The Present and Future of MLF

IMSS KEK / J-PARC Center
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パルス中性子・ミュオン発生40周年記念シンポジウム 2020/12/23
Neutron Instruments in MLF

- 23 Neutron Beam Ports
- Operation: 21 (April, 2018)
- Commissioning: 0

VIN-ROSE (NSE): opened to users @2017B

POLANO (Polarization Analysis Spect.):
Opened to users @2019A
**Status of MUSE (muon facility)**

**S-Line** under commissioning.
Surface $\mu^+(30 \text{ MeV/c})$ S1 area is ready to extract $\mu^+$ beam. (Open to users)

**U-Line**
Ultra Slow $\mu^+$ ($0.05-60 \text{ keV}$)
First Ultra Slow muon beam is under commissioning.

**H-Line under construction.**
Surface $\mu^+$ For Mu-HF, $g$-2/EDM $e^-$ up to 120 MeV/c For DeeMe $\mu^-$ up to 120 MeV/c For $\mu$CF Muon Microscopy Electromagnetic coils in H-Line tunnel were installed.

**MUSE Facility @MLF**

**D-Line in operation**
Surface $\mu^+(30 \text{ MeV/c})$
Decay $\mu^+$/$\mu^-$ (5-120 MeV/c)
Trouble in power supply of septum coil was happened. (Open to Users)
General Proposals to MLF at 2020B+2021A

- # of proposal ~650 /y
- # of users ~1100 / y
- Competition rate ~1.6
- Operation days ~170 days

Applicants’ Affiliations

- Universities in Japan 40%
- Companies in Japan...
- Research Institutes in Japan... 40%
- Foreign Countries ※ 29%
- Cross 5%
- KEK 5%

Approved/Reserved/Not approved/Conducted proposals(#)

Available BT(Initial) / Instruments(#)

- Available BT(days) / Instruments(#)
- Operation days ~170 days
- KEK 5%
- CROSS 5%
- Neutron + Muon
Number of publications of MLF

Source data: 2020-07-07, Citation data: 2020-07-20, Figure revision: 2020-07-21
Research areas of publications (2006-2020 total)

- Physics: 52%
- Chemistry: 25%
- Materials Science: 15%
- Engineering: 5%
- Geosciences: 1%
- Biology & Biochemistry: 1%
- Others: 1%

Source data: 2020-07-07, Citation data: 2020-07-20, Figure revision: 2020-07-22
MLF outcomes

• Covering a wide range of fields from basic science to industrial applications

Highly frustrated $S=1/2$ quantum spin system (Tanaka, TIT)

Development of all-solid ceramic buttery (Kanno, TIT)

Design of high-performance tire (Sumitomo Rubber Inds.)
Development of All Solid State Ceramic Battery

Prof. Kanno, TIT

Analysis of diffusion path of Li atom with neutron diffraction stimulated the developments of novel material which Paves the way for the practical application of all-solid-state batteries.

Li$_{10}$GeP$_2$S$_{12}$

Nature Materials (2011)

1679 citation (2020 Jul)

Li$_{9.54}$Si$_{1.74}$P$_{1.44}$S$_{11.7}$Cl$_{0.3}$

Nature Energy (2016)

776 citation (2020 Jul)

Single crystal β-alumina (NaAl$_{11}$O$_{17}$)

β-alumina (NaAl$_{11}$O$_{17}$)

LGPS-family

Discovered in 2011

1D diffusion path

Discovered in 2016

3D diffusion path

Li bis-(trifluoromethanesulfonyl)-imide (LiTFSI) in EMI-TFSI

PMMA-based polymer gel electrolytes containing NH$_4$PF$_6$
Fe-based SC (Magnetism) & Semiconductor (Hydrogen)

**Collaborative use of quantum beam**

Nat. Phys. 10, 300 (2014)
M. Hiraishi, J. Yamaura, H. Hiraka, et. al.

1. Discovery of magnetically ordered phase (AF2) in over doped region.
   → We proposed the origin of the high-$T_c$.

2. Magnetic structure (Neutron)
   Polar structure (S. R.)

**Electronic structure of H in IGZO**

K.M. Kojima, M. Hiraishi, R. Kadono, et. al.

1. Conducting band
   → Mu$^0$/H$^0$

2. Subgap
   → Mu$^0$/H$^0$

3. Valence band
   → Dilute H in IGZO is an electron donor.

KEK & Tokyo-TECH collaboration (MEXT Element Strategy)
Trend of Approved Proposals in Ibaraki BLs

① Percentage of approved industrial proposals in J-PARC MLF
- Industrial Use: 21%
- Academic Use: 79%

Applications from Industries are 21%

② Percentage of Ibaraki BL's proposals to total approved Industrial proposals of J-PARC MLF

3. Trend of approved proposals (FY2008-2019)

- Industrial Use
- Pref.Pj. Use
- MLF Use
- Industrial Use Rate

- Earth Quake
- Hadron Accident
- Target Trouble

【FY2008-19: 835 proposals】
- Industrial Use: 506
- Prefectural Pj. Use (R&D): 422
- J-PARC MLF General Use: 184
- 合計: 1,112 proposals
Neutron diffraction monitoring of ductile cast iron under cyclic tension–compression

- Ductile cast irons are important structural materials
- The relationship between internal stresses and work hardening and the role of graphite remains questionable

Fig. 1. (a) Image quality map and (b) inverse pole figure map of 820 steel before deformation.

Neutron diffraction monitoring of ductile cast iron under cyclic tension–compression

- The increase in ferrite strength played an important role in the work hardening of the ductile cast iron.
  - Contributions of Cementite and graphite are small.
We succeeded to detect nondestructively Li metal deposition on the graphite anode by measuring muonic X-rays through a laminated package. We also demonstrated that, taking advantage of depth resolution of muons, a location of the deposition can be detected.
Cross Correlations in Material Science

A new elementary excitation?
- finding orbiton by polarized neutron

J. Nasu and S. Ishihara, PRB 88 (13) 205110

model calculation on YVO$_3$
calculated orbital excitation
(a) bare orbital excitation in YVO$_3$
(b) separated orbital excitation levels with correlating orbitals and phonons

Contrast Variation can be typically realized by H (1.76 barn)/D (5.59 barn) replacement in Soft Materials.

Resolve correlations in multi-component softmatter systems

“Multi Components” is a key to realize new phenomena & functions of softmatter.

“Self Terms”

“Cross Terms”

In ternary system, 6 contributions (3 self terms + 3 cross terms) must be considered.

Polarized Neutron can directly observe spin dynamics (orbital-lattice coupling)
Construction of H-line and S-line

H-line infrastructure ¥0.6B

S-line cost ¥1.4B

S1: GP-µSR + ultralow temperature
S2: High time resolution µSR
S3: Pulse excitation µSR
S4: µPMS

Proton beam
Accident at Hadron Facility
〜 10 months interruption due to the earthquake
〜 1 month interruption due to the fire in MLF
Interruption due to troubles of Hg-target

Beam Power History at MLF

as of June 27, 2020
New Neutron and Muon Target (TS2)

A unified target for neutron and muon

- **Muon capture solenoid coil**
- **Rotating tungsten target**
- **Moderator/Reflector**
- **Neutron focusing device**
- **Neutron detector**
- **Proton beam**

**Neutron**
- Target: 10 x devices 2
- → 20 times in brightness

**Muon**
- Target: 10 x capture solenoid 5
- → 50 ~ 100 times in intensity

**Accelerator Upgrade**
- Power: 1 MW → 1.5 MW (TS1:1MW, TS2: 0.5MW)
- Repetition: 25 Hz → 25 Hz (TS1:17Hz, **TS2: 8Hz**) Long wavelength

<table>
<thead>
<tr>
<th></th>
<th>1 MW</th>
<th>1.5 MW</th>
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<tbody>
<tr>
<td>Peak current</td>
<td>[mA]</td>
<td>50</td>
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<tr>
<td>Pulse width</td>
<td>[ms]</td>
<td>500</td>
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<tr>
<td>Repetition</td>
<td>[Hz]</td>
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<tr>
<td>Average current</td>
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<tr>
<td>Max energy in linear</td>
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<td>Max energy in RCS</td>
<td>[GeV]</td>
<td>3</td>
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**Calculation of Intensity**

Peak Science (1)

**Neutron high brightness, muon high intensity ➔ micro beam** (complementary use)

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**Extreme Condition**  
(High pressure, High external field)

- **High Brilliance:** small sample

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**Earth and Planet Sci.**

- Super conductivity in Sulfur hydride under high pressure

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**Bio Science**

- **High brightness ➔ Small sample**

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- Photosynthesis protein
- Proton transfer protein
- **Long wavelength ➔ Slow dynamics of protein**
  
  \[ t = \frac{h}{m} \frac{\gamma L H l}{v^3} \sim H l \lambda^3 \]

- Human derived protein for drug discovery
- Fluctuations of structure ➔ Cancer suppression mechanism

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- **Spin echo**
- **IDP**
- New approach for drug development
**Imaging**

- Parallel neutron beam
- Diffraction microscope
- 3D imaging by negative muon

**Neutron microscope**

- Muon microscope

**Active site**

- micro \(\mu\)SR
- muonic X-ray analysis

**Neutron holography**

- Active site below fraction of 1%

**Industrial Applications**

- Visualization of system and module (structure, stress, magnetic field)
- Visual sensing

**Fundamental Physics**

- Meitron EDM
- Muon EDM

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**Top Science (2)**

**Neutron high brightness, muon high intensity**

(complementary use)

Real Space (nonuniform system) → Industrial applications
MLF TS2 Construction Schedule

- J-PARC center is responsible: Joint Project of KEK and JAEA
- User facility: Neutron/muon beam line
- Needs human resource:
  - FY 1~2: additional 10 members
  - FY 3~10: additional 40 members
  - FY 11~: additional 40 members

- Concept design
- Installation
- Test run
- Operation

- Beam Power (MW):
  - 0
  - 1.0
  - 1.6

- Timeline:
  - FY 1
  - FY 2
  - FY 3
  - FY 4
  - FY 5
  - FY 6
  - FY 7
  - FY 8
  - FY 9
  - FY 10
  - FY 11

- Accelerator upgrade
- Neutron/muon target technical design
- Neutron/muon target construction
- Proton beam line technical design
- Proton beam line component technical design
- Proton beam line component construction
- Experimental hall technical design
- Experimental hall construction
- Proton beam line building construction
- Neutron/muon beam line technical design
- Neutron/muon beam line construction

- Budget:
  - Total 250 M$
  - Proton beam line/building: 60M$
  - Neutron/muon target: 70M$
  - Neutron beam line: 40M$
  - Muon beam line: 40M$
  - Experimental hall: 40M$
<table>
<thead>
<tr>
<th>Year</th>
<th>Accelerator</th>
<th>Neutrino</th>
<th>Hadron</th>
<th>MLF-n</th>
<th>MUSE</th>
<th>ADS-R&amp;D</th>
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<tbody>
<tr>
<td>2021</td>
<td>Beam Power Upgrades</td>
<td>Neutrino Measurements</td>
<td>COMET Experiment</td>
<td>TS1 Improvements towards 1 MW</td>
<td>Muon g-2/EDM construction</td>
<td>SC low-beta LINAC prototyping/ beam controlling tech. development</td>
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<td>HD-Hall Extension / Commissioning</td>
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<td>Pb-Bi target development/ Irradiation tests@PSI/ Corrosion test w/ OLLOCHI</td>
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Issue: Strengthen functions and roles as a large-scale facility

- Huge operating expenses
- User support for 10,000 users*days per year
  - ~100 users/day
- Establishment of a sustainable operation system
- Development of a wide range of applications and promotion of advanced applications
- Comprehensive use of Quantum beam
- Internationalization