Hadron-Beam Based Physics at a Neutrino Factory Complex

(Who want 10 MW class high-intensity beams other than neutrino and muon physicists?)

+ a few slides on the J-PARC Status if time allows

Shoji Nagamiya

KEK

June 9, 2003
Research Areas with High Intensity Beams

- Neutrino Physics: Already covered by many speakers
- Muon Physics: See the talks by A. Baldini and K. Ishida
- Kaon Physics:
  - Studies of double-strangeness hypernuclei, rare decays.
- Heavy-Ion Physics:
  - Search for strange matter, usage of radioactive nuclear beams far from the stability line.
- Antiproton Physics:
  - Creation of anti atoms, slow/trapped antiprotons.
- Hyperon Beam Physics:
- Physics with Other Beams such as Polarized Protons:
- Neutron Sciences:
  - Neutron scatterings to study dynamical structure of proteins and DNA, spin excitation in a magnetic alloy, etc.
- Accelerator Driven Nuclear Transmutation:
  - Usage of high-flux neutrons to change lifetimes of radioactive nuclei.
Various Beams Obtained by p+A Collisions
Three Dimensional Nuclear Chart

S = 0
S = -1
S = -2

Neutron Number

Double Hypernuclei
Ξ Hypernucleus
Λ, Σ Hypernuclei

Strangeness

Proton Number

Neutron Number
S = -2 Hypernuclei

Energy Spectrum of S=-2 systems

- Hypernuclei
- Spectroscopic studies on S=-2 systems

\[(K^-, K^+)\]: Hypernuclei

\[(K^-, K^+)\] events/MeV/day for 1 MW beams

\[(K^-, K^+)\] double-hypernuclei (g.s.)

\[(K^-, K^+)\]: double-hypernuclei (excited states)

HyperBall

\(\Xi\)-scattering:

- Hypernuclei

Strangelet and $H^0$

Strangelet $Z(u) = +2/3 \, e$
$Z(d) = -1/3 \, e$
$Z(s) = -1/3 \, e$

Strangelet $Z_{\text{strangelet}} = \frac{2n_u-n_d-n_s}{3} \, e$ 
$\approx \frac{(n_u-n_s)}{3} \, e \geq 0$

$\frac{Z}{\Lambda}$ \text{strangelet} $\approx \frac{(n_u-n_s)}{3(m_u+m_d+m_s)}$ \text{e: small positive}

$Au + Au$ at 10 A•GeV: $n_s \approx$ a few 100 !

$H^0$ (the most simple strangelet)

spin = isospin = charge = 0

Note

If $m_{\Lambda\Lambda} > m_{H^0} \rightarrow H^0$ stable
If $m_{\Lambda\Lambda} < m_{H^0} \rightarrow \Lambda\Lambda He$ stable
Strangelet and Heavy-Ion Collisions

RHIC, LHC
100 A·GeV Collider

\[ T \approx 150 \text{ MeV} \]
\[ \varepsilon \approx 1 \text{ GeV/fm}^3 \]

Hadronic Matter

Quark-Gluon Plasma

Heavy-ions at NuFact

Normal Nucleus

10-100 A·GeV

\[ q, \bar{q} \quad \text{pion} \quad (r \approx 0.6\text{fm}) \]

\[ q, \bar{q} \quad \text{nucleon} \quad (r \approx 0.8\text{fm}) \]

\[ \frac{\rho}{\rho_0} \approx 5-20 \]

\[ (1.8/0.8)^3 \approx 10 \]
Creation of Radioactive Isotope (RI) Beams

Accelerated Heavy-Ion Beams

N/P = 1.6 for $^{238}\text{U}$

Proton or Nuclear Target

N = Neutron
P = Proton

Break-up $\rightarrow$ Formation of Short-Lived Nucleus

Neutron-Rich Radioactive Beams

RIKEN, GSI, etc.

CERN, TRIUMF, etc.
Nuclei on the r-Process Path

\[ ^{132}\text{Sn} \]

\( \Gamma_\beta \) must be < \( \Gamma(n,\gamma) \)

Need precise measurement of \( \sigma(n,\gamma) \) with UCN
(\( L > 10^{27} \text{ s}^{-1}\cdot\text{cm}^{-2} \))

\[ ^{122}\text{Zr} \]

gnd st. property
\( \Gamma_\beta, I_{\text{delayed neutron}}, S_n, \) etc.

Creation of \( ^{122}\text{Zr} \) via fragmentation reaction with \( ^{132}\text{Sn}-\text{Radioactive Beams} \)
(\( I(^{132}\text{Sn}) > 10^{11} \text{ pps} \))

K. Miyatake, et al.
ATHENA Experiment at CERN

Goal: CPT Test down to $10^{-14}$


R. Hayano, et al.

Electric trapping of antiprotons

antiproton → positron → antihydrogen

Nested trap

Si strip detectors

511 keV gamma

2.5 cm mixing trap electrodes

charged tracks

Trap potential (V)

antiprotons

positrons

Length (cm)
High resolution spectroscopy of \( H \) and \( \bar{H} \)
- \( f_{1S-2S}(H) = 2\,466\,061\,413\,187\,103\,46 \) Hz  
  Niering et al. PRL84(00)5496
- \( f_{1S-2S}(\bar{H}) = ? \)

Hyperfine transition: magnetic moment
- \( f_{HF}(H) = 1.42\,040\,575\,176\,67 \) GHz (hydrogen maser)
- \( f_{HF}(\bar{H}) = ? \) (1000 ppm --> 1 ppm)

Magnetic trapping of antiprotons
Much colder antiproton trap

Y. Yamazaki, et al.
Uniqueness of Neutron Scattering

X-rays interact with electrons.
→ X-rays see high-Z atoms.

Neutrons interact with nuclei.
→ Neutrons see low-Z atoms.

Hen Egg-White Lysozyme

Neutron Scattering

X-rays

Water molecules
Observed with neutrons

N. Niimura, et al.
Movement of H atoms

High-intensity pulse neutrons

Low-intensity or Reactor pulse neutrons
One of unsolved issues in the 20th Century...

Mechanism of High-Tc S.C.
Spin-mechanism (New scenario) or phonon-mechanism (BCS)?

Polarized neutrons can separate spin excitations from phonon excitations!

Intensity for polarized protons < 10% of intensity for unpolarized neutrons

High intensity protons (10 MW) are needed!!!

A strange excitation mode is observed in the high-\( T_c \) Superconducting phase.

M. Arai, et al.
Biological Examples of Neutron Scatterings

\[
\begin{align*}
\text{nH}^+ & \quad \text{Proton Transportation} \quad \text{Energy Storage} \\
\text{4H}^+ & \quad \text{Water Molecule} \quad \text{DNA Recognition} \\
\text{Water} & \\
\text{Water} & \\
\text{DNA} & \\
\text{Cytochrome C Oxidase} & \\
\text{Membrane} & \\
\end{align*}
\]

This protein plays the key role for the creation of energy in animal body.

Protons in Proteins                           Water Molecules in DNA

Which protons participate?

Measurement up to 300 nm
requires 10 MW beams!
Coherent Structure Function with Pol. n

\[ S(q, \omega) \propto \left| q \cdot C_{i,j} \right|^2 \]

where

- \( q \) : Scattering Vector
- \( C_{i,j} \) : Oscillation Amplitude Vector between \( i \)-th and \( j \)-th atoms

Mechanism of dissolving a sugar in protein ???

Correlation studies with polarized neutrons

N. Niimura, et al.
3 Dimensional Movie for Industrial Usage

Real-time 3D Neutron Imaging

- Real-time 3D Imaging of Bulky Body Containing Light Elements
- Elements Identification in Bulk
- Industrial Application
  - Factory Product Testing
  - Aircraft, Aerospace Vehicle
  - Automobile

Y. Morii, et al.

10 MW allows 3-D studies

Hyper- JSNS

Real-time Strain Distribution Measurement

Variation of Strain Distribution

- $t = t_0$ (before ignition) $\rightarrow$ $t = t_1$ (after ignition) $\rightarrow$ $t = t_2$......

- Large Size Components
- In-situ Measurement in Operating Condition
- Time-sliced Measurement
Accelerator-Driven Transmutation (ADS)
Thermal Power: $P_{th}$

To transmute all MA produced in Japan, thermal power ($P_{th}$) of about 3200 MW is necessary in ADS. When we use 1 GeV proton beam, $P_{th}$ is proportional to beam power $P_b$.

$$P_{th} = P_b \times M$$

We usually use $M = 40$.

Therefore, $P_b = 80$ MW is necessary.

"4 accelerators of $P_b = 20$ MW" is our reference case.
J-PARC = Japan Proton Accelerator Research Complex
Phase 1 and Phase 2

- Phase 1 + Phase 2 = 189 billion Yen (= $1.89 billion if $1 = 100 Yen).
- Phase 1 = 133.5 billion Yen for 6 years (= 2/3 of 189 billion Yen).
- Construction budget does not include salaries.
Construction Budget for Phase 1

- Flat Budget

- Fiscal Year

- Start

- Now

- Beam

- BYen

- Integrated Expenses (incl. future plans)

- Amount of Purchase

- Committement (incl. future plans)

- KEK

- JAERI

- 100%

- 50%

- 100%

- 50%