Neutron Electric Dipole Moment Experiment at TRIUMF

The TUCAN Collaboration

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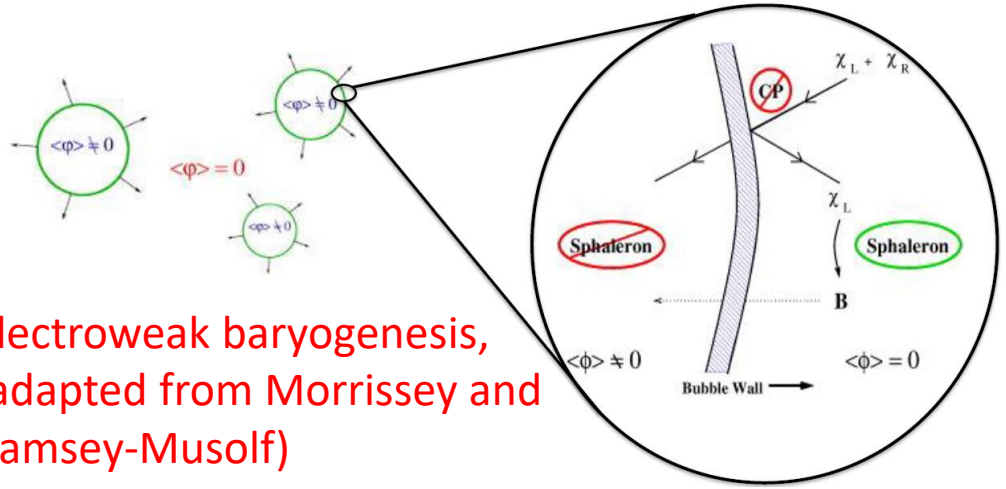
Physics of Neutron Electric Dipole Moment

- Search for new sources of CP violation beyond the standard model.
- Motivated by:
  - Strong CP problem / Peccei-Quinn, axions
  - SUSY CP problem / new TeV-scale physics for electroweak baryogenesis
  - Other new physics scenarios, e.g. color breaking baryogenesis (G. White, *et al*.)
- Ancillary measurements:
  - Precision clock comparison (axionlike particles, Lorentz violation, background cosmic field, …)
  - Time-dependent EDM's (axionlike dark matter)



Electroweak baryogenesis, (adapted from Morrissey and Ramsey-Musolf)

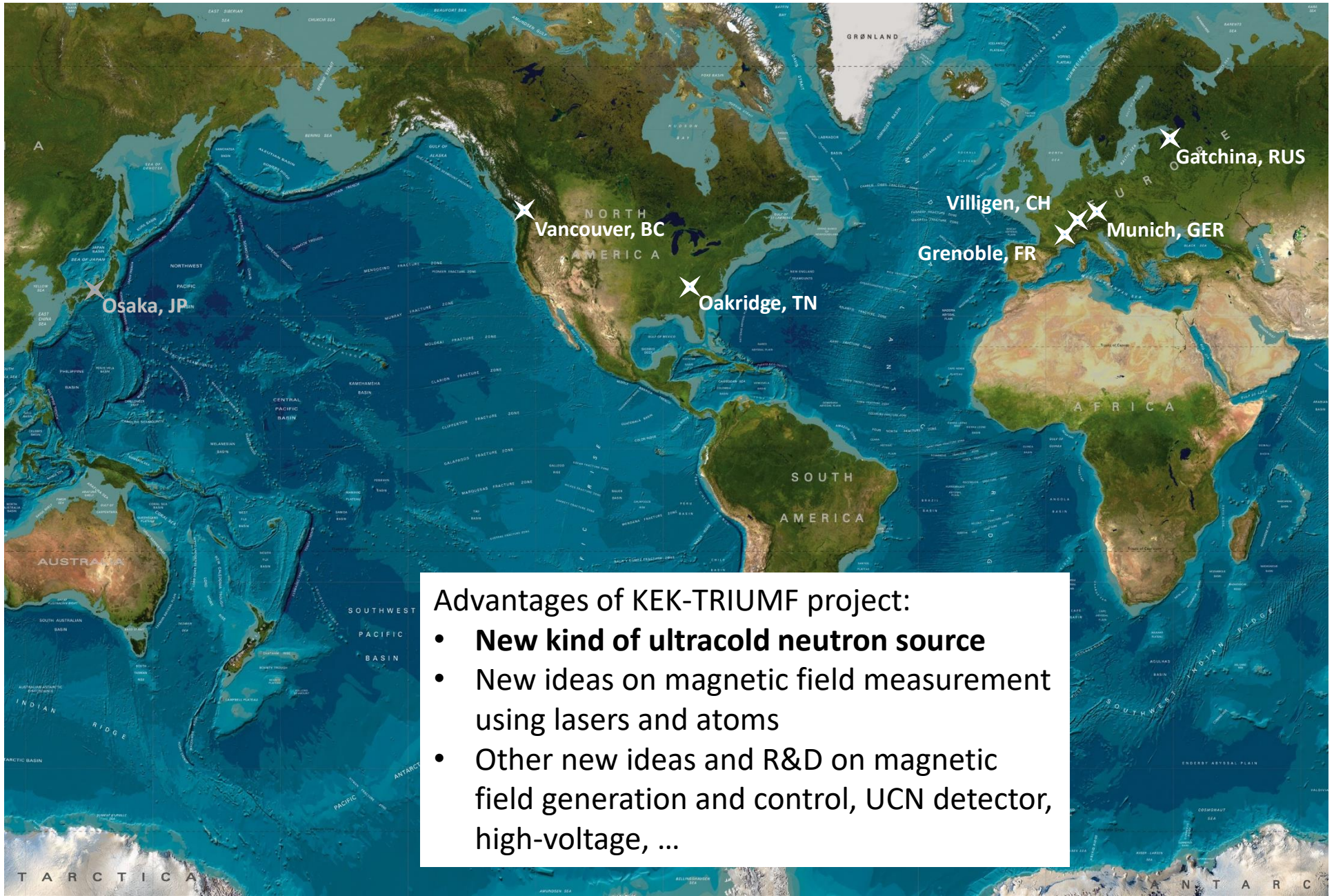
Neutron EDM – world status

- Free neutrons: $d_n < 3.0 \times 10^{-26}$ e-cm
  (ILL-Sussex-RAL; Baker et al. 2006, Afach et al. 2016 revised)
- Many groups pursuing < 10^{-27} e-cm measurement (PSI, ILL-Gatchina, ILL-Munich, SNS, TRIUMF, …)

- Recent Hg-EDM implies: $d_n < 1.6 \times 10^{-26}$ e-cm (Graner et al. 2016) – Schiff screening
- Expectation that PSI group will beat this limit by some factor (<2) within next few years.

- Many orders of magnitude before standard model background (CKM) $d_n < 10^{-31}$ e-cm is reached.

Neutron EDMs worldwide



Advantages of KEK-TRIUMF project:

- **New kind of ultracold neutron source**
- New ideas on magnetic field measurement using lasers and atoms
- Other new ideas and R&D on magnetic field generation and control, UCN detector, high-voltage, …

Ultracold Neutrons (UCN)

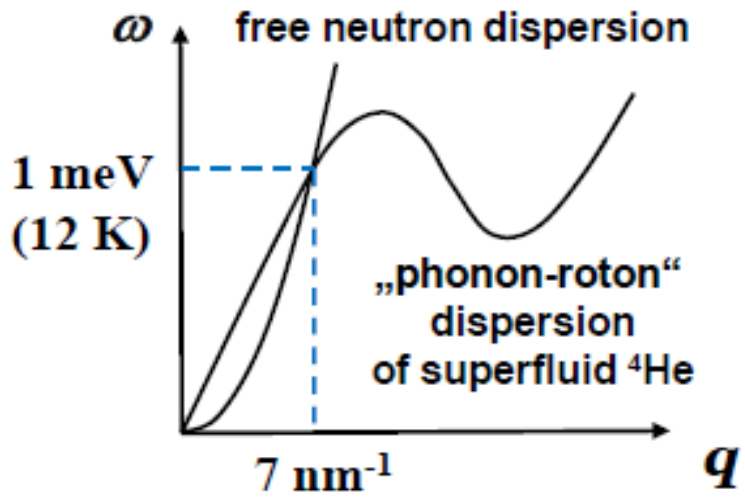
- Neutrons that are moving so slowly that they bounce off surfaces and can be bottled.
  - $v < 8$ m/s = 30 km/h
  - $T < 4$ mK
  - K.E. < 300 neV

- Interactions:
  - Gravity: $V = mgh$ mg = 100 neV/m
  - Magnetic: $V = -\mu \bullet B$ μ = 60 neV/T
  - Strong: $V = V_{eff}$ $V_{eff} < 335$ neV
  - Weak: τ_n = 886 s = 15 mins.

Two leading superthermal UCN source technologies

- Superfluid ^{4}He
  - Nearly ideal two-state system
  - Small losses
  - Challenges are T < 0.8 K and extraction

Courtesy O. Zimmer



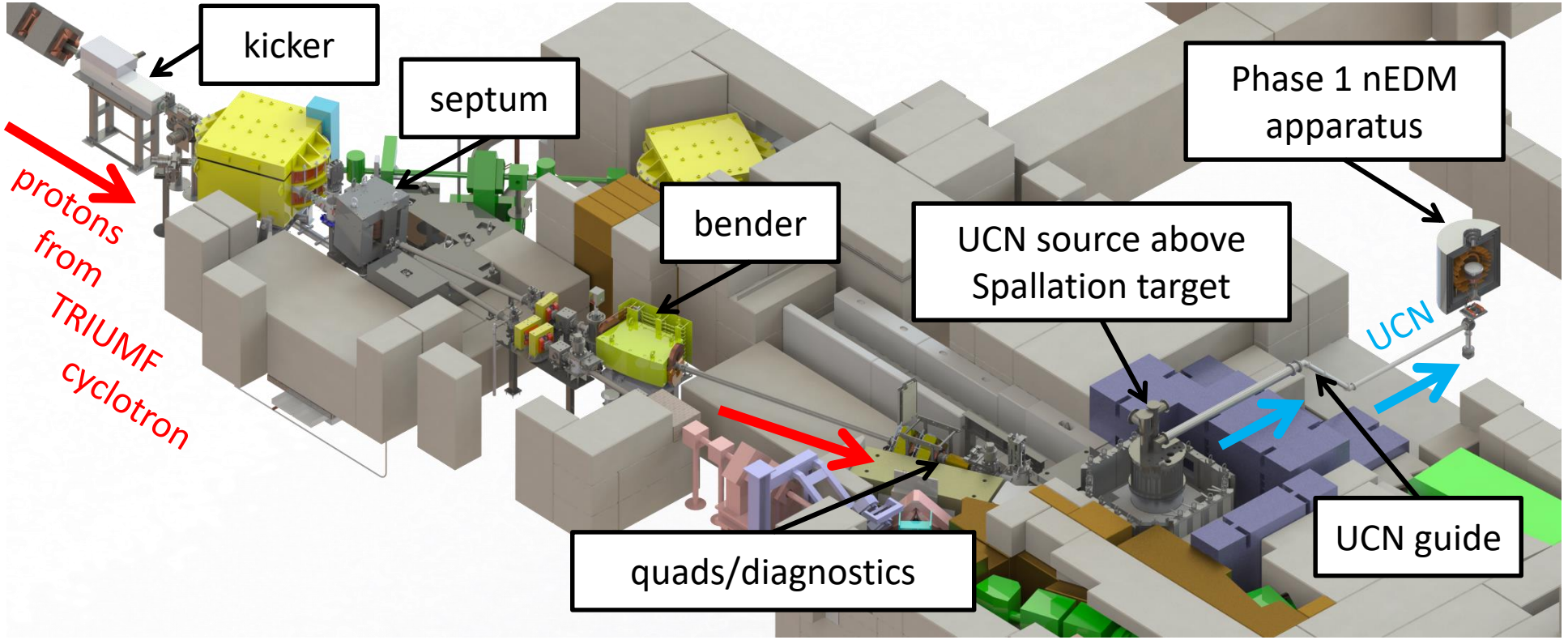
- Solid ortho-D_2
  - Many more scattering states, high production
  - Large losses
  - Challenges are short UCN lifetime and crystal quality

Survey of UCN Sources Worldwide

Place	Neutrons	UCN converter	Status
ILL	Reactor, CN	Turbine	Running
J-PARC	Spallation	Doppler shifter	Running
ILL SUN-2	Reactor, CN	Superfluid He	Running
ILL SuperSUN	Reactor, CN	Superfluid He	Future
RCNP/KEK/TRIUMF	Spallation	Superfluid He	Installing/Future
Gatchina WWR-M	Reactor	Superfluid He	Future
LANL	Spallation	Solid D2	Running/Upgrading
Mainz	Reactor	Solid D2	Running
PSI	Spallation	Solid D2	Running
NSCU Pulstar	Reactor	Solid D2	Installing
FRM-II	Reactor	Solid D2	Future

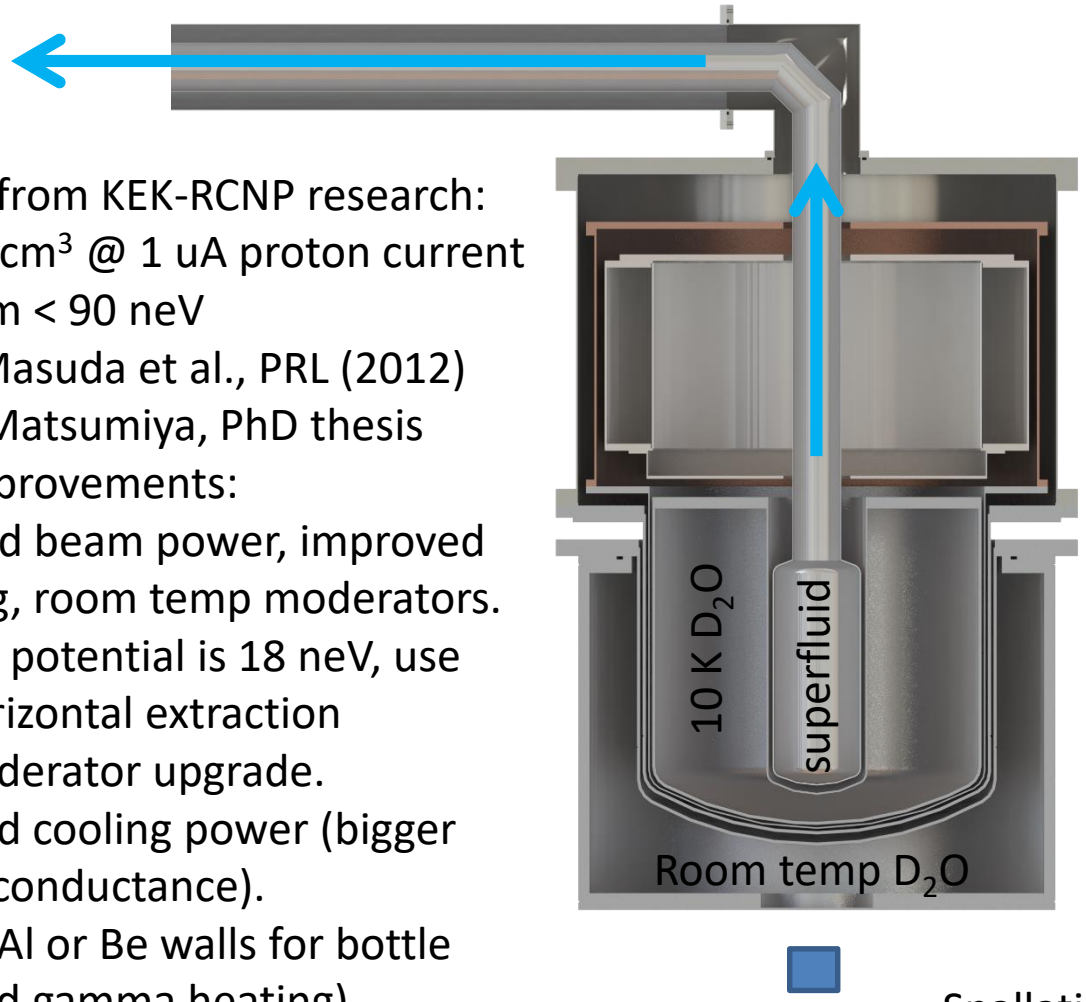
KEK-TRIUMF combination of spallation target and superfluid helium is unique.
Upgrade schedule is competitive with other leading sources of UCN.

UCN Facility at TRIUMF - Overview



Facility as of today – shielding blocks removed.

Vertical superfluid He cryostat



Key results from KEK-RCNP research:

- 26 UCN/cm^3 @ 1 uA proton current
- Spectrum < 90 neV
  - Y. Masuda et al., PRL (2012)
  - R. Matsumiya, PhD thesis

Possible improvements:

- Increased beam power, improved targeting, room temp moderators.
- Material potential is 18 neV, use near-horizontal extraction
- Cold moderator upgrade.
- Improved cooling power (bigger pumps, conductance).
- Thinner Al or Be walls for bottle (beta and gamma heating)

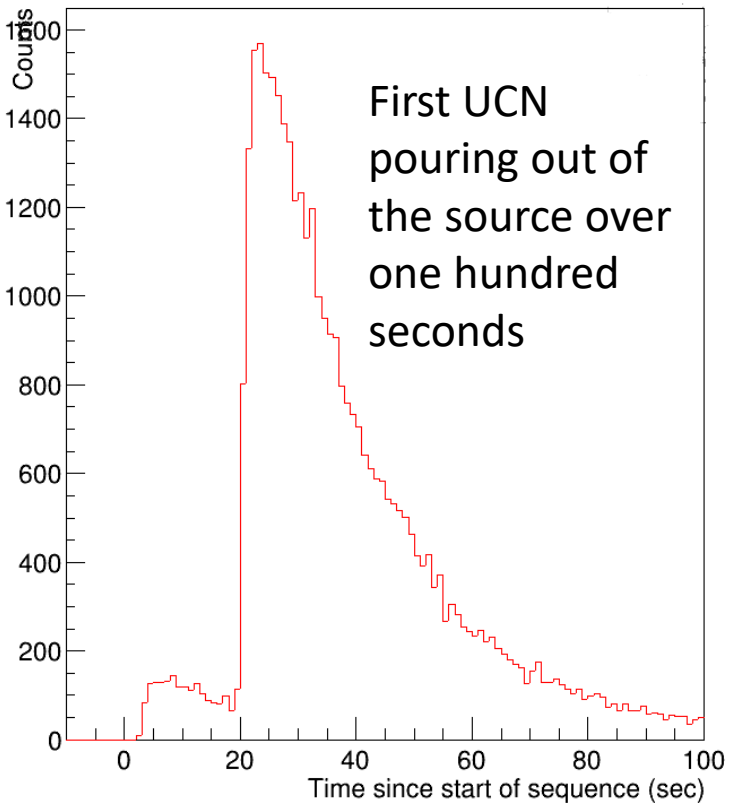
Surrounding graphite, steel not shown

Spallation target/neutron source

Recent progress in Canada (TRIUMF)

- First beam delivery to target - Nov. 22, 2016
- Installation of vertical UCN source – Jan.-Mar., 2017
- sub-1K cold test *in situ* – April 2017
- Fall 2017 – problems with cryostat operations.
- **Nov. 13, 2017 – First UCN production in Canada!**
- **Nov-Dec 2017 – comprehensive UCN production and transport experiments. Cryogenic He-II characterization. Focused on future UCN source design.**
- Continued nEDM R&D at Universities
- Offer made to Project Manager

First UCN at TRIUMF



First UCN pouring out of the source over one hundred seconds

kek.jp

TRIUMFで超冷却中性子(UCN)の生成に初めて成功　KEK、RCNP、TRIUMF、ウィニペグ大学の共同研究で

NOVEMBER 21, 2017

MAKIO

所要時間：約3分

TRIUMF's (ultra)cool experiment fires up

triumf.ca

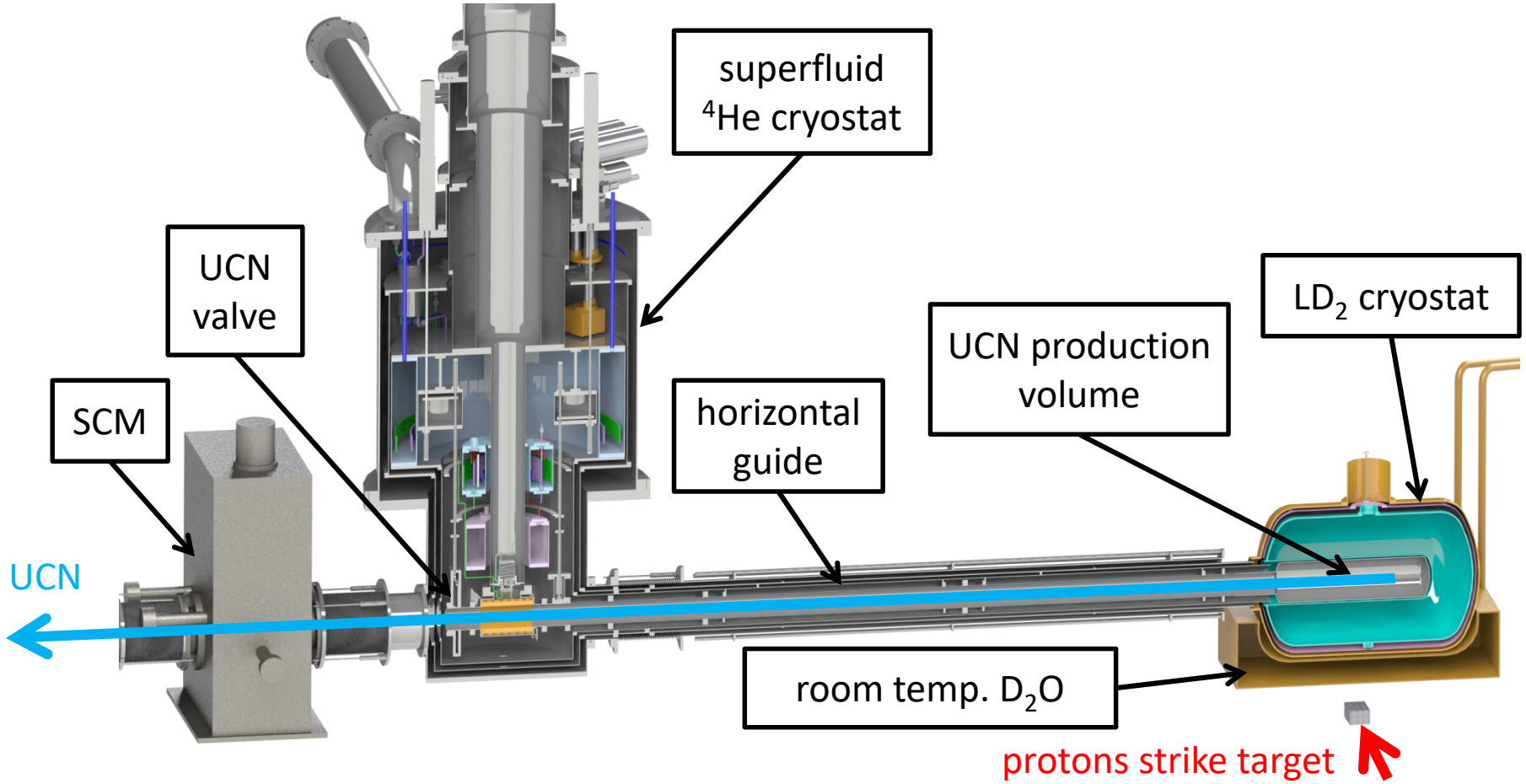
20 November 2017

New record for most UCN produced with this source: 325,000 UCN for 10 uA proton beam current, 60 s irradiation. See parallel session (R. Picker).

Recent progress in Japan (KEK)

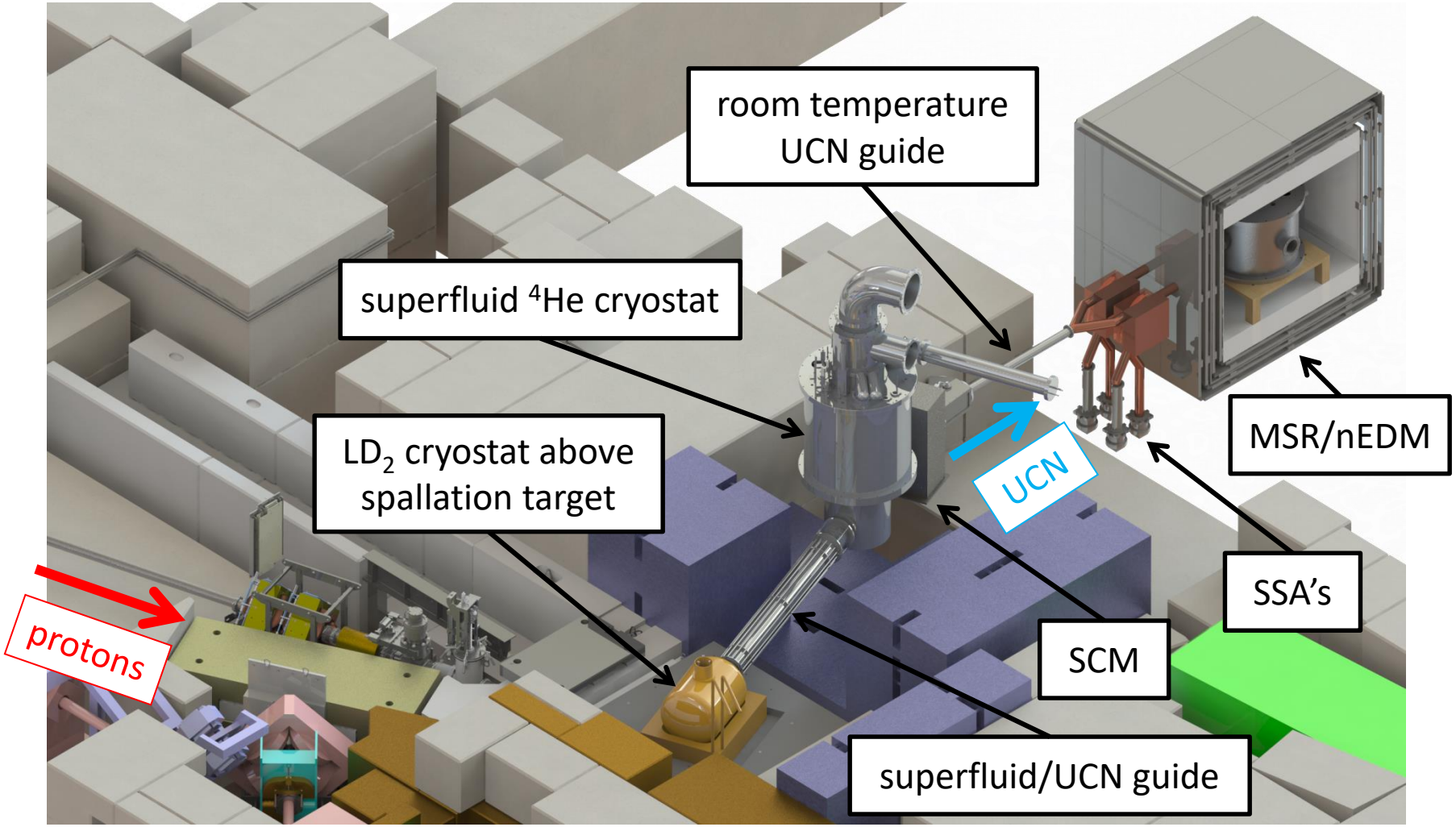
- New UCN source design from UCN and cryogenic perspectives
- Superfluid helium as a cryofluid, Kapitza conductances and heat exchanger design for 3He refrigerator
- Proposal for new experiments to measure Kapitza conductances and superfluid helium thermal conductance at KEK (in cooperation with Hosoyama-san's group)
- Moderator design, new idea for diamond nanoparticles as neutron reflector, studies of VCN source/moderator characterization line.
- Building collaboration in Japan, including Nagoya group.

Plan for 2019



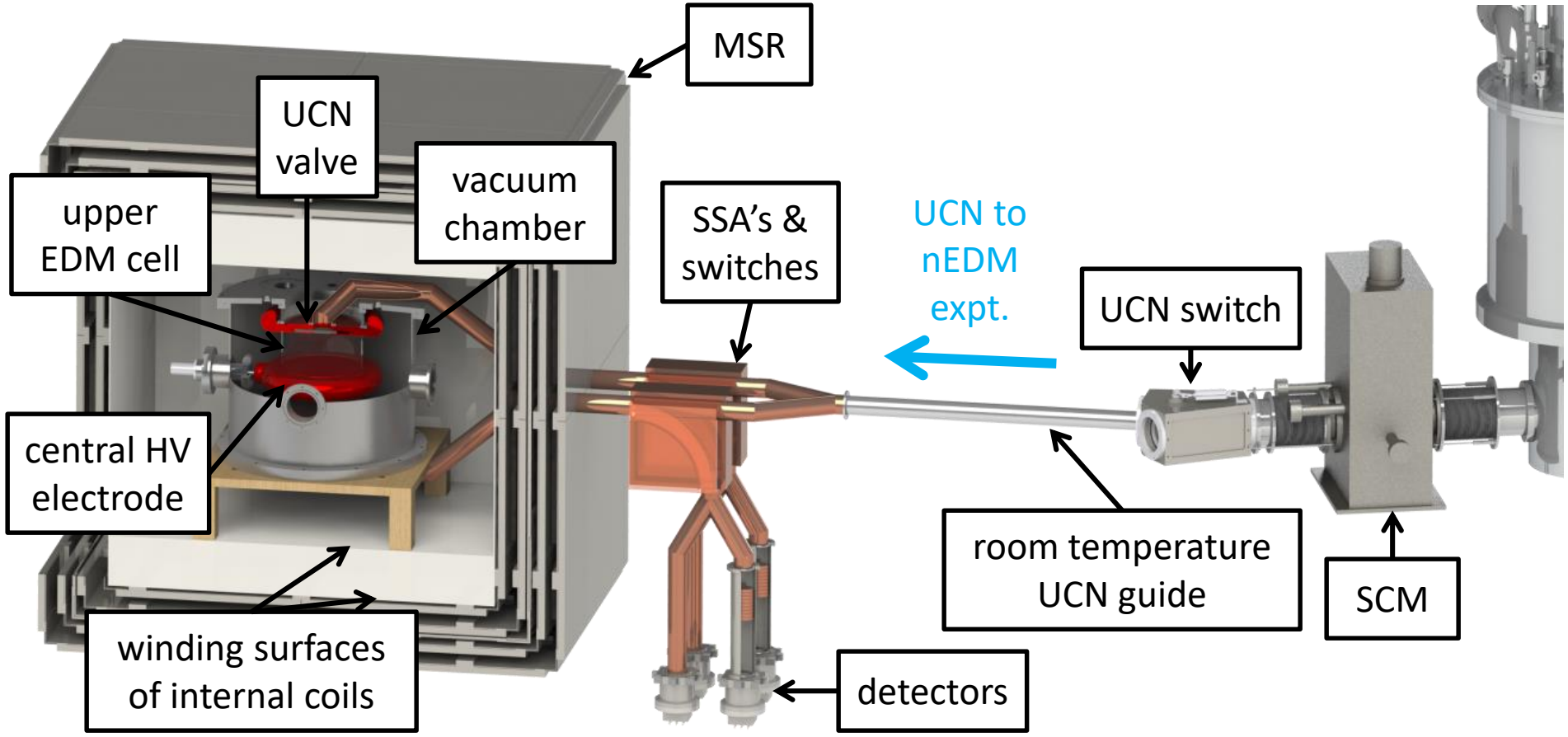
- New 3rd-gen UCN source to be built in Japan
- New LD_2 moderator to be built in Canada

Plan for 2020



- nEDM (Phase-2) experiment, 600 UCN/cm^3 delivered to two EDM cells.

Phase 2 nEDM Experiment



Funding Status

- Project is fully funded in Canada. ($13.6M including partner contributions secured/expected, $1.6M contributed by TRIUMF in 2015-2020)
- Need Japan commitment/plan for next-generation UCN source (and nEDM experiment).
- Need expertise of key KEK collaborators including UCN source leader (S. Kawasaki, T. Okamura, Y. Makida, K. Mishima), and Nagoya, RCNP Osaka groups.

Issues to be discussed in parallel session

- Project management (identified as issue in recent review in Tokyo)
- Manpower issues in Japan, how to engage new collaborators in Japan.
- Commitment of collaboration to running experiment at TRIUMF vs. designing future UCN source.
- What kind of development do we have to do before ready to build new UCN source?
- What is a reasonable schedule to complete R&D, CDR, to Gate 2 level? Gate 2 = ready to fund/proceed to technical design.
- Milestones/conditions leading to Gate 2.

Agenda of Parallel Session

- R&D for Cold and Ultracold Neutrons — M. Kitaguchi (Nagoya)
- Recent Results and Progress at TRIUMF — R. Picker (TRIUMF)
- New source design, Progress at KEK — S. Kawasaki (KEK)
- Cryogenic Design Studies for UCN Project — T. Okamura (KEK)
- Neutronics for new source — T. Kikawa (TRIUMF)
- Discussion

  S. Kawasaki (KEK), J. Martin (Winnipeg), K. Hatanaka (RCNP)

Summary

- High science impact.
- Good progress in past years, resulting in completion of proton beamline at TRIUMF and a key milestone of UCN production.
- Need to take project to next stage with new UCN source and EDM experimental apparatus.