ANTs @ ILF(SB)F
SLAC

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Based on work with Tim Gershon

Outline

- Introduction…In light of B-factories…the need for high luminosity
- New and some old ANTs
- Possibilities at LHC?
- Compatibilty with LHC-ILC
- Summary

The need for high luminosity in light of B-Factory Results.

- Spectacular performance of the B-factories
- Allowed us to attain an important milestone in understanding CPV phenomena
- For the 1st time we have a striking confirmation of the CKM-paradigm….

(emerging picture since Feb. 2001)

However,NONE of our tests is good enough to exclude O(10%) deviations due BSM

Should 10% tests be good enough?

Vital Lessons from our past

- ***LESSON # 1: Remember ε_K***
- **Its extremely important to reflect on the severe and tragic consequences if Cronin et al had decided in 1963 that O(10%) searches for ε were good enough! Imagine what an utter disaster for our field that would have been.**

Note also even though CKM-CP-odd phase is O(1) (as we now know) in the SM due to this O(1) phase only in B-physics we saw large effects… in K (miniscule), D(very small), t(utterly negligible).

Understanding the fundamental SM parameters to accuracy only of O(10%) would leave us extremely vulnerable …..Improvement of our understanding should be our crucial HOLY GRAIL!

Lesson #2

Remember m_ν

Just as there was never any good reason for $m_\nu = 0$ there is none for BSM-CP-odd phase not to exist

$\Delta m^2 \sim 1 eV^2$ ~ 1980 -> $\Delta m^2 \sim 10^{-4} eV^2$ …'97

Osc. Discovered….

Similarly for BSM-CP-odd phase, we may need to look for much smaller deviations than the current O(10%)

The need for high luminosity

- **(Arguments & Rationale NOT based on "SUSY" or its ghosts "around the corner") but**

Rather on "Key BENCHMARK Processes":

- **I) Pristine determination of UT..,**
- **$\gamma(\varphi_3)$ from {"B KD"; "BsKD"};**
- **$\alpha(\varphi_2)$ from {$\pi\,\pi$, $\rho\pi$, $\rho\rho$}and $\beta(\varphi_1)$ from "ΨKs"**
- **II) Approx. Null Tests (ANTs)**
- **a_{CP} (B -> $X_{s(d)}\,\gamma$)**
- **S(t) {B -> [K^*,K π…] γ}**
- **S(t) {B -> K_S [η , φ….]}**
- **a_{CP} (trans. Pol) {B -> X_C(D) $\tau\,\nu$…..**

In light of B-factories results: ANTs of SM become very important

Main message from B-factories:

SM-CKM paradigm is the dominant contributor to the observed CPV → effects of NP are likely to be a small perturbation -> To fecilitate search for NP need:

1. **Precise predictions from theory**
2. **Lots^2 of clean B's**

NULL tests (i.e SM predicts vanishingly small asymmetries) are a very important class of precision tests. Since CP is not a symmetry of the SM cannot (i.e. extremely difficult) have EXACT null tests…

-> approximate null tests (ANTs) e.g. $\Delta S = S[B \to \eta'(\Phi..)K_S] - S[B \to \psi K_S] \sim O(\lambda^2)$ an ANT that's recently much in news as BABAR+BELLE indicate a violation atabout 2 σ. Its confirmation is exceedingly important…

Motivates us to develop additional null tests that are as strict as possible.

Some Examples of null tests

A class of semi-inclusive hadronic B-decays as null tests of the SM
Jure Zupan & A.S. (hep-ph/0510325)

- SM-CKM paradigm predicts completely negligible partial width diff &CP Asymmetry in B^{+-} -> $M^0(\overline{M}^0)X_{s+d}^{+-}$ where M^0 is either

1) An e.s. of s<->d switching symmetry; e.g K_S , K_L , ή, any charmonium state

2) If M^0 & $\overline{M}^0$ are related by s<->d transformation, e.g. K^0 , K^{0*} , D^0

Some Remarks

- These are precision null tests wherein the PWD or the CP asy. Suffer from double suppression, i.e. CKM unitarity constraints~$O(\lambda^2)$ and U-spin symmetry of QCD ~$O(m_s/\Lambda_{QCD})$

(The corresponding radiative case studied extensively By Hurth and Mannel; see also Soares)

Theoretical considerations

Using the decomposition of the $\Delta S = 1$ decay width

$$\Gamma(B^- \to M^0 X_s^-) = |\lambda_c^{(s)} A_c^s + \lambda_u^{(s)} A_u^s|^2, \qquad (2)$$

where $A_{u,c}^s$ denote the terms in the amplitude proportional to corresponding CKM matrix elements $\lambda_c^{(s)} = V_{cb} V_{cs}^* \sim \lambda^2$ and $\lambda_u^{(s)} = V_{ub} V_{us}^* \sim \lambda^4$ (with $\lambda = \sin\theta_c = 0.22$), the corresponding $\Delta S = 1$ PWD is

$$\begin{aligned} \Delta\Gamma^s &= \Gamma(B^+ \to M^0 X_s^+) - \Gamma(B^- \to M^0 X_s^-) \\ &= 4 J \mathcal{I}m[A_c^s A_u^{s*}], \end{aligned} \qquad (3)$$

with $J = \mathcal{I}m[\lambda_c^{(s)} \lambda_u^{(s)*}] = -\mathcal{I}m[\lambda_c^{(d)} \lambda_u^{(d)*}]$, the Jarlskog invariant. Note that $A_{u,c}^s$ are complex due to strong

Similarly for the ΔS=0 case

$$\Delta\Gamma^d = \Gamma(B^+ \to M^0 X_d^+) - \Gamma(B^- \to M^0 X_{\bar{d}}^-)$$
$$= -4J\mathcal{I}m[A_c^d A_u^{d*}].$$

Role of Uspin

The transformation $s \leftrightarrow d$ exchanges X_s and X_d final states, while it has no effect on $B^\pm$ and M^0 states. In the limit of exact U-spin thus $A_{u,c}^s = A_{u,c}^d$, giving a vanishing PWD in flavor untagged inclusive decay

$$\Delta\Gamma^{s+d} = \Delta\Gamma^s + \Delta\Gamma^d = 4J\mathcal{I}m[A_c^s A_u^{s*} - A_c^d A_u^{d*}] = 0.$$

Uspin breaking

To the extent that U-spin is exact,ΔΓ(s+d) =0,an EXACT Null test. Quite generally the breaking can be parameterized as:

$$\Delta\Gamma^{s+d} \equiv \delta_{s\leftrightarrow d}\Delta\Gamma^{s}, \tag{7}$$

leading to an expectation for the CP asymmetry of the decay into untagged light flavor

$$\mathcal{A}_{CP}^{s+d} = \frac{\Delta\Gamma^{s} + \Delta\Gamma^{d}}{\bar{\Gamma}^{s+d} + \Gamma^{s+d}} \sim \delta_{s\leftrightarrow d}\lambda^{2}, \tag{8}$$

The Uspin breaking parameter delta(s<->d) is channel dependent, though expect O(ms/lambda_qcd) ~0.3

Numerical estimates

M^0	$A_{CP}(d+s)$
$D^0 + \bar{D}^0$	O(0.1%)
ή	O(0.1%)
K^0	O(0.04%)

Asymmetries are all a lot less than 1%

Stress that motivation for going after ANTs is that along the way you are likely to find NP………

Remarks relevant to expts.

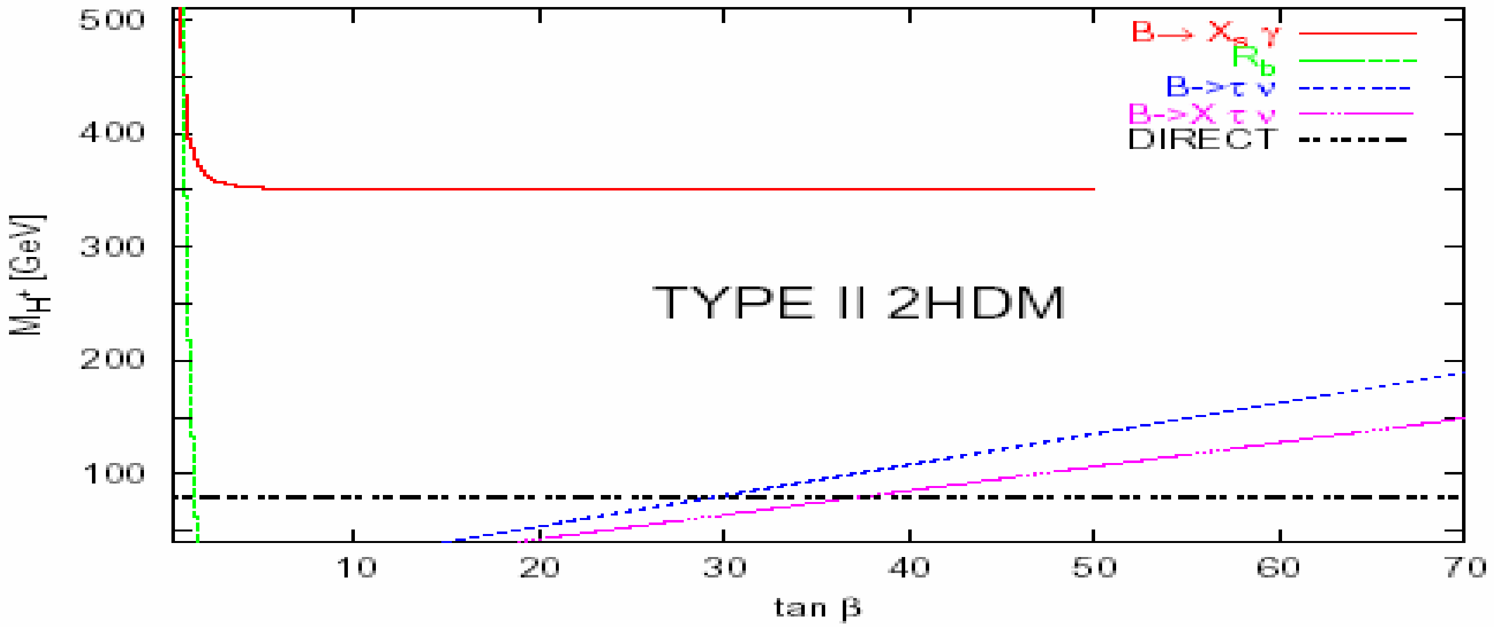
- These tests are semi-inclusive …larger Br; Also need no tagging and no time
- dependent measurements
- However require vetoing against neutral B's
- Since M^0 takes about ½ the energy, the hadron complex X has only about ~2-2.5GeV available energy…so it should hadronize into relatively low multiplicity events…This should help in the strategy where the inclusive state is built by a sum of exclusive modes.
- At the SuperB one may use the alternate approach of fully inclusive analysis on the recoil. This requires reconstruction of one (charged) B and then M^0 is searched in the remaining event. Assuming an efficiency
- **For reconstruction same as the B-factories, around 10^{-3} , sensitivity to asymmetry of 1% requires over 10^{11} B's…..**
- **While this may appear daunting, it is important to remember, here and below throughout, that the key point about these precision ANTs is that along the way one may find signs of EXOTICA!**

ANTs using Radiative decays

I. Direct CP of b-> s γ
II. Direct CP of b-> d γ
III. Direct CP in untagged b->X γ
IV. Time dependent CP in excl. modes

Illustrative Examples of constraints on models from $B \to X_s \gamma$

[Direct Collider Versus (S)BF]



Direct and indirect lower bounds on M_{H^+} from different processes in the 2HDM of Type II as a function of $\tan\beta$. See Gambino and Misiak, hep-ph/0104034

Direc CP violation in Radiative B decays in and beyond the SM

Kiers, soni and Wu hep-ph/0006280 (some input from refs. below)

Model	$A_{CP}^{B\to X_{s\gamma}}(\%)$	$A_{CP}^{B\to X_{d\gamma}}(\%$
SM	0.6	-16
2HDM (Model II)	≈ 0.6	≈ -16
3HDM	-3 to +3	-20 to +20
T2HDM	$\approx$ 0 to +0.6	$\approx$ -16 to +
Supergravity[*]	$\approx$ -10 to +10	-(5 - 45) and (2
SUSY with squark mixing[+]	$\approx$ -15 to +15	
SUSY with R-parity violation[+*]	$\approx$ -17 to +17	

* : T. Goto et al hep-ph/9812369; M. Aoki et al, hep-ph/9811251. + : C.-K Chua et al hep-ph/9808431; Y.G.Kim et al NPB544,64(99); Kagan and Neubert,hep-ph/9803368.

A_{CP} : Current status

- A_{CP} (B ->$X_s \gamma$) = 0.004\pm 0.03 [HFAG->B&B with ~2.5X10^8 B's]
- Translating it as A_{CP} (B ->$X_s \gamma$) <0.08 We can anticipate that we need

  5X10^{10} B's for sensitivity to SM dir asymmetry in b ->s
- For b->d, the Br is smaller by about factor O(20) but **asymmetry is larger byO(30)** , so IF backgrounds can be handled….**A BIG IF**
- …***then A_{CP} (B ->$X_d \gamma$) may become accessible perhaps with fewer # of B's….***
- **See Table….along the way chance of EXOTICA AGLORE**

Mixing Induced CP

- ***I. Exclusive Radiative decays (e.g.$K^*\gamma$) can be used as a precision tool!***….Atwood, Gronau,A.S'97

Based on the observation that in B decays the γ is predominanly RH …

II. Atwood, Gershon, Hazumi, A.S('05)

Generalized AGS so that many more final states (e.g. $K_S\,\pi^0$ $(\eta',\eta)\,\gamma$…) can ALSO be used

III. Grinstein, Grossman, Liget, Pirjol('05)

QCD corrections are rather large…

AGS estimated asy S(t) ~3% -> ~10% (estmates not reliable)

BUT AGHS emphasized that study of dependence of S(t) on γ energy can be used to distinguish…Provides a data driven way to separate LO contribution …

Experimental Status of S(t)

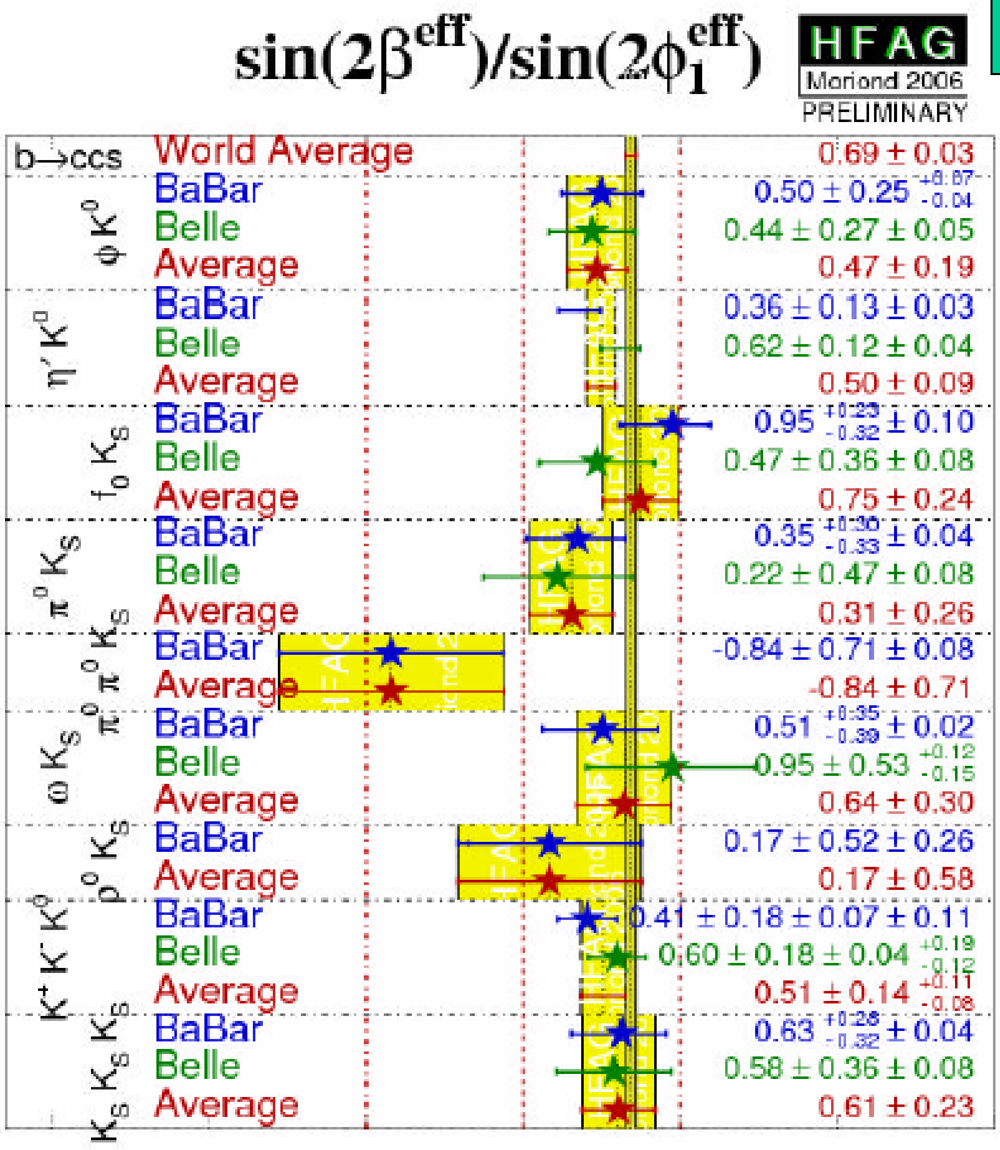
- HFAG (B&B) gives

  S(Kπγ) = 0.00 \pm 0.28
- -> Need $5X10^{10}$ to monitor S(t)~few%

III

A tantalizing possibilty:

Signs of a BSM CP-odd phase in penguin dominated b ->s transitions?



v.sharma@s>stone'60

Taken individually, each decay mode in reasonable agreement with SM

but (almost) all measurements are lower than sin2β from ccs

Naïve $b \to s$ penguin average
$\sin 2\beta_{eff} = 0.50 \pm 0.06$

Theory models predict SM pollution to **increase** $\sin 2\beta_{eff}$!!

Eη'igma or a Blessing: Continuing Saga of η'

CLEO discovers vary large Br's for B->η'(X_S ,K)
"Observation of High Momentum eta-prime production in B decay,
T. Browder et al [CLEO Collab] hep-ex/9804018

"B-> η' + X_S and the QCD anomaly", Atwood & A.S. hep-ph/9704357

"Desperately seeking nonstandard phases via direct CPV in
b->s g processes", Atwood &A.S., hep-ph/9706512

"Measuring the CP angle Beta in Hadronic b->s penguin Decays",
London & A. S, hep-ph/9704277

Brief remarks on the old study(with London, PLB'97)

- With London suggest use of MICP in [η', η, π^0, ρ^0, ω, φ….] K_S to test CKM-paradigm via $\sin 2\varphi_1(\beta)$
- Present simple (naïve) estimates of T/P …for all cases find, T/P <0.04
- Due to obvious limitations of method suggest conservative bound $\Delta S_f < 0.10$ for the SM

Expectations for ΔS in the SM

Mode	QCDF(MB)	QCDF+FSI(CCS)	BHNR
ή K_S	.01(.01,-.01)	.00(.00,-.04)	.01(.02)
φK_S	.02(.01,-.01)	.03(.01,-.04)	.02(.01)
3K_S		.02(.00,-.04)	.

MB=>Beneke (hep-ph/0505075
CCS=Cheng et al (hep-ph0502235;0506268)
Buchalla et al (hep-ph/0503151)

Conclusion: (eta’,phi,3)K_S are CLEANEST channels

Some More on ΔS

- **ΔS REMAINS an EXCELLENT TEST**
- **Sign of ΔS theoretically NOT reliable**

(in model calculations small central value with rather large errors…see also Williamson&Zupan for η'K negative)

- ***CONCLUSIVE evidence for NP demands $|\Delta S| > 0.10$ IN EACH of several of the CLEAN modes***

Are the EWP too fat?

IV

EWP are, for sure, an excellent place to
Look for NP…but before one can say
Whether they are fat (contain NP) or not
We have to 1st unambiguously see EWP
In (hadronic) modes

That the EWP may be seeing effects of NP
has also been empasized recently by (e.g.)
Buras & Fleischer

Are the EWP too fat?

A Rigorous Sum-Rule FOR EWP

- For π K modes:

$2\Delta(\pi^0 K^+) - \Delta(\pi^+ K^0) - \Delta(\pi^- K^+) + 2\Delta(\pi^0 K^0) = 0$

Δ=PARTIAL WIDTH DIFF.

Assumes only isospin; therefore, rigorously measures EWP…see Atwood and A.S. PRD'98

See also Lipkin (hep-ph/9810351; Gronau (hep-ph/0508047)

Are the EWP too fat?

V

Dir CP in $B^+ \to \pi^+\pi^0$ an important `null' test

- $\pi^+\pi^0$ is I=2 final state so receives no contribution from QCDP and only from EWP + tree (of course)
- SM provides negligibly small (less than about 1%) asymmetry even after including rescattering effects
  - → Especially sensitive to NP and should be exploited

→ Similarly $\rho^+ \rho 0$

see CCS for details

Expt. Prospects

Now	2/ab	10/ab
.01(.06)	.03	.02

Cheng,Chua,A.S.,hep-ph/0409317

TABLE IV: Same as Table II except for $B \to \pi\pi$ decays.

Mode	Expt.	SD	SD+LD
$\mathcal{B}(\overline{B}^0 \to \pi^+\pi^-)$	4.6 ± 0.4	7.6	$4.6^{+0.2}_{-0.1}$
$\mathcal{B}(\overline{B}^0 \to \pi^0\pi^0)$	1.5 ± 0.3	0.3	$1.5^{+0.1}_{-0.0}$
$\mathcal{B}(B^- \to \pi^-\pi^0)$	5.5 ± 0.6	5.1	5.4 ± 0.0
$\mathcal{A}_{\pi^+\pi^-}$	0.31 ± 0.24	-0.05	$0.35^{+0.15}_{-0.14}$
$\mathcal{S}_{\pi^+\pi^-}$	-0.56 ± 0.34	-0.66	$-0.16^{+0.15}_{-0.16}$
$\mathcal{A}_{\pi^0\pi^0}$	0.28 ± 0.39	0.56	$-0.30^{+0.01}_{-0.04}$
$\mathcal{A}_{\pi^-\pi^0}$	-0.02 ± 0.07	5×10^{-5}	$-0.009^{+0.002}_{-0.001}$

DIRECT CP in $\pi^-\pi^0$ is a very important NULL Test of the SM

Transverse τ polarization in $B \to \tau \nu_\tau X$

VI:

A very stringent Null test

Extremely sensitive probe of CP-odd phase ($\chi^{H^\pm}_{BSM}$) from charged Higgs exchange.

Due to CPT, $\not{C}$P observables can be split into 2 categories.

* T_N even, (e.g. $< E_\tau >$ or PRA) $\Rightarrow \propto$ Im Feynman Amp i.e. $\sin \delta_{st}$; δ_{st} is the CP-even "strong" phase.
* T_N odd , (e.g.$< p^t_\tau >$) $\Rightarrow \propto$ Re Feyn amp i.e. $\cos \delta_{st}$

$p^t_\tau \equiv \frac{S_\tau \cdot p_\tau \times p_X}{|p_\tau \times p_X|}$ Thus,

$\Rightarrow < E_\tau >, A_{PRA}$ due to Im Feyn. ampl $\Rightarrow \propto \frac{\alpha_s}{\pi} \approx 0.1$

Also, for $< E_\tau >, A_{PRA}$, W-H interference requires amplitude $\propto Tr[\gamma_\mu L(\not{p}_\tau + m_\tau)(L,R)\not{p}_\nu] \Rightarrow \propto m_\tau/m_B$

THEREFORE $\frac{<p_\tau>}{<E_\tau>(A_{PRA})} \approx 30$

[see Atwood, Eilam and Soni, PRL'93] For effect of power corrections, see fig below from Grossman and Ligeti '94

Experimental detection of P^t_τ, via decay correlation in $\tau \to \pi\nu, \mu\nu\nu, \rho\nu$ etc. expected to be much harder than energy or rate asymmetry.

Assuming effective detection efficiency for p^t_τ is **0.1%**

for detection of $< p^t_\tau > \approx 1\%$ with 3-sigma significance

Need over $5X10^{10}$ B's

Fake asymmetries due to FSI can arise if only τ^- or τ^+ is studied. GENUINE (i.e. CP violating) p^t_τ will swich sign from τ^- to τ^+.

Clearly Rate and/or Energy asymmetries should also be studied esp. if detection efficiencies for those is higher.

Super-B should allow to improve search for p^t_τ by an order of magnitude, down to around 0.1%

ANTs @ ILF(SB)F

Observable	SM expectation	Current expt. status(# B's used)	# of B's needed	
$A_{CP}^{s+d}(M^0 X_{s+d})$	$\lesssim 0.1\%$		$\gtrsim 10^{11}$	
$A^s_{CP}(\gamma X_s)$	$\approx 0.5\%$	$\lesssim 0.10 (\approx 10^8)$	5×10^{10}	
$A^d_{CP}(\gamma X_d)$	$\approx -20\%$		5×10^9	*
$A_{CP}^{(s,d)}(l^+ l^- X_{(s,d)})$				
$a_{FB}(l^+ l^- X)$				
$S[\gamma(K^*, K_s \pi^0, ...)]$	$\approx a\ few\%$	$\lesssim 0.60 (10^8)$	10^{11}	
$\Delta S[K_s(\eta', \phi, K_s K_s ..)]$	$\lesssim 0.10$	$\lesssim 0.50 (10^8)$	10^{10}	*
$\Sigma\Delta(\pi K)$	0	$\lesssim 20 (10^8)$		
$A_{CP}(\pi^+ \pi^0)$	$\lesssim 1\%$	$\lesssim 13\% \ (10^8)$	5×10^{10}	
$< p_t^\tau > (D(X_c) \tau \nu_\tau)$	0		10^{11}	

TABLE III: Illustrative sample of ANTs, SM expectation, current experiemntal status and number of B's needed for sensitivity to the predictions of the SM

Remarks

- ***In some instances, even though getting to SM test may seem very demanding, it is useful to stress again that along the way one has ample opportunity to detect contributions from EXOTICA***

Issues

- Can we make a case in light of BF Results?
- Is it relevant in the LHC era?
- Can’t LHCb do the job?
- Isn’t it better to wait to see (some) results from the LHC?
- Isn’t it better to shoot for ILC rather than

an ILF(SB)F ?

Isn't it better to wait to see (some) results from the LHC?

- **Clearly we cannot predict the precise scenario of EWSB that LHC will discover.**
- **Broadly speaking we can envision 3 scenes:**
- **I) Low energy "SUSY" aglore!**
- **II) SM like Higgs & seemingly nothing else**
- **III) "nothing"**
- **In scenario I) …ILFF/ISBF can provide info on CP-phases and flavor-mixing**
- **In scenarios II & III, ILFF/ISBF can be a powerful probe**

For NP thresholds via indirect search of effects of HDO which are in general NOT accessible directly to LHC

RECALL neutron beta decay vs. discovery of W's…..~50 years!

ILFF/ISBF nicely complements LHC in ALL cases

ILFF/ISBF vs ILC

- In scenario I (“SUSY” aglore) ILFF/ISBF AND ILC can all be extremely useful in complementing the LHC and significantly extending its reach.
- In scenario II as well as in scenario III, ILFF/ISBF is at least as important if not much more than ILC.

Can't LHCb do the job?

- LHCb would have access to > 10^{11} b's !!!
- Without a doubt it would do great B-physics, **esp. B_S TD**
- at the same time it is important to recognize that many of the **precious precision tests of the SM will be very difficult in that environment; Examples**
- **B ->X_s γ, X_d γ . Recall rates; dir CP are vitally important**
- **Time dependent CP in B -> K^* γ , K π γ…..**
- **B -> X l l Rates, CP…**
- **Time dependent CP in B -> K_S [η φ π….]**
- **B -> X (D) τ ν**

Summary & Conclusions (1 of 2)

- While there is compelling theoretical rationale for a BSM-CP-odd phase, in light of B-factories results, its effects on B-physics likely to be small -> Null tests highly desirable …discussed new & some old

-> B^{+-} -> M^0 (M^0) X_{s+d} , Asy <+ O(0.1%) for M^0 = D^0 ,ή, $K^{0(*)}$

-> ΔS=S [(ή,φ,3)K_S] – S(ΨK_S) < a few %; host of tests using raditive B-decays

-> A (B^{+-} -> π^{+-} π^0) < 1%; -> Δ (Kπ) ~ O(few %)

-> B -> D(*, X_C) τ υ , <$p_{t\tau}$> =0 .Stringent NULLTEST

Null tests aglore. Several of them require over 10^{10} B's

***In addition provides opportunity for SPECTACULAR c, τ phys*.**

-> ***NEED ILF(SB)F WITH ~10^{11} of clean B's***

Summary & Conclusion

- **ILFF/ISBF …extremely well motivated**
- **It COMPLMENTS LHC and in fact extend its reach greatly.**
- **Should be a parallel effort with ILC**
- ***Needs:ILFF-FUSION-(I)KEKSBF***
- **Health & vitality of the field strongly suggests we seek a new, high lumin.**

$e^+ e^-$ B-facility as expediously as possible