Operational experience of J-PARC neutrino beam-line

Ken Sakashita (KEK/J-PARC) for J-PARC neutrino facility
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- Recent beam operation status
- Beam window replacement
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J-PARC & Neutrino beam-line

Neutrino beam-line & Near detector
T2K (present) → T2K-II, HK

to Kamioka

Linac
25Hz, 330m
H- 400MeV, 50mA

3GeV Synchrotron (RCS)
25Hz, 350m, 1MW

30GeV MR
0.3Hz, 1.6km, 470kW (present) → 1.3MW

Material/Life Science Facility

Hadron Experimental Facility

Bird's eye photo in January of 2008
T2K (Tokai-to-Kamioka) experiment

Long base-line neutrino oscillation experiment with muon (anti-)neutrino beam generated at J-PARC and detected at Super-Kamiokande
Physics motivation

- Physics motivation (after discovery of $\nu_e$ appearance) is
  - Lepton CPV
  - 2-3 mixing angle $\theta_{23}$ is maximal or not
  - $\nu_1$ mass < $\nu_3$ mass ? (mass hierarchy)
  - Check the 3-flavor mixing framework
- T2K latest results show hint of the lepton CPV
  - CP conservation ($\delta = 0, \pi$) is excluded with 95% C.L.

more details by K.JIAE talk tomorrow
Toward lepton CPV

- Accumulate more data with improving the beam power

My talk: Operational experience of neutrino beam-line so far

Next (Sekiguchi-san’s) talk: Upgrade of J-PARC accelerator and neutrino beam-line toward 1.3MW
T2K neutrino beam

- Accelerator-based $\nu$ beam
- $\nu$ energy is narrow with off-axis method $L = 295\text{km} \rightarrow$ oscillation peak at 0.6GeV
- $\nu / \bar{\nu}$ can be switched by flipping horn polarity
Neutrino flux and its error

- $\nu$ flux is calculated based on
- measurement of proton beam profile
- $\pi$, K yield measurements by CERN NA61/SHINE experiment

• Total absolute flux uncertainty is $\sim 10\%$
  (similar size for anti-nu beam)
• Far-to-near extrapolation is also calculated
J-PARC Neutrino facility

- Muon Monitor
  - Si array + IC array
- Horn
- Beam monitors
  - 3 Horns w/ 320kA of design current
  - Graphite, Φ26 x 900 mm long
  - Helium cooling
- To Far detector
- Near detector (at 280m from target)
- Beam Dump
- Decay Volume
- Target
- Operation since 2009 Apr.

Si array + IC array

Super-Condensing Magnets

proton beam
Accumulated POT and beam power

Accumulated $14.7 \times 10^{20}$ POT for neutrino mode and $7.6 \times 10^{20}$ POT for ant-neutrino mode
(total POT corresponds to 29% of the T2K approved POT)
Accumulated POT and beam power

Accumulated $14.7 \times 10^{20}$ POT for neutrino mode

$7.6 \times 10^{20}$ POT for ant-neutrino mode

(total POT corresponds to 29% of the T2K approved POT)
470kW operation

- Power 471kW
- $3.1 \times 10^{13}$ protons per bunch (ppb) x 8 at injection
- $2.44 \times 10^{14}$ ppp @end of acc.
- Loss at MR ~800W which is less than the MR collimator limit of 2kW
- Loss at 3-50BT is 100W which is less than the 3-50BT collimator limit of 2kW
- RF anode power supply tripped several times by the current limit. Limited the beam power
- Longitudinal instability happened frequently > 480kW

(see also Y.Sato's talk)
510kW trial

- Betatron tune (21.35, 21.45)
- 2\textsuperscript{nd} harmonic rf

The MR has capability to achieve >1MW with the high repetition rate operation.

Also, we can successfully extract 510kW beam to \(\nu\) beam-line without no major issues at \(\nu\) beam-line

<table>
<thead>
<tr>
<th>Notes</th>
<th>Protons per pulse</th>
<th>Bunch number</th>
<th>Repetition period (sec)</th>
<th>Beam power (kW)</th>
<th>Beam loss (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>measurement</td>
<td>2.64 \text{e}14</td>
<td>8</td>
<td>2.48</td>
<td>511</td>
<td>1.7</td>
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<tr>
<td>estimation</td>
<td>2.64 \text{e}14</td>
<td>8</td>
<td>1.16</td>
<td>1092</td>
<td>3.6</td>
</tr>
</tbody>
</table>

Total beam loss ~ 1.7 kW
Accumulated POT and beam power

\( \times 10^{20} \) (POT=protons on target)

Total Accumulated POT for Run 1 to Run 8

\( \nu \)-Mode Beam Power
\( \bar{\nu} \)-Mode Beam Power

470kW stable operation


\[7.5 \times 10^{20} \ \bar{\nu} \ \text{mode} \quad 7.5 \times 10^{20} \ \nu \ \text{mode} \]


\[7.6 \times 10^{20} \ \bar{\nu} \ \text{mode} \quad 14.7 \times 10^{20} \ \nu \ \text{mode} \]

Double \( \nu \) data in this 6month run!
Primary beam-line

- Beam orbit from the extraction to the target is controlled anytime to keep less beam loss
- Successfully handling the 470kW beam stably with less beam loss
  - residual dose is generally low (~10 µSv/h)
  - high residual dose at most downstream of beam-line (~4.5mSv/h)
    - suspected source is back scattering from the collimator, target or beam window
    - remote maintenance of the beam-line equipment is necessary if we need some work just after the beam running
- Basically ready for high beam power up to 750kW (several improvement needed for 1.3MW)
Target and horn

Target
- Graphite $\Phi 26\text{mm} \times 900\text{mm}$ long
- Designed to work at 750kW
- Replaced in 2013 when horn1 replaced
- He pipe leaked and repaired in 2015

Horn
- Three horns
- Operating (250kA) stably with no major trouble
- Replaced in 2013 with some improvements
- Needs three sets of new power supplies/trans for 1.3sec & 320kA operation

Both target and horn stably operated with 470kW
Some improvement is necessary for 750kW and beyond
(see Sekiguchi-san’s talk)
Muon monitor

- Monitor the beam direction and intensity of muons every spill (every bunch)
- Stably operated with 470kW (good performance of direction and intensity measurement)
- Some problems are appearing as beam power increases
  - new detector R&D is in progress

Signal decrease (1%/5e20POT) was observed (could be radiation damage of Si. Under investigation)

Si yield / IC yield in Run8 (Last Run)

IC attenuator
0dB $\rightarrow$ 6dB

by H. Kubo (Kyoto U)
Beam stability

- Proton beam position, angle and width at target is controlled to make the $\nu$ beam direction stable

**x position**

**y position**

**x width**

**y width**
Event rate is stable ~1%
- Beam direction is stable within much better than 1mrad
- 1mrad corresponds to a 2% shift of peak $\nu$ energy at SK
Beam window replacement

- Beam window separates the proton beam-line vacuum and He vessel
- 0.3mm Ti, double layered, He flow in gap for cooling
Beam window replacement

- Initial beam window used since 2009 until 2017
- The present beam window has been exposed to $2.2 \times 10^{21}$ protons
  - It corresponds to 1.8 DPA (displacement per atom)
- This value exceeds the existing measurement
- This motivates to replace the present beam window with new one for safe operation
Beam window replacement

- Since the beam window is activated, the replacement was performed with a remote maintenance scheme
- **Successfully replaced with a new beam window**
  - from visual inspection, some damage on the old beam window was found. Further investigation on going
Summary

- J-PARC MR and neutrino beam-line 470kW stable operation is achieved
- there is no major issue
- Beam window replacement was successfully performed
- Based on the operational experience so far, we plan to improve some beam-line equipment for future high beam power operation