Colloquia: TOP2010

Fourth generation—Towards effect of large Yukawa coupling

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Summary. — In this paper we cover two threads regarding the 4th generation: on CP violation, from Earth up to the Heavens, *i.e.* from accelerator-based experimental studies, towards baryon asymmetry of the Universe; and on direct search bounds on $m_{t'}$ and $m_{b'}$, towards the possibility of electroweak symmetry breaking through large Yukawa couplings. Prospects and discussions are presented.

PACS 11.30.Er – Charge conjugation, parity, time reversal, and other discrete symmetries.
PACS 11.30.Hv – Flavor symmetries.
PACS 12.60.Jv – Supersymmetric models.
PACS 13.25.Hw – Decays of bottom mesons.

1. – Introduction: the four statements

Interest in the fourth generation (4G, or SM4) seems warming up. Not only there is this dedicated invited talk at the TOP2010 workshop, but the summary "Four Statements about the Fourth Generation" [1] of a dedicated workshop held in September 2008 at CERN, received 50+ citations within a year of posting. The four statements are:

1) The fourth generation is not excluded by EW precision data.

2) SM4 addresses some of the currently open questions.

3) SM4 can accommodate emerging possible hints of new physics.

4) LHC has the potential to discover or fully exclude SM4.

A followup *2nd Workshop on "Beyond 3 Generation Standard Model"*, subtitled *"New Fermions at the Crossroads of Tevatron and LHC"*, `http://indico.cern.ch/conferenceDisplay.py?confId=68036` was held January 2010 in Taipei. It would likely be followed up further.

In this paper, we limit ourselves to two threads related to the 4th generation. The first thread is on CP violation (CPV). We start from "hints from B factories" that link to "CPV in $B_s \to J/\psi\phi$ at Tevatron" (both under Statement 3), and discuss "LHCb prospects" (under Statement 4). The real importance is beyond CPV studies on Earth, but with Heavenly implications, *i.e.* the possibility to address "new CPV source for BAU" (Baryon Asymmetry of the Universe, which is under Statement 2)!

A second thread starts from "Tevatron direct search" (under Statement 3) for the t' and b' quarks, which naturally links to "ATLAS and CMS discovery prospects" (under Statement 4). This offers "new perspective on Higgs naturalness" (under Statement2), in particular, perhaps touching on the mechanism underlying electroweak symmetry breaking. As such, it could "impact on Higgs searches" at the LHC (under Statement 4).

2. – CPV4U: from Earth to Heaven

2˙1. *Earthly thread*. – Direct CPV (DCPV) in $B \to K\pi$ decay, and the difference between charged and neutral modes, are rather personal to me.

In his plenary talk at ICHEP2004, Yoshi Sakai (now a Belle spokesperson) showed the emerging 2.4σ difference between DCPV in $B^+ \to K^+\pi^0$ and $B^0 \to K^+\pi^-$ from the Belle experiment. He showed the Z-penguin diagram for $B^- \to K^-\pi^0$ decay, and offered the questions: Large EW penguin? New Physics? These words were coming from my first draft writing of ref. [2]. Personally, I was quite shaken. Though not yet significant (but consistent with BaBar!), the difference is staggeringly large, larger than the -10% asymmetry in the neutral B mode. The latter is generated by the strong penguin, with the help of some "hadronic" CP conserving phase. How can some effect that enters this difference between the $B^+ \to K^+\pi^0$ and $B^0 \to K^+\pi^-$ modes be so large?

I recalled my first B paper—also my first 4G paper—on the nondecoupling of large top quark mass effect on $b \to s\ell^+\ell^-$ (and $s\nu\bar{\nu}$) rate [3]. Compared with the photonic penguin, where naive counting gives it at αG_F order, one would have thrown away the Z-penguin, which is at G_F^2 order. Even after noticing the mismatch of mass dimensions, taking m at m_b scale, $G_F m_b^2$ is still much smaller than α. Direct computation, however, showed that m is closer to m_t, and the Z-penguin can overwhelm the photonic penguin for $m_t \sim M_W$ or heavier. This evasion of the familiar decoupling theorem (which works in QED and QCD) is because the heavy mass not only appears in propagators (hence damps the amplitude—decoupling), in spontaneously broken chiral gauge theories, masses can appear in the numerator as Yukawa couplings. Thus, this nondecoupling is a special dynamical phenomenon in χGT that undergo SSB, such as the electroweak theory.

With this backdrop, I worked out, with Makiko Nagashima and Andrea Soddu, that [4] the t' quark could indeed jack up $A_{K^+\pi^0}$, turning it positive as compared with $A_{K^+\pi^-} \simeq -10\%$. Besides enjoying nondecoupling, the heavy t' quark brings in new CPV phase in $V_{t's}^* V_{t'b}$, while $V_{ts}^* V_{tb}$ has practically no phase within 3G.

The nondecoupling of t and t' in the Z-penguin is echoed in the better known box diagram for B^0–$\bar{B}^0$ mixing. Thus, if there is a large CPV effect in the $b \to s$ Z-penguin, a corollary is that the box diagram for B_s^0–$\bar{B}_s^0$ mixing would pick up a large CPV phase, and tagged time-dependent CPV (TCPV) in $B_s \to J/\psi\,\phi$, as well as $A_{\rm SL}$, should yield a large effect. A prediction [4] of $\sin 2\Phi_{B_s} \sim -0.2$ to -0.7 was given for TCPV in

$B_s \to J/\psi\,\phi$. When Δm_{B_s} became precisely measured by CDF in 2006, we refined the prediction [5] to

$$(1) \qquad\qquad \sin 2\Phi_{B_s} \sim -0.5\ -\ -0.7, \qquad (m_{t'} = 300\,\text{GeV})$$

by comparing Δm_{B_s} with $\mathcal{B}(B \to s\ell^+\ell^-)$. We used $A_{K\pi}$ difference only to select the sign of $\sin 2\Phi_{B_s}$, since there is some controversy of "hadronic effect" on the $A_{K\pi}$ difference.

Thus, large CPV in B_s mixing is possible, despite Δm_{B_s} and $\mathcal{B}(B \to s\ell^+\ell^-)$ both being SM-like (these have f_{B_s} or form factor dependence, respectively). Although measurement would be a sure thing once LHCb has data, Tevatron now has a chance for big discovery, and for this sake I made a dedicated trip to Fermilab in Spring 2007, to present the case to a joint B audience from CDF and DØ. Somewhat spectacularly, first in December 2007 by CDF, then February 2008 from DØ, followed by a summer 2008 update[1] by CDF, three consecutive measurements at the Tevatron yielded large central values consistent with eq. (1), although the significance was not much more than 2σ. The SM3 expectation is -0.04. After much work, the final combined significance [6], announced at EPS-HEP2009, is 2.1σ. But more data is in store at the Tevatron.

Indeed, there is very recent new activity. Two weeks before TOP2010, DØ reported [7] a significant signal for same-sign dimuons,

$$(2) \qquad A_{\text{sl}}^{\text{b}} = -0.00957 \pm 0.00251\,(\text{stat}) \pm 0.00146\,(\text{syst}), \qquad \text{DØ, } 6.1\,\text{fb}^{-1},$$

which is a combination of A_{sl}^s and A_{sl}^d, the respective dimuon asymmetries arising from B_s^0 and B_d^0. The result of eq. (2) is 3.2σ from the SM expectation of $-0.00023^{+0.00005}_{-0.00006}$, which is practically zero compared to the DØ value. The central value is in fact almost identical to the 2007 result, but DØ was able to reduce the error by a factor of 2, strengthening the discrepancy with SM on the $\sin\phi_s$–$\Delta\Gamma_s$ plane (note that $\sin 2\Phi_{B_s} = -\sin 2\beta_s = \sin\phi_s$, where $-2\beta_s$ is the notation of CDF, while DØ uses ϕ_s).

Very shortly after the DØ announcement, CDF updated [8] (at FPCP2010, the week before TOP2010) their tagged $B_s \to J/\psi\,\phi$ study, to a dataset of $5.2\,\text{fb}^{-1}$, almost doubling the data from 2008. Δm_{B_s} is remeasured with the new data, which is impressive. The value for β_s has weakened, to only a variance of 0.8σ from SM. What is intriguing is that, adding the extra data, a wedge is drawn right up the previous most likely β_s value, so the diminished β_s value is actually the combination of equal likelihood of near zero, or some value even larger than before. In other words, it smells like large fluctuations.

What can one make of these new developments? First, DØ and CDF are consistent with each other, though $\sin 2\Phi_{B_s}$ seems weaker than before. Second, using the formulas and arguments from ref. [9], A_{sl}^s, a derived quantity from the measured A_{sl}^{b} (called $A_{\text{SL}}^{\text{TeV}}$ in ref. [9]) by input of B_s^0 and B_d^0 production fractions, is equal to $\Delta\Gamma_s^{\text{SM}}/\Delta m_s \times \sin\phi_s$. Hence, $|A_{\text{sl}}^s| < 0.008$ if one uses the Lenz-Nierste result [10] for $\Delta\Gamma_s^{\text{SM}}$, the CDF measured value for $\Delta m_s \equiv \Delta m_{B_s}$, and saturating $|\sin\phi_s|$ by 1. That this bound is already violated by the DØ result means that $\Delta\Gamma_s^{\text{SM}}$ is larger than the Lenz-Nierste estimate, which implies "hadronic" enhancement may be present. This enhancement seems sizable, if one

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[1] In the summer 2008 public note (CDF/ANAL/BOTTOM/PUBLIC/9458) from CDF, I had the special honor of being quoted as "George Hou predicted the presence of a t' quark with mass between ~ 300 and $1000\,\text{GeV}/c^2$ in order to explain the Belle result and predicted *a priori* the observation of a large CP-violating phase in $B_s^0 \to J/\psi\,\phi$ decays", citing refs. [4] and [5].

considers a smaller, rather than larger, value for $\sin 2\Phi_{B_s}$ as indicated by CDF update. Alternatively, assuming that the DØ result stays, perhaps New Physics affects Γ_{12}^s [11], *i.e.* width-mixing, which is usually viewed as more exotic than affecting mass-mixing. The 4th generation does not affect Γ_{12}^s in any significant way.

In fact, because of rising $m_{t'}$ bounds (as we shall soon turn to), we have reinvestigated the 4G impact with heavier $m_{t'} = 500\,\text{GeV}$, and found [12]

$$\sin 2\Phi_{B_s} \sim -0.33, \qquad (m_{t'} = 500\,\text{GeV}). \tag{3}$$

This is in remarkable agreement with the softening of $\sin 2\beta_s$ from CDF update, and rhymes also with the direct $m_{t'}$ bounds that are now higher than the $300\,\text{GeV}$ value used in eq. (1). The bad news, for Tevatron at least, is that such lower $\sin 2\Phi_{B_s}$ values probably can never be "observed" at the Tevatron, and would need LHCb to verify.

LHCb data is eagerly awaited.

2˙**2.** *Heavenly touch—Towards BAU*. – In his acceptance speech at Nobel 2008 ceremonies, Kobayashi sensei mentions "Matter dominance of the Universe seems requiring new source of CP violation." Let us try to understand the meaning of this statement.

Kobayashi and Maskawa received the Nobel prize because the B factories, *viz.* the BaBar and Belle Collaborations, measured the CPV phase that verified the nontrivial realization of the CKM unitarity condition $V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$. There is one subtlety, as we all learned in particle physics class: Any degeneracy of a like-charge quark pair would allow a freedom to absorb the unique CPV phase within SM3. Effectively, one goes back to the 2 generation case where of course there is no CPV. This subtlety is nicely summarized in the so-called Jarlskog invariant [13] for CPV,

$$J = (m_t^2 - m_u^2)(m_t^2 - m_c^2)(m_c^2 - m_u^2)(m_b^2 - m_d^2)(m_b^2 - m_s^2)(m_s^2 - m_d^2)\, A, \tag{4}$$

where A is the area of any unitarity triangle, such as the aforementioned "$b \to d$ triangle". J can be derived [13] from the algebraic quantity Im det $[M_u M_u^\dagger, M_d M_d^\dagger]$. What Kobayashi meant, then, is that J is short by at least 10^{-10} from what is needed for BAU. To illustrate numerically, compared with the dimensionless number $n_{\mathbf{B}}/n_\gamma$ (baryon over photon density) measured by WMAP to be $(6.2 \pm 0.2) \times 10^{-10}$, a dimensionless analysis by normalizing with the phase transition temperature $\sim 100\,\text{GeV}$, gives $J \sim 10^{-20}$, hence falling short by over 10^{-10}.

Let me make a jump and state that Belle published a paper in the journal *Nature* in 2008. In a single paper, Belle measures both $A_{K^+\pi^0}$ and $A_{K^+\pi^-}$ and finds [14]

$$\Delta A_{K\pi} \equiv A_{K^+\pi^0} - A_{K^+\pi^-} = 0.164 \pm 0.037, \qquad (\text{Belle, } \textit{Nature 2008}) \tag{5}$$

which is a 4.4σ effect. Note that the effect is stronger than the measured DCPV in B decay, $A_{K^+\pi^-} \simeq -10\%$. *The difference is large*, experimentally established (together with BaBar), and *was not predicted*. Across the Atlantic, however, many dismiss this effect as likely due to "hadronic effects" in "enhanced color-suppressed tree" ...

I mention this *Nature* paper because, as a principal author, in trying to "explain the importance of CPV to biologists", I literally went "out of my mind": the mindset was very different from our daily living as particle physicist. One day in early Fall 2007, I noticed that, if one shifts by one generation, *i.e.* from $123 \to 234$, eq. (4) becomes

$$J_{(2,3,4)}^{sb} = (m_{t'}^2 - m_c^2)(m_{t'}^2 - m_t^2)(m_t^2 - m_c^2)(m_{b'}^2 - m_d^2)(m_{b'}^2 - m_b^2)(m_b^2 - m_s^2)\, A_{234}^{sb}, \tag{6}$$

where A_{234}^{sb} is an approximate triangle that governs the large CPV effect in $b \to s$ transitions. Plugging in numbers, with $m_{t'}$ and $m_{b'}$ ranging in between 300 to 600 GeV, $J_{(2,3,4)}^{sb}$ (eq. (6)) is typically enhanced by 10^{13} to 10^{15} compared to J (eq. (4)), and the gain is mostly through the *large Yukawa couplings* of 4G quarks. By simply going from 3G to 4G, one seems to gain enough CPV for BAU! When I filed the simple writeup from a Zürich hotel room in early March 2008, Providence was indicated in the number [15]— .1234—returned by arXiv, for a paper on the 4th generation! Would Nature use this? One should note that the real staggering factor is this 1000 trillion enhancement. To me, this is the single most important motivation for the existence of the fourth generation (this line was quoted by David Shiga in his New Scientist article dated June 1, 2010, which was stimulated by the DØ result of eq. (2)).

It is mind boggling to think that, as we look up to the starry heavens (Kant!!), what we do on Earth matters—to understand the disappearance of antimatter from the Universe! We caution, of course, that there is still the unresolved issue of the order of phase transition [15], and it is not clear yet whether 4G can help resolve it.

2˙3. *Unfinished on Earth*. – There are other predictions, such as on $A_{\mathrm{FB}}(B \to K^* \ell^+ \ell^-)$. But let me give a more general comment on boxes and penguins.

It was through the quark level box diagram for K^0–$\bar{K}^0$ mixing that we first learned the GIM mechanism, inferred the charm quark mass, and accounted for ε_K (with the top). It was through the $s \to d\bar{q}q$ electroweak or Z-penguin, that we learned of a diminished ε'/ε, and of the strength of $K \to \pi\bar{\nu}\nu$ (which still awaits precision measurement). It was through the quark level box diagram for B_d^0–$\bar{B}_d^0$ mixing that we first learned that the top is rather heavy, allowing also the clean measurement of $\sin 2\phi_1/\beta$ ($\sin 2\Phi_{B_d}$ in our definition). It was through the Z-penguin dominance with heavy top that the $b \to s\ell^+\ell^-$ rate was first estimated in 1986, which was measured only by 2002. All these effects, practically all the important FCNC and CPV effects within the 3G KM model (SM3), are due to effects of nondecoupling, because of large Yukawa coupling of the top quark (and charm for Δm_K).

All these were just with 3 generations. If a 4th generation exists, every aspect above would be touched by t': B_s system, A_{FB} in $B \to K^* \ell^+ \ell^-$ ($B \to X_s \ell^+ \ell^-$), and $K \to \pi\bar{\nu}\nu$; or by b', *e.g.*, in D^0–$\bar{D}^0$ mixing (especially the CPV part). Besides the study of the B_s system, of particular importance would be a future measurement of $K_L \to \pi^0\bar{\nu}\nu$, which is purely short distance CPV. It would provide us access to $V_{t'd}$ in the future [12]. The KOTO experiment (E14) at J-PARC is to be watched.

Of course, nothing beats the direct discovery of the t' and b' quarks for establishing SM4, and the LHC would soon take the lead.

3. – Direct search: large Yukawa coupling and EWSB?

We now turn to the Tevatron thread of direct search for t' and b' quarks. We would be more cursory, as much work is towards the future, and no discovery can yet be claimed.

3˙1. *Tevatron thread—t' and b' search status*. – CDF has had a long stretch of an effort [16], lead by the UC Davis group, in searching for heavy top-like signals. Specifically, one searches for pair-produced $t'\bar{t}'$ with $t' \to Wq$, where one W undergoes leptonic decay, so the signature is ℓ plus missing p_T (E_T) plus 4 or more jets. No b-tagging is imposed for sake of efficiency, with the advantage that no assumptions are made of the decay q flavor from t'. Starting from sub-fb^{-1} data, the interesting, if not nagging feature is some

high $M_{\rm reco}$ activity (projected on $M_{\rm reco}$-H_T plane, where $M_{\rm reco}$ is the reconstructed mass mimicking $m_{t'}$, and H_T is a variable measuring amount of transverse activity), that do not seem to go away as the data increases.

In the latest public result in CDF Note 10110 [16], once again the limit on t' cross section *vs.* $m_{t'}$ does not drop as expected, "saturating" roughly at $0.1\,{\rm pb}^{-1}$ beyond $\sim 250\,{\rm GeV}$ (close to the published limit [16]), giving the observed bound

$$(7) \qquad\qquad m_{t'} > 335\,{\rm GeV\ at\ 95\%\ CL}, \qquad {\rm CDF,\ } 4.6\,{\rm fb}^{-1},$$

by comparing with theoretical cross sections. The expected sensitivity is $372\,{\rm GeV}$. Figure 3 of CDF Note 10110 compares the seeming excess in H_T and $M_{\rm reco}$ with a t' signal at $450\,{\rm GeV}$. The excess has less than 2σ significance, and if it were from a $450\,{\rm GeV}$ t', the cross section would be too high.

With increased dataset, CDF has pursued another mode, searching for $b'\bar{b}'$ pair production, followed by $b' \to Wt$ decay [17]. The presence of more than 3 Ws in the final state allows the ultra clean signature of same-sign dileptons (much higher in p_T than the many more low-p_T events that lead to eq. (2)), together with missing energy and multijets. Based on $2.7\,{\rm fb}^{-1}$ data, two events are seen, one with 4 and the other with 5 jets, whereas signal would have preferred more jets. Because of the cleanness of the signature, a stringent bound of [17]

$$(8) \qquad\qquad m_{b'} > 338\,{\rm GeV\ at\ 95\%\ CL}, \qquad {\rm CDF,\ } 2.7\,{\rm fb}^{-1},$$

was extracted, which should be compared with the t' bound of eq. (7). A more stringent bound can be extracted for the so-called "top-partner" quarks with charge $+5/3$.

While Tevatron has more data to unfold before us, the LHC has finally started running, albeit at half the design energy at $7\,{\rm TeV}$. It is clear that, once the LHC has real data, it would quickly overtake the Tevatron in the direct search of heavy new particles. The CMS experiment has illustrated recently its potential with the official LHC target of $1\,{\rm fb}^{-1}$ at $7\,{\rm TeV}$ by the end of 2011. In the public CMS Note-2010/008 [18], CMS showed that, with just $100\,{\rm pb}^{-1}$ data, the mass bound on b' via the aforementioned same-sign dilepton approach would already surpass the current bound from CDF. These results are based on $14\,{\rm TeV}$ (done in 2008), then $10\,{\rm TeV}$ simulation studies, then scaled down in energy to $7\,{\rm TeV}$. The same document showed that, with $1\,{\rm fb}^{-1}$ at $7\,{\rm TeV}$, the exclusion bound on b' would reach $500\,{\rm GeV}$. It would likely reach beyond $500\,{\rm GeV}$, as LO cross sections were used in the study.

Hereby one touches a new, different nerve. At $500\,{\rm GeV}$, one is approaching the so-called partial wave unitarity bound [19], where strong Yukawa coupling of these heavy chiral quarks would lead to a breakdown of probability. Translated, it means that one would need to solve the strong Yukawa coupling theory nonperturbatively.

3˙2. *Nambu legacy—$\overline{Q}Q$ condensation by large Yukawa coupling.* – Half of the 2008 Nobel Prize went to Nambu sensei, "for the discovery of the mechanism of spontaneous broken symmetry in subatomic physics".

The thought goes far back to the original observations of Nambu in the early 1960s, in the form of the Nambu–Jona-Lasinio (NJL) model. In 2007, when my mind was full of thoughts about large Yukawa couplings, nondecoupling, and CPV for the Universe, I re-traced this thread with the help of several papers by Bob Holdom [20]. Holdom emphasized the old thought that large Yukawa coupling (or the strong interaction theory

behind it) could lead to $\overline{Q}Q$ condensation, illustrating with nothing but the old and venerable NJL model. Discussions go back to the late 1980s, as the top grew heavier, by Bardeen, Hill and Lindner and others, even entertaining the thought of a heavy 4th generation. From a "dual" AdS/CFT strong-weak coupling correspondence point of view, Gustavo Burdman recently promoted the "holographic 4th generation" [21]. In short, the conjecture is: *Could electroweak symmetry breaking (EWSB) be due to b' and t' quarks above the unitarity bound of 500–600 GeV?* The fascination resonated with the gain of 1000 trillion (through eq. (6)) on CPV for heavy 4G quark masses in the range of 300–600 GeV, *i.e.* large Yukawa couplings. And then Nambu received the other half of the 2008 Physics Nobel Prize.

In part because I was given the task to "lecture on the recent Nobel prize" [22] at FPCP2009, I literally retraced the thread that started with Nambu. Nambu expressed strong doubts about the origin of the "Higgs mechanism" and the nature of the Higgs particle. In his Nobel lecture (delivered by Jona-Lasinio), on mass generation for the gauge field, he expressed "I thought the plasma and the Meissner effect had already established it." In regard to fermion mass generation in the electroweak Standard Model, he compares with several examples of fermion-pairing that exhibit BCS type of SSB, such as ^{3}He superfluidity and nucleon pairing in nuclei, and comments: "my biased opinion, there being other interpretations as to the nature of the Higgs field", as if it should also arise from some fermion pairing phenomena.

Let us learn once more from Nambu!

3'3. *Higgs-Yukawa on a lattice*. – Out of sheer curiosity, I started talking to local lattice theorists since early 2008, regarding putting the Higgs-Yukawa sector on a lattice. It seemed the natural approach towards strong Yukawa coupling, and would become the only approach if things are nonperturbative. Note that people are implementing "walking technicolor" on the lattice. For Higgs-Yukawa on a lattice, it is known that there are issues of "triviality", that if one sends the cutoff to infinity, the coupling constant would have to vanish. So, strong coupling would imply that the cutoff is not far away.

Introduced through a colleague, I learned of the work of Gerhold and Jansen, who already studied [23] the phase structure (and Higgs mass bounds) of the Higgs-Yukawa model on a lattice, but had not explored the issues more intrinsic to EWSB. So in the aforementioned *2nd Workshop on "Beyond 3 Generation Standard Model"* held in January 2010, we set up a *Forum* to discuss "Higgs-Yukawa Model on a Lattice". Through a follow-up one-day meeting in May, the intent now is to pursue this well-defined topic. If one could show $\langle \overline{Q}Q \rangle \neq 0$, *i.e.* $\overline{Q}Q$ can condense through large Yukawa, then, *Who needs the Higgs for v.e.v. generation?* Of course, in the Higgs-Yukawa model, the Yukawa coupling is defined through the Higgs field. However, if there are two sources for the v.e.v., then one can explore the meaning of the redundancy of the Higgs field. Can one do away with the (elementary) Higgs field altogether? After all, we have never observed an elementary scalar particle yet.

On a related but separate note, the study of Higgs-Yukawa on a lattice can in principle go beyond the "glass ceiling" of (partial wave) unitarity violation [19], and the outcome should have implications when LHC search enters this terrain, which could become reality with the 14 TeV run of LHC, beyond 2012.

4. – Prospects

Measurement of $\sin 2\Phi_{B_s}$ in $B_s \to J/\psi\phi$ is the current frontline, and recent news from CDF has weakened the discrepancy with the SM3 expectation of -0.04. At the

same time, the new same-sign dimuon measurement by D∅ indicates a 3.2σ discrepancy with SM3 expectation. Since the value for A_{sl}^s seems to violate a bound even with maximal $\sin 2\Phi_{B_s}$, it seems that $\Delta\Gamma_s$ receives long-distance, hadronic corrections—if the D∅ measurement is confirmed. If one applies the lower expectations for $\sin 2\Phi_{B_s}$ from CDF, then this "hadronic enhancement" would need to be a factor of 3 or 4. A new physics effect on Γ_{12}^s would have to be numerically of this order. Unfortunately, the same-sign dimuon asymmetry probably cannot be easily confirmed by other experiments. Furthermore, if the trend seen by CDF is correct, then the Tevatron would not be able to "observe" an enhanced $\sin 2\Phi_{B_s}$, and we have to wait for LHCb for the definitive measurement.

A similar story holds for direct search. Impressive limits have been extracted for both t' and b' by CDF. For t' there is some nagging, unexplained activity that dampens the bound slightly. For b', an update with more data would be of great interest. However, the Tevatron study is now approaching the limit of diminished returns, because of dropping cross sections. At the LHC, although running at half the design energy, once CMS and ATLAS get their data, even $100\,\mathrm{pb}^{-1}$ would lead to bounds surpassing the Tevatron. If $1\,\mathrm{fb}^{-1}$ data at $7\,\mathrm{TeV}$ is delivered, the bound would approach $500\,\mathrm{GeV}$ via $b' \to tW$ study. Thus, LHC has good discovery potential, and in a few years, we would need to understand what happens at or above the unitarity bound of $500\,\mathrm{GeV}$ or so.

If the pursuit of 4th generation quark search at the LHC bears fruit, we may simultaneously touch upon two of the greatest problems in particle physics, and even cosmology: source of EW symmetry breaking (raison d'être for LHC); and source of CPV for BAU (raison d'être for ourselves). There would be further implications for flavor and other physics. For example, an early discovery of a greatly enhanced $K_L^0 \to \pi^0\bar{\nu}\nu$.

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