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ECFA **EUROPEAN COMMITTEE FOR FUTURE ACCELERATORS**

Report on the INFN Super Flavour Factory Project

Working Group set up by the restricted meeting of ECFA

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Introduction

INFN requested European Committee for Future Accelerator (ECFA) to form an opinion on their Super Flavour Factory project during its restricted meeting (RECFA) in Lisbon on 29th of March 2008. Following a proposal by the ECFA chair, K. Meier, RECFA asked one of its members, T. Nakada, to form and chair an internal working group who should prepare a report, which should then be endorsed by ECFA. The working group consists of the four authors of this report. The report consists of a physics section describing the current status of flavour physics and the significance of a future Super Flavour Factory, a short description of the INFN project as understood by the working group, consideration of the global situation, and finally a summary.

The working group adopted the following working practices:

1) To use the existing material as much as possible, in particular for the physics case where many workshops have been held.
2) To have direct communication with the proponents of the project.
3) To consider the worldwide situation in particle physics.

The working group activities included:

1) TN attended the final meeting of the International Review Committee for the INFN Super Flavour Factory project held in Rome in April in order to follow their deliberations.
2) The working group proposed to RECFA the working practice, scope and timescale for producing this report in its May meeting in Uppsala and obtained an approval.
3) All of the working group members visited the INFN Super Flavour Factory project workshop held in Elba in May-June to discuss with many proponents.
4) Two members (FL and TN) visited KEK in June to understand the KEKB upgrade plan.
5) TN visited SLAC in July to understand their intention for how to participate in the INFN project.
6) An intermediate report was orally presented to RECFA during its meeting in July at DESY.
7) In October, YK, FL and TN met with the INFN management and proponents in Frascati to discuss the content of this report in order to avoid factual mistakes.
8) A draft of the report was distributed and an oral presentation was given to RECFA during its meeting in October in Athens in order to collect comments and opinions for the final report to be presented to the Plenary ECFA meeting at CERN in November for an approval.

We would like to thank to all people who provided us crucial input for producing this report.

Physics

Flavour physics has an excellent track record for probing higher energy scales than are directly accessible. Notable examples are the postulations of the doublet quark family structure and charm quark, the third quark family, and the top quark mass that was much larger than speculated previously. Flavour physics has made many essential contributions to establishing the Standard Model.

Flavour physics will undoubtedly continue to play a crucial role as our understanding of phenomena beyond the Standard Model emerges in coming years. If indeed new particles were to be discovered by the high energy frontier general purpose experiments, ATLAS and CMS, flavour physics would provide information needed to identify the exact nature of the New Physics. It is also not excluded that precision flavour physics would provide first evidence for new phenomena, due to the ability to indirectly probe much higher energy scales than those accessible by the direct observation of new particles at the LHC.

BaBar, Belle, CDF and D0 are successfully pursuing this road using B mesons. They have tested very well the Standard Model in $b \to d$ flavour changing neutral current processes, in particular with the accurate measurement for the $B^0 - \overline{B}^0$ oscillation frequency and the CP asymmetry in $B \to J/\psi K_S$ decays, in combination with the $|V_{ub}|$ and $|V_{cb}|$ measurements. All the measurements are generally in good agreement with a unique and consistent description of the Cabibbo-Kobayashi-Maskawa (CKM) mass mixing matrix. The $b \to s$ processes have been explored less thoroughly, the only well-measured quantity being the $B_s - \overline{B}_s$ oscillation frequency. However, there are small discrepancies seen, although not yet statistically significant. For example, the time dependent CP asymmetry in $B_s \to J/\psi\phi$ decays shows a deviation from the Standard Model at a level of about 2σ. CP asymmetries in B^0 decays into hadronic final sates predominantly produced by $b \to s$ penguin processes also show a small deviation. Another interesting puzzle is the difference in the CP asymmetries between $B^0 \to K^+\pi^-$ and $B^\pm \to K^\pm\pi^0$, although this could be due to a not understood hadronic effect.

Starting from 2009, the LHCb will continue this tradition and produce physics based on a 10 fb^{-1} data sample by 2015. If the much speculated anomaly in the $B_s \to J/\psi\phi$ decays were to exist at the level seen now, LHCb would soon establish this unambiguously, and investigation of CP violation in $B_s \to \phi\phi$ might bring a new insight to the current possible deviation from the Standard Model seen in $B_d \to \phi K_S$ if BaBar or Belle fails to resolve this earlier. By that time, LHCb may also discover the effect of New Physics in the area of rare decays, such as $B_s \to \mu^+\mu^-$, $B^0 \to K^{*0}\mu^+\mu^-$ and $\phi\gamma$, where a sizable contribution from New Physics has not yet been excluded.

An integrated luminosity of ~10 ab^{-1} from an e^+e^- collider, i.e. about ten times more than that collected by the current generation of B factories, would address similar physics objectives to LHCb, but with a complementarity coming from their strength in reconstructing final states with multi-π^0's and neutrinos. A real next step requires a data sample in excess of 50 ab^{-1}. This is the goal of the Super Flavour Factory. It will provide a rich physics programme in a wide range of subjects related to flavour physics in both the hadron and lepton sectors (e.g. $\tau \rightarrow e\gamma$) as well as in spectroscopy and QCD studies. It would introduce welcome diversity in the research programme of elementary particle physics and appears to be manageable on a national or at most regional scale. It would also serve as an excellent training ground for students.

It is worth noting that when the construction of the current B factories was discussed, the CKM parameters were actually already quite well known, although CP violation had not been observed outside of the neutral kaon system, nor had it been excluded that its cause would be outside of the Standard Model. With the measured values for Reε and $\Delta m(B^0)$, the required luminosity to test the Kobayashi-Maskawa mechanism for CP violation using the $B^0 \rightarrow J/\psi K_S$ decay mode was well defined and the machine designs were aimed to go beyond. Such a clearly defined luminosity goal cannot be set for a Super Flavour Factory as the New Physics is unknown. A definite luminosity requirement can be given only when we know the values of some New Physics parameters, not limits as now. However, this uncertainty also applies to accelerator projects at the high energy frontier.

INFN Super Flavour Factory Project

Machine design issue

Projected high luminosities of $\geq 10^{36}$ $cm^{-2}s^{-1}$ could be achieved by colliding the two beams with a similar size needed for a linear collider. Unlike a linear collider, where the beams are discarded right after the collision, they must continue to circulate in the storage rings for the next collisions. The emittance required for the beams are that of a damping ring of a linear collider. The two beams are crossing with an angle to avoid unwanted parasitic collisions other than at the interaction point. A crab waist scheme is introduced in order to maintain the beam-beam tune shift. This scheme is being tested at Frascati using the DAFNE storage ring working at $\sqrt{s}$=1 GeV, and showing very encouraging results, although their operating parameters are still far from what would be required. Comprehensive simulation studies are still required in order to fully understand the DAFNE test and to extrapolate safely to the Super Flavour Factory environment. This would be one of the crucial elements for completing the Technical Design Report, which is expected in one to two years.

Project organisation issue

It appears that INFN alone may not have a sufficient number of accelerator physicists and engineers to carry out the whole work needed to complete the Technical Design Report. Institutes from Asia, North America and Europe have been invited by INFN to participate in this design study. This activity would be formalised by a Memorandum of Understanding between INFN and the head of the participating institutes. It is worth noting that SLAC is expected to play a major role. Already now, some experienced machine physicists are participating in the design study.

For the construction and operation, INFN envisage to establish an international consortium with a bilateral agreement between the Italian and corresponding governments to share the cost. As a host country, Italy would contribute at least half of the cost.

For the construction, reusing of the existing components at SLAC, i.e. most of the PEP-II and injection system, as well as the mechanics and magnet of the BaBar spectrometer would reduce the cost of the project considerably and a request of transfer has been made by INFN to SLAC, which has been favourably seen by the US Department of Energy. Italian regional governments have declared their intention to provide the infrastructure such as the tunnel and buildings for a new laboratory. The remaining cost is estimated to be of the order of 200 M€ by INFN.

Since the beam currents are similar to that of PEP-II, requiring only 17 MW of RF power, the operation cost of the machine would not be too high.

Global considerations

Although a Super Flavour Factory, given its total cost estimate of the order of 500 M€ (of which about 200 M€ is still to be found), can be built with a regional effort rather than a worldwide effort, it will have an impact on the international landscape of particle physics, which should be taken into account in the decision process. It is conceivable that the physics case and strategy for a Super Flavour Factory can further be solidified by results from the LHC experiments. The results from the LHC experiments are required for the final decision on the construction of an e^+e^- linear collider in order to optimize the machine parameters.

At KEK, an upgrade of the KEKB is being proposed to achieve a peak luminosity of up to 8×10^{35} $cm^{-2}s^{-1}$. According to the current plan, the KEKB will continue to run in 2009. A three-year shutdown would then start from April 2010 to upgrade the machine and the detector. Data taking would resume from 2013 with a goal to achieve an integrated luminosity of 10 ab^{-1} by around 2016. Their next step would then be to obtain a data sample of 50 ab^{-1} by 2020. The KEK management has already requested a dedicated R&D fund for the fiscal year 2009 together with their plan for the upgrade. Although the designed peak luminosity is less ambitious, their objective is not far from that of the INFN Super Flavour Factory. In their current design, one of the key ingredients for achieving higher luminosities is to store more currents, thus very large RF power of ~60 MW would be needed. It is worth noting that KEK has a well-proven track record in constructing the world highest luminosity e^+e^- storage rings with a strong experienced machine group.

The LHCb experiment is expected to complete the first phase of its physics analysis with $10 fb^{-1}$ data by ~2015. Once any indication of new physics emerges at LHC, there is a serious possibility to upgrade the LHCb detector such that a more than 10 times increase in statistics could be achieved. This would further extend the physics programme in the CP violation and rare decays in the B_s sector as well as purely charged final states such as $K^*\mu\mu$ beyond what can be achieved by a Super Flavour Factory. Whether the final states with multiple-π^0's and missing energy would bring a unique advantage depends on the type of new physics we would be addressing at that time. Studies of lepton flavour violating decay, notably $\tau\to\mu\gamma$ remains unique for an e^+e^- machine[1].

Summary

We consider that **flavour physics should be seen as an important part of the European research programme of elementary particle physics**, complementary to physics provided by the energy frontier experiments. For the coming ~5 years, LHCb will do this job in the b and c quark sectors. To follow-up this progress, **collecting 50 ab^{-1} or more at Υ(4S) energy with e^+e^- storage rings by the end of the next decade would be a significant milestone, if this can be realised at a moderate cost**.

The INFN Super Flavour Factory project team proposes a novel scheme to obtain a luminosity of $\geq 10^{36}$ $cm^{-2}s^{-1}$, two orders of magnitude more than what has been achieved up to now, without increasing the beam currents. This is a distinct advantage for some of the machine operation aspects and background to the experiment, as well as for the running cost of the machine. This idea of obtaining a high luminosity with tiny beam spots at the collision point based on very small emittance beams and crab waist collisions could revolutionize the design of the future colliders. **Therefore, we strongly support the R&D effort to see if such a machine can really be built.**

The current tests at DAFNE are promising and we would like to congratulate the team for this impressive achievement. **However, a substantial amount of work is still required**

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1 For tau and charm physics, an e^+e^- Tau Charm Factory is being considered in Novosibirsk based on the similar concept to the INFN Super Flavour Factory.

for producing a Technical Design Report, which will be a base for establishing an international consortium for the realisation of the project. **A strong core team of experienced accelerator physicists and engineers based at one location should be established already for the TDR work**. Without it, contributions from the various interested laboratories cannot be effectively utilized. **A strong team of experienced machine physicists will be needed also for the operation**. This machine has to achieve its design luminosity in order to be truly competitive.

Given the complexity of the project, we feel that **a clear plan containing realistic technical milestones and resource requirements together with a strategy how to obtain them is needed as a necessary condition for an approval of the project**. Such a plan should aim at **obtaining an integrated luminosity of significantly more than 50 ab^{-1} by not much later than the end of the next decade**. Given the very ambitious time scale, a clear decision taking process must be established soon.