FPCP 2012 Summary Talk on Experiments

Jeffrey A. Appel
Fermilab, Batavia, IL 60510, USA

In over forty presentations on experiments at the 2012 conference on Flavor Physics and CP Violation (FPCP 2012), there was an abundance of beautiful and significant results. This summary of these experiment presentations begins with a reminder of the context in which the measurements have been made and the motivations for making the specific measurements reported at the symposium. Given the number and breadth of physics topics covered at the meeting, this review covers only a limited set of highlights, sort of a traveler’s set of souvenir postcards of favorite slides. The selected slides are grouped into eight overlapping categories as an aid to flipping through the postcards and being reminded of the high points of the conference. Finally, there are some summarizing comments about how the experiment results presented here compare to expectations and what we may hope for the future.

I. INTRODUCTION

Before turning to the experiment presentations at FPCP 2012, it may be useful to review the broader context of the FPCP conference and of the measurements. We often say that particle physics is the study of matter, energy, space, and time. What do we really want to know?

For matter, we want to know:

- Why is the universe so dominantly matter; why is there so little antimatter around?
- Why is matter made of quarks and leptons, antiquarks and antileptons?
- Why are these constituents spin \( \frac{1}{2} \) particles?
- Why do quarks and leptons come in three generations? (And, are there only three?)
- Why do the quark generations have such different masses?
- Why are neutrino masses so small; and why different by generation? Are neutrinos Dirac or Majorana particles?
- Why do quarks come in three colors?

For energy:

- Why is so little of the energy density in the universe composed of the mass that I just listed?
- What is the dark matter we claim is the rest of the matter?
- Why are the force carriers spin 1; not spin 0 for example? Why are gravitons spin 2?
- Why are the strong and electroweak forces flavor independent?
- Why aren’t all interactions flavor independent?

And, for space and time:

- Why are there three obvious spatial dimensions? Are there more?
- Why is the expansion of the universe accelerating? Or, do we not understand gravity/space?

As an aside, note the preponderance of the number three in my list of questions: three dimensions, three generations, and three colors. Are all these trinities related? Are any of them related?

Sometimes we have ideas about possible keys to unlocking the answers to some of these questions:

- Some kind of substructure to explain the pattern of quarks and leptons and generations we see.
- The Higgs mechanism as what nature has chosen for ElectroWeak Symmetry breaking? Do the masses of the \( W \) and \( Z \) come from the same mechanism as that for quark masses.
- A seesaw mechanism involving very massive right-handed partners as the source of the very light neutrino masses.
- The neutrino sector as the source of the matter/antimatter asymmetry of the visible universe. We know now that the asymmetry is not from the CKM matrix in the quark sector (inadequate by 8-10 orders of magnitude).

Not all these ideas are directly testable. Those that are, we are working hard to test. We are doing it by going to higher energies at the LHC and by making more and more precise measurements in the flavor sector. The latter is the focus of our FPCP conferences, of course.

I am reminded of the story of the drunk and the lamp post. Maybe this is only well known in the West, so indulge me if I tell it here. A drunk has lost his keys and is spending a long time looking for them under a lamp post. When asked why he is still looking there, he says that that is where there is enough light to see them! We need to be careful not to make the same mistake. Certainly, look where we think we may find the answers because we have good models to test. However, in parallel, probe as deeply as we can where we don’t have such light to guide us. We have vast new data sets, and we need to check for the unexpected,
too. As a trivial example, in studying decays of particles with heavy flavor to \( h^\pm \ell^+\ell^- \), look for \( h^\pm \ell^+\ell^- \), etc. as well. No matter what our theorist friends tell us about where the answers lie, we have already seen the preferred space of minimal SUSY disappear. And, the space for the Higgs to hide is also closing down. Sorry, I am supposed to say that we are closing in on the Higgs at about 125 GeV/c²! (I note in this post conference write-up the announcements from the LHC and Tevatron after the FPCP 2012 conference indicating the possible discovery of a Standard-Model Higgs boson [1, 2].)

II. RESULTS SHOWN AT FPCP 2012

This brings us to the beautiful results shown at FPCP 2012, many results new since the last meeting, some shown here publicly for the first time. Since I cannot include all my favorite slides in the write-up of the talk, I can only refer the reader to the slides for this summary available from the Proceedings link on the conference web site [3] as an accompaniment to reading this article. As you look over the slides I have selected from the meeting, you will see a personal selection. Afterall, choosing post cards when you are on travel is a personal matter. So, I show some of my favorite postcards from FPCP 2012, those I found especially pretty or revealing.

I won’t repeat all the excellent explanations of the results. I could not do as well as we have heard from the presenters themselves. These explanations are available in slides from the other talks, also available at the conference web site, or in the individual write-ups from the presenters, also available on links from the conference web site.

I would certainly choose a postcard each to remind me of the conference site, the Chinese opera we saw, and the Bao Gong Memorial Park. However, there are also lots of postcards to select with pretty plots and physics content.

My souvenir postcards are organized in eight categories:

- Standard-Model confirmations
- Significant reductions in uncertainty
- New-Physics space ruled out
- Tension with the Standard Model
- New signals and structures
- Hints of new physics
- New techniques and looking beyond the lamp post
- Postcards of the future

Remember, these are just souvenir post cards, visually impressive views of the various physics topics presented, not part of a guide book. See the individual talks for details at the level of a guide book. It should also be obvious that most measurements that I reference could be listed for more than one category.

A. Standard-Model confirmations

New measurements of the speed of neutrinos have confirmed that the earlier measurement of neutrino speed by the OPERA experiment (now revised also by OPERA itself) was wrong. Neutrinos are not superluminal. They do not travel faster than the speed of light. In his talk, Andrew Cohen noted [4] that we should have realized this from known physics, in particular the lack of radiation by high-energy neutrinos from very far away, for example. The OPERA result did motivate serious thinking about the issue, and generated calculations of new, very sensitive limits on the violation of Lorentz invariance by neutrinos.

Andrzej Bozek showed Belle’s result on the rate of \( D_S \rightarrow \tau \nu \), consistent with lepton universality [5]. There is also continuing progress in measurements of \( CP \) violation in the quark sector. Giovanni Marchiori showed BaBar’s first three-sigma evidence of \( CP \) violation in the decay of the \( B \) to three \( K_S \)’s from an analysis of the time-dependence of the decays [6]; and we saw the first three-sigma evidence of \( CP \) violation in \( B_S \) decays from LHCb as shown by Irina Nasteva [7]. Also, note the evidence shown by Yuehong Xie that the heavier \( B_S \) lives longer than its lighter sister (also from LHCb) [8].

Finally, the window for a Standard-Model Higgs continues to be better defined with the more precise measurements of the \( W \) mass by CDF and DZero at the Tevatron [9]. The continued reduction in the “oval of uncertainty” in the Higgs mass from ever more precise top-quark and \( W \) mass measurements at the Tevatron (consistent with a light Higgs as predicted from electroweak measurements and possibly observed as announced soon after the FPCP meeting [1, 2]).

B. Significant reductions in uncertainty

Perhaps the most startling reduction in a measurement uncertainty has come with the surprisingly-quick measurement of \( \theta_{13} \) of the neutrino-mixing matrix parameterization as shown in the talks of Werner Rodejohann, Jianglai Liu, and Phillip Litchfield [10, 12]. The value measured, first and best so far by the Daya Bay experiment, is near the previous upper limit on this parameter. The optimists were right in this case.

There is also the improvement in the uncertainties in the parameters of the so-called unitarity triangles of the CKM quark-mixing matrix as shown in individual presentations and summarized in the talk by Sebastien Descotes-Genon [13].
Also impressive are the measurements of the properties of the $h_C$ by BESIII shown by Guangshun Huang \cite{14} and improvements in the now-lower value of $y_{CP}$ in $D^0$ decays, including the new measurements from BaBar and Belle, reported by Chunhul Chen \cite{15}.

Finally, I note separately the improvements in $B_S$ mixing parameters, including the value of $\phi_S$ reported by Sebastien, Fabrizio Ruffini, and Yuchong Xie \cite{13,16}, progress in reducing the semileptonic decay uncertainties, e.g., in bottom decays as reported by Vera Luth \cite{17}, and in charm form factors from BESIII as reported by Jonas Rademacker \cite{18}.

C. New physics space ruled out

The parameter space for physics beyond the Standard Model is multidimensional. We have become used to presentations of limits when models are reduced to two relevant parameters, whether we are talking about dark matter in terms of cross sections and particle mass or SUSY models at the selected internal-parameter level. Some of the slides presented show measurement limits for physical parameters with a range of model-possibility predictions of the parameters as generated by Monte Carlo techniques to give a sense of how effective the measurements are in restricting the range of model parameters. Other limits come directly from two-dimensional plots of possible model parameters with sections of the space ruled out by the measurements. Some of the plots are quite colorful and artistic in appearance, as well as providing physics insight.

Some of my favorite plots come from the presentation on dark-matter search limits by Xinchou Lou \cite{19} both for generic dark matter and for a possible dark Higgs. Improved limits on new physics come from lepton-flavor violation searches as in the slide on $\mu \to e\gamma$ shown by Francesco Renga \cite{20} and from the ratio of leptonic two-body $K$ decays, $B_K = \Gamma(K \to e\gamma) / \Gamma(K \to \mu\nu)$ shown by Evgenii Goudzovski \cite{21}. Two of the most colorful plots are those shown by Vincenzo Chiochia where constraints on new physics come from top-quark-production asymmetries (forward-backward and charge asymmetries) measured at the Tevatron and LHC \cite{22} and by Nicola Serra showing limits from the rare processes $B \to \mu\mu$ and $B_S \to \mu\mu$ \cite{23} taken from the presentation by David Straub at the EW Rencontres de Moriond this year. Finally, I would include in my postcard collection, the distributions of observed events in the search for $\tau \to \mu\mu\mu$ at LHCb shown by Paul Seyffert \cite{24}.

D. Tension with the Standard Model

Various fits to measurements of CKM unitarity triangles have been shown to highlight possible discrep-

ancies in the single-phase paradigm of the Standard Model. Tensions with the Standard-Model overall fits have been observed, mention being made by Sebastien Descotes-Genon \cite{13} and Koji Hara \cite{25} of issues between the value of $\sin(2\beta)$ and the rate of $B$ decay to $\tau\nu$. Also mentioned by Sebastien were the semileptonic asymmetry in $B$-decay and $B_S$-decay parameters and the same-sign dimuon charge asymmetry measured by CDF and DZero at the Tevatron. Amarjit Soni showed a nice plot from a fit without inputs from semileptonic decays to address concerns over sensitivity to $V_{cb}$ \cite{26}.

Vera Luth noted that the “tension” between inclusive and exclusive analyses of semileptonic B decays remains \cite{17}, while stated uncertainties on the branching fractions and on $|V_{ub}|$ and $|V_{cb}|$ are being reduced. The search for discrepancies between measurements and Standard-Model predictions of $B$-decay rates has revealed a significant excess of events in $B \to D\tau\nu$ and in $B \to D^*\tau\nu$ (3.4 $\sigma$ when the two BaBar excesses are combined). This feature cannot be easily explained. Finally, I would point to the nice plots in the presentation by Rick Van Kooten \cite{27} showing some tension in $B_S$ decay parameters.

E. New signals and structures

Clearly, the observation of electron neutrinos coming from the oscillation of muon neutrinos, giving the large observed value of $\theta_{13}$, is a new signal. I show two more plots on this, which include the individual measurements from Daya Bay, Reno, Double Chooz, T2K, MINOS, KamLAND, and solar-neutrino measurements \cite{11,12}.

We also saw unexpected structures in baryonic $B$ decays from BaBar as shown by Irina Nasteva \cite{7} and, at 6.3 $\sigma$, the first observation of $B_S \to \phi\mu\mu$ from CDF shown by Rick Van Kooten \cite{27}.

The evidence for new $Z$-onium states is becoming more and more compelling, given the nice plots of $Z_{1,2} \to h_b(1, 2)\pi$ from Belle shown by Jin Li \cite{28}. Another visually compelling set of plots demonstrated the suppression of the production the heavier upsilon mesons relative to the ground-state upsilon in heavy-ion collisions as shown by Zebo Tang \cite{29}.

Another signal that is becoming clear with the recent increase of data at LHCb is the zero-crossing point in the forward-backward asymmetry in the decay of $B \to K^*\mu\mu$ shown by Nicola Serra \cite{23}. I have also selected three slides from the presentation of BESIII results shown by Guangshun Huang \cite{14}: the newly observed isospin-breaking decay of $\eta(1405) \to f_0(980)\pi^0$, an anomalous lineshape of the $f_0$ in the decay $J/\psi \rightarrow \gamma f_0\pi^0$, and the first evidence of $\psi(2S) \rightarrow \gamma\gamma J/\psi$.

Perhaps the most unusual new signal was the first direct observation of time-reversal-symmetry violation
in any system. The direct observation comes from using entangled $\Upsilon(4S)$ decays to tagged $B$ mesons. The results shown by Pablo Villanueva Perez [30] come from BaBar.

As already noted, from a time-dependent Dalitz-plot analysis, we saw the first evidence of CPV in $B_S \to K_SK_SK_S$ in the talk by Giovanni Marchiori.

F. Hints of new physics

Among the hints of new physics is the forward-back asymmetry in $tt$ production at CDF and DZero, increasing with the mass of the $tt$ system at CDF as shown by Marc Besancon [31]. There are also hints of the Higgs at ATLAS and CMS shown by David Charlton [9], preceding the already-mentioned announcements after the FPCP conference. I continue to think of this as new physics, though most of you may already consider this a part of the Standard Model.

The surprisingly-large $D^0$ mixing observed has led to suggestions that there might be $CP$-symmetry violation in the charm sector. Combining LHCb and CDF results on the difference of $CP$ asymmetries in $D^0$ decays to $K^-K^+$ and $\pi^-\pi^+$ led Vincenzo Vagnoni to say that the data is consistent with no $CP$ violation at 0.006% CL [22]. Even stated in this way, of course, at this point, we can only say that the data is inconsistent with no asymmetry at the given confidence level. The issue of $CP$ violation is still being debated among theorists! Can the asymmetry be due to Standard-Model long-distance effects?

G. New techniques and looking beyond the lamp post

New techniques include both the application of new analysis methods and improvements made to previous analyses. Manuel Tobias Schiller showed LHCb multibody-decay results using combined Gronau-London-Wyler (GLW) and Atwood-Dunietz-Soni (ADS) methods and also taking advantage of the strong variation of hadronic parameters over the Dalitz-plot phase space [23]. David Charlton showed how analysis improvements allowed CDF to obtain more precise results in their search for the Higgs boson than what one would expect from the simple increase in data as the integrated luminosity grew over time [9]. Similar improvements have been made at DZero, and we may expect similar things from the LHC experiments too, as they accumulate more data and experience.

As mentioned earlier, searching for the unexpected is looking beyond the lamp post. Liang Sun showed the event distributions for searches for an unexpected $B^+ \to D^-\ell^+\bar{\nu}$ by Belle [24].

H. Postcards of the future

I was going to reserve the last slide for postcard images of the new facilities shown in the first session of the final day. However, I decided to focus on the physics we expect most. The fact is, I am less certain what to expect than I have been for many years. So, I have left space in my postcard collection for next year’s souvenirs!

III. SUMMARY

As we flipped through the souvenir picture postcards of experiment results selected from all those presented at FPCP 2012, we have seen a wonderfully-rich abundance of new results. Yet, the selection presented here is necessarily incomplete. At best, it gives a sense of the impressive range of activity in flavor-physics and $CP$-violation experiments, and of the very high quality of the data and analyses being generated.

There were over 40 experiment talks! In these talks, there were presentations of results which included Standard-Model confirmations, significant reductions in uncertainty, New Physics spaces ruled out, new signals and structures, hints of New Physics, and still some tension with the Standard Model. And, there were also places where results were presented which explored the possibility of unexpected signals, looking beyond the lamp post.

There were, perhaps, fewer outstanding experimental issues relative to what was presented at FPCP 2011, less tension with the Standard Model this year. Nevertheless, there is growing disquiet over not seeing directions for the answers to the questions about matter, energy, space, and time that were listed in my introduction. There is no certainty about the direction of the needed New Physics. [The signals around 125 $GeV/c^2$ shown by ATLAS and CMS after FPCP 2012 also seems consistent with the Standard-Model Higgs boson, though this is by no means yet proven.] We may hope for one or more bright new ideas that could provide additional lamp posts to light our way. But this hope is not something that we can count on soon. Thus, it is hard to predict what the post cards will look like next year at FPCP 2013 in Buzios, Brazil. Nevertheless, given the huge data sets collected and anticipated, there is excellent reason for hope! As has happened in the past, data may be the key to future progress in our understanding.

Acknowledgments

I close this last talk of the Flavor Physics and CP Violation 2012 meeting with a big and sincere thank
you to all the presenters. Obviously, I have taken freely from their presentations for this summary. I also want to thank especially the organizers of this very enjoyable, interesting, and informative meeting.

My work is supported, in part, by the US Department of Energy through Fermilab, which is operated by Fermi Research Alliance, LLC under Contract No. DE-AC02-07CH11359 with the Department of Energy.

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