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Summary of the HQL2012 New Experiments Session

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Several new experiments were presented at the The XIth International Conference on Heavy Quarks and Leptons, Prague, June 2012. They mainly belonged to the area usually called Intensity Frontier (or sometimes Precision Frontier). The main rationale for these experiments is to probe New Physics in an indirect way: studying the rare and forbidden processes with the unprecedently high precision and thus unveiling the scale and nature of processes unaccessible by current High Energy experiments. The proposals were coming from several areas (Kaon Physics, B-meson experiments, neutrino projects) and are of different stage of approval or construction. One long-term project has been introduced: the Fermilab Project X.

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1. Introduction

We have been witnessing the recent CERN report about the discovery of the Higgs-like boson. If this is confirmed, it will corronate the great success of the Standard Model (SM) in describing the elementary particles and their fields. However there are numerous hints about effects and measurements, that cannot be explained within the SM and need other mechanisms to be developed. Several theoretical concepts have been proposed to explain the new phenomena and they need to be experimentally tested. Hence there are several proposals for the experiment that can provide testing field for the new models to indicate the right direction to go. The flavour experiments have been providing important insight into the areas innaccessible by existing accelerators since sixties. It is natural they offer their abilities now as well. These experiments are usually grouped in the Intensity (or Precision) Frontier, in contrast to the Energy and Cosmic Frontier projects. This summary aims at bringing together the main goals and features of the experiments presented in the New Experiments session of the the The XIth International Conference on Heavy Quarks and Leptons. More information can be found in the proceedings papers and references therein.

2. Kaon Experiments

Three kaon experiments have been presented in the New Experiments and in the Kaon Physics session: NA62 [1], KOTO [2] and ORKA [3]. They all want to study the kaon decays having the contribution of the flavour changing neutral currents (FCNC) that are forbidden at the tree level of the SM. Current situation is challenging: there exist quite precise theoretical predictions of the branching ratios in the SM[4]:

$$\mathscr{B}_{\text{th}}(K_L^0 \to \pi^0 \nu \bar{\nu}) = (2.43^{+0.39}_{-0.36} \pm 0.11) \times 10^{-11}$$
$$\mathscr{B}_{\text{th}}(K^+ \to \pi^+ \nu \bar{\nu}) = (7.81^{+0.72}_{-0.64} \pm 0.43) \times 10^{-11}$$

while the experimental precision lags behind very much [5, 6]

$$\mathscr{B}_{\text{exp}}(K_L^0 \to \pi^0 \nu \bar{\nu}) < 2.6 \times 10^{-8}$$
$$\mathscr{B}_{\text{exp}}(K^+ \to \pi^+ \nu \bar{\nu}) = (1.73^{+1.15}_{-1.05}) \times 10^{-10}$$

KOTO took its name after the Japanese music instrument, and this reflects the fact, that this project is constructed at the Japanese accelerator centre J-PARC. This experiment aims at studying neutral K-meson decays, namely to obtain the first observations of this decay and to collect 100 events of the SM type. The difficulties arise from the fact that there is no charged particle produced in the decay, and the experimental signal is presence of 2 photons from the neutral pion decay in the detector with defined kinematics. However backgrounds from competing processes must be carefully eliminated.

It is a continuation of the E391a experiment [5], with several improvements, some are listed here:

- factor of 40 increase of the K_L flux
- CsI crystal replacement

- replacement of collimator assemblies

The schedule of KOTO has been affected by the March 2011 earthquake in Japan, and the current plans assume the first physics run at spring of 2013.

The ORKA ('Golden Kaon') experiment aims to study the charged kaon decays. It has been proposed for realisation in Fermilab. In November 2011 the Stage 1 has been approved. The experiment plans to extract a 95-GeV proton beam from the Main Injector ring and select a 600-MeV/c K^+ beam after the target. The charged kaons will be slowed down and get at rest in the middle of the detector, and from their decays, the positive pions will be tracked and identified. The two other decay products, neutrino and antineutrino leave undetected. This poses the main experimental chalenge. The key for background discrimination is the efficient particle identification and full photon detector coverage. The design of ORKA will follow the successful BNL E787 and E949 [7] experiments. Due to many improvements the expected kaon rate is roughly 200/year (a factor of 100 more than in the previous Brookhaven experiments).

The same ultra-rare decay will be studied by the NA62 experiment at CERN. It uses a completely different experimental technique. Here 400 GeV/c-protons from the CERN Super Proton Synchrotron (SPS) hit a beryllium target. Then a secondary beam of positively charged particles with a (75 ± 0.7) GeV/c momentum is extracted. The K^+ fraction there is only 6%. Due to many pions and protons the detectors upstream of the decay region see about 800 MHz rate, and the downstream detectors are subject to a total integrated rate of about 10 MHz, due toK^+ decays and halo particles. Matching both upstream and downstream tracks is possible thanks to precise timing and spatial information. This experiment is under preparation now and the data taking should start in 2014. Within 2 years about 100 events should be seen with a 10% background.

3. B-meson Experiments

Studying processes with heavy quarks and leptons contributed significantly to the forming of the Standard Model, namely in the sector describing CP violation. Most of the experimental results from this area came until recently from two B factories PEP-II at SLAC and KEKB at KEK. Here beams of e^+e^- collided with the unprecedented luminosity at the Υ resonance. 96 % of Υ created decay to $B\bar{B}$. Due to the asymmetry in the energy of electron and positron beams the $B\bar{B}$ system is boosted. This arrangement, in combination with precise vertex reconstruction, allows to register the decay time of the B's and to study time dependence of observed decays. Belle and BABAR, two detectors built at the KEKB and PEP-II, respectively, have accumulated 1500 fb^{-1}, corresponding to over 1 billion $B\bar{B}$ pairs. Because flavour experiments run at low energies have been always very instrumental in uncovering the phenomena of much higher energy scale, 2 new B factories are under preparation, aiming at luminosity increased by almost 2 orders of magnitude. SuperB is planned to be built in Tor Vergata, while KEK started to construct SuperKEKB collider with Belle II detector. Both projects have been presented in this section[8, 9]. Recently a new, strong competition from the LHCb, an LHC experiment devoted to heavy flavour studies has arisen to the B-factories. The LHCb results have been shown extensively in other conference session. Here, plans for the LHCb upgrade were presented[12].

3.1 Super flavour factories

The SuperB factories will be able to perform a broad range of measurements: $B^{0(\pm)}$ meson decays to $B_s^{(*)}$ meson decays, charm physics, τ lepton physics, spectroscopy, and pure electroweak measurements. The strength of these super-flavour factories can be seen at the Fig. 1.

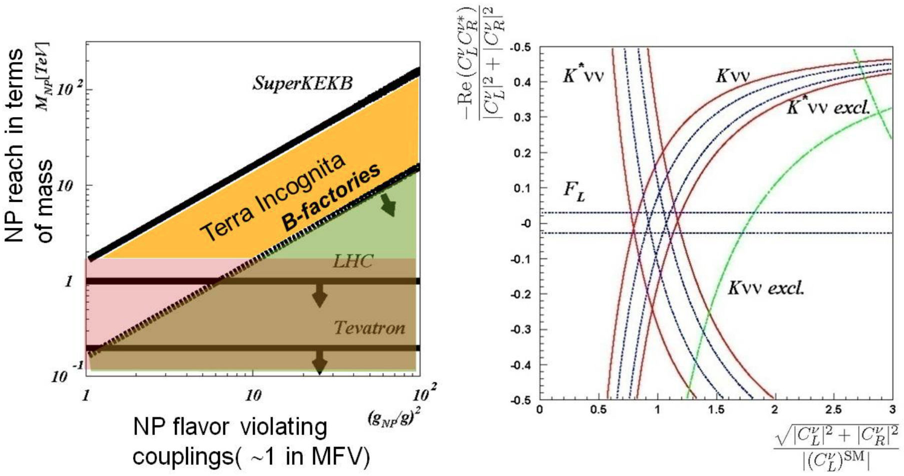

Figure 1: Left: Illustrative region of sensitivity to NP as a function of the flavour violating couplings (relative to the SM) in the indirect searches at KEKB and SuperKEKB, and direct searches at the LHC and the Tevatron. Right: Constraints on the NP right-handed couplings arising from the measurements of $\mathscr{B}(B \to K^{(*)}\nu\bar{\nu})$ with 50 ab^{-1}. The green curves represent current exclusion limits from the existing upper limits on the branching ratios for the two decays. The red curves are the contraints arising from the SuperB factory measurements described in the text, and the blue curves denote the theoretical accuracy (adopted from [10]).

The Super-B factory in Japan is designed as an upgrade of the existing KEKB collider operating since 1999 at the High Energy Accelerator Research Organization KEK in Tsukuba. It has been closed in 2010 after it reached world record luminosity of $\mathscr{L}_{\max} = 2.1 \times 10^{34}\text{cm}^{-2}\text{s}^{-1}$ and brought an integrated luminosity of 1.014 ab^{-1}. The upgrade project has been approved and the upgrade is already on the way with the scheduled startup at 2015. The new machine dubbed SuperKEKB should eventually run at $\mathscr{L}_{\max} = 8 \times 10^{35}\text{cm}^{-2}\text{s}^{-1}$ delivering 50 ab^{-1} by 2022 (see Fig. 2).

In order to exploit fully the luminosity increase at background levels increased by factor of 10-20, substantial upgrade of the Belle detector (called Belle II) is prepared. Large number of the detector components will be reused, but many others (namely electronics) have to be replaced to prevent compromising the detector performance. The baseline design of the Belle II detector is illustrated in Fig. 3

SuperB factory planned to be built in Tor Vergata, near Rome, is even more ambitious both in instantaneous and integrated luminosity. The machine should deliver up to 75 ab^{-1} at the $\Upsilon(4S)$ resonance in the first 5 years of its running. The advantage compared to the Japanese machine is the beam polarisation and ability of running at the τ and charm threshold. Fig. 4 shows the detector proposed for this collider[1].

[1]The latest info [11] says, that the expected funding of this project could not be delivered under current economic

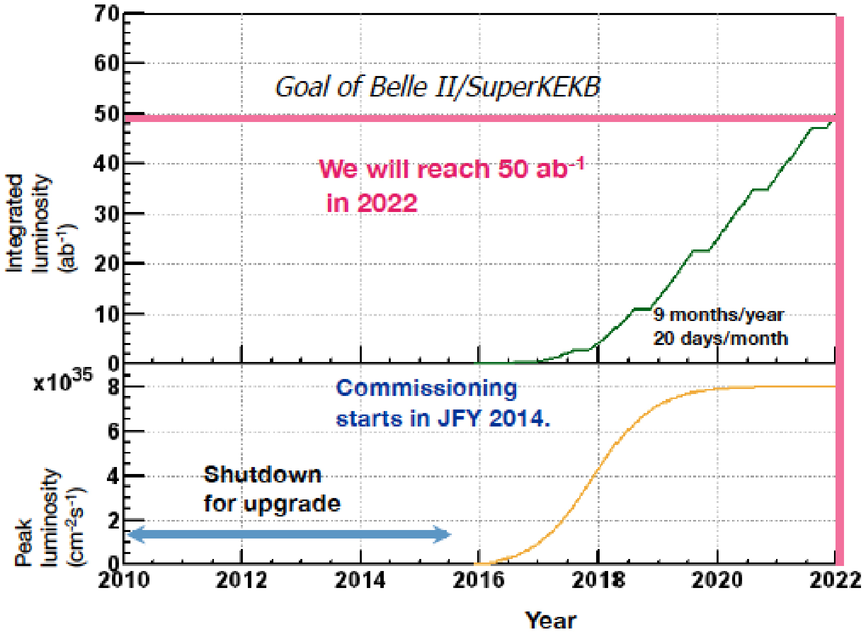

Figure 2: SuperKEKB luminosity prospects

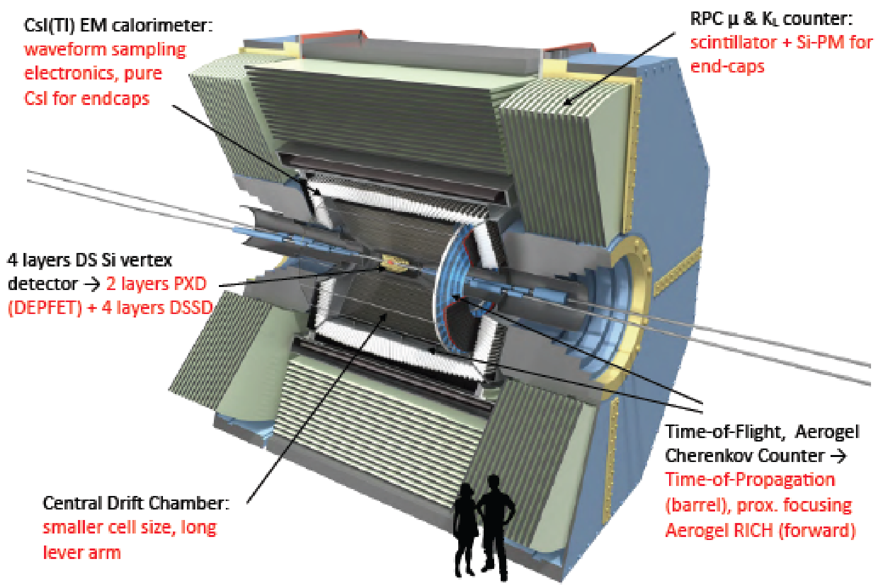

Figure 3: The Belle II detector upgrade

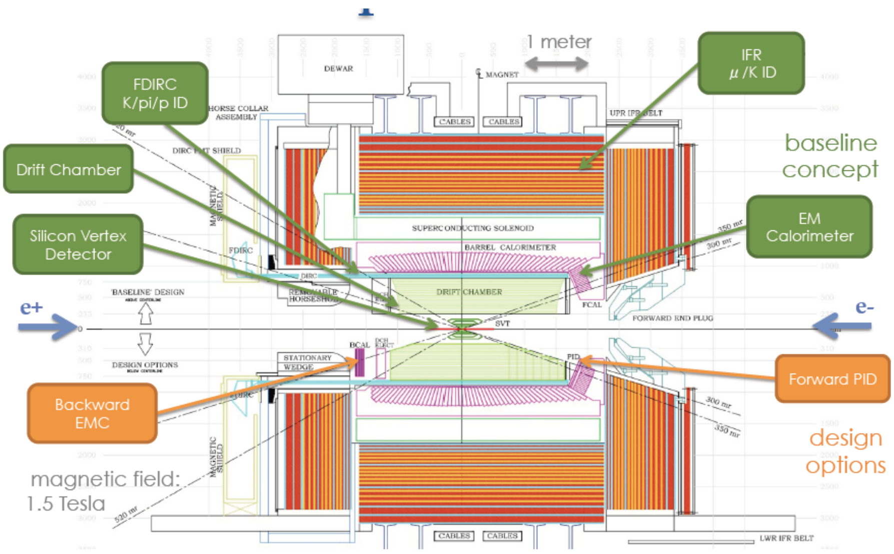

Figure 4: The SuperB detector

3.2 LHCb Upgrade

The LHCb Collaboration decided to upgrade the spectrometer, in order to expand the current physics programme of the experiment to utilize fully the luminosity of the LHC collider. The upgrade plans to increase the readout rate to 40 MHz. The increase of the data rate expected ranges from a factor of ten for the muonic channels to around factor of twenty for decays with fully hadronic final states. The main aim of the measurement with the upgraded detector is to attack the New Physics phenomena, and to search for long-lived exotic particles and to perform detailed study of the weak mixing angle.

The main systems to be upgraded in the LHCb detector are the tracking and particle identification subdetectors. There are still several options for the new tracking system. For the upstream part these are modified planar sensors read out by new ASIC vs. pixel sensors bump bonded to the VeloPix readout ASIC based on the latest MediPix3 chip. For the downstream section silicon micro strip sensors or silicon scintillating-fibres based modules will replace the whole central section of the tracker, while existing gas modules will stay for the remaining part. The PID part, consisting of two RICH detectors, will use new radiator in one of them, and the readout will be replaced by the multi-anode photomultipliers with external readout electronics capable of sending data at 40 MHz. The readout electronics will be changed also in the calorimeter.

4. Neutrino Experiments

Neutrino physics has been quite evolving field already for several years. Recent measurement of θ_{13} by the Daya Bay collaboration added even more to the interest of the subject. The current situation is overviewed in the Neutrino Physics summary[14]. This summary deals with future

circumstances and the τ and charm factory is foreseen instead.

experiments and projects only. Two new neutrino experiments have been presented in this session SNO+ and NOνA.

The SNO+ experiment [13] is a multipurpose neutrino experiment in the final phase of its preparation. It follows the Sudbury Neutrino Observatory installed in the deepest operating underground laboratory SNOLAB in Canada. It will have 2 phases where different detection techniques will be employed. The first, pure liquid scintillator phase is aimed to detect low energy solar neutrinos, with particular interest in CNO and pep neutrinos, geo neutrinos, reactor neutrinos and possibly supernova neutrinos. The current detector of SNO using heavy water will be filled with 780 t of liquid scintillator. It has lower resolution, but its large volume provides for low signal-to-background ratio. Afterwards, the Nd-loaded scintillator will be used instead. Then the SNO+ will concentrate on the search of the neutrinoless double beta decay of ^{150}Nd. First test data was taken this year, and in 2013 the waterfill run will be used to commission the detector. The liquid scintillator should be filled in still in 2013.

Another presented project, NOνA [15] , is an accelerator experiment under construction in Fermilab. Its main mission is to measure simultaneously electron neutrino appearance and muon neutrino disappearance rates. The muon neutrino beam should have energy around 2 GeV. These measurements should contribute to solution of these key problems:

- precision measurement to determine the Dirac phase δ_{CP} of the PMNS matrix
- structure of the neutrino mass states and their relation to the flavour states
- precision measurement of all the neutrino mixing parameters

The NOνA experiment will use three detectors: 15 kt far detector, and 1/4 sized near detector (this will allow to perform the oscillation measurements). An additional smaller (200 ton) near detector has been already built and used to validate design. All these detectors are calorimeters. The active medium is liquid scintillator, read out by Avalanche Photodiodes via the wavelength shifting fibers. The detectors are in an 'off-axis' configuration, i.e. at a small angle off the primary axis, which helps to get neutrinos in a narrow energy band.

The far detector construction started in 2012. First 5 kt of the far detector is planned to be operational by May 2013, the final 15 kt configuration should be installed in the spring of 2014.

5. Long Term Projects

Most of the above presented projects and proposals are in the full swing of design, prototyping, and some of them are already under construction. The real project of the future is Project X, introduced in this session as well [16]. The existing accelerator chain at Fermilab is currently used for several projects already mentioned. For several of them the facilities will have to be upgraded partially. The Project-X program at Fermilab integrates the needed upgrades and transforms the existing accelerator into a high intensity facility which is capable of supporting and expanding the physics sensitivities of the long baseline neutrino program, searches for lepton flavour violation in the muon sector and high precision kaon decay measurements.

The primary features of the Project-X program are:

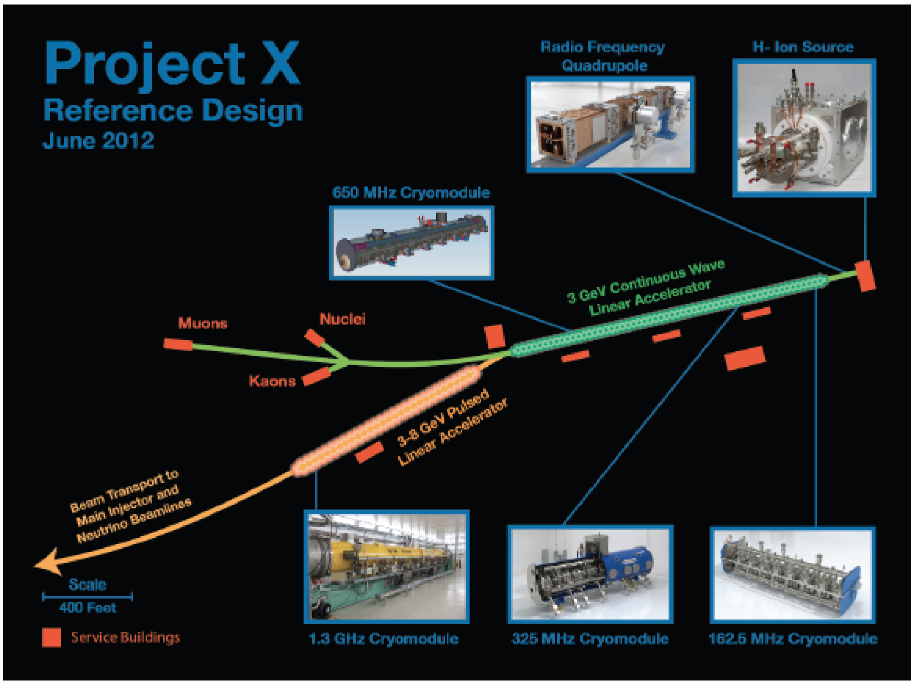

Figure 5: The Project-X reference design

- 2 MW class proton source with an energy between 60-120 GeV for a next generation program of long baseline neutrino oscillation measurements
- high intensity, low energy proton beams to enable a new programs of high precision kaon, muon, nuclei and short baseline neutrino oscillation experiments
- path towards a muon source for a future neutrino factory or muon collider
- establishing beam facilities that can be used to investigate basic energy applications and including driven subcritical systems.

The Project-X reference design, shown in Fig. 5, uses a continuous wave linear accelerator which will replace the current 400 MeV linac. The second accelerator system utilizes a pulsed linac to deliver 300 kW of beam power between 3-8 GeV to support a short baseline neutrino program (precision neutrino oscillations and cross-section measurements). Both the Fermilab main injector and recycler complexes are planned to be upgraded as well to meet the requirements for a 2 MW class beam. The physics capabilities of the Project-X program can be described through the different power stages (details at Fig. 6):

- Stage-0: NOνA Era
- Stage-1: LBNE Era
- Stage-2: Muon Era

Program:	Stage-0: Proton Improvement Plan	Stage-1: 1 GeV CW Linac driving Booster & Muon, EDM programs	Stage-2: Upgrade to 3 GeV CW Linac (MI>70 GeV)	Stage-3: Project X RDR (MI>60GeV)	Stage-4: Beyond RDR: 8 GeV power upgrade to 4MW
MI neutrinos	470-700 kW**	515-1200 kW**	1200 kW	2300 kW	2300-4000 kW
8 GeV Neutrinos	15 kW + 0-50 kW**	0-40 kW* + 0-90 kW**	0-40 kW*	85 kW	3000 kW
8 GeV Muon program e.g. (g-2), Mu2e-1	20 kW	0-20 kW*	0-20 kW*	85 kW	1000 kW
1-3 GeV Muon program	-----	80 kW	1000 kW	1000 kW	1000 kW
Kaon Program	0-30 kW** (<30% df from MI)	0-75 kW** (<45% df from MI)	1100 kW	1100 kW	1100 kW
Nuclear edm ISOL program	none	0-900 kW	0-900 kW	0-900 kW	0-900 kW
Ultra-cold neutron program	none	0-900 kW	0-900 kW	0-900 kW	0-900 kW
Nuclear technology applications	none	0-900 kW	0-900 kW	0-900 kW	0-900 kW
# Programs:	4	8	8	8	8
Total* power:	585-735 kW	1660-2240 kW	4230 kW	5490 kW	11300kW

Figure 6: Project-X power staging plan and and the amount of beam power available to physics programs at each stage

6. Conclusion

Many excellent designs and projects presented show that the field of heavy quarks and lepton has a clear path to future experiments and facilities. Let's hope the projects will find their way to funding agencies and there will be no more news like the one about SuperB financing from November 2012.

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