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Experimental Summary

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In this review the 21 experimental contributions to the 2013 Kaon Physics International Conference are summarized. 10 talks were devoted to Kaon measurements, 3 contributions to flavor physics other than Kaons, 8 talks discussed future Kaon experiments.

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1. Constraints on Unitary Triangle

C. Lazzeroni [1] on behalf of the LHCb collaboration reported recent results on B physics relevant for the unitarity triangle constraints using mostly 1 fb^{-1} of analyzed data. Using tagged $B^0 \to J/\psi K_S$ decays, $\sin 2\beta = 0.73 \pm 0.07(stat) \pm 0.04(syst)$ was measured. With tagged $B^0 \to J/\psi K^{0*}$ and tagged $B^0 \to D^- \pi^+$ events, $\Delta m_d = 0.516 \pm 0.005(stat) \pm 0.003(syst)$ ps^{-1} was quoted. In the B_S^0 system, using $B_S^0 \to D_S^- \pi^+$ decays, $\Delta m_S = 17.768 \pm 0.023(stat) \pm 0.006(syst)$ ps^{-1} was presented, while studying $B_S^0 \to J/\psi K^+ K^-$ and $B_S^0 \to J/\psi \pi^+ \pi^-$ events, it turns out that $\phi_S = 0.01 \pm 0.07(stat) \pm 0.01(syst)$ rad, $\Gamma_S = 0.661 \pm 0.004(stat) \pm 0.006(syst)$ ps^{-1} and $\Delta\Gamma_S = 0.106 \pm 0.011(stat) \pm 0.007(syst)$ ps^{-1}. Using 3 fb^{-1} of $B \to DK$ decays a measurement of $\gamma = (67.2 \pm 12.0)^\circ$ was presented.

2. CP Violation and CPT Tests

P. De Simone [2] reported recent KLOE results. Using 1.7 fb^{-1} of data, profiting of the associate production of K_S and K_L at the DAFNE ϕ factory and using a K_L signal in the KLOE calorimeter ("K_L crash") to tag the K_S, a 90% CL limit on $BR\left(K_S \to 3\pi^0\right) < 2.6 \times 10^{-8}$ was set, corresponding to $|\eta_{000}| < 0.088$. With 174 pb^{-1}, tagging a charged kaon decay with the opposite charge kaon (decaying into a muon and a neutrino), 45054 3-pions decays were selected giving a measurement of $BR(K^+ \to \pi^+\pi^-\pi^+) = 0.05526 \pm 0.00035(stat) \pm 0.00036(syst)$ with a relative precision of 9.2×10^{-3}.

A. De Santis [3] discussed the limits on CPT and Lorentz symmetry violation set by the KLOE experiment. Thanks to the entangled production of neutral kaons at DAFNE, using the same decay ($\pi^+\pi^-$) for both kaons, one can look at the difference in the proper time of the decays ordering the two kaons with the momentum direction referred to the fixed stars. Limits on parameters called $\Delta a_0, \Delta a_X, \Delta a_Y, \Delta a_Z$ around 10^{-18} GeV were presented.

A. Di Domenico [4] elaborated about tests of time reversal violation which can be pursued at KLOE-2 (the upgrade of the KLOE experiment) when 10 fb^{-1} will be collected. Using again the entangled production of neutral kaons and using CP tagging decays ($\pi\pi$ or $\pi^0\pi^0\pi^0$) on one side and flavor tagging decays (with a charged lepton) on the other side, four observables can be constructed which cannot be mimicked by CP violation and are genuine tests of time reversal violation. The measurement seems to be feasible but very difficult.

3. Kaon Physics Beyond the Standard Model

A. Puig [5] reported about rare B decays measured by LHCb. The long-sought $B_S^0 \to \mu^+\mu^-$, potentially very sensitive to the presence of new physics phenomena, was finally detected by this experiment and $BR\left(B_S^0 \to \mu^+\mu^-\right) = \left(3.2^{+1.5}_{-1.2}\right) \times 10^{-9}$ was quoted, in good agreement with expectation from the Standard Model. For the analogous, but more elusive, decay of the B^0 meson only un upper limit was set: $BR\left(B^0 \to \mu^+\mu^-\right) < 9.4 \times 10^{-10}$ at 95% CL. Another potential source of new interactions, the decay $B^0 \to K^{(*)0}\mu^+\mu^-$, was studied in detail with particular emphasis to angular observables and lepton forward-backward asymmetry (with the first measurement of the zero asymmetry crossing point), with no sign of beyond of the standard model physics.

G. Ruggiero [6] presented the most precise measurement of the so-called R_K, the ratio of the purely leptonic decay widths of the charged kaon, $R_K = BR(K_{e2})/BR(K_{\mu 2})$, where K_{e2} are the decays of $K^{\pm}$ into an electron and a neutrino, $K_{\mu 2}$ into a muon and a neutrino. Data were collected by the NA62 experiment at CERN in 2007 and 2008 with a monochromatic 75 GeV/c momentum kaon beam. 145958 K_{e2} candidates were selected, with background ranging between 8% and 12% depending on running conditions for K^+ decays and between 12% and 18% for K^- decays. The final result was $R_K = (2.488 \pm 0.007(stat) \pm 0.007(syst)) \times 10^{-5}$, with a 0.4% relative accuracy, in good agreement with the Standard Model expectations.

M. Moulson [7] discussed the prospects to search for forbidden Kaon and Pion decay modes in NA62 (from 2014). The lepton number violating decay $K^{\pm} \to \pi^{\mp}\mu^{\pm}\mu^{\pm}$ was studied in NA48/2 comparing events with same-sign and opposite-sign charge muons, finding 52 candidates with an expected background of 52.6 ± 19.8, which allowed to set a limit $BR(K^{\pm} \to \pi^{\mp}\mu^{\pm}\mu^{\pm}) < 1.1 \times 10^{-9}$ at 90% CL; studies are ongoing to improve the analysis of the same data, while for NA62 there is a potential sensitivity at the 10^{-12} level. Similar sensitivities are expected for many forbidden kaon decays, while for π^0 decays, using the $K^+ - \pi^+$ missing mass from $K^+ \to \pi^+\pi^0$ as a tagging tool, sensitivities in the range of 10^{-11} are expected.

S. Strauch [8] reported on the prospects of the TREK collaboration, a two-stages upgrade of the stopping-kaon E246 experiment at J-PARK. The first phase, called E36, with a partial upgrade of the apparatus in 2014-2015, plans to reach a relative precision of 0.25% in R_K and to perform searches on heavy neutrinos and “dark” photons. The second phase, called E06, when high beam power will be available at J-PARK, plans to improve the measurement of the tranverse muon polarization in $K^+ \to \pi^0\mu^+\nu_\mu$ to 2×10^{-4}, to be compared with the present limit of E246 ($|P_T| < 5 \times 10^{-3}$ at 90% CL) and the expections of the Standard Model including final state interactions (around 10^{-5}).

4. $\Delta S = 1$ Charged Currents: Kaons vs. Taus

I. Nugent [9], on behalf of the BaBar collaborations, discussed recent measurements of τ branching ratios. So-called one-prong τ decays were carefully studied, with a single charged tracks (an electron, a muon, a pion or a Kaon) and one or two neutrinos in the final state; the branching ratios, divided by that with an electron, are called R_μ, R_π, R_K. R_K/R_π gives access to a measurement of $|V_{us}|$ of 0.2229 ± 0.0021; R_K alone gives $|V_{us}| = 0.2214 \pm 0.0022$ and the average with all the τ decays gives $|V_{us}| = 0.2202 \pm 0.0015$, a bit below with respect to results from Kaon decays.

M. Raggi [10] reported about the measurements of semileptonic charged kaon form factors by NA48/2. The Dalitz plots, pion energy vs lepton energy in the kaon rest frame, in the muon and electron case, were fitted, after background and acceptance corrections, with form factors as free parameters. The momentum-transfer dependence of the form factors can be parametrized in several ways: the polinomial and the pole parametrizations were shown. The combination of the electron and the muon channels fits were also shown. In the pole parametrization the vector mass component gave 877 ± 6 MeV, in good agreement with the expected K^* mass, the scalar mass component gave 1176 ± 31 MeV, which has no obvious correspondence. Finally, the world average of all kaon measurements for $|V_{us}|$ was shown: $|V_{us}| f_+(0) = 0.2163(5)$ where $f_+(0)$ is the vector form factor at zero momentum transfer.

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5. Rare and Radiative Decays

G. Graziani [11] presented the new limit of K_S decays into a muon pair by LHCb. This LHC experiment is a real kaon factory, with 10^{13} K_S per collected fb^{-1} and a good mass resolution. Data from 2011 at 7 TeV center of mass energy were used; a boosted decision tree (BDT), with variables related to reconstruction quality and kinematics, other than invariant mass and muon identification, was discussed as a standard tool to set limits. LHCb produced the best result to date in this channel, $BR(K_S \to \mu^+\mu^-) < 11(9) \times 10^{-9}$ at 95%(90%) of CL.

6. $\pi - \pi$ Scattering and Low Energy QCD Predictions

L. Nemenov [12], on behalf of the DIRAC collaboration, discussed the study of exotic atoms, bound states of $\pi^+\pi^-$, $K^+\pi^-$ and $K^-\pi^+$. The pionium lifetime was measured with a 4% precision, $\tau = (2.9 \pm 0.1) \times 10^{-15}$ s, giving access to the absolute difference of the $\pi\pi$ scattering lengths with isospin 0 and 2 with 2% precision. In the $K\pi$ atoms access is given to the absolute difference of scattering lengths of isospin 1/2 and 3/2. 44000 $\pi\pi$ atoms were collected in 2001-2003 and in 2008-2010, while in the same periods 720 ± 49 $K\pi$ atoms were selected.

B. Bloch-Devaux [13] presented a detailed analysis of low energy QCD measurements with the NA48/2 experiment. $K^\pm \to \pi^\pm\pi^0\pi^0$ ($K_{3\pi}$) decays show a "cusp" behaviour in the $\pi^0\pi^0$ invariant mass which allows a precise measurement of the $\pi\pi$ scattering lengths. Charged Kaon $Ke4(+-)$ decays ($K^\pm \to \pi^+\pi^-e^\pm\nu$) can be studied by fitting the spectrum of the five Cabibbo-Maksymowicz kinematic variables in terms of 4 real form factors and one phase. These form factors are parametrized as a function of $\pi\pi$ and $e\nu$ invariant masses and the ratios of these parameters with respect to a reference one were fitted. 1.1 million $Ke4(+-)$ decays were selected and used to measure the Branching Ratio $BR(K^\pm \to \pi^+\pi^-e^\pm\nu) = (4.257 \pm 0.016(exp) \pm 0.031(ext)) \times 10^{-5}$, giving access to the absolute values of the form factors parameters.

7. Non Leptonic Decays and Chiral Perturbation Theory Tests

B. Bloch-Devaux [14] discussed a detailed study of charged Kaon $Ke4(00)$ decays ($K^\pm \to \pi^0\pi^0e^\pm\nu$) with the NA48/2 experiment. The final state can be described by only 3 kinematic variables, thanks to the presence of two identical particles, and can be fitted in term of a single form factor, which can be parametrized as a function of $\pi\pi$ and $e\nu$ invariant masses. A "cusp" behaviour was observed in the $\pi^0\pi^0$ invariant mass, in agreement with what expected from the known values of the $\pi\pi$ scattering lenghts. The branching ratio $BR\left(K^\pm \to \pi^0\pi^0e^\pm\nu\right) = (2.585 \pm 0.010(stat) \pm 0.010(syst) \pm 0.032(ext)) \times 10^{-5}$ was measured with 60000 signal events, giving access to the absolute values of the form factor parameters.

C. Lazzeroni [15] reported on the study of the rare decay $K^\pm \to \pi^\pm\gamma\gamma$ by the NA48/2 and the NA62 collaborations. 130 ± 12 signal candidates (background subtracted) were selected by NA48/2 with data collected in 2004 and 163 ± 13 by NA62 in 2007. The $\gamma\gamma$ invariant mass spectrum was fitted both with a Chiral Perturbation Theory parametrization at $O(p^4)$ and at (partial) $O(p^6)$, with evidence of a "cusp" behaviour at the $\pi\pi$ threshold. The parameter $\hat{c}$ was measured (combining the two data sample, in the $O(p^6)$ parametrization), $\hat{c} = 2.00 \pm 0.24(stat) \pm 0.09(syst)$ giving access in a model dependent way to the branching ratio $BR(K^\pm \to \pi^\pm\gamma\gamma) = (1.01 \pm 0.06) \times 10^{-6}$.

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8. Future Prospects

F. Hahn [16] presented the status of the construction of the NA62 experiment at CERN aimed at a precise measurement of $BR(K^+ \to \pi^+ \nu\bar{\nu})$. A technical run was performed in November 2012 and the first physics run is foreseen for October 2014, with two-three full years of data taking. NA62 must withstands high rates (750 MHz hadron beam, 10 MHz muon rates in the downstream apparatus) and needs high time resolutions for many detectors (100-150 ps). Low mass tracking of beam particles is achieved with a silicon pixel detector, while Kaon decays particles are measured by a magnetic spectrometer based on straw chambers in vacuum. Hermetic vetoing for γs up to 50 mrad is reached thanks to several calorimeters, while muon rejection is achieved by a dedicated muon veto system divided in 3 stations. Particle identification is performed by Cherenkov detectors both for beam particles (KTAG) and Kaon decays products (RICH).

G. Ruggiero [17] discussed the prospects for the $BR(K^+ \to \pi^+ \nu\bar{\nu})$ measurement by NA62. Preliminary results from the 2012 technical run were shown, indicating very good time correlations and resolutions between several detectors. Given the monochromatic Kaon beam, detecting two γs from π^0 decay, the missing mass of $K^+ \to \pi^+\pi^0$ showed a clear and isolated peak at the π^+ mass. For the data taking with the full apparatus, in one year, with 4.8×10^{12} Kaon decays in the fiducial region, 47 signal events are expected (assuming Standard Model decay rates) with less than 10 background events, dominated by $K^+ \to \pi^+\pi^0$.

T. Masuda [18] reported on the detector status of the KOTO experiment at J-Park which aims at the first evidence of $K_L \to \pi^0\nu\bar{\nu}$. A 30 GeV/c momentum proton beam will hit a target and produce K_L at 16^o from the beam line. $K_L \to \pi^0\nu\bar{\nu}$ decays will be identified by reconstructing the $\pi^0 \to \gamma\gamma$ decay with a CsI crystal calorimeter placed at the downstream end of a vacuum tank which also contain various veto detector in a cylindrical geometry, to suppress in particular $K_L \to \pi^0\pi^0$ decays. At the end of 2012 all the detectors inside the vacuum chamber were completed. Few engineering runs were performed between December 2012 and January 2013, demostrating stable operation conditions of all the detectors in vacuum. Reconstructed $K_L \to 3\pi^0$ and $K_L \to 2\pi^0$ events were shown, confirming the good performances of the CsI crystals calorimeter.

M. Togawa [19] presented the status and future prospects of the KOTO experiment. Starting from the experience with the E391a experiment, which reached an upper limit on $BR\left(K_L \to \pi^0\nu\bar{\nu}\right)$ of 2.6×10^{-8}, particular care was taken to suppress neutron induced backgrounds with a collimator system for the neutral beam and a neutron collar counter. A short physics run was made for 12 days in March 2013 and at the beginning of May 2013 a long physics run (more than 30 days) was started, which should allow the crossing of the Grossman-Nir limit of $BR\left(K_L \to \pi^0\nu\bar{\nu}\right)$. The addition at the end of 2013 of an Inner Barrel to the existing Main Barrel, to veto extra γs from $K_L \to \pi^0\pi^0$, will improve the signal to background ratio to 1.8. The Standard Model expectation of the branching ratio should be reached by the end of 2017, allowing the collection of few signal events. A future upgrade of the apparatus (KOTO-step2) is in preparation with a higher intensity beam with the target to collect 100 signal events.

E. Worcester [20] discussed a new experiment proposal, ORKA, to measure $BR(K^+ \to \pi^+\nu\bar{\nu})$ at Fermilab with a stopping-kaon technique similar to the BNL E787/E949 experiment. The P996 detector will be placed inside the former CDF solenoid, profiting of all the present infrastructure. 95 GeV/c momentum protons from the Main Injector will be used to produce 600 MeV/c momentum charged kaons. A factor 100 improved sensitivity is expected with respect to the BNL experiment, a factor 10 coming from the beam intensity and another factor 10 from the detector improvement, aiming at collecting 1000 signal events and 5% precision in the BR in 5 years of data taking.

D. Jaffe [21] addressed the Kaon physics possibility with the Fermilab Project X. $K_L \to \pi^0 \nu \bar{\nu}$ can be studied with an experiment using the former KOPIO collaboration technique: a high intensity, micro-bunched, low energy proton beam (3 GeV/c momentum, 20 ps wide, every 40 ns) would produce K_L whose momentum could be measured by their time of flight. A high efficiency and pointing calorimeter would reconstruct π^0 decays and a 4π solid angle photon and charged particle veto would deeply suppress the unwanted kaon background decays. Of the order of 200 signal events per year could be collected with a signal to background ratio between 5 and 10, aiming at a precision in the branching ratio of 5%.

9. Conclusions

After more than 50 year from mesons discovery, Kaon physics is still a crucial ingredient of Particle Physics, both for the flavor part and for low energy QCD. Several new measurements are continuosly provided and a new generation of experiments is in preparation to address fundamental issues and to search for new phenomena in a complementary way with high energy machines like the LHC.

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