Null tests of the SM (ANTs @ ISBF)

Amarjit Soni
HET, BNL
(soni@bnl.gov)

Outline

- Introduction
- Any exact null test?
- New and some old ANTs
- Possibilities at LHC?
- Summary

Introduction

I. What are ANTs & why are they important?

II. What is ISBF & why is it important?

I

B-factories attain an important Milestone in our understanding of CPV:

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. $\Delta S = S[B \to \acute{\eta}(\Phi..)K_S] - S[B \to \psi K_S] \sim O(\lambda^2)$ an ANT that's recently much in news as BABAR+BELLE indicate a violation at about 2 σ. Its confirmation is exceedingly important…Motivates us to develop additional null tests that are as strict as possible.

Why NULL Tests are important (2)

To drive the point home even clearer;
It is clearly difficult to establish NP when SM effect is 1% and NP contribution makes it 1.1%
But when SM expects 0.1% and NP jacks it up to 1.1% …things become simpler

REMEMBER ALSO $\varepsilon_K \sim 10^{-3}$ -> effect of an O(1) phase due BSM MAY WELL BE <<1

II. ISBF=International SBF

- Past few years discussions :
- B-Factories ~ 10^{34} /cm^2 s
- SuperBF ~ 10^{35} /cm^2 s

Bearing in mind the physics need, & the tremendous success of the current BFs. like to

Suggest that the B-physics community ought to make a concerted worldwide effort for a more powerful machine -> ISBF ~ 10^{36} /cm^2 s

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

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

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 $A^s_{u,c} = A^d_{u,c}$, 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, $\Delta\Gamma(s+d) = 0$, 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

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

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

Numerical estimates

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

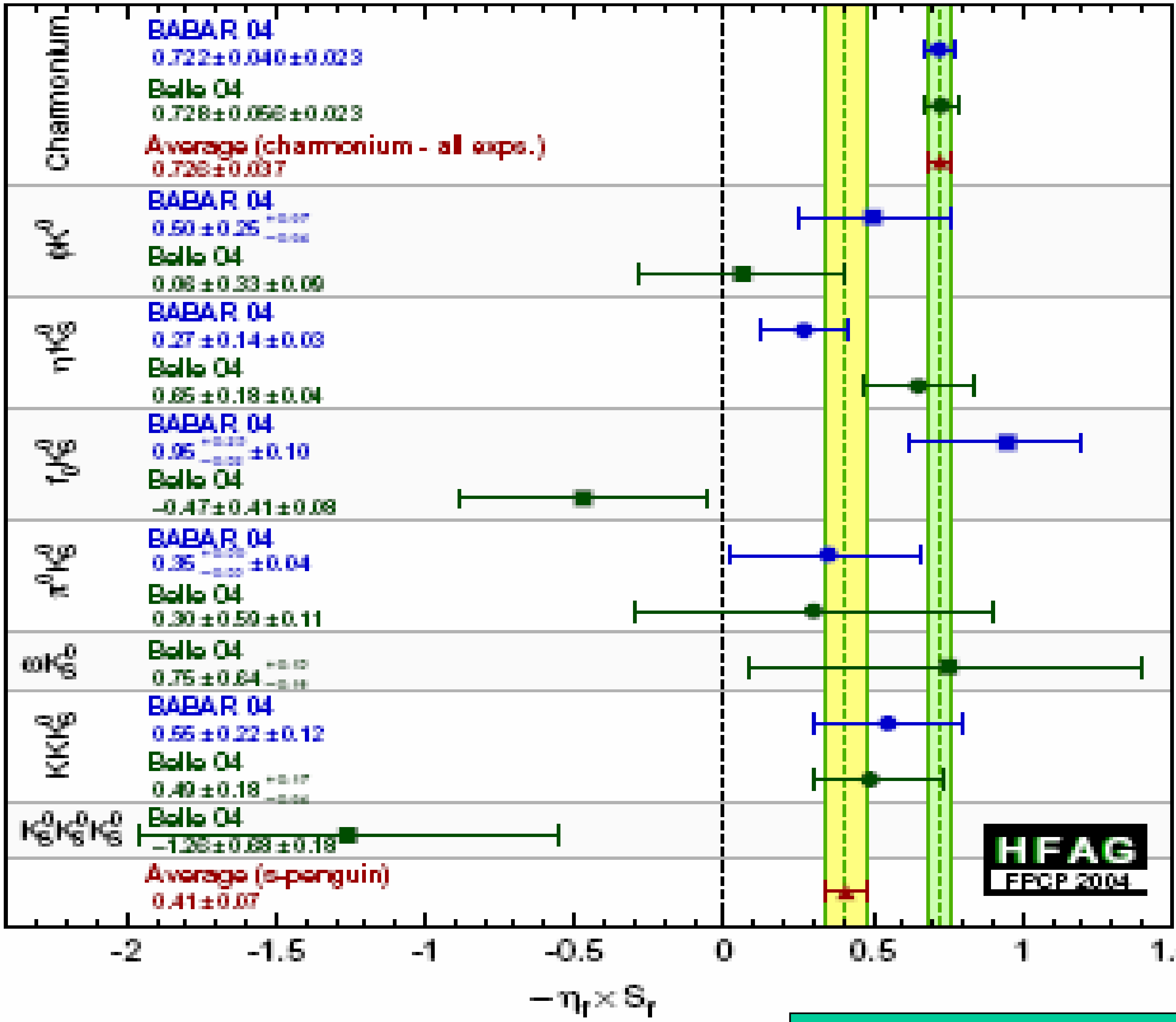
Remarks relevant to expts.

- These tests are semi-inclusive …larger Br
- No tagging
- No time dependent measurnments
- However require vetoing against neutral B's

II

A tantalizing possibilty:

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



A. Soni

HFAG’04

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 ΔS_f<0.10 for the SM

A possible complications: large FSI phases in 2-body B decays

- The original papers predicting $\Delta S_f = S_f - S_{\psi K} \sim 0$ used naïve factorization ideas; in particular FSI were completely ignored.

A remarkable discovery of the past year is that direct CP in charmless 2-body modes is very large-> (LD)FS phases in B-decays need not be small

SINCE THESE ARE INHERENTLY
Non-perturbative model dependence becomes unavoidable

FSI are formally $O(1/m_B)$ and are Model dependent in EVERY APPROACH

1) pQCD uses "ad-hoc" parameter k_t (parton transverse momentum)

2) "QCDF introduce "ad-hoc" parameters,

$\rho_{A,H}$ chosen to fix signs of dir CP asymmetries

3) We (CCS) use QCDF for SD, set $\rho_{A,H}$ =0,

And invoke optical theorem to include FSI

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

Are the EWP too fat?

III

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?

IV

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
-.02(.07)	.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

V

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

An EXACT 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 $\frac{<p_T>}{<E_\tau>(A_{PRA})} \approx 30$

[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 [illegible] **0.1%**

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

[illegible] **Need about $3X10^{10}$ 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%

NULL TESTS AGLORE!

Search for New Physics at a Super-B Factory

Final State	Observable	Theoretical Cleanliness	Sensitivity to NP
$\gamma[K_s^*, \rho, \omega]$	TDCP	5*	5*
$K_s[\phi, \pi^0, \omega, \eta', \eta, \rho^0]$	TDCP	4.5*	5*
$K^*[\phi, \rho, \omega]$	TCA	4.5*	5*
$[\gamma, l^+l^-][X_s, X_d]$	DIRCP	4.5*	5*
same	Rates	3.5*	5*
$J/\psi\ K$	TDCP, DIRCP	4*	4*
$J/\psi\ K^*$	TCA	5*	4*
$D(*)\tau\nu_\tau$	TCA (p_t^τ)	5*	4*
same	Rate	4*	4*

Table 6. Final states and observables in B - decays useful for searching effects of New Physics. Reliabilty of SM predictions and sensitivity to extensions of SM are each indicated by stars (5 = *best*)

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Browder&A.S,hep-ph/04 10192

Many of these Null tests need over 10^{10} B's

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

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

-> $\Delta S = S[(ή, \varphi, 3)K_S] - S(\Psi K_S)$ < a few %

-> $A(B^{+-} \to \pi^{+-} \pi^0) < 1\%$

-> $\Delta(K\pi) \sim O(\text{few } \%)$

-> $B \to D(*, X_C)\, \tau\, \upsilon$, $\langle p_{t\tau} \rangle = 0$ .EXACT NULL TEST

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

-> NEED ISBF WITH 10^{36} of clean B's

Synergy

I. Semi-inclusive FS X_{s+d} serves as an excellent "ALIGNMENT-METER", i.e. its esp. suited for testing alignment of NP quantas with quarks

II. B-> $D(X_C)\ \tau\ \nu_\tau$ @ISBF : t ->B(b) $\tau\ \nu_\tau$ at a top Factory i.e. LHC   EXACT NULL TEST OF SM

III. Few years down when LHC finds "SUSY" with O(100) parameters, interpretation of this vast jungle will require all the help from B-physics….ISBF will thru such studies greatly extend the reach of LHC