JSNS$^2$ Experiment

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for JSNS$^2$ group
Introduction

• Anomalies ($\Delta m^2 \sim 1\text{eV}^2$) have never been understood for ~20 years are shown

<table>
<thead>
<tr>
<th>Experiments</th>
<th>Neutrino source</th>
<th>signal</th>
<th>type</th>
<th>Significance $\sigma$</th>
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<tbody>
<tr>
<td>LSND</td>
<td>$\mu$ Decay-At-Rest</td>
<td>$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$</td>
<td>appearance</td>
<td>3.8</td>
</tr>
<tr>
<td>MiniBooNE</td>
<td>$\pi$ Decay-In-Flight</td>
<td>$\nu_\mu \rightarrow \nu_e$</td>
<td>appearance</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$</td>
<td>appearance</td>
<td>2.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>combined</td>
<td></td>
<td>4.7</td>
</tr>
<tr>
<td>Ga(calibration)</td>
<td>e capture</td>
<td>$\nu_e \rightarrow \nu_X$</td>
<td>disappearance</td>
<td>2.7</td>
</tr>
<tr>
<td>Reactors</td>
<td>Beta decay</td>
<td>$\bar{\nu}_e \rightarrow \bar{\nu}_X$</td>
<td>disappearance</td>
<td>3.0</td>
</tr>
</tbody>
</table>

• The hidden oscillation between active and 4th neutrino?
  $\rightarrow$ Sterile neutrino
LSND Anomaly

LSND $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ Signal

800 MeV proton beam from LANSCE accelerator

Water target
Copper beamstop

LSND Detector
L=30m

$\pi^+ \rightarrow \mu^+ \nu_\mu$

$e^+ \nu_e \bar{\nu}_\mu$

Oscillations?

$\bar{\nu}_e$

Saw an excess of:
$87.9 \pm 22.4 \pm 6.0$ events.

With an oscillation probability of
$(0.264 \pm 0.067 \pm 0.045)\%$.

3.8$\sigma$ evidence for $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$

Los Alamos Meson Physics Facility, LANL 1993-1998

JSNS$^2$ experiment ; Direct test of the LSND result with modern technics
JSNS$^2$ experiment

JSNS$^2$ (J-PARC Sterile Neutrino Search at J-PARC Spallation Neutron Source)

- Neutrino; $\mu^+$(Decay at Rest) → $e^+ + \nu_e + \overline{\nu}_\mu$
- Target volume; Gd-loaded Liquid Scintillator
- Detection; IBD (Inverse Beta Decay)
- Baseline; 24m
- Beam: 3GeV Proton, 600kW Pulsed beam
- 10inch PMT x 120 (96 target, 24 Veto)
JSNS$^2$ Collaboration

10$^{th}$ Collaboration meeting at J-PARC(2020/Feb)

63 collaborators
Spokesperson
T. Maruyama (KEK)
Co-spokesperson
S. B. Kim (SKKU)

6 institutions
27 members
JAEA
KEK
Kitasato U
Kyoto U
Osaka U
Tohoku U

10 institutions
28 members
Chonbuk National U
Chonnam National U
Dongshin U
GIST
Kyungpook U
Seoul U
Seoul National U of Sci & Tech
Soongsil U
Sungkyunkwan U

4 institutions
7 members
Alabama U
BNL
Florida U
Michigan U

1 institutions
1 members
Sussex U
Experimental Site, J-PARC

J-PARC Facility (KEK/JAEA)

Rapid Cycle Synchrotron
Energy: 3 GeV
Repetition: 25 Hz
Design Power: 1 MW

Main Ring
Energy: 30 GeV
Design Power: 0.75 MW

Materials and Life Experimental Facility

Neutrino Beams (to Kamioka)

181 MeV Linac
400 MeV
3 GeV RCS

CY2007 Beams
JFY2008 Beams
JFY2009 Beams

Bird’s eye photo in January of 2008
MLF: Neutron and Muon source for Material and Life Science

J-PARC Spallation Neutron Source
Experimental set-up

MLF Cut model around Hg target

JSNS$^2$ detector

MLF 3rd Floor

Neutrinos 24m

MLF 1st Floor

3GeV Proton

Hg position
Neutrino; source and detection

Fig. 2.2.3: Schematic drawing of mercury target structure

Fig. 2.2.4: Schematic drawing of mercury target structure without the safety hull

Hg Target Cell

Proton Beam

Neutron Beam

Hg

ν
µ
π+
µ+
νµ

24m

Proton (p)

Neutron (n)

Gd

Prompt Signal

Delayed Signal

γ
νe
π+
µ+
νµ

e+
νe

γ

LS detector
Status of experiment

• Detector construction

• Stainless tank was built at HENDEL building in J-PARC.

• Acrylic tank was built in Taipei and delivered to HENDEL.

• PMTs were mounted in side frame. Acrylic install in stainless tank.
Status of experiment

• 2020/02/19 & 20 Detector transport and set in MLF
Status of experiment

- 2020/06/05 – 6/15
  JSNS\(^2\) 1\(^{st}\) physics run

Total charge vs time

\(^{252}\text{Cf}\) source calibration

The detector performed as expected and recorded a variety of data.
Neutrino flux from mercury target

- No data; 3 GeV proton injected mercury.

Proton Beam

Hg

\( \pi^+ \)

\( \mu^+ \)

\( \bar{\nu}_\mu \rightarrow \bar{\nu}_e \)

24m

\( \mu^- \)

\( \bar{\nu}_e \)

\( \pi^- \)

JSNS\(^2\) target

- To measure \( \mu^+ \) decay, \( \nu_e + C \rightarrow e + N_{gs} \)

It can reduce error of flux (10%)

JSNS\(^2\) Background

- No calibration with measurement (50%)

If error can reduce to 10%, Sensitivity is improved greatly

Energy (MeV)

Events/4MeV

0 10 20 30 40 50 60

50%

10%

LSND 99% C.L

LSND 90% C.L

50%

JSNS\(^2\) best case

Total

\( \bar{\nu}_e \) from \( \bar{\nu}_\mu \) oscillation

\( \nu_e \) from \( \mu^- \)

\( ^{12}C(\bar{\nu}_e,e)N_{gs} \)

Accidentals

0 5 10 15 20 25 30 35 40

0 10 20 30 40 50 60

Energy (MeV)
Various MCs are studied

- **FLUKA** (current default)
  - Targe simulation only
  - Applied G4 rate
- **Geant4**
  - V9.4p04 with QGSP_BERT
- **PHITS**
  - Most precise geometry
  - Default MLF design
  - Different beam profile ($\sigma_x=18\text{mm}, \sigma_y=0.8\text{mm}$)

$\Rightarrow 1.3-1.7$ times difference is obtained as MC uncertainty

**Motivation 1 to join NA61/SHINE low-E beamline**

**Comparison of MC Models**

<table>
<thead>
<tr>
<th>FLUKA</th>
<th>$\pi^+ \rightarrow \mu^+ \rightarrow \nu_{\mu}$</th>
<th>$\pi^- \rightarrow \mu^- \rightarrow \nu_{\mu}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi/p$</td>
<td>$6.49 \times 10^{-1}$</td>
<td>$4.02 \times 10^{-1}$</td>
</tr>
<tr>
<td>$\mu/p$</td>
<td>$3.44 \times 10^{-1}$</td>
<td>$3.20 \times 10^{-3}$</td>
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<tr>
<td>$\nu/p$</td>
<td>$3.44 \times 10^{-1}$</td>
<td>$7.66 \times 10^{-4}$</td>
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<tr>
<td>$\nu$ after 1$\mu$s</td>
<td>$2.52 \times 10^{-1}$</td>
<td>$4.43 \times 10^{-4}$</td>
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<tr>
<th>Geant4</th>
<th>$\pi^+ \rightarrow \mu^+ \rightarrow \nu_{\mu}$</th>
<th>$\pi^- \rightarrow \mu^- \rightarrow \nu_{\mu}$</th>
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<tr>
<td>$\pi/p$</td>
<td>$5.41 \times 10^{-1}$</td>
<td>$4.90 \times 10^{-1}$</td>
</tr>
<tr>
<td>$\mu/p$</td>
<td>$2.68 \times 10^{-1}$</td>
<td>$3.90 \times 10^{-3}$</td>
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<td>$8.02 \times 10^{-1}$</td>
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<tr>
<td>$\mu/p$</td>
<td>$4.46 \times 10^{-1}$</td>
<td>$2.76 \times 10^{-2}$</td>
</tr>
<tr>
<td>$\nu/p$</td>
<td>N/A</td>
<td>N/A</td>
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Need to cross-section data of 3GeV Proton + Mercury target
MLF measure the neutron flux from MLF target with thin metal plate. JAEA-Data-Code-2015-033

Neutron flux from Hg target

Length : 2m
Front 0.29(width) x 0.1(Height) m
Motivation 2 to join NA61/SHINE low-E beamline

- The activities of the radioactive products were measured using Ge detector.

- Because of the time required for removal, only a relatively long half-life response can be measured.

- Self shield effect of mercury is large.

- Estimated results were in agreement within ±30%

- MLF want to measure neutron production with thin mercury target.

- For 2nd MLF plan, MLF group want to know rate of Neutron production with mercury in detail. And if possible we want to measure Neutron production with Tw
Idea

• Beam condition
  Proton beam: 1, 3, 5, 7, 10 GeV

1) JSNS$^2$ Neutrino Flux
   - P + Hg → π, K cross section
   Using NA61 detector
   + thin Hg target (3 type)

2) MLF Neutron production
   - Set film around target. Then
gamma spectrum of activated
film is measured with our
Ge-detector
   - Set neutron detector if event rate
is low.
Summary

- JSNS$^2$ is a new experiment of the sterile neutrino search at MLF, J-PARC. JSNS$^2$ is a direct test of the LSND result.

- JSNS$^2$ detector was finished to construct, fill LS and set in MLF on June.

- JSNS$^2$ experiment started 1$^{\text{st}}$ physics run. 2$^{\text{nd}}$ physics run will start from Dec to June 2021.

- For the improvement of physics and facility quality, JSNS$^2$ want to take data using 3 GeV proton beam with mercury.