Charge exchange reaction(s), hadronic probe for neutrino-nucleus reactions

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Contents

• (n,p)-type Charge Exchange Reaction
• Development of CNS Active Target
Neutrino-nucleus reaction

\[ \bar{\nu}_e + Z A \rightarrow e^+ + Z_{-1} A \quad \text{GT+ (n,p)} \]
\[ \nu_e + Z A \rightarrow e^- + Z_{+1} A \quad \text{GT- (p,n)} \]
\[ \nu + Z A \rightarrow \nu' + Z A^* \]

Charged Current vN reaction

=> Charge Exchange Reaction
Charge Exchange Reaction

\[ C = \frac{1}{\sqrt{(2 T_o + 1)(T_o + 1)}} \]

n-rich \quad (p,n) \quad (n,p)

p-rich \quad (n,p) \quad (p,n)

N=Z \quad (n,p)/(p,n)

In N=Z nuclei, \( B(GT^+) \sim B(GT^-) \)?

cf. Sasano-san

G.A. Needham et. al, NPA385(1982)349
Electron Capture Rate of Iron-group Nuclei

- Life time and scale of Supernova explosion
- Nucleosynthesis in Supernova explosion

\[ \bar{\nu}_e + p \rightarrow e^+ + n; \quad n + ^{64}\text{Ge} \rightarrow ^{64}\text{Ga} + p; \quad ^{64}\text{Ga} + p \rightarrow ^{65}\text{Ge}; \ldots \]

- B(GT+) strengths above the electron capture threshold in Iron-group and heavier (\(^{56}\text{Ni}, ^{64}\text{Ge}\) etc.) nuclei are needed
- Gamow Teller (GT) transition
  - \(\Delta T=1, \Delta S=1, \Delta L=0\)
Measurement of B(GT+) strengths

- $\beta^+$/Electron Capture
- below $Q_{\beta/EC}$
- gives the absolute value of B(GT+) from log$ft$ value

- (n,p) type charge exchange (CX) reactions
  - bound and unbound excited states
  - gives a relative strength distribution
  - needs “unit cross section”

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$^{56}\text{Ni}$ $\beta^+/\text{EC}$ $^{56}\text{Co}$

K. Langanke et al., PLB436(1998)
(n,p) type CE reactions

- normal kinematics
  - (n,p), (d,^{2}\text{He}), (t,^{3}\text{He})
- inverse kinematics
  - (n,p), (d,^{2}\text{He}), (t,^{3}\text{He}), (^{7}\text{Li},^{7}\text{Be}\gamma)
- n/t targets are difficult
- Extraction of GT strength
  - \Delta T = 1, \Delta S = 1 are tagged by reaction selectivity
  - \Delta L is extract or decomposed by using angular distribution of differential cross section
\((^7\text{Li}, ^7\text{Be}\gamma)\)

- Invariant mass and/or gamma spectroscopy
  - Inv. mass for unbound states
  - Gamma for bound states
- GT Transition is tagged by 0.43 MeV gamma ray
  - Needs good S/N for gamma detection
- Angular resolution of 0.1 deg in lab. frame is required
- Resolution of excitation energy depends on mainly angular resolution
(d,\(^2\)He)

- Missing mass spectroscopy in inverse kinematics
- Momentum of \(^2\)He is reconstructed by invariant mass
- Bound and unbound states are measurable at the same time
- GT Transition is tagged by \(^1\)S\(_0\) proton pair (called \(^2\)He)
- \(\delta\)Ex depends on angular and energy resolution
- S/N becomes better due to vertex measurement

C. Bäumel et al. (2003)
2p system

relative energy distribution

\[ \varepsilon < 0-2 \text{ MeV} \quad ^1S_0 \text{ is dominant} \]

Migdal-Watson formulation  
T. Onishi, D-thesis
Kinematics in inverse kinematics

- $^2H(^{56}\text{Ni},^{56}\text{Co})^2\text{He}$
  - most recoils emitted around 80-90 deg. (sideway)
  - $\delta \theta \approx 14$ mrad for $dE_x$ = 1 MeV @ $E_{\text{lab}} = 1$ MeV
  - $\delta E_x \approx 0.5$ MeV
- angular resolution is important
  - multiple scattering
Range of low energy recoiled particles

Ranges in Deuterium Gas

We need to use gas target and vertex detector
Configuration of CNS Active Target

- 400 pads read out each pad
- 10 cm
- 21 kV/25 cm
- 60 Nals
- Election multiplier: 3 GEMs discharge occurs with >300 kpps beam
- 1-atm. Pure D₂ gas
- 127 pads center (beam)
- 180 cm
Requirement from kinematics

$\delta \theta_{\text{lab}} \sim 1-2\text{deg}$

$\delta T_{\text{lab}} \sim 10\%$

$\theta_{\text{CM}} > 1\text{deg} \Rightarrow \text{range} > 15\text{mm} \quad (\text{TKE} > 0.3\text{MeV})$

$T_{\text{recoil}} \quad (\text{MeV/u})$

$\theta_{\text{CM}} \quad (\text{deg})$

Ex=1MeV

G.S.

Tracked and Reach at NaI

Stop in TPC
Test exp. at HIIMAC

56Fe
250MeV/u
300kpps
limited by stability of GEM

60x2-31x31x70 mm³ NaI
Td>2MeV
Tp>1.6MeV

1-10x10x25 cm³ cage
Td~0.3-0.8MeV
Tp~0.3-0.6MeV
dE>10keV/10mm
Td<16MeV
Tp<8MeV

µHodoscope
30x2(XY)-1x1x30mm³ PL
Timing
Position reference

Deuterium gas with 3 GEMs
Setup photo

- preamp+buffer
- mylar 100µm
- Al 100µm
- NaI
- μHodoscope
- $^{56}\text{Fe}$ 250MeV/u
Typical Event

- 100kPa D₂
- 20-21kV at top plate of field cage
- 3 GEMs
- recoiled event found
- total 30-hr data
- data size is not so large since lower-intensity beam is used than expected

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Summary

• B(GT+) measurement w/ (n,p) type reaction
  • (d,²He) by measuring two protons which have small relative energy
• Active Target is under development
  • designed so as to detect low (>300 keV) protons
• test experiment w/ pure D₂ target was done