1. Summary of project:

The project has been started in April 2011, with the conceptual design and first test installations in August 2011. The construction was finished in May 2012, followed by detector tests with radioactive sources. First signals from proton and other ions in the complete installation were obtained, starting from mid-August 2012. The next year was spent with the installation of the second detector arm that is supposed to normalize the intensity of the ion source, and investigations to characterize the stability. In the last year, it was found that insertion of a known gas – hydrogen for the use as an ultra-stable proton source, and helium, nitrogen, or deuterium for the use in the lab, requires a redesign ion source. This ion source has been built over the summer, and will be operational in the next few weeks. Multiple students have gained experiments with current research equipment while working on the project.

2. Costs:

The total project costs (not including salaries) to date are about $100k, out of which $16,824.40 were charged to Jefferson Trust in the reporting period ending in September 2012, $4,671.64 in the reporting period ending in October 2013, and $16,324.04 in the reporting period ending in September 2014.

3. Project completion

The project is behind the original schedule. We are still working on the stabilization of the proton source which is needed to use it for the characterization of the proton detector of the Nab experiment. Peter Carr, a summer student, who obtained a departmental fellowship for his work
at the ion source, has made a measurement plan for the use in the intermediate lab. Project completion is expected in one year.

4. Available balance:

A budget of $50k that has been approved by the Jefferson Trust; out of which about $12k is still available for the project. The main remaining budget items are related to the new ion source and to a DAQ system needed for the proton detector characterization.

5. Successes of the project

In the last year, we have learnt to operate the mass spectrometer / proton source at the design voltage of 30 kV (which is needed for the planned detector tests), and we installed a second detector arm to detect two ion species at the same time. The new setup is shown in Fig. 1, together with the students working on the project. Nicholas Roane presented first results at the Fall Meeting of the Division of Nuclear Physics of the American Physical Society.

Fig. 1: Photograph of the proton source. From left to right: Americo Salas Bacci, Research Scientist, Dane Warner, Peter Carr, Nicholas Roane, all UVa undergraduates and Jan-Phillip Burchert, on an internship funded by the German Academic Exchanges Service (DAAD).
The next diagram (Fig. 2) shows the ratio of the count rate of protons to $\text{H}_2^+$ ions. This ratio confirms expectations from the known cross sections for the ionization processes. The stability of the ratio is already beyond what is known from competing groups, but our goal, 100 ppm/h, is still below that. The purpose of the new-designed ion source is to circumvent the problems uncovered for the first iteration of the ion source: count rate is too low; the ionization region is not well defined. The gas to be analyzed is diluted over the whole vacuum system.

![Image of ratio graph]

**Fig. 2:** Count rate ratio of protons and $\text{H}_2^+$ ions as a function of time.

The purpose of the design and construction phase of the project, apart from the delivery of a working proton source and mass spectrometer, is to serve as a training ground for students. Student involvement is discussed in section 7 and 8.

### 6. Problems

While we are satisfied with the recent results, progress has been much slower than originally anticipated. We do not have a person working full-time on the project – this is good for undergraduate research, but undergraduate students have to take classes besides doing the research.
7. **People working on the project:**

Since project inception, eight undergraduate students and two graduate students worked on the project. The project is supervised by Dinko Počanić, and the PI. Americo Salas Bacci, a postdoc, is very active in mentoring the students.

8. **Student involvement:**

The purpose of a university is education of students, and therefore student involvement in the development is essential to reach the goal for the project. The major part of the development, construction, and testing work has been performed by undergraduate students. The first student was Aaron Ross, who did the detailed design and performance studies, and helped setup the ionization chamber electronics. Ryan Slater worked on the data acquisition system. He and Aaron were the first to put everything together and to get a proton signal. Martin Schlegel performed a series of careful measurements to find the cause of proton flux count rate variations, which he found as the electron flux from a filament. Carl Whittaker constructed the second arm, and operated the system at the design voltage of 30 kV. Nicholas Roane took the data shown in Fig. 2, and worked on the stability. Panaiot Zotev has installed a magnetic field probe that can be used to stabilize the magnetic field in the bending magnet. Nicholas Roane has characterized beam fluctuations in the second detector arm. David van Petten has performed simulations of the new ion source with finite element software (COMSOL). Dane Warner has constructed a readout module for the electron current. Peter Carr has built the hydrogen gas handling system, has studied hydrogen safety. He has made a measurement plan for the use in the intermediate lab, and has performed some of the proposed measurements. Jan-Philipp Burchert has written the last version of the control software, and has performed the latest measurements with hydrogen.

For Aaron Ross, Carl Whittaker, Panaiot Zotev, David van Petten and Dane Warner, their work was/will be topic for the course PHYS 3995 (Research).

9. **General Impact:**

The students involved in design and construction gain technical experience and hands-on training on modern scientific equipment, and scientific data treatment and analysis. Several students learnt how to use the leading general purpose data acquisition system, Labview. The students in
my lecture about Electricity and Magnetism (PHYS 2610) benefit from a demonstration of how the topics we discuss in class can be used to do real research.

10. Impact on University

The work on the proton source impressed the German Academic Exchange Service (DAAD) sufficiently to provide funding for a research internship for a German undergraduate student for the second time, and we were happy to host Jan Philipp Burchert from the University of Goettingen. In this way, the project furthers international exchange.

11. Plans for continuation after completion

We anticipate the use as a lab experiment in 2015. While the stability of the proton current is no major concern here, we have to invent and document a measurement program for students who use the source as an intermediate or advanced lab.

Furthermore, the PI will use it in his research to characterize silicon detectors. Dinko Počanić, and the PI, have obtained funding from the NSF (National Science Foundation) for this purpose.

Sincerely,

Stefan Baessler
Physics Department