Detectors for Nuclear Physics

Susumu Shimoura
CNS, University of Tokyo
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  – J-PARC & RIBF

• Detectors for Elementary Particles
  – PANDA at FAIR
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  – Gamma-ray tracking array (AGATA/GRETA & CNS-GRAPE)

• Heavy-ion Detectors
  – BigRIPS/SHARAQ/SAMURAI at RIKEN
    • 3-15000 (dE/dx)_{min} ; v < 0.7c

• Summary
J-PARC = Japan Proton Accelerator Research Complex

Materials and Life Science Experimental Facility

Hadron Beam Facility

Nuclear Transmutation (Phase 2)

Linac (330m)

3 GeV Synchrotron (25 Hz, 1MW)

50 GeV Synchrotron (0.75 MW)

Neutrino to Kamiokande

Joint Project between KEK and JAEA
Hadron Hall
Experimental Programs

$K_L^0 \to \pi^0 \nu \bar{\nu}$

K meson
Implantation of Kaon and the nuclear shrinkage

$J/\Psi$ implantation?
RI=Radioactive Isotope  B=Beam  F=Factory
Mass production of radioactive isotopes as secondary beams
RI=Radioactive Isotope  B=Beam  F=Factory
Mass production of radioactive isotopes as secondary beams
Facility for Antiproton and Ion Research

GSI, Darmstadt
- German National Lab for Heavy Ion Research
- Highlights:
  - Heavy ion physics
  - Nuclear physics
  - Atomic & plasma physics
  - Cancer research

FAIR: New facility
- Rare Isotope Beams
- Heavy ions
- higher intensities & energies
- Antiprotons at HESR

Overview by SMYRSKI, Jerzy
High Energy Storage Ring

HESR Parameters
- Injection of $p$ at 3.7 GeV
- Slow synchrotron (1.5-15 GeV/c)
- Storage ring for internal target
- Luminosity up to $L \sim 2 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$
- Beam cooling (stochastic & electrons)

Resonance Scan
- Energy resolution $\sim 50$ keV
- Tune $E_{CM}$ to probe resonance
- Get precise $m$ and $\Gamma$

Overview by SMYRSKI, Jerzy
Physics Goals of PANDA

**Hadron Spectroscopy**

*Experimental Goals:* mass, width & quantum numbers $J^{PC}$ of resonances

*Charm Hadrons:* charmonia, D-mesons, charm baryons
  - Understand new XYZ states, $D_s(2317)$ and others

*Exotic QCD States:* glueballs, hybrids, multi-quarks

*Spectroscopy with Antiprotons:*
  - Production of states of all quantum numbers
  - Resonance scanning with high resolution

**Nuclear Physics**

*Hypernuclei:* Production of double $\Lambda$-hypernuclei
  - $\gamma$-spectroscopy of hypernuclei, YY interaction

**Hadron Structure**

*Generalized Parton Distributions*
  - Formfactors and structure functions, $L_q$

*Timelike Nucleon Formfactors*

*Drell-Yan Process*

Overview by SMYRSKI, Jerzy
Detector Requirements

Physics benchmarks:
- Hybrid charmonium: e.g. 7 photons, PWA
- Charmonium decays: e.g. \( J/\Psi \rightarrow e^+e^- / \mu^+\mu^- \), or with \( \pi^0 \) & \( \gamma \)
- Charm mesons: Weak decays in \( K^0_S \) and \( K^\pm \)
- Hypernuclei: Hyperon cascades
- Wide angle Compton scattering: High energy photons
- Proton formfactors: Efficient \( e^\pm \) identification

Detector requirements:
- 4\( \pi \) acceptance
- High rate capability: \( 2 \times 10^7 \) s\(^{-1} \) interactions
- Efficient event selection \( \rightarrow \) Continuous acquisition
- Momentum resolution \( \sim 1\% \)
- Vertex info for D, \( K^0_S \), Y (\( c\tau = 317 \) \( \mu \)m for \( D^\pm \)) \( \rightarrow \) Good tracking
- Good PID (\( \gamma \), e, \( \mu \), \( \pi \), K, p) \( \rightarrow \) Cherenkov, ToF, \( dE/dx \)
- \( \gamma \)-detection 1 MeV – 10 GeV \( \rightarrow \) Crystal Calorimeter

Overview by SMYRSKI, Jerzy
Hyper Nuclear Physics at J-PARC
Systematic Study of Double hypernuclei

1. New-type Hybrid-Emulsion Experiment

J-PARC
A. pure K-beam (purity x3.5)
B. a large volume emulsion (x3)

2. Overall scanning
A. independent on counter data
B. fast scan of overall emulsion plates
C. Detect events with 3 vertices

10 times more than Hybrid method
• ~1000 double hypernuclei
• Measurement of ΛΛ biding energies

3. Theoretical calculation
Identification of
Spin, Parity, Level
of Double hypernuclei.

K. Nakazawa (Gifu Univ.)
1. New-type Hybrid-Emulsion Experiment

Double-sided Silicon Strip Detector (DSSD)

DSSD-emulsion hybrid system result of test experiment (140 MeV protons at RCNP)

(prototype)
Silicon: 32 x 64mm area, 300µm thick
50µm strip pitch -> 16µm resolution
readout; VA-chip

Incident angle (deg.)

Predicted accuracy of position on the emulsion (µm)

K. Nakazawa (Gifu Univ.)
# 2. overall scanning 🌀

(Fully automated image capture)

<table>
<thead>
<tr>
<th>Current Status of R&amp;D</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Camera:</strong> 100Hz (CCD)</td>
</tr>
<tr>
<td><strong>OS</strong> : Win2000 sp4</td>
</tr>
<tr>
<td><strong>CPU</strong> : 3.0 GHz 1.57GB RAM</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

1. More fast camera [1kHz]
2. x20 Lens => expansion of visual field [0.25x0.25 mm²]

=> faster system ×100

*K. Nakazawa (Gifu Univ.)*
2. overall scanning ② (automatic detection of double hypernuclei)

Detection of events with 3 vertices

original image
filtering + binary coded
contour tracing

thinning + Hough trans.

vertices detection

Time required ~ 6 sec/cycle [thinning~60%]

K. Nakazawa (Gifu Univ.)
Hyperball (Ge array for hypernuclear $\gamma$ rays)

Tohoku/ Kyoto/ KEK, 1998

- Large acceptance for small hypernuclear $\gamma$ yields
  Ge (r.e. 60%) x 14
  $\Omega \sim 15\%$, $\varepsilon \sim 2.5\%$ at 1 MeV

- High-rate electronics for huge background

- BGO counters for $\pi^0$ and Compton suppression

Resolution of hypernuclear spectroscopy:
1 MeV -> 2 keV FWHM
Hypernuclear $\gamma$-ray data

$^7\text{Li} (\pi^+, K^+\gamma)$ KEK E419
$^9\text{Be} (K^-, \pi^\gamma)$ BNL E930(98)
$^{10}\text{B} (K^-, \pi^\gamma)$ BNL E930(01)

$^6\text{Li} \rightarrow 1/2^+ 0$
$^7\text{Li} \rightarrow 1/2^+ 3.88$
$^9\text{Be} \rightarrow 3/2^+ 2.050$

$^{12}\text{C} (\pi^+, K^+\gamma)$ KEK E566

$^{11}\text{B} (\pi^+, K^+\gamma)$ KEK E518

$^{13}\text{C} (K^-, \pi^\gamma)$ BNL E929 (Nal)

$^{16}\text{O} (K^-, \pi^\gamma)$ BNL E930(01)

References:
- PRL 84 (2000) 5963
- PLB 579 (2004) 258
- PRC 73 (2006) 012501
- NPA 754 (2005) 58c
- EPJ A33 (2007) 243
- PRL 86 (2001) 4255
- PRC 65 (2002) 034607
- PRC 77 (2008) 054315
- PRL 93 (2004) 232501
- EPJ A39 (2007) 247
Hyperball-J (2011~)
A new generation Ge detector array for high radiation and counting rates
Usable with much higher intensity beams at J-PARC

The lower half

- **Ge crystal**
- **PWO counter**
- **Beam**
- **Mechanical cooler**

PWO background suppression counter

-> Faster signals for high counting rates

Mechanically-cooled lower temperature (~75K)
**Ge detector**
( > 90K by LN$_2$ cooling)

-> Suppress radiation damage

Russian doped PWO w/ cooled at -10°C

This is the first application of PWO in low energy (0.1~1 MeV) nuclear physics.

+ Faster readout electronics for waveform analysis under development
Hyperball-J
under assembly

Photo-peak eff. ~6% at 1 MeV
Ge counting rate limit: 100~200 kHz
Ge energy rate limit: 1~2 TeV/s

Lower half
Gamma-ray spectroscopy in low-energy nuclear physics

![Graph showing the evolution of gamma-ray detector technology from 1900 to 2025. The graph illustrates the discovery of radioactivity, the development of Geiger-Muller absorbers, the use of NaI, Ge(Li), Compton Suppression & HPGe, Gammasphere Euroball, and Ge Shell & Tracking. The y-axis represents measured relative intensity on a log scale, and the x-axis represents spin (h) and year. The inset graph shows the Yrast sequence in $^{156}$Dy with intensity $2^+ \rightarrow 0^+ = 1$. The calculated resolving power is a measure of the ability to observe faint emissions from rare and exotic nuclear states. This is illustrated in the left hand insert, which indicates the strong inverse relationship between resolving power and the experimental observational limit. Taken from the NSAC 2002 Long Range Plan document, page 132.]

GRETA White Paper
CONTRIBUTION TO THE NS AC LONG-RANGE PLAN

THE FUTURE OF GAMMA-RAY SPECTROSCOPY: GRETA, THE GAMMA-RAY ENERGY TRACKING ARRAY

December 2006

1. Management Advisory Committee
2. Contractor Project Manager
3. GRETINA Advisory Committee
4. Working Groups and Chairs

AGATA demonstrator
AGATA Technical Design Report
Gamma-Ray Energy Tracking Array
GRETA White Paper
Gamma-ray tracking (concept)

This figure illustrates the basic principles of Gamma-ray tracking. Instead of individually shielded Ge detectors and collimators, as in Gammasphere, a tracking array will consist of a closed shell of segmented Ge detectors. Pulse-shape analysis of signals from segments containing the interaction(s), as well as analysis of transient signals in adjacent segments, allows the determination of the three-dimensional locations of the interactions, and their energies. Tracking algorithms, which are based on the underlying physical processes such as Compton scattering or pair production, are able to identify and separate Gamma-rays and to determine the scattering sequence. Note, while the topmost drawings are to scale, to illustrate the dimensions of the arrays, the expanded drawing showing 4 individual detectors are not to scale. They are shown to illustrate the two different concepts, and the gain obtained by removing Compton suppressors and hevimet absorbers. Gamma-rays, which hit a Compton suppressor or an absorber, are lost for spectroscopic purposes.
Gamma-ray tracking (GRETA/AGATA)

Segmented Electrodes
Mirror-charge pulses give information on hit position

GRETA White Paper

This figure illustrates the basic principles of gamma-ray tracking. Instead of individually shielded Ge detectors and collimators, as in Gammasphere, a tracking array will consist of a closed shell of segmented Ge detectors. Pulse-shape analysis of signals from segments containing the interaction(s), as well as analysis of transient signals in adjacent segments, allows the determination of the three-dimensional locations of the interactions, and their energies. Tracking algorithms, which are based on the underlying physical processes such as Compton scattering or pair production, are able to identify and separate gamma rays and to determine the scattering sequence. Note, while the topmost drawings are to scale, to illustrate the dimensions of the arrays, the expanded drawing showing 4 individual detectors are not to scale. They are shown to illustrate the two different concepts, and the gain obtained by removing Compton suppressors and hevimet absorbers. Gamma rays, which hit a Compton suppressor or an absorber, are lost for spectroscopic purposes.

AGATA Technical Design Report
18x2 segmented Ge detectors (6cm$^\phi$ x 2cm$^t$)

- High Resolution
  - 2.5 keV intrinsic resolution for 1.3 MeV $\gamma$

- High Sensitivity
  - $\epsilon\Omega > 3\%$ for 1 MeV $\gamma$

- Position Sensitive
  - Resolution of Doppler Correction $\sim 2\%$

CNS GRAPE @RIBF
(Gamma-Ray detector Array with Position and Energy sensitivity)
Performance of GRAPE

Position from pulse-shape analysis

$^{32}$Mg with $\beta \sim 0.26$

Doppler-shift corrected
Digital Pulse Processing Circuit

For GRAPE:
• 8ch => 9ch + Sum(internal)
• Module with DC power
  Two cards ([9+1]*2) + One daughter card (for pos.)
  One module for One GRAPE detector

- Diff. + Pole Zero Amplification
  Course (digital)
  Fine (digital/analog)
  Anti-Aliasing low pas filter

- Digital Filtering
  Trapezoidal shaping
  -> Trigger (Fast), E (Slow)

100MHz 14bit
ADC
FPGA
CPU & Ethernet
Digital Pulse Processing Circuit for GRAPE
Digital Pulse Processing Circuit for GRAPE

Throughput

Throughput

Input Count Rate (Kcps)

Output Count Rate (Kcps)

分解能 (KeV)

計数率 (Kcps)

1 μs
2 μs
3 μs
4 μs
5 μs
6 μs
7 μs
8 μs
Data taking system

Digital signal Processor
APV7110 by TechnoAP

Digitizer + Digital Filtering (E, T) + Timestamp + Waveform data
Control / DAQ via Ethernet
RIBF at RIKEN
Exploration of the Limit of Existence

- Stable nuclei
- Unstable nuclei observed so far
- Drip-lines (limit of existence) (theoretical predictions)
- Magic numbers

4000 species to be produced (1000 more new isotopes)

- Ni ~0.1 particles/sec. (2007)
- by 10 pnA 350 MeV/u U-beam

- Neutron emission

- New Element
  - 278113
  - 04 July 23 18:55
  - 57 fb

- Ni 10 particles/sec. (goal) by 1 pμA

Projectile Fragmentation

In-flight U fission & P.F.
Superconducting Ring Cyclotron
World’s First and Strongest
K2600MeV
400 MeV/u Light-ion beam
345 MeV/u Uranium beam

BigRIPS In-flight Separator
World’s Largest Acceptance
9 Tm
Superconducting RI beam Separator
~250-300 MeV/nucleon RIB
Beam line detectors at BigRIPS
From light nuclei to heavy nuclei, up to U beam

\( \frac{dE}{dx} \sim 150 \text{ to } 15000 \ (dE/dx)_{\text{min}}. \)

- Beam transport / diagnosis
- Particle identification

\( \Delta E \text{-TOF-B}_\rho \text{ method with track reconstruction} \)

Primary beam (\( \sim 350 \text{MeV/u} \))

\[9 \text{ Tm} = 2.7 \text{ GeV/c}\]

T. Onishi (RIKEN)
Requirements for detectors

- **Timing resolution**
  - Plastic + PMT $\sim 0.1$ nsec (r.m.s)
  - F3–F7: 47m 120ns (300MeV/A)
    - TOF resolution $< 1 \times 10^{-3}$ (r.m.s)

- **Position resolution**
  - $\sigma < 1$ mm, Momentum dispersion 3300
  - B $\rho$ resolution $\sim 1 \times 10^{-3}$ (r.m.s)

- **$\Delta E$ resolution**
  - $\sigma \sim 2 \%$

- **A/Q resolution** $\sim 1 \times 10^{-3}$ (r.m.s)
- **Z resolution** $\sim 1\%$ (r.m.s)

- **Required area**
  - $240 \times 150 \text{ mm}^2$

- **Rate**
  - $\sim 10^6 \text{ Hz}$

T. Onishi (RIKEN)
Standard beam-line detectors

DL-PPAC (Position)

Plastic scinti. (Timing)

MUSIC (ΔE)

Si (ΔE)

Ge for isomer γ-decay measurement (Isomer PID)

Nal (TKE)

Intensity monitor (primary beams) @F0

Plastic scinti.

FCT T. Onishi (RIKEN)
Signal transport system with optical fiber

- We can transport with long distance (>100m)
- The electric ground level of the detector is isolated from that of the counting room
- It is easy to add a long delay time.

T. Onishi (RIKEN)
100 m Coaxial cable

100 m fiber cable

output
input

PPAC

output
input

NIM

T. Onishi (RIKEN)
Particle identification at BigRIPS

\[ Z \leftarrow \Delta E = f(Z, \beta) \quad A/Q = B\rho/\gamma\beta m_u \]

2008  U + Be 3 mm, Bρ = 7.99 Tm, ΔP/P = ±3%

Zr (Z=40)

\( \sigma_z : 5.5 \times 10^{-3} \)

A/Q resolution: \( 3.5 \times 10^{-4} \) (σ)

High enough to well identify charge states thanks to the track reconstruction!

T. Onishi (RIKEN)
SHARAQ

- **SHARAQ**
  = Spectroscopy with High-resolution Analyzer and RadioActive Quantum beams

- **BigRIPS × High-resolution Beamline × SHARAQ spectrometer**
  - **BigRIPS**
    provides Intense RI beam
  - **High-Resolution beamline**
    realizes dispersion-matching transport against large momentum spread of RI Beam
  - **SHARAQ spectrometer**
    analyzes momentum of reaction products with high resolution
    \[ \Delta p/p \sim 1/15000 \text{ (FWHM)} \]
    \[ \Delta \theta \sim 1 \text{ mrad} \]
High-resolution Beamline

- Dispersion-matching condition against Large momentum spread RIB
  - $^{12}$N at 200A MeV $\Delta p/p = \pm 0.3\% \rightarrow \Delta E_{\text{RIB}} \sim 30$ MeV
  - Dispersion matching condition is fulfilled between BigRIPS-F3 and S2

Tracking devices at Foci
$\Delta p/p \sim 1/15000$ (FWHM)
$\Delta \theta \sim 1\text{mrad}: t \sim 10^{-4}L_R$
DAQ @ each Focus
Low-Pressure Multiwire Drift Chamber at Foci (in vacuum)

- Configurations 4 cathode layer + 3 Anode layer
- Effective area $216 \text{ mm } (x) \times 144 \text{ mm } (y)$

- Anode Layer
  - Anode wire ($0 \text{ V}$): Au-W $20 \mu m$, Potential wire ($-HV$): Cu-W $75 \mu m$
  - Cell size: $9 \text{ mm } (x, u, y (v)) \times 9 \text{ mm } (z)$
  - Readout channel (Anode wire)
    - $24 (X) + 24 (U) + 16 (Y (V)) = 64$

- Cathode layer
  - Al-Mylar, Thickness $1.5 \mu m$
  - Outside Cathode
    - Stripped and connected to delay line
  - Inside Cathode
    - Foiled

- Window layer
  - Al-Mylar $10 \mu m$

- Counter Gas
  - Pure isobutene $i-C_4H_{10}$
  - $10 - 50 \text{ kPa}$

\[ \Delta \theta \sim 1 \text{ mrad} \]
\[ \text{dE/dx} \sim 3 \text{ to } 300 \text{ (dE/dx)min.} \]
**Readout Electronics**

- **LP-MWDC**
  - X 24ch
  - U 24ch
  - Y 16ch

- **REPIC RPA-130/131**
  - Amplifier & Discriminator card

- **CAEN V1190 A/B**
  - Multihit TDC

**Amp. shaper Discri.**
- Gain: 450 mV/pc
- Integral time: 16 ns

**Sample output signal**
- Source: α-ray (241Am)
- Gas: 10 kPa, Bias: -800V
- 70 mV
- Rise time: < 20 ns

**Obtained timing**
- Leading edge
- Trailing edge

**Logic signal**
- Leading edge
- Trailing edge

**Pulse width**
- LSB: 98 ps

**Threshold level**
- Analog signal
- Logic signal
Discrimination of δ-ray

$^{14}\text{N}$
Pressure 10 kPa
Voltage -1100 V

Signals from anode X layer at one run

Select the wire with maximum pulse width for each trigger event.

Multiplicities

14N

Signals from beam is identified.

Signals from beam can be identified at run of high multiplicity.
Performance at pure isobutene of 10 kPa

- Position resolution and track finding efficiency of 250\(\mu\)m (FWHM) and 90 %, respectively.
Achieve the Position resolution and the tracking efficiency of 250µm (FWHM) and 90 %, respectively.
Performance of beam rate dependence

- Measurement of performance of beam rate dependence

- Beam $^{12}$N
  - Energy: 200 MeV/nucleon
  - Intensity: 1kHz – 1MHz / cell

- Operation condition of LP-MWDC
  - Gas: Pure isobutene, 10kPa
  - Voltage: 1000V
## Diamond Detector

**Physical Property at 300 K**

<table>
<thead>
<tr>
<th>Property</th>
<th>Diamond</th>
<th>Silicon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band gap [eV]</td>
<td>5.45</td>
<td>1.12</td>
</tr>
<tr>
<td>Electron mobility [cm$^2$/Vs]</td>
<td>2200</td>
<td>1500</td>
</tr>
<tr>
<td>Hole mobility [cm$^2$/Vs]</td>
<td>1600</td>
<td>600</td>
</tr>
<tr>
<td>Breakdown field [V/m]</td>
<td>$10^7$</td>
<td>$3 \times 10^5$</td>
</tr>
<tr>
<td>Resistivity [Ω cm]</td>
<td>$&gt;10^{13}$</td>
<td>$2.3 \times 10^5$</td>
</tr>
<tr>
<td>Dielectric constant $\varepsilon_r$</td>
<td>5.7</td>
<td>11.9</td>
</tr>
<tr>
<td>Thermal conductivity [W/cm K]</td>
<td>20</td>
<td>1.27</td>
</tr>
<tr>
<td>Lattice constant [Å]</td>
<td>3.57</td>
<td>5.43</td>
</tr>
<tr>
<td>Energy to remove an atom from lattice [eV]</td>
<td>80</td>
<td>28</td>
</tr>
<tr>
<td>Energy to create an e-h pair [eV]</td>
<td>13</td>
<td>3.6</td>
</tr>
</tbody>
</table>

Very fast, radiation-hard detectors

Possible candidate for event-by-event tagging for $v/c < 0.7$ particle under high rate condition
**p-CVD Diamond Detector at CNS**

**Signals from diamond detector**

- **Yellow**: Pad (B)
- **Cyan**: Strip (A, Left)
- **Magenta**: Strip (A, Right)

**CVD Diamond detector**

Size $30 \times 30 \, \text{mm}^2$, Thickness $200 \, \mu\text{m}$

- **Side A**
  - 4 strips,
  - Readout from both ends

- **Side B**
  - 1 pad,
  - 4 readout from corners

Bombarded by 32-MeV $^4\text{He}$ particles:

- **Pulse shape**:
  - Rise time 0.7ns, Decay time 10ns
- **Charge collection depth**: $190 \, \mu\text{m}$

*p-CVD diamond is available as a very fast particle detector.*
• Sites where detectors can be arranged:
  – Secondary target
  – S1 (Just after D1)
  – S2 (final momentum dispersive focus)
Low-pressure CRDC for SHARAQ Spectrometer

Schematic view of CRDC

Performance

Thickness:
< 1 mrad of multiple scattering

Gas:
isobutane 2 or 4 kPa

Detection Efficiency
~100 % for 300A MeV triton

Read-out information
T,Q from Sensing wires
Q from 512 Cathode pads

Ch. Number: total 4 ch.
2 ch Anode
2 ch Cathode (256-ch multiplexed)

Position-measurement:
x: induced charge distribution
y: drift time

Resolution (CRDC/on FP):
x: 0.61mm / 0.32mm (FWHM)
y: 0.73mm / 0.36mm (FWHM)

Counting Rate:
up to 1 kHz
Efficiency of CRDC

- $^{14}_N$ at 30 torr
- $^{14}_N$ at 15 torr
- $^{9}_Li$
- $^{6}_He$
- $p=30$ torr

Voltage of anode wires (V):
- Left: 500 to 900 V
- Right: 700 to 900 V
Dispersion Matching

• For a primary beam ($^{14}$N)
  Lateral and angular dispersion match
  are simultaneously fulfilled!

Commissioning in May, 2009
RIBF at RIKEN
SAMURAI
-- new spectrometer in RIBF --

Superconducting Analyzer for Multi-particle from Radio Isotope Beam with 7Tm of bending power

Kinematically complete measurements by detecting multiple particles in coincidence

- Superconducting Magnet 3T with 2m dia. pole (designed resolution 1/700)
- 80cm gap (vertical)
- Heavy Ion Detectors
- Proton Detectors
- Neutron Detectors
- Large Vacuum Chamber
- Rotational Stage

Invariant Mass Measurement
Missing Mass Measurement

K. Yoneda (RIKEN)
Detector System – \((\gamma, n)\) measurement mode

\((\gamma, n)\) reaction: neutron-rich side

- **Detectors for Heavy Ion**
  - Position measurement
    - Drift Chambers
    - Beam
    - Fragments before/after
  - Charge measurement
    - Ion Chambers
    - Beam / Fragments
  - Velocity measurement
    - Plastic hodoscope
  - Charge measurement
    - Cherenkov counter
  - Total E measurement
    - Pure CsI detector

- **Neutron Detector**
  - Plastic scintillator
    - 240 modules
      - (120mm x120mm x1.8m / module)
    - Effective Area: \(3.6 \text{ m} \times 1.8 \text{ m} \text{ (V)}\)
      - ~ 100 % coverage @ \(E_{\text{rel}} \leq 3 \text{ MeV}\)
      - ~ 40 % coverage @ \(E_{\text{rel}} \sim 10 \text{ MeV}\)
    - Efficiency ~ 66 % (Half: ~40 %)

Half volume is ready

K. Yoneda (RIKEN)
Detector System – \((\gamma, p)\) measurement mode

- **Detectors for Heavy Ion**
  - same as \((\gamma, n)\)
- **Detectors for Proton**
  - Proton Drift Chamber
  - Plastic Hodoscope
- **Silicon Strip Detector**
  - Broad dynamic range (~10,000)
  - High density signal processing
  - Both proton & heavy ion \((Z < 50)\) hit the detector
  - Signals of about 2500ch in total

Under development
Based on ASIC technology
in collaboration with
Texas A&M Univ. and
Washington Univ. in St. Louis
HINP16C --- 16ch processing in 1 chip
two output for energy and timing

\((\gamma, p)\) reaction: proton-rich side

K. Yoneda (RIKEN)
Various Configuration

SAMURAI allows versatile usage

K. Yoneda (RIKEN)

(γ, n) reaction: neutron-rich side

(γ, p) reaction: proton-rich side

(p, p'), (p, 2p), (p, pn), …

pol. d-induced reaction

EOS measurement

Various usage → Variety of physics subjects covered with SAMURAI
Summary

• Some detector systems for nuclear physics are introduced

• Detectors for elementary particles are developed with similar concept as Particle Physics

• High-resolution gamma-ray detectors are developed for a high energy-rate background (Hyperball) and for tracking with position sensitivities
  – Digital waveform processing

• Heavy-ion Detectors with 3 to 15000 (dE/dx)min.
  – Resolution in PID for a wide dynamic range (BigRIPS)
  – Thin detectors in vacuum (SHARAQ)
  – Multi-purpose spectrometer (SAMURAI)