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EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Status Report to the ISOLDE and Neutron Time-of-Flight Committee

VITO setup: Status Report

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Abstract

Versatile Ion polarized Techniques Online (VITO) is a dedicated beamline for producing nuclear-polarized beams and for conducting experiments on a wide range of sample environments at ISOLDE-CERN. The new beamline is a modification of the formerly existing UHV beamline hosting the ASPIC apparatus. Once operational, VITO will open a wide range of possibilities for carrying out versatile and multidisciplinary experiments in the areas of nuclear and solid-state physics, fundamental interaction physics and biophysics. In its final stage the new beamline will provide three end stations: ASPIC, the β-asymmetry end station where highly-polarized ions will be available and an open station for travelling experiments requiring rare polarized atoms (or ions). The bio-β–NMR station will be movable and the same location will also be used for a dedicated β-γ detection station for fundamental interaction studies on highly-polarized ^{35}Ar ion beams. The line will operate in two modes, providing both ion beams and spin-polarized ion beams to all three end stations.

In 2014 the following milestones were successfully completed: the design of the beamline was finalized based on the ion-optical simulation results, the construction of the beamline was launched and finished reaching the first phase of the design allowing the collection of radioisotopes on three separate end stations and the first on-line PAC experiments with two different Cu isotopes were successfully performed.

1. Motivation, experimental setup and technique

The Versatile Ion-polarized Techniques Online (VITO) setup is a medium scale experiment permanently installed at the RB0 line situated in-between the WITCH platform and the central beamline in the low-energy part of the ISOLDE experimental hall, as shown in Fig 1. The VITO beamline is a modification of the former Ultra High Vacuum (UHV) beam line hosting ASPIC (RB0 + RB2).

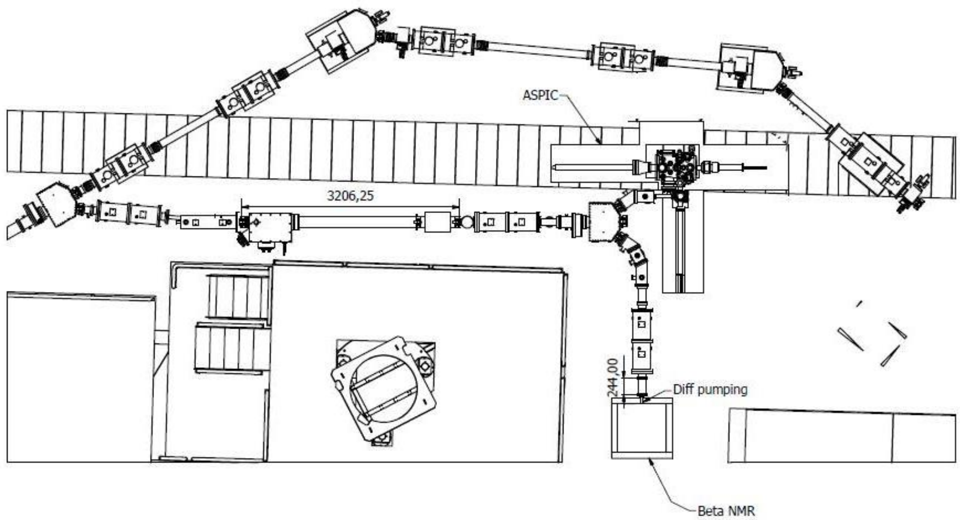


Fig. 1. Implementation of the VITO beamline in the low-energy part of the ISOLDE experimental hall.

The major enhancement of the new beam line is the introduction of laser-induced nuclear spin polarization of isotope beams at the RB0 line, which will allow for a wide range of experiments to be realized at all end-stations.

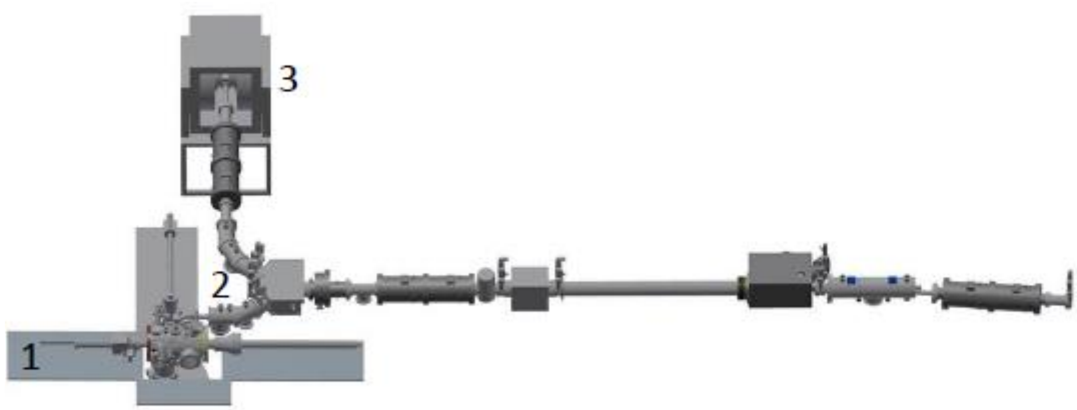


Fig. 2. Layout of the VITO beamline showing the three end stations (in-beam direction): ASPIC apparatus (left), open end (middle) and β-asymmetry line with a visible β-NMR setup (right).

As shown in Fig. 2, the new beam line will provide three end stations after the upgrade is finished: 1) ASPIC end station at RB1 (left) 2) an open station for movable experiments at RB2 (middle) and 3) β-NMR spectroscopy or β-γ asymmetry at the β-asymmetry end station at RB3 (right). The ASPIC station will remain unchanged for Perturbed Angular Correlation of γ-rays

(PAC) spectroscopy on sensitive surfaces and interfaces and only after the second upgrade, intended for 2016, will it be extended for β-NMR spectroscopy in UHV environment. If not occupied, the RB2 station will be used for monitoring spin-polarization during β-NMR or –β–γ asymmetry experiments on the RB3 station. The β-NMR spectroscopy end-station will be equipped with a strong differential pumping system allowing for online bio-β-NMR on liquid samples and online PAC spectroscopy in volatile matter, such as biochemically relevant aqueous solution. The set-up will be removable, so that other experiments requiring highly-polarized ion beams can be installed, such as a highly-efficient beta-gamma detection set-up for weak-interaction studies.

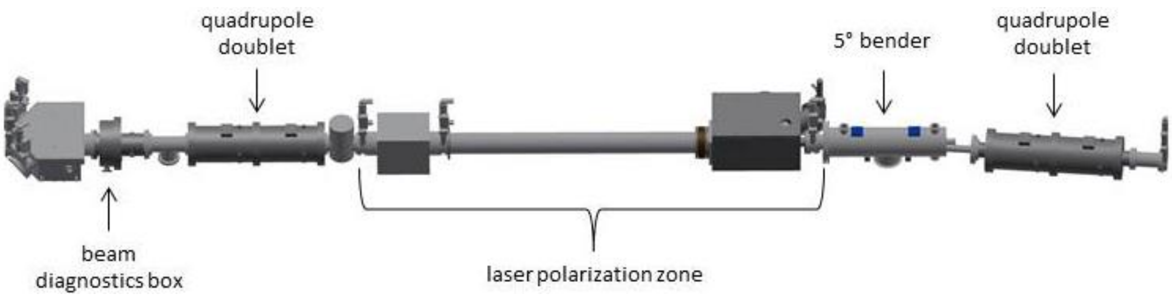


Fig. 3. Breakdown of the VITO beamline.

Fig. 3 presents the breakdown of the VITO beamline. As can be seen, the experimental line comprises of: a 5° beam bender allowing for the introduction of the laser light into the system (designed by M. Bissell, R. F. Garcia Ruiz, A. Gottberg and M. C. Ribeiro Da Silva; built and assembled in the CUNHOL workshop in Portugal), two quadrupole doublets (from the former UHV line) separated by the laser polarization zone (described in detail in the following section), beam diagnostics box (wire scanners and Faraday cups), three automatic VAT valves with interlocks and multiple pumps. The required UHV pumping power is achieved by using four turbo molecular pumps, three titanium sublimation ion getter pumps, two cryo-pumps, and several primary pumps.

Laser polarization zone

The laser polarization zone consists of a charge exchange cell (CEC) a 1.5 m long drift tube that can be put to various high-voltage potentials, and the He re-ionization cell (He cell), as shown in Fig. 4.

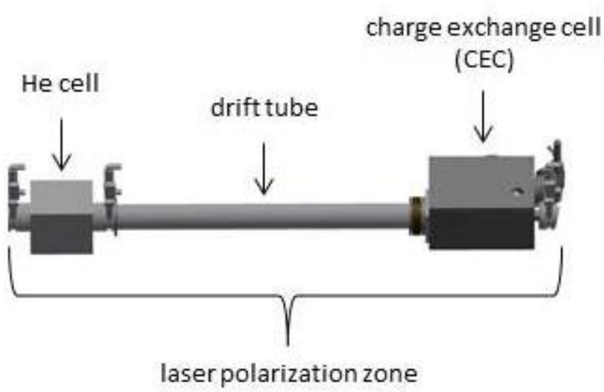


Fig. 4. Laser polarization zone and its components.

The CEC and the He-cell will be used for elements where the polarization schemes are only available for atoms and not for ions. For elements which allow polarization of the ions or experiments which do not require polarized (the majority of experiments) the CEC and He-cell remain off and they will serve as a prolongation of the polarization region. The CEC chamber consists of an alkali vapour cell, beam diagnostics (Faraday cup and a collimator) and five cylindrical electrodes used for tuning the beam velocity. It has been designed by M. Bissell and R. F. Garcia Ruiz for Ca experiments at COLLAPS (IS529) [1] and it will be transferred permanently to the VITO line only when the experiments at COLLAPS are finished. The He-cell will be a copy of a cell used at TRIUMF [2] and once operational it will be filled with He exchange gas.

The Doppler tuning of the beam, to match the desired optical transition, will be provided by five cylindrical electrodes placed between the CEC and at the beginning of the drift tube. In practice this will be done by applying a variable voltage of maximum ±10 kV stepwise to each electrode. However, for experiments with ion beams and spin-polarized ion beams the CEC will remain empty and the four cylindrical electrodes, placed inside the CEC, will be used for adjusting the beam velocity. Optical excitation of ions or atoms will be performed in the drift tube. This insulated interaction region will be kept at a potential different from the post-acceleration region by 200-500 V to avoid unwanted excitations in any places other than the tube itself (similarly as done at COLLAPS). Here the ion beam velocity, and thus the Doppler shift of the desired optical transition, will be fine-tuned. For the technical realization at VITO, this is the easiest way of tuning the optical resonance to the laser frequency. The drift tube and the remaining part of the beam line will be placed in a weak longitudinal magnetic field preserving the created longitudinal polarization.

Lasers for the VITO experiment will in a first phase be provided by the COLLAPS laser system at ISOLDE and therefore will not be taken into consideration in this document. Also, the ASPIC and β-NMR apparatuses have been described previously and therefore are not presented here. Detailed information about both systems can be provided to the INTC committee upon request. The highly-efficient β-γ detection set-up for precision studies on the β-γ in ^{35}Ar decay is currently in a design phase at KU Leuven. A proposal to perform first tests on laser polarization of the ^{35}Ar beam using the COLLAPS beam line has been submitted to the INTC (P-426).

2. Status of the setup (including plans for 2015)

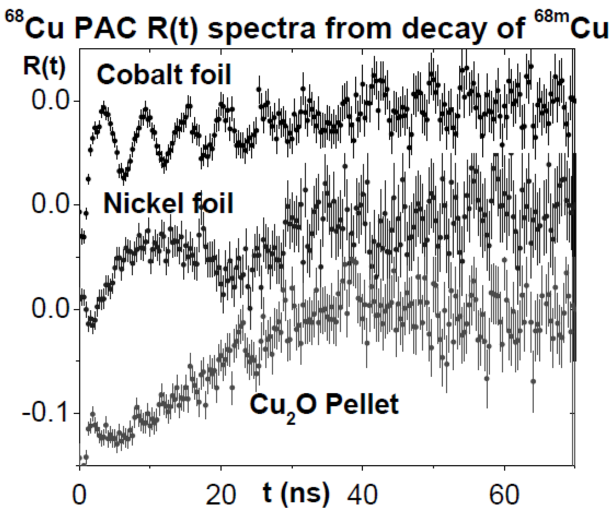
The VITO beamline was approved by the ISCC committee meeting held on 22 October 2013. The former UHV beamline was dismounted in March 2014 and the ASPIC apparatus was moved close to its final position at the new beamline. The first stage of the new beamline – VITO - was finished in November 2014 and the first stable beam was taken 28 November 2014.

The major milestones reached in 2013-2014 were:

1. The VITO collaboration was established and the steering committee was selected. Prof. Manfred Deicher, Prof. Gerda Neyens and Prof. Lars Hemmingsen accepted to lead the collaboration in the first term 2014-2015.
2. A close collaboration with the β-NMR group from TRIUMF (A. MacFarlane, R. Kiefl and G.D. Morris) has been established, resulting in, among others: technology and know-how exchange between our groups and a common MA student project.
3. The final design of the beamline was fixed based on the detailed ion optics simulations including CA0, CB0, the VITO beamline and two end stations (ASPIC and β-asymmetry set-ups). Prior to the simulations the geometry of the entire beamline including both end stations was implemented into the ISOLDE environment and elaborated in detail and a full and detailed set of CAD drawings was created. At the ASPIC collection point the simulation yielded a transmission of 99.8%, with a beam spot of about 1.5 mm x 1 mm. For the bio-β-NMR site, transmission through a set of three 4 mm pinholes (the smallest possible aperture arrangement) was calculated to be about 70%, while during test runs at COLLAPS only 16% could be reached.

4. Missing elements of the beam line were designed and prepared by different workshops. These included: the 5° deflector chamber and deflector plates, the 55° bender to the β-asymmetry setup and the 35° deflector to the ASPIC station. The 5° deflector chamber and benders were manufactured and assembled in Portugal and checked during stable and radioactive tests in the last two weeks of the operation of ISOLDE in 2014.
5. Three research proposals – IS582 [3], IS583 [4] and IS585 [5] - were approved by the INTC committee giving 30 on-line shifts for experiments with polarized beams and 16 on-line shifts for experiments at ASPIC. One more research proposal – P426 – is currently under consideration of the INTC committee (a letter of clarification has been requested for this proposal).
6. The VITO website was published: www.vito.web.cern.ch.
7. Safety files were prepared and the first electrical safety inspection was undertaken. It should be noted that only the VITO line was cleared for conducting experiments. Additional files need to be prepared for ASPIC and β-asymmetry setups. This is currently on-going.
8. The entire beamline was aligned element by element (also inside) with the help of the CERN survey team. The misalignment does not exceed 0.5 mm in any direction.
9. The entire VITO beamline was implemented into the ISOLDE control system and the missing 16 power supplies were ordered. It should be noted that from the operational point of view the VITO beamline is treated as part of the ISOLDE infrastructure and thus the support for the power supplies and beamline operation will be provided by ISOLDE. This meant higher initial effort but should result in more support during operation and the possibility of employing the newly developed tools for automated ion beam tuning. The vacuum system on the beamline is, however, on the experimental side and therefore no support from the vacuum group at CERN will be provided.
10. A CERN Knowledge Transfer Fund grant of about 100 kCHF was obtained for setting up a dedicated β-NMR apparatus for liquid samples. The new chamber and differential pumping system will be permanently placed at the β-NMR end station of the VITO line in 2015.
11. A dedicated VITO publication regarding research possibilities at the new line has been submitted to the physics journal [6] and two related publications have been published [7] and submitted [8].
12. A new PhD student – Stavroula Pallada – was enrolled within the CERN-HERMES program in March 2014. Her project is dedicated to the VITO beamline with a special focus on bio-β-NMR.
13. Abel Fenta – the second PhD student connected to the VITO project – has advance significantly in DFT-based hyperfine interaction calculations as a preparation for on-line measurements with Hg- and Cd ions implanted into 2D electronic structures beams which are planned at ASPIC (IS585).
14. A KU Leuven PhD student (Wouter Gins) and post-doc (Philippe Velten) are in charge of respectively the production of a highly-polarized ^{35}Ar beam (with feasibility study during 2015 on the COLLAPS beam line) and the design and construction of a dedicated highly-efficient beta-gamma detection set-up.
15. The first MA thesis regarding the VITO beamline was delivered by Tomasz Wlodarski at the AGH University of Science and Technology in Krakow, Poland. The project included: the beamline design and implementation into the existing environment respecting the new safety regulations at CERN.

On 28 November 2014 the **first stable beam** of ^{27}Al beam from a surface ion source with energy of 40 keV was sent throughout the entire system. In less than 6 hours a transmission of 96% was reached in the Faraday cup at the very end of the beamline (with secondary electron suppression repelling voltage of -200 V). This was achieved partly by manual and partly by automatic tuning. On 8 December 2014 the transmission could be confirmed with a new set of voltages and with stable, laser-ionized Cu ions. Then the **first short-lived radioactive beam** of ^{68m}Cu ($T_{1/2}$ = 3.75min) was taken to the sample holder mounted inside the quartz finger collection chamber set up at the end of the middle station (RB2). Using the Perturbed Angular Correlation (PAC) technique with FPGA and List mode digital setups, and high resolution $LaBr_3$ gamma detectors the appropriate cascade could be resolved leading to the first ever on-line (and off-line) PAC experiment performed on a Cu isotope. Several PAC time spectra were obtained by implantation and continuous measurement into Ni and Co foils - aimed to probe the magnetic interactions – and Cu_2O and $Y_2Cu_2O_5$ compressed powders - aimed to probe the quadrupole interactions. All spectra were recorded within 12 hours beamtime. In addition, at the end of the beamtime, implantation of ^{61}Cu into Cu_2O was performed for offline PAC measurements of the quadrupole interaction onto ^{61}Ni. Data from this run, three of which are shown in Fig. 5, are being analyzed by two VITO PhD students: Abel Fenta and Stavroula Pallada, from where the magnetic and quadrupole moments of the 2+ 84.1keV, 7.84ns excited (PAC) state on ^{68}Cu should be measured.



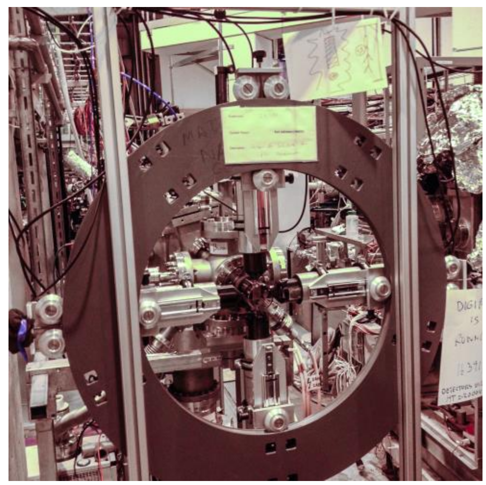


Fig. 5 Left: ^{68m}Cu/^{68}Cu PAC time spectra observable function R(t), as measured on cobalt and nickel foils and on a pressed Cu_2O pellet. Right: the $LaBr_3$ PAC detector setup mounted at the VITO beam line.

The preliminary analysis yields the presence of clear magnetic interactions in the cases of ^{68m}Cu implanted into the Co foil (upper spectrum) and Ni foil (middle spectrum). Possibly combined magnetic-quadrupole interactions are observed for ^{68m}Cu implanted into (hcp) Cobalt that lead to the small beating around 30 ns. Differently, a pure quadrupole interaction is observed for ^{68m}Cu implanted into the Cu_2O pellet (lower spectrum). Still only a fraction of a period is observed, what is fully compatible with the expected small quadrupole moment, but the data is good enough to extract the Q value upon analysis. Some slow trends observed on both the spectra of the Ni and Co foils are due to the implantation distribution of defects, which are not annealed since the measurements were done as-implanted, at room temperature. These first measurements show that ^{68m}Cu is a very promising new PAC probe, especially for studying magnetic phenomena.

The milestones foreseen for 2015:

1. Connecting ASPIC to the RB1. This will require:
   a) Exchange of the main pump connected to the measurements chamber.
   b) Production of the 35° deflector plate, a suitable chamber has been developed and the 3D integration has been performed.
   c) Maintenance of the LEED and Auger spectrometers.
   d) Final alignment of the apparatus at the new location.

2. Setting up the β-NMR end station. This will require:
   a) Production of the 55° deflector plate, a suitable chamber has been developed and the 3D integration has been performed.
   b) Design, production and assembling of the new β-NMR apparatus.
   c) Alignment of the entire RB3 line.
3. Setting up the polarization system at VITO. This will require:
   a) Laser-light transfer from the COLLAPS laser room to the 5° deflector.
   b) Setting up the laser box and mirror system at the line.
   c) Designing and setting up the guiding magnetic field for maintaining the achieved polarization. This will be especially important at the total bend of 90° to the β-NMR end station (35° the bender inside the switchyard and 55° bender right after it).
   d) Connection and testing of the already ordered power supplies for the polarization region.
   e) Commissioning of the polarized beam line, initially using an ion beam (so without CEC and re-ionization cell).
4. Production of the He-cell based on the technical drawings from TRIUMF.
5. Implementation of the vacuum remote operation of the entire beamline (control and interlocks). Remote operation of ASPIC and β-NMR vacuum systems should be considered.
6. Finalizing the safety files and undergoing all remaining safety inspections (electrical and cryogenics).

The milestones listed above are subject to the local microscheduling of Torben Mølholt and Karl Johnston, the new VITO coordinators. The work on ASPIC will be done under supervision of Lino da Costa Pereira from IKS Leuven, Belgium, and the local support of Abel Fenta, Guilherme Correia and Torben Mølholt. The setup of the polarization system at VITO will be done under supervision of Magdalena Kowalska and Mark Bissell. The new bio-β-NMR chamber will be designed and assembled by Monika Stachura, with the local help of Karl Johnston, Stavroula Pallada and Torben Mølholt. The VITO beamline itself will be finalized by Torben Mølholt with a constant support of Monika. Last but not least, the production of the He-cell and the remote control of the vacuum system at the VITO beamline will be done by Monika and Torben.

Experiments planned for 2015:
1. PAC experiments on mono- and low-number of stacking layers at ASPIC: IS585 proposal investigating the interaction and dynamics of add-atoms with 2-dimentional structures.
2. Polarization test with Cu ions within the framework of the IS583, proposal accepted in October 2013.
3. If possible, performing ^{31}Mg β-NMR experiments on liquid samples described in details in the IS582 proposal.

3. Status of already accepted proposals and LOIs

So far no shifts have been taken from the approved experiments (IS582, IS583, IS585). The only experiments performed at the VITO line were the PAC tests with ^{68m}Cu presented to the INTC committee in November 2014 (the proposal currently awaits approval). This beam was chosen as test beam for VITO since it could make the most efficient use of the existing infrastructure in the time available for online tests, while approved experiments required either polarization, a connected ASPIC system, or extended beam time. In addition, the ^{35}Ar proposal – P426 – is also awaiting the final approval of the INTC committee.

References:

[1] CERN-INTC-2014-022 / INTC-P-313-ADD-1.

[2] TRIUMF 1999 Annual Report, contribution by G.D. Morris and R. Kiefl on "β-detected Nuclear Magnetic Resonance at ISAC".

[3] CERN-INTC-2013-033; INTC-P-392.

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[5] CERN-INTC-2013-038; INTC-P-395.

[6] R.F. Garcia Ruiz et al. "Perspectives for the VITO beam line at ISOLDE, CERN"", submitted for publication

[7] A. Gottberg et al., "Billion-Fold Enhancement in Sensitivity of Nuclear Magnetic Resonance Spectroscopy for Magnesium Ions in Solution", CHemPhysChem 15 (2014) 3929.

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