3 Reviews of the Canadian Spallation Ultracold Neutron Source Project

As a part of the planning process for CSUNS, J.W. Martin has presented the CSUNS project to review committees four times over the past year, and has organized two collaboration meetings.

The UCN source project was most recently reviewed by the TRIUMF Special Experimental Evaluation Committee (March 2008). Presentations were made by J.W. Martin, Y. Masuda, and W.D. Ramsay from the CSUNS collaboration. The committee concluded that "a high density UCN source will support a fundamental physics program at TRIUMF well into the future, thus maintaining the strong tradition at the laboratory of a broad program of measurement of nuclear interactions, nuclear structure, nuclear astrophysics, and fundamental symmetry tests. Like the latter it will furthermore bridge the gap between particle and nuclear physics." Such a strong endorsement has resulted in a great deal of enthusiasm.

The project was presented again by J.W. Martin to the Advisory Committee on TRIUMF (ACOT) on May 9, 2008. This committee also gave a favorable review to the project. The membership of both ACOT and the TRIUMF EEC includes some of the most well-known nuclear and particle physicists in the world. The membership of ACOT includes representatives from the National Research Council Canada (NRC) and from NSERC.

4 Figures and Tables

Location	Technology	critical energy E_c (neV)	storage time τ_s (s)	density in experiment ρ_{UCN} (UCN/cm^3)
TRIUMF	spallation He-II	210	150	$1 - 5 \times 10^4$
ILL Grenoble	CN beam He-II	250	150	1000
SNS ORNL	CN beam He-II	134	500	150
Munich	reactor SD_2	250		10^4
NCSU	reactor SD_2	335		1000
PSI	spallation SD_2	250	6	1000
LANL	spallation SD_2	250	1.6	145

Table 1: Future UCN sources worldwide. The Los Alamos National Lab (LANL) source is currently in operation on a testing basis. All other sources are proposed (future) sources, including a future He-II source at the ILL reactor for the CryoEDM project. These are the Spallation Neutron Source (SNS) at Oak Ridge National Lab (ORNL) for the n-EDM project there, the Munich FRM-II reactor (Forschungsneutronenquelle Heinz Maier-Leibnitz), the North Carolina State University nuclear reactor (NCSU), and the Paul-Scherrer Institut source (PSI). The TRIUMF source figures are quoted for 20 kW peak power delivered to the spallation source. The range indicated for the TRIUMF source results from use of differing cold moderator materials, as discussed in the text.

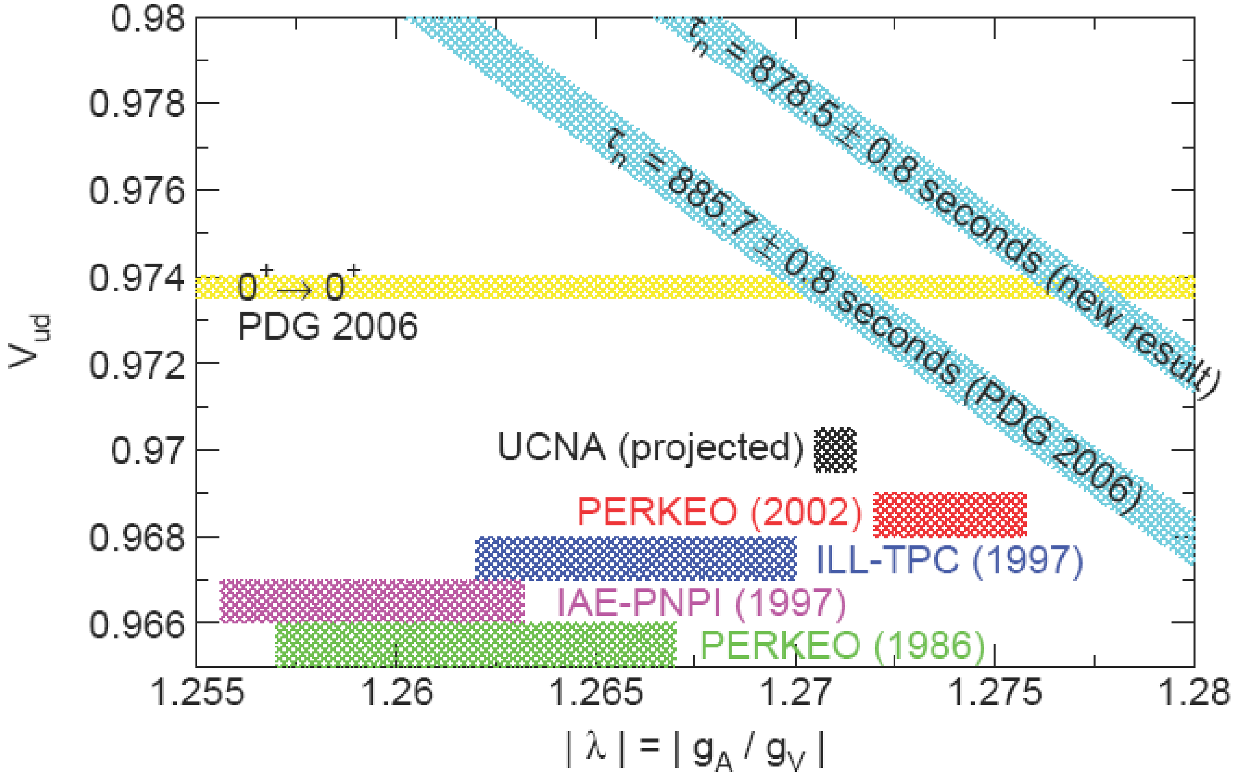

Figure 1: Current status of V_{ud}. Yellow horizontal band indicates current best determination by $0^+ \rightarrow 0^+$ nuclear beta-decay. Diagonal bands indicate current discrepancy between the two most recent measurements of the neutron lifetime τ_n which both use UCN confined to material traps. Coloured bands at the bottom of the figure are to be interpreted as vertical bands indicating recent measurements of the beta-asymmetry in neutron decay. The most precise of these, labelled UCNA is an ongoing measurement being conducted at the Los Alamos UCN source

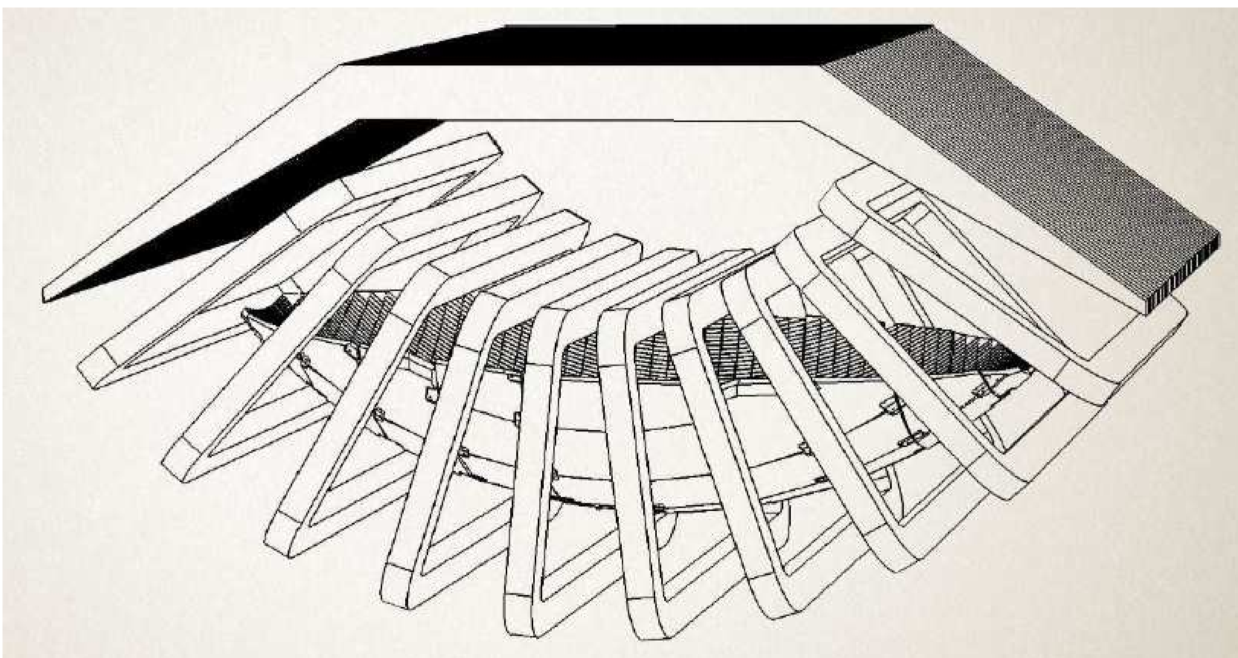

Figure 2: LANL-designed UCN trap, showing iron yoke, guide-field coils, and permanent-magnet bowl [6]. The vacuum chamber, which contains the bowl, but is inside the guide-field coils, and the detectors that are placed in the space between the end guide-field coils and the yoke, are not shown. The bowl depth is 0.5 m.

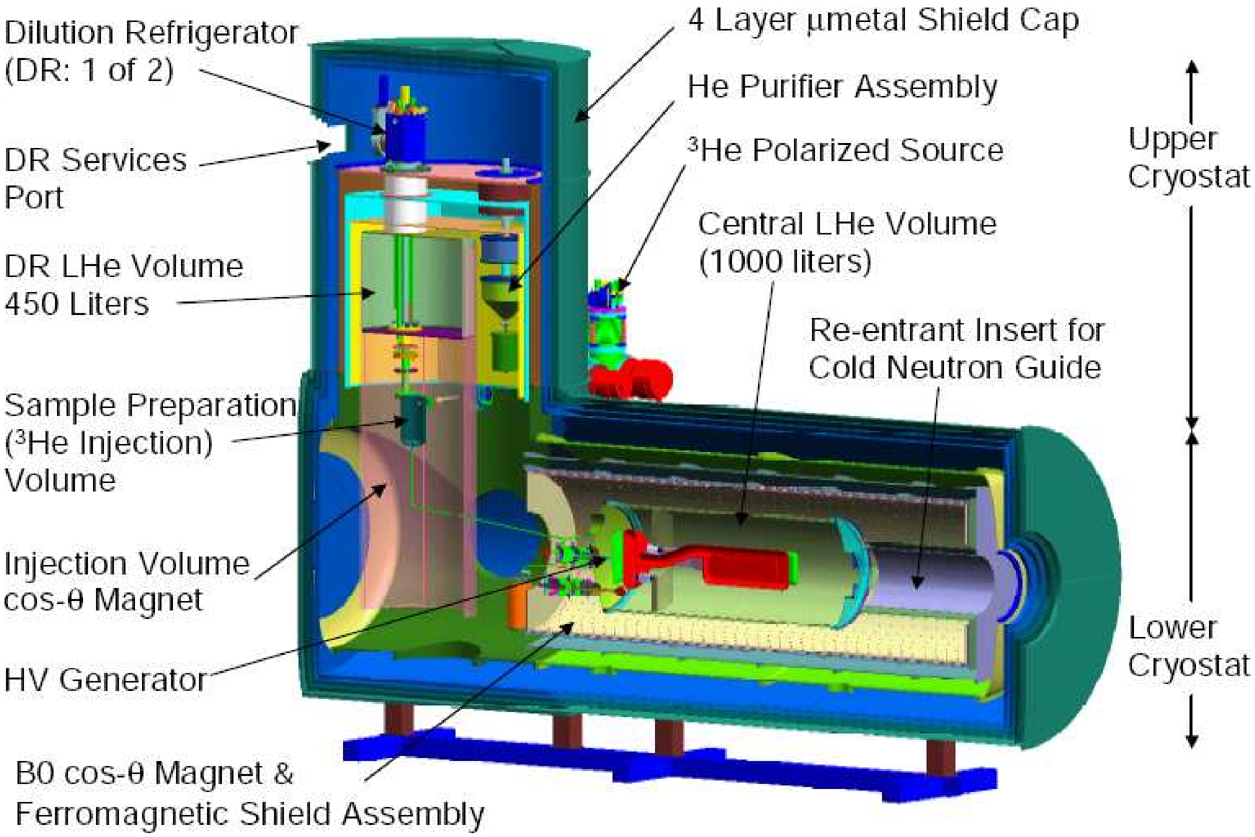

Figure 3: Schematic diagram of the proposed SNS EDM apparatus from Ref. [21]. The measurement volume consists of two cells of volume 4 L each.

5 References

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TRIUMF UCN Source Parameters

At TRIUMF, the 500 MeV proton beam will be used at 40 uA peak current is desired. The production scales approximately proportional to beam power, giving a factor 51 projected increase in UCN density over the prototype UCN source at RCNP, Osaka. Other gains will be had from a reconfiguration of the source. The configuration of the superfluid 4He (He-II) in the source will be altered from the present vertical arrangement at RCNP to the horizontal arrangement displayed in Fig. 4. In this way, the cold neutron flux in the He-II will be doubled simply by decreasing the average distance of He-II from the spallation target.

A UCN density in the 4He of 55,000-110,000 UCN/cc is expected internal to the superfluid volume, where a conservative storage lifetime of 150 s was assumed (limited by wall losses, and to a lesser extent phonon upscattering). After the production, UCN are extracted horizontally into a UCN guide, and transported to experiments. This horizontal extraction gives another relative gain over the RCNP prototype source. Taking this into account, the UCN density at the experimental port of the CSUNS source would be 10,000 UCN/cc at E_C=90 neV. The horizontal guide quality will be improved over E_C=90 neV, however we keep the estimate of 10,000 UCN/cc as a conservative estimate.

The UCN source will initially use 20 K heavy water (D2O) as the cold neutron moderator, which we intend to eventually upgrade to liquid deuterium (D2). D2O is preferred initially for is comparability to the existing Japanese source, the simpler safey issues compared to LD2, and due to cost considerations. The disadvantage of D2O at 20 K, is that the CN temperature will be 80 K, while for LD2 it would be truly 20 K. D20 is therefore not as well-matched to the phonon dispersion curve in superfluid 4He. The better matching of LD2 would increase the relevant CN flux, resulting in an eventual UCN density of 50,000 UCN/cc. The LD2 moderator would be pursued as a future upgrade to the TRIUMF UCN source.

The comparison of some of the parameters of this source to the rest of the world's UCN projects is summarized in Table 1 (found in the additional pages at the end of the "Quality of the Research or Technology Development" section). For TRIUMF, the numbers for both D2O and D2 moderators are included.

The beam power we can accept is limited by gamma heating from neutron captures in the surrounding material. According to a computer simulation, the power deposited by gamma heating in the He-II is 8 W for our design 20 kW proton beam power. Fortunately, this heat can be quickly removed by making use of the excellent thermal properties of superfluid helium to transfer the heat rapidly to a 3He cryostat and through a heat exchanger. As a result, the heat is transferred to 3He gas via 3He vaporization, and then removed by 3He pumping. The latent heat of 3He is 35 J/mol. The cooling power of the 3He pumping is represented as the product of the latent heat of vaporization times the vapor pressure times the pumping rate divided by RT, where R is the ideal gas constant and T temperature. The saturated vapor pressure of 3He is 3 Torr at 0.8 K. Therefore a pumping speed of $1\text{x}10^4$ cubic meters per hour applied to the 3He at 3 Torr removes a heat of 17 W. To further reduce the heat load, a cold neutron filter will be developed, to reduce the capture rate and hence gamma heating. The Bragg condition forbids low energy neutrons passing through a solid material except at cold neutron energies, explaining the principle behind the CN filter, which would be a material placed between the cold moderator and the He-II volume to screen out neutrons that are not cold.

Therefore, we estimate that the heat loads expected for instantaneous 20 kW beam power are well in hand for TRIUMF. We note that taking the technology to significantly higher beam currents, such as those available at PSI, SNS, or JPARC (the Japan Proton Accelerator Research Complex), would not be advisable. However, it is possible that, after the completion of CSUNS, an adequate solution would be found for this limitation in beam current. It is therefore only the demonstration of this new technology in Canada that will lead to future, even higher density UCN sources worldwide. This is an important reason for the creation of CSUNS in its own right.

In order to operate at TRIUMF, the source will require additional infrastructure particular to the implementation in Canada, and primarily particular to the creation of a dedicated user facility at significantly increased beam power over the RCNP prototype UCN source. It is mainly this infrastructure which would be supported by CFI funds. The details of the UCN source infrastructure is described in more detail in the "budget justification" section.

Tables and Figures

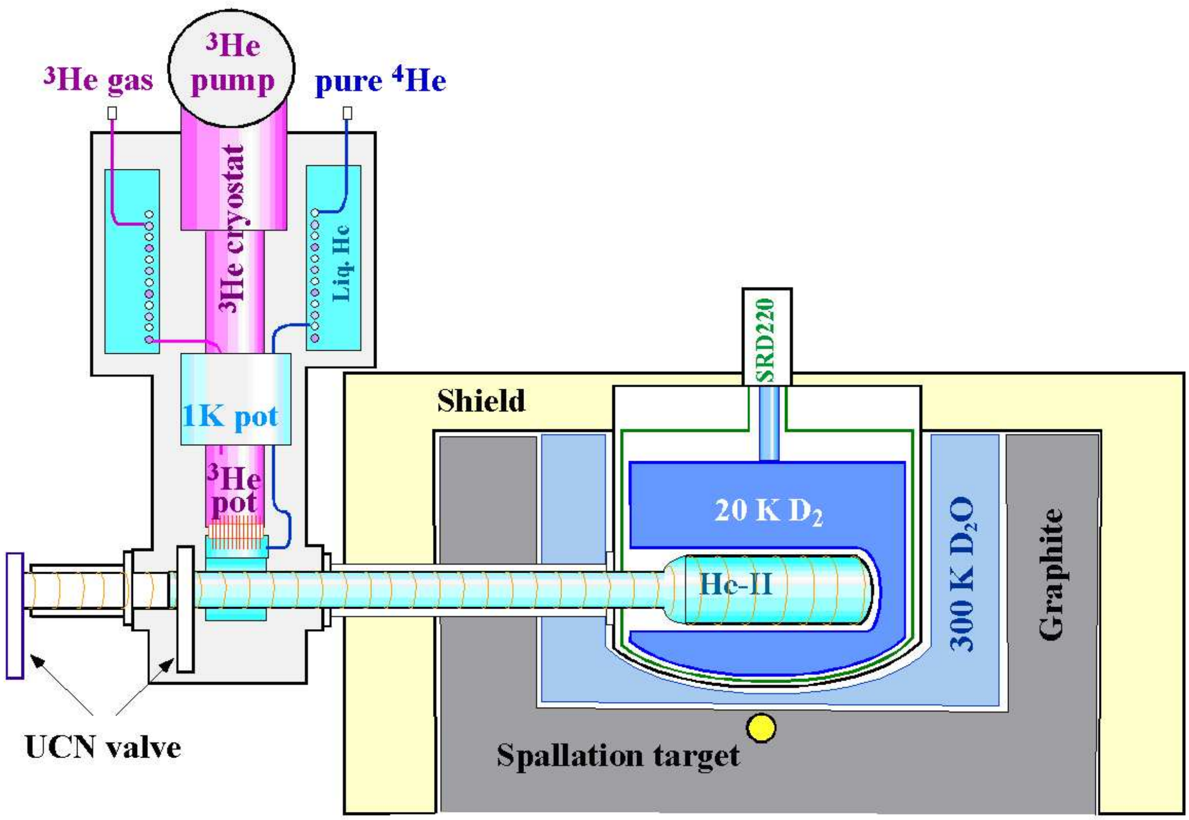

Figure 4: Schematic diagram of the superfluid 4He spallation UCN source for TRIUMF. The beam direction in the figure is into the page, i.e. an end-on view of the cylindrical spallation target is shown. Neutrons produced by spallation are moderators in surrounding D_2O and graphite, thereby becoming cold neutrons. Cold neutrons are downscattered to ultracold temperatures by phonon production in the superfluid 4He (He-II) volume. The ultracold neutrons are then transported out to experiments through guide tubes and a series of UCN valves.

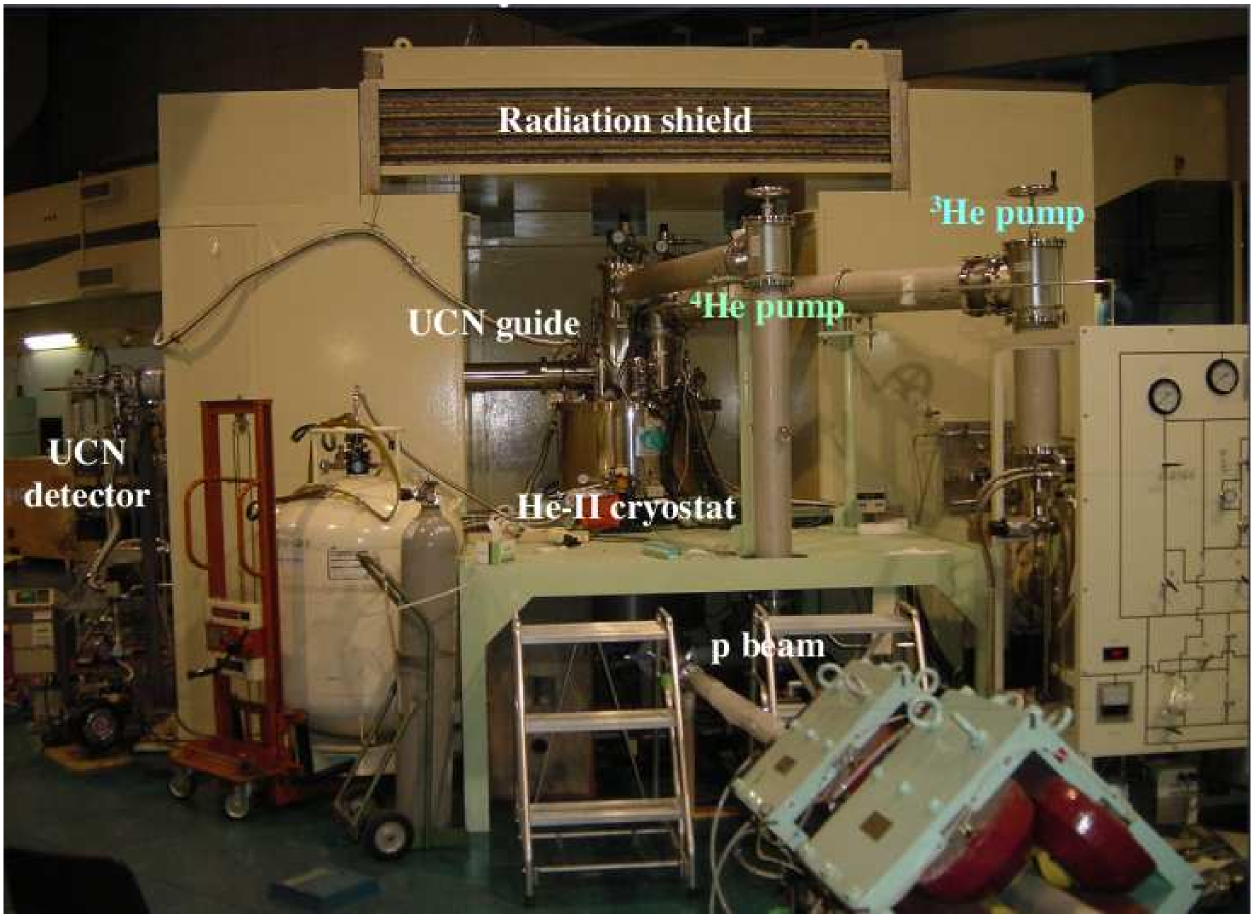

Figure 5: Y. Masuda's UCN source at Research Center for Nuclear Physics, Osaka.

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Report on UCN workshop at TRIUMF

Many of these collaborators were attracted in the context of the "International Workshop: UCN Sources and Experiments" which was held Sept. 13-14, 2007 at TRIUMF [28], and was supported jointly by TRIUMF and NCSU/TUNL (Triangle Universities Nuclear Laboratory). The organizing committee was chaired by J.W. Martin. The program of the workshop focused mainly on the comparison of our eventual UCN source at TRIUMF with those proposed at other institutes world-wide: ILL, FRM-II (Munich), NCSU, LANL, PSI, KEK, and Mainz. Several sessions were held where opinions of the community were solicited, specifically in relation to the project at TRIUMF.

The consensus arose from the worldwide UCN community that a spallation-driven superthermal source of UCN, based on production from superfluid He, should be pursued. Currently, the only group in the world working on such technology is Y. Masuda's group in Japan. In Canada, TRIUMF, with its availability of high-current proton beam, is therefore uniquely poised to take advantage of this new development in UCN source technology.

Fundamental physics and materials science experiments planned for these sources were also discussed. While the top priority for the field is the precise determination of the neutron EDM, the gravity and UCN lifetime experiments were regarded as excellent and timely physics goals. Additionally, a UCN surface physics apparatus was discussed and new applications in nanotechnology "molecular rotors" were reported. Such innovation might also one day be pursued at CSUNS. Overall, the workshop was an astounding success, and confirmed that the CSUNS project is on the right track.

Partnership with Acsion Industries

Discuss.

References

[28] The workshop agenda and presentation materials shown at the workshop are available from the following web address: http://www.triumf.info/hosted/UCN/agenda.htm.

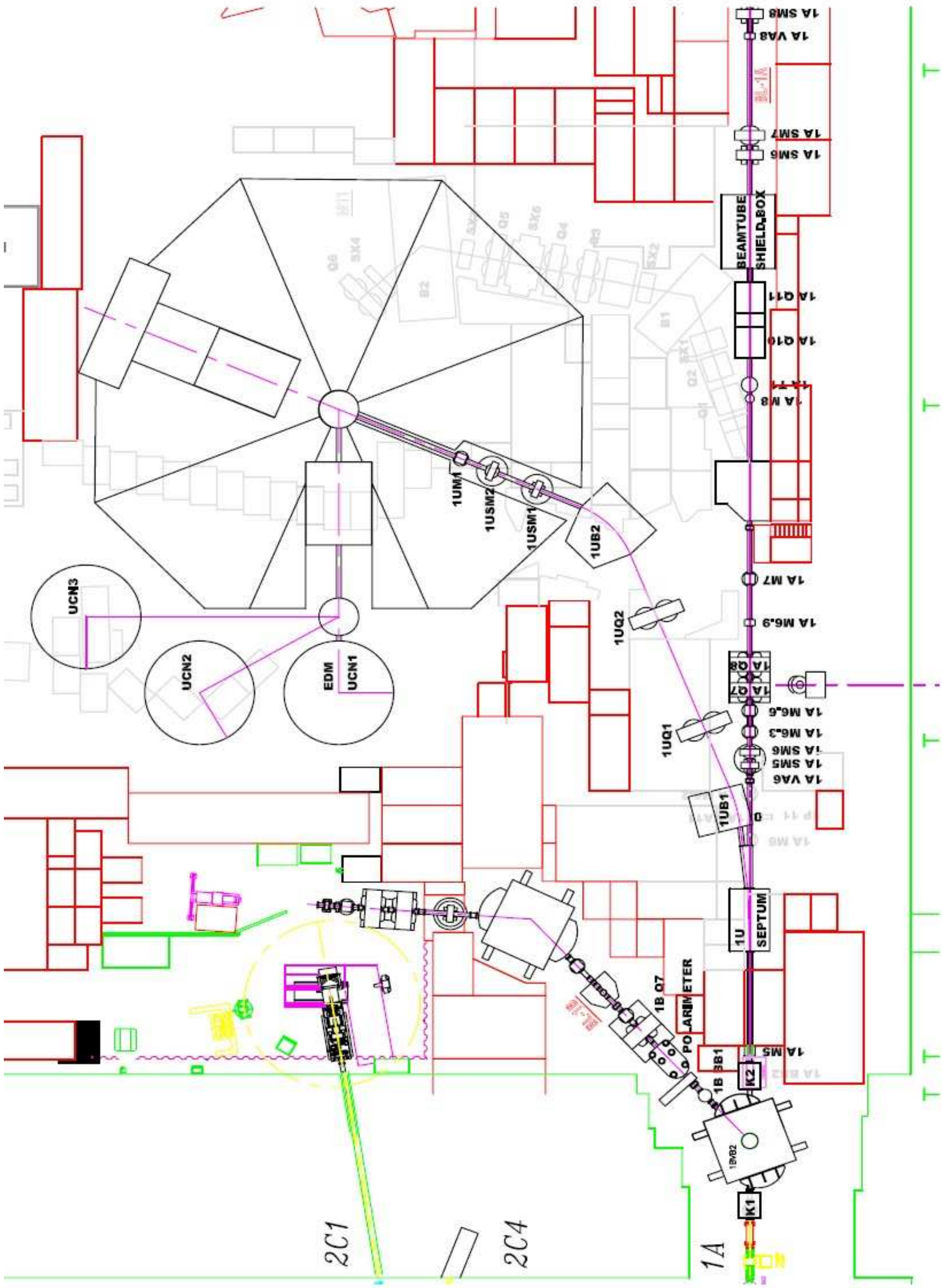

Figure 6: Floorplan indicating the location of the UCN facility in the Meson Hall at TRIUMF.