholtz Dipole magnet

Hyp-TPC

Trigger with hodoscope

$\pi$ beam
HypTPC

**Large acceptance H-target inside TPC**

**High-rate capable TPC**
- Gating Grid
- GEM (Gas Electron Multiplier)
  - Suppression of positive-ion backflow causing position distortions

**Good position resolution with magnetic field and fine-segmented pads**
- $\pi/K/p$ separation
- $dE/dx$ vs $p$

**Gating grid wires**
- GEM (e amplification)
- Pad plane

**Field cage (sensitive volume)**
- P-10 gas

**Target holder**
- Liquid H target

**Beam**
- $\pi^-$

**Electron drift**
- Ionization

**Gas vessel**
- $E=180V/cm$
- $B=1.5T$

**Dimensions**
- 70$\phi$
- 500$\phi$
- 550$\sim$

$\pi$ beam

$e^-$

$\pi^+$
**GEM (Gas Electron Multiplier)**

- 4 GEM (250mmx250mm) sheets
- 3-GEM layers
- 50μm + 50μm +100μm thick
- Gain ~ $10^4$

**Segmented electrodes**

- to reduce spark rate / electrode
- to minimize acceptance loss when an electrode is broken due to discharge
Readout pad configuration

Pad size
2.4 x 9 mm² (inner layer)
2.4 x 13 mm² (outer layer)
32 pad rows (rings)
No. of pads = 5768

Position resolution <300μm
(L>10cm)

Δp/p=1-3% (π,p)
Detector simulation (GEANT)

Elastic scattering
(Same trigger condition)

3-body reaction

Cut on coplanarity cut.
Only 3-body reaction can be survived.

Rejected events by coplanarity cut

\[ \pi^- p \rightarrow \pi^- \pi^0 p \] reaction

MM\(^2\)(\(\pi^\pm p\))

Coplanarity = cosine of angle between \(p_1\) and \((p_2 \times p_3)\)
Particle identification

\[ \pi^- + p + K^+ + p^- + K^- + p \]

\[ \pi^- / K : p \leq 0.5 \text{ GeV/c} \]

\[ \pi^- / p : p \leq 1.1 \text{ GeV/c} \]

w/ Hodoscope TOF

\[ \sigma_T = 100 \text{ps} \]
Trigger efficiency

2-charged particle trigger (inefficiency due to double hit)

Proposed hodoscope with 32 segments.

\[ p(\pi^+, \pi_p^0) \]
\[ p(\pi^+, \pi_+^0)n \]
Acceptance

\[ \pi^+ p \rightarrow \pi^+ \pi^0 p \text{ reaction} \]

\[ \text{Beam momentum: } 0.835 \text{ GeV/c} \]
\[ \text{1.235 GeV/c} \]
\[ \text{2.0 GeV/c} \]

\[ \text{Acceptance vs. } \cos(\theta_{\text{C.M. proton}}) \]

\[ \text{Acceptance vs. } \pi\text{-beam momentum (GeV/c)} \]

\[ \pi p \rightarrow \pi^+ \pi^- \]
\[ \pi p \rightarrow \pi^0 \pi^0 \]
\[ \pi^+ p \rightarrow \pi^+ \pi^- n \]
\[ \pi^+ p \rightarrow \pi^0 \pi^0 n \]
\[ \pi^- p \rightarrow \pi^+ \pi^0 p \]
Data statistics

- \((\pi,2\pi)\) cross section: \(~2\) mb
- \(\pi\) Beam rate: \(~10^6\) / cycle (6s)
- Liquid H target: 5cm length
- TPC acceptance: 40%

\(\Rightarrow 160\) events / cycle

Dominant background: elastic scattering
\((\sigma_{\text{total}} = 40\) mb \(\rightarrow\) trigger rate = 3200 events / cycle \(\sim 800\) Hz in maximum (4s flat top))

- Energy range: 1.50 – 2.15 GeV
- No. of bins:
  - \(\pi^-\) beam: 24 (energy) \(\times\) 20 (angle)
  - \(\pi^+\) beam: 23 (energy) \(\times\) 20 (angle)

- No. of events / bin: 32 K

\(\Rightarrow 30M\) events in 15 days

Increase world’s \(\pi\piN\) data (240K) by factor of 130
TPC prototype test
NIMA763(2014)65-81

- Beam test at RCNP
  - Proton beam at 400 MeV
  - Beam rate up to $10^6$ Hz/cm$^2$

Hit position distortion <0.1mm

Ion backflow ~ 5% (bench test)

Position resolution (B=0)

\[ \sigma_x = 0.40 \text{mm} \text{ (4mm pad)} \]
HypTPC test

GET (General Electronics for TPC) readout system

r-CoBo (data collector)

Mar 2015
HypTPC test with $^{55}\text{Fe}$ (x-ray) source

Gain: 120fC, Shap T: 70ns, GEM Curr.: 315 μA

$\Delta E/E : 14.3 \pm 0.2 \%$

(Peak)/(Esp. Peak): 0.52 ± 0.01

Diffusion size: $1.87 \pm 0.02$ mm

cf. prototype TPC (5 cm to 10 cm): 1.7 ~ 2.0 mm

The TPC operation is consistent with the prototype TPC!!
Physics possibilities with HypTPC

• H-dibaryon (E42) : \( K^-C \rightarrow K^+H \ X, \ H \rightarrow \Lambda \Lambda, \Lambda \pi^-p \)

• \( \Lambda(1405) \) : \( \pi^-p \rightarrow K^0\Lambda(1405) \)
  \( \Lambda(1405) \rightarrow \Lambda\gamma \) (KN compositeness, T. Sekihara, PRC89 (2014) 025202)

• \( K^-pp \) : \( \pi^+d \rightarrow K^+K^-pp \)
  \( K^-pp \rightarrow \Lambda p, \Sigma^0p, \Lambda\pi^0p, \Sigma^0\pi^0p \)

• \( \Xi \) excited states:
  \( K^-p \rightarrow K^+\Xi^-*, \ \Xi^-* \rightarrow \Lambda K^-, \Sigma^0K^-, \Sigma^-K^0, \Xi^-\pi^0, \Xi^0\pi^-, \Xi^-\gamma \)
  \( K^-p \rightarrow K^0\Xi^0*, \ \Xi^0* \rightarrow \Lambda K^0, \Sigma^0K^0, \Sigma^+K^-, \Xi^-\pi^+ \)
Summary

• J-PARC-E45 is proposed to study baryon excited states in \((\pi, 2\pi)\) reactions, which will improve previous data statistics by two orders of magnitude.

• Large acceptance TPC in high rate operation will realize the experiment.

• E45 spectrometer will be ready for beams in 2016 with the TPC and the magnet.

• PWA with dynamical coupled channels model in collaboration with theorists (H. Kamano, T. Sato,..)
E45 collaboration list

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46 people form USA, Japan, Korea, and Europe