

Call:CERN-RO

Project acronym: NA62

CERN Research Programme / Experiment: NA62

Annual Summary Document¹

Year: 2022

Months: 12

Project Title: Study of rare kaon decays at the CERN SPS / NA62

Project Work Plan (according to the contract)

Stage: I. HASC Maintenance & Operation (MO), reconstruction and MC software development; Exotic and Precision decays studies - part I

Activities:

- I. 1. - HASC MO, reconstruction and MC software development;
 - ALP study (Production of muon background, Finalization of analysis);
 - BR($K^+ \rightarrow \pi^+ \pi^0$; $\pi^0 \rightarrow e^+ e^-$) (Background sources identification, relevant theory survey; MC implementation, Selection criteria - testing and optimizations).

Allocated budget: 1,032,000.00 lei

Realized budget: 1,032,000.00 lei

¹ Please fill in all the required items and do not alter the template

Study of rare kaon decays at the CERN SPS (NA62) - 2022 Annual Summary -

1a. Group list (physicists, staff, postdocs, students):

Name	Position
Alexandru-Mario BRAGADIREANU	Research scientist (CS III) – IFIN-HH
Stefan-Alexandru GHINESCU	Physicist – IFIN-HH, PhD Student (<i>Physics</i>)
Ovidiu-Emanuel HUTANU	Engineer - IFIN-HH, Master Student (<i>Electronics</i>),
Petre-Constantin BOBOC	Physicist – IFIN-HH, PhD Student (<i>Physics</i>)
Neagu IONEL	Engineer –IFIN-HH
Alina MOTORGA	Accountant- IFIN-HH

1b. Specific scientific focus of group (state physics of subfield of focus and group's role)

Physics: Standard Model

Subfield: Flavor Changing Neutral Current decays with neutrinos in the final state with focus on the measurement of the very rare kaon decay $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ at the CERN SPS (NA62 Experiment).

Group role: Originally, to identify the π^+ coming from the $K^+ \rightarrow \pi^+ \pi^+ \pi^-$ decay (source of background in the $m_{miss}^2 := (p_K - p_{track})^2$ distribution) with a hadron sampling calorimeter (HASC). The HASC was shown to be efficient also as photon veto in the rejection of background coming from $K^+ \rightarrow \pi^+ \pi^0$ decay, the upgrade of HASC being proposed in 2018. Evaluation of NA62 sensitivity to various dark matter decays to visible particles. Implementation of various variance reduction techniques in the official Monte Carlo software of NA62. Precision measurement of the $\pi^0 \rightarrow e^+ e^-$ branching ratio.

1c. Highlights of accomplishments in the last year

Concerning HASC upgrade we:

- Upgraded the HASC reconstruction software and HASC online monitoring software for multi-threaded operation;
- Maintained the HASC continuous operation during the ongoing NA62 Physics Run;
- Proposed an upgraded version of HASC in a Letter of Intent for a new experiment, by NA62 Collaboration, the High Intensity Kaon Experiment (HIKE).

In the autumn of 2021, NA62 collected a dataset in beam dump mode. In 10 days of data-taking, around 1.4×10^{17} protons on TAX were collected. This dataset made possible investigating physics case of a dark photon (A') decaying to a pair of leptons. The analysis of the $A' \rightarrow \mu^+ \mu^-$ channel has been finalized in July 2022 and new exclusion limits have been set. The internal note has been completed and a paper is in preparation for publication.

At the end of 2021, one of our group members started working in the Precision Measurements Working Group, on the measurement of the branching ratio of the process $K^+ \rightarrow \pi^+ \pi^0$; $\pi^0 \rightarrow e^+ e^-$. In the Chiral Perturbation Theory, the $\pi^0 \rightarrow e^+ e^-$ can be used to improve predictions of other pseudo-scalar meson decays to pairs of leptons. The selection has been finalized and the internal note is expected to be completed in 2023.

2. Scientific goals (2 pages)

The main goal of NA62 experiment [1] is to measure the branching ratio of the ultra- rare kaon decay $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ at the CERN SPS. The standard Model (SM) prediction for the branching ratio is calculated with high precision [2],

$$BR(K^+ \rightarrow \pi^+ \nu \bar{\nu})_{SM} = (0.84 \pm 0.10) \times 10^{-10}$$

while significant deviations from the SM value are predicted by new physics models [3,4,5]

In addition to the main objective, thanks to its high beam intensity and detectors performance, NA62 has a wide physics programme: precise measurements of lepton universality in $K^+ \rightarrow l^+ \nu$ decays, searches for Lepton Number (LNV) and Lepton Flavor Number Violating (LFNV) processes and searches for exotic particles such as Dark Photons, Heavy Neutral Leptons, axion-like particles (ALPs), etc. In the framework of Physics Beyond Collider initiative, prospects for data taking in beam dump mode has been addressed too.

In order to reach its main goal, NA62 needs to collect about 100 in-flight $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ events, and to keep the total systematic uncertainty small. Assuming a 10% signal acceptance and a $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ branching ratio of 10^{-10} , at least 10^{13} K^+ decays are required.

Since the $\nu \bar{\nu}$ pair is undetectable, the technique adopted by NA62 is to match an upstream K^+ track with a downstream π^+ track and to use the squared missing mass distribution $m_{miss}^2 := (P_K - P_\pi)^2$ to discriminate the signal from background (Fig. 1). The main background events are expected to come from the other K^+ decay channels and accidental matching of an upstream track with a K^+ .

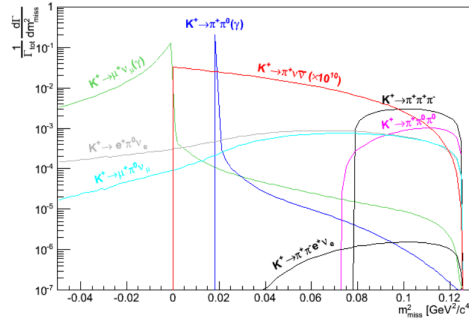


Figure 1: Squared missing mass distribution

2.1 NA62 Hadron Sampling Calorimeter (HASC)

The NA62 experimental setup proposed in the Technical Design Document [6] was improved, by the IFIN-HH team, with a new hadron calorimeter to veto the $K^+ \rightarrow \pi^+ \pi^+ \pi^-$ events in which the π^- undergoes hadronic interaction in the first STRAW chambers and the more energetic π^+ (~ 40 GeV/c) which is traveling through the beam hole, not being detected by the IRC, then emerging at $Z > 253$ m.

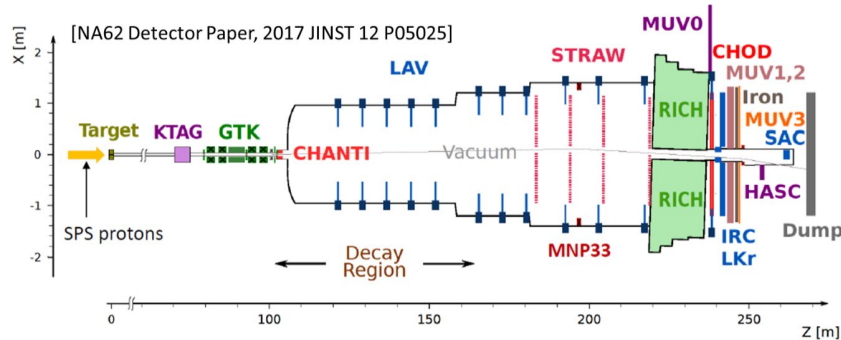


Figure 2: NA62 Experimental setup

Using the data coming from the upstream detectors (Fig. 2) to select the $K^+ \rightarrow \pi^+ \pi^+ \pi^-$ decays, namely the CEDAR and GTK for K^+ identification and the STRAW together with RICH, CHOD and MUV to identify one of the π^+ , while HASC has to detect the second π^+ traveling through the beam pipe and deflected by the bending magnet (Fig. 2).

HASC has been demonstrated to be effective (2016-2018 $\pi^+\nu\bar{\nu}$ dataset) as photon veto, complementary to LAV, LKr, IRC and SAC calorimeters, an additional 30 % reduction of $\pi^+\pi^0(\gamma\gamma)$ background being obtained with HASC. This fact, stimulated the idea of using a second calorimeter HASC-like in a position symmetrical with respect to the beam axis, to double the π^0 rejection.

Each HASC station is made up of 9 identical modules recovered from a prototype developed by NA61 Collaboration. Each module is a sandwich of 120 lead/scintillator alternating tiles, with a total volume of $10 \times 10 \times 120 \text{ cm}^3$ (W x H x L). The sampling ratio is 4:1, the scintillator tiles having a dimension of $100 \times 100 \times 4 \text{ mm}$ while the lead thickness is 16 mm.



Figure 3: HASC module longitudinal section (left) and optical readout couplings (right)

Each HASC module is organized in 10 longitudinal read-out sections, each scintillator tile of every single section being optically coupled with 1 mm^2 round Wave-Length Shifting (WLS) optical fibers. In the rear side of each module there are 10 optical connectors, originally designed to be coupled with $3 \times 3 \text{ mm}^2$ green sensitive Micro-pixel Avalanche Photodiodes (MAPD), currently S12572-015C Hamamatsu SiPM sensors being used.

The FE electronics and SiPM's installed on the new HASC station, are cooled down to about $21 \text{ }^\circ\text{C}$ using a system designed by our group, which consists of 3 Peltier thermoelectric coolers / module and a water-air heat exchanger used to blow cold air in the modules endcap cases. The temperature is maintained constant by a temperature controller – MCU based – which regulates the Peltier supply voltage via a PID routine. Due to last moment mechanical incompatibilities, we were not able in June 2021 to upgrade the old HASC station with new mechanics and Peltier cooling, but we were able to accommodate the cooling with air, which lowered the nominal temperature of SiPM's from $36 \text{ }^\circ\text{C}$ to about $24 \text{ }^\circ\text{C}$.

2.2 Study of dark matter

Thanks to its high beam intensity and detectors performance NA62 can achieve sensitivity to new-physics scenarios. Since 2018, IFIN-HH team is actively involved in the study of dark matter in various portals [7]. Our original goal, the study of the Higgs-coupled dark scalar, had to be postponed due to the urgency of finalizing the $ALP \rightarrow \gamma\gamma$ sensitivity evaluation. Significant efforts have been made during 2020-2021 to simulate the muon-induced background for this physics case. However, the analysis has been halted when NA62 collected another beam dump sample (1.4×10^{17} POT). The Exotics Working Group started investigating the physics case of a dark photon (A') decaying into a pair of leptons. The dark photon is a vector field, symmetric under $U(1)$ transformations, that feebly interacts with the Standard Model fields. Both the mass $m_{A'}$ and the coupling ϵ are free parameters of the model. More details on the model can be found in [8,9]. For masses below 700 MeV , the dark photon decay width is dominated by lepton-antilepton final states. NA62 is sensitive to such decays only for ϵ of the order of $10^{-7} - 10^{-5}$ [10].

Our team is highly involved in several aspects of this analysis. The primary goal was to simulate a Monte Carlo (MC) sample of size at least at the level of the data. To this purpose, our experience with variance reduction techniques (biasing) has proven to be of paramount importance. Additionally, we are actively contributing to the event selection algorithm and data-quality assessment.

2.3 Precision measurement of the $\pi^0 \rightarrow e^+e^-$ decay rate

In the framework of Chiral Perturbation Theory, the $\pi^0 \rightarrow e^+e^-$ decay rate measurement provides a tight experimental constraint on calculations. The process has negligible short-distance contributions and is the best-measured pseudo-scalar decay to a pair of leptons. Immediate benefits of the decay rate precision measurement are improved predictions of rates for other pseudo-scalars decays to lepton pairs, such as $\eta \rightarrow \mu^+\mu^-$ and the long-distance contribution of the $K_L^0 \rightarrow \mu^+\mu^-$ decay. In the latter case, the short-distance contribution is a potential source of information on $|V_{td}|$.

The NA62 experiment has the potential of performing the measurement of the rare $\pi^0 \rightarrow e^+e^-$ decay, the neutral pion originating from the $K^+ \rightarrow \pi^+\pi^0$ decay [11]. The current PDG average branching ratio is $B_{PDG}(\pi^0 \rightarrow e^+e^-) = (6.46 \pm 0.33) \cdot 10^{-8}$, the average being influenced mainly by the KTEV result $B_{KTEV}(\pi^0 \rightarrow e^+e^-) = (6.44 \pm 0.25 \pm 0.22) \cdot 10^{-8}$, result obtained from 794 events originating from $K_L \rightarrow 3\pi^0$ decay [12]. The preliminary estimations show about 900 $K^+ \rightarrow \pi^+\pi^0; \pi^0 \rightarrow e^+e^-$ events in the NA62 dataset.

Efforts to measure the $\pi^0 \rightarrow e^+e^-$ decay rate within NA62 have been made in the past, but conclusions were never reached. The analysis was restarted by one of our Ph.D. students in June 2022, with the goal of measuring the branching ratio of the $K^+ \rightarrow \pi^+\pi^0; \pi^0 \rightarrow e^+e^-$. An internal note is expected in 2023.

3. Scientific achievements in the last three years corresponding to the actual program funding

In 2019 we started the upgrade of HASC by purchasing 9 new HASC like calorimeter modules from NA61 Collaboration. We developed a completely new mechanical structure to support the SiPM sensors and the associated front-end electronics (FEE); we developed a new FEE board for the read-out of 10 SiPM sensors as a substitute of old HASC FEE; we designed and produced a hybrid cooling system based on a water-air heat exchanger and Peltier coolers controlled via a PID routine running on a micro-controller.

5 out of the 9 new HASC modules were tested in IFIN-HH with cosmic rays (Fig. 6), by employing a TDC triggered whenever a HASC section was hit.

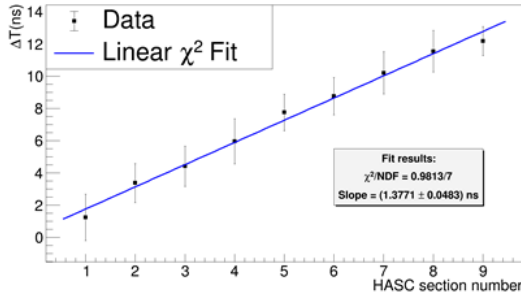


Fig. 6: TOF between successive HASC sections

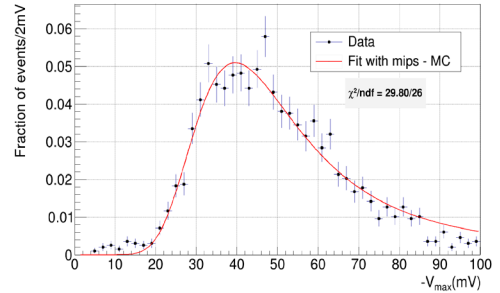


Fig. 7: Signal amplitude / section when all 10 sections are hit

In 2020 we continued the testing of new HASC modules, this time employing a 5 GS /s, 12-bit digitizer. Fig. 7 shows the distribution of SiPM signals when the 10 sections of a HASC module are passed by a cosmic ray muon. The fit with Monte Carlo simulated deposited energy distribution/section shows good agreement with data.

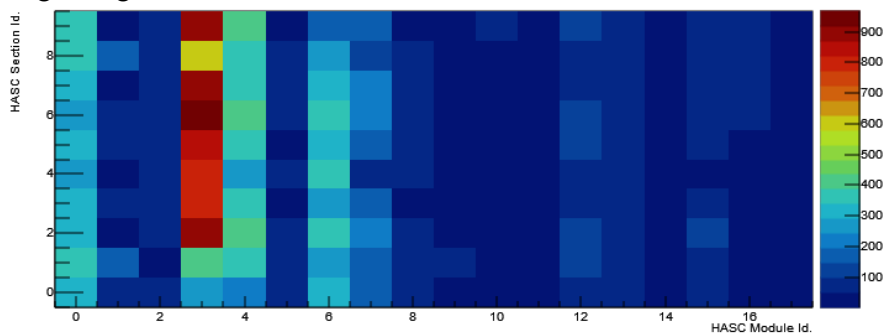


Fig. 8: Screenshot of the 2D hit map used in the Online Monitor of NA62

The installation and commissioning of new HASC was finalized at the end of June 2021. We then updated the Online Monitor tool, which is used during data-taking by shifters in order to ensure a smooth operation. Fig. 8 shows the 2D hit-map with modules 0-8 belonging to the old HASC and 9-17 to the new HASC that is always on display during the run.

Up to 2021, the HASC detector performance in NA62 was evaluated by means of a complex selection procedure in which $K^+ \rightarrow \pi^+\pi^+\pi^-$ decays with one π^+ traveling in the beampipe, undetected, were analyzed. However, the 2021 data has been dominated on one hand by large beam fluctuations and on the other hand by instabilities of the GTK detector, which is responsible for the accurate determination of the K^+ momentum. Moreover, the π^+ can never be in the acceptance of the new HASC station, due to the magnet right before the detector. This prompted the idea to study the HASC performance through its response to muons, which is now possible considering the cooling system improves tremendously the SiPM signal characteristics in terms of gain and photon detection efficiency [13].

The momentum and position of muons are determined by the STRAW (Fig. 2), together with requiring a MUV3 signal associated both geometrically and in time. Fig. 9 shows the time difference between the muon (MUV3 time) and the closest HASC signal in time. We emphasize that, there is a large improvement in the time resolution of the old HASC, the current time resolution being less than half with respect to 2018 data, while the time resolution of new HASC is even better due do better cooling.

Since the beam is highly charge-asymmetric, with the majority of the particles being positive, the thresholds on the old HASC ToT boards had to be set higher in order not to congest the TEL62, while for the new HASC, this operation is not needed. Consequently, in Fig. 10, the number of sections fired by an incoming muon has more pronounced peaks at 10 and 20 for the new station, corresponding to 1 and 2 entire modules.

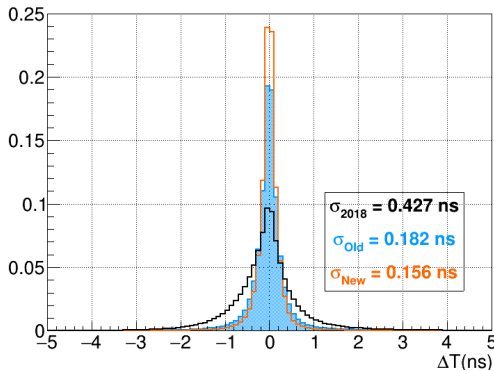


Fig. 9: Muon – HASC time difference, blue for the old station and orange for the new one

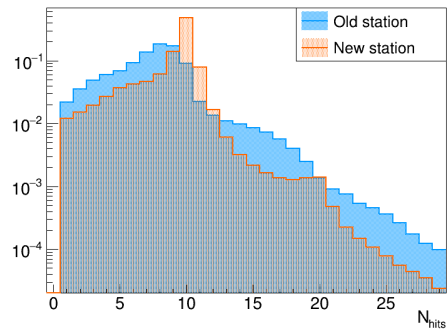


Fig. 10: Number of sections fired by a muon

One of the main problems of the beam in 2021 is a spike in intensity at the beginning of the burst. This has affected most of the NA62 subdetectors. We studied the effective efficiency of the HASC as function of event time stamp. In Fig. 11 we show that neither station experiences a visible drop in efficiency at the beginning of the burst (1.2s-1.5s). Fig. 12 shows that the study with muons can also be used to assess the stability of the HASC through the run.

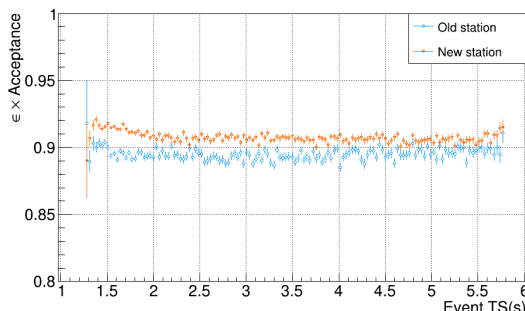


Fig. 11: Effective efficiency by station, blue for old and orange for new

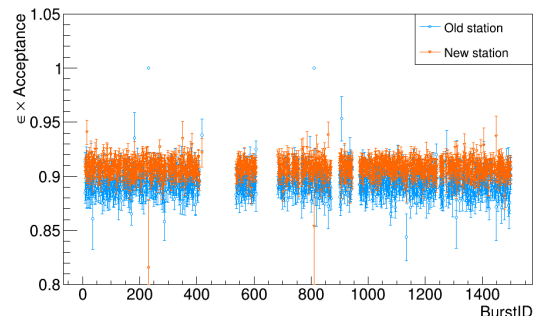


Fig. 12: Effective efficiency by station through a run, blue of old and orange for new

In 2022, a campaign was started to make it possible to run the NA62 reconstruction software in multi-threaded mode. This feature is critical in view of the increased beam intensity, for online monitoring purposes. The IFIN-HH team participated in this task by rewriting most of the reconstruction software for HASC and parts of the software for other detectors.

Still on the reconstruction side, we have investigated possibilities to improve the clustering algorithm of HASC aiming at reducing the random veto. Up to now hit clustering was performed using temporal information only. One of the drawbacks of this method is that hits in both stations are clustered together if they are close enough in time. A promising algorithm that uses both spatial and temporal information is a variation of the “Density-based spatial clustering of applications with noise” (DBSCAN) algorithm [14]. DBSCAN groups together points that are closely packed in space. In the case of HASC this is given by hits in neighboring cells on either direction, so any uninterrupted chain of hits is considered a cluster. Additionally, we only allow hits within 5 ns of each other to be clustered together. All hits that have no neighbors or are far away in time from any other hit are marked as noise. Preliminary studies using muons show that the random veto decreases with this method by about 20%. However, the definitive test will be conducted in collaboration with the $\pi\nu\bar{\nu}$ in 2023.

NA62 has been given green light for data-taking until the end of 2025. Afterwards, the ECN3 building will host another experiment. The NA62 Collaboration formulated a proposal for the High Intensity Kaon Experiment (HIKE). The Letter of Intent (LoI) has been finalized and submitted to the SPS Committee in November 2022 [15]. Our group contributed to the LoI with a proposal for an upgraded version of the HASC, with emphasis on signal rates, temporal resolution, and geometrical coverage.

The total signal rate observed in HASC (both stations) during the NA62 data taking in 2022 at nominal intensity is about 1.21 MHz (with 1 MHz generated by the Old HASC). The most active channel counts at most 0.05 MHz. Therefore, signal rates do not pose a problem in the operation of HASC in HIKE, assuming linearity with beam intensity.

The main issue in the operation of the current HASC at the HIKE intensity is the random veto. It is determined chiefly by the time resolution of the detector, presently at 370 ps (430 ps) FWHM for the New HASC (Old HASC). For HIKE, the resolution should be improved to about 100 ps. We proposed solutions for using either SiPM’s or Photomultiplier Tubes (PMT’s):

- HAMAMATSU S13362-3050DG SiPM [16] with time resolution of 110 ps (FWHM) [17], 4 times lower dark counts and 5 times higher gain.
- HAMAMATSU H14220A PMT [18], which could be used to readout individual scintillator plates (instead of groups of 6, as done presently).

Finally, we studied the geometrical coverage of HASC for the $K^+ \rightarrow \pi^+\pi^+\pi^-$ and $K^+ \rightarrow \pi^+\pi^0$ backgrounds for $K^+ \rightarrow \pi^+\nu\bar{\nu}$. We showed that the current setup of HASC provides near-optimal coverage.

In 2019 we have completed a Toy MC tool for the study NA62 sensitivity to the Higgs-mixed dark scalar (S) in the singlet portal including the associated production mechanism (production by secondaries of beam interactions in TAX). The result was an updated value for the sensitivity enhancement factor by the associated production (1.4 w.r.t 1.7 obtained by SHiP [19]).

In early 2020, part of the Exotics Working Group asked our help in implementing a dedicated scheme for their study on Axion-like particles (*ALP*). *ALP* is another dark matter candidate for which the NA62 setup and beam dump dataset (1.6×10^{16} POT) are competitive at a world-wide scale.

NA62 is most sensitive to the $ALP \rightarrow \gamma\gamma$ final state and the main sources of background are due to halo muon interactions and K^+ inelastic interactions in the material of the last station of GTK. For the hadronic component, the $K_S \rightarrow \pi^+\pi^-$ and $\Lambda \rightarrow p\pi^-$ decays are dominant but due to their short life times, only very high momentum particles contribute to this background, but the rate of their production is low. Given our experience with variance reduction in Geant4, our main contributions to the $ALP \rightarrow \gamma\gamma$ consisted of simulating a suitable background sample for both sources. For the hadronic component we devised a biasing scheme that led to an increase of 1 order of magnitude in

statistics (with no modification of the CPU time) with respect to the brute-force simulation. The simulation of the muon halo proved to be more complex. We devised an algorithm [14] that enhances the number of muons produced in proton interactions in thick absorbers by a factor 2000. The algorithm does not alter the physics engine of Geant4; hence we were able to simulate completely the background for this search. Thanks to our efforts, we were included on the list of authors for this search.

At the end of 2021, NA62 collected another beam dump sample, approximately 10 times larger (1.4×10^{17} POT). Moving the $ALP \rightarrow \gamma\gamma$ analysis to this dataset is a complex and long process. While studies continued, the focus of the Exotics Working Group shifted to another interesting physics case, that of a dark photon (A') decaying to a pair of leptons. This time, the IFIN-HH group contributed significantly to this analysis by:

- developing tools to assess the data quality;
- studying the efficiency of various cuts used in the selection algorithm;
- simulating the background induced by halo muons.

To maximize the scientific output, the analysis has been split in 2 parts. Up until august 2022, we focused on the $A' \rightarrow \mu^+\mu^-$ channel. The 90% CL exclusion region set by NA62 with this dataset is shown in Fig. 13. Gray areas correspond to previously excluded parameters. A paper is in preparation for publication.

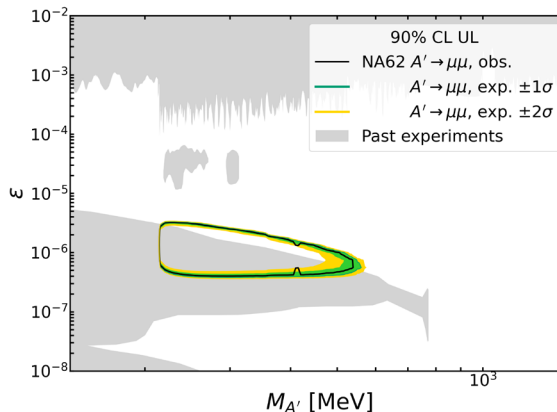


Fig. 13: The region of the parameter space within the solid line is excluded at 90% CL. The color filled area represents the expected contour uncertainty in absence of a signal: green (yellow) corresponds to one (two) sigma statistical coverage.

The analysis of the $A' \rightarrow e^+e^-$ channel is also in a well-developed stage. Preliminary results indicate that this part of the analysis will extend the exclusion region significantly at low dark photon masses with minor contributions in the large mass range. We expect the internal note to be available by the end of 2022 and another paper will be published during 2023.

In 2022, one of our PhD students started working in the Precision Measurement Group, on the measurement of the branching ratio of the $\pi^0 \rightarrow e^+e^-$ decay. The analysis is based on the reconstructed invariant mass of the electron and positron tracks (m_{ee}) forming a vertex in the fiducial volume ($105 \text{ m} < z_{vtx} < 180 \text{ m}$). Contributions were focused on the selection algorithm, resulting in increased signal acceptance and higher particle identification (PID) efficiency with respect to previous studies.

The analysis is in a well-developed stage, with good preliminary data-MC agreement (Fig. 14). So far, only the 2017 and 2018 datasets were considered, with about 900 reconstructed $K^+ \rightarrow \pi^+\pi^0$; $\pi^0 \rightarrow e^+e^-$. Studies for the estimation of the background and uncertainties (trigger, PID, random veto) are ongoing. The inclusion of the 2021 and 2022 datasets is under consideration. The internal note on the analysis will be prepared in 2023 and, depending on the result, a paper could be published.

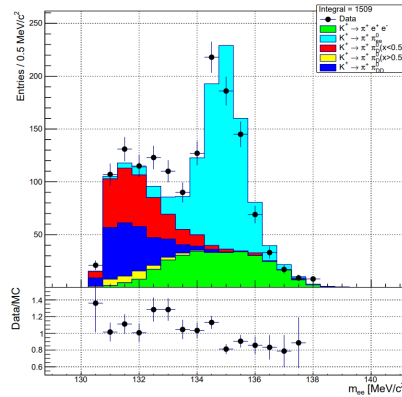


Figure 14: Data – Monte Carlo comparison of the reconstructed mass of the e^+e^- pair using the updated selection. The data sample contains the runs collected in 2017 and 2018.

4. Group members (table)

- List each member, their role in project(s) and the % time on each project (analysis, R&D, detector operation, detector construction, etc.)

Name	Role	FTE
Alexandru-Mario BRAGADIREANU	HASC upgrade, maintenance and operation; detector control system; reconstruction software.	0.61
Stefan-Alexandru GHINESCU	Data analysis, MC simulation and reconstruction software	0.58
Ovidiu-Emanuel HUTANU	HASC upgrade, maintenance and operation;	0.71
Petre-Constantin BOBOC	Data analysis	0.63
Neagu IONEL	HASC upgrade and maintenance	0.45
Alina MOTORGA	Project accountant	0.25

- List former students (in last 5 years) and current position/job and institution

- Victor-Radu Voicu – Programmer, Bit Soft srl, Bucharest
- Andreea Căluț - Student, Faculty of Physics, Bucharest University

5. Papers and talks in last year

5.1 Papers:

- E. Cortina Gil et al, NA62 Collaboration, *A search for the $K^+ \rightarrow \mu^- \nu e^+ e^-$ decay*, submitted to Phys. Lett. B.
- E. Cortina Gil et al, NA62 Collaboration, *A measurement of the $K^+ \rightarrow \pi^+ \mu^+ \mu^-$ decay*, JHEP 2022 (11) 011, 2022.
- E. Cortina Gil et al, NA62 Collaboration, *Performance of the NA62 trigger system*, submitted to JHEP.
- E. Cortina Gil et al, NA62 Collaboration, *Search for lepton number violating $K^+ \rightarrow \pi^-(\pi^0)e^+e^-$ decay*, Phys. Lett. B 830, 137172 (2022).

5.2 Talks:

- [Search for dark photon to \$e+e^-\$: background estimate and plans](#), NA62 Exotics WG meeting, 27 October 2022.
- [First results for searches of exotics decays with NA62 in beam-dump mode](#), ICNFP 2022, Kolymbari Greece, 10 September 2022.
- [A HASC for HIKE](#), NA62 Collaboration Meeting 2022, 02 September 2022.
- [HASC Status in 2022](#), NA62 Collaboration Meeting 2022, 29 August 2022.

- [Check on the upstream prompt background and plot blessing](#), NA62 Exotics WG meeting, 04 July 2022.
- [Update on the search for DP di-muon decays](#), NA62 Exotics WG meeting, 29 June 2022.
- [Status report on the search for DP di-muon decays](#), NA62 Exotics WG meeting, 23 June 2022.
- [Background evaluation procedure for BD analyses](#), NA62 Exotics WG meeting, 31 March 2022.
- [MC for halo in beam dump](#), NA62 MC Validation WG meeting, 30 March 2022.

6. Further group activities (1 page)

- Collaborations, local synergies

The multifunction rack control unit (MRCU) hardware was developed and built in the framework of NUCLEU 16 42 01 03 Project. The MRCU firmware and the high-level software were developed in the framework of the present project, the MRCU unit being operated at CERN ECN3 since July 2016 being part of the HASC Control system.

The MRCU will be included in the PANDA Controls Technical Design Report, to be published in 2020, as the solution to control the electronics racks used by PANDA Experiment at FAIR (Darmstadt).

7. Realized Budget for 2022

		lei
Type of expenditures		2023
1	PERSONNEL EXPENDITURES, from which:	439,864.00
	1.1. wages and similar income, according to the law	430,185.00
	1.2. contributions related to salaries and assimilated incomes	9,679.00
2	LOGISTICS EXPENDITURES, from which:	278,739.39
	2.1. capital expenditures	178,137.87
	2.2. stocks expenditures	29,698.02
	2.3. expenditure on services performed by third parties (including the contribution to CERN)	70,903.50
3	TRAVEL EXPENDITURES	52,410.40
4	INDIRECT EXPENDITURES – (OVERHEADS) *	260,986.21
TOTAL EXPENDITURES (1+2+3+4)		1,032,000.00
Indirect Expenditures = General IFIN-HH Overheads (35% from 1+ 2.2 +3) + Particle Physics Department Overheads (15 % from 1 + 2.2 +3)		

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- [1] NA62 Collaboration, *Proposal to Measure the Rare Decay $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ at the CERN SPS*, CERN-SPSC-2005-013, 2005.
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