C Hyperon-Proton Scattering at the J-PARC

- Motivation
  - historic background
  - YN scattering experiment at KEK-PS
  - ... and at J-PARC
- Objective
- Method
- High-Speed Image Delay Tube
  - What is it?
  - Characteristics & Performances expected
- a simulation

IEIRI Masaharu

これから研究会
09.02.21 @ Miyazaki
Historic Background

Experiment
- ('32 neutron)
- ('47 π⁺ - meson)
- pp, np scattering
- (YN scattering)
- ('74 J/ψ) (Hypernuclei)

Theory
- ('35 meson theory)
- '51 hard-core OPE @long-range
- ('64 Quark hypothesis)
- '77 H-particle
- QCM
- Inspired by SU(3)f
- NN&YN by Lattice... based on SU(2)/SU(3)f

Idea
- established

Support

(get the picture)
Available Yp scatt. Data [1]
- bubble chamber era '60-'70s -

✓ bubble chamber era '60-'70s

Numbers of data points in angular distributions:

<table>
<thead>
<tr>
<th>Channel</th>
<th>pp</th>
<th>pn</th>
<th>YN</th>
</tr>
</thead>
<tbody>
<tr>
<td>dσ/dΩ</td>
<td>2080</td>
<td>3777</td>
<td>23(±39)</td>
</tr>
<tr>
<td>P</td>
<td>1275</td>
<td>814</td>
<td>a few</td>
</tr>
<tr>
<td>Other</td>
<td>1444</td>
<td>304</td>
<td>0</td>
</tr>
</tbody>
</table>

from Arndt et al. PRD28(83)97

from Dover & Feshbach Ann.Phys.198(90)321
Available Yp scatt. Data [2]  
- at 12 GeV KEK-PS -

☑ at 12 GeV KEK-PS

- E251, E289 for $d\sigma/d\Omega (\Sigma^+p & \Sigma^-p)$
- E452 for polarization ($\Sigma^+p & \Lambda p$)

(b) $\Sigma^+p \rightarrow \Sigma^+p$

350 $\leq P_{\text{lab}} \leq 750$ MeV/c

RGM-FSS $P_{\text{lab}}=450$ MeV/c
RGM-FSS2 $P_{\text{lab}}=450$ MeV/c

Ref. [12] (300 $< P_{\text{lab}} < 600$ MeV/c)
This work

E251, E289

E452

$\Sigma^-p \rightarrow \Sigma^-p$ elastic

400 $< P_{\Sigma^-} < 700$ MeV/c

Jülich
FSS

E289
Baryon-Baryon potential

\[ V(r) \text{ [MeV]} \]

\[ S_0 \]

-40 -20 0 20 40

\[ \pi - \Sigma + \Sigma - \Sigma_0 \]

\[ \Sigma^- \Sigma \Sigma^0 \Sigma^+ I_3 \]

\[ n \rightarrow 0 \rightarrow p \]

\[ \Sigma^- \Sigma^0 \Sigma^+ \]

\[ \Sigma^- \Sigma^0 \Sigma^+ \]

OBE
- HC, \( \omega \), \( \rho, \sigma \), \( \pi \), \( \ldots \)

QCM
- (\( \lambda, \lambda \))\( (\sigma, \sigma) \)
- Pauli
- Tokyo
- Kyoto
- Tubingen
- Flavor SU(3)
**Baryon-Baryon potential**

- **OBE**
  - Paris
  - Nijmegen
  - Bonn-Julich

- **QCM**
  - (l·σ)(s·σ)
  - Pauli
  - Tokyo
  - Kyoto
  - Tubingen

- **Flavor SU(3)**
Experimental Objectives at J-PARC

- S = -2

Anti-symmetric spin-orbit

\[ M = a + c (\alpha_n^1 + \alpha_n^2) + b (\alpha_n^1 - \alpha_n^2) + m\alpha_n^1\alpha_n^2 + g(\alpha_p^1\alpha_p^2 + \alpha_K^1\alpha_K^2) + h(\alpha_p^1\alpha_p^2 - \alpha_K^1\alpha_K^2) \]

\[ I_0 P_y = 1/4 \operatorname{Tr}(M M^T \sigma_n^1) = 2 \operatorname{Re}[(a+m)c^* + (a-m)b^*] \]

( \( I_0 A_y = 1/4 \operatorname{Tr}(M \sigma_n^2 M^T) = 2 \operatorname{Re}[(a+m)c^* - (a-m)b^*] \) )
Calculation by Models

S=-2
\( \Xi^-p \rightarrow \Lambda \Lambda, \Xi^-p \rightarrow \Xi^-p \)

Polarization observables
(≈ Anti-symmetric spin-orbit)

\( \Sigma^+p \rightarrow \Sigma^+p \)
\( P_\Sigma(\theta) \)
\( \rho_\Sigma = 450 \text{ MeV/c} \)

\( \Xi^-p \rightarrow \Xi^-p \)
\( P_\Xi(\theta) \)

\( \Delta(\sigma) \approx 10\% \)

\( \Delta(\text{pol}) \approx \text{a few - 10\%} \)
“double” scattering & decay (self-polarimeter)

- Production $\pi^+ + p \rightarrow K^+ + \Sigma^+$ (CH)n
- Scattering $\Sigma^+ + p \rightarrow \Sigma^+ + p$ (CH)n
- Decay $\Sigma^+ \rightarrow p + \pi^0$ (51.57 %, $\alpha = -0.980$)
  $\Sigma^+ \rightarrow n + \pi^+$ (48.30 %, $\alpha = 0.068$)

Mean range of related charged particles...

- $\Sigma^+$ (incident) 8 mm
- $\Sigma^+$ (scattered) 5 mm
- p (recoil) 18 mm
- p (decay) 19 mm
- $\pi^+$ (decay) 44 mm
“double” scattering & polarimeter

The Polarimeter
“MUSASHI”

1982-1987
Experiments at KEK-PS

Heart of experiments (DUMAS & MUSASHI ≈ SciFi & IIT)

Scintillating Fiber (or Liquid Scintillator) with IIT-CCD Camera triggered by Spectrometer system
Experiments at KEK-PS

IIT & Triggers
- Phosphor Decay Time
  - a few µs
- Decision Time
  - several hundreds ns
- CCD image handling
  - several tens ms

Double trigger system for IIT

Beam rate ≤ $10^5$Hz
Image rate ≤ 10Hz
Requests & Works at J-PARC

for $\Xi^-p(S=-2), \Sigma^+p$ and $\Lambda p$ (polarization obs.)
— reasonably doable at J-PARC

☑ Requests
  ▶ Separated beam line around 1.5 - 1.8 GeV/c
  ▶ $K^-$ intensity $10^7$/sec with $K/p > 1$
  ▶ Liquid hydrogen facility

☑ Work
  ▶ Realistic Optimization of Setup
  ▶ Background estimation (physical & instrumental)
  ▶ Fast imaging device
  ▶ Trigger consideration

Improve “rate limit”
$10^5$Hz $\rightarrow$ $10^7(8)$Hz
Prototypes

- **ON THE OPTOELECTRONIC SCHEME OF A SCINTILLATING FIBRE TRACKING DETECTOR FOR FUTURE LARGE HADRON COLLIDER**
  J.P.Fabre, T.Gys and M.Primout: CERN/EF/4147H/TG/mnb 8 November 1988

- **THE BASIC PRINCIPLE OF A VACUUM IMAGE PIPELINE**

- Conceptual design for an optoelectric delay line

- **OPTOELECTRONIC DELAY FOR THE READ-OUT OF PARTICLE TRACKS FROM SCINTILLATING FIBRES**
  T. Gys et al.: CERN/EF 89-25, DERN/LAA-SF91-3, CERN/DRDC 92-42

- **OPTO-ELECTRIC DELAY TUBES**
  T. Gys et al.: DERN/LAA/SF 90-20

- **A high-speed gateable image pipeline**
  Berkovski et. al. NIM A380(1996)537
**High-Speed Image Delay Tube**

- What is it?

**LENGTH: 60 cm**

**PHOTOCATHODE**

**G1** **G2** **G3** **G4** **G5**

**READOUT**

**Electron drift velocity ≈ 1 m/µs**
1. Visit Dr. T.Gys at CERN in June ... learn things and hints ...

2. examine the structure of a tube, 
   and decide to assemble as a sectional detector
   ... drawing & drawing & ...

   ▶ Input photocathode and output phosphor, grids, field-shaping 
     electrodes, ceramic insulation, solenoid magnet, pulse 
     generator, ...

3. now assembling and test will be started soon ...
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3. now assembling and test will be started soon ...
Yp scattering exp. at J-PARC

<table>
<thead>
<tr>
<th>Channels</th>
<th>T</th>
<th>Observables</th>
</tr>
</thead>
<tbody>
<tr>
<td>p,n</td>
<td></td>
<td></td>
</tr>
<tr>
<td>pp → pp</td>
<td>1</td>
<td>dσ/dΩ, Py, D, ..</td>
</tr>
<tr>
<td>pn → pn</td>
<td>1, 0</td>
<td>dσ/dΩ, Py, D, ..</td>
</tr>
<tr>
<td>Λ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Λ p → Λ p</td>
<td>1/2</td>
<td>dσ/dΩ, Py, AyT, D</td>
</tr>
<tr>
<td>Σ⁺</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Σ⁺ p → Σ⁺ p</td>
<td>3/2</td>
<td>dσ/dΩ, Py, AyT, D</td>
</tr>
<tr>
<td>Σ⁻</td>
<td></td>
<td></td>
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<tr>
<td>Σ⁻ p → Σ⁻ p</td>
<td>3/2, 1/2</td>
<td>dσ/dΩ, Ay</td>
</tr>
<tr>
<td>Σ⁻ p → Λ n</td>
<td>1/2</td>
<td>dσ/dΩ, Py</td>
</tr>
<tr>
<td>Ξ⁻</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ξ⁻ p → Ξ⁻ p</td>
<td>1, 0</td>
<td>dσ/dΩ, Py, AyT (, D)</td>
</tr>
<tr>
<td>Ξ⁻ p → Λ Λ</td>
<td>0</td>
<td>dσ/dΩ, Py, AyT (, D)</td>
</tr>
</tbody>
</table>
Yp scattering exp. at J-PARC

with a CDC tracking detector

SciFi & HSIDT

Y^-p \rightarrow \Lambda \Lambda

- Target 5 cm wide x 20 cm long
  - A: production 1 cm Liq. Hydrogen
  - B: degrader 0.5 cm Tungsten
  - C: scattering 2 cm Liq. Hydrogen

- K^+ spectrometer
  - \theta_{spectrometer} \sim 25^\circ at center

- K^- beam (assumption @ LOI)
  - Intensity \(10^7\) K/sec
  - Momentum 1.7 GeV/c
  - Size
    - \sigma_{horizontal} 15 mm
    - \sigma_{vertical} 1 mm

\begin{tabular}{c|c|c}
  & Liquid Hydrogen & Tungsten \\
  P_\Xi just before decay [MeV/c] & & \\
  \hline
  0 & & \\
  400 & & \\
  800 & & \\
  1200 & & \\
\end{tabular}
$a$ simulation

- K- intensity $[s^{-1}]$ 10$^7$
- Number of Hydrogen $/[cm^2]$ 8.5$\times$10$^{23}$
- Spectrometer $[deg]$ 25
- Spectrometer TOF $[m]$ 5
- Trigger rate (K$^+$) $[s^{-1}]$ 11
- Momentum of $\Xi^-$ $[MeV/c]$ 300 - 1100

$\Xi^-p \rightarrow \Lambda\Lambda$

- reaction rate $[s^{-1}]$ 0.009 0.0043
- 100 days 78000 37000
- Detectable number 2300 550
Designing a Yp experiment

- Realistic Optimization of Setup for selected Yp channel
- Background estimation (physical & instrumental)
- Fast imaging device
- Trigger consideration

High-Speed Image Delay Tube (made in Japan) will soon be available

- Delay capability, Intrinsic time resolution of ≈10ns,
  Data reduction ≈10^{-3}, Space resolution of ≤30µm,
  Good efficiency ...

- Next step: Fast readout device keeping good space resolution
  with large area
極限状態の物理

弾性散乱
≈極低温反応

Yp弾性散乱
≈これからの極低温反応@strangeness

“二回散乱”と“偏極”