T2K Muon Monitor

Kento Suzuki (Kyoto University)
2010.08.31
NBI Talk
Role and Requirement

- Monitor $\nu$ beam direction and intensity by measuring $\mu$
  - Beam direction by measuring $\mu$ beam profile center
    - Requirement: $< 0.25\text{mrad}$
  - Intensity by measuring $\mu$ yield
    - Requirement: $< 3\%$
- Required dynamic range
  - 1% to 100% ($=0.75\text{MW}$)
    - Estimated muon flux (profile center):
      $\sim 8 \times 10^7 \mu/\text{cm}^2/\text{spill at 0.75MW}$

$\leftarrow$ Typical profile of $\mu$ beam measured by MUMON
Role and Requirement

- **Bunch by bunch measurement**
  - Bottom fig.: structure of T2K beam

- **Reliability**
  - Beam operation will be stopped if MUMON has trouble
  - Need to work under high radiation environment
    - 100 kGy per year at 0.75MW operation

- Spill cycle: 3.5s interval
- Bunch interval: 581ns
- Bunch width: 58ns
Location of T2K Muon Monitor

SK

0 m

295 km to Super-Kamiokande

Near Detector (ND280)

118 m

Beam Dump & Muon Monitor

Muon Monitor

Beam Dump

Decay Volume

(96 m)

Decay Volume

Horn1 + Target

Horn2

Horn1

Primary beamline

Decay Volume

Super-conducting combined function magnets

Target station: target & 3 horn system

1st horn & Target

Helium vessel

Horn3

J-PARC
T2K Muon Monitor “MUMON”

- Composed of two independent detector → redundancy and wide-dynamic range
  - Si PIN Photodiode: high S/N ratio even when beam intensity is low.
  - Ionization chamber: radiation tolerant
- Each detector has 49 sensors (7×7) which are arranged at 25cm intervals in each array.
- Covered Area: 150cm×150cm
Photo

μ beam
We prepared for high rad. situation by making components of MUMON radiation tolerant.

- Ionization chamber (detail is in later slide):
  - Almost all parts are composed of aluminum.
  - PEEK (Poly–Ether–Ether–Ketone), ceramic or polyimide for insulator
- Polyimide cable for electronics
- Non–halogen polyethylene (PE) insulated cable and Ethylene–Propylene–Rubber (EPR) insulated cable for power supply cable.
Si PIN Photodiode

- Product of “Hamamatsu Photonics“
- Active size: 1cm × 1cm
- Wide dynamic range
  - S/N ~200 (even at 1% intensity)
- Weak against radiation
  - Expected life time is ~1 month at 0.75MW operation.
  - Exchange is needed for full beam intensity
- Covered up by aluminum package
  - Can exchange quickly under radiation environment.
  - PEEK is used for mounting Si PIN Photodiode and being put on the package.
We referred NuMI Muon Monitor

- Active size: 7.5cm × 7.5cm
- Gap: 3mm
- Radiation tolerant.
- Gas (130kPa, 34°C)
  - Ar + N₂ (2%)
    - For low intensity (<200kW)
      - Avoid saturation of signal due to recombination b/w electrons and ions.
  - He + N₂ (1%)
    - For high intensity (>200kW)
      - Lower ionization yield than that of Ar.
  - Purpose of N₂ contamination
    - To get fast response of signal.
      - In case of He, this effect is smaller than case of Ar.
      - To avoid signal fluctuation.
  - Two types of gas system to cover required dynamic range.
    - Confirmed linearity at 200V in beam test.

Left: Ar+N₂(2%)
Right: He+N₂(1%)
Control for gas and temperature for IC

- Keep appropriate conditions strictly
  - Temperature: 34°C
    - Monitored by Pt100 resistance thermometer.
    - Kept by PID-controlled heater.
      - The deviation is within ±0.2°C.
  - Pressure: 130kPa
    - Monitored by pressure transducers.
    - PID control of solenoid valve is located at most downstream of exhaust line.
      - This keeps the pressure at 130 ± 0.1 kPa.
  - O₂ contamination <100ppm
    - Monitored by oxygen analyzer.
    - Absorption of drift electrons cause losses of signal.
      - More than 1% loss if O₂ > 100ppm
    - Gas flow ~ 100 cc/min
      - suppress O₂ increasing.
      - We already achieved around 5ppm during physics run.

- Monitor these values in real time
Measurement
What do we detect?

- Left fig.: $p-\theta$ distribution of $\pi$ whose daughter ($\nu_\mu$) reaches at SK
- Right fig.: $p-\theta$ distribution of $\pi$ whose daughter ($\mu$) reaches at MUMON
  - $P_\pi > 5\text{GeV}/c$, $\theta < 100\text{mrad}$

$\theta$: emission angle of pion with respect to beam axis
$P_\pi$: Momentum of pion

Both are MC simulations
How to Achieve Direction and Intensity of $\mu$ Beam

- Analysis method is simple

Fit $w/ \ 2D$ Gaussian Function

$$ A \exp\left[ -\frac{(x - x_0)^2}{2\sigma_x^2} - \frac{(y - y_0)^2}{2\sigma_y^2} \right] $$

Quote Fit Parameters
- $A$: Peak Charge (nC)
- $x_0$: Profile center in $x$ direction
- $y_0$: Profile center in $y$ direction
- $\sigma_x$: Profile width in $x$ direction
- $\sigma_y$: Profile width in $y$ direction

Read by 65MHz FADC

Integrate each bunch and get sum for each ch.

Make 2D-histogram by filling each collected charge into
each bin.
Calibration System

- MUMON has two movable stand for calibration
  - Si PIN Photodiode
    - There is a reference detector which can be moved w/ moving stand behind the silicon arrays.
    - All channels (49ch) can be calibrated by using this ref. detector
  - Ionization Chamber
    - Can be moved by ±25cm w/ moving stand attached to IC itself.
    - Measure at 9 positions and get relative gain of each channel.
  - Can relatively calibrate with precision of 0.1% for Si and 0.4% for IC.
Horn Focusing

Confirmed horn focusing by MUMON

- Top fig.: horn current vs collected charge at center channel
- Bottom fig.: profile of μ beam
Result of Measurement

RMS < 1 cm

Si Profile Center (cm)

Date

01/24 01/31 02/24 02/28 03/21 03/24

04/18 04/25 05/16 05/30 06/13 06/27

+1 mrad

-1 mrad

• X Center

• Y Center
Result of Measurement

Fluctuation is relatively large due to resolution of CT measurement

RMS/Mean < 1%
How About Resolution?

- Estimation by using beam.
  - By comparing two independent detectors, fluctuation of beam direction, intensity and horn current is canceled.
  - Resolution
    - For Intensity measurement (left): 0.12%
    - For direction measurement (Right): 1.5mm
T2K Muon Monitor “MUMON” measures $\nu$ beam direction and intensity by measuring $\mu$.
MUMON has two independent detectors, Si PIN photodiode and Ionization chamber.
During physics run, MUMON had been very stable and had good data taking.
We are waiting for more beam.
Back Up
Start T2K commissioning ~20kW
Commissioning Run (Beam study)

20kW ~ 70kW
Physics Run (including beam study time)

Next Run: Middle of Nov.~
Shut down (Upgrade of Hardware, installation of new detector)

Gas System
DAQ

- COPPER–FINNESSE Flash ADC
  - COPPER–FINNESSE:
    - Developed by KEK for Belle experiment
    - Mother board (COPPER) has ethernet ports as an external interface
    - Sub-board (FINNESSE) which is inserted to COPPER works as Flash ADC
  - Sampling rate: 65MHz
  - Accuracy: 12bit
  - Input range: ±1V
  - Shaping time: 52.8ns

- Trigger
  - We use timing of signal from CT as a trigger
    - CT also uses COPPER–FINNESSE Flash ADC and its sampling rate is 160MHz
    - About CT, please hear Shibata-san’s talk
Study for Understanding MUMON Performance

- Top fig. : profile width vs horn current
- Bottom fig. : proton position at target vs profile center  
  - Parallel beam
Systematic Error for Direction Measurement

- For direction measurement

<table>
<thead>
<tr>
<th>Error Source</th>
<th>Error Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detector Calibration</td>
<td>0.3 cm</td>
</tr>
<tr>
<td>Upstream Materials</td>
<td>~ 2.4 cm</td>
</tr>
<tr>
<td>Alignment</td>
<td>0.7 cm</td>
</tr>
<tr>
<td>Misalignment in target and horn</td>
<td>Under study</td>
</tr>
<tr>
<td>Total</td>
<td>2.5 + ? cm</td>
</tr>
</tbody>
</table>

\(11.8 \text{ cm} = 1 \text{ mrad}\)
P–θ distribution of Pion

All horns at 0kA

All horns at 320kA
Flux Measurement

<table>
<thead>
<tr>
<th>Profile, Mar 10</th>
<th># of tracks / 4x10^11 pot</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Data (250kA)</td>
</tr>
<tr>
<td></td>
<td>Data (0kA)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>X (cm)</th>
<th>0kA</th>
<th>250kA</th>
</tr>
</thead>
<tbody>
<tr>
<td>-80</td>
<td>5000</td>
<td>5000</td>
</tr>
<tr>
<td>-60</td>
<td>4500</td>
<td>4500</td>
</tr>
<tr>
<td>-40</td>
<td>4000</td>
<td>4000</td>
</tr>
<tr>
<td>-20</td>
<td>3500</td>
<td>3500</td>
</tr>
<tr>
<td>0</td>
<td>3000</td>
<td>3000</td>
</tr>
<tr>
<td>20</td>
<td>2500</td>
<td>2500</td>
</tr>
<tr>
<td>40</td>
<td>2000</td>
<td>2000</td>
</tr>
<tr>
<td>60</td>
<td>1500</td>
<td>1500</td>
</tr>
<tr>
<td>80</td>
<td>1000</td>
<td>1000</td>
</tr>
</tbody>
</table>

| Fit peak        | 10924±126       | 40768±468       |

Momentum module
μ beam
Flux modules
Signal Waveform

Si PIN photodiode

Ionization chamber
Candidate of detector in near future

- MCT

- Diamond detector

Study is ongoing