CREMLINplus WP Technical Report – 1st reporting period

Period: 01 February 2020 – 31 July 2021

For the first periodical report we need input from you as WP Leader and Co-leader. We kindly ask you to formulate a summary of your WP progress for the first reporting period (M1-M18) by the given subjects/questions below.

You are free in writing the text. It should be concise and readable. Please write in a clear style, avoiding any abbreviations.
Redundancies should be avoided.

Please use the box below to insert your text. The given subjects/questions give you an idea what is needed.

Technical Report WP5 SCT

1. Objectives of WP5 SCT (as described in Annex 1 of the Grant Agreement)

Aim of this task is to support efforts devoted to promotion of the SCT project in Europe and world-wide

- *To support and develop EU and Russian scientific cooperation in the SCT project*
- *To make an example of good practice on establishing collaboration around Russian RI with extensive participation of EU institutions*
- *To support joint EU - Russian efforts on development of future lepton colliders*
- *To increase visibility of SCT project in EU and world-wide scientific and decision-makers communities*

2. Overall status

- Please describe the overall status of the WP (e. g. specific achievements/successes of WP; Is the WP overall in line with the Objectives?)

Please describe the overall status of the WP (roughly max. 2000 characters excluding spaces).

Input by WP lead:

The Super charm-tau (SCT) factory denotes an electron-positron collider project to perform precision experiments with tau lepton and charmed hadrons and searches for new physics. WP5 fosters the EU-Russia collaboration within the high-energy physics community around the SCT project with an emphasis on novel particle detector technologies required for the SCT detector.

The WP5 tasks are devoted to four frontiers:

1. Internationalization of the SCT project
2. Development of electron-positron collider technologies
3. Development of software for the SCT detector
4. Development of critical particle detection technologies needed to the SCT detector

The 1st point includes dissemination of information about SCT in different ways, including press-releases, dedicated seminars in research organizations and development of the public SCT experiment website. It also includes launching formal collaboration around the SCT experiment as reflected in MS27.

The 2nd point reflects natural synergy in development of future colliders

The 3rd and 4th point constitute the most prominent activity within WP5 and serves as the most powerful driver for collaboration between EU and Russian scientific groups. Five different particle detection technologies are being developed, simulated, and prototyped by the WP5 community.

Communication and cooperation inside the WP5 community is fostered by several measures:

1. Dedicated email lists are established (general, software, and other)
2. Regular general WP5 meetings have been organized:
   a. 28-29.09.2020: https://indico.inp.nsk.su/event/37/
   b. 17-18.02.2021: https://indico.inp.nsk.su/event/44/
   c. 08-09.07.2021: https://indico.inp.nsk.su/event/58/
3. Holding regular meetings within each task (e.g., weekly SCT software meetings)
4. For joint software development two repositories have been installed: a Git server git.inp.nsk.su and a software development server proxima.inp.nsk.su
5. A Wiki server has been set-up as a tool for sharing technical information: https://ctd.inp.nsk.su/wiki

The overall status of WP5 is particularly good despite inevitable delays and restrictions related to the COVID-19 pandemic.

3. Tasks and achievements

- We have listed the WP specific tasks as described in the Description of Action (DoA) (Annex 1 of the Grant Agreement (GA)). Please describe the work carried out during the reporting period towards the achievement of the listed tasks and specify by which beneficiary (if possible).
- Please name highlights as well as unexpected issues.
- Please describe the overlap with other WP or external experts.
- Please comment on Deliverables and Milestones achieved so far. (Please find all relevant Deliverables and Milestones for the first reporting period on the last page of this template.)
- Please finalize each task with a statement that the task is well on track (or something similar along these lines). If this is not the case, please list the task in "5. Deviations" of this template and add the reason for the deviation.
- You may also add pictures/diagrams/scientific data (including a title/brief description) – this will be highly appreciated.

Task 5.1: Fostering internationalization and visibility of the SCT project, support of outreach activities related to SCT

Please describe the work carried out during the reporting period towards the achievement (roughly max. 2000 characters excluding spaces).

Input by WP lead:
Internationalization and visibility of the SCT project is achieved by several measures:

1. Outreach and PR activities
2. Establishing a formal agreement on an international collaboration around the SCT experiment
3. Presenting achievements in detector technologies and advances in the physics case of the SCT experiment at specialized conferences.

All three directions were developed during the M1-M18 period. Outreach activity was concentrated on setting up a new public SCT project website. The first version is available on https://super-charm-tau.herokuapp.com/. In addition, the BINP PR department regularly issues press-releases in which the progress of the SCT and WP5 are reflected (link1, link2, link3 in Russian).

The progress on particle detector technologies, detector software and physics case were presented

- on main professional conferences like CHARM 2020 (link)
- on a dedicated workshop (Joint International Workshop for Super-Charm Tau Facility)
- at an event on strategic planning in high energy physics Snowmass21 (link)
- and on several dedicated seminars in research organizations (LPI, PNPI, JINR). The program of seminars in research organizations suffered from the pandemic situation. The original plan included visiting EU research organizations (INFN institutes, Giessen university and others) had to be canceled, and it was only possible to cover organizations located in Russia.

Establishing a formal collaboration around the SCT experiment is the main objective of this task. Reaching this objective has been delayed partially due to the pandemic restrictions and partially due to the recent development of the status of the SCT project in Russia. Currently, BINP develops a detailed plan of reaching this objective still in 2021. The plan was discussed on the general WP5 meeting in July 2021 and will be described in the forthcoming MS27 report.

In conclusions, global visibility of the SCT project is being gradually increased since the CREMLINplus project started, and the CREMLINplus serves as a good driver for it.

Task 5.2: Development of collider technologies and fostering synergy between SCT, CLIC, and FCC-ee collider projects

Please describe the work carried out during the reporting period towards the achievement (roughly max. 2000 characters excluding spaces).

Input by WP lead:

The scope of collider technologies developments for SCT is far wider than the WP5 objectives. Task 2 of WP5 is devoted to

- fostering interactions between LAL-CNRS and BINP accelerator groups and
- fostering synergy between SCT and FCC-ee collider projects, principally involving BINP and CERN

Launching interaction between LAL-CNRS and BINP groups experienced difficulties related to failures of hiring a post-doc in the LAL-CNRS group. Two attempts were not successful. Therefore, the planned calculation of the double aperture dipole has not started yet. A new hiring attempt was launched, aiming for a candidate to start working in fall 2021.

Interaction between SCT and FCC-ee collider teams has started before the CREMLINplus project and successfully continues. Synergy between the two projects is very natural (e.g., machine detector interface, final-focus (FF) quadrupoles, crab waist collision scheme are similar). WP5 task 2 supports work on optimization of the collider optics to reach satisfactory 6d dynamic aperture. In the SCT collider lattice four wigglers were installed that allowed to decrease damping times from 300 ms to 50 ms at beam energy E=1.5 GeV. We studied degradation of 4d dynamic aperture with crab sextupoles, found that the reason of degradation is interference of nonlinear aberrations from the FF quadrupole fringes, and crab sextupoles. Therefore, we installed decapoles and octupoles in the FF quadrupoles and increased 4d dynamic aperture in horizontal plane from 16 sigma to more than 30. The dynamic aperture in the vertical plane became diminished but stayed sufficient. We increased the length of the FF quadrupoles from 0.2 m and 0.3 m to 0.5 m both and decreased nonlinear detuning from quadrupole fringes by factor of 2. Momentum aperture is still not sufficient providing only 35 sec of Touschek lifetime at low energy, having a full-strength crab sextupole.

The main objective of the task 2 is the design and production of the high-current collider prototype. The design of the collider prototype is finished. Collider lattice with feasible magnets, sufficient 6d dynamic aperture and beam lifetime is available. The technical designs of FF magnets are ready. Due to limited funding, we did not yet proceed with developing this development further.

We analyzed different designs of the radiofrequency (RF) guns investigating the longitudinal and transverse beam dynamics in terms of beam quality (emittance, energy spread, beam length etc). We calculated beam properties with different electric field distributions for the time range right after beam injection (non-relativistic case). The results will be presented in the papers and reports.

In order to study different metallic photocathodes, we made the prototype of the RF gun with standard design and the modulator for the RF stands with the klystron. The modulator consists of the charging line, the thyratron type key, the source of the charging voltage and the transformer. Now we are waiting for the source of the charging voltage and planning the tests with the klystron. Additionally, we are developing the waveguide line to connect the klystron to the RF gun.

We are still developing the stand for the 4th harmonic laser and waiting for delivery of the bought parts.

We prepared photocathodes based on the IrCe and are waiting for completion of the laser stand to test the photocathode quantum efficiency.

In conclusion, objectives of task 2 are well on track, although they depend on the general development of the SCT project and therefore share its global risks.

Task 5.3: Development of software for the design of an SCT detector

Please describe the work carried out during the reporting period towards the achievement (roughly max. 2000 characters excluding spaces).

Input by WP lead:

Task 5.3 is devoted to development of a full software package for the realistic simulation of the SCT detector and for producing simulated data having the same format as experimental data.

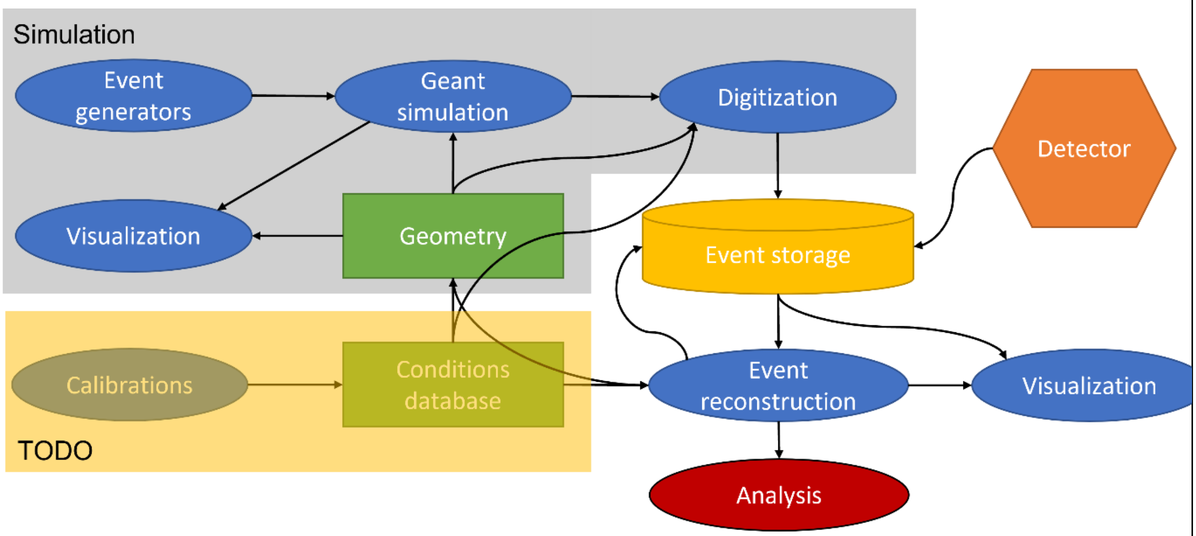


Figure 1. Scheme of the SCT detector software

This task requires working on several subtasks:

1. Development of a software framework that is aware about features of experiment (the event abstraction, temporary and persistent data storage in specific formats, consecutive execution of algorithms to process events etc.)
2. Development of a detailed model of the SCT detector (including geometry, materials description, model of signal digitization and reconstruction of particles based on digitized signals of the detector subsystems).
3. Development of software related to physics (primary event generators, algorithms for event analysis and selection)

This task requires input from all SCT detector subsystem teams and therefore integrates efforts of colleagues involved in tasks 4, 5 and 6.

Activity within this task is distributed among WP5 partners as follows:

- the BINP team coordinates all activities, develops the software framework “Aurora”, implements the model of the particle identification detector FARICH
- the INFN (Ferrara, Frascati, Torino) team implements the model of the C-RWELL detector (an option of inner tracker)
- the INFN (Bari, Lecce) team implements the model of the TraPID drift chamber (an option of main tracker)
- the JLU team implements the model of the FDIRC Cherenkov detector (an option of particle identification detector).

Development of the SCT software has two guiding principles:

- Reuse of well-trusted software widely used in high energy physics (e.g., ROOT, Geant4, Gaudi), to avoid duplication of work and to profit from central development and support from within the particle physics community.
- Be in touch with the Key4hep initiative suggesting standardization of software for future HEP experiments.

The CERN team of CREMLINplus plays a central role in following up on these guiding principles.

The results achieved were presented on the vCHEP 2021 conference (link). The proceedings are going to be published in 2021.

D5.1 "Status report on the software for the SCT detector" contains a detailed description of software development during M1-M18.
Report on MS26 “Release of the software framework for SCT detector” contains description and references related to issuing the SCT detector software framework “Aurora”.

Summarizing, task 5.3 is well on track. SCT software development is the platform bringing together most of the WP5 community and motivates all groups involved to communicate more actively.

Task 5.4: Development and design of Inner Tracker for the SCT detector

Please describe the work carried out during the reporting period towards the achievement (roughly max. 2000 characters excluding spaces).

Input by WP lead:

This task implies development of two alternative technologies for the SCT inner tracker: a classic time projection chamber (TPC) and a cylindrical μ-RWELL gaseous detector (C-RWELL). A prototype is going to be produced for both technologies.

The TPC option is being developed by the BINP team. Current activity is focused on two items:

1. Investigating gas mixtures via simulation. Drift velocity, transverse and longitudinal diffusions, and expected spatial resolution were studied for six different gas mixtures (Figure 2).
2. Design and production of the TPC prototype. The field cage is already assembled (Figure 3). Design of the end-cap detector parts carrying readout electronics is being finalized. The technical design for the TPC prototype is scheduled in November 2021.

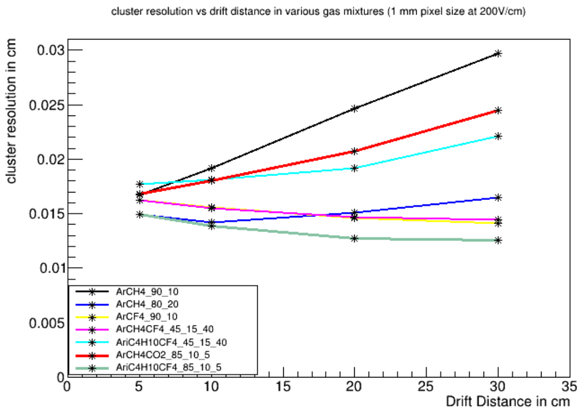


Figure 2. Expected spatial cluster resolution in TPC as function of drift distance for different gas mixtures.

Figure 3. Field cage for the TPC prototype.

The C-RWELL development is carried out under the responsibility of groups from INFN-LNF (Frascati) and INFN-Ferrara, in collaboration with industry and CERN. The detector represents several technological challenges, such as the cylindrical geometry, openable detector, the spark protection (intrinsic to μ-RWELL), low mass and high position resolution. Over the first 18 months good progress has been made with the technology. The design of the first prototype in fully flexible geometry was completed and orders of its components have been placed. Assembly of the mechanical components and the electronic signal readout system is ongoing as illustrated in Figure 4. The prototype is expected to be completed well in time for beam tests foreseen for 2022. In parallel significant progress has been made with the C-RWELL software tools such as the geometry description included in Aurora v 1.0.1, the simulation of energy deposition and detector response, and the digitisation ready to be merged in the official software. The next steps will focus on event reconstruction and analysis together with the full integration of the C-RWELL components in the full SCT Aurora software framework (see Task 5.3).

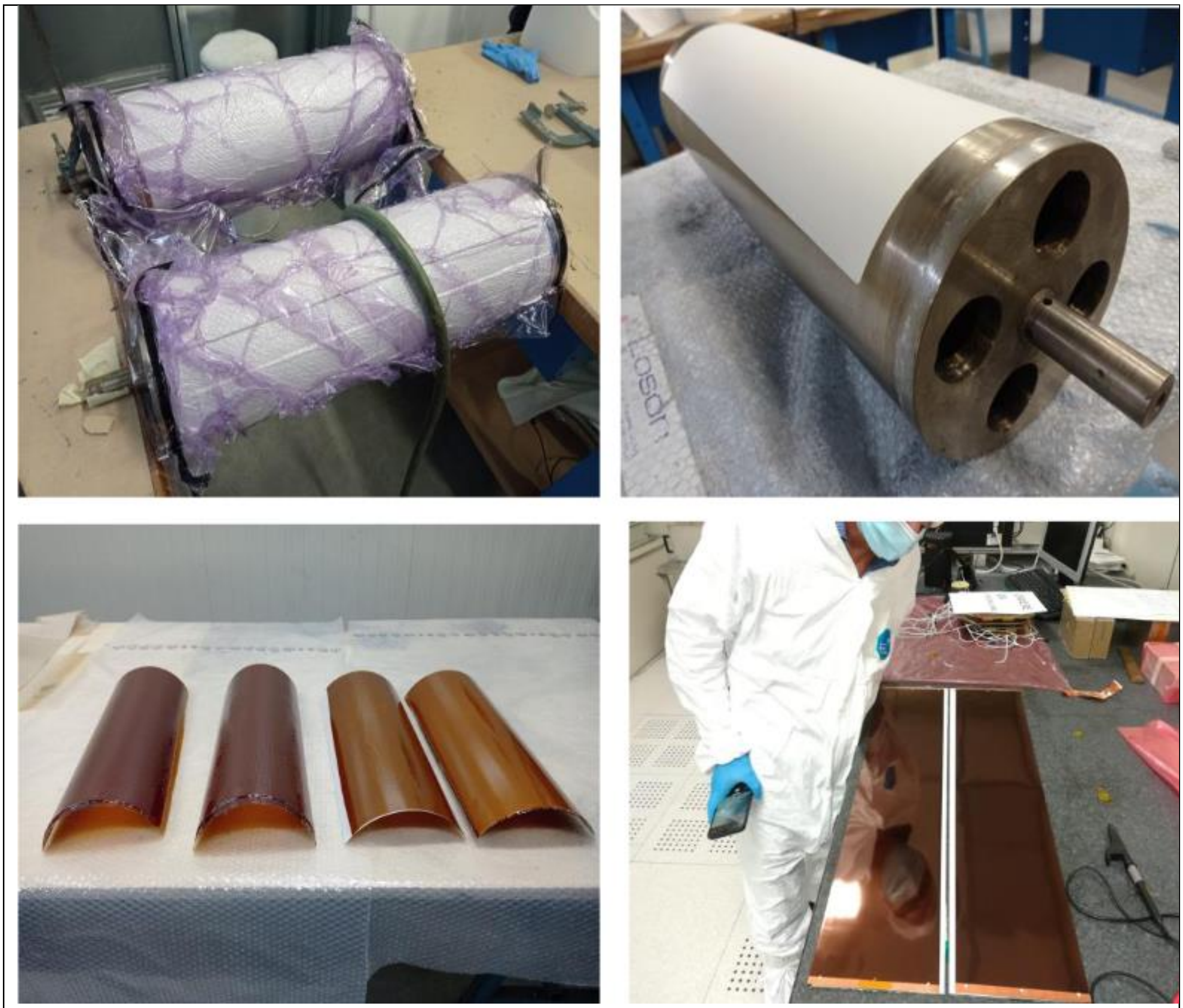


Figure 4. Production of parts for the muRWELL prototype

In summary, this task is very well on track. Two prototypes are expected to be assembled this year and comprehensively tested next (2022) year.

Task 5.5: Development and design of Central Tracker for the SCT detector

Please describe the work carried out during the reporting period towards the achievement (roughly max. 2000 characters excluding spaces).

Input by WP lead:

This task strengthens collaboration between BINP and INFN in the field of drift chambers technologies. A next-generation drift chamber as main tracker was proposed for the SCT detector. The project features full stereo wire geometry, very low material and cluster-counting readout, resulting in significantly improved resolution in momentum and energy deposition.

The main objective of this task is the design, production and test of a fully operating prototype that, if successful, will serve as drift chamber upgrade of the CMD3 detector in BINP.

Current activity is devoted to three topics:

1. **Mechanical design**. It includes a novel tension recovery scheme that minimizes material in front of the end-plate calorimeter. The conceptual design of the entire mechanical structure of the prototype (designed to fit the tracking system of the CMD3 detector) has been completed. The Finite Element Analysis of all mechanical components is in progress. The

construction of a full-scale portion of one end cap is planned, in order to verify the expected stress-strain relations.

2. **Carbon wires coating technology**. Continuous improvements are being introduced in the magnetron sputtering facility realized at BINP. Silver coated 40 μm aluminum wires have been successfully gold coated (up to 30 nm thickness) without affecting the mechanical properties of the wires. Moreover, a stable coating process with nickel has been reached for long pieces (3 m) of carbon monofilaments. Attempts at coating procedures with copper, in order to reduce the linear resistivity of the coated carbon wires, are ongoing. New materials for continuing the test campaign have been procured.
3. **FPGA-based fast digitizer for the cluster counting regime**. The aim of this activity is to isolate in the digitized signal spectrum of a drift cell the relevant features related to the drift of individual ionization clusters, in real time. The advantage of this procedure is twofold: it allows for a reduction of the amount of data to transfer to the recording devices and, at the same time, it provides, in conjunction with analogous proximity information, details which can be used to correlate hits to form track segments, again, in real time. After the successful tests done with a single drift channel, new and more sophisticated hardware has been acquired to treat simultaneously two channels and to prove the feasibility of correlating contiguous hits.

In summary, this task is on track. A lot of work is still ahead for building the prototype, but good communication between the INFN and BINP teams makes the objective reachable.

Task 5.6: Development and design of a Particle Identification system for the SCT detector

Please describe the work carried out during the reporting period towards the achievement (roughly max. 2000 characters excluding spaces).

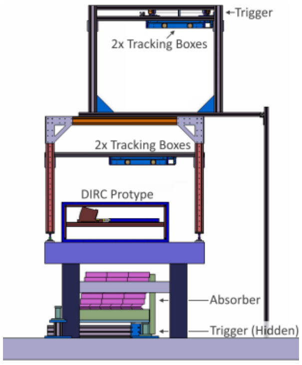
Input by WP lead:

This task enforces collaboration between BINP and JLU in the field of Cherenkov particle detectors. The JLU group suggested a focusing DIRC (FDIRC) as a device for identification of charged particles in the SCT detector. The BINP group suggested a Cherenkov detector based on a focusing four-layer aerogel radiator (FARICH) for the same purpose. Each group aims at developing full simulation of the corresponding device within the SCT software framework and to produce and test a prototype demonstrating the concept.

Work of the two groups is highly synergetic in many aspects. E.g., simulation of both devices requires dealing with optical photons (which is an unusual task), both devices and can use the same photon detectors.

Software packages for standalone simulation of both options (FDIRC and FARICH) were developed and used for optimization of main prototype parameters and development of reconstruction algorithms.

The cosmic station (GCS) and mini cosmic station (MGCS) were launched in operation in Giessen for testing the FDIRC prototype components and for comparison between different photon sensors. The GCS is currently used in combination with a FDIRC prototype containing a full-sized quadrant made of fused silica from Nikon as shown in Figure 5. PetSys TOFPET 2 readout ASICs are used for reading out an MCP-PMT photon detector that is attached to one fully equipped readout module for Cherenkov light detection. A preliminary reconstruction of the Cherenkov angle indicates a good agreement with previously obtained Monte-Carlo results. The MGCS shows promising results using SiPM matrices in combination with a scintillator and different Cherenkov radiators.



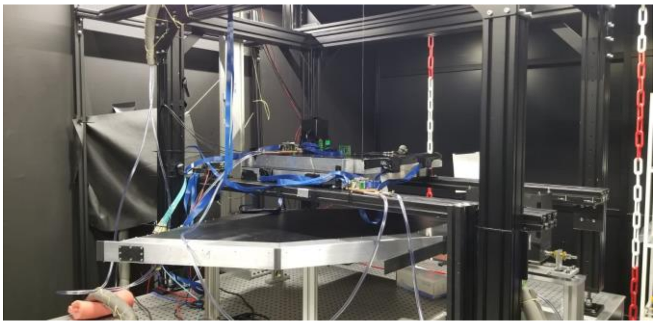
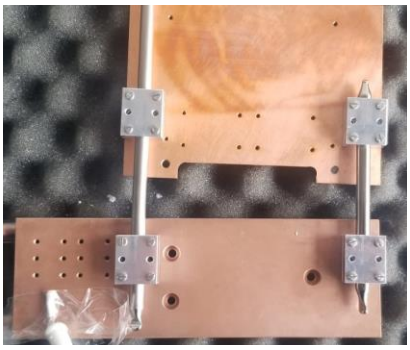


Figure 5: A sketch (left) and a picture (right) of the Giessen Cosmics Station in combination with the installed FDIRC prototype.

A dedicated cooling system for the electronic part of the FDIRC is being developed. It will be tested in combination with the photosensors in a light-tight box that contains a feed-through for a single-photon laser and permanent magnets to create a magnetic field inside the box. The results of the performed simulations and picture of a first prototype are presented in Figure 6.



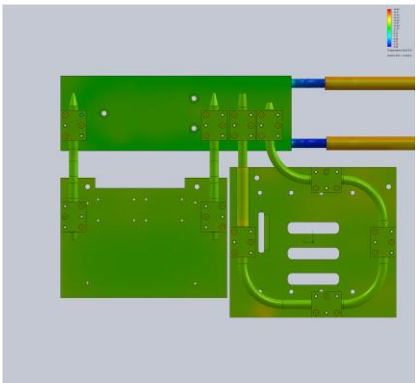


Figure 6: A photo (left) and simulation results (right) of the proposed cooling system for the FDIRC readout electronics.

Several 4-layer focusing aerogel samples with sizes of 10x10x35mm for the FARICH prototype were produced in 2020. The samples were tested with 3 GeV electrons during three beam runs performed at VEPP-4M test beam facility in BINP.

The first version of the compact front-end electronics based on FPGA-time-to-digital was produced in July 2021. The tests in the lab have started. A testbench for mass tests for a comparison of SiPM arrays for the FARICH prototype was designed and its production has started. The actual tests are expected to begin in September 2021.

In summary, this task is well on track.

4. Outlook

Please give a short outlook on the next steps and upcoming tasks (roughly max. 1000 characters excluding spaces).

Input by WP lead:

All WP5 tasks are going to be developed during the whole period of CREMLINplus. Here is a list of main goals to be completed within the next 12 months:

- Launching formal collaboration around the SCT experiment (reaching the delayed MS27) (task 5.1)
- Developing, implementing, and testing algorithm for track finding and reconstruction in the SCT detector within the Aurora software framework (task 5.3)
- Assembling the TPC (time-projection chamber) prototype for the inner tracker of the SCT detector (task 5.4)
- Assembling the C-RWELL prototype for the inner tracker of the SCT detector (task 5.4)
- Finalizing technical design of the drift chamber prototype for the SCT detector (task 5.5)
- Refining technical design of the FARICH prototype for the particle identification system of the SCT detector (task 5.6)

We are going to make all important results publicly available via publications in peer-review journals or/and via conference contributions.

5. Deviations from Annex 1 & 2 of Grant Agreement

- Explain the reasons for any deviations from the DoA, the consequences and the proposed corrective actions.
- Include explanations for tasks not fully implemented, critical objectives not fully achieved and/or not being on schedule. Explain also the impact on other tasks, on the available resources and the planning.
- ☐ Not applicable

Please insert your text here (roughly max. 2000 characters excluding spaces).

Input by WP lead:

There is one deviation in WP5: a 6-month delay for MS27 “Kick-off meeting of international collaboration around the SCT detector”.

Two reasons led to the delay:

- The COVID-19 pandemic. MS27 requires signatures of managers of research organizations. The pandemic hampered direct negotiations at managerial level between BINP (the coordinator of establishing collaboration) and other parties.
- Change of probable location and host laboratory of the SCT factory. Status of the SCT project in Russia has changed in 2020. New probable location is Sarov, and new probable host laboratory is ROSATOM. The collaboration agreement must reflect these changes.

The WP5 partners reached agreement about the form and timing for establishing formal collaboration around the SCT experiment considering ROSATOM as new major stakeholder. Our plan includes signing the Memorandum of Partnership (MoP) in fall 2021. BINP is the collaboration coordinator, but not the host laboratory. The MoP is going to be host-laboratory agnostic. A draft of the MoP is already circulating among potential parties of the partnership.

Implementation of this plan will allow us to reach MS27 within 6-month delay.

This delay is not critical for the WP5 objectives. No impact on other tasks is expected.

6. Critical Risks

- In Annex 1 of the Grant Agreement we have identified potential risks for your WP. Please find below the foreseen risks stated in the Grant Agreement.
- If the risk materialized, please formulate a statement which risk-mitigation measures you have applied.

***Description of Risk**:*	*R&D of the SCT detector subsystems is a very challenging business. There is always a probability of not achieving the expected parameters to fit the physics programme or collider conditions*	
Proposed Risk-Mitigation Measures:	*To minimise possible effects of these risks at least two options for each SCT detector subsystems are to be developed*	
Did you apply the risk-mitigation measures?	☒ **YES**	☐ **NO**
Did the risk materialize?	☐ **YES**	☒ **NO**
Please add your comments here. If the risk-mitigation measures couldn't be applied, please explain why (roughly max. 1000 characters excluding spaces).		
Input by WP lead: As stated in the proposed risk-mitigation measures, we perform R&D for at least two options for each critical detector subsystem from the very beginning.		

***Description of Risk**:*	*Mass production of the novel detector technologies could be limited by modern state of the high-tech industry: aerogel production, carbon fibres, photolithography on polymide3 substrates, DLC sputtering, metal coating of carbon monofilament, SiPMs and other front-end electronics with good enough radiation tolerance*	
Proposed Risk-Mitigation Measures:	*Throughout the R&D activities, it is necessary to look for reliable industrial partners for mass production of detector components and to produce some small trial batches of component materials to determine most risks of the mass production in advance.*	
Did you apply the risk-mitigation measures?	☒ **YES**	☐ **NO**
Did the risk materialize?	☐ **YES**	☒ **NO**
Please add your comments here. If the risk-mitigation measures couldn't be applied, please explain why (roughly max. 1000 characters excluding spaces).		
Input by WP lead: The R&D phase is carried out together with several industrial partners. No mass production is launched for the SCT project so far.		

7. Unforeseen Risks *(if applicable)*

- Did an unforeseen risk arise during the first period?
- If so please describe the risk and the risk-mitigation measures you have applied.

Description of Risk:	*Change of the probable location for the SCT factory (from Novosibirsk to Sarov) and probable host laboratory (from BINP to ROSATOM State Corporation)*
Proposed Risk-Mitigation Measures:	*Adapting technical details of the SCT project to the new location, communicating the details to ROSATOM, modifying agreement about formal collaboration around the SCT experiment accordingly.*

Please add your comments here. If the risk-mitigation measures couldn't be applied, please explain why (roughly max. 1000 characters excluding spaces).

Input by WP lead:
The change of probable host laboratory is very important for the SCT experiment. Support of the SCT project by ROSATOM significantly increases the probability of actual implementation of the project. We included this circumstance in the list of unforeseen risks because appearance of this new stakeholder in the project inevitably requires adjustment of many aspects of the project that takes time and efforts.

One consequence of that risk is a 6-month delay of launching formal collaboration around the SCT project (MS27). This delay was necessary to correctly reflect the updated status of the SCT project in the collaboration agreement.

Description of Risk:	*The COVID-19 pandemic*
Proposed Risk-Mitigation Measures:	*Extensive use of online communication to partially compensate difficulties of traveling and personnel exchange.*

Please add your comments here. If the risk-mitigation measures couldn't be applied, please explain why (roughly max. 1000 characters excluding spaces).

Input by WP lead:

The COVID-19 pandemic has already resulted in about 6 months delay for most of hardware works within WP5. This delay is not critical, and all WP5 objectives can be met in time. The risk will be much more severe for WP5 if the pandemic continues for several years.

Deliverables Period 1

Deliverable Number	**Deliverable Title**	***Due Date (in months)***	***Delivery (in months)***	***Status***
D5.1	Status report on the software for the SCT detector	M18	**M18**	Done

Milestones Period 1

Milestones Number	**Milestones Title**	***Due Date (in months)***	***Delivery (in months)***	***Status***
MS26	Release of the software framework for SCT detector	M18	M18	**Done**
MS27	Kick-off meeting of international collaboration around the SCT detector	M18	M24	**Delayed**

Terminology

DoA Description of Action (Annex 1 of the GA)

GA Grant Agreement

WP Work package