Proposal for TRIUMF Commitment (5YP 2015-2020)

Date:
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PROJECT/COMMITMENT TITLE: Fundamental symmetry studies with laser-trapped francium atoms

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PROJECT DESCRIPTION:

Physics with laser-cooled and trapped francium, in particular tests of fundamental symmetries, is one of the primary motivations for the actinide target program ISAC. Three experimental programs have been awarded shifts by the EEC: *E1010 Hyperfine Anomaly Measurements in Neutron Deficient Francium Isotopes*, *S1065 Weak Nucleon-Nucleon Interactions by Parity Non-Conservation Measurements in Francium*, and *S1218 Towards an Optical Parity Violation Experiment in Francium: Spectroscopy of the 7s-8s Transition*.
The francium project has a dedicated beamline at ISAC I, ending in an electromagnetically shielded, environmentally controlled room, the francium trapping facility (FTF), housing several high-end laser systems. In September 2012, we successfully commissioned the facility by laser-trapping francium isotopes 209, 207, and 221 with good efficiency and reliability. This allows us to go ahead with the physics program in November 2012, at first measuring hyperfine anomalies in a series of isotopes to study the distribution of nuclear magnetism inside these nuclei. The project is operated by the international FrPNC collaboration that has extensive expertise in atomic physics, quantum optics, radioactive beams, nuclear physics, and fundamental symmetries tests.

SCIENTIFIC JUSTIFICATION:

Francium, the heaviest alkali atom (Z = 87), possesses a unique combination of structural simplicity due to its single valence s-electron and a great sensitivity to effects such as atomic parity non-conservation (APNC) and possible permanent electric dipole moments due to its high nuclear charge. The attractiveness of Fr for APNC experiments has been discussed since the early 1990s in the context of searches for 'new' physics beyond the Standard Model (SM). APNC arises from the parity-violating exchange of Z-bosons between electrons and the quarks in the nucleus, leading to a mixing of atomic levels of opposite parity. As a result, otherwise forbidden electric dipole transitions can be excited between states of the same parity, and parity-violating electron quark couplings can be extracted. APNC scales with the nuclear charge roughly as Z^2 N, favoring experiments in heavy atoms, but a successful extraction of the weak interaction physics from the measured atomic quantity also requires a detailed understanding of the atomic wavefunctions. The atomic theory of Fr can be understood at a level similar to that of Cs (Z = 55) where the best measurement so far has been done, yet the APNC effect is almost 20 times larger.
Even in the LHC era, low energy experiments have an important role to play in the search for physics beyond the SM. For example, when new states are discovered at the LHC, it will be

important to know their couplings to the first generation of particles. Electrons and muons can be distinguished in the LHC detectors, but up/down quark jets cannot be separated from jets of other generations. APNC and other low-energy experiments are in a unique position to assist with this question. Recently, in an effort to explain the deviation observed in the anomalous magnetic moment of the muon, Marciano et al. have postulated a light (10-500 MeV), "dark" Z-boson, to which APNC possesses extremely high sensitivity, that couples weakly to the electromagnetic current and mixes with the SM Z boson [Davoudiasl et al., PRL 109, 031802 (2012)]. It should also be noted that different low-energy experiments such as APNC, Møller, and Qweak, have very different sensitivities to various extensions of the SM.

The plan of S1065 is to measure anapole moments in francium isotopes, a consequence of parity-violating nucleon-nucleon interactions inside the nucleus. Data on this phenomenon is extremely sparse, and we intend to use a new method relying on precision microwave spectroscopy.

RELATIONSHIP TO BROADER CANADIAN RESEARCH COMMUNITY:

There are strong connections to the Canadian research community both in terms of the facility/experimental techniques as well as in terms of the physics. One of the Canadian members is based at Manitoba, as well as a graduate student. Through adjunct status, the TRIUMF members are planning to supervise a UBC grad student. A co-op student will join the team in early 2013. We have tight relations with TRINAT and the collinear spectroscopy group, with graduate students and collaborators from UBC and McGill. From a physics point of view, there is strong overlap with the electron scattering group at Manitoba/UNBC, which investigates parity violation with very different techniques, yet similar goals. Canadian universities are also well represented in terms of theory, e.g. S. Godfrey at Carleton and P. Blunden at Manitoba, who actively work on APNC related topics, also A. Czarnecki at Alberta. The francium effort fits very well into the core program of TRIUMF/ISAC - carrying out cutting edge work at the forefront of radioactive beam science - and makes use of a core capability, the actinide target that can deliver very large quantities of isotope-separated, clean beams of francium. TRIUMF is a unique place world-wide for this work.

From an international point of view, there are groups working on francium trapping, at Legnaro, Italy and in Sendai, Japan. Among them, the TRIUMF project is currently most advanced. In terms of parity violation measurements, there are several groups world-wide that try to carry out next-generation APNC measurements, both in stable and unstable atoms, such as Yb at Berkeley, Ba^+ in Seattle, and Ra^+ in Groningen. Anapole measurements in molecules are in preparation at Yale and in Groningen. At this point, the community is more collaborative than competitive, freely exchanging information and ideas.

BROADER IMPACTS:

In terms of people and knowledge, project like the francium effort have a big impact, in the sense that they provide some of the highest quality scientific training for students and postdocs, in fields that also have a serious economic impact. The HQP gets extensive exposure to high-end laser equipment and state-of-the-art electro-optics and microwave/RF technology as used in the communications industry. The trapping apparatus requires ultra-high vacuum conditions at the 10^{-10} mbar level. The relatively small size of the collaboration requires that all HQP become familiar with all these aspects of the project, leading to very broad training in fields associated with the high-tech economy.

MAJOR MILESTONES:

Description	Date
Commissioning of the francium trapping facility	Sep 2012
Begin of the physics program (hyperfine anomalies)	Nov 2012
Installation and commissioning of the "science" trap chamber	summer 2013
Begin of micowave anapole and optical 7s-8s spectroscopy experiments	fall 2013
NSERC Fr project grant renewal	2015
First anapole microwave measurement results	2014-2015
First 7s-8s spectroscopy results	2014-2016

RESOURCE REQUIRMENTS:

CASH FLOW REQUIREMENTS						
\YEAR SOURCE \	ONE	TWO	THREE	FOUR	FIVE	TOTAL
TRIUMF	10k	10k	10k	10k	10k	ca 100k
EXTERNAL	350k	350k	350k	350k	350k	ca. 2000k
TOTAL	360k	360k	360k	360k	360k	2100k
TRIUMF NON-CASH RESOURCES						
\YEAR RESOURCE\	ONE	TWO	THREE	FOUR	FIVE	TOTAL
Tech-Elec-Design	4 FTEW	4 FTEW	4 FTEW	4 FTEW	4 FTEW	
Tech-Elec-Assembly	2 FTEW	2 FTEW	2 FTEW	2 FTEW	2 FTEW	
Te-Ma-Manual machining	2 FTEW	2 FTEW	2 FTEW	2 FTEW	2 FTEW	
Te-Mech-Design	2 FTEW	2 FTEW	2 FTEW	2 FTEW	2 FTEW	

EXTERNAL FUNDING INFORMATION: Currently, operating support is via NSERC ($145k/a until 2015) and NSF ($139k/a until 2012, renewal in progress). DOE equipment grant for 2010-2014 (total around $800k), NSERC RTI $147k, 2012. Expect modest increase of operating funds in next funding period, occasional RTI.

ONGOING OPERATIONAL REQUIREMENTS: By 2015, the infrastructure for the Fr experiments will have been essentially established. At this point, progress will be made in the laser/microwave/electronics setups which will not require much support from TRIUMF. Occasional machine shop and electronics shop work is anticipated, also HVAC maintenance.

DECOMMISSIONING REQUIREMENT: No particular decommissioning needs; the optics/electronics/microwave equipment will be retrieved by the owners. The contaminated beamline section is small and can be dealt with in a standard way. The electromagnetically shielded room is a permanent, high-quality, structure that could be used for other purposes in the future.

Accepted: Date: