RAON-5: muon Spin Relaxation/Resonance (μSR)

중이온가속기 활용 국제공동연구기획사업

연차 워크샵

μSR Group 최광용

성균관대학교

2021. 11. 18

RAON-5 : μSR

■ 연구개발목표

RAON에 물성연구시설로 구축될 μSR의 활용도를 높이기 위해 **해외 뮤온 시설을 활용**하여
자성체, 초전도체 등 다양한 **물성분야에서 실험**을 수행 우수한 **신진 연구 인력**을 양성

■ 성과목표

해외 μSR 대형연구시설을 활용하여 물성분야의 전문 연구인력 양성 및 μSR 활용분야 국제 경쟁력 확보

■ 연구내용

- 해외 대형 뮤온 연구소와 국제협력 프로그램을 통해 대학원생, 박사후 연구원을 파견하여 연구인력 육성 및 확대
  - 해외가속기 연구소와의 교류협력 방안 수립
  - 국제공동연구 과제 발굴 및 수립
  - 국제공동연구 과제를 통한 대학원생 및 박사 후 과정 인력 양성
- μSR 활용 관련 미래 연구 주제 발굴
  - 해외 시설에서 진행되는 μSR 실험과 차별화된 실험 제안

■ 연구성과물:

- 국제공동연구 과제계획서
- 연수결과보고서
- 출판논문
- 연구의향서

RAON-5 μSR : 국내 인력 및 국제 공동 연구 그룹 구성

■ 국내 참여 연구 인력 현황

- 중이온가속기사업단 : 이원준, 이주한
- 성균관대학교 : 이수헌, 최광용
- 중앙대 : 이찬현
- 가톨릭대: 서병진
- 국민대: 장지훈
- 서울대: 윤성원

■ 국제 공동 연구 그룹 구성 현황

- UCLA L. Li 그룹: 자성위상절연체
- 프린스턴대 Cava그룹: 양자 자성체
- MPI Stuttgart Takagi: 스핀-오빗 얽힌 물질
- NTU R. Sankar 그룹: 저차원 양자자성체
- TRUMF K. Kojima: 극한에서 μSR 스펙트로미터 개발

Letter of Intent to Max-Planck Institute for experiment with the RAON-μSR User Community

Natures of orders in spin-orbit entangled compounds with hidden multipoles

Abstract

We are going to investigate hidden magnetic orders in the Ta chlorides, A_2TaCl_6 (A = Rb, Cs), and its isostructural compounds based on the W and Mo ions, with the multipolar degrees of freedom. Because they show the cubic symmetry with the $5d^1$ electronic state, the pure J_{eff} = 3/2 quartet state features charge quadrupoles and magnetic octupoles. This is because the pure J_{eff} = 3/2 quartet does not have any magnetic dipolar moment but hosts hidden pseudo-dipolar moments accompanied by charge quadrupoles and magnetic octupoles. The Ta chlorides Cs_2TaCl_6 and Rb_2TaCl_6 are known to be correlated insulators with $5d^1$ Ta^{4+} ions in a regular Cl octahedron. Their effective magnetic dipolar moment is substantially suppressed to approximately 0.2 μ_B. In addition, two-phase weak transitions are observed at low temperatures. We propose to employ muons at TRIUMF to clarify the nature of the magnetic transitions in the quartet state with the collaboration of Prof. Takagi's research group at Max Planck Institute.

Sungwon Yoon[1,2], Yipeng Cai[2,3], Tomohiro Takayama[4,5], Hidenori Takagi[4,5,6], Kenji M. Kojima[2,3], Kwang-Yong Choi[1]

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[3] Stewart Blusson Quantum Matter Institute(SBQMI), University of British Columbia, Vancouver, British Columbia V6T 1Z4, Canada

[4] Max Planck Institute for Solid State Research, Heisenbergstrasse 1, 70569 Stuttgart, Germany

[5] Institute for Functional Matter and Quantum Technologies, University of Stuttgart, Pfaffenwaldring 57, 70550 Stuttgart, Germany

[6] Department of Physics, University of Tokyo, 7-3-1 Hongo, Tokyo 113-0033, Japan

Spokesperson: Sungwon Yoon (indrasw81@gmail.com)
Contactperson: Kenji M. Kojima (kojima@triumf.ca)

MAX-PLANCK-GESELLSCHAFT

TRIUMF

중이온가속기이용자협회

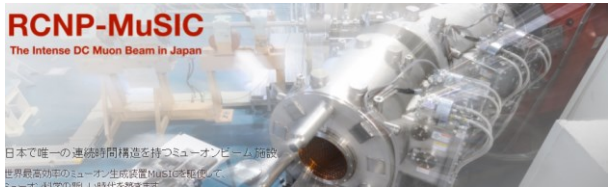
현재 가동중인 μSR 시설 현황

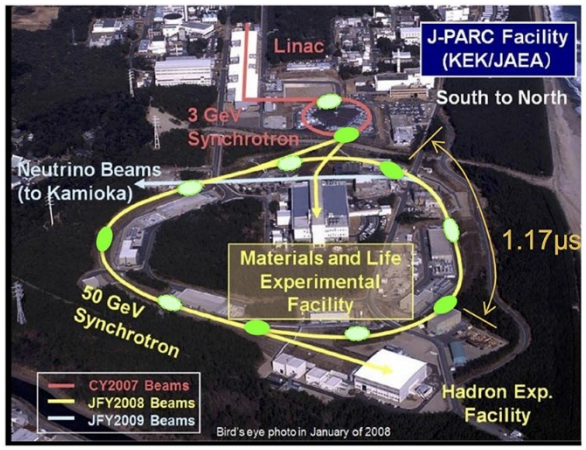
Science & Technology Facilities Council
ISIS Neutron and Muon Source

PAUL SCHERRER INSTITUT
PSI

TRIUMF

J-PARC





건설 중이거나 향후 건설 예정인 μSR 시설

SNS 中国散裂中子源
China Spallation Neutron Source

US MUON WORKSHOP 2021
A road map for a future Muon Facility

A VIRTUAL WORKSHOP
February 1-2, 2021
Co-sponsored by the Department of Energy, Basic Energy Sciences, and the National Science Foundation

MRS

Program | Proposed Beamlines

The goal of this two-day virtual workshop was to bring scientists and engineers from around the world together to discuss the construction of a world class facility for Muon Spectroscopy (μSR) at the Spallation Neutron Source (SNS) of Oak Ridge National Laboratory (ORNL).

μSR is a technique that uses spin-polarized muons implanted in a material to provide extremely sensitive measurements of the static and dynamic properties of the local magnetic field distribution within the sample.

The opportunity to leverage the existing accelerator and scientific infrastructure, as well as combine scientific and industrial capabilities with combined Single Event Effects (SEE), will allow us to realize a project that would likely cost close to $1 billion if constructed as a standalone facility.

This workshop, co-sponsored by the Department of Energy, Basic Energy Sciences, and the National Science Foundation, brought together experts on scattering techniques to discuss a road map for a future muon facility in the United States. Given the scale of the proposed facility, a bi-agency collaboration is important to ensure the success of the project.

Organizers


Despina Louca
University of Virginia

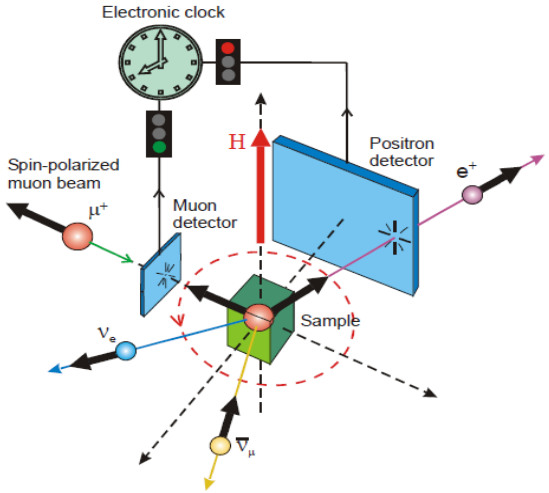

Gregory MacDougall
University of Illinois at Urbana-Champaign


Travis J. Williams
Oak Ridge National Laboratory

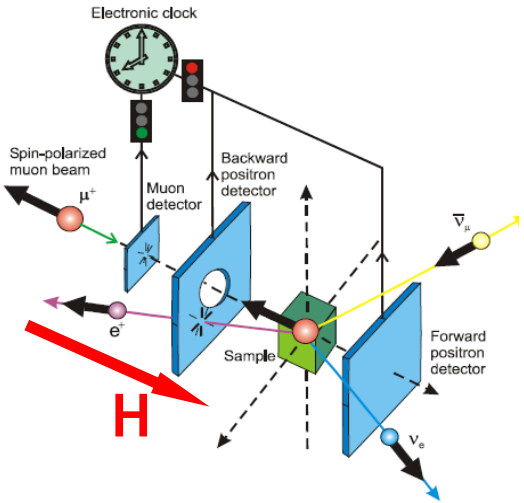
SNS SPALLATION NEUTRON SOURCE

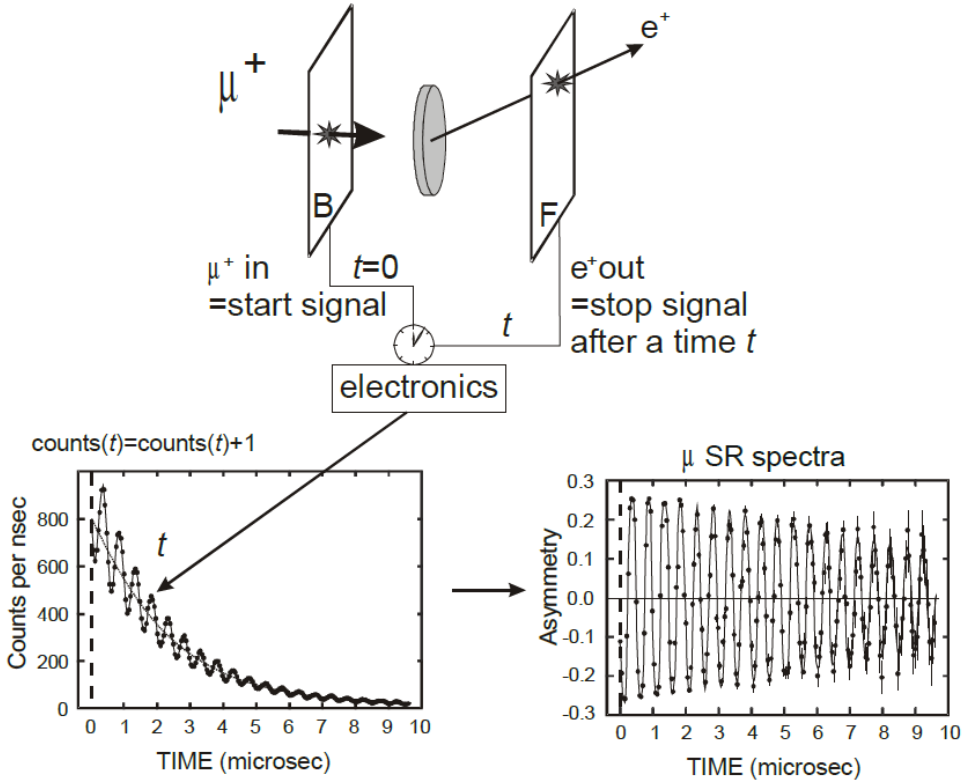
μSR 분광기의 도식도

Transverse field



Zero/Longitudinal field





$$N_{e^+}(t) = B + N_0 e^{-t/\tau_\mu}\left[1 + A\frac{P_\mu(t)}{P_\mu(0)}\right]$$

$$P_\mu(t) = \boldsymbol{P}_\mu(t)\cdot \boldsymbol{P}_\mu(0)/P_\mu(0) = G(t)\,P_\mu(0)$$

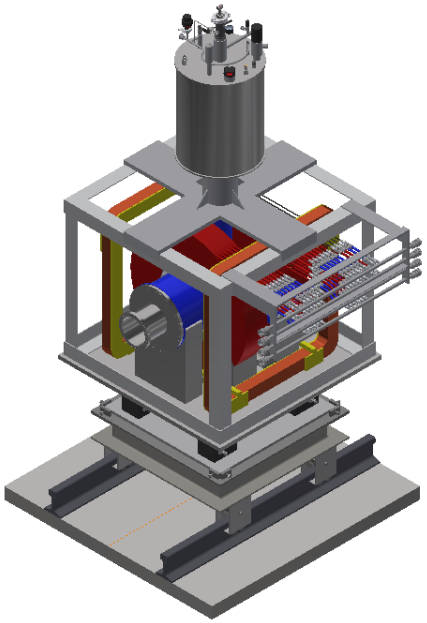
$$G(t) = \frac{\langle \boldsymbol{S}(t)\times\boldsymbol{S}(0)\rangle}{S(0)^2}$$

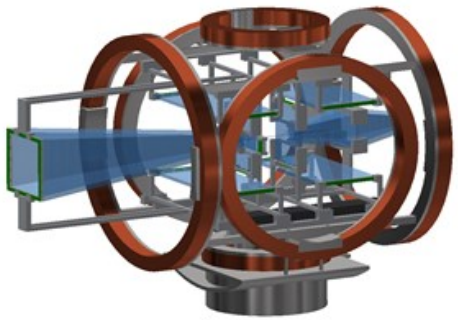
μ⁺-spin auto-correlation function
→ μ⁺- depolarization function
→ μSR signal

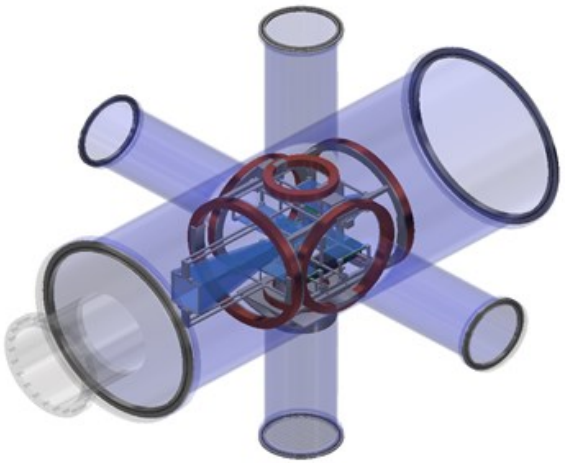
뮤온 스핀 분광기 장치구축일정표

구분	업무내용	2021	2022				2023				2024	
		4Q	1Q	2Q	3Q	4Q	1Q	2Q	3Q	4Q	1Q	2Q
	마일스톤		공학 설계 완료		제작 착수			설치 착수		설치 완료 / 시운전 착수		
뮤온 스핀 분광기 구성 요소	냉각기		구매						설치			
	챔버		제작 설계		제작				설치			
	전자석				제작 설계	제작			설지			
	검출기		추가 공학 설계		제작 설계		제작		설치			
	하부 구조 및 냉각기 및 자석 냉각수 지지대				제작 설계	제작			설치			
	작업 플랫폼						제작 설계	제작	설치			
뮤온 스핀 분광기	전체 조립품									시운전 (cold test)		

※ 특이 사항





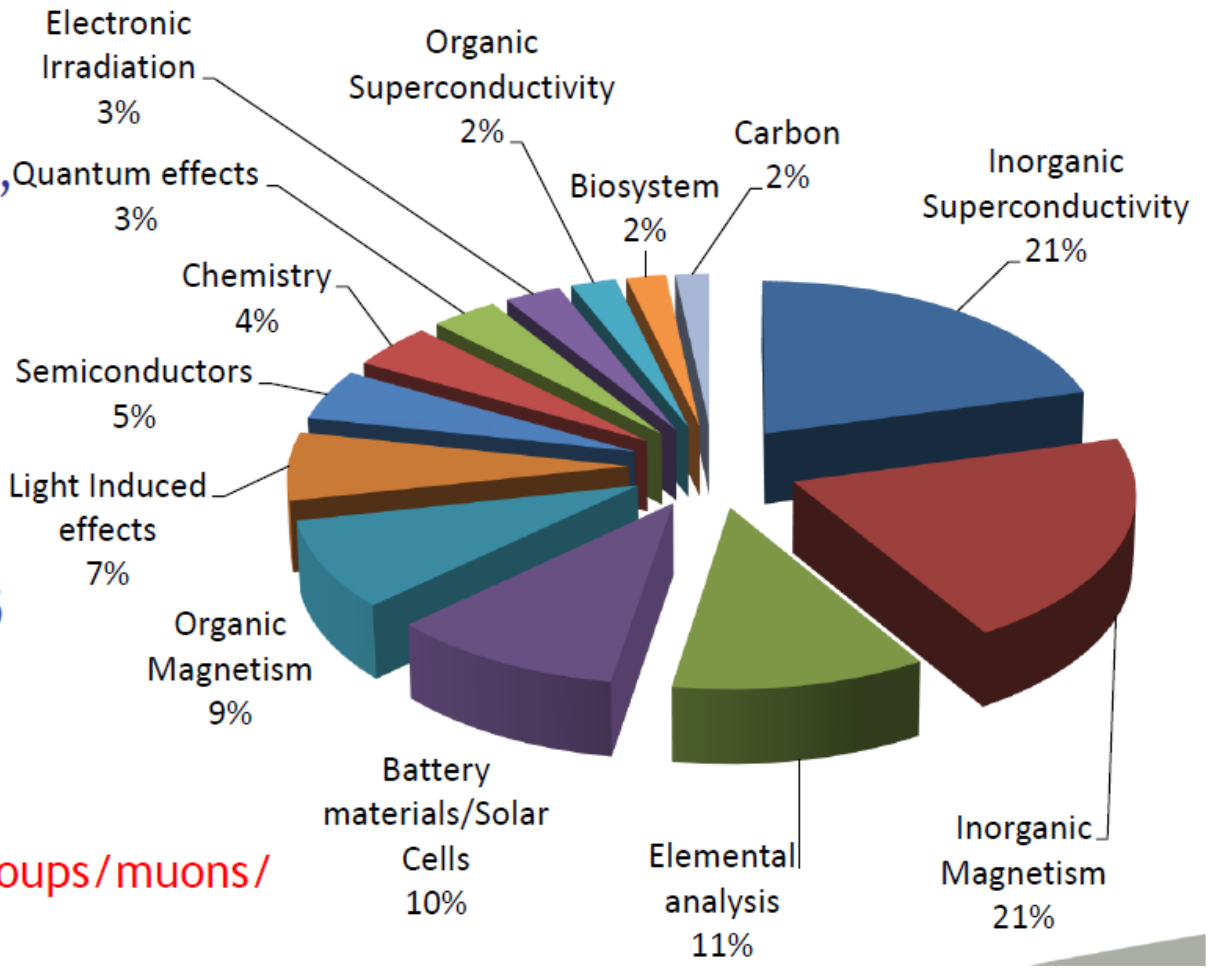


μSR을 이용한 연구분야 (ISIS 예)

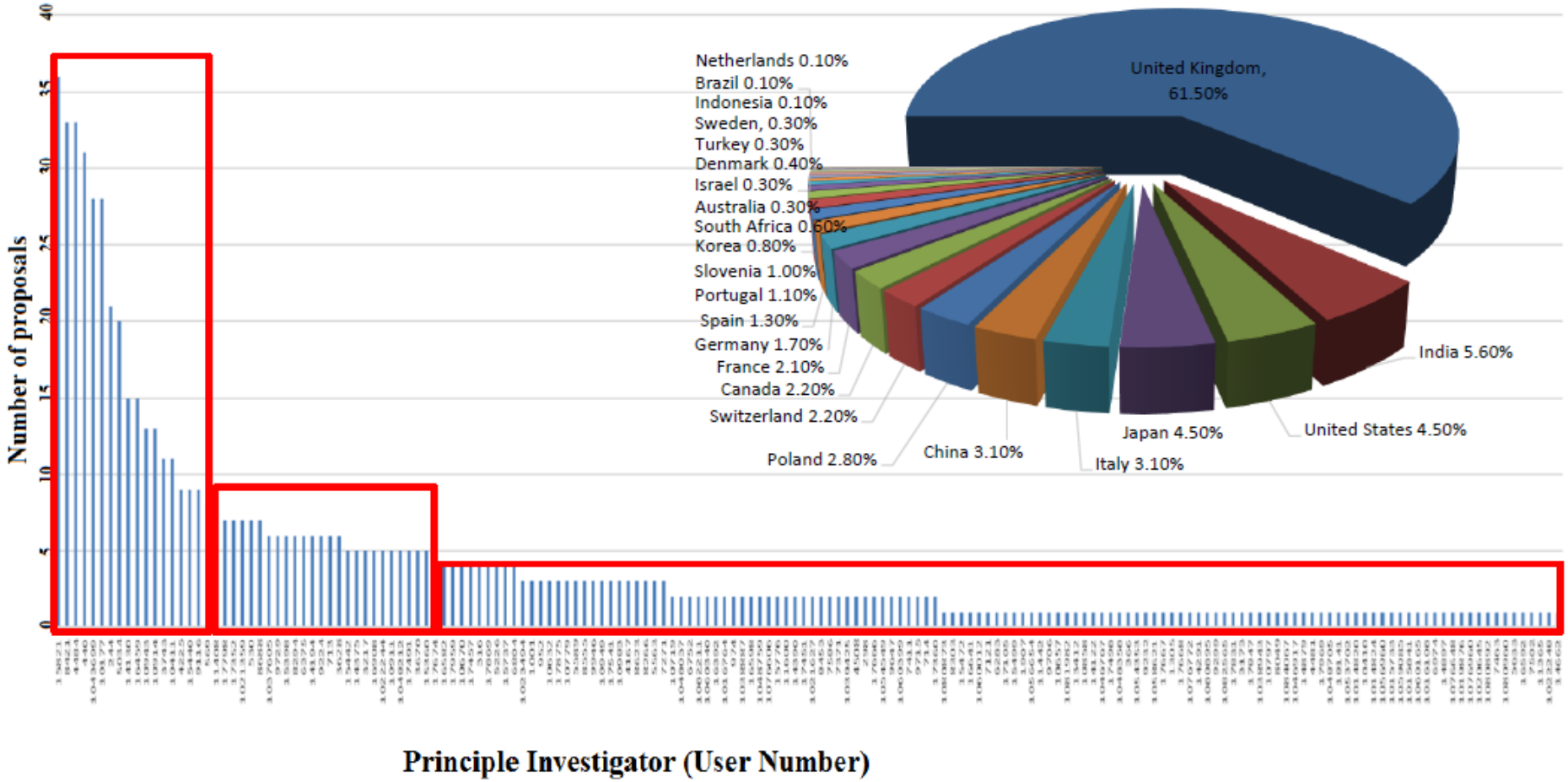
MUONS:

- Versatile probes of magnetic, superconducting, molecular systems
- Complementary to other techniques ISIS / PSI / J-PARC all have n and μ facilities
- Around 60 groups from 15 countries using ISIS muons
- Further details:

http://www.isis.stfc.ac.uk/groups/muons/



μSR을 이용자 분포 (ISIS 예)



2021년 전반기에 수행된 μSR 빔 타임 및 연구 내용

(1) **06.08** : Exploring the nature of a ground state in the H-intercalated Kitaev magnet $H_3LiIr_2O_6$
(Dolly spectrometer, Paul Scherrer Institute, 스위스)

(2) **06.04-2021.06.07**: Kondo impurities in the Kitaev spin liquid candidate α-$(Ru,Cr)Cl_3$
(GPS and HAL-9500 spectrometers, Paul Scherrer Institute, 스위스)

(3) **06.06-06.08**: Crossover of spin transport mechanism by one-dimensionalization in the anisotropic triangular antiferromagnet $Ca_3ReO_5Cl_2$ (GPS spectrometer, Paul Scherrer Institute, 스위스)

(4) **06.04-06.08, 07.04-07.06** : Possible spin liquid state in the hexagonal perovskite $Ba_6Y_2Rh_2Ti_2O_{17}$
(LAMPF and DR spectrometer, TRIUMF, 캐나다: Princeton대 Cava)

(5) **06.16-06.18**: Electronic and magnetic phase diagram of $Ni_{1-x}Co_xS_2$
(LAMPF spectrometer, TRIUMF, 캐나다: Kenji Kojima 박사(TRIUMF, 캐나다), 김창영교수 (SNU IBS))

(6) **06.19 - 06.25**: Investigations of spin dynamics in magnetic topological insulators, $(MnBi_2Te_4)(Bi_2Sb_3)_m$
(LAMPF spectrometer(M20 beamline), TRIUMF, 캐나다; Kenji Kojima 박사(TRIUMF, 캐나다), L. Li (UCLA))

(7) **06. 25 - 07. 04**: Natures of orders in spin-orbit entangled compounds with hidden multipoles
(LAMPF spectrometer(M20 beamline), TRIUMF, 캐나다: H. Takagi (MPI Stuttgart))

(8) **10.25 - 10.29:** Electronic and magnetic phase diagram of $Ni_{1-x}Co_xS_2$ ($0.5 \leq x \leq 1$)
(DR spectrometer, TRIUMF 캐나다)

(9) **12. 14 -12.15** : Spin diffusion in the quasi-one dimensional S=1/2 antiferromagnetic spin chain $KNaCuP_2O_7$ (Dolly spectrometer, Paul Scherrer Institute, 스위스)

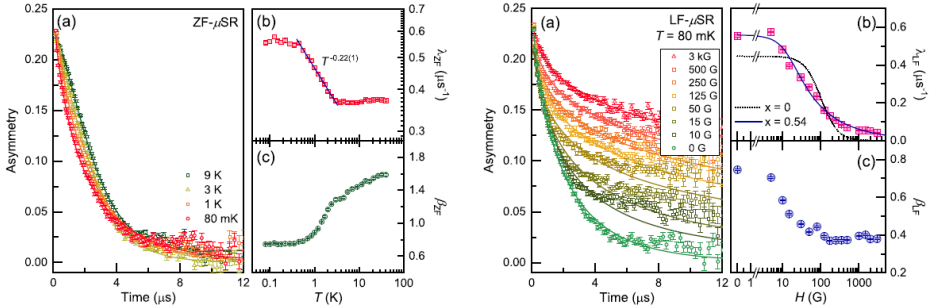
2021년 출판된 μSR 논문

- **삼각형 자성체 $Na_2BaCo(PO_4)_2$: 양자 스핀액상의 실험적 발견**
  - ZF- 및 TF-μSR ISIS 실험수행

PHYSICAL REVIEW B **103**, 024413 (2021)

Temporal and field evolution of spin excitations in the disorder-free triangular antiferromagnet $Na_2BaCo(PO_4)_2$

S. Lee,[1,2,*] C. H. Lee,[1,*] A. Berlie,[2] A. D. Hillier,[2] Devashibhai T. Adroja,[2] Ruidan Zhong,[3] R. J. Cava,[3] Z. H. Jang,[4] and K.-Y. Choi[1,5,†]

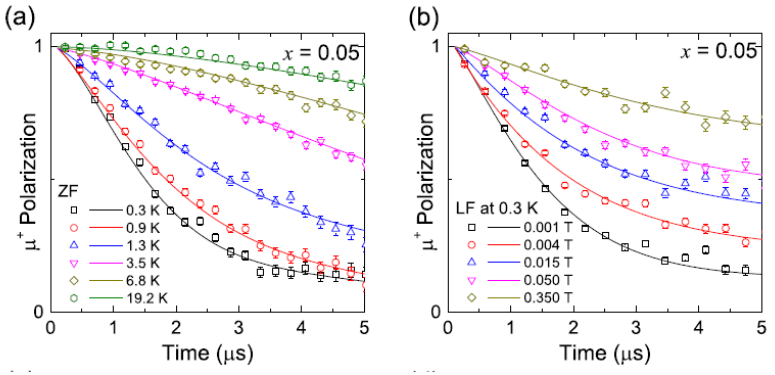


- **찌그러진 s=1/2 사각격자 $Sr_2Cu(Te_{1-x}W_x)O_6$**
  - ZF- 및 TF-μSR J-PARC D1 & S1 라인 실험수행
  - Quenched disorder에 의해 유발되는 양자 상전이 및 위상적 질서에 대한 논문

PHYSICAL REVIEW MATERIALS **5**, 014411 (2021)

Quantum disordered state in the J_1-J_2 square-lattice antiferromagnet $Sr_2Cu(Te_{0.95}W_{0.05})O_6$

Sungwon Yoon,[1,2] Wonjun Lee,[1] S. Lee,[1,3] J. Park,[1] C. H. Lee,[1] Y. S. Choi,[1] S.-H. Do,[1,4] Woo-Jae Choi,[5] Wei-Tin Chen,[6,7] Fangcheng Chou,[6,7,8] D. I. Gorbunov,[9] Yugo Oshima,[10] Anzar Ali,[11] Yogesh Singh,[11] Adam Berlie,[3] I. Watanabe,[12] and Kwang-Yong Choi[1,13,*]



- **Breathing 파이로클로어 격자에서 발현하는 새로운 양자상태에 관한 연구**
  - ZF- 및 TF-μSR TRIUMF 실험수행

npj | Quantum Materials

www.nature.com/npjquantmats

ARTICLE OPEN

Check for updates

Dichotomy in temporal and thermal spin correlations observed in the breathing pyrochlore $LiGa_{1-x}In_xCr_4O_8$

S. Lee[1,2], S.-H. Do[1], W. Lee[1], Y. S. Choi[1], J. van Tol[3], A. P. Reyes[3], D. Gorbunov[4], W.-T. Chen[5,6] and K.-Y. Choi[7]✉

- **스핀-2를 갖는 망간 기반 카고메 반강자성체 $CsMn_3F_6(SeO_3)_2$의 고전적인 스핀 액체 연구**
  - ZF- 및 TF-μSR TRIUMF 실험수행

Time-scale distributions of spin fluctuations in the $S = 2$ kagome antiferromagnet $CsMn_3F_6(SeO_3)_2$

Suheon Lee,[1,*] Tianyu Zhu,[2,*] Y. Oshima,[3] T. Shiroka,[4] C. Wang,[4] H. Luetkens,[4] Haoming Yang,[2] Minfeng Lü,[2,†] and K.-Y. Choi[5,‡]

[1] *Center for Integrated Nanostructure Physics, Institute for Basic Science, Suwon 16419, Republic of Korea*
[2] *School of Environmental and Chemical Engineering, Jiangsu University of Science and Technology, Zhenjiang 212003 Jiangsu, China*
[3] *Meson Science Laboratory, RIKEN Cluster for Pioneering Research, Hirosawa 2-1, Wako, Saitama 351-0198, Japan*
[4] *Laboratory for Muon Spin Spectroscopy, Paul Scherrer Institute, 5232 Villigen, Switzerland*
[5] *Department of Physics, Sungkyunkwan University, Suwon 16419, Republic of Korea*

초기 실험 주제 발굴

■ 2022년 μSR 빔타임 확보를 위한 프로포절 준비 중

(1) 카고메 금속 CsV_3Sb_5에서 time-reversal breaking의 메커니즘 규명 [SKKU Tuson Park]

(2) Transverse Ising magnet $SrCo(SeO_3)_3$의 양자 상전이 연구 [Academia Sinica]

(3) 카고메 반강자성체 $YCu_3(OH)_{6.5}Br_{2.5}$에서 스핀액상 연구

(4) Coupled tetrahedral and honeycomb lattice $Cu_3Te_2O_9H_4$의 ground state 연구

[Jiangsu University]

■ 향후 μSR 그룹 유지 전략

- 중이온가속기사업단 : 이원준박사
- 성균관대학교 IBS-YSF: 이수헌박사

PARMA 2020 la cultura batte il tempo | CAPITALE ITALIANA DELLA CULTURA

Con il Patrocinio del Comune di Parma

UNIVERSITÀ DI PARMA

Science & Technology Facilities Council
ISIS Neutron and Muon Source

Evento di aggiornamento scientifico.

μSR2020

The 15th International Conference on Muon Spin Rotation, Relaxation and Resonance

29 August - 2 September, 2022 Parma, ITALY

Student Day for Ph.D. students will be held on 28 August 2022