Short Minutes of the BVR 55
Meetings of 05 – 07 February 2024

1 Meetings of the Committee

closed meetings:	Tuesday, February 06, from 09:00 – 12:30 Wednesday, February 07, from 09:00 – 12:00
present:	L. Baudis G. Colangelo C. Curceanu B. Filippone (chair) G. Greene C. Hoffman M. Iodice P. Kammel M. Ramsey-Musolf B. Sauer A. Signer (secretary) U. Uwer
beam time coordinator:	St. Ritt
ex officio:	K. Kirch
apologies:	D. Bryman P. Riedler

2 Overview

In addition to beam requests for ongoing experiments and student practical lab courses as well as reports from ongoing experiments, four new proposals and three test-beam requests were submitted. Due to high demand on beamlines πE1, πE5, and πM1, not all beam requests could be accommodated. Thus, the committee has recommended a number of adjustments and reductions as outlined below.

3 New Proposals

R23-01.1: τSPECT (M. Fertl *et al.*)

This experiment proposes to use a large UCN magnetic trap to make a precise measurement of the lifetime of the free neutron. In the last year the collaboration has transported the τSPECT device to PSI and installed and tested it on the UCN West port. As the neutron

loading and storage used here differs from earlier experiments, this will be an important check on systematic effects.

The committee is happy to recommend approval for a new high-impact experiment being developed for PSI's UCN source and recommends the requested beam time. It is understood that this activity should not interfere with the commissioning and running of n2EDM. The committee looks forward to hearing details on systematic uncertainties and the stability of the UCN loading normalization.

R23-02.1: QUARTET (B. Ohayon *et al.*)

QUARTET proposes high-precision measurements of the 2p to 1s X-ray transitions in light muonic atoms. This multi-year program should lead to a factor 10 improvement in the charge radii of several light elements. In 2023, QUARTET conducted a test run, successfully operating the detector system on the πE1 beamline. The system's capability to operate successfully for over 90% of the time was demonstrated, together with the achievement of outstanding resolution from the metallic magnetic calorimeter (MMC). Progress was also made towards understanding systematic effects through a simultaneous measurement of muonic atoms with a mixed-isotope lithium target with both silicon drift detector and MMC detectors. The committee acknowledges these accomplishments, approves the QUARTET experiment, and recommends allocating up to two weeks of beam time at πE1.

R-23-03.1: ReferenceRadii (T. Cocolios *et al.*)

The collaboration had a productive test run in 2023 to determine the nuclear charge radii in a number of Cl, K, and Ag isotopes. The challenge is in the preparation of the samples. They have also demonstrated the ability to study samples as small as 5 μg, which widens the range of possible targets. However, data collection could be several days per sample as opposed to a few hours for mg scale targets. The collaboration now proposes to measure isotopes of La and Lu in 2024.

It has been suggested that it would be ideal to schedule these measurements immediately after MIXE and before QUARTET to ensure efficient transition between the setups. Given the significant oversubscription on πE1, the committee recommends one week of beam time for this experiment.

R24-01.1: X-lent (J. Collar *et al.*)

This new proposal aims to search for new long-lived, low-velocity neutral bosons X via the decay mode $\mu^+ \to e^+X$. This decay has been explored previously via the observation of the (Michel) positron spectrum, looking for a superimposed monochromatic peak determined by m_X, the mass of the new X boson. So far, the sensitivity has mainly been limited by the energy resolution of the calorimeters employed and by the background due to the Michel positrons.

The proposed search plans to overcome these limitations with much better energy resolution, by using a high-purity Ge detector as a μ^+ stopping target and e^+ detector, with a

muon telescope providing the trigger for the measurement in the Ge detector. The proponents performed a test run at TRIUMF with a small n-type detector. With a two-day exposure to the beam an upper limit on the branching ratio (BR) for $\mu^+ \to e^+ X$ with $m_X \gtrsim 100\,\text{MeV}$ of around 10^{-5} was found.

At PSI the plan is to increase the sensitivity by using a larger, dedicated p-type Ge detector as a 'beam dump' for low kinetic energy antimuons at the μE1 beamline. They also need to maximize the efficiency of detecting the full energy deposition of positrons up to 20 MeV and minimize backgrounds due to partial energy loss by the positrons. At higher positron energies (smaller m_X), radiative energy losses limit the applicability of Ge detectors as the stopping target.

The collaboration requests one week of beam time at μE1, to reach a value for the BR of 10^{-7} for sufficiently large m_X. The committee recommends approval for the requested beam time and the proponents are encouraged to seek collaborators at PSI.

Test: RadLength (S. Koch *et al.*)

This test beam request aims to determine the material budget of ATLAS ITkPix and CMS CROC pixel detector modules using multiple scattering of low-energy ($\sim$ 100 MeV) positrons. The method has been demonstrated in an earlier campaign at PSI and at CERN. Due to the overbooking of the beamline only 1 week at πM1 is recommended.

Test: IOV1 (M. Losekamm *et al.*)

This request aims to test radiation detectors designed to fly on the International Space Station. The proposed test would be undertaken using pions in πM1. Since the beamline is overbooked it is recommended that the request be declined. Any new request for 2025 should include more detail on when the results from these tests are needed as well as a discussion of whether they can be made elsewhere.

Test: μRwell (M. Poli Lener *et al.*)

The proponents aim to study micro R-Well sensors under heavy irradiation to qualify the technology for the usage in the LHCb muon detector. Given the overbooking of the beamline the committee recommends to grant only 1 week of beam time at πM1.

4 Progress Reports and Beam Requests

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

The committee congratulates the MEG II collaboration for significant progress over the last year, with smooth data taking in 2023, the recently published results from 2021 data, and the advances in the analyses for the 2022-2023 data. With the 2023 data the expected

sensitivity reaches the level of 10^{-13}, a factor 5 better than MEG. The expectation for the ultimate sensitivity is $\sim 5 \times 10^{-14}$ after about 70 weeks of data taking.

Details have been provided showing a significant increase in the trigger efficiency from 2021 (80%) to 2023 (90%) and expected further increase in 2024 (95%). All the detectors were running successfully. While the new drift chamber will be not be ready before June, it will only be used if the old one has serious problems. The decrease of the photon detection efficiency of the LXe detector is following the expected trend and the annealing procedure worked well. However, a small leak was reported (without major impact on the experiment) that may need further investigation.

The situation regarding the computing at PSI is still being discussed, following an initial decision to centralize it in Lugano with a 100 Gbit connection. We emphasize that efficient and reliable computing facilities are absolutely crucial for MEG II.

The analysis of the data for the search of the X17 particle is progressing well. Data were collected primarily for excitation of the ^{8}Be state at 17.6 MeV. The unblinding is foreseen for March.

The committee supports a long data-taking period for MEG II in 2024 (July to December) up to the requested 29 weeks to maximize statistics and enhance sensitivity. In light of the interest of the Mu3e collaboration to potentially perform some tests at the end of the run cycle, we ask the MEG collaboration to prepare a short report on the status of the 2024 data-taking by 1st September. Given the advanced status of the experiment, it is not foreseen to continue with the extensive half-day reviews next year.

R-05-03.1: Measurement of the neutron EDM (n2EDM) (B. Lauss, G. Pignol *et al.*)

The n2EDM collaboration has made excellent progress in the last year. They have delivered spin polarized UCN to the EDM cell and performed their first Ramsey spectroscopy. The neutron detectors are working with high efficiency and low background. The uncorrected Ramsey spectra demonstrate the excellent magnetic field control and stability of the new apparatus. A magnetic gradient was observed, probably due to a change in position of the EDM cell coils relative to the shield. This can be compensated with the existing gradient coil system. The Hg and Cs magnetometry systems are behind schedule, but there is a realistic plan to install and commission them by the start of the summer.

The high voltage supply had to be replaced. Currently, a unipolar device with a mechanical switch is used. An automatic switch might need to be integrated into the apparatus.

The unexpectedly low number of UCN stored in the cell is a more serious problem (presently a factor of 6 below expectations). The collaboration is working intensively to overcome this issue. The successful operation of the previous nEDM cell inspires confidence that possible coating problems (causing UCN losses) can be overcome.

The committee recommends the full beam-time request be approved.

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

In addition to providing further input to the proton radius determination using both electron and muon scattering, MUSE provides a unique check on a wide range of physics such as the study of radiative corrections, including details of two photon exchange. As a result, the continuing importance of MUSE is reaffirmed by the committee.

MUSE had extended run time in 2023 and the MUSE team is to be commended for bringing into operation their entire ensemble of detectors. During 2023, they obtained 3×10^9 valid scattering events. This corresponds to about 20% of the envisaged total statistics. Based on this experience, MUSE indicates that they might be able to complete their data collection program with two more years of high quality data-taking in 2024 and 2025.

Despite this success, MUSE operations in 2023 were not without problems and interruptions. Gas leaks in the straw tube trackers, and electronics failures in of one of the GEMs required repair. Excessive humidity in the area required the installation of a tent and dehumidifier. More significantly, an operation failure of the liquid hydrogen target led to overheating that created a leak. Fortunately, the incident occurred while the target was filled with neon. While the target safety systems were not seriously challenged, the incident was significant and precluded subsequent target operations. The target control system has been changed to include a manual override that would prevent a similar event in the future.

The BVR54 committee requested that MUSE provide details on their planned analysis procedure. This was submitted in a timely fashion and provided a thoughtful outline of the analysis plan.

In the subcommittee meeting MUSE presented a blinding scheme that they have also submitted for publication. However the committee is concerned that MUSE has not adequately explained how the blinded data can be analyzed in such a way that they are confident that the unblinded data will yield a physically sensible result. The committee asks that MUSE prepare a detailed strategy describing how the blinded data (or some subset thereof) can be studied. This strategy should describe how such a 'pre-analysis' of the blinded data will provide an appropriate level of confidence such that, when the data is fully unblinded, it will provide physically reasonable results. The committee then requests that this strategy be applied to a suitable subset of data (for example the 2023 data) and the results presented in the form of a report to the committee in advance of BVR56. The committee also asks the collaboration to consider the benefit of having additional independent analyses as a crosscheck in order identify and eliminate analysis errors.

The committee recommends that MUSE be given a total of approximately 5 months of beam time at πM1, split into two blocks of 10 and 12 weeks.

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

The Mu3e collaboration achieved a significant milestone by acquiring 241 wafers of the fully functioning final MuPix11 HV-MAP sensor. This quantity is adequate to fully equip the

stage I silicon tracker, assuming an overall yield of 33% in chip production and installation can be attained. Another notable development was the completion of the tuning for the entire compact muon beam line, reaching the desired rate of $7.5 \times 10^7\,\mu$/s at the target location inside the Mu3e magnet. An important integration run involving two MuPix ladders and a SciFi module proved largely successful.

While 2023 was envisaged as the production year for most detector components, serious issues arose during the preproduction stage. Quality control issues and complications with custom micro-twisted pair cables caused a delay of approximately 9 months for the vertex detectors. These challenges were recently surmounted, and successful transmission over a full vertical slice was demonstrated. Similar delays affected other major systems, including the SciFi tracker, tile counter, and outer silicon tracker, causing them to lag behind expectations. In response, the collaboration revised its schedule, aiming to assemble the full vertex detector by summer 2024, conduct a 3-months cosmic test, and prepare for a beam test within the magnet at the end of the 2024 beam period, incorporating the SciFi and tile modules.

The committee is unwilling to recommend 8 weeks of access to πE1 while MEG is in full production mode. Instead the collaboration is asked to provide, by September 1, 2024 an updated report including the plan for the minimum time requirement for a meaningful vertex detector commissioning run. It is possible the collaboration will also be asked to participate in zoom discussions with subcommittee members the following week. Based on these interactions and a report on MEG's data-taking status, the committee may recommend up to 6 weeks conditional beam time for vertex detector installation and commissioning.

While acknowledging the collaboration's need to install crucial infrastructure, this must be done with minimal impact on precious beam time. The committee recommends close collaboration with PSI management and encourages PSI to give the collaboration sufficient access to service personnel to achieve these goals efficiently beginning as soon as possible during the current shutdown and if not possible, starting after the beam time is completed.

R-14-02.1: muCool (A. Antognini *et al.*)

After successfully demonstrating cooling, the muCool collaboration is now advancing to the next phase of extracting the eV μ^+ beam through a mm-scale orifice. This involves intensive efforts in conceptualization, simulations, and the construction and characterization of new target prototypes. The expanded setup necessitates a comprehensive redesign of the vacuum and cryogenic system.

The complexity of the E-field configuration and the definition of the He density profile after the introduction of a significant mass flow raises concerns about the lack of diagnostic tools. To address this, the collaboration has conducted a thorough set of ANSYS calculations, providing a strong case for the design's robustness.

Considering the ambitious schedule ahead, the committee expresses concerns about timely readiness. The committee recommends 3.5 weeks of beam time in πE1, contingent on a report from a full-system dry run to be delivered 2 weeks in advance of the beam allocation. Interaction with muonEDM regarding the PSC magnet availability will also be important.

R-19-01.1: MuMass (P. Crivelli *et al.*)

The group made significant progress in the production and detection of a 2S metastable muonium beam and the laser technology needed to excite muonium to the 2S state. While no beam time was requested this year, the committee anticipates future requests.

R-20-01.1: OMC4DBD (D. Zinatulina *et al.*)

The collaboration has collected significant data over the past three years, including new data on ^{48}Ti in 2023. The primary challenge now appears to be completion of data analysis. The collaboration has obtained a preliminary result for the muon lifetime in ^{48}Ti and has nearly completed the analysis of previously collected data in ^{76}Se. The committee encourages the collaboration to complete the analysis as expeditiously as possible.

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

This is an exciting opportunity to greatly extend the sensitivity of the muon EDM to BSM physics. The muonEDM collaboration has continued to work on modelling the experiment, while starting to make experimental tests of some components of the apparatus. Some of the major systematic effects to be addressed are the clockwise vs. anticlockwise injection of the muons, and the effect of the magnetic field pulse on the stored muons.

We congratulate the collaboration on the publication of a paper describing systematic effects, and the completion of a PhD thesis. Regarding the beam requests, two of the three beam requests for the coming year are to investigate aspects of component performance and systematic issues. The third request is to investigate changes to the beamline which would allow the muonEDM experiment to share the beam with other experiments. The committee recommends the full request for μE1, 1 week in πE1 and up to 2 weeks in πM1. If the kicker is not ready, the beam time in πM1 and πE1 can be reduced. In addition, the committee expects to set up a subcommittee to perform a half-day review of muonEDM in advance of BVR56.

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

In 2023, the experiment collected and analyzed data on muon-catalyzed fusion in liquid deuterium across various temperatures and pressures, which proved instrumental towards validating the data analysis procedures. Additionally, they made several technical improvements and optimizations in preparation for a series of DD and deuterium-tritium (DT) muon-catalyzed fusion rate measurements spanning a wide range of conditions. Furthermore, the GEANT4 muon-catalyzed fusion simulations developed by the collaboration were approved for inclusion in the GEANT4 2024 fall release.

The series of measurements proposed for 2024 is basically the same as that proposed for 2023 as the anvil cell did not perform properly. The committee notes however, that early this year the collaboration successfully operated the cell as expected and identified the causes of the cell failure experienced in 2023.

The committee continues to strongly encourage the collaboration to carefully evaluate the

sensitivity of their method and to characterize the systematic uncertainties, in particular in determining D-T sticking, by analyzing simulated data through their full analysis chain. The DT measurement campaign remains contingent upon resolving safety issues related to tritium target management, which fall outside the committee's control. The committee expects to discuss future plans based on available information at the next committee meeting, including progress on simulation. The committee recommends allocating two weeks of beam time at πE1 for 2024, provisional to a report showing successful operation of the high pressure anvil target cell in beam-like operating conditions.

R-22-01.1: Studies of rare pion decays (PIONEER) (D. Bryman, D. Hertzog, T. Mori *et al.*)

PIONEER is an approved rare pion decay experiment with a strong physics case. No beam time is requested for 2024.

We congratulate the collaboration on the impressive progress since the last meeting including detector design, simulation framework, development of the low-gain avalanche diode (LGAD) detector, and beam-time tests of a LYSO crystal array as an alternative calorimeter to liquid xenon. The baseline technology for the active target tracker was selected as LGADs. In addition, the sensor R&D as well as the work on the interfaces and electronics is well underway. The seven ton liquid xenon calorimeter was redesigned with the forward cone closed, to provide higher coverage. At present LYSO crystals are still being considered and tested as a compact alternative to LXe. The committee anticipates setting up a subcommittee to conduct a half-day review of the experiment just prior to BVR56 where a variety of questions can be addressed such as:

- What is the path and schedule for deciding between LXe or LYSO?
- How will simulation of optical photons be improved?
- What are the properties to be studied and what are the critical decision points for the photosensors?

R-22-02.1: A next generation atomic physics and gravity experiment using muonium atoms (LEMING) (A. Soter *et al.*)

The committee acknowledges the significant progress made by LEMING in advancing towards addressing the goals of studying gravitational free fall and 1S-2S laser spectroscopy using cold muonium (Mu = e^- bound to μ^+) atoms. Progress during the past year was reported on the cryostat, cryogenic target and entrance detector, and initial commissioning for the phase I experiment.

One notable achievement is the successful extraction of a horizontal Mu beam from a vertical superfluid helium (SFHe) layer using microscopic slits in a Si substrate filled with SFHe.

The Mu beam was emitted from SFHe at temperatures ranging between $80 - 350$ mK. Interestingly, no change in Mu conversion and emission was observed at lower temperatures, although there were indications of scattering effects above 250 mK. Furthermore, LEMING is actively developing a comprehensive Monte Carlo simulation environment and statistical analysis to characterize the diffusion and surface emission processes of Mu in SFHe. Progress has also been made in the development of the atomic electron detector, with perovskite nanocrystals identified as the most promising low-threshold detector material. However, challenges remain in achieving high voltages (> 3 kV) on metal electrode surfaces covered with SFHe.

The primary objectives of the new beam request include optimizing the microfluidic source, commissioning a Si tracker prototype, and demonstrating a functional design for electron detection. The committee recommends approval of the request for 3 weeks at πE1.

5 Miscellaneous

Mauro Iodice (INFN Roma Tre) was welcomed as a new member of the BVR committee.

6 Next Meeting

The next meeting (BVR 56) is again planned as a 3-day meeting and will take place from 10-12 February 2025. The deadline for proposals and beam-time requests is 24 January 2025.

April 11, 2024 B. Filippone, A. Signer