次世代(K-,K+)反応用
高分解能磁気スペクトロメータ
の光学設計

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2010/03/22
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Introduction -- 1

There is still a full uncertainty about “$S=-2$” world.

It’s important to understand $\Xi-N$ and $\Lambda-\Lambda$ interaction, and also $\Xi N-\Lambda\Lambda$ coupling dynamics.

- Unified description of $B-B$ int. based on $SU_f(3)$
- Strange nuclear matter in astrophysics

We will perform $\Xi$-hypernuclear Spectroscopy.

Beyond E05,

Direct Production of Double-$\Lambda$ hypernuclei using ($K^-,K^+$) reaction
Introduction -- 2

Direct Production of Double-$\Lambda$ Hypernuclei using ($K^-,K^+$) reaction

- Missing mass spectroscopy is possible.
- Statistical study is possible. c.f.) emulsion
- can observe excited states of double-$\Lambda$ hyp.
- sensitive to $\Xi N$-$\Lambda\Lambda$ coupling strength.

But,

✓ Cross section may be very small.

No peak were observed.
Upper limit : 6~10 nb/sr

P.Khaustov et al., PRC61(2000)054603

K.Yamamoto et al., PLB478(2000)401

( one order of magnitude lower than $\Xi$-hyp. )
Theoretical Calculation for $^{16}_{\Lambda\Lambda}C$, via $\Xi^{-}$ doorways in the $^{16}O(K^{-},K^{+})$ reaction at 1.8 GeV/c

Two-step process

One-step process

Theoretical Prediction

20aBD-10
T. Harada, Y. Hirabayashi, A. Umeya

Assume 6M $K^{-}$/spill,

Yield = 30~60 events / 100 days

(3g/cm$^2$ target, 20msr, 50% $K^{+}$ decay, tracking eff.$\sim$0.5)
In order to observe peak structure precisely and compensate lack of statistics, we need a **High-Resolution Spectrometer** at J-PARC!!
Requirements -- 1

Requirements for the Spectrometer

- Especially for $(K^-, K^+)$ reaction @ 1.8 GeV/c
  - Double-$\Lambda$ hypernuclei and of course $\Xi$-hypernuclei
- High-Resolution: $\sim 5 \times 10^{-4}$ (corresponds to $\Delta M_{\text{FWHM}} < 1.5$ MeV)
- Reasonable Acceptance: $\sim 20$ msr
- Path Length as short as possible:
  
  \[ K_{\text{survive}} = 50\% \rightarrow 6.8 \text{ m} @1.3 \text{ GeV/c} \]
**Requirements -- 2**

--- Central Momentum & Momentum Acceptance ---

\[ K^- + ^{12}\text{C} \rightarrow K^+ + X \]

\( p_{\text{init}} = 1.8 \text{ GeV/c} \)

\[ ^{12}\Lambda\Lambda\text{Be} \]

\[ ^{10}\text{Be} + \Lambda + \Lambda \]

\[ ^{11}\text{Be} + \Xi^- \]

\[ \theta = 0 \text{ deg} \]

\[ K^- + p \rightarrow K^+ + \Xi^- \]

\( p_{\text{scatt}} = 1.3 \text{ GeV/c} \)

**Scattered \( K^+ \) Momentum [MeV/c]**

- 1300
- 1400
- 1500

**Required Momentum Acceptance** = 1.25 ~ 1.45 GeV/c
Optics Design
Primary Optics Design

- At first, we selected standard QQD-type configuration.
  (There is existing high-resolution spectrometer: HKS@JLab)

- D-magnet: 1.5 T (Normal Conducting), 3 m (→ 60° bend), 20 cm gap

- Point-to-point focus
  ← For resolution & acceptance

- Adjusted by mainly B of Q-magnets

- Geometry of the elements should be fixed by more specific design later. → Not so concerned now.
Result of Optics Calculation -- 1

Point-to-Point Focus

8.2 m

x' = y' = 5°

Q1  Q2  D

1st order

TRANSPORT
## Result of Optics Calculation -- 2

### Transfer Matrix (1st order)

<table>
<thead>
<tr>
<th></th>
<th>( x )</th>
<th>( x' )</th>
<th>( y )</th>
<th>( y' )</th>
<th>( l )</th>
<th>( \delta )</th>
</tr>
</thead>
<tbody>
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<td>( x )</td>
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<td>0.00000</td>
<td>0.00000</td>
<td>3.14436</td>
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<tr>
<td>( x' )</td>
<td>-8.39270</td>
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<td>( y )</td>
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<td>-7.55338</td>
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<tr>
<td>( y' )</td>
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<td>-12.91958</td>
<td>-0.13239</td>
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<tr>
<td>( l )</td>
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<td>1.00000</td>
<td>-0.51019</td>
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<tr>
<td>( \delta )</td>
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<td>0.00000</td>
<td>0.00000</td>
<td>0.00000</td>
<td>1.00000</td>
</tr>
</tbody>
</table>

**Point-to-Point Focus**

- Magnification: -0.71
- Dispersion: 3.14 cm/%
- \( \sigma_x = 300 \mu m \)

**Equation**

\[
\Delta \delta = \sqrt{\left(1 + R_{11} \right)^2 \sigma_x^2 + R_{12}^2 \sigma_\theta^2} \div R_{16}
\]

**Results**

- \( \Delta p/p = 2.8 \times 10^{-4} \) (FWHM)
- \( \Delta p = 0.36 \text{ MeV/c} \) @ \( p = 1.3 \text{ GeV/c} \)
## Missing Mass Resolution

\[ \Delta M^2 = \Delta_{\text{Beam}}^2 + \Delta_{\text{Scatt}}^2 + \Delta_\theta^2 + \Delta_{E_{\text{strag}}}^2 \]

<table>
<thead>
<tr>
<th></th>
<th>( \Delta_{\text{Beam}} )</th>
<th>( \Delta_{\text{Scatt}} )</th>
<th>( \Delta_\theta )</th>
<th>( \Delta M ) w/o ( \Delta E_{\text{strag}} )</th>
<th>( \Delta E_{\text{strag}} )</th>
<th>( \Delta M )</th>
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</thead>
<tbody>
<tr>
<td>( K^- + {}^{12}\text{C} \rightarrow K^+ + X )</td>
<td>0.56</td>
<td>0.45</td>
<td>0.10</td>
<td>0.73</td>
<td>1.0</td>
<td>1.24</td>
</tr>
<tr>
<td>( K^- + {}^{12}\text{C} \rightarrow K^+ + X )</td>
<td>0.56</td>
<td>2.27</td>
<td>0.10</td>
<td>2.34</td>
<td>2.0</td>
<td>3.08</td>
</tr>
</tbody>
</table>

**Sufficiently Small!!**

\( \Delta p_b/p_b = 3.3 \times 10^{-4} \) (K1.8BS)
\[ \Delta \theta = 5 \text{ mrad} \]

\( \Delta M = 1.24 \text{ MeV} \) (FWHM) @ \( \theta = 5^\circ \)

3 g/cm\(^2\) Target

**Dominant contribution is Energy-loss Straggling!!**

**c.f.) In the case of SKS**

\( K^- + {}^{12}\text{C} \rightarrow K^+ + X \)
Primary Optics Design

Focus Point

D

pole rot. = 0 deg

B = 1.5 T
60° bend
gap = 20 cm

pole rot. = 0 deg

Horizontal Focus
B = 0.77 T
half-aperture = 14.5 cm

Q2

Vertical Focus
B = 0.85 T
half-aperture = 12 cm

Q1

p₀ = 1.3 GeV/c

1 m
Primary Optics Design

Total Length = 8.2 m

$K_{\text{survive}} = 43\%$

Acceptable !!

$p_0 = 1.3$ GeV/c
Acceptance Calculation

\[ p_0 = 1.3 \text{ GeV/c} \]

20 msr @ 1.3 GeV/c \( \pm 15\% \) (1.1~1.5 GV/c)

*Enough Acceptance!! c.f.) requirement was 1.25~1.45 GeV/c*
Summary

We attempt to make a primary optics design of the high-resolution spectrometer for the next generation (K⁻, K⁺) reaction. We could achieve the requirements.

- Momentum Resolution ~ 3 x 10⁻⁴ (FWHM)
- Acceptance ~ 20 msr @ 1.3 GeV/c ±15 %
- \( K_{\text{survive}} = 43 \% \)

Prospects

- This result is only a primary design yet. → must be improved !!
  - Is this configuration really the best answer ?
  - How about other configurations ?
- Need more discussion for detail design .
  - optics design & mechanical design
    ( alignment, coil, yoke, cooling, etc...... )