OAK RIDGE National Laboratory

SEEMS: Muon Spectroscopy

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Neutron Sciences Directorate

Oak Ridge National Laboratory

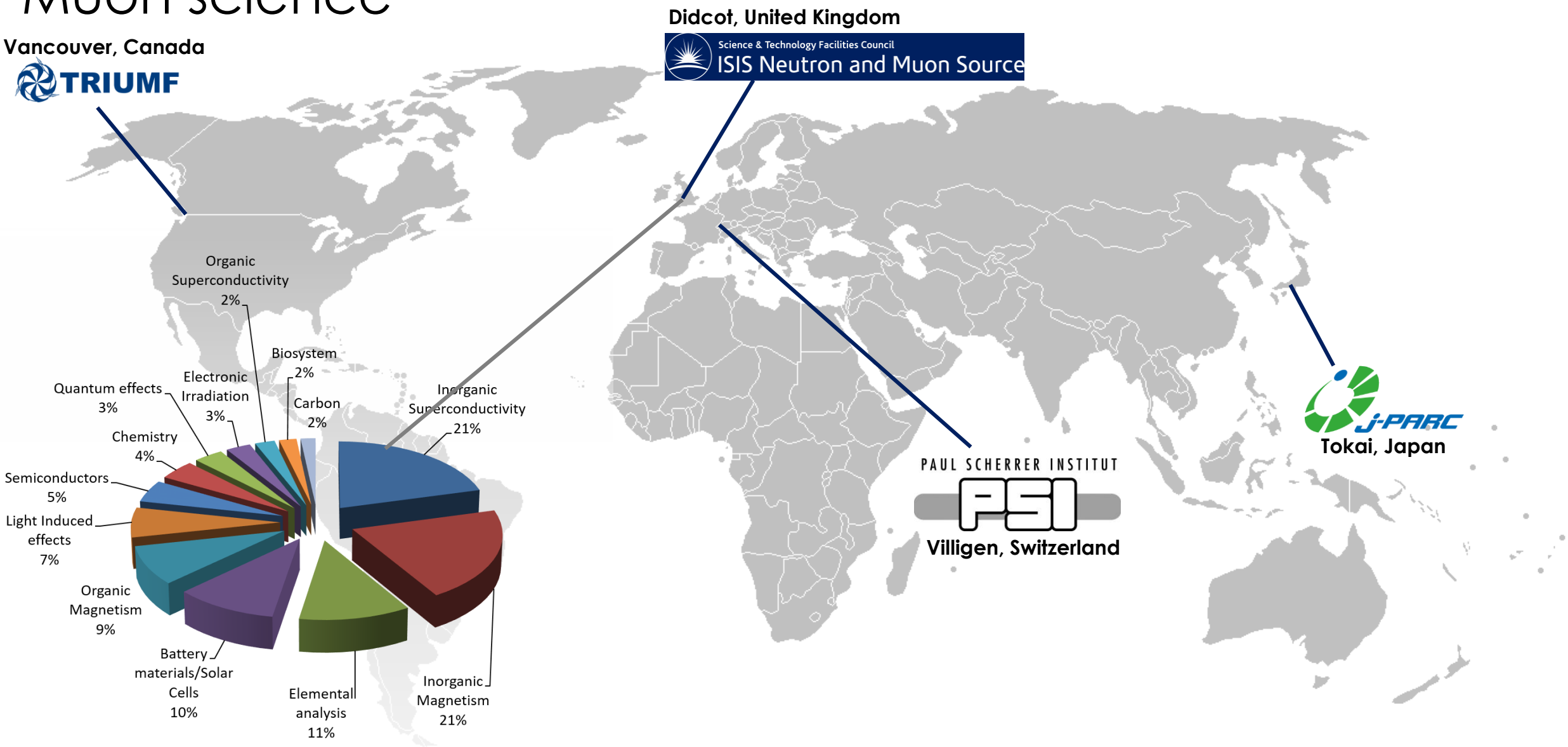
ORNL is managed by UT-Battelle, LLC for the US Department of Energy

U.S. DEPARTMENT OF ENERGY

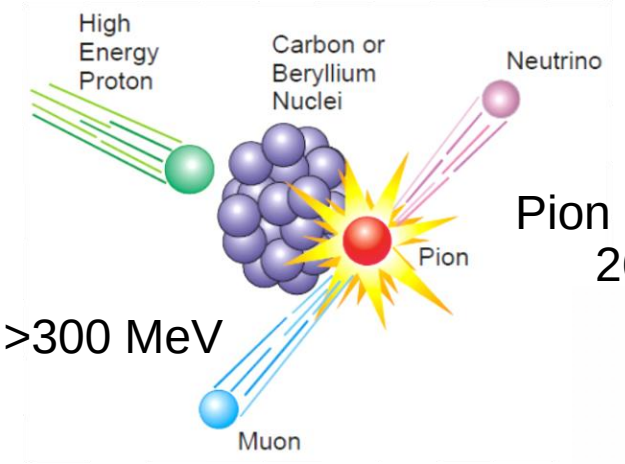
SEEMS: World-leading muon spectroscopy capabilities

- **The world's best muon source for performing μSR experiments not possible anywhere else.**
  - Fills a missing US capability that is needed by the scientific community.
  - Has better resolution and 200x more flux than any existing muon source.
  - Will allow for new types of experiments that are not currently possible.
- **Making use of a world-class accelerator, without disrupting any of its current missions.**
  - No impact on neutron scattering mission or Second Target Station, while benefiting from the Proton Power Upgrade.
- **This allows tremendous cost savings by leveraging existing infrastructure.**
  - Projected cost ~$142M, versus >$1B if built from green field.

Muon science

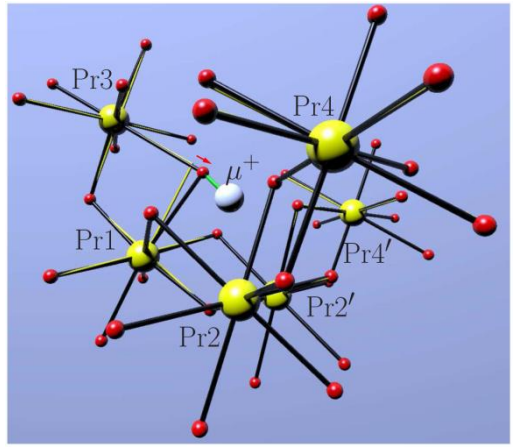


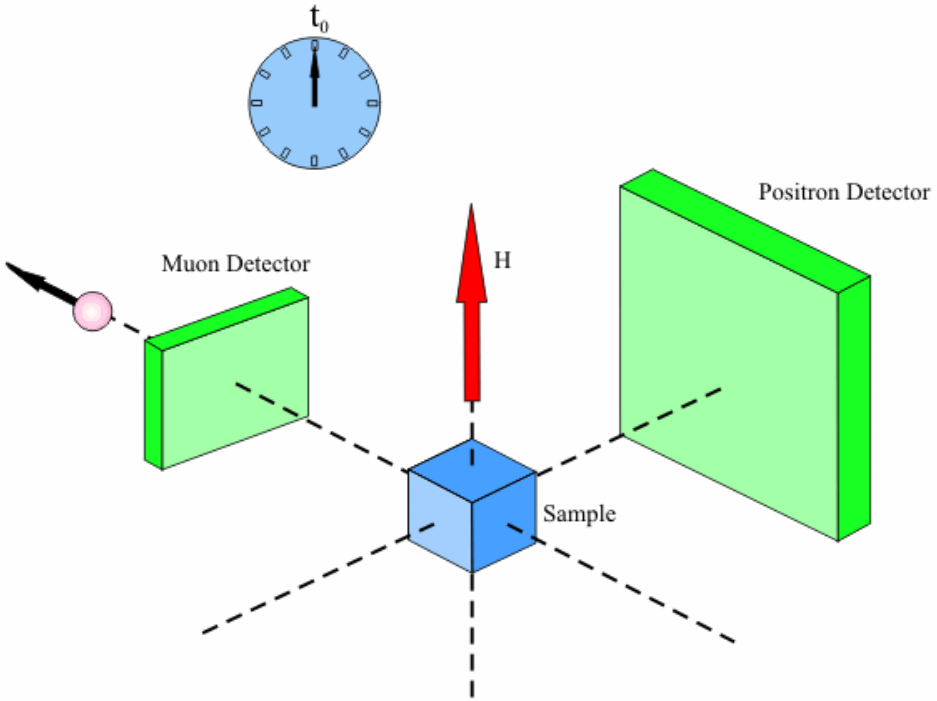
Muon Spin Relaxation/Rotation/Resonance (μSR)

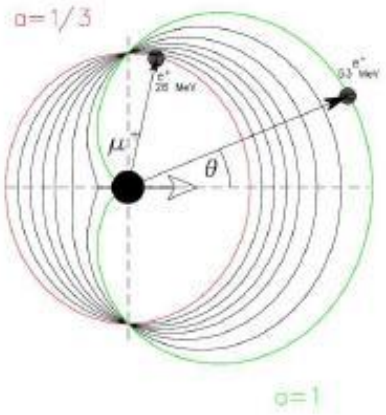


>300 MeV

Pion Lifetime
26 ns



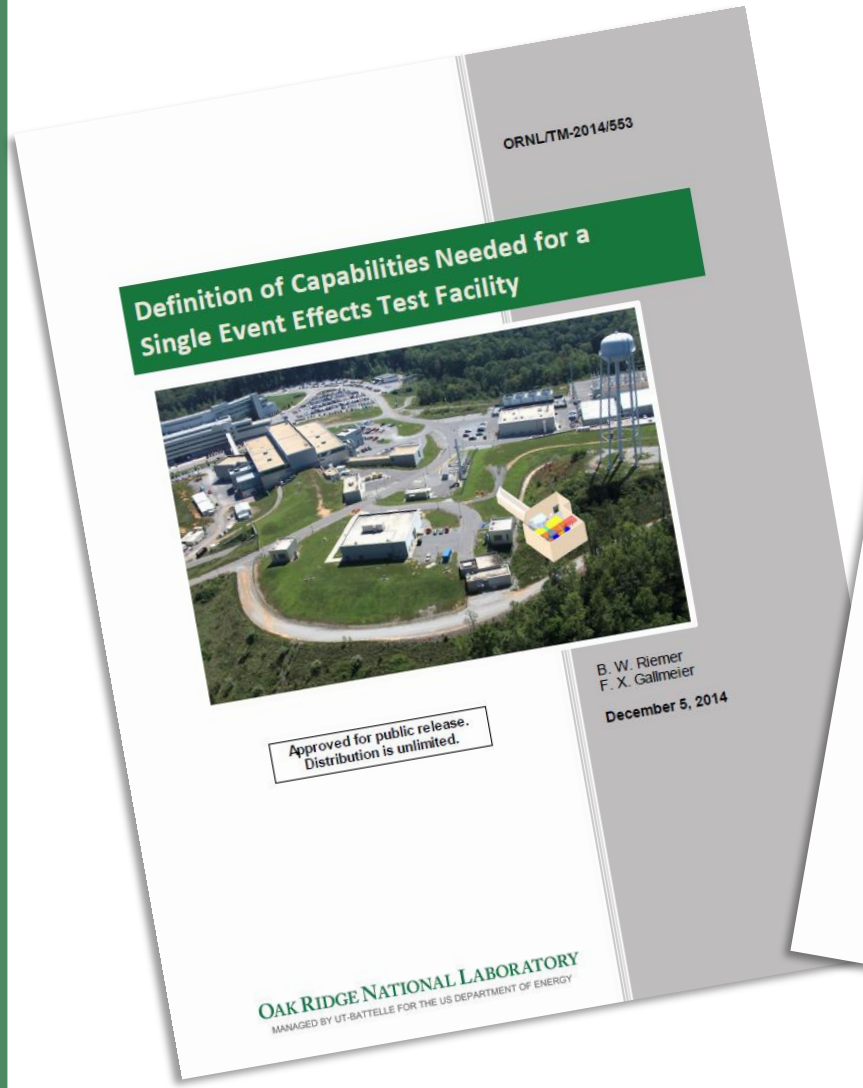


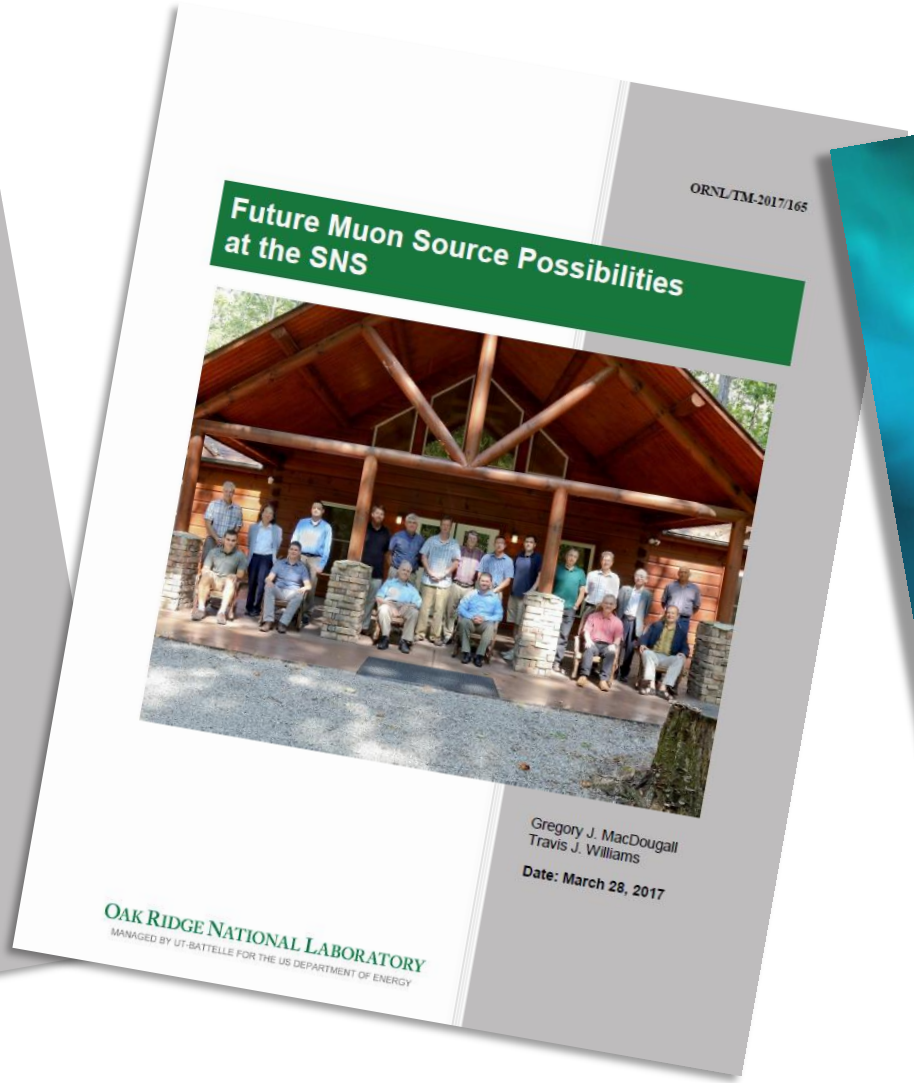


"A significant expansion of the use of μSR in the United States will probably require new facilities as currently, there is no operating facility in the USA. It should be considered whether it makes sense to build a muon facility co-located with SNS…"

- Berkeley Grand Challenges Workshop: "Quantum Condensed Matter," (2014) R.J. Birgenau, R. Ramesh and S.E. Nagler (Chairs).

A novel collaboration





Dec. 2014 → Mar. 2017 → Nov. 2018

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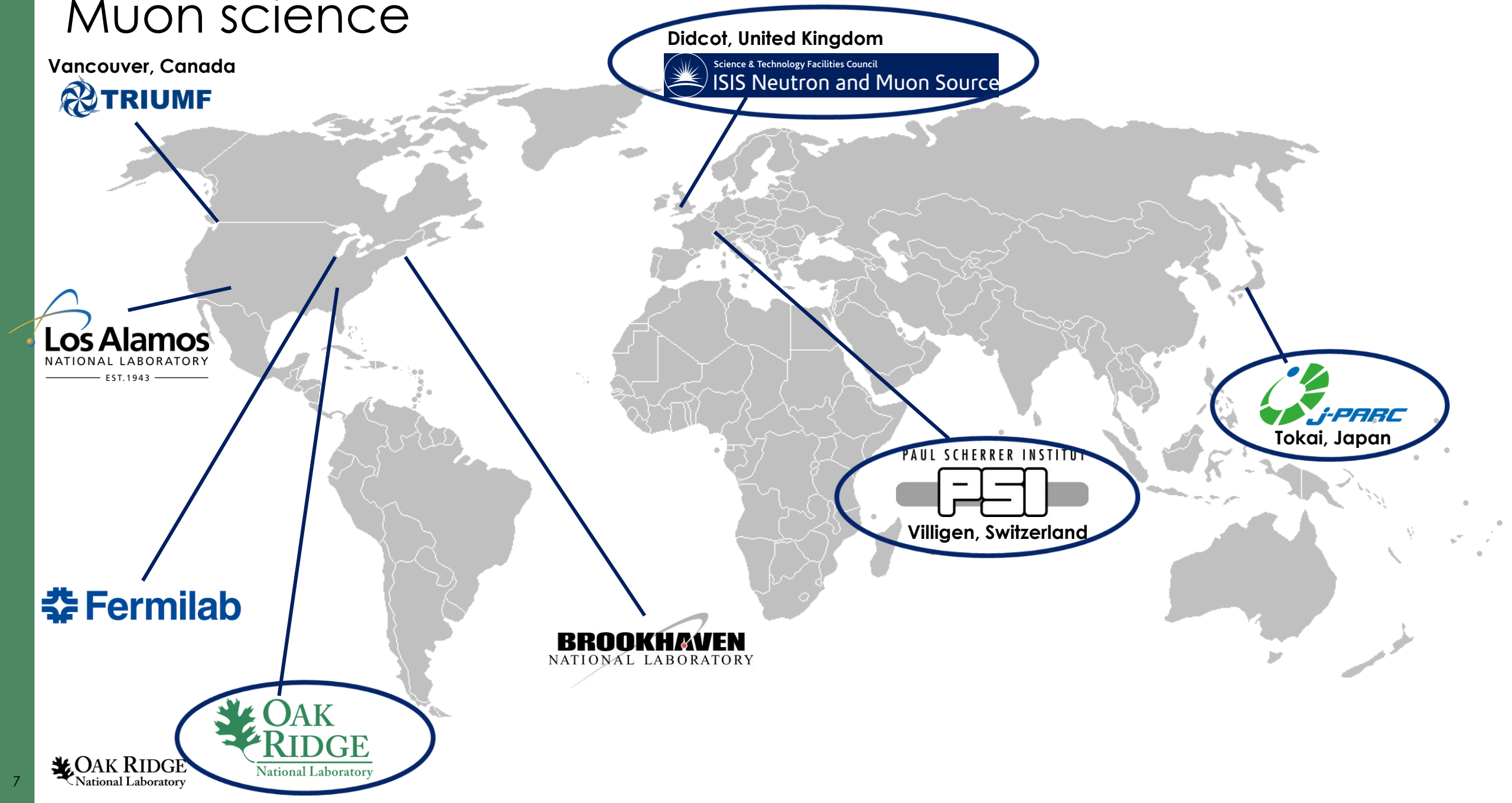
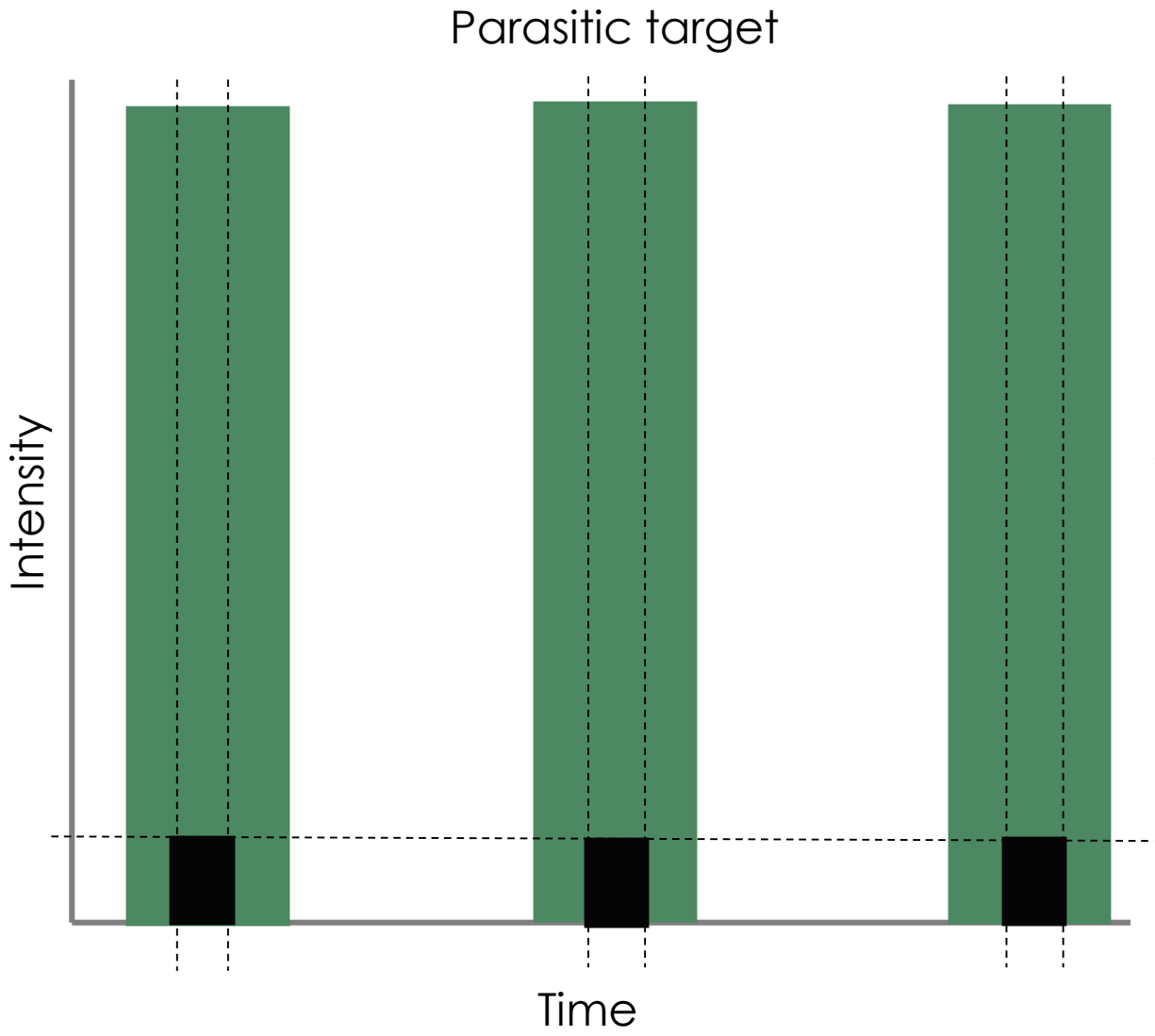
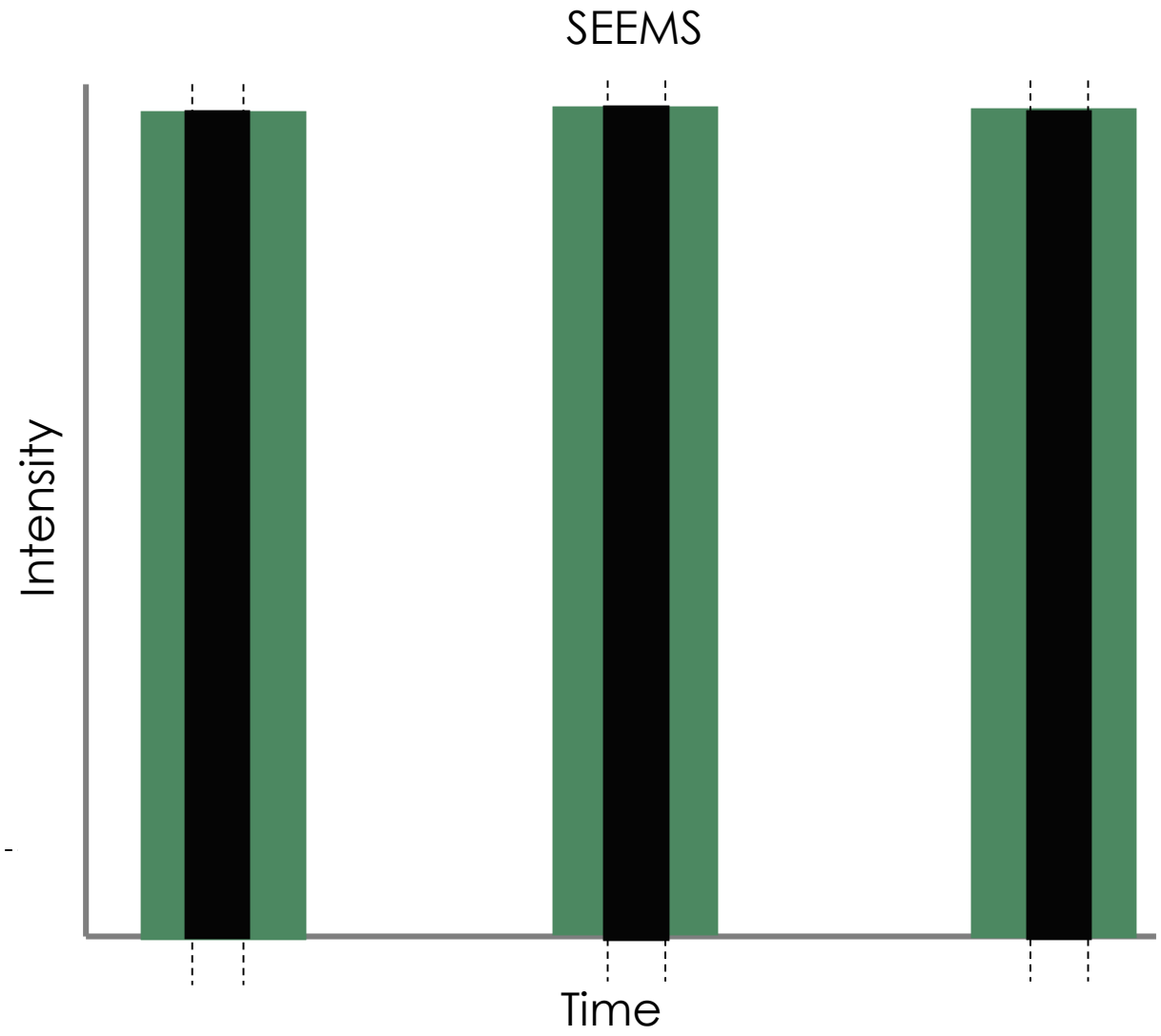
Muon science

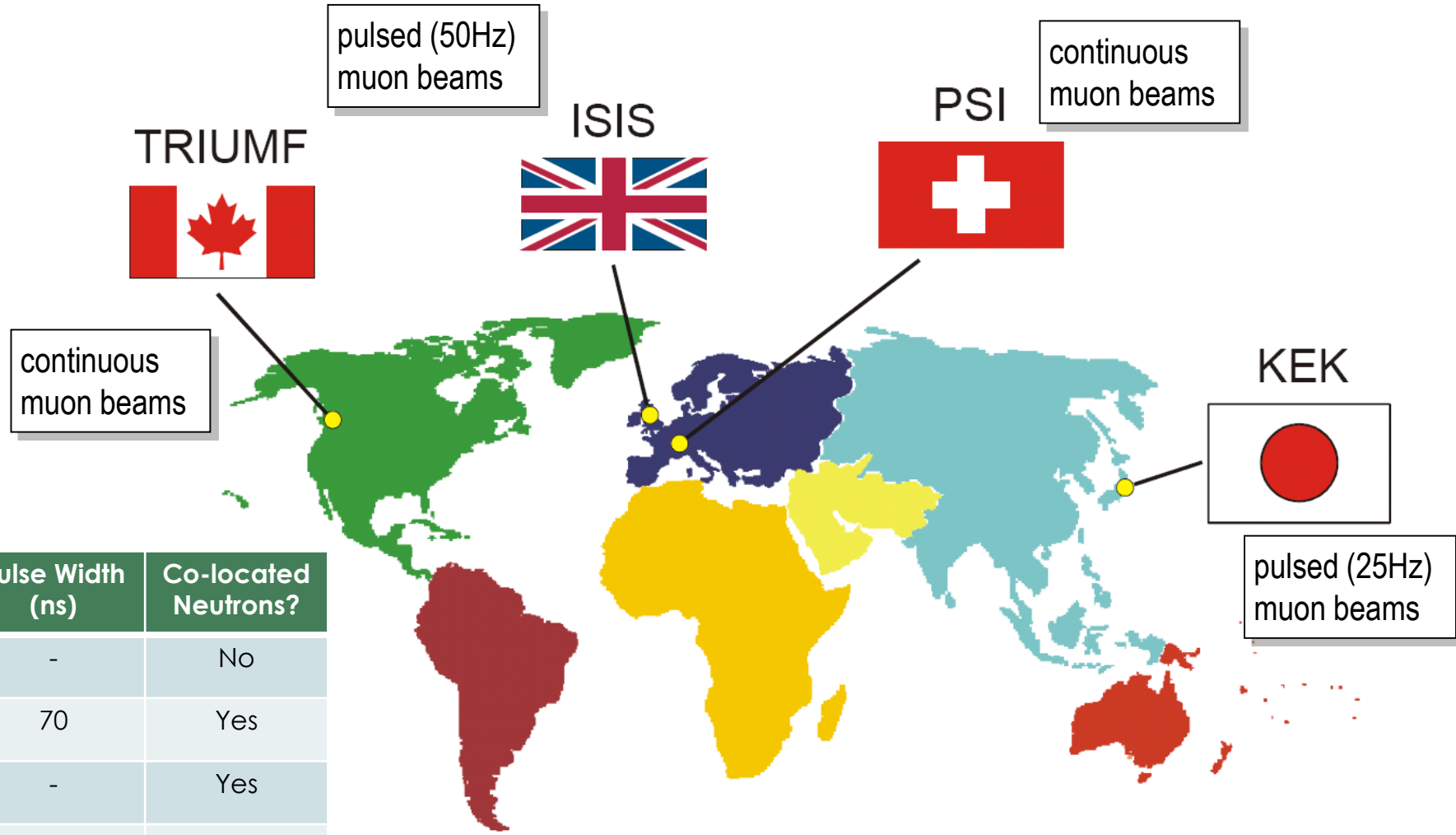


SEEMS versus Parasitic beam





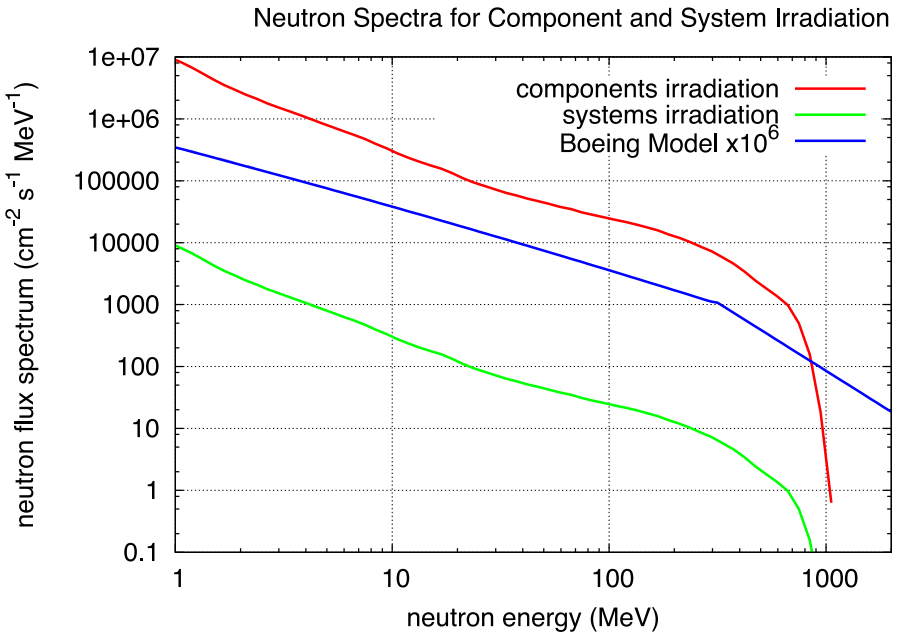
Existing muon sources

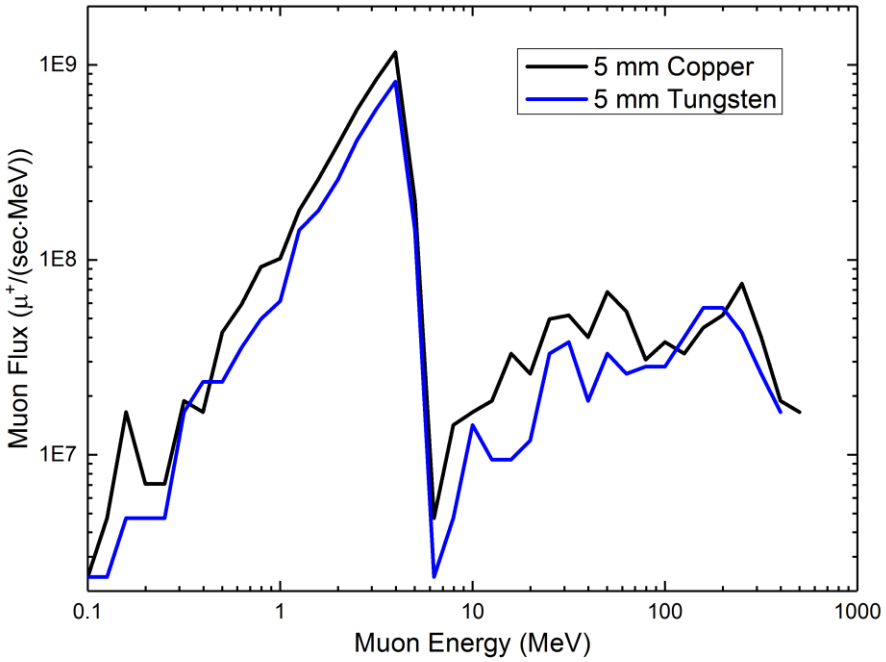


Facility	Source Type	Flux (μ^+/sec)	Pulse Width (ns)	Co-located Neutrons?
TRIUMF	Continuous	5.0×10^6	-	No
ISIS	Pulsed	1.5×10^6	70	Yes
PSI	Continuous	7.0×10^4	-	Yes
J-PARC	Pulsed	1.8×10^6	100	Yes
SEEMS (proposed)	Pulsed	4.3×10^8	50	Yes

Target simulations

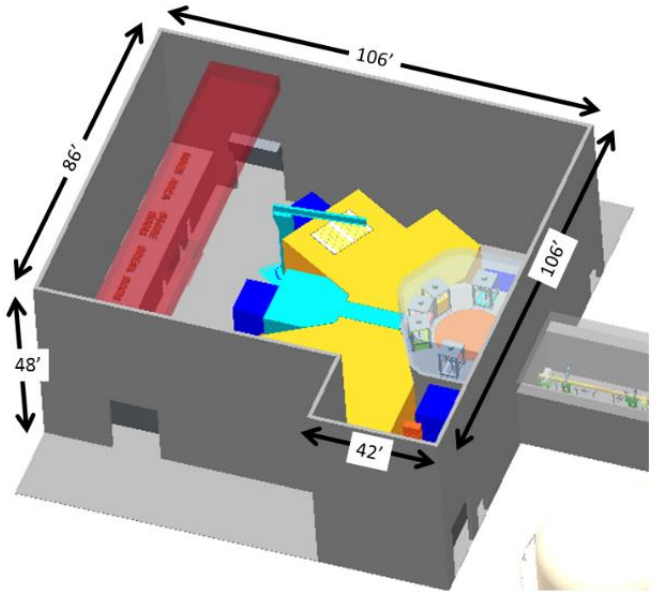
- Monte Carlo simulations were carried out on several materials, geometries and sizes.
  - Carbon, copper, nickel, tungsten
  - Long rod versus plate
  - 2mm up to 10mm thick
- Proton-pion-muon conversion 2.9×10^{-4} μ^+/p^+
- Flux ~ 6.8×10^9 μ^+/sec (facility)

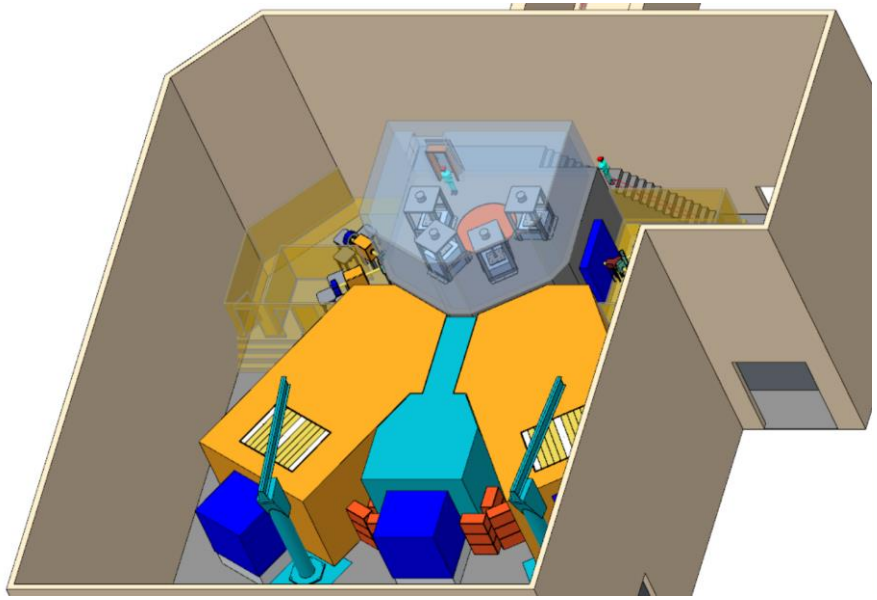


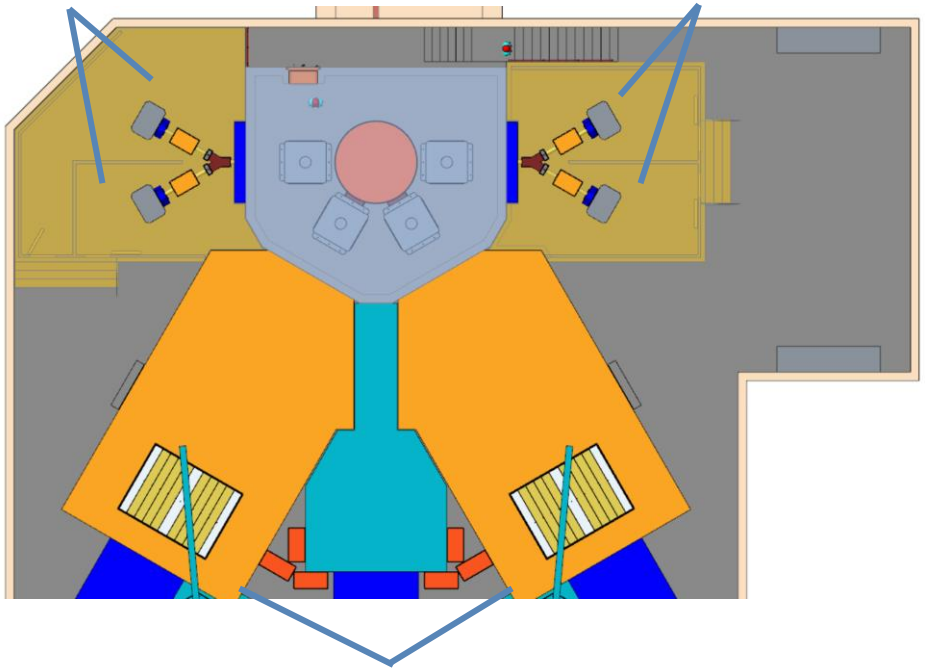


Facility layout

- SEE and μSR missions are very compatible, and can share a building and target.
  - This produces a dual-purpose facility, which will produce ~30% cost savings compared to building separate facilities.



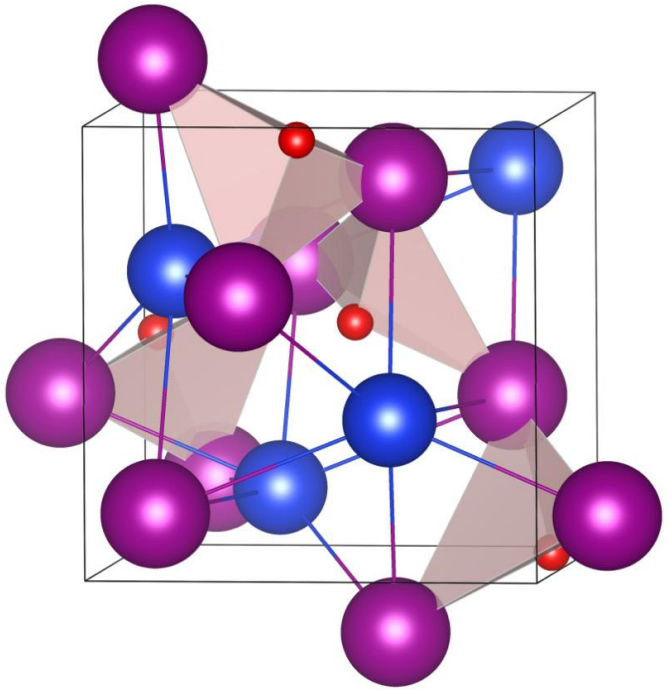




Neutrons reveal tremendous information, and…
… muons fill in the gaps.

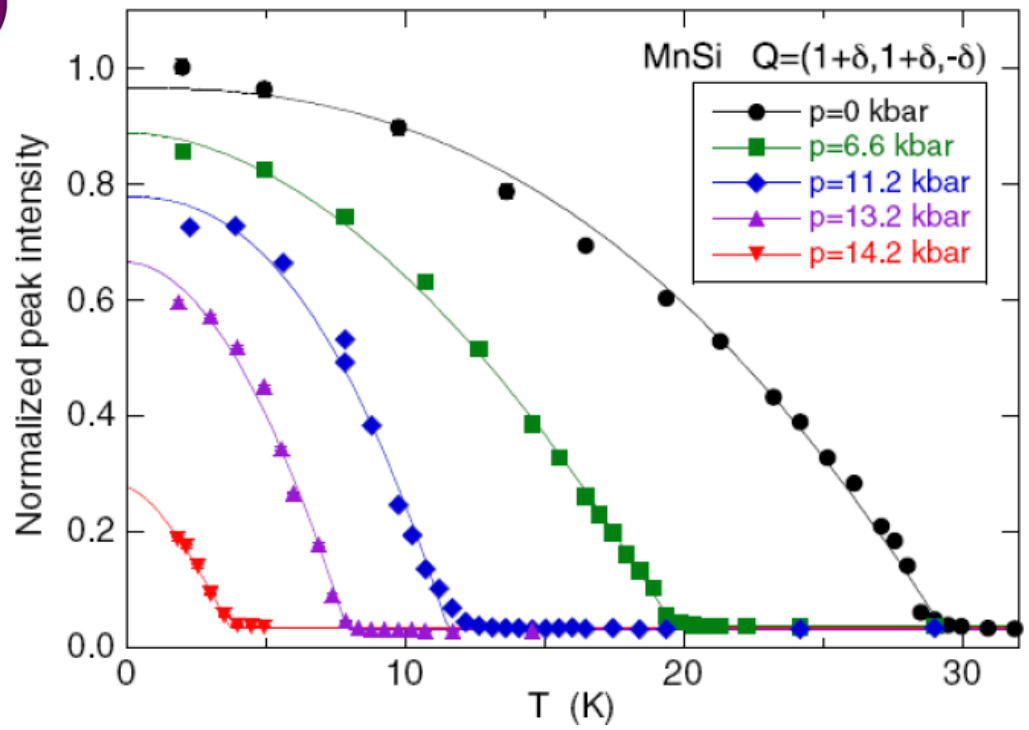
- Neutrons are a bulk, reciprocal space probe.
  - This means neutrons are very sensitive to long-range correlations.
  - **Muons measure the local environment, short-range effects and phase separation.**
- Neutrons measure energies on the order of μeV to meV.
  - This means neutrons measure fluctuations on the order of MHz to THz.
  - **Muons extend this timescale to fluctuations occurring in Hz or kHz.**
- The magnetic moment of the neutron is small.
  - Magnetic neutron scattering is most effective at measuring large moments (~ 1μ_B).
  - **Muons are very sensitive to magnetism, able to measure 0.01 μ_B easily.**

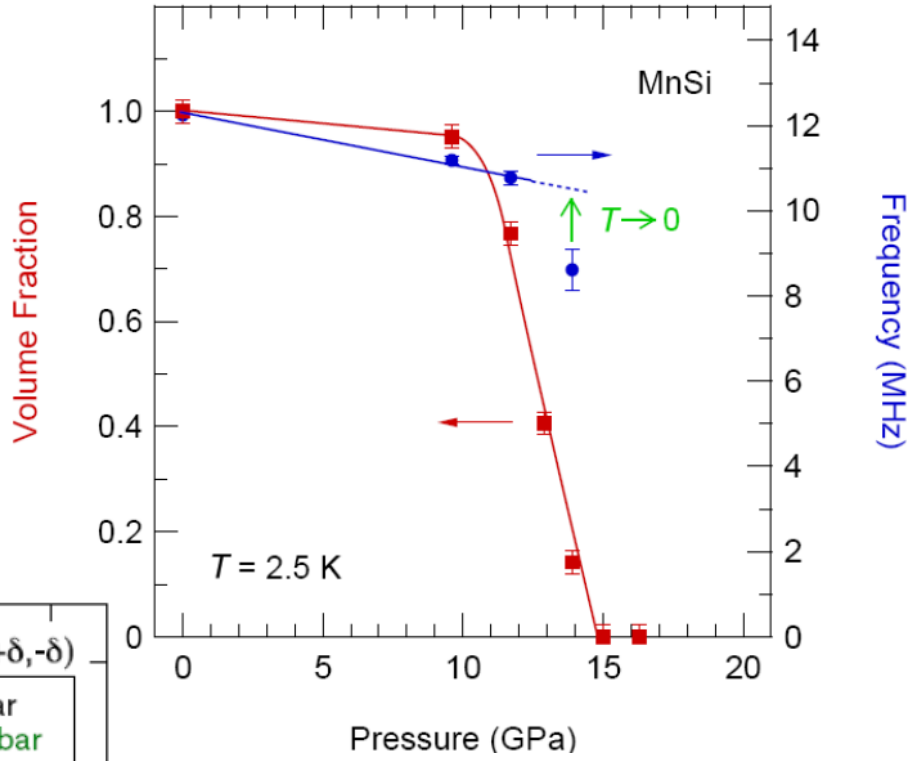
Prof. Tomo Uemura - Columbia



Topological
Quantum Materials

Neutron Scattering

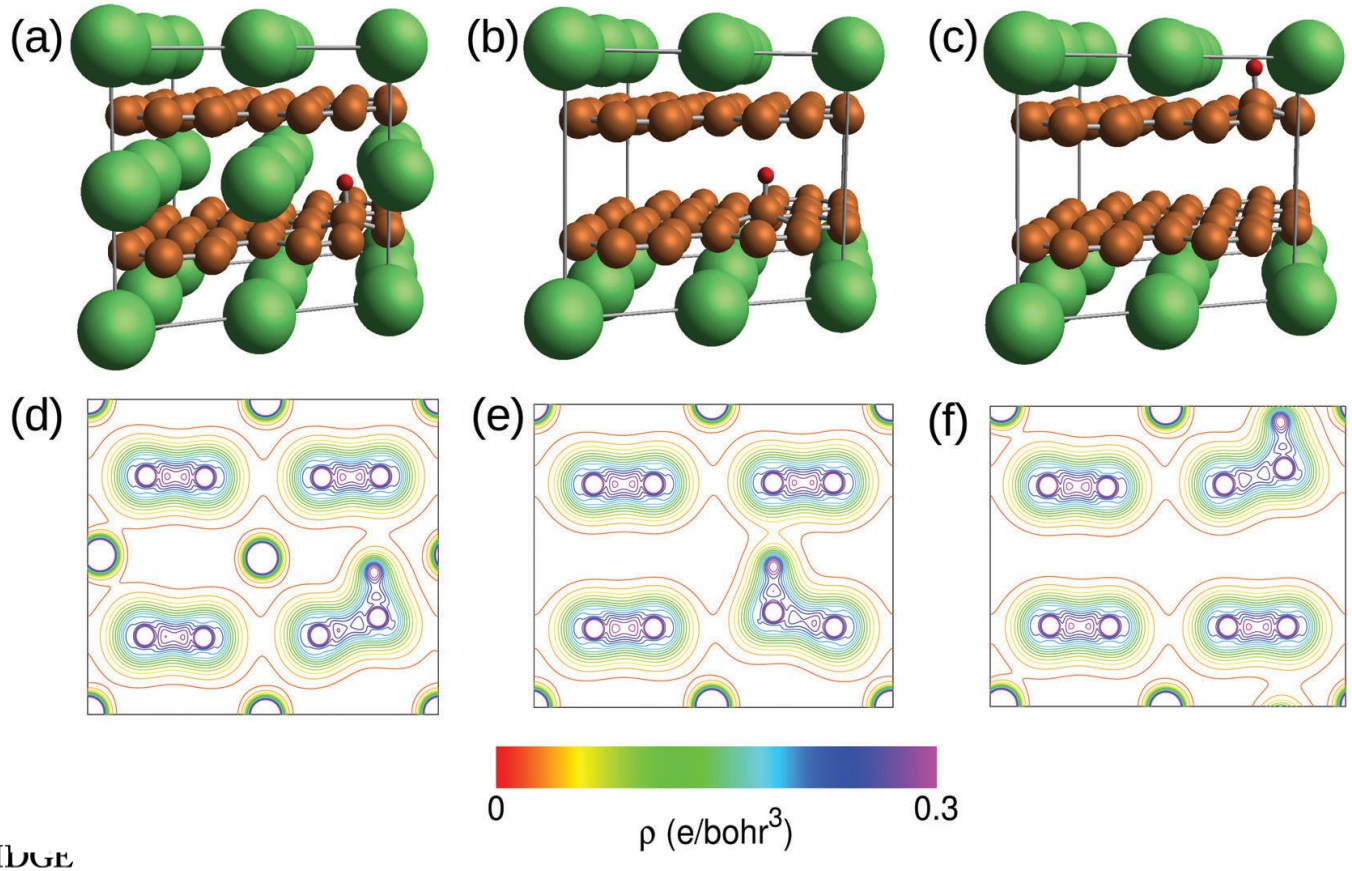


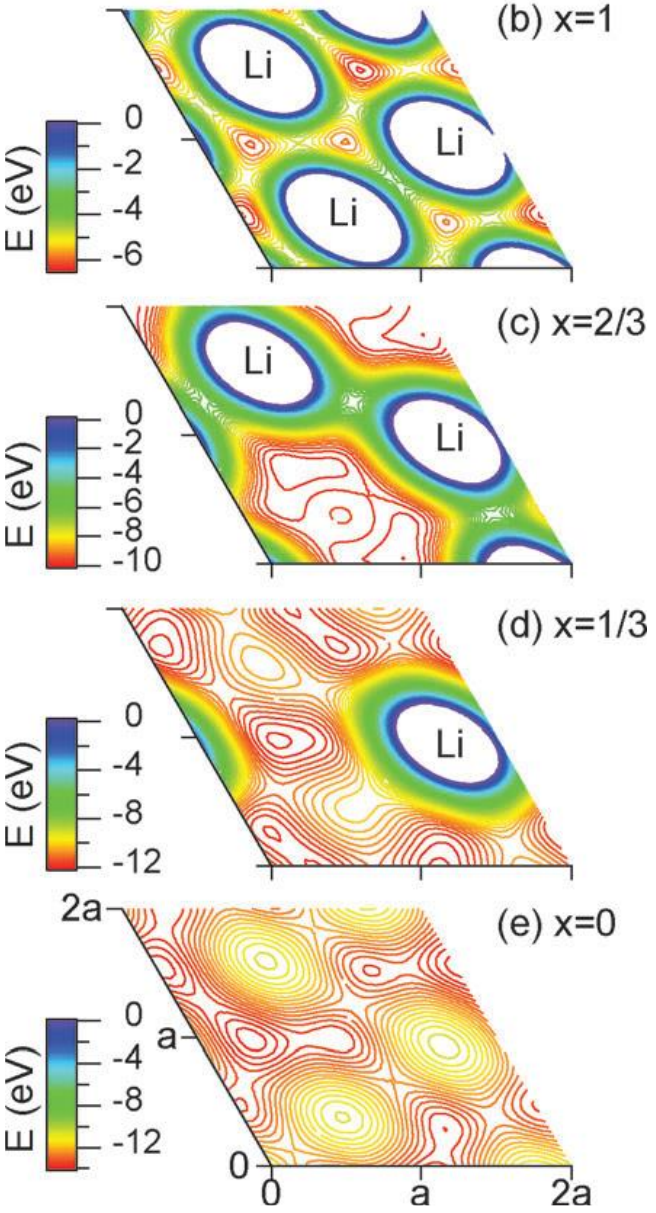


μSR Measurements

Dr. Jun Sugiyama – Toyota

- Studying Li intercalation for Li-ion batteries.





μSR Beamline capabilities

- Four beamlines for μSR experiments.
  - These could support surface muon beams (34 MeV/c^2), decay muons (higher muon energies), or low-energy muons.
  - It would also support complex sample environments, including high or low temperatures, applied pressure and field, and other *in situ* testing.
  - Each beamline would receive pulsed muon beams with a FWHM of 50 ns and a flux of 4.3 x 10^8 μ^+/s.
- New capabilities:
  - Higher flux (>200x) and better resolution, with a tunable pulse structure.
  - Low-energy muon beams with sufficient flux for depth-resolved and thin film studies.
  - Muon microscopy: focused beams for device measurements.
  - Integration with high-performance computing for simulation of data.

SEEMS: A new user facility for ORNL at the SNS