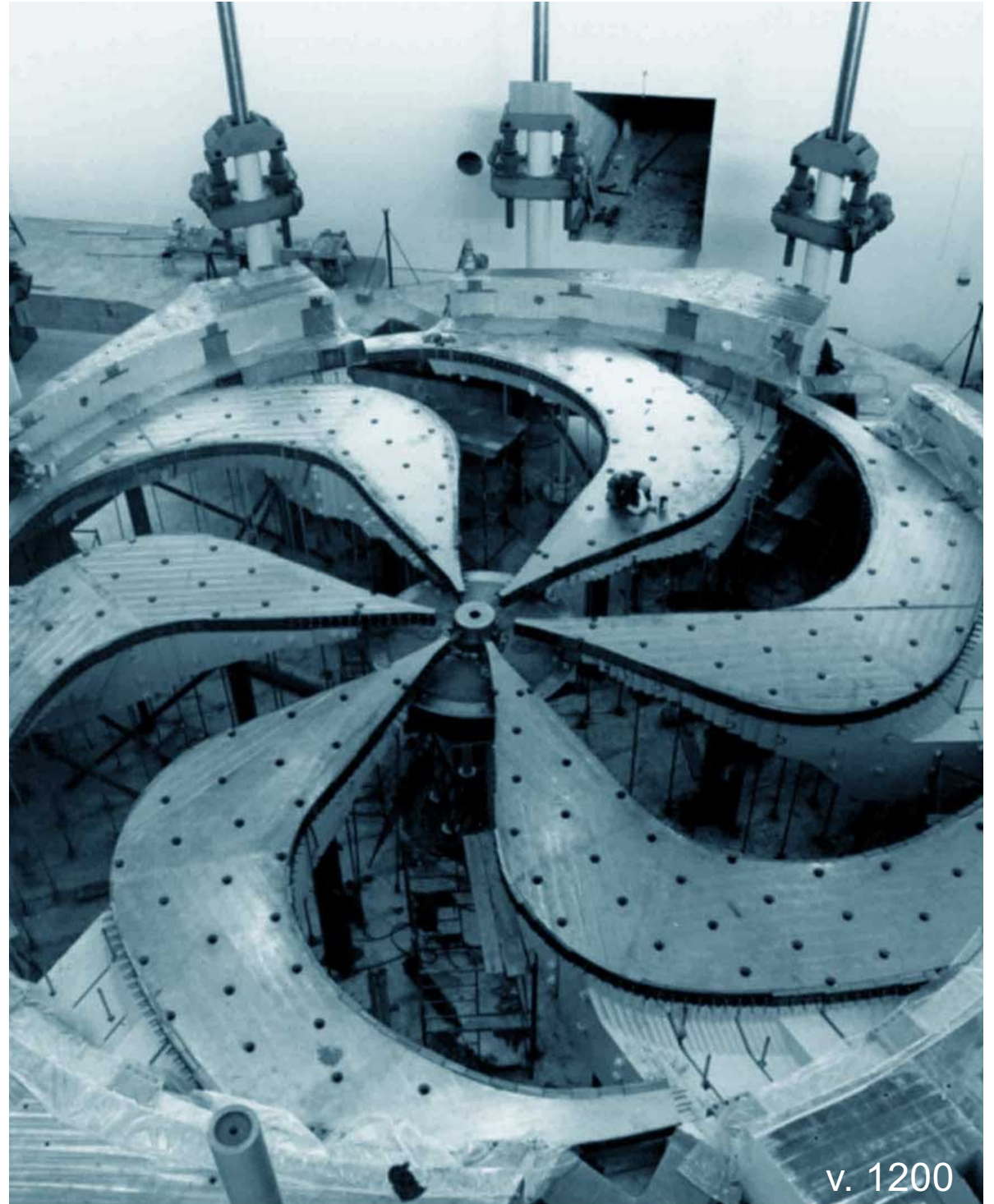


CMMS Activities, focused on Muon Imaging and Muonic X-Ray Analysis

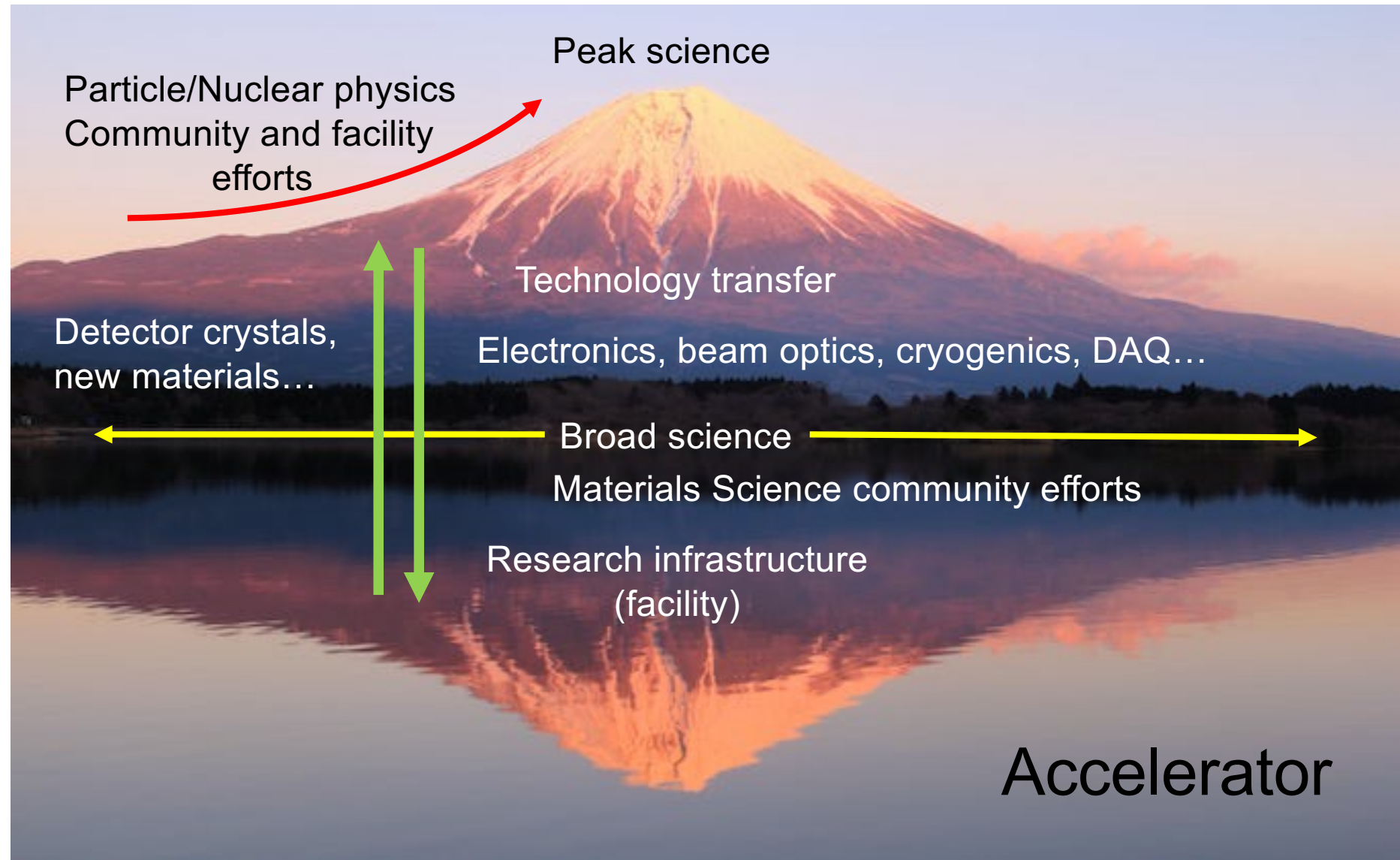
Kenji M. Kojima
Centre for Molecular and Materials Science
(CMMS), TRIUMF and
Stewart Blusson Quantum Matter Institute
(SBQMI), University of British Columbia

2026-09-28



v. 1200

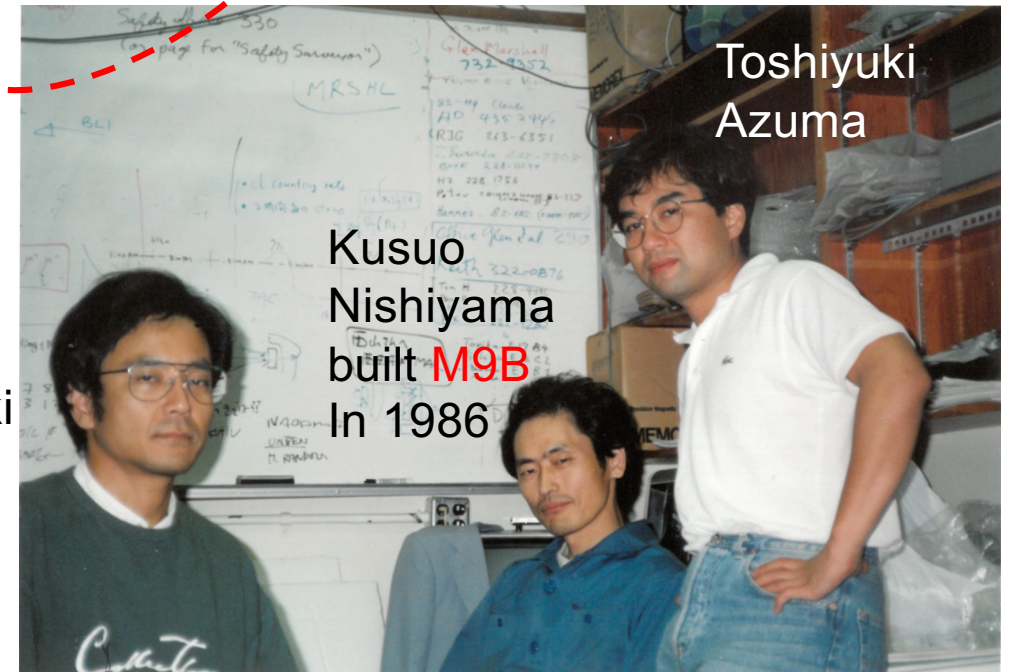
Particle / Nuclear physics and Materials Science (my view)



People Trajectories

- Kenji Kojima
 - 1968 born in Niigata
 - 1991 Nagamine gr.
 - 1996~ Columbia U.
 - 1998~ U. Tokyo
 - 2009~ KEK, IMSS
 - built μ SR spectrometers
 - 2018~ TRIUMF
 - 2025 M9B→M9H
- Makoto Fujiwara
 - 1991 Torikai gr.
 - 1992 UBC Gren Marshall gr.
 - μ CF at TRIUMF
 - 2005~ ALPHA at CERN
- Shoji Asai
 - 1990 Orito gr.
 - ATLAS at CERN
- Toshiyuki Azuma
 - KEK muon user

3



Yasunori Yamazaki

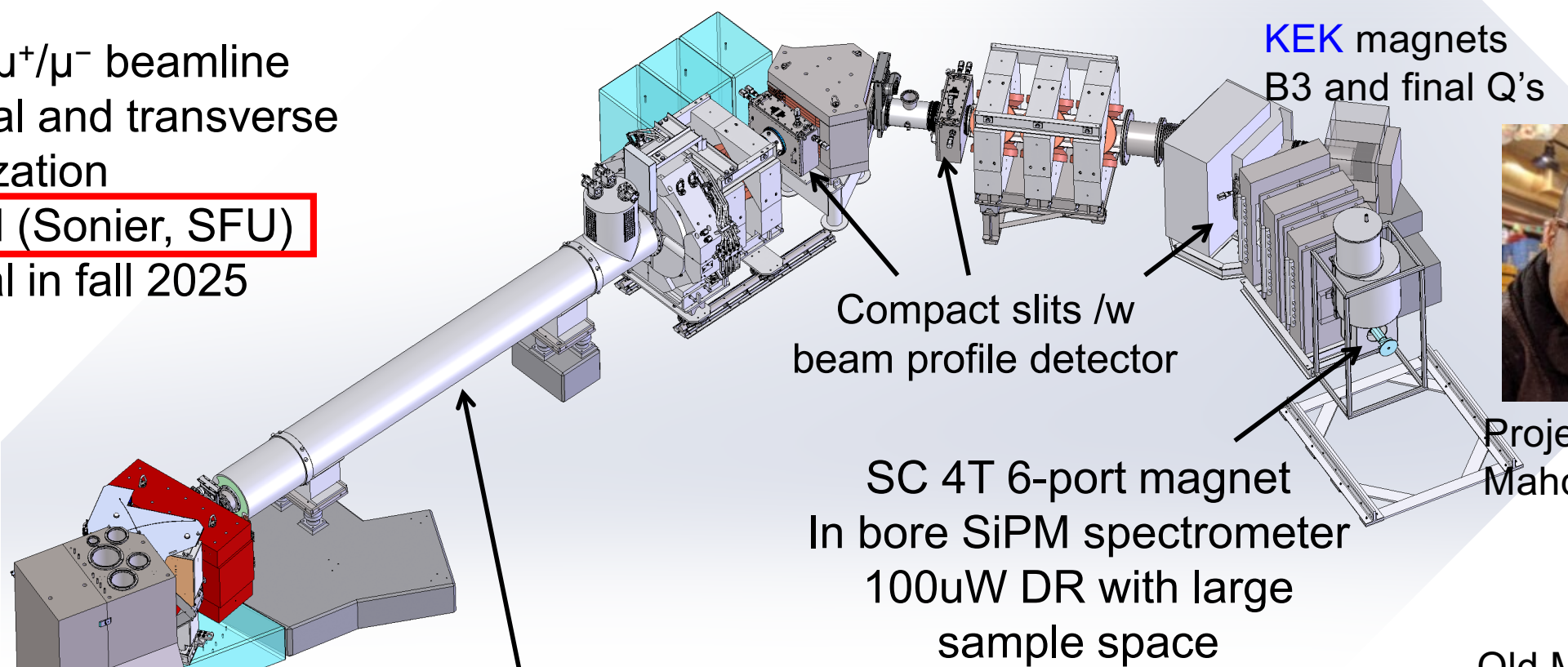
Kusuo Nishiyama
built M9B
In 1986

Toshiyuki Azuma

μ SR Beamlines: M9H (completed and operational 2026/1~)

- Backward μ^+/μ^- beamline
- Longitudinal and transverse spin polarization
- CFI funded (Sonier, SFU)
- Operational in fall 2025

T2-M9 front
end repaired in
2020



5T recondensing RT-bore solenoid, operates in persistent mode with a robust 10hr hold time during total power loss or interruption



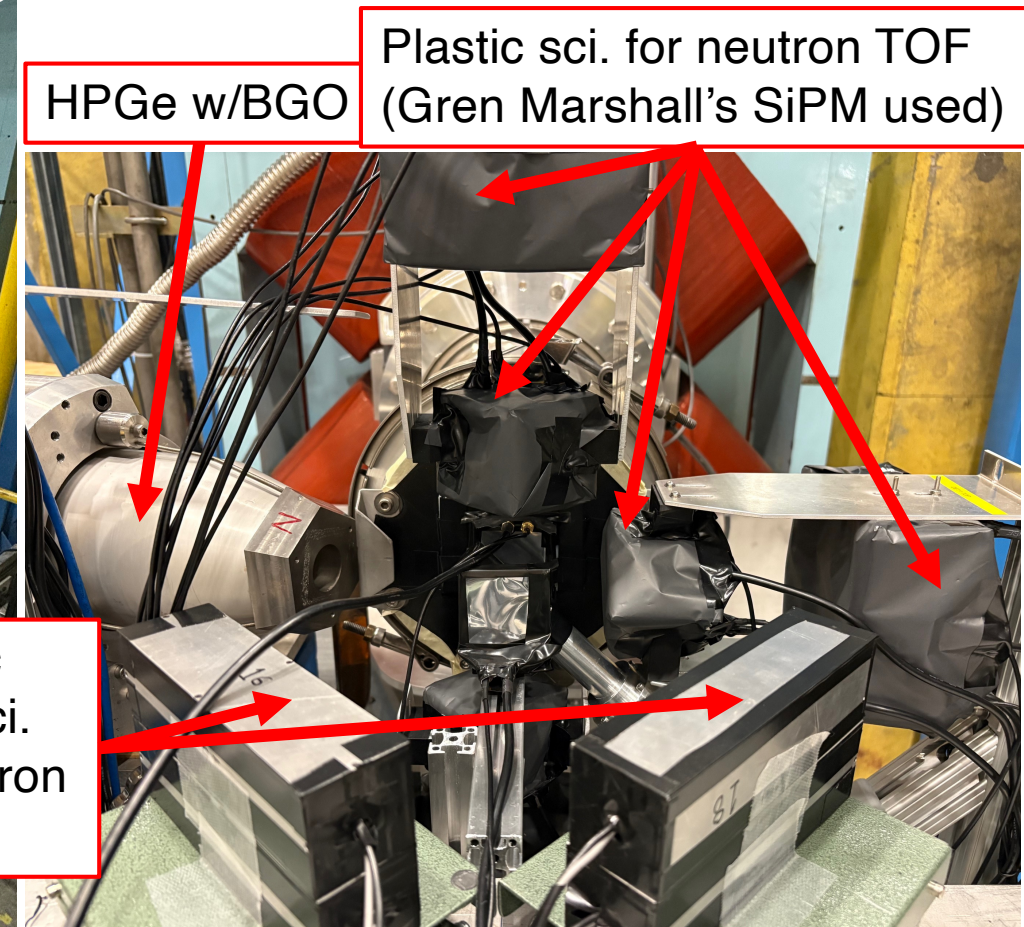
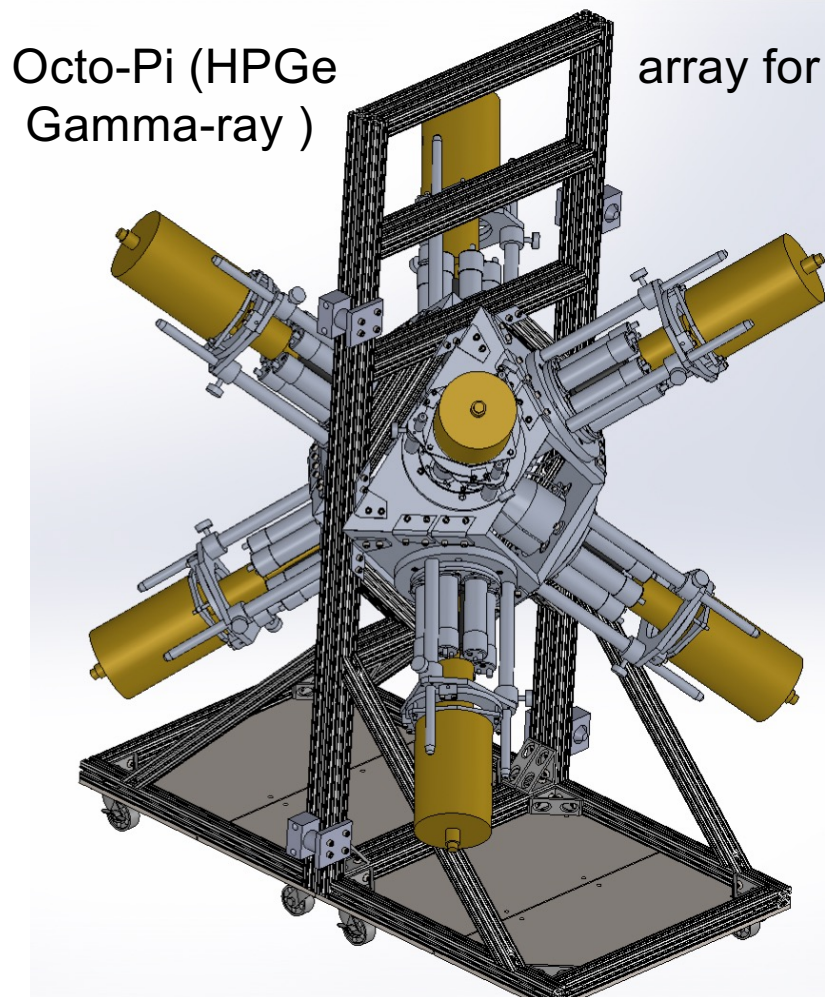
Old M9B solenoid
(1986~2024)



Project Engineer
Mahdiar Khosravi

1. The first negative muonic X-ray measurement

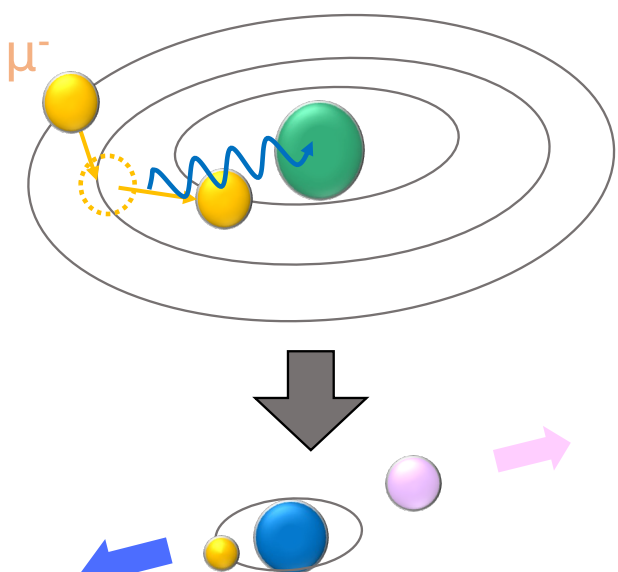
- Rurie Mizuno + Kris Starosta gr. (SFU) and TRIUMF Nucl. Phys. gr.
 - 2025/4~2026/2 (JSPS oversea fellow at TRIUMF)
 - 2026/3~ (Riken postdoc at Nishina Centre)



Idea of Rurie's experiment

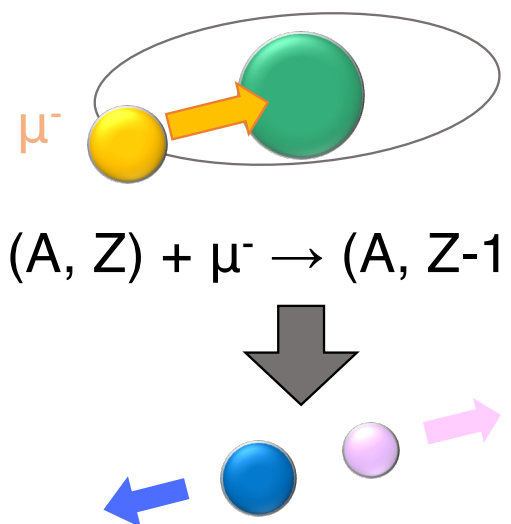
Two fission modes for >Uranium (Actinides)

**Prompt fission
(muon-catalyzed fission)**



Fission after excitation by the energy of transition X-ray (~ 6 MeV)
Time scale : ~ ps

**Delayed fission
(muon capture fission)**

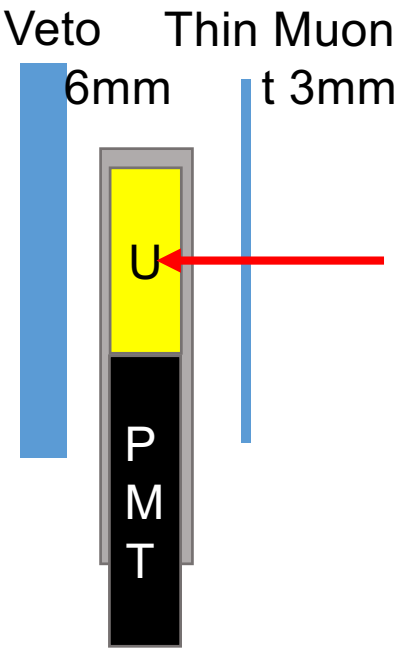
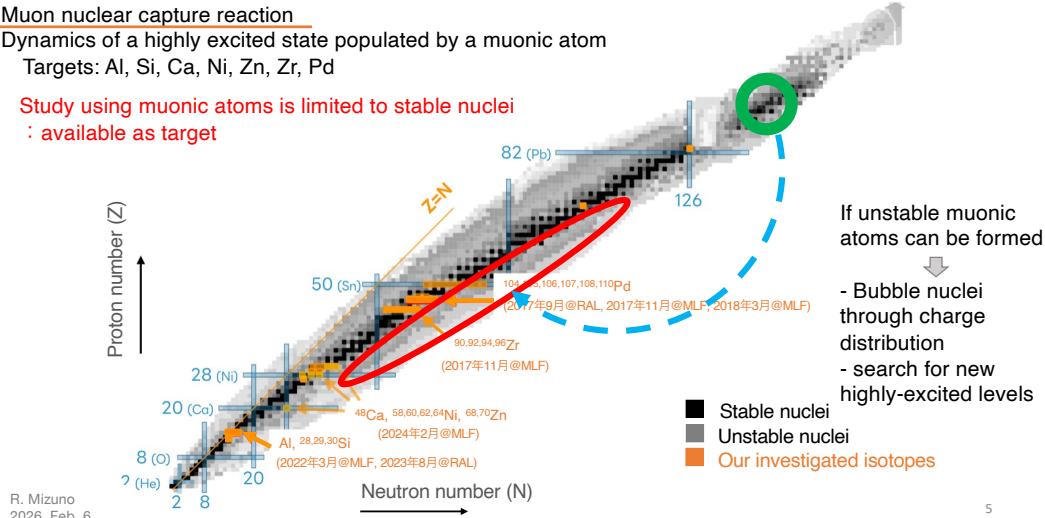


$(A, Z) + \mu^- \rightarrow (A, Z-1)^* + \nu_\mu$

Fission after excitation by Muon nuclear capture reaction (20 MeV in average)
Time scale : ~70 ns

Initial target material is ²³⁸U

Negative muon stays with the fission product: **muonic X-ray analysis of n-rich rare isotopes**

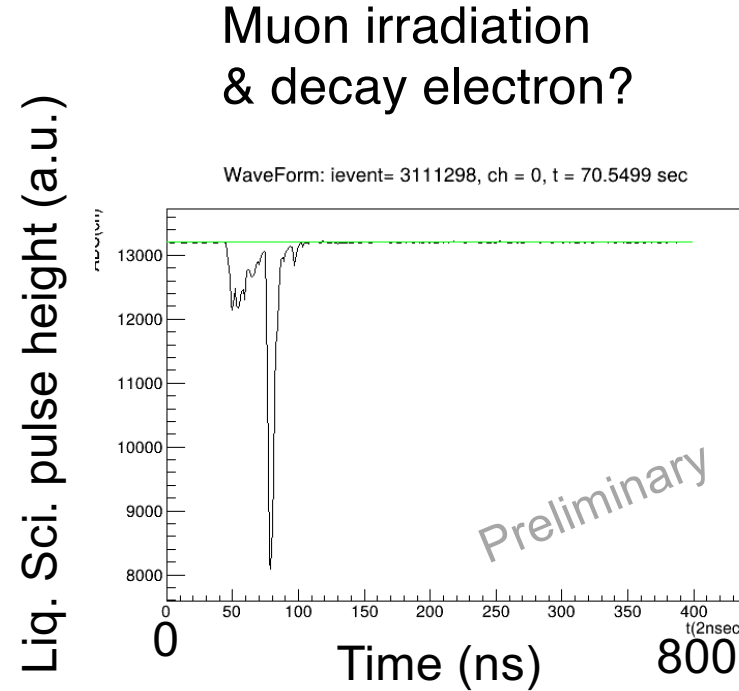


²³⁸U + liq. Sci.

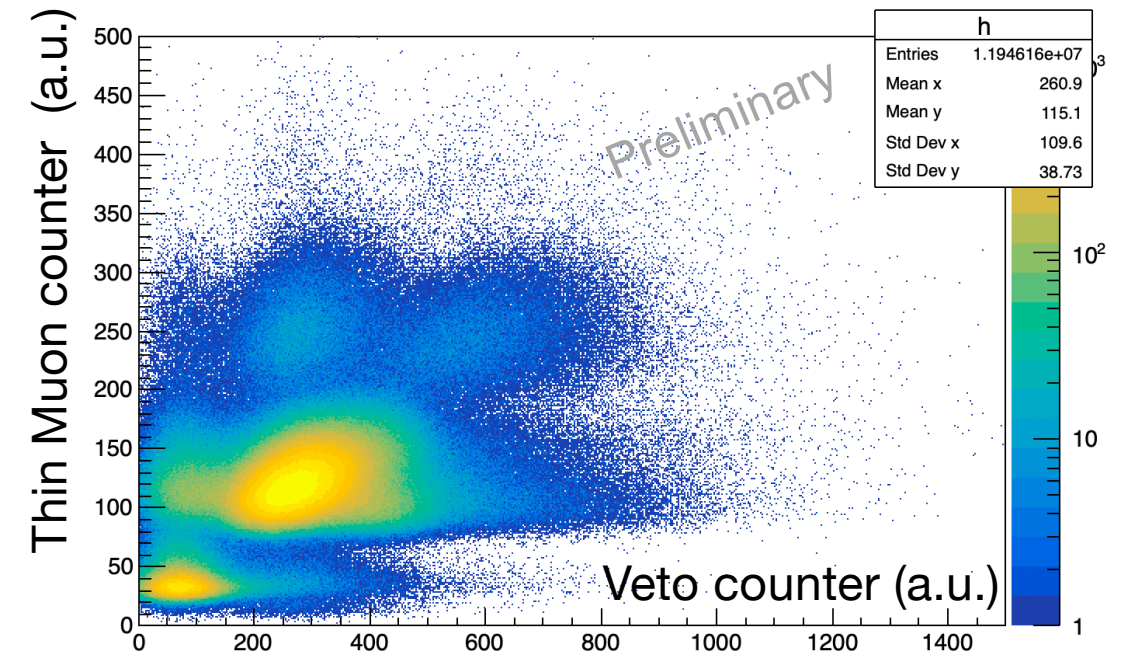
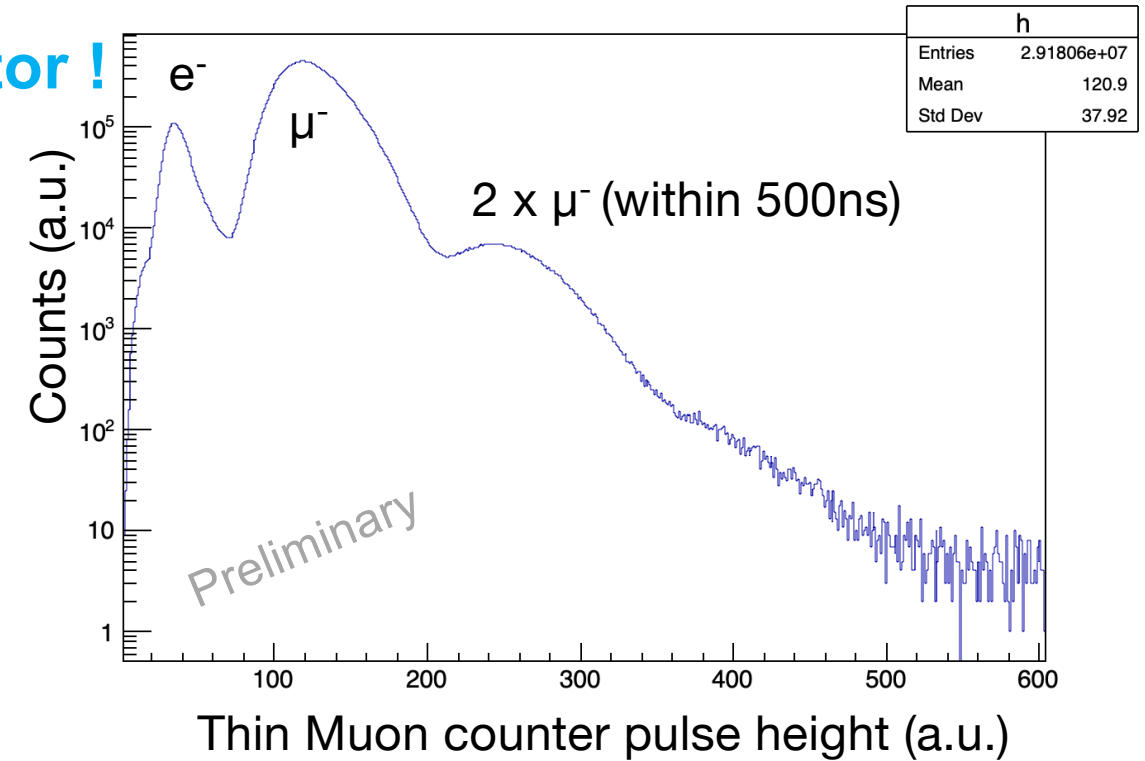
Muon was already too bright with liq. scintillator !

Commissioning of M9H

- 01/28~29 2026
(Positive muon)
60, 90 MeV/c,
max. **80k μ +/sec**
(one Q magnet is off)
- 01/29~02/02 2026
(Negative muon)
60 MeV/c + X-ray
10~50k μ -/sec
10~15% e- contamination.
- 02/02 2026 (Mon)~
long shutdown 2026

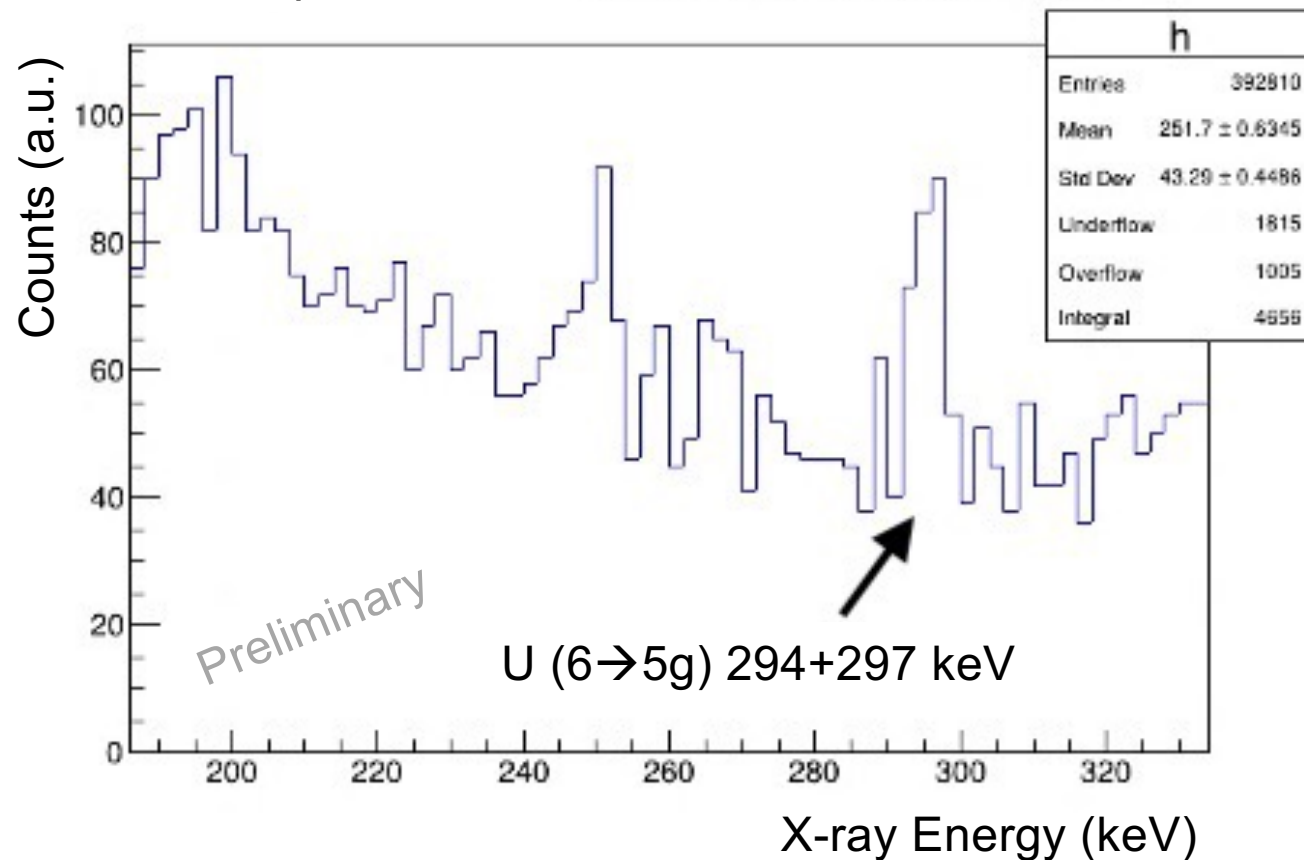


We were expecting that
Uranium fission gives much
brighter signal than single
muon / electron event
→ **No, muon signal
dominates liq. scintillator.**

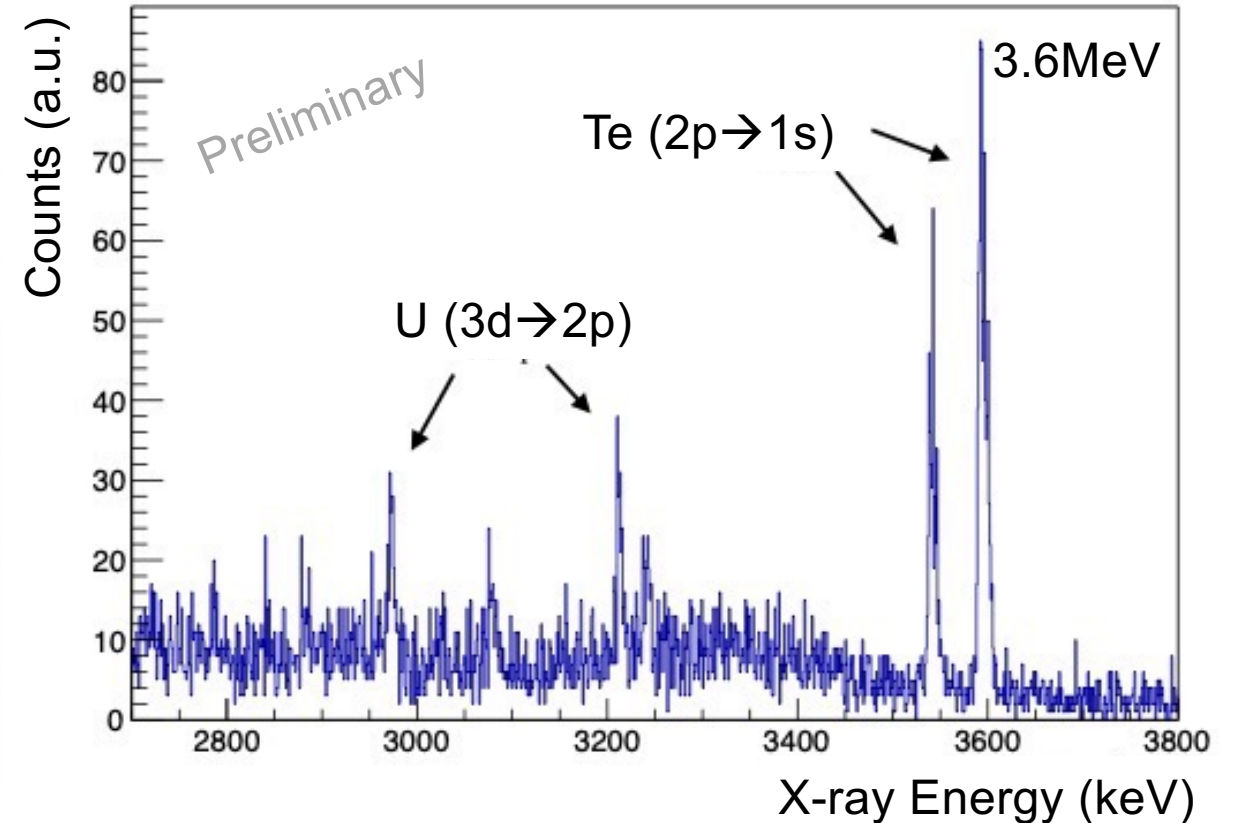


Muonic X-ray spectrum of Uranium

U + liq. scintillator



UTe2 Superconductor: μ SR sample degraded. ⁸
Courtesy from Dunsiger et al.



First Uranium (and Tellurium) muonic X-ray signals from M9H were observed !

Negative muon experiments in the future

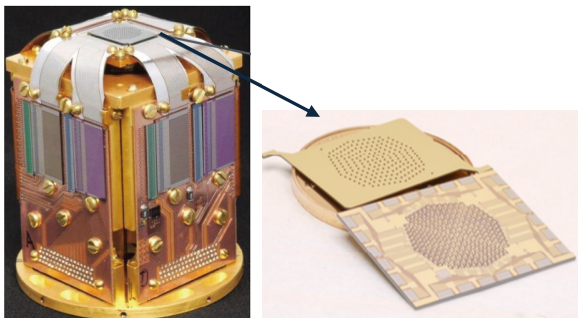
Nuclear physics experiments

Rurie's

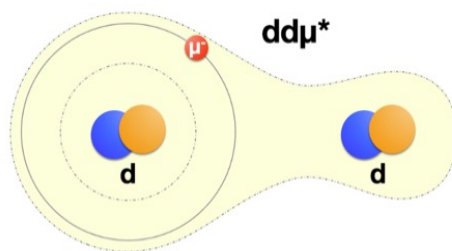
muon-induced fission detection
→ Fission chamber + Si detector
being developed at RIKEN.



Other experiments being consulted:
e.g. Moonshot for μ CF (S. Okada). -- KEK-QUP ?



Rev. Sci. Instrum. 90, 123107 (2019)



Azuma's slide

Archeology / Indigenous study in Canada

Muonic X-ray analysis of elements in the depth
→ NSERC Discovery Horizons application with
Museum of Anthropology, UBC (deadlined
Oct. 19, 2026).

TRIUMF's DC beam is deadtime **efficient**

Collaboration framework:

K. Shimomura's (KEK) leading

New Horizons in Negative Muon Science group grant (学術変革)

KEK/J-PARC pulsed beam is
~10 years ahead of TRIUMF in μ^-



New Horizons in Negative Muon Science:
A Transdisciplinary Integration of Knowledge Bridging Matter, the Universe, and Humanity

<https://mu-horizons.kek.jp/en/>

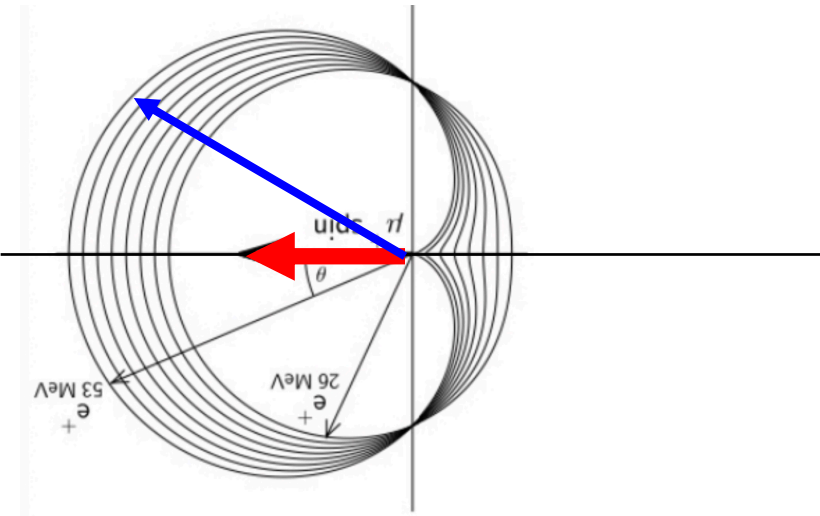
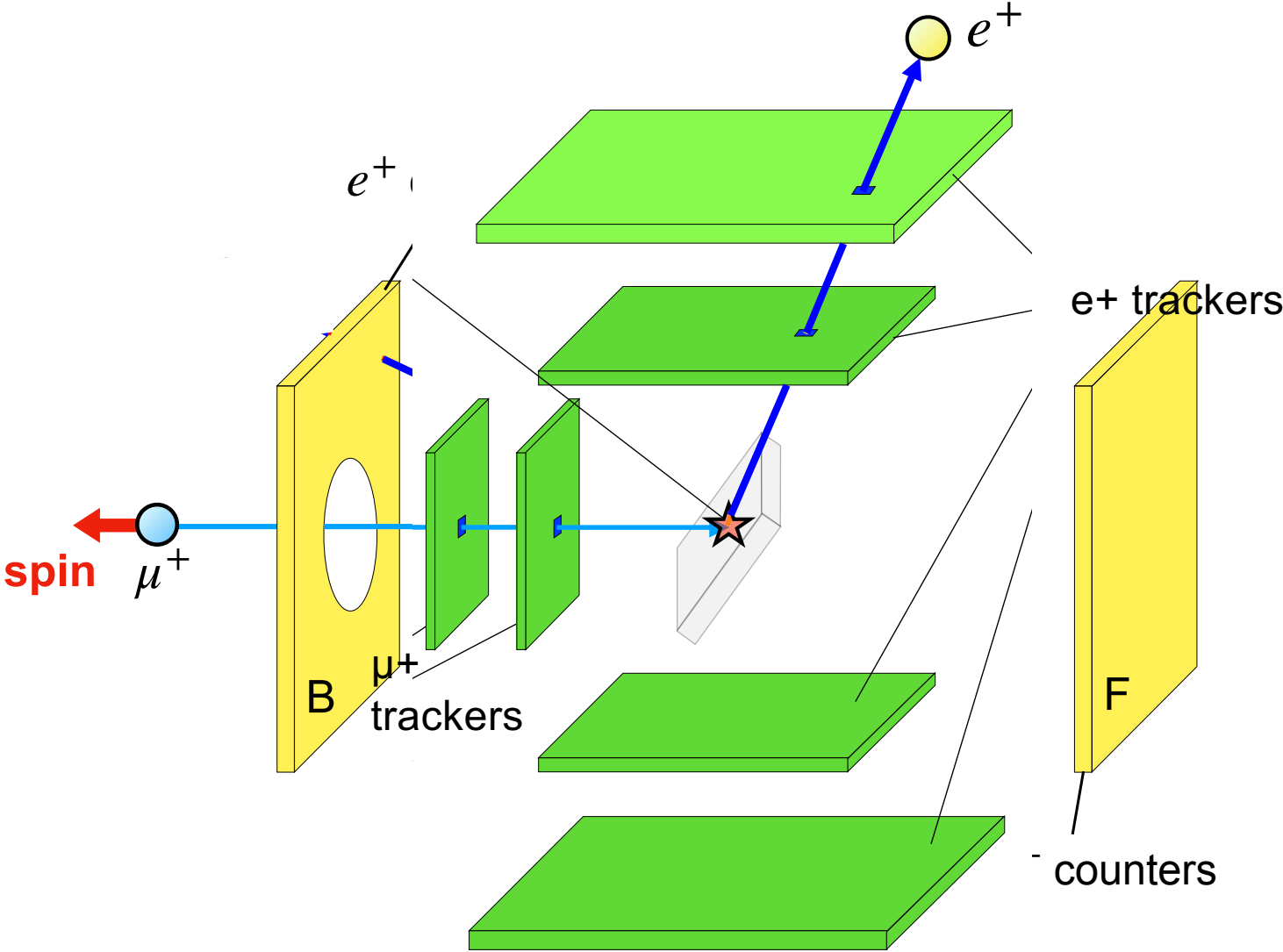
HOME Message About News Projects Open Call Achievements Reports Publications

D01 医療用核種 D02 人類技術
C02 太陽系の進化 A02 低速化技術
C01 基本対称性 A01 核データ
B02 ソフトエラー
B01 不安定核物理

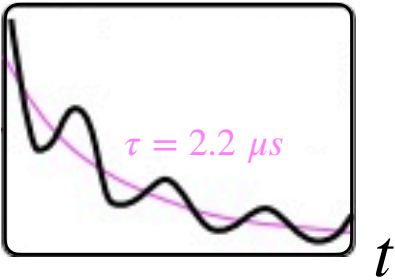
μ^- 知融合

2. Muon Spin Imaging (beyond conventional μ^+ SR)

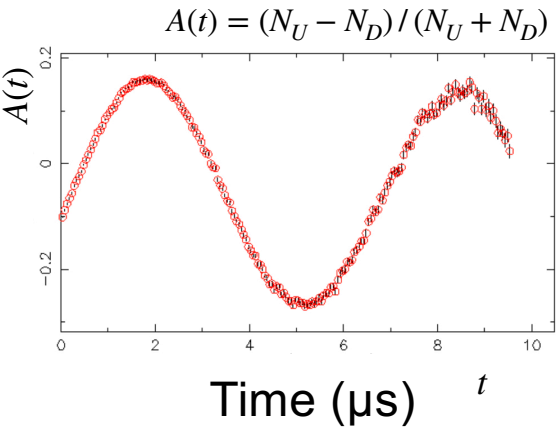
Slide from M. Mihara (Osaka U.) 10



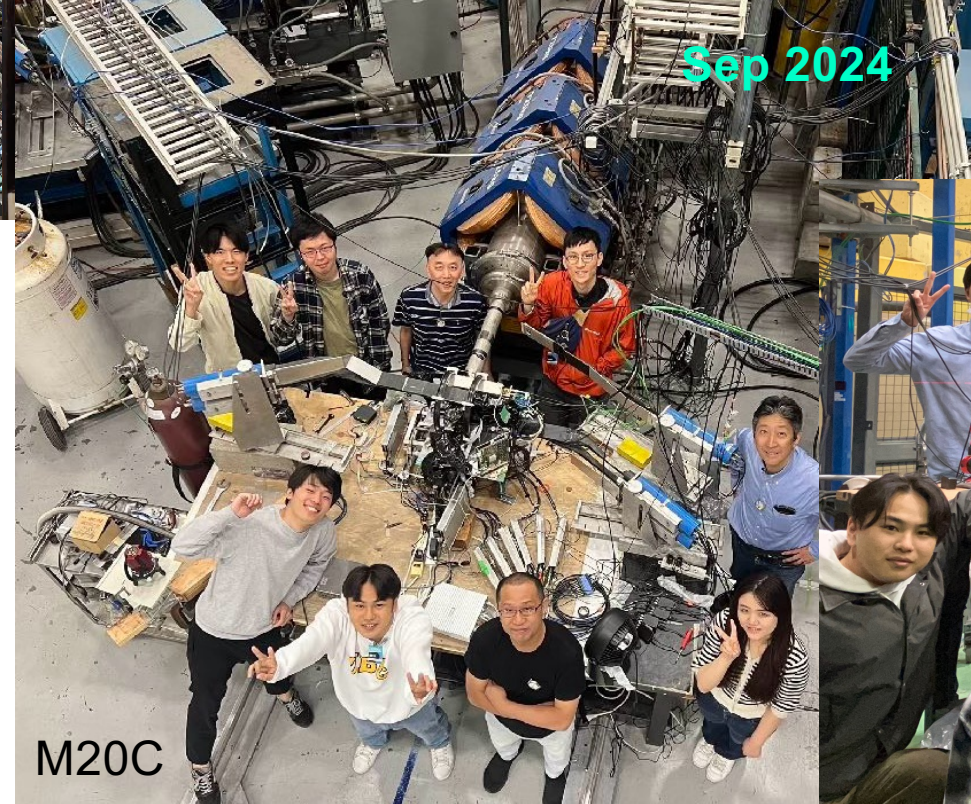
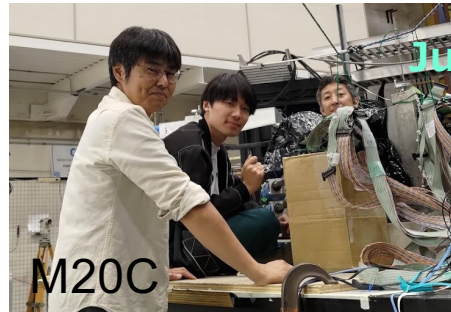
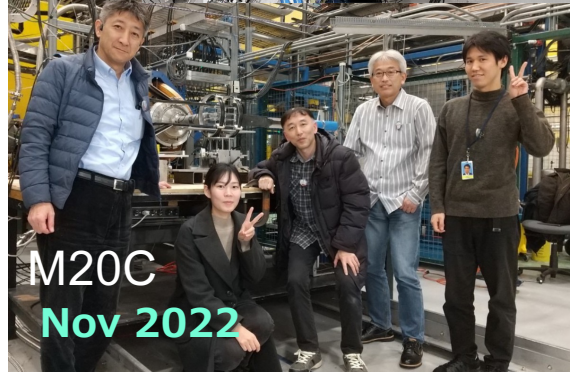
μ -e decay time spectrum



μ SR spectrum



Collaboration with Osaka U. since 2022 at TRIUMF



KEK-TRIUMF EPECR

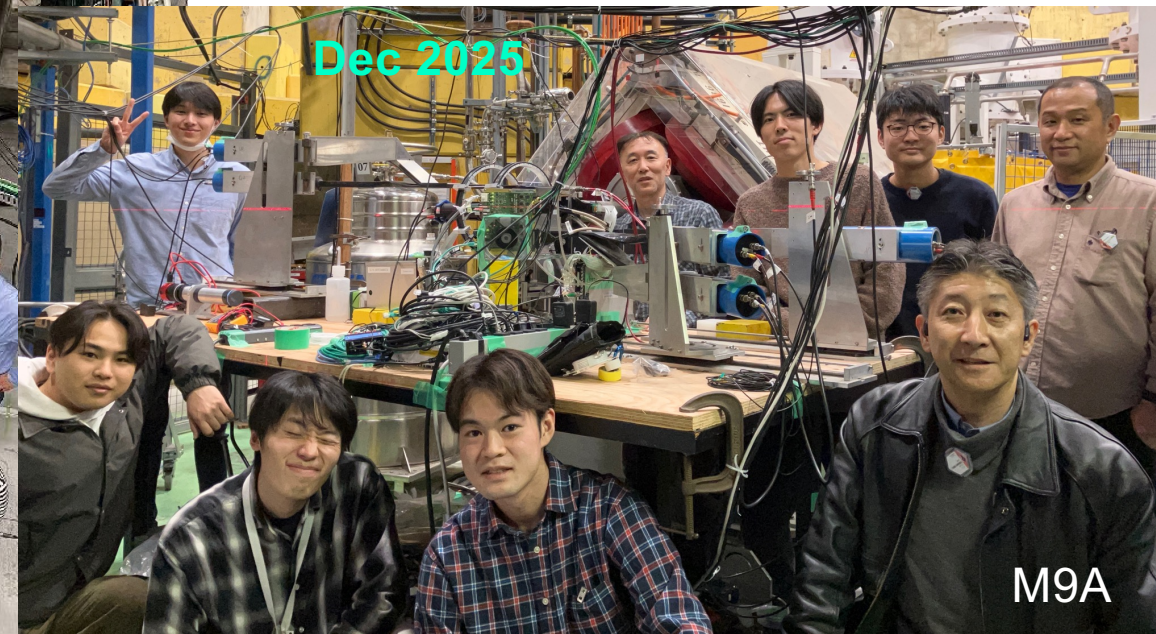
FY2023: Takato Sugisaki



FY2025: Soshi Ishitani

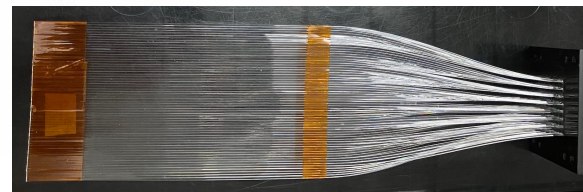
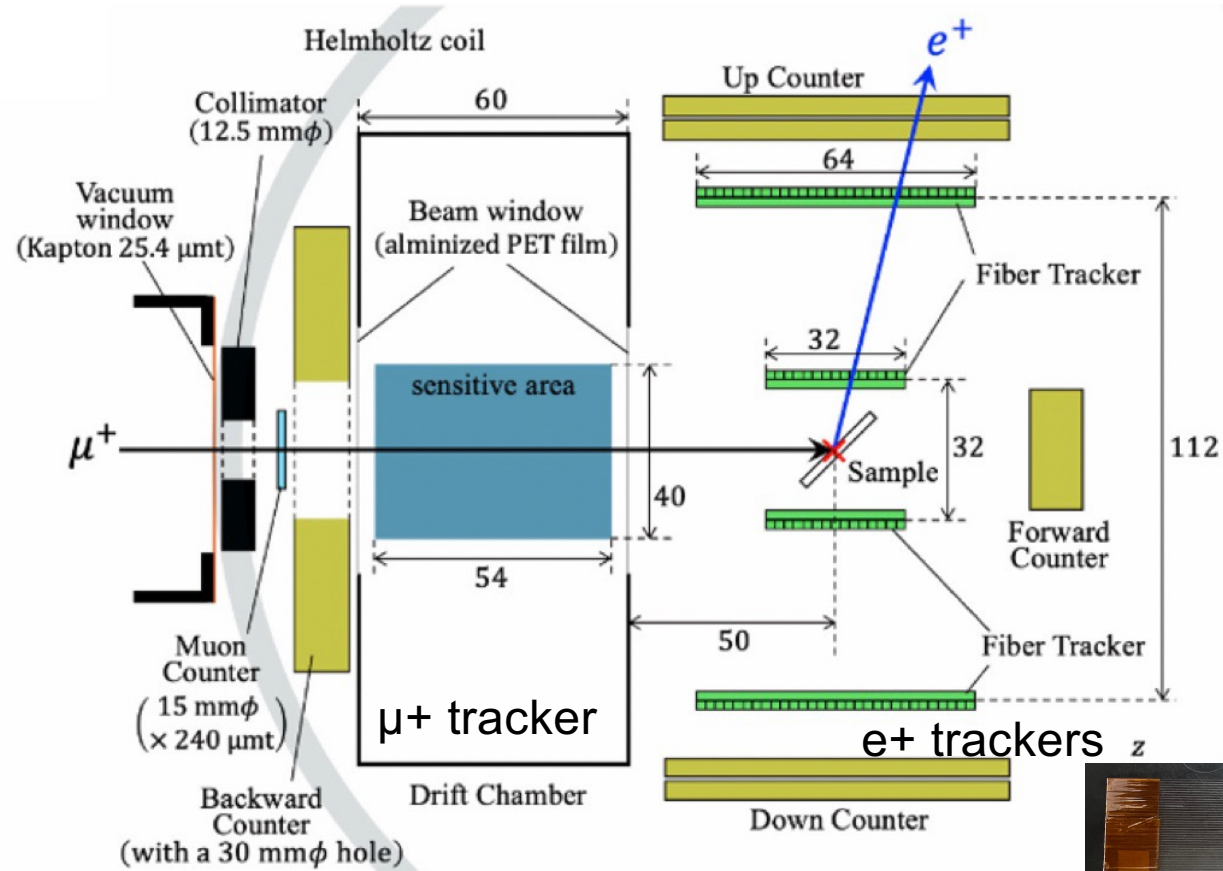


Affiliation :
CMMS, TRIUMF,
Dept. Phys., Osaka U.,
KYOKUGEN, Osaka U.,
Osaka Elec. Comm. U.,
KEK, Kanazawa U.,
Kyushu U., Tokyo City Univ.,
Tokyo Agri. Eng. Univ.



Set up at TRIUMF

Slide (re-arranged) from
M. Mihara (Osaka U.)



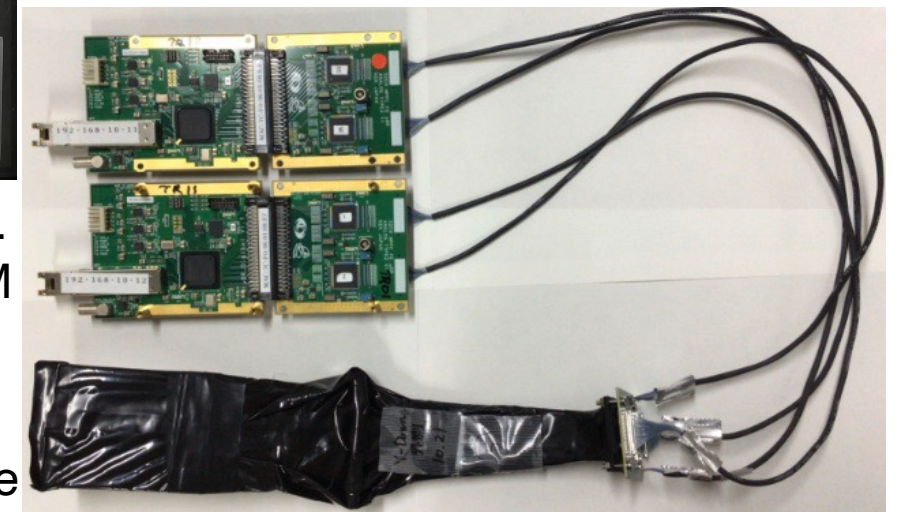
e+ trackers: 64 ch fibre sci.
+SiPM

Readout electronics:

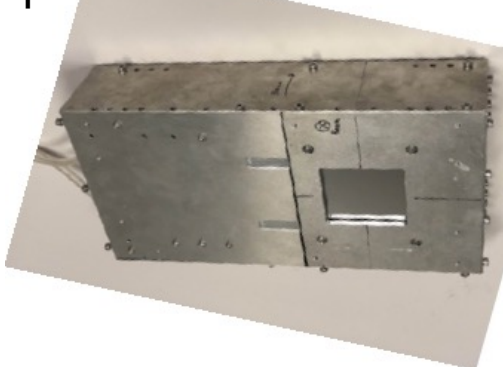
2022, 2023: VME TDC (Riken)

2024: Kalliope ASD+TDC (KEK: Kojima)

2025: EASIROC (KEK: Honda) + Kalliope



μ^+ trackers: Drift Chamber

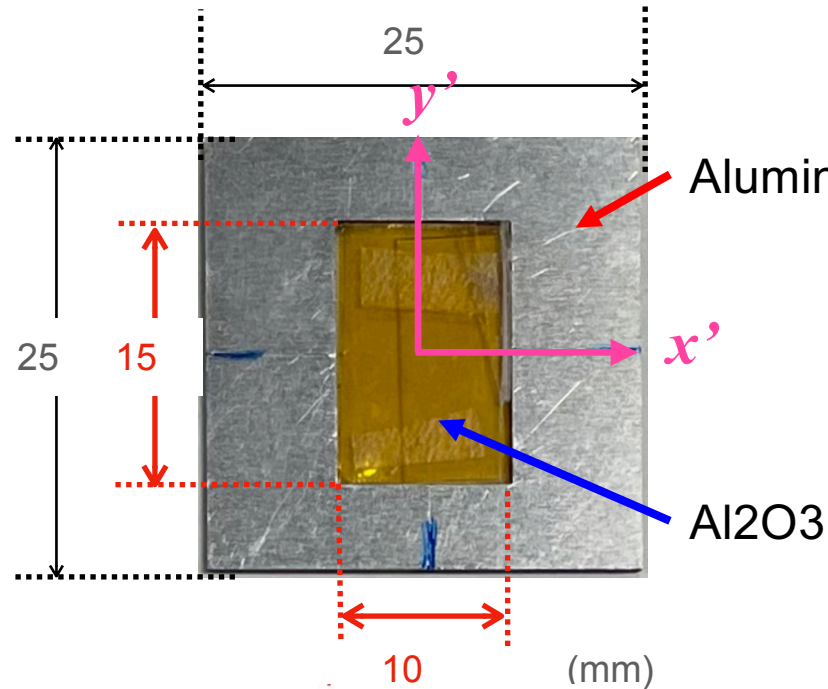


A. Sato
(Osaka U.)

Muon Spin Imaging at TRIUMF

Slide (re-arranged) from
M. Mihara (Osaka U.)

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2D image of $A(t)$ (pixel size = 1 x 1 mm²)

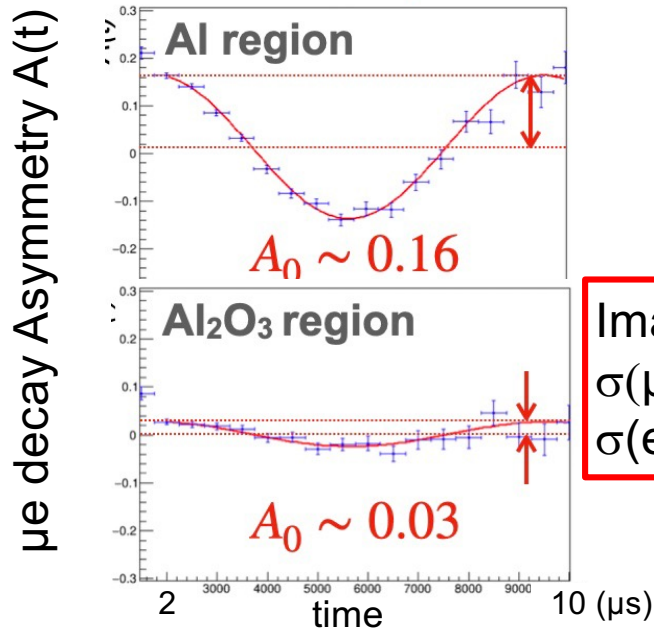
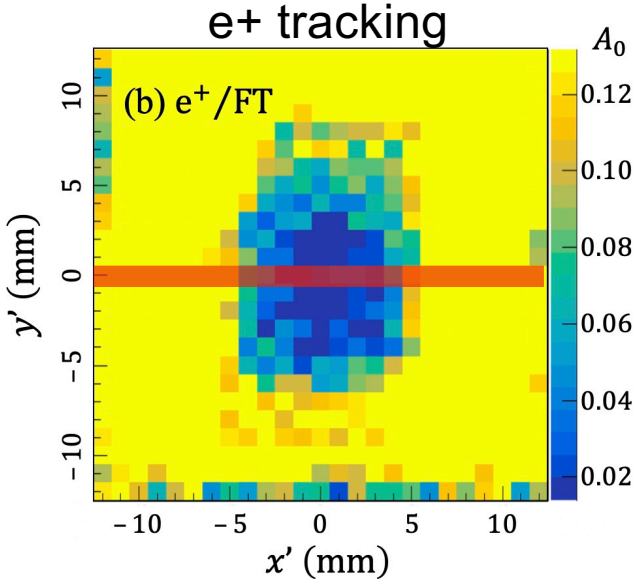
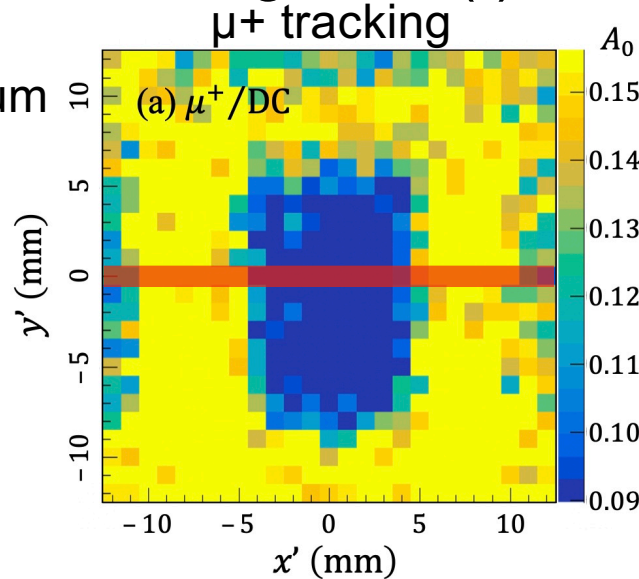
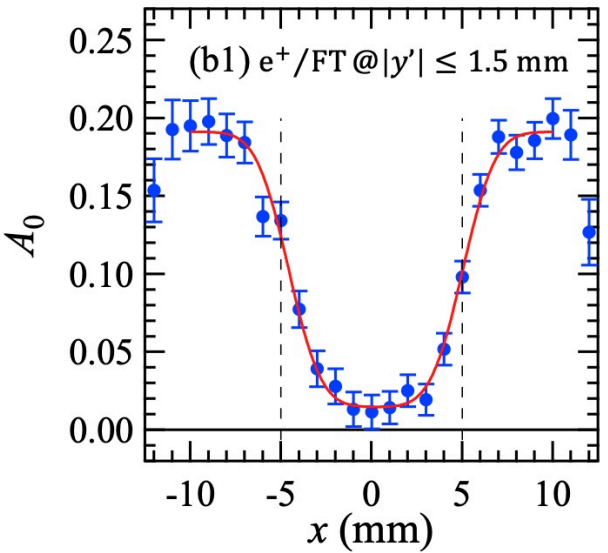
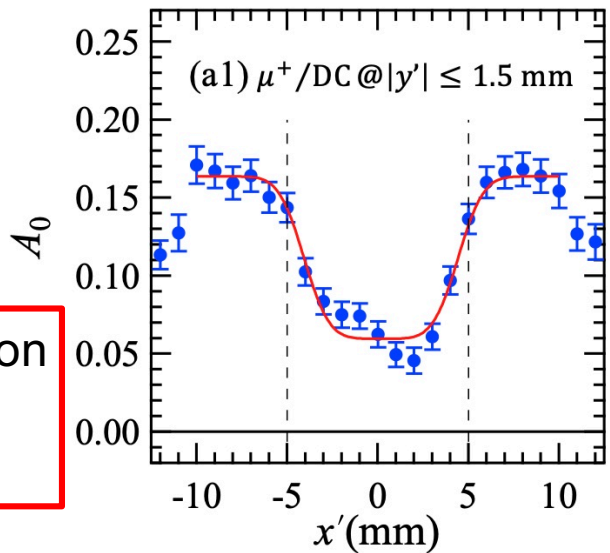


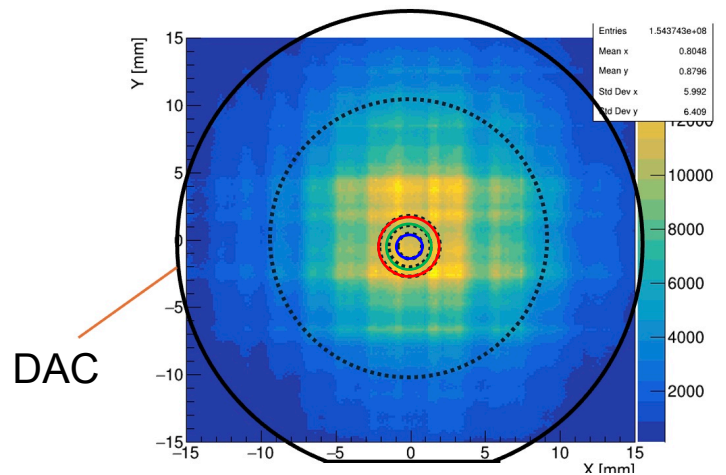
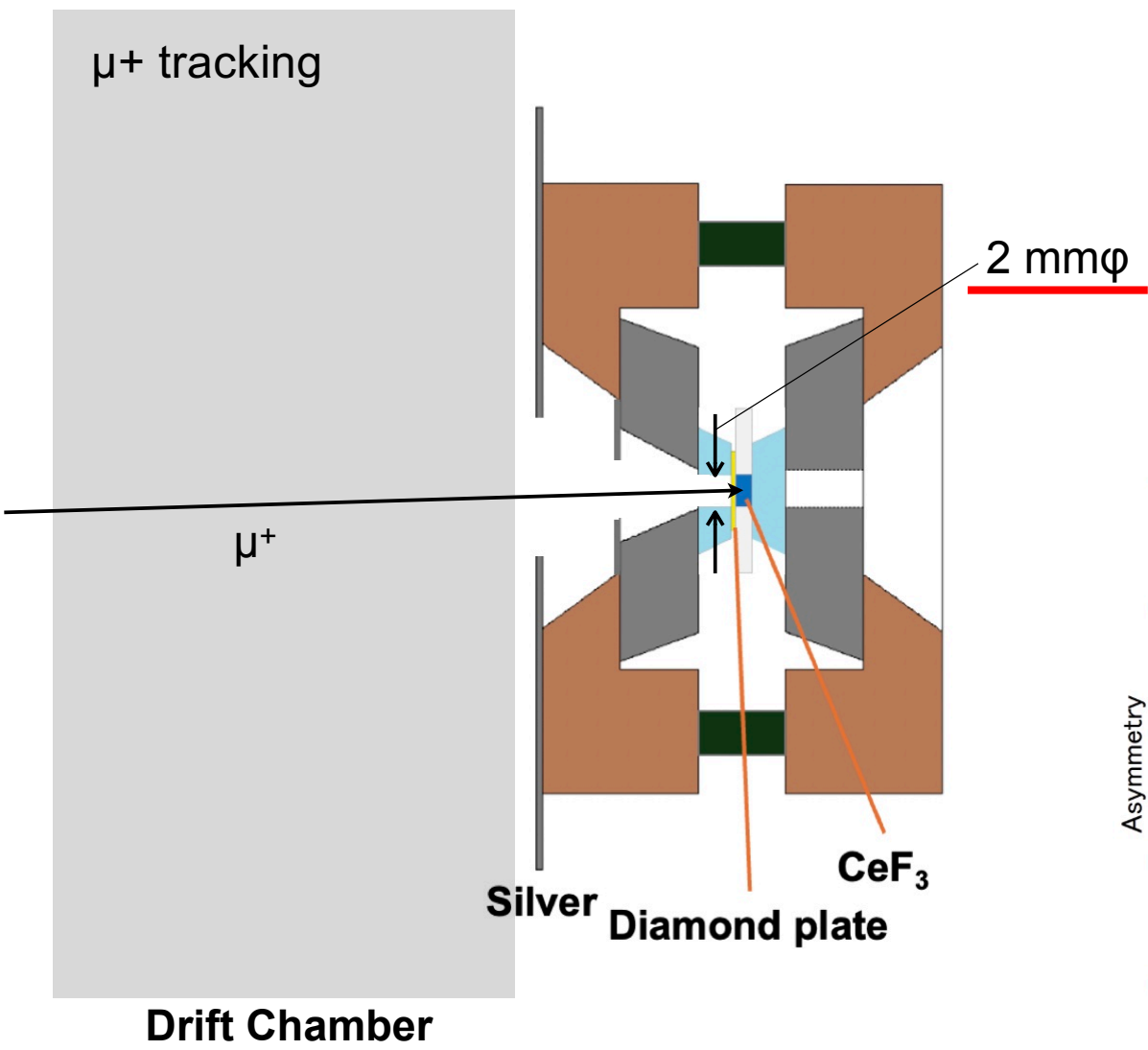
Image resolution
 $\sigma(\mu^+) \sim 1.0\text{mm}$
 $\sigma(e^+) \sim 1.6\text{mm}$



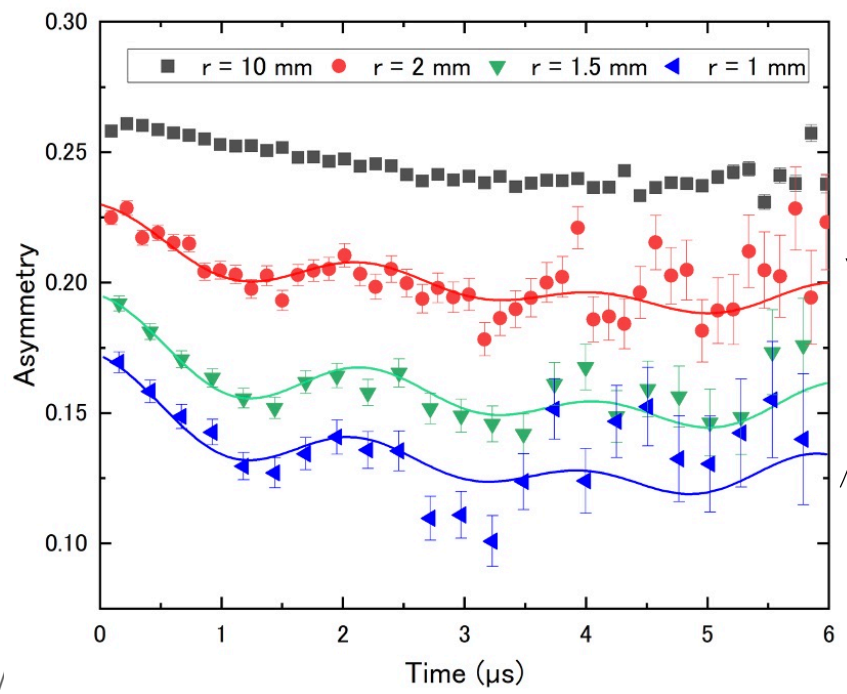
Application of Muon Imaging to Materials Science

JPS meeting Sep. 2026

Measurement in Diamond Anvil Cell for high pressure



M. Fukushima



μSR signal of CeF_3 in $2\text{ mm}\phi$ hole observed.

“Developing of muon spin imaging”, M. N

Muon Imaging experiment in the future

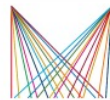
- Osaka collaboration: real sample with structures

- Meteorite
- Biological sample
- Fuel cell: water vs. ice

K. Morishima is leading a group grant: A2 section is mainly KEK

15

文部科学省 科学研究費補助金 学術変革領域研究 (A) 2025~2030



MSMI

マルチスケールミュオンイメージングで「見る」
兆候から解明へ

<https://msmi.jp>

公募要項

Multi-scale muon imaging

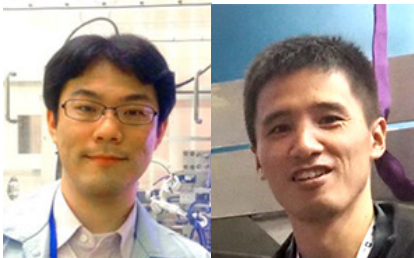
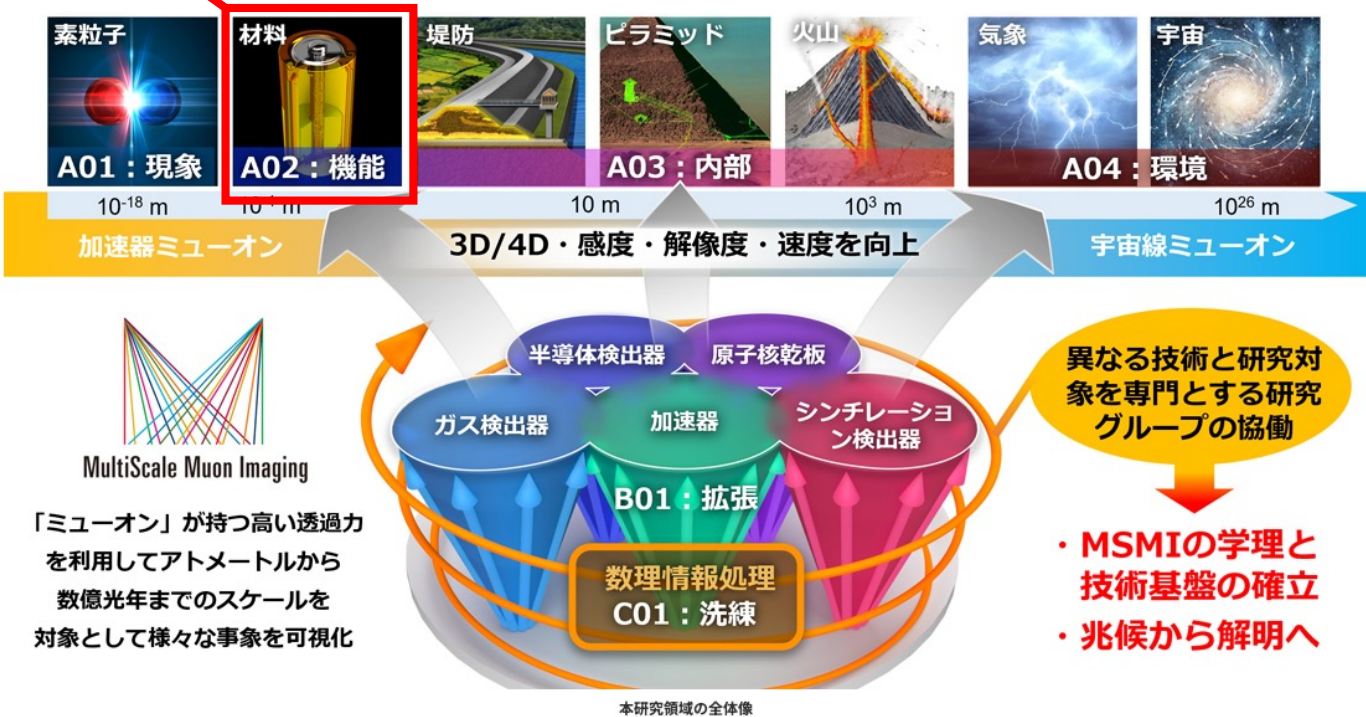
マルチスケールミュオンイメージングで「見る」：兆候から解明へ

領域代表：森島邦博（名古屋大学理学研究科・准教授）



Ni-Fe

Rock



S. Takeshita and
M. Hiraishi (KEK)

Collaborators / Acknowledgement

Muon Induced fission fragment spectroscopy

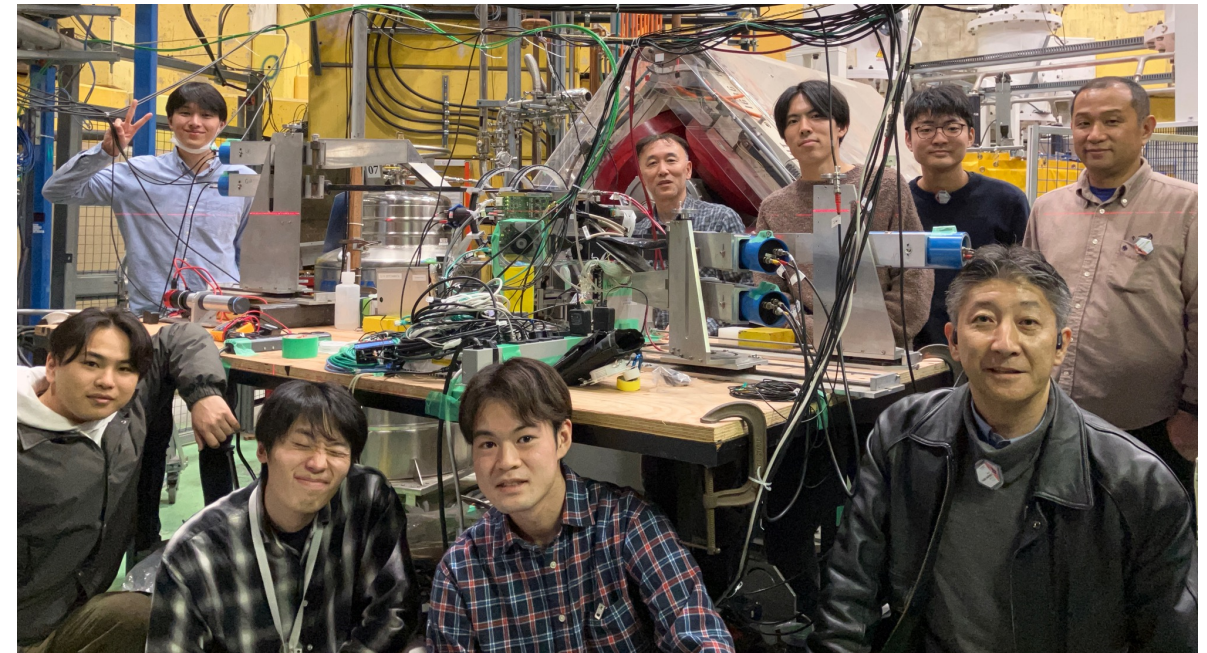
R. Mizuno, M. Niikura, S. GO, T.Y Sato,
T. Matsuzaki (Riken)
H. Asch, A. Redey, Alex Woinoski, Z. Yu,
C. Andreoiu, K. Starosta (SFU)
Eiji Ideguchi, A. Sato, D. Tomono (Osaka U.)
K. Nishio, K. Hirose (JAEA)
K. Ninomiya (Hiroshima U.)
H. Nishibata, S. Kawase (Kyushu U.)
B. Reed, G. Christian, G. Lotay, I. Dillmann, C. Ruiz
(TRIUMF)

- Multidisciplinary PhD Program for Pioneering Quantum Beam Application (PQBA) at Osaka University.
- Scholarship of Graduate School of Science of Osaka University for Overseas Research Activities.
- Fundamental Electronics Research Institute (FERI), Osaka Electro-Communication University (OECU).
- JSPS Kakenhi Grant Number JP22H00110, JP25K01029, 26H01500.
- [KEK-TRIUMF Exchange Program for Early Career Researchers](#) (EPECR)
- NSERC Discovery Grant RGPIN-2021-03467

Muon Spin Imaging

M. Mihara, S. Ishitani, K. Yasuda, G. Takayama, A. Sato,
M. Fukuda, R. Taguchi, S. Shimizu, K. Horie, R. Imai, S. Ide,
S. Sugano (Dept. Physics, U. Osaka)
K. Shimizu, M. Kamon, M. Fukushima (KYOKUGEN, U. Osaka)
Y. Mizoi (Osaka Elec. Comm. U)
A. Koda, S. Kanda (KEK)
B. T. Mizukami, W. Sato (Kanazawa Univ.)
D. Nishimura (Tokyo City U)
M. Fukutome, M. Tanaka (Kyushu Univ.)

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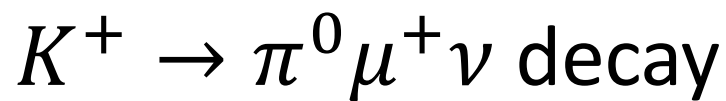
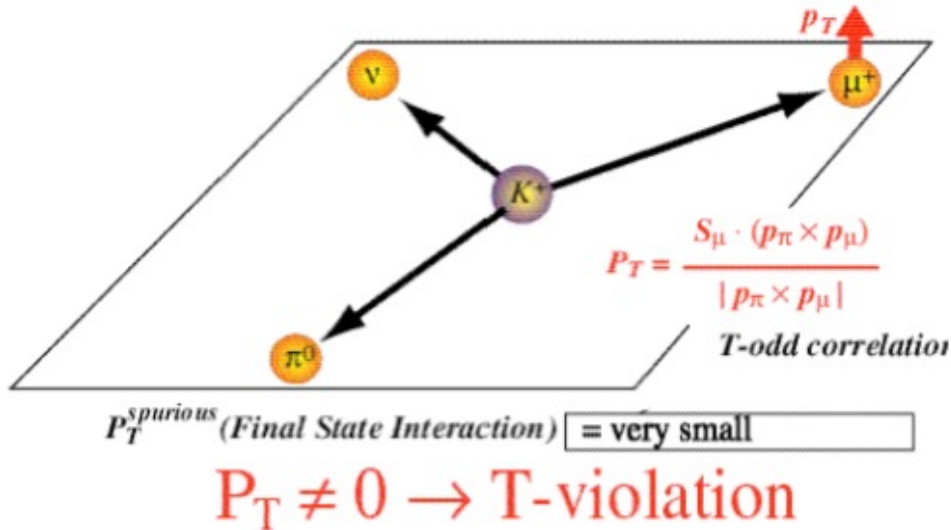


Technology transfer from Materials science to Particle physics

■ CeF_3 scintillator which holds muon polarization

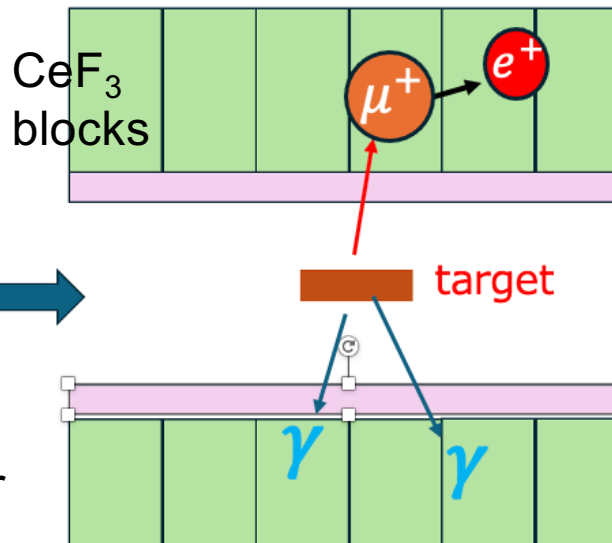
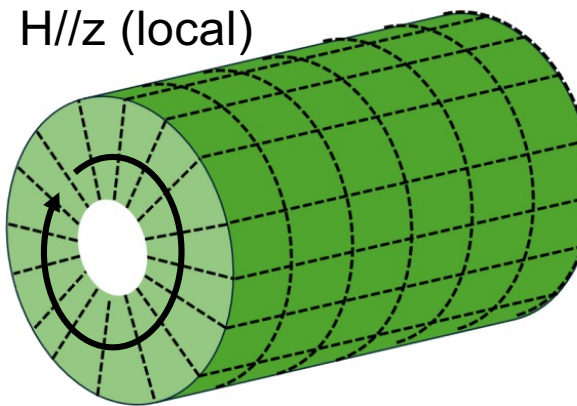
Slide from S. Shimizu
(Osaka. U)

17

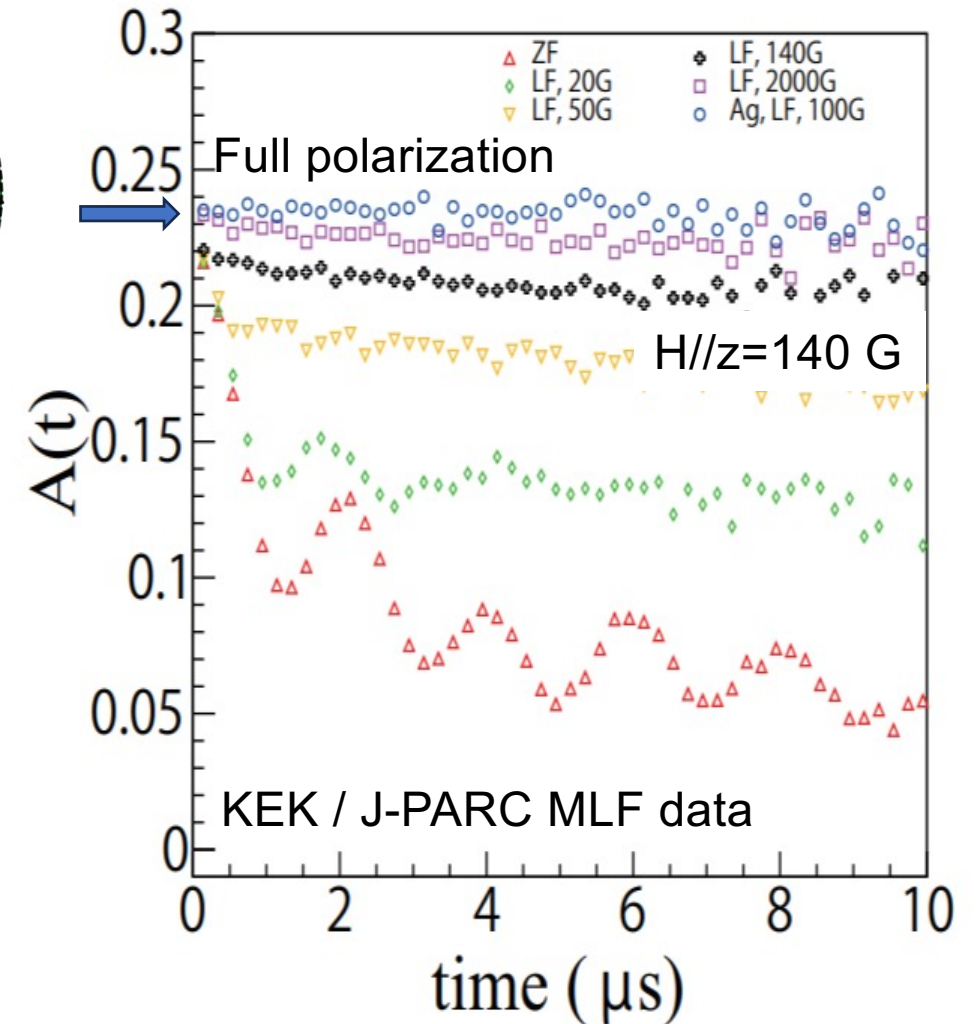


In NaI (Alkaline Halides), muon quickly depolarizes.

CeF_3 blocks as the muon stopper
muon and positron scintillator / calorimeter



K. Horie et al.,
Nucl. Instrum. Methods A 1037 (2022) 166932



Summary

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- TRIUMF is equipped with **M9H** the pion decay channel
 - Capability of negative muons + high momentum muons
 - Complementary to KEK / J-PARC's **MLF D-line** muons
- TRIUMF has developed **Muon Spin Imaging**
 - μ SR has gained imaging capability
 - Complementary to KEK / J-PARC's **imaging project**
- Collaborations with KEK-lead group funds (学術変革) on μ - and **muon imaging** are underway

μ -: <https://mu-horizons.kek.jp/en/>
Muon imaging: <https://msmi.jp>