Negative muon experiments at J-PARC MUSE

KEK IMSS Muon Science Laboratory
Izumi UMEGAKI

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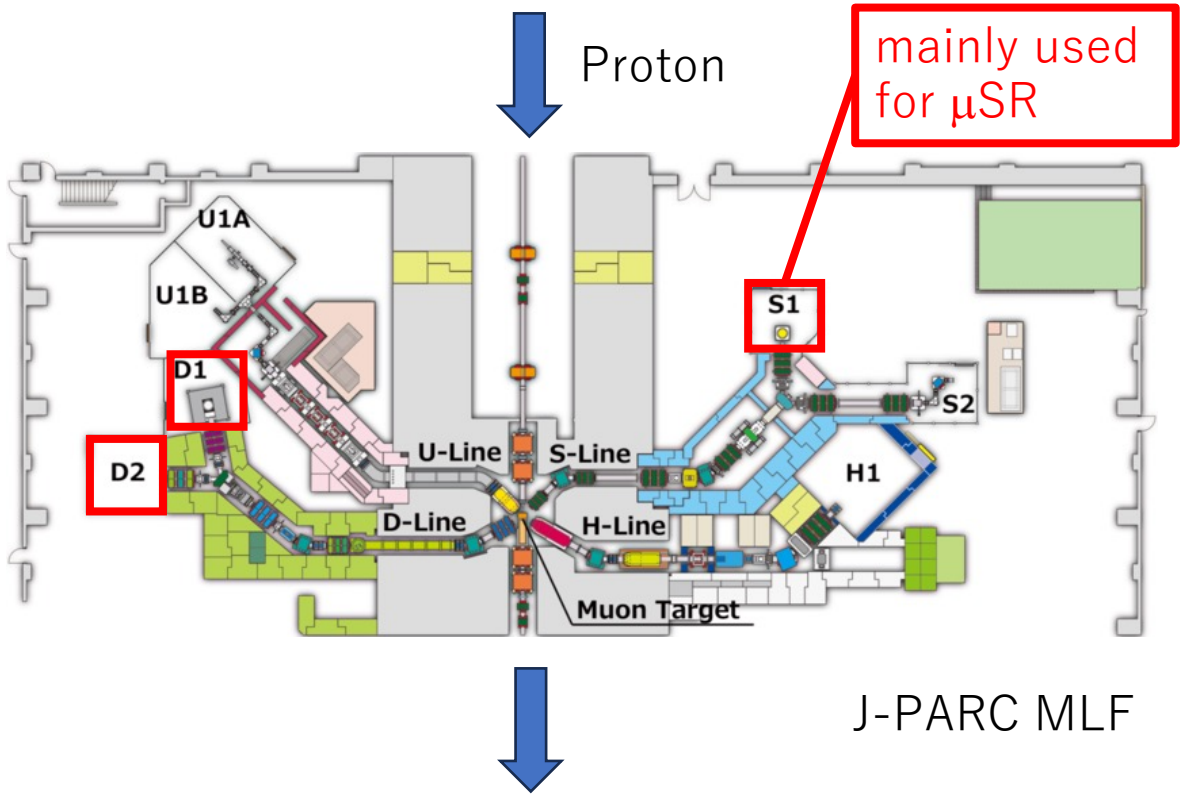
J-PARC MUSE

We call proposals for three beamlines

S1 Surface muon / spectrometer
μSR measurement

D1 **Decay** ・ Surface muon /spectrometer
μSR with DR for low temperatures
μSR with pressure cells
Lifetime measurements
Negative μSR(μ⁻SR)

D2 **Decay** muon
Elemental analysis
Muonic atom
Muon imaging
Particle physics Experiments
Soft error

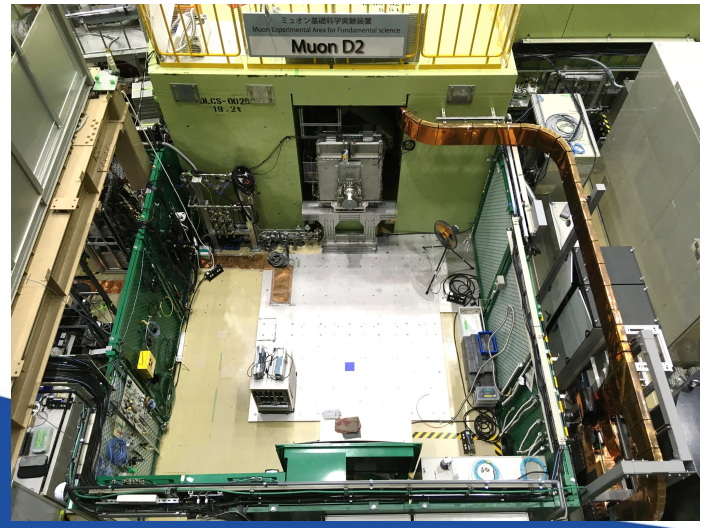


※Positive/ Negative decay muons
momentum : 4.5 – 120 MeV/c

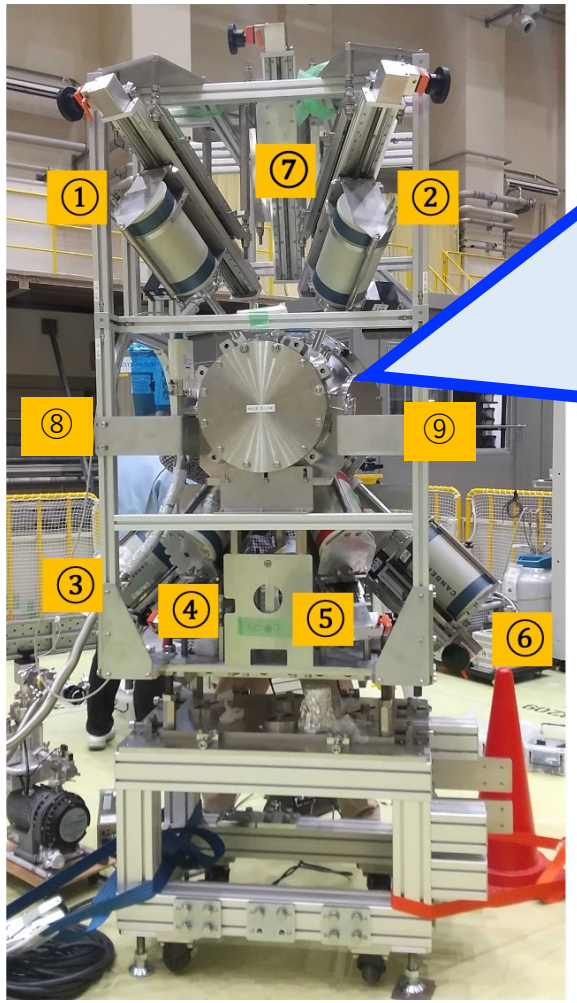
Measurement system for elemental analysis

Nine Ge detectors can be installed in the Measurement System, **hemispherical chamber**.

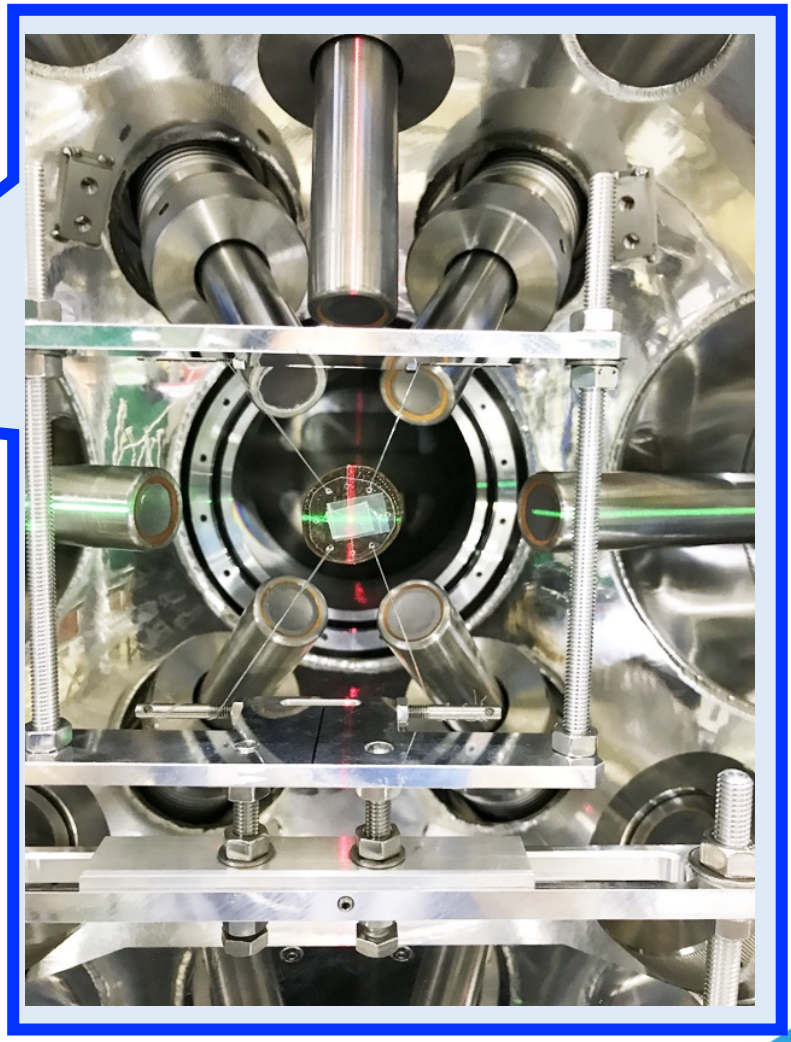
Sample condition can be changed depending on experiments.
(in vacuum, He atmosphere, air)



D2 exp. area



Measurement System



System with 9 detectors and a sample

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Cultural heritages measured by muonic x-rays

Nagoya Castle (Aichi)

Collaborations with museums work well at J-PARC MSUE

Golden statues on the top of the castle

緒方洪庵使用薬箱(2点)　右:壮年期　旧緒方栽吉氏蔵、左:晩年期　旧緒方惟之氏蔵

Japanese doctor's medical sample in a closed bottle in Edo era (1800s).

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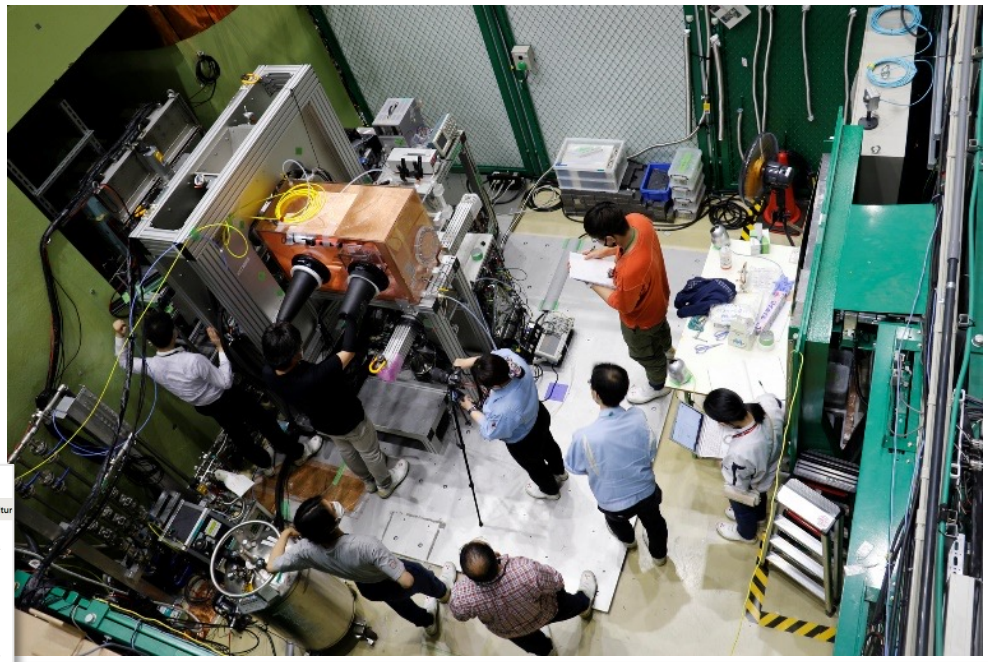
J-PARC MUSE's highlights

Muonic X-ray non-destructive element analysis of samples brought back by Hayabusa-II from Ryugu asteroid

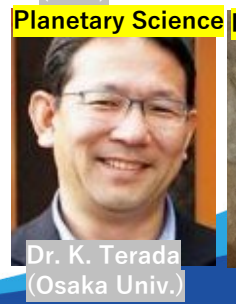
Hayabusa-II (CG image)

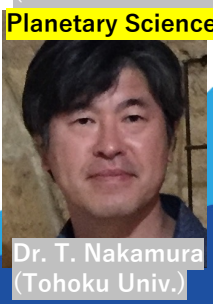
PRESS

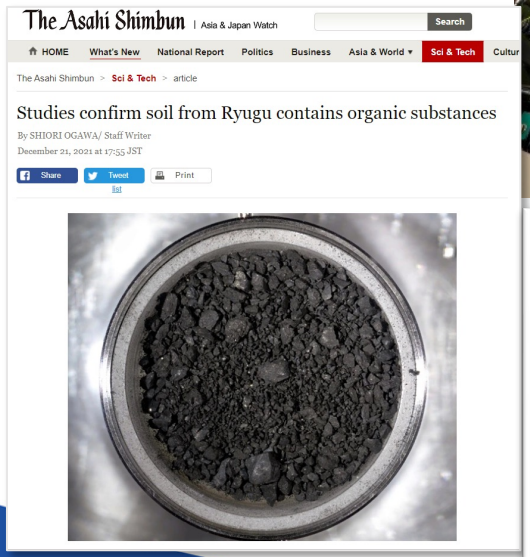


Formation and evolution of carbonaceous asteroid Ryugu : Direct evidence from returned samples

The sample from Ryugu is to be a new standard of the composition of the Solar system.







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Studies confirm soil from Ryugu contains organic substances

By SHIORI OGAWA/ Staff Writer

December 21, 2021 at 17:55 JST

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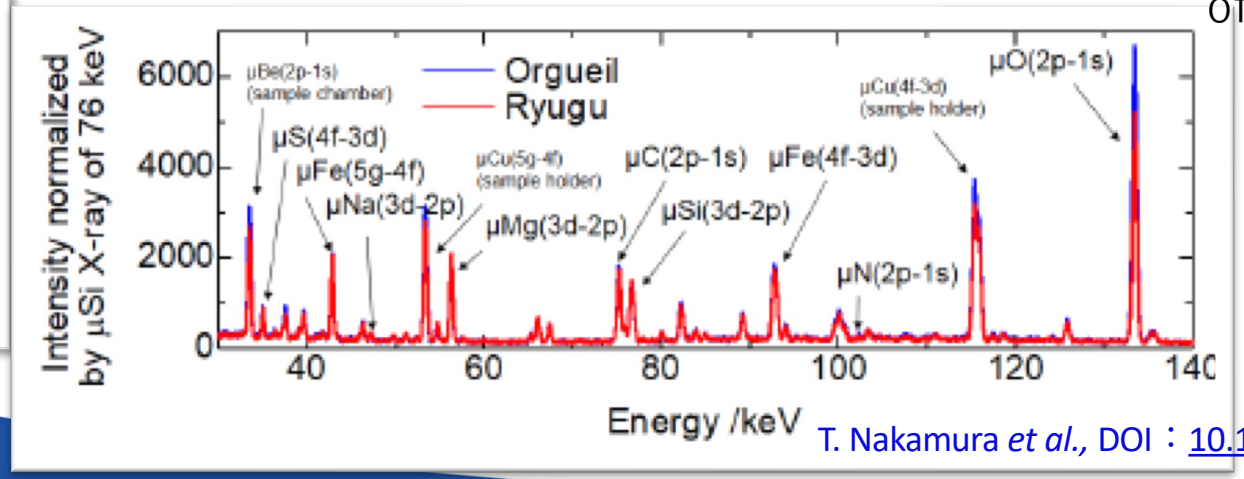
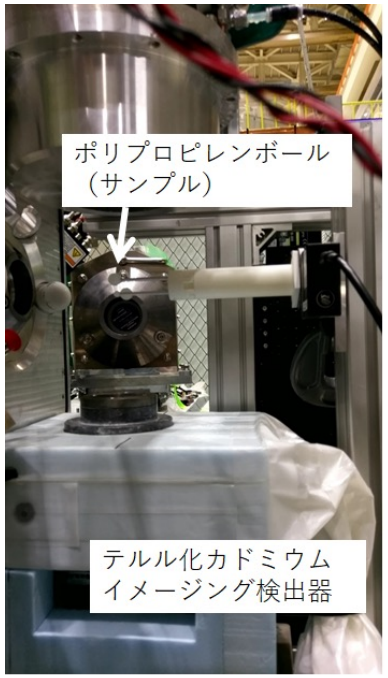


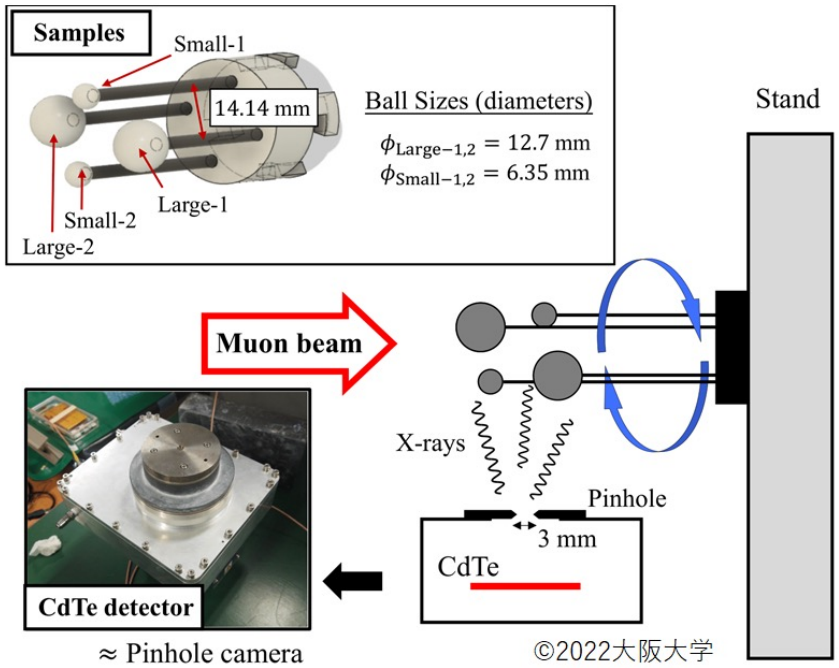
T. Nakamura *et al.*, DOI：10.1126/science.abn8671

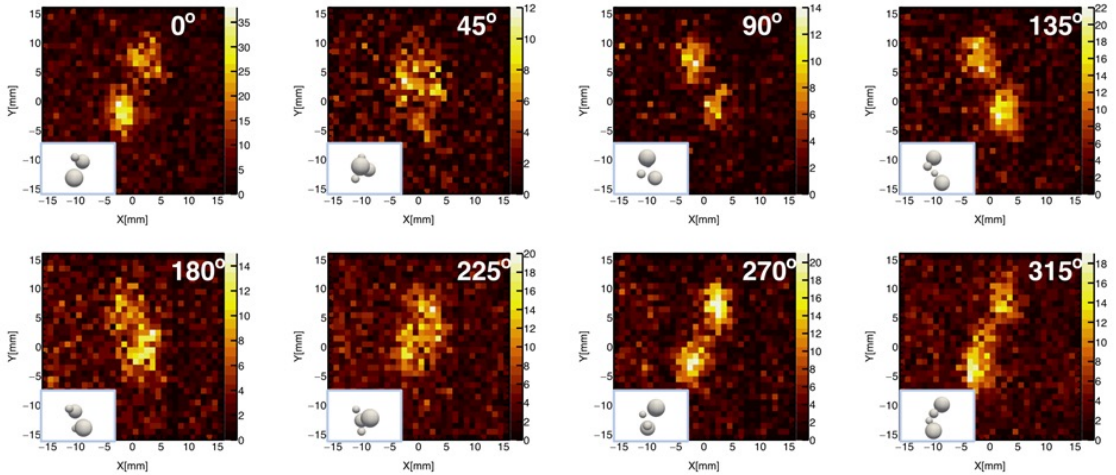
J-PARC MUSE's highlights

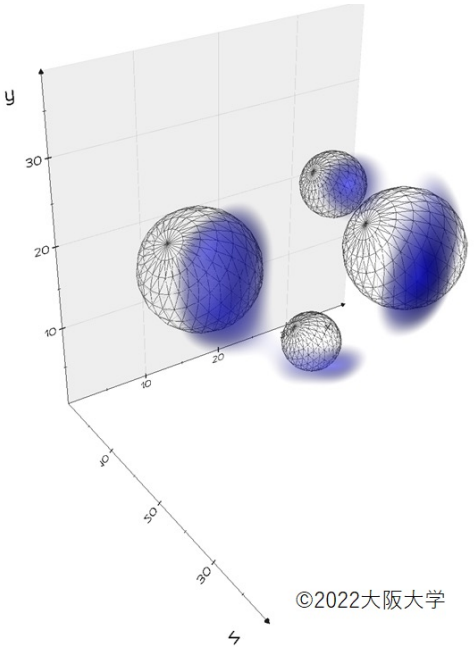
3D imaging of muonic x-rays by CdTe detectors

PRESS RELEASE（2022.4.26）
Successful Nondestructive 3D Elemental Analysis Using Elementary Particle Muons - New Technology Development by Quantum Beam Technology Meets Space Observation Detector









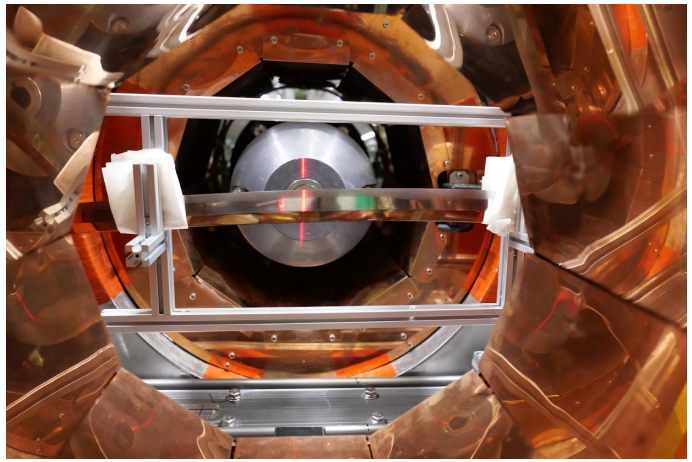
Three-dimensional elemental distribution is reproduced using 3D image reconstruction used in medical diagnosis.

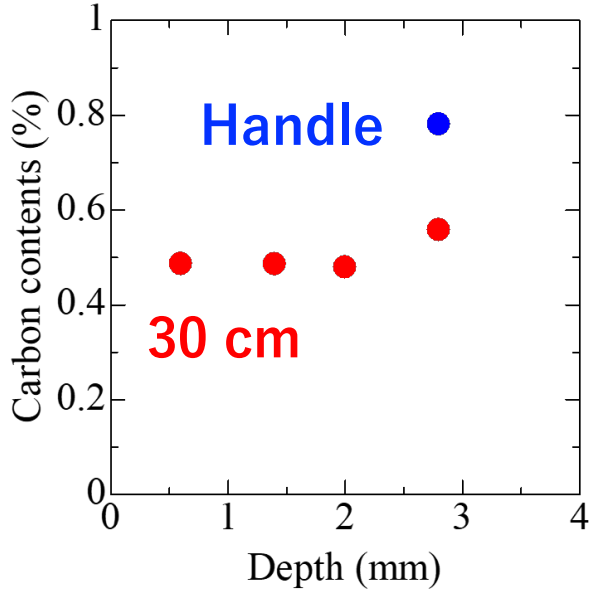
I - Huan Chiu et al.,
Scientific Reports 12, 5261 (2022).

J-PARC MUSE's highlights

Measurements on Japanese short sword made of steel.
Limitation of small amount of carbon in steel is 140 ppm.

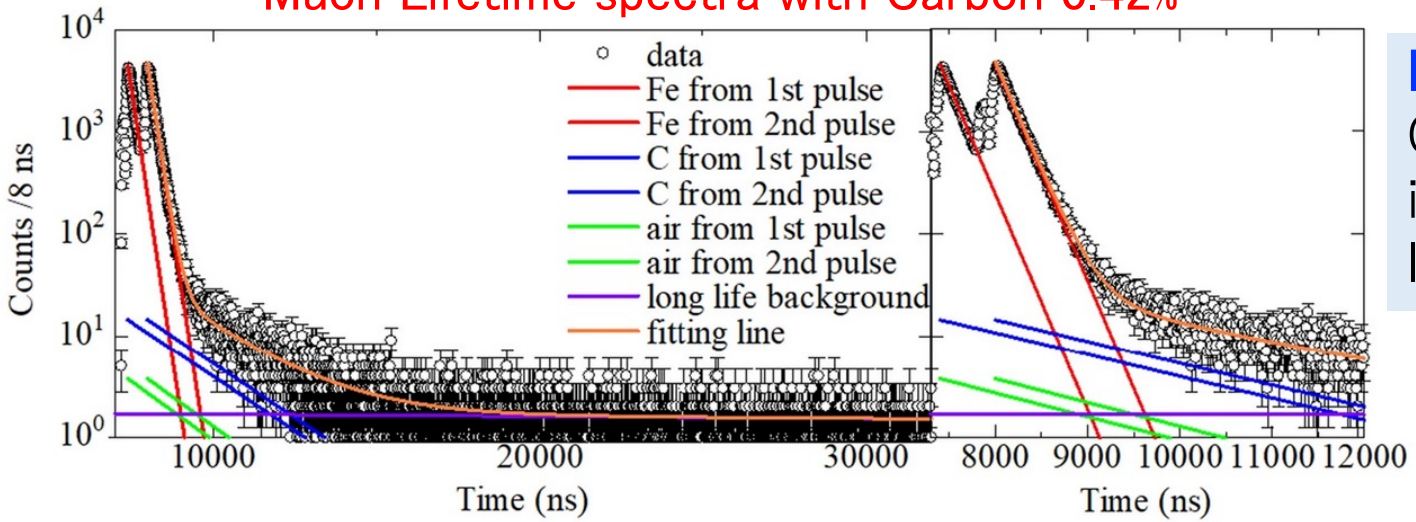
脇差 Short sword
長さ Length 51.8 cm
銘文 九州 肥後 同田貫 兵部





analysis

Muon Lifetime spectra with Carbon 0.42%



Muon lifetime spectrum of a C content of 0.42 wt% steel. (left) Entire fitted region and the (right) 7300–12,000 ns region. The fitting results including each component of Fe, C, air and background are also shown.

Lifetime measurements

Composition of elements can be investigated by the time spectra with lifetime of muons captured in the atoms.

Scientific Reports 14, 1797(2024).

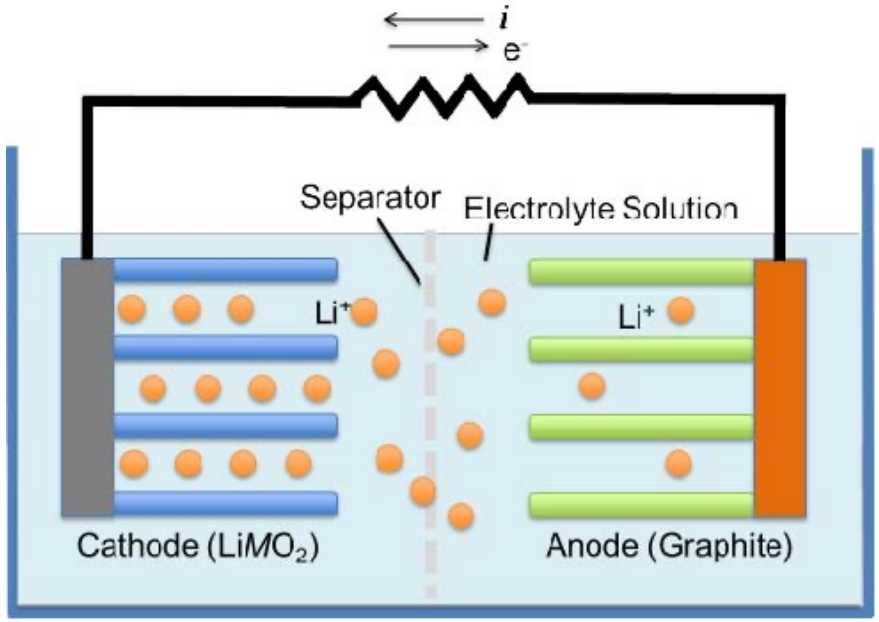
'24. 2. press

Li-ion battery with muons

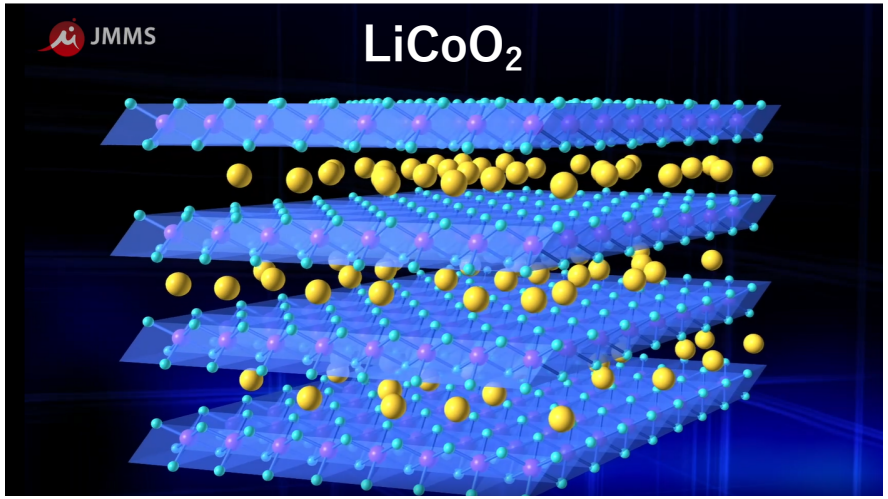
Japan Muon and Meson Society Webpage
http://jmeson.org/image/musr-video

$Li_{1-x}MO_2 \rightarrow xLi^+ + xe^- + MO_2$ **(Cathode)**

$6C + Li^+ + e^- \rightarrow C_6Li$ **(Anode)**



Schematic drawing of a LIB
in charging process



Li ion diffusion in active materials → μSR

J. Sugiyama *et al.*: PRL, **103**, (2009) 147601.
…
K. Ohishi *et al.*,: *ACS Phys. Chem Au* 2, 2, 98 (2022).
I. Umegaki *et al.*,: *J. Phys. Chem. C* , 126, 25, 10506(2022).

Existence of Li in active materials
→ muonic x-rays

M. Tampo *et al.*; submitted
I. Umegaki *et al.*,;JPS Conf. Proceedings. 21, 011041(2018).

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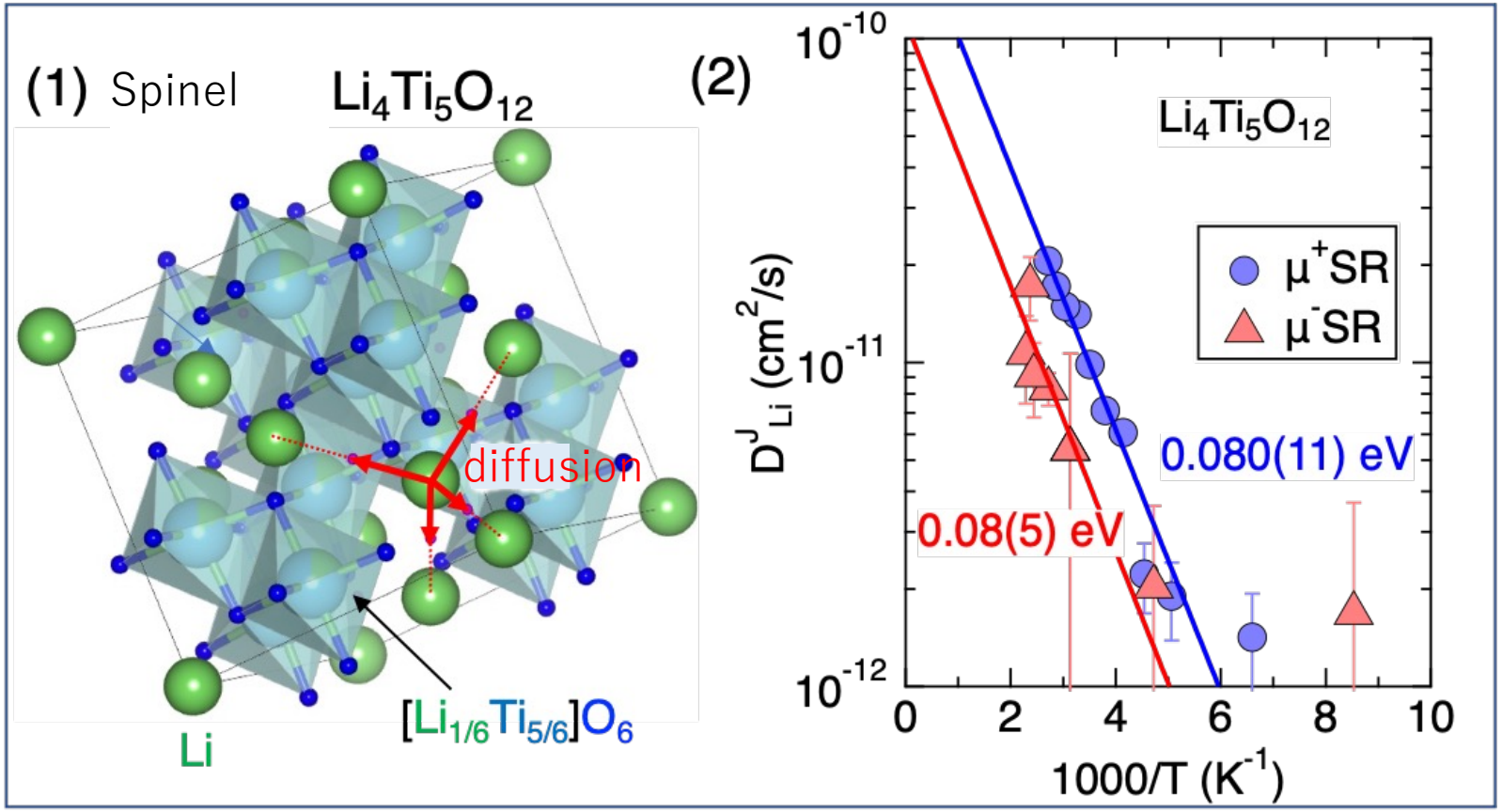
Diffusive phenomena observed by μ±SR



Species diffusing observed by μ^+SR is confirmed as Li by μ^-SR.

	μ^+SR	μ^-SR
site	near Oxygen	nucleus
Spin polarization	100%	20%

I. Umegaki et al., J. Phys. Chem. C, 126, 25, 10506-10514 (2022).

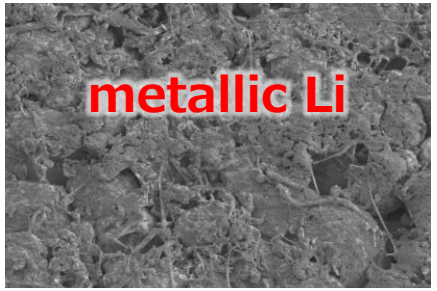
Results of μ^-SR with low statistics help qualitative understanding.
It is note that these results are not enough for quantitative discussion.

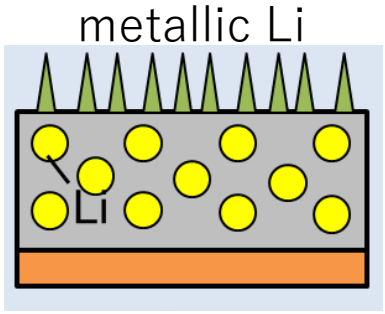
Safety issue and Metallic Li deposition

・A LIB is very popular
・**Reuse and recovery** of **used LIBs** is highly demanded in today's society
・**Safety cost** avoids promotion of reuse

・An **inappropriate use** causes **metallic Li deposition**

for example;
-cold environment
-high charge rate
-exclusive over charge



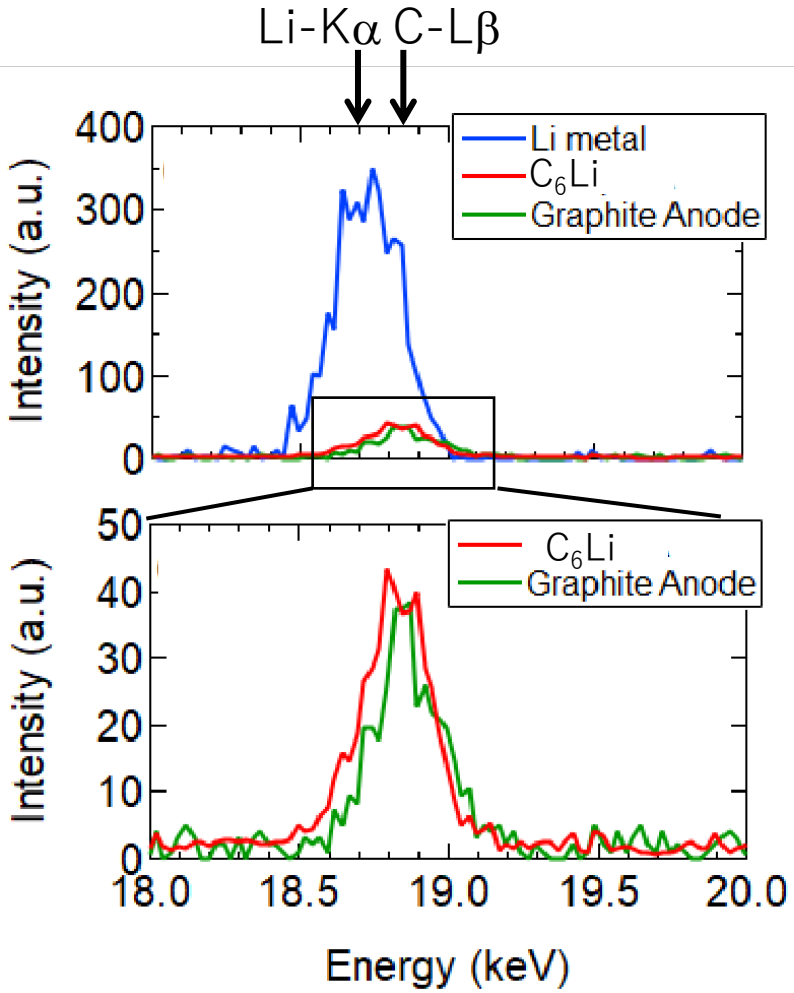


$Li^+ + e^- \rightarrow Li$

- **Less Thermal Stability**
- **Short circuit**
- **Charge capacity degradation**

It is desired to detect nondestructively metallic Li deposition in a LIB.

Energy resolution to detect Li in a Li-ion battery



Li Kα (2-1) 18.7 keV
C Lβ (3-2) 18.83 keV

To see Li contribution to the signal changes, we introduced a parameter I_{CLi},

$$I_{CLi} = \frac{I_{Li-K\alpha} + I_{C-L\beta}}{I_{C-K\alpha}}$$

numerator

denominator

ratio : constant

C Kα (2-1) 75 keV

- Battery always contains Carbon in an electrode, separator, or additives.
- The ratio of $I_{C\text{-}L\beta}$ and $I_{C\text{-}K\alpha}$ is conserved in the material.
  It is noted that the ratio depends on chemical states in the material.

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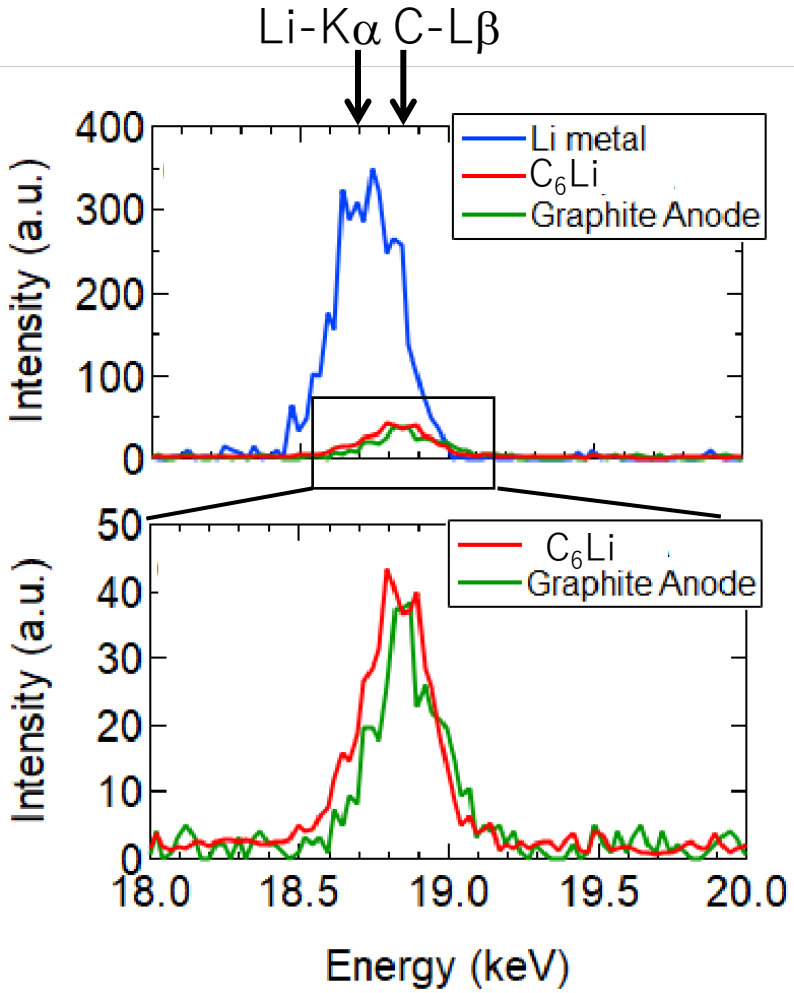
Metallic Li can be detected with high sensitivity



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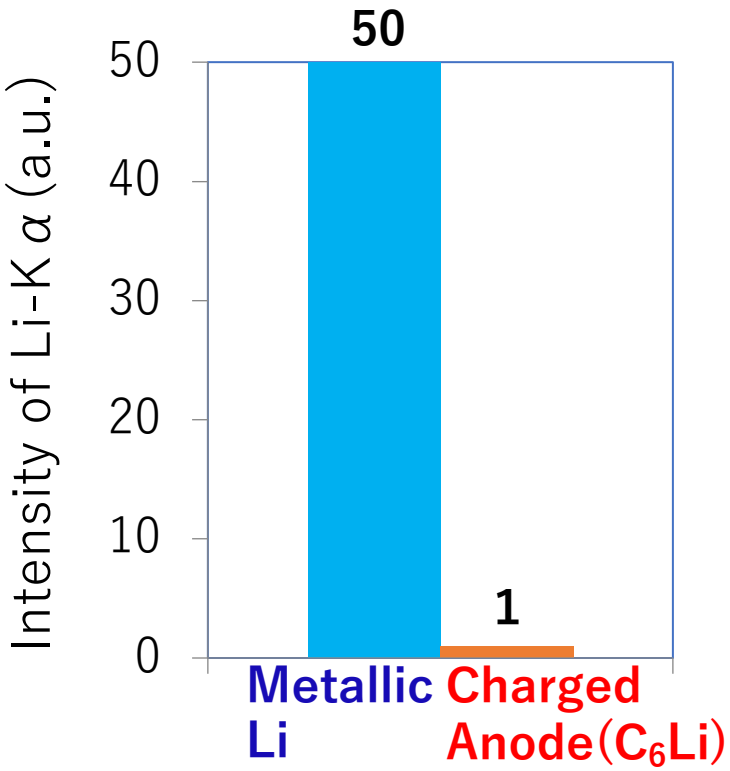

I.Umegaki *et al.*, Analytical Chemistry 92, 12, 8194-8200 (2020).

per C atom muonic Coulomb capture ratio:
$A(Li,C)=0.12\pm0.03$
For C_6Li

Atomic ratio:
C : Li = 6 : 1 (C_6Li)

$A(Li, F)=0.10\pm0.08$ for LiF

$A(Li,Cl)=0.19\pm0.08$ for LiCl

Insight through Accelerators.
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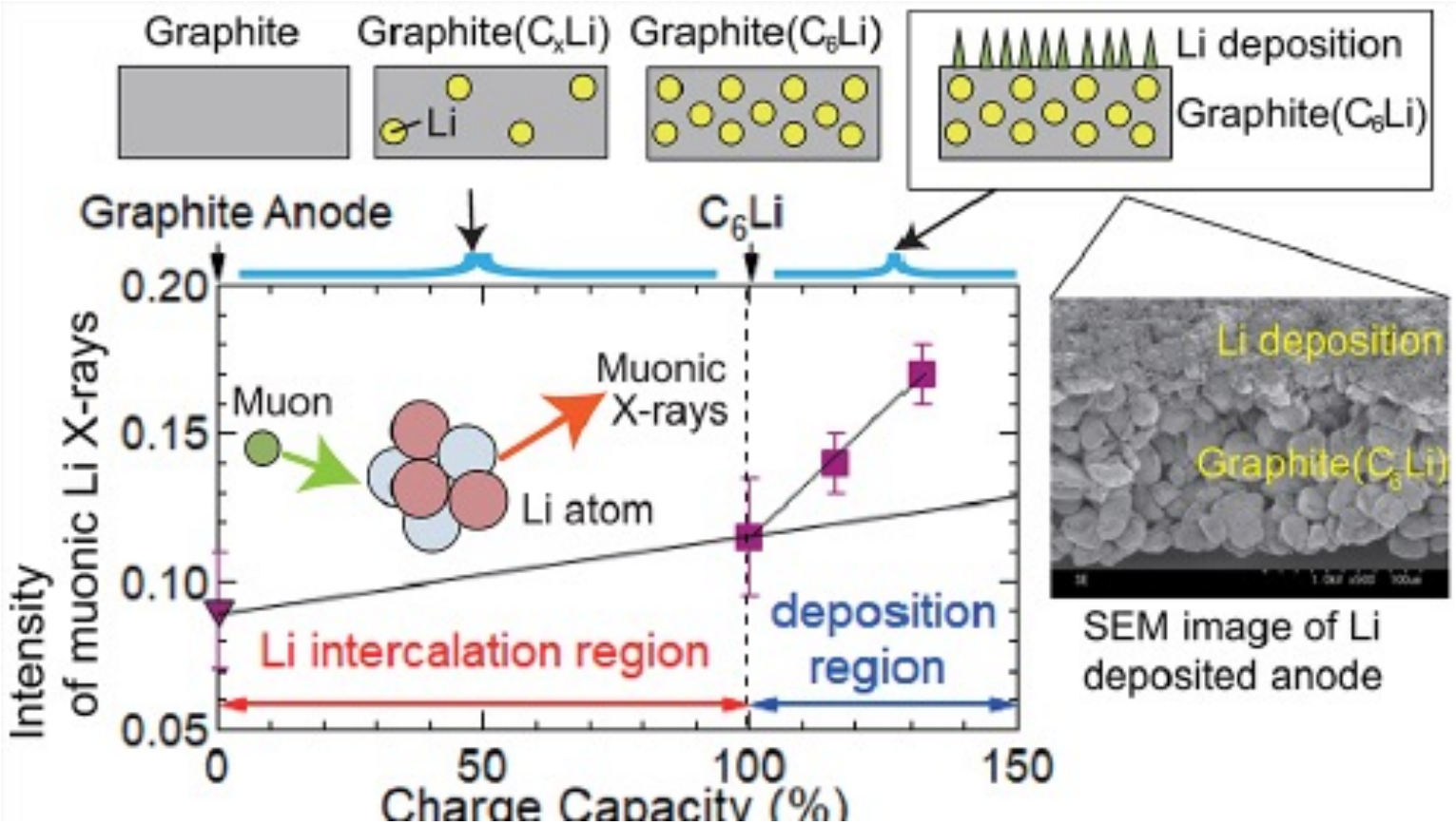
Metallic Li can be detected with high sensitivity



I. Umegaki et al., Anal. Chem. (2020) 92,12,8194-8200.

Metallic Li can be detected **with high sensitivity** because Li in a charged anode graphite is relatively less observed.

Negative muon experiments at J-PARC MUSE

- Elemental analysis with muonic x-rays
- Negative μSR (μ^-SR)
- Lifetime measurements
- Soft error

Common or respective requirements are

- Calculation of muon stopping range in a sample
- Estimation of intensity of muonic x-rays
  - Ratio of signals (composition, branches)
  - Chemical effect on the muonic cascade