Short Minutes of the BVR 52

Meetings of 25 – 29 January 2021

1 Meetings of the Committee

closed meetings:	Wednesday, January 27, from 15:30 – 16:45 Thursday, January 28, from 15:30 – 19:30
present:	L. Baudis D. Bryman G. Colangelo C. Curceanu B. Filippone (chair) G. Greene C. Hoffman P. Kammel St. Passaggio M. Ramsey-Musolf P. Riedler B. Sauer A. Signer (secretary) U. Uwer
beam time coordinator:	St. Ritt
ex officio:	K. Kirch A. Amato
apologies:	none

2 New Proposals

The committee has received two new proposals, a letter of intent and several test-beam requests. Some beam-time slots allocated in the previous year were severely disturbed due to the pandemic situation.

R-21-01.1: Search for neutron to mirror-neutron (N.J. Ayres *et al.*)

The committee supports the continuation of the mirror neutron search in the UCN Area West. The proposed experiment offers some discovery potential as well as providing a useful input for the n2EDM apparatus, e.g. by exploring possible anomalous UCN losses. The committee recommends the allocation of the requested beam time with the proviso that the mirror neutron work must not impact progress on the n2EDM effort in any way. This not only

includes allocation of beam time, but also the use of any other PSI resources.

R-21-02.1: Search for a muon EDM (P. Schmidt-Wellenburg *et al.*)

The committee is intrigued with the idea of greatly improving the sensitivity to the muon EDM as discussed in this LOI. The concept, with the potential to improve the sensitivity by three orders-of-magnitude, is a big step in the search for fundamental particle EDMs. Several technical approaches were presented in the LOI and it appears that the proponents are close to convergence on the conceptual design. Of course there are significant challenges ahead, both in designing a feasible experiment and in understanding systematic uncertainties. The committee looks forward to a future full proposal that presents a compelling science case for this experiment and the path to even greater sensitivity as well as providing a detailed technical design for the experiment. Allocation of the requested beam time of 1 week at πE1 is recommended.

R-21-03.1 Diamond anvil muon catalyzed fusion (A. Knaian *et al.*)

The committee welcomes a new group who proposes a novel idea based on a diamond-anvil pressure cell to significantly increase the parameter space studied in muon catalyzed fusion with respect to pressure and temperature. However, we feel that the readiness of the hardware as well as the supporting simulations proving the feasibility of the approach and its systematic uncertainties, in particular regarding the difficult, yet important sticking measurement, have not reached the full proposal level. We recommend a staged approach to first establish basic experimental parameters, like beam tunes, stopping rate and background levels with a simplified set-up, which will inform the simulations and final experimental design. It is also important that the group interact closely with PSI on safety issues associated with gas handling for both the deuterium and tritium phases. They should also consider strengthening the collaboration with some muon-beam expertise and should consider having a serious presence at PSI in advance of the beam time in order to make best use of their data-taking time. Following this a detailed proposal, based on the experience acquired, is encouraged for the next BVR. This proposal should include a detailed discussion of the technical design of the experiment, the status of the needed hardware and a full Monte Carlo simulation of the detectors and apparatus including both signal and background estimates such that the required sensitivity is demonstrated. The collaboration should provide a readiness report to PSI in August which describes the readiness of the apparatus and provides details of the measurement plan. The committee recommends allocation of 4 weeks of test beam time for this experiment.

R-20-01.1: Ordinary muon capture as probe of properties of double beta decay (D. Zinatulina *et al.*)

This experiment proposes to use ordinary muon capture as a way to constrain the nuclear matrix elements needed to interpret the results from on-going and future searches for neutri-

noless double beta-decay. The committee remains excited about the opportunity for PSI to potentially play an important role in this issue of critical importance to nuclear and particle physics. As the experiment received no beam time in 2020 due to Covid-19, the committee recommends allocation of the requested beam time.

R-08-01.3: Search for muon catalysed d^{3}He fusion (P. Kravchenko *et al.*)

This experiment aims to measure the rate for muon-catalyzed d^{3}He fusion utilizing the MuSun detector and a sophisticated target gas. Measurement of this rate could be of some astrophysical interest. The 2020 data-taking was not possible due to problems with the kicker that compromised the run. The specific request is for 4 weeks in πE1. It is suggested that the collaboration work to get the kicker set up in advance of the the run to avoid losing additional beam time. The committee recommends approval of this request and anticipates that the collaboration will complete their data-taking for this experiment with this beam time.

Test: Muonium (A. Soter *et al.*)

The committee remains highly supportive of this innovative project to develop a cold, mono-energetic and parallel muonium beam and to explore the possibility to test the weak equivalence principle with muonium. Significant progress was achieved last year in commissioning a beam guide system for implanting muons in a superfluid He surface and designing a detector to separate muonium ejected from this surface from the ubiquitous background from μ^+ decay. However the final step, the verification and characterization of the emitted muonium flux, could not be done because of Covid-19 caused delays in the delivery of required components. The requested 2021 beam time will be used to fully commission the cryogenic muonium detector and to measure and optimize the yield of the new muonium source, which is an important milestone in the project. The committee recommends approval of the full requested beam time and expects to receive an experiment proposal, possibly staged between source development and gravity experiment, for future sizable beam assignments.

Test: microRWELL (G. Bencivenni *et al.*)

The beam time for this request has to be postponed.

Test: PAD-Micromegas (M. Camerlingo *et al.*)

The beam time has been moved to July.

Test: muSR pixel (F. Meier *et al.*)

This test has strategic importance for HIMB and beam time is allocated as requested.

Test: LCNS detectors (M. Loosekamm *et al.*)

The request of 1 week at πM1 can be granted but has to be shifted to July.

Test: CMS diamond detectors (D. Hits *et al.*)

These tests are a continuation from last year. Two times 1 week at πM1 can be granted, but have to be partially moved forward.

Test: DMAPS detectors (L. Caminada *et al.*)

The beam-time request for 1 week at πM1 is granted..

Test: IDEA detector (G. Cibinetto *et al.*)

Since the collaboration cannot move the test to an earlier time it has to be postponed to next year.

Test: VOXES spectrometer (A. Scodro *et al.*)

The collaboration was offered to move beam time to September but as this was not possible for them, the request has to be postponed.

Test: LHCb pixel (O. Steinkamp *et al.*)

As the chip design is not yet completed the tests need to be moved. It is anticipated they get beam time in early 2022.

3 Progress Reports and Beam Requests

R-99.05.2: Search for $\mu^+ \to e^+ \gamma$ (MEG II) (T. Mori, A. Baldini *et al.*)

MEG-II remains at the forefront of the laboratory's muon physics program. Despite many difficulties, 2020 was a fruitful year for the collaboration as they were able to

- repair the beam transport solenoid
- run the experiment in engineering mode both with positive muon and with negative pion beams
- finalize the design of the WaveDream and trigger boards and the tender for their procurement
- operate the drift chamber at full MEG-II beam intensity at the end of the year, albeit only for few days.

Nonetheless, several areas of serious concern remain and need to be addressed:

- the persistent wire fragility of the present drift chamber strongly suggests that the construction of a new and significantly more robust chamber is mandatory

- there is no clear understanding of the onset mechanism for the high corona current that rendered the drift chamber unusable at the end of 2019
- the persistent degradation of the gains of the SiPM and PMT photo-detectors, and the worse-than-design LXe energy and timing resolutions (which would lead to significant degradation of the sensitivity of the experiment) are important issues to be addressed, with a full understanding of the annealing procedure still lacking.

One of the main goals of the 2021 run is to operate and collect data from the full detector, aiming at a short preliminary physics run by the end of the year. We strongly support this. To make this achievement possible, we endorse the collaborations request for a 2 week window of unimpeded access to the upstream side of the Cobra magnet for installation and cabling of the Drift Chamber and the Timing Counter as soon as they are ready (possibly early May, but to be optimized in consultation with Mu3e), as well as an uninterrupted beam time allocation on the πE5 beam line of 21.5 weeks until the end of the 2021 beam time (assuming the upstream install takes only two weeks, otherwise the run should be shortened).

In parallel to the mainstream goals, with no associated beam request, the collaboration intends to use few days of the scheduled maintenance beam shutdowns to start preparations for a quick study of the ^{7}Li(p,e+e-)^{8}Be reaction, where a puzzling anomaly in the e+e- relative angle distribution has been observed at Atomki Lab in Hungary.

Further details will be provided in the MEG subcommittee report.

R-05-03.1: Measurement of the neutron EDM (P. Schmidt-Wellenburg, G. Pignol *et al.*)

Even with the significant challenges posed by the restrictions due to Covid, the collaboration has made significant progress in the construction of the new experiment including installation of the room-sized magnetic shield. Following vendor repairs and detailed B-field measurements, it appears that the performance greatly exceeds the required specifications providing the largest volume of low B fields in the world. Progress was also demonstrated in the construction of the more than 100 Cs magnetometers needed to measure variations in the local B field, adjacent to the measurement cells.

It is anticipated that commissioning of the full experiment could begin at the end of the 2022 run period. All needed UCN time for commissioning or testing is recommended with top priority.

R-12-01.2: Studying the "Proton Radius Puzzle" with μp elastic scattering (MUSE) (R. Gilman *et al.*)

The committee was impressed with the progress reported by the MUSE collaboration. This was particularly notable given the constraints imposed by the Covid-19 shutdown. The committee was also appreciative of the clarity and completeness of the report and presentations.

Particularly noteworthy was the progress in the evaluation of the electron radiative corrections which represent the largest systematic difference in the extraction of a proton radius

from electron vs muon scattering. The collaboration demonstrated their seriousness in addressing this issue by sponsoring a major workshop to consider this issue. The collaboration has also made a significant hardware addition that will greatly assist in the study of these effects. This downstream lead glass photon detector will help suppress initial-state radiation effects by providing a novel diagnostic that has not been available in previous electron scattering experiments.

MUSE has also made significant progress in understanding the detailed characteristics of the input beam. Scans taken at the intermediate focus have been compared with a beamline model and the collaboration is now in a position to make detailed comparison between the model and measurements. The collaboration plans to continue to extend the modeling to understand the origin of a remaining 1.5% discrepancy in quadrupole magnetic fields potentially due to upstream beam optics imperfections.

MUSE has incorporated a modern approach to the survey of detector components that integrates contacting metrology with laser tracker measurements to determine component positions with respect to the PSI beamline survey. Ultimately this survey will incorporate detector data to allow event positions to the requisite 100 um accuracy.

Among other newly reported data, the committee was pleased to see agreement between the holographic representation of the target chamber determined from scattering with the mechanical model.

Under the best assumptions for the resumption of on-site activities and the delivery of components from off-site laboratories, MUSE anticipates that they will be ready to accept beam in September; including the critical repairs/modifcations of the Straw Tube Tracker (STT). Following this, MUSE requests the rest of the 2021 beam time in πM1 for data acquisition.

We recommend that MUSE receives 12 weeks of beam time in one continuous session. We anticipate that this beam time will be used to fully commission all hardware components and demonstrate that MUSE will be ready for dedicated proton radius production running in 2022. The committee anticipates that this readiness will be fully documented in the January 2022 BVR 53 report on MUSE. For this report, MUSE should perform a sufficient degree of analysis on real data, including tracking, timing and PID systems as well as beam transport properties, to clearly demonstrate that they are of sufficient quality to provide a determination of the proton radius at the requisite level of sensitivity. The collaboration should also provide to PSI a readiness report in summer indicating the hardware and personnel readiness for data-taking in September.

R-12-03.1: Search for the decay $\mu^+ \to e^+ e^- e^+$ (Mu3e) (A. Schoening, St. Ritt *et al.*)

In the search for charged lepton flavour violation, Mu3e is unique in addressing the $\mu \to eee$ process, and complements the worldwide high priority program on the other reaction channels at PSI, Fermilab (US) and JParc (Japan). As Mu3e, in its final phase, requires two-orders of magnitude higher muon flux than is currently available, it is an important scientific driver for the future HIMB project; also discussed at this BVR.

The collaboration has made significant progress in 2020. The magnet was delivered to PSI

by Cryogenics Ltd and passed all acceptance tests in November. The Mu3e Technical Design Report provides an impressive compilation of all technical aspects, and will be published in NIM shortly. The full-sized MuPix10 chip was delivered in May and is working, albeit with problems. The production readiness of all systems has advanced, though slowed down by Covid-19, which did not allow for the planned 2020 integration run with beam at πE5.

The new MuPix10 chip improved upon the performance of MuPix8 in several important respects, including the final larger sensor dimension, reduction of analog cross talk by an order of magnitude, improved pixel threshold tuning and additional features. However, it also showed some unanticipated issues with the differential control bus, inferior time resolution, slower system clock and low breakdown voltage after thinning to nominal 50 μm. The submission of a new sensor MuPix11 is planned for Q2, 2021, but the committee recommends not to rush this production, as long as the issues with MuPix10 are not understood.

Significant progress was made in the He gas cooling system, by reducing the complexity of the circuit. Successful tests were performed with a heater mock up using a new turbo compressor. This novel cooling system still defines the critical path. The collaboration requests beam time in πE5 and πM1. The committee considers the following requests most important and recommends their allocation with priority:

πE5: commissioning of the beam line with the new magnet.

πE5: Mu3e integration and commissioning run with prototype of all components.

πE5: irradiation studies of SiPMs, electronics and polyamide.

πM1: SciFi tests

The πM1 request (SciFi) for one week in weeks 45-50 was withdrawn by the collaboration based on news that the MuTrig2 electronics will be ready and tested already during the integration run. As regards the request for 2 weeks of Mupix11 tests, the collaboration should report its readiness to PSI in August, which could allocate additional beam time in case it becomes available. The allocation of the full requested πE5 beam should be coordinated by PSI according to the following considerations. MEG requests two weeks of installation time in May with the walls to the Mu3e upstream area removed, preventing beam delivery to Mu3e. The exact timing of this break depends on the MEG drift chamber readiness. The committee recommends optimizing this timing, so that the downtime is also beneficial for Mu3e. The lost time should be appended to the subsequent Mu3e beam time such that the collaboration receives their requested allocation. Further details will be provided in the Mu3e subcommittee report.

R-16-02.1: Hyperfine splitting in muonic hydrogen and helium (HyperMu) (A. Antognini *et al.*)

The committee acknowledges the good progress made by the collaboration in 2020 on the laser system and cavity. In particular, the collaboration developed an injection seeded TDL oscillator capable of delivering laser pulses up to 25 mJ, within a latency time shorter than

1 μs and a pulse-to-pulse stability of 2%. Various cavities were developed and tested with a prototype setup to assess the cavity's performance. The committee congratulates the collaboration for the patent declaration (December 2020), based on their work on the laser system, in the field of nonlinear optical frequency conversion that allows to extend the availability of high-power lasers to a wavelength region where they were not previously available, and for the acceptance of the Nature paper: "Measuring the α-particle charge radius with muonic helium-4 ions". While continuing laser and cavity developments in 2021, together with the test of the down-conversion stage, the collaboration requires 12 days of beam time for measuring the muon beam rate and the electron contamination at the different locations just after the triplet following the separator and at the end of the CMBL. The committee supports and recommends a two week beam allocation between the end of the Mu3E run and the start of the MEGII run.

R-19-01.1: Muonium laser spectroscopy (Mu-Mass) (P. Crivelli *et al.*)

The group proposes to accurately measure the 1S-2S transition in Muonium leading to a ppb determination of the muon mass, and also perform related QED tests including measurement of the Muonium Lamb shift. The immediate goals represent 2 orders of magnitude improvement with further progress possible. Good progress has been made on developing the high power CW 244 nm laser system; 20 W circulating power has been achieved with hour-long stability and further stability improvements are ongoing. In previous measurements (2020) the 2S state was detected and bound electrons from Muonium were observed in coincidence with positrons. Other experimental aspects required for the measurements have been readied including the frequency reference system. In 2021, the group proposes to do the Lamb shift measurement and initiate the 1S-2S measurements. While the request is for the LEM beam and outside the scope of this committee, the objectives of this experiment and the beam-time requests are strongly supported.

4 Miscellaneous

Due to Covid-19 the meeting was held remotely and extended to a full week.

5 Next Meeting

The next meeting (BVR 53) is again planned as a 3-day meeting and will take place from 24–26 January 2022 which will be extended to 28 January in case the meeting is remote. The deadline for proposals and beam time requests is 10 January 2022.

April 16, 2021 B. Filippone, A. Signer