Search for New Physics with the NA62 Experiment at CERN

C.Lazzeroni, N.K.Watson (Birmingham); N.Brook, H.Heath, J.Rademaker (Bristol); D.Britton (Glasgow); J.Dainton, J.Fry (Liverpool)

The NA62 experiment at the CERN SPS is designed to use rare kaon decays to make decisive tests of the Standard Model in a manner complementary to the programme of direct searches for the Higgs boson and other potential new particles at the LHC. Approved by the CERN Research Board in December 2008, it appears in the CERN long-term plan running for two or three years from 2012. There is a unique opportunity for the UK to get involved, broadening the national particle physics programme at a modest cost by building on existing physicists and technical expertise to develop the key kaon-identification component.

Physics motivation

The NA62 experiment (CERN-SPSC-2007-035 SPSC-M-760) addresses a wide-ranging programme of measurements covering rare-decays, medium-rare decays, radiative kaon decays and tests of lepton universality. The apparatus has been optimised for the most difficult channel, which provides a stringent test of the Standard Model by precisely measuring the Branching Fraction of the very rare kaon decay $K^+ \to \pi^+\nu\bar{\nu}$. This decay is currently observed at the 10^{-10} level based on three signal events seen by E787 at Brookhaven. The NA62 experiment would run for two or three years from 2012 and achieve a signal to background ratio of about 10:1.

The decay $K^+ \to \pi^+\nu\bar{\nu}$, and the related channel $K_L \to \pi^0\nu\bar{\nu}$, are dominated by short-distance dynamics that depend on a single semileptonic operator for which data render hadronic uncertainties to negligible levels (hep-ph/0304132). New effects in supersymmetric models can be induced through additional box- and penguin-diagram contributions involving charged Higgs or charginos and stop. A comparison of direct new-physics contributions in the $s \to d\bar{\nu}\nu$ amplitude or in $B^0\bar{B}^0$ (e.g. Rev. Mod. Phys. 80, 965 (2008)) concludes that the rare decays K^+ branching ratios can be computed to an exceptionally high precision, not matched by any other loop-induced meson decay, and have a sensitivity to new physics comparable to, or better than, B decays. To date, the process $K^+ \to \pi^+\nu\bar{\nu}$ has only been studied with kaon decays at rest. BNL-AGS-E787 (E949) used data from 1995–1998 (2002) to determine $BR(K^+ \to \pi^+\nu\bar{\nu}) = 1.47^{+1.30}_{-0.89} \times 10^{-10}$ with limited precision (Phys. Rev. Lett. 93, 031801 (2004)). Progress on the $K_L \to \pi^0\nu\bar{\nu}$ mode has been even slower: E391a (KEK) recently published an improved upper limit: $< 6.7 \times 10^{-8}$, 90% CL (Phys. Rev. Lett. 100, 201802 (2008)), and an experiment (E14) to explore Single Event Sensitivities to the Standard Model level at the new J-PARC facilities has been proposed.

Beyond the headline channel, the NA62 experiment will enable precision measurements of many other decay modes of the kaon. The good photon energy resolution will enable the study or radiative decays with unprecedented precision, offering important inputs to the extraction of Chiral Perturbation Theory parameters. Lepton universality can be studied through the ratio of two-body decays $R_K = \Gamma(K \to e\nu)/\Gamma(K \to \mu\nu)$ in which many of the theoretical and experimental uncertainties cancel.

The NA62 Experiment

The physics goals of NA62 demand a signal-over-background ratio of $S/B \simeq 10$, and with two undetectable neutrinos in the final state this necessitates redundant measurements of the event kinematics, hermetic vetoes and excellent particle identification. Particular care has to be taken to suppress the two-body decays $K^+ \to \pi^+\pi^0$ and $K^+ \to \mu^+\nu$ which have branching ratios up to 10^{10} times larger than the expected signal. Kinematic reconstruction of the two-body decays may suffer from non-gaussian tails, and backgrounds may enter if photons are undetected in $K^+ \to \pi^+\pi^0$ or if muons are mis-identified as pions in $K^+ \to \mu^+\nu$. Backgrounds from K^+ three- and four-body decays are at a lower rate, but harder to eradicate as the kinematics of the system are not closed, and therefore depends critically on particle identification (CERN-SPSC-2007-035 SPSC-M-760).

Estimates of beam time required to achieve the physics goals are based on a decade of NA48 experience, assuming a comparable duty cycle to NA48 in 2003–4, and demonstrate that the experiment will not be limited by the SPS proton flux. By using 400 GeV/c protons from the SPS to make a secondary kaon beam, fewer protons are needed to achieve a given kaon flux as the production cross-section increases with proton energy, thus reducing the non-kaon-related accidental activity. The higher kaon energy makes photon detection easier, simplifying the suppression of the backgrounds originating from $K^+ \to \pi^+\pi^0$. A challenge arising from making kaons in this way is that pions and protons cannot be separated efficiently from kaons at the beam level: upstream detectors which measure the momentum and the direction of the kaons are exposed to a particle flux about 17 times larger than the useful (kaon) one. In contrast, magnetic spectrometers and the other principal detectors downstream of the decay region are unaffected because the protons, the undecayed kaons and pions are kept in vacuum, and the muons from pion decays are mostly contained in the non-instrumented region of the detector. A beam pion interacting with the residual gas in the vacuum tank may be mistaken as a signal if no other visible particles are produced in the process. To keep this source of background to less than one fake event per year, the vacuum should be better than 6×10^{-8} mbar. This very challenging requirement can be relaxed by an order of magnitude by positively tagging the kaons.

It is therefore critical to make a positive identification of the ~ 6 % of kaons in the high rate environment before they decay. This will be achieved by placing a H_2-filled differential Čerenkov counter (CEDAR) in the incoming beam. Providing this essential part of the experiment is the basis of the current proposal, as outlined below.

UK Opportunity: the CEDAR Detector

NA62 costs are reduced by adapting large parts of the existing infrastructure of the NA48 setup. The CEDAR detector (CERN Report CERN-82-13) is a particularly interesting example of this approach, and one which allows the UK to join this recently approved experiment without the typical associated expenditure.

The Čerenkov light produced in the gas is reflected by a Mangin mirror via a chromatic corrector lens through a diaphragm and via condenser lenses onto eight locations for photon detectors. By appropriate reduction of the diaphram aperture, only photons originating from incident K^+ are selected, excluding light induced by pions and protons. A test run at CERN in 2006 successfully demonstrated that one of the CERN "West" (N_2-filled) CEDARs can be adapted in this way to distinguish kaons from pions, with no "show-stoppers" identified.

Although only Čerenkov photons from kaons are selected, the expected rate is 50 MHz rate, and hence a timing resolution of $\sim$ 100 ns is required. The present photomultipliers and associated readout and trigger electronics are inadequate and will be replaced.

Motivation and Goals of the Proposal

The two goals of the proposal are to provide the complete Čerenkov-based particle identification system essential for NA62, and prepare software for data taking in 2012, with the aim of using a fraction of the existing GridPP resources. Starting from an existing differential Čerenkov counter (CEDAR) at CERN, we will will carry out R&D and subsequently adapt its optics, photodetectors and readout/triggering electronics for the high intenstity environment of NA62. The experience of the proposing institutes is well matched to the demands of this project: Birmingham is an acknowledged leader in high speed triggering and electronics, Bristol has proven expertise in both photodetectors and distributed computing from LHCb and CMS as well as optical design experience from the LHCb RICH, Glasgow is the leader of the GridPP project and Liverpool have a long-standing track record of designing and building cutting-edge detector systems 'in house'. Preliminary discussions in GridPP indicate that some effort would be made available to NA62 should its proposal succeed. The Director of PPD has indicated that, in the event of approval, he would explore all possibilities for PPD effort and expertise to contribute appropriately.

Resource Request and Schedule

The project is for 36 months from July 2009, and will deliver a critical part of the NA62 experiment and results from low luminosty tests at CERN, ready for physics running. It will also provide the foundation to exploit the physics potential of NA62. The programme requires an average of 7.33 FTE per year between the four institutes, of which 3.6 FTE are currently researchers/technicians supported by university PP Rolling Grants, 1.57 FTE are academics and 2.17 FTE are new resources. The total cost for equipment is £0.64M for equipment and £70k for travel, and costs at CERN for Common Fund and Infrastructure Support are (summed over the three years) CHF 300k (£200k), respectively. The total cost to STFC over three years is £2.1M (including 10% working allowance and contingency), of which £1.25M is 'new money' (i.e. excluding existing posts). This research proposal, which is achievable based on the track records of the proponents, offers both a timely enhancement of the UK programme and takes strategic advantage of CERN membership.