Precocious signs of the Beyond in Flavor Physics

KEK, Mar.19,’08

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Outline

- I. Introduction & Motivation
- **Status of the CKM-Paradigm**
- **The importance of being precise**
- **II.Possible Signs of NP:**
- **a) Δ S (penguin modes)**
- **b) $\Delta_{K\pi}$**
- **c) B->X_s v**
- **Mixings: B & D**
- **III. Illustrative models: T2HDM, 4th family,**

  Warped X-Dim, Z', SUSY

. **Repurcussions for the SFF, LHC**

- **Summary& outlook**

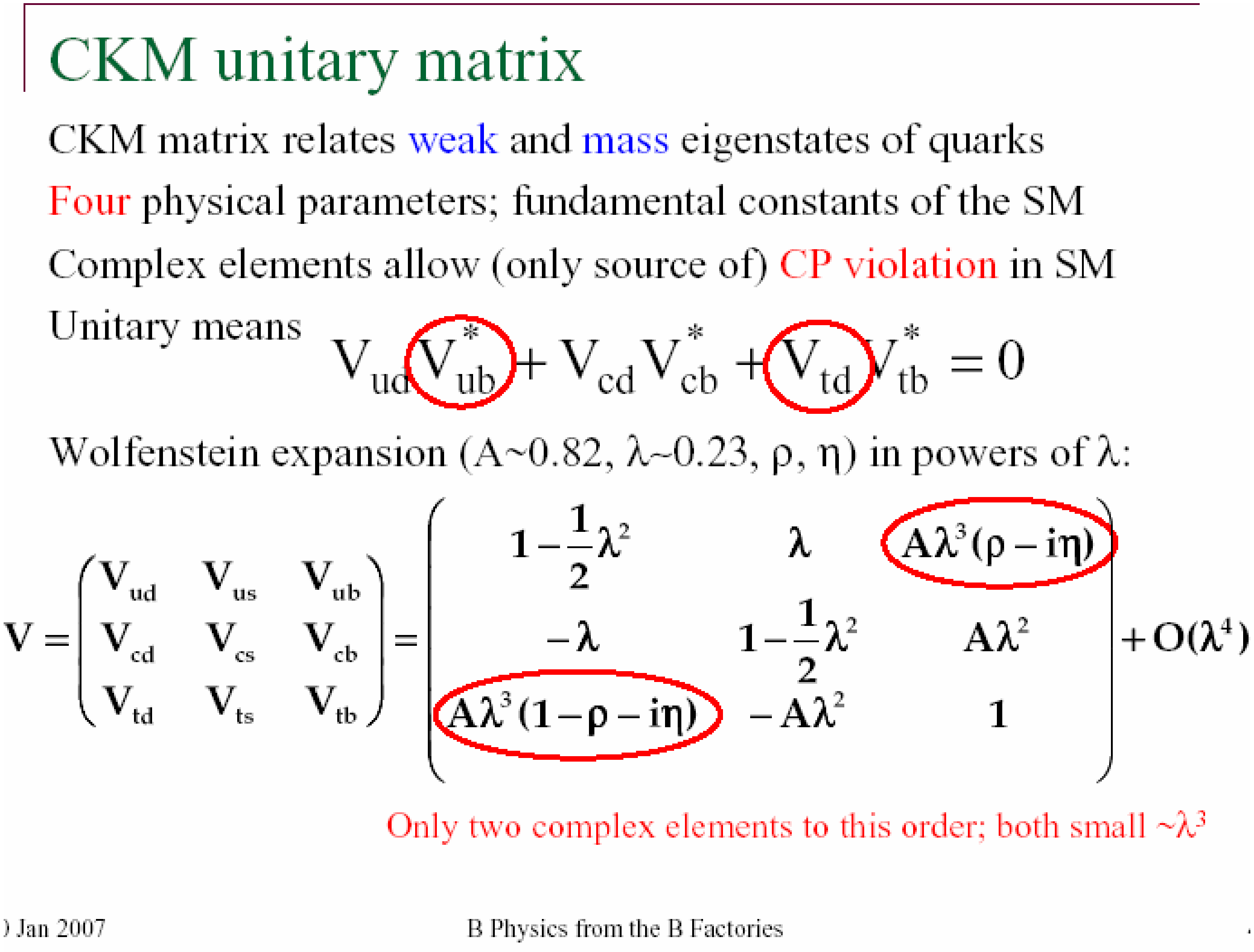
Introduction & Motivation

- **While a conclusive evidence for breakdown of SM in flavor physics cannot be made at present , in the last few years several interesting (and rather strong) hints have emerged.**
- **Although, taking too seriously every little deviation is not desirable and may be counterproductive;**
- **disregarding or overlooking the hints can be equally unwise and in fact can be more damaging. Following these up in flavor & collider physics and in theory may prove beneficial.**

{ based in part on Enrico Lunghi + A. S. arXiv:0707.0212 + in Prep}

1st ('01-'04) confrontation of BFs with the SM

Lightning recap to SM-CKM paradigm of CPV



CKM unitary matrix

CKM matrix relates weak and mass eigenstates of quarks

Four physical parameters; fundamental constants of the SM

Complex elements allow (only source of) CP violation in SM

Unitary means $V_{ud}V_{ub}^{*} + V_{cd}V_{cb}^{*} + V_{td}V_{tb}^{*} = 0$

Wolfenstein expansion (A~0.82, λ~0.23, ρ, η) in powers of λ:

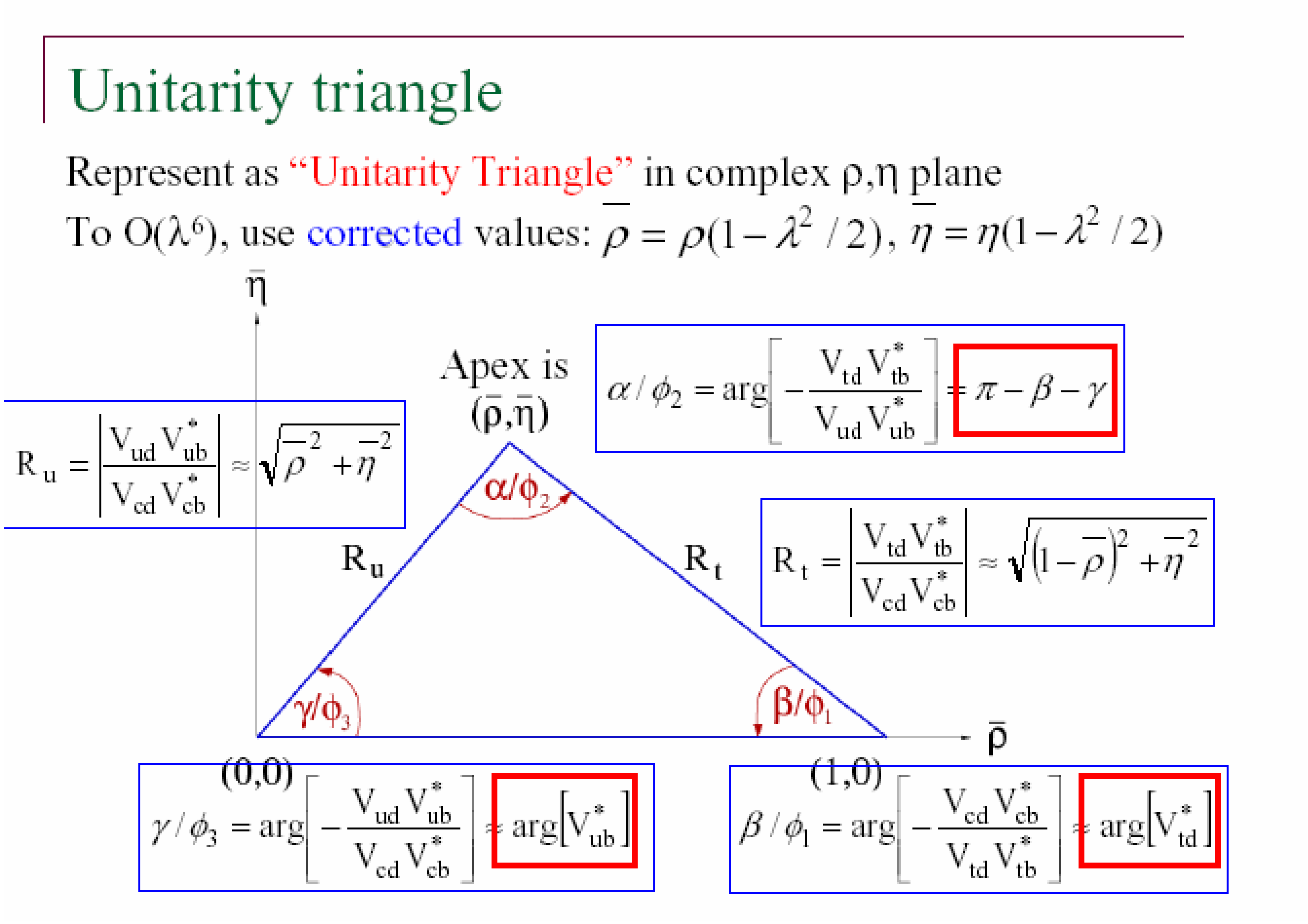
$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$

Only two complex elements to this order; both small ~λ^3

) Jan 2007 B Physics from the B Factories

Precocious signs of
Beyond ....A.Soni

Youngjoon Kwon



Unitarity triangle

Represent as "Unitarity Triangle" in complex ρ,η plane

To O(λ^6), use corrected values: $\bar{\rho} = \rho(1-\lambda^2/2)$, $\bar{\eta} = \eta(1-\lambda^2/2)$

$$R_u = \left|\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right| \approx \sqrt{\bar{\rho}^2+\bar{\eta}^2}$$

Apex is $(\bar{\rho},\bar{\eta})$

$$\alpha/\phi_2 = \arg\left[-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right] = \boxed{\pi-\beta-\gamma}$$

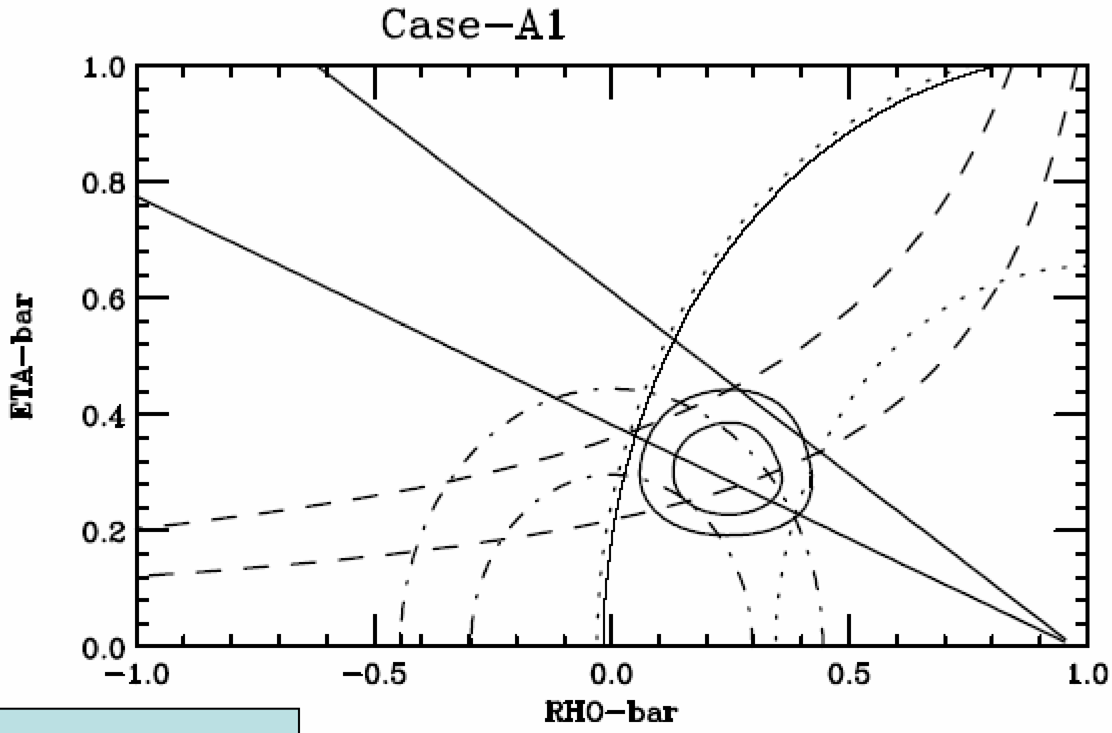
$$R_t = \left|\frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*}\right| \approx \sqrt{(1-\bar{\rho})^2+\bar{\eta}^2}$$

$$\gamma/\phi_3 = \arg\left[-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right] \approx \boxed{\arg\left[V_{ub}^*\right]}$$

$$\beta/\phi_1 = \arg\left[-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right] \approx \boxed{\arg\left[V_{td}^*\right]}$$

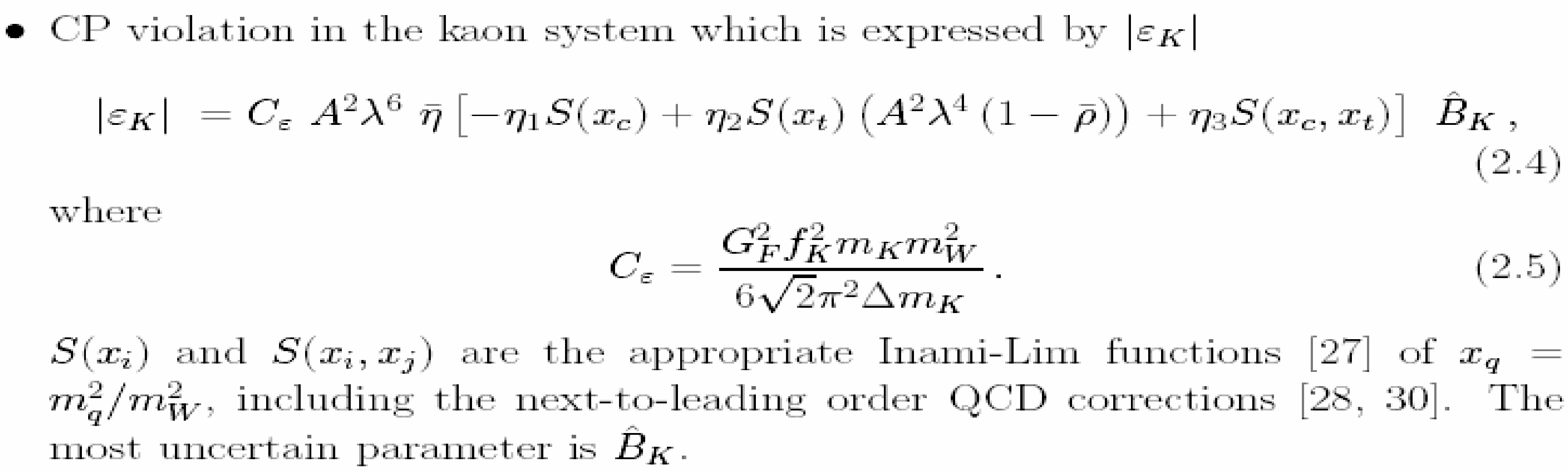
1st Hints of confirmation Of CKM-CP violation

Atwood&A.S,
hep-ph/0103197



Most bands due
To theory errors

Theoretical Underpinnings (see e.g. Ciuchini et al, hep-ph/0012308)



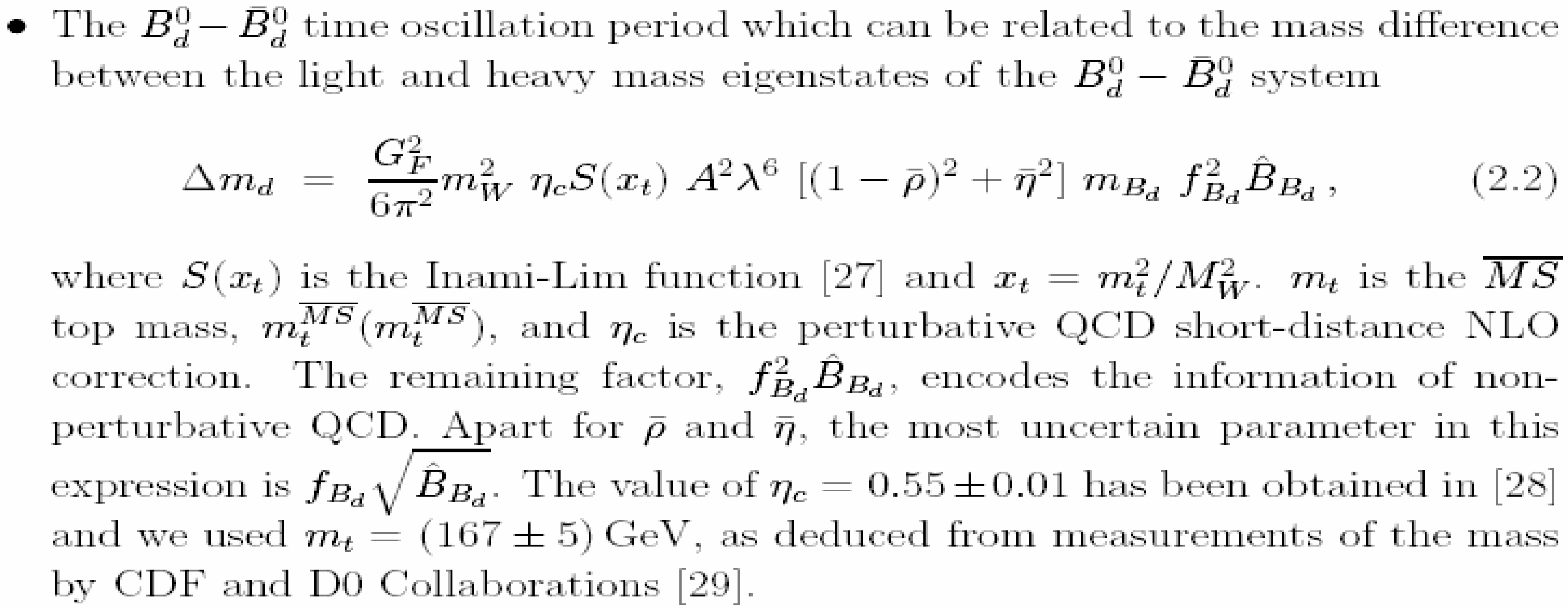
- CP violation in the kaon system which is expressed by $|\varepsilon_K|$

$$|\varepsilon_K| \ = C_\varepsilon \ A^2\lambda^6 \ \bar{\eta} \left[-\eta_1 S(x_c) + \eta_2 S(x_t)\left(A^2\lambda^4\left(1-\bar{\rho}\right)\right) + \eta_3 S(x_c, x_t)\right] \ \hat{B}_K \ , \tag{2.4}$$

where

$$C_\varepsilon = \frac{G_F^2 f_K^2 m_K m_W^2}{6\sqrt{2}\pi^2 \Delta m_K} \, . \tag{2.5}$$

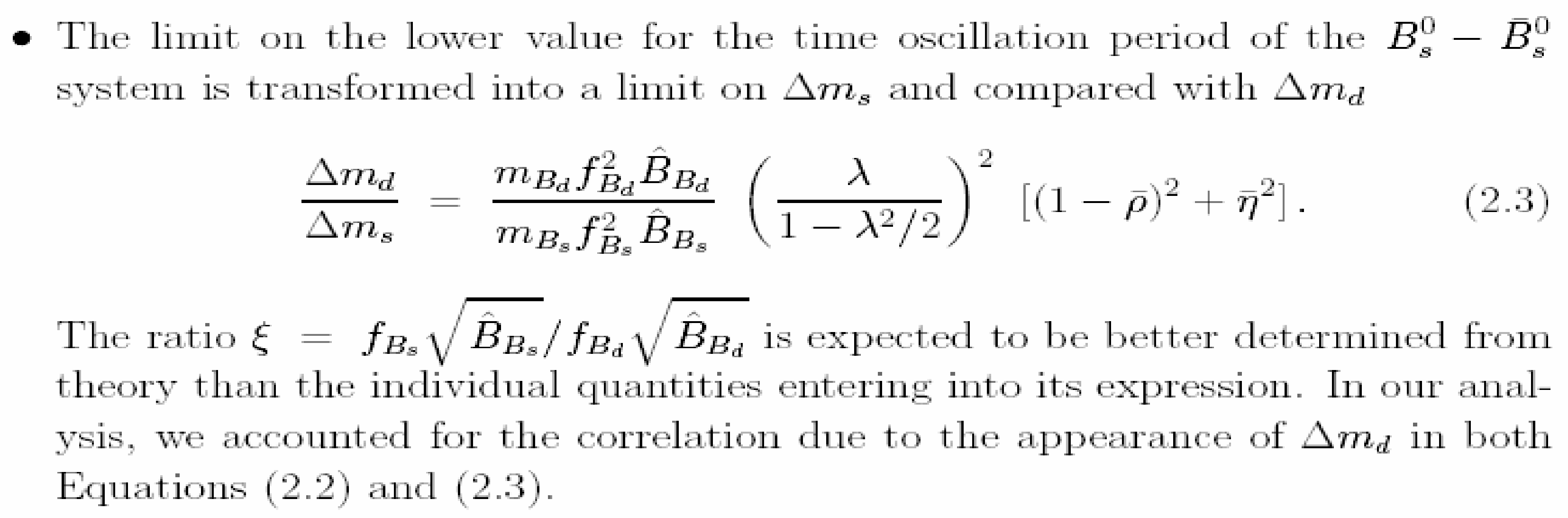
$S(x_i)$ and $S(x_i, x_j)$ are the appropriate Inami-Lim functions [27] of $x_q = m_q^2/m_W^2$, including the next-to-leading order QCD corrections [28, 30]. The most uncertain parameter is $\hat{B}_K$.



- The $B_d^0 - \bar{B}_d^0$ time oscillation period which can be related to the mass difference between the light and heavy mass eigenstates of the $B_d^0 - \bar{B}_d^0$ system

$$\Delta m_d \ = \ \frac{G_F^2}{6\pi^2} m_W^2 \ \eta_c S(x_t) \ A^2\lambda^6 \ \left[(1-\bar{\rho})^2 + \bar{\eta}^2\right] \ m_{B_d} \ f_{B_d}^2 \hat{B}_{B_d} \, , \tag{2.2}$$

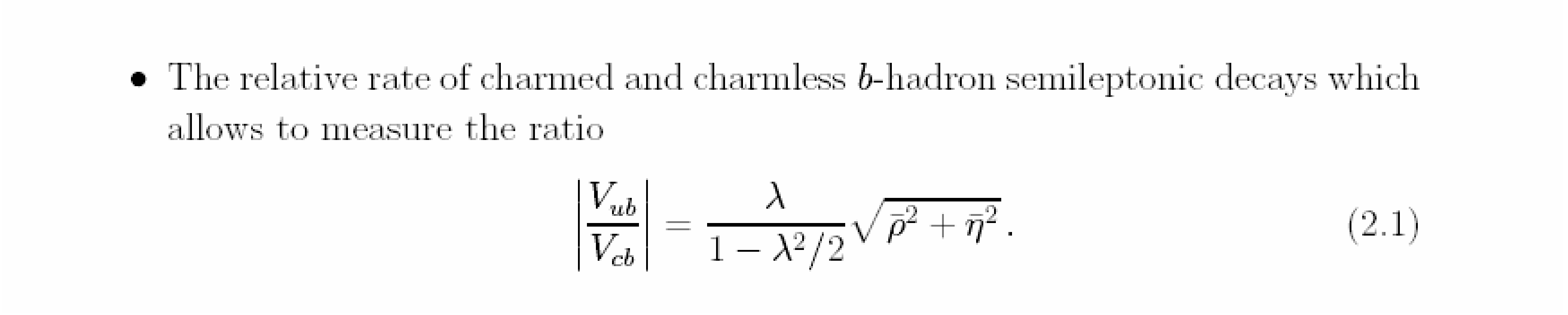
where $S(x_t)$ is the Inami-Lim function [27] and $x_t = m_t^2/M_W^2$. m_t is the $\overline{MS}$ top mass, $m_t^{\overline{MS}}(m_t^{\overline{MS}})$, and η_c is the perturbative QCD short-distance NLO correction. The remaining factor, $f_{B_d}^2 \hat{B}_{B_d}$, encodes the information of non-perturbative QCD. Apart for $\bar{\rho}$ and $\bar{\eta}$, the most uncertain parameter in this expression is $f_{B_d}\sqrt{\hat{B}_{B_d}}$. The value of $\eta_c = 0.55 \pm 0.01$ has been obtained in [28] and we used $m_t = (167 \pm 5)$ GeV, as deduced from measurements of the mass by CDF and D0 Collaborations [29].



- The limit on the lower value for the time oscillation period of the $B_s^0 - \bar{B}_s^0$ system is transformed into a limit on Δm_s and compared with Δm_d

$$\frac{\Delta m_d}{\Delta m_s} = \frac{m_{B_d} f_{B_d}^2 \hat{B}_{B_d}}{m_{B_s} f_{B_s}^2 \hat{B}_{B_s}} \left(\frac{\lambda}{1-\lambda^2/2}\right)^2 \left[(1-\bar{\rho})^2 + \bar{\eta}^2\right]. \qquad (2.3)$$

The ratio $\xi = f_{B_s}\sqrt{\hat{B}_{B_s}}/f_{B_d}\sqrt{\hat{B}_{B_d}}$ is expected to be better determined from theory than the individual quantities entering into its expression. In our analysis, we accounted for the correlation due to the appearance of Δm_d in both Equations (2.2) and (2.3).

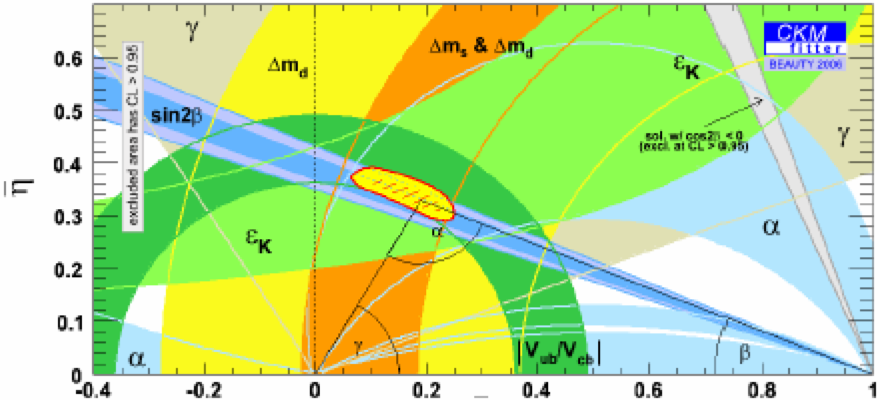


- The relative rate of charmed and charmless b-hadron semileptonic decays which allows to measure the ratio

$$\left|\frac{V_{ub}}{V_{cb}}\right| = \frac{\lambda}{1-\lambda^2/2}\sqrt{\bar{\rho}^2 + \bar{\eta}^2}\,. \qquad (2.1)$$

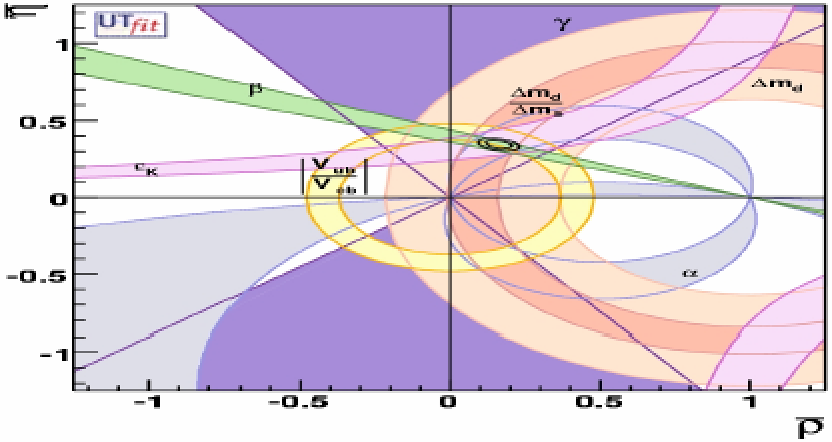
B-Factory “early” result & implication

Overall CKM agreement



Frequentist

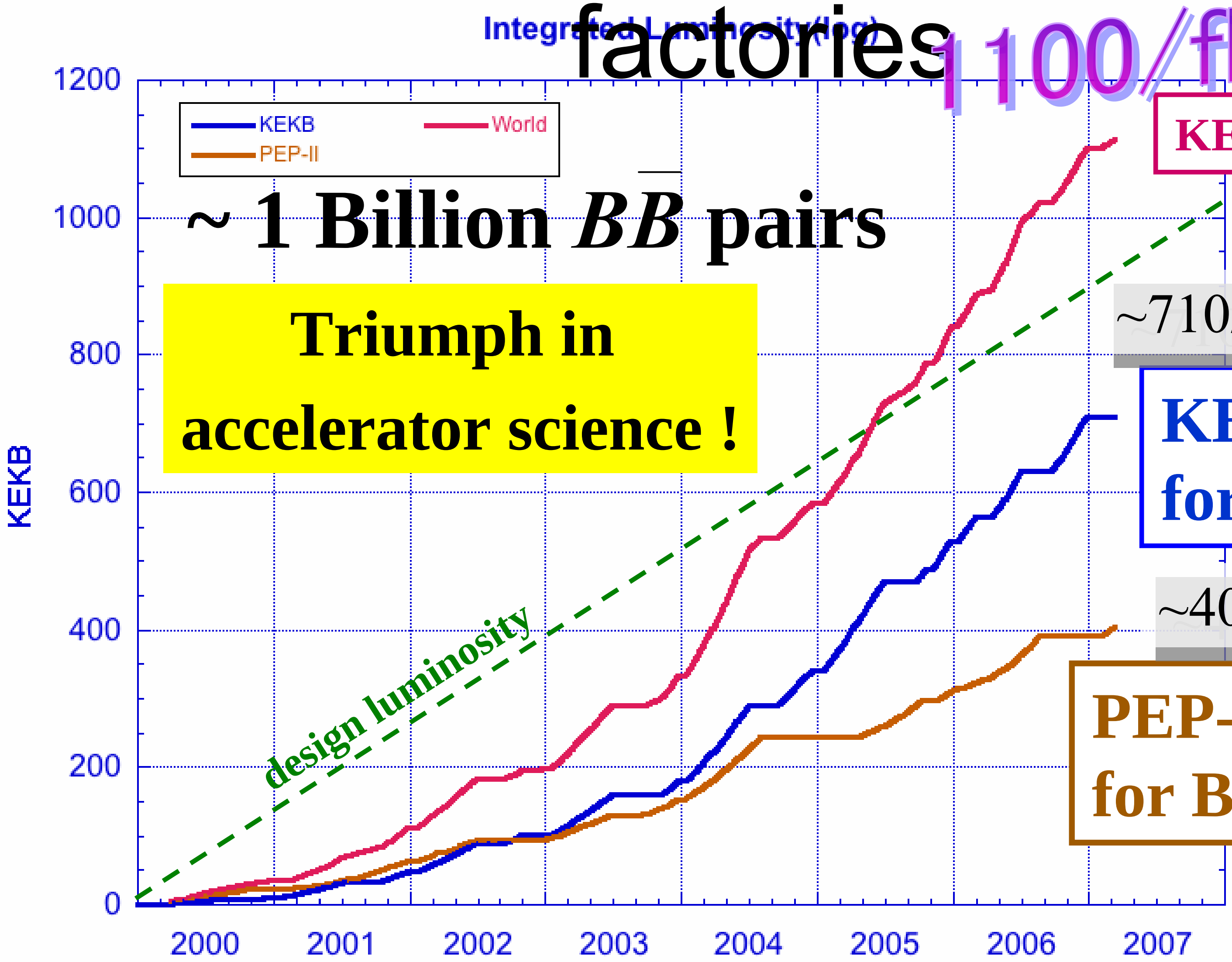
Bayesian



Conclusion is the same:

All measurements agree with SM picture of CKM matrix within errors

Integrated luminosity at B factories



1100/fb !!

KEKB + PEP-II

~ 1 Billion $B\bar{B}$ pairs

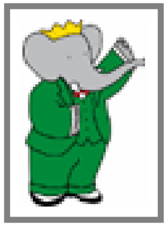
Triumph in accelerator science !

~710/fb (Jan 07)

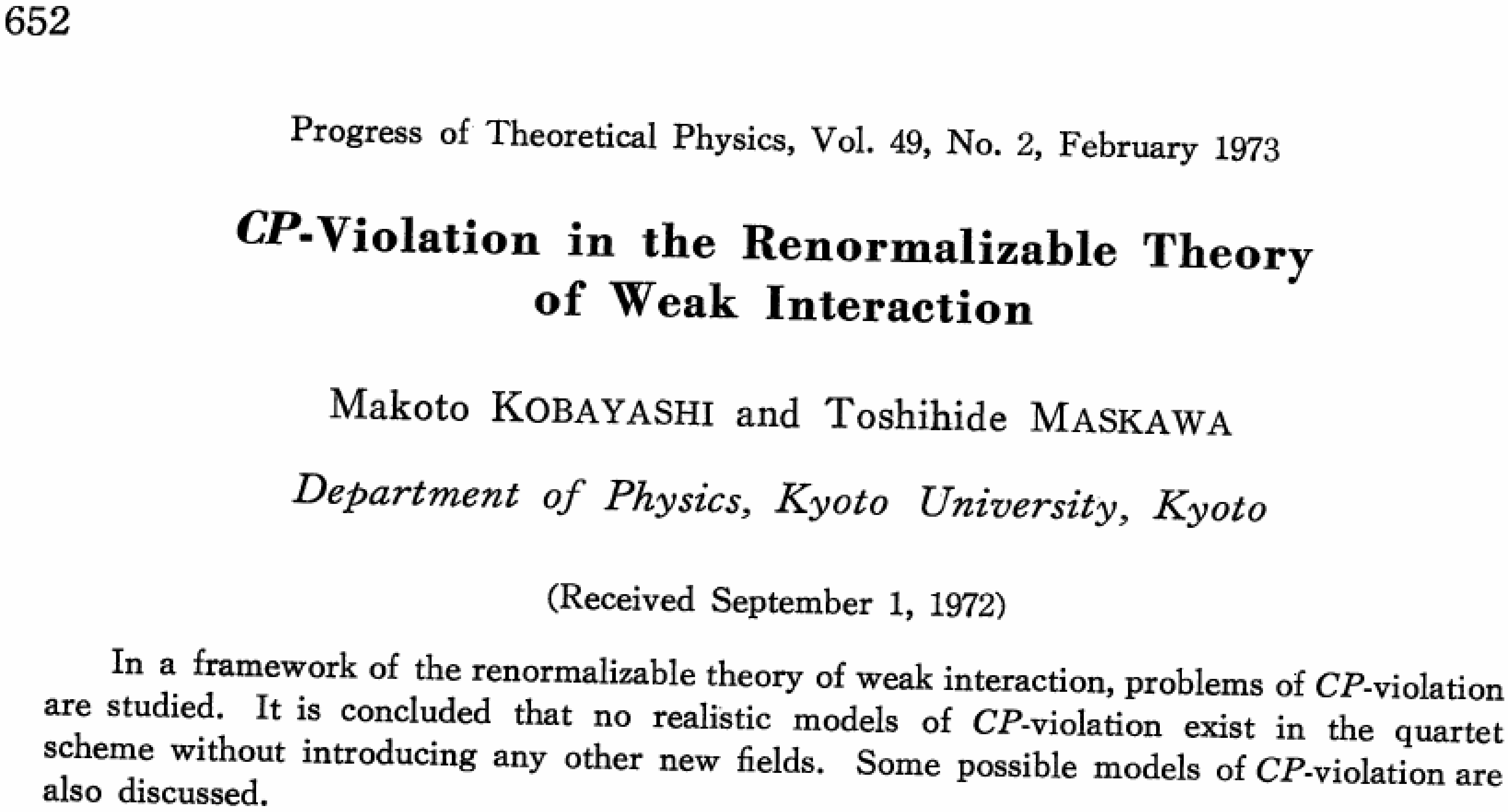
KEKB for Belle

~400/fb

PEP-II for BaBar



Celebration II: A beautiful theory paper which not only suggested the need for the 3rd family, before the discovery of charm and tau, its framework is vindicated in detail through exhaustive experimentation ~35 years later!!



652

Progress of Theoretical Physics, Vol. 49, No. 2, February 1973

CP-Violation in the Renormalizable Theory of Weak Interaction

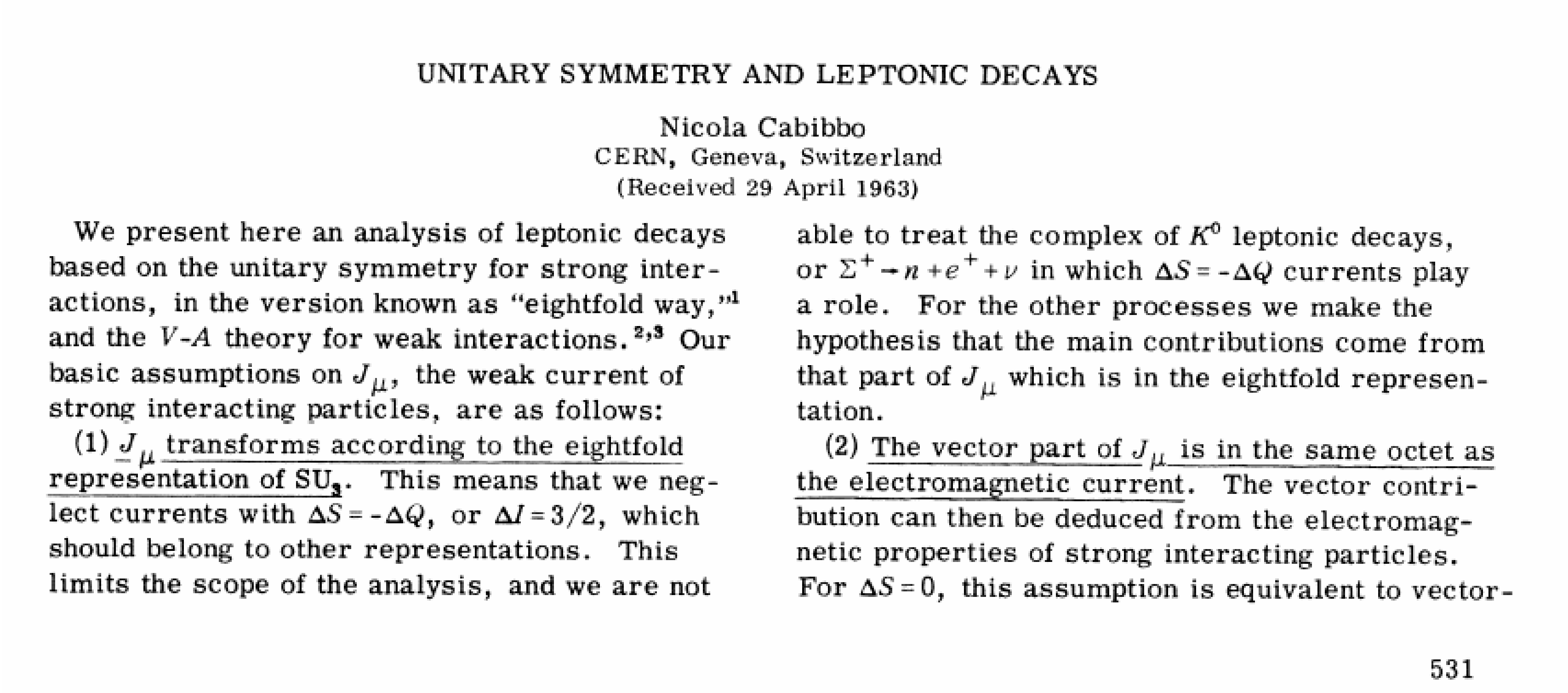
Makoto KOBAYASHI and Toshihide MASKAWA

Department of Physics, Kyoto University, Kyoto

(Received September 1, 1972)

In a framework of the renormalizable theory of weak interaction, problems of *CP*-violation are studied. It is concluded that no realistic models of *CP*-violation exist in the quartet scheme without introducing any other new fields. Some possible models of *CP*-violation are also discussed.

And of course we must not forget the C!



UNITARY SYMMETRY AND LEPTONIC DECAYS

Nicola Cabibbo
CERN, Geneva, Switzerland
(Received 29 April 1963)

We present here an analysis of leptonic decays based on the unitary symmetry for strong interactions, in the version known as “eightfold way,”[1] and the V-A theory for weak interactions.[2,3] Our basic assumptions on J_μ, the weak current of strong interacting particles, are as follows:

(1) J_μ transforms according to the eightfold representation of SU$_3$. This means that we neglect currents with $\Delta S = -\Delta Q$, or $\Delta I = 3/2$, which should belong to other representations. This limits the scope of the analysis, and we are not able to treat the complex of K^0 leptonic decays, or $\Sigma^+ \to n + e^+ + \nu$ in which $\Delta S = -\Delta Q$ currents play a role. For the other processes we make the hypothesis that the main contributions come from that part of J_μ which is in the eightfold representation.

(2) The vector part of J_μ is in the same octet as the electromagnetic current. The vector contribution can then be deduced from the electromagnetic properties of strong interacting particles. For $\Delta S = 0$, this assumption is equivalent to vector-

The importance of being precise

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). Therefore, most likely the effects of a BSM-phase on B-physics will only be a perturbation.

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_ν =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%)

-> This Clearly demands greater precision from expt. & from theory

Post BFs Mantra: For Theory and for Experiment

- **PRECISION has become OF THE UTMOST IMPORTANCE**

-> its of limited use to measure quantities

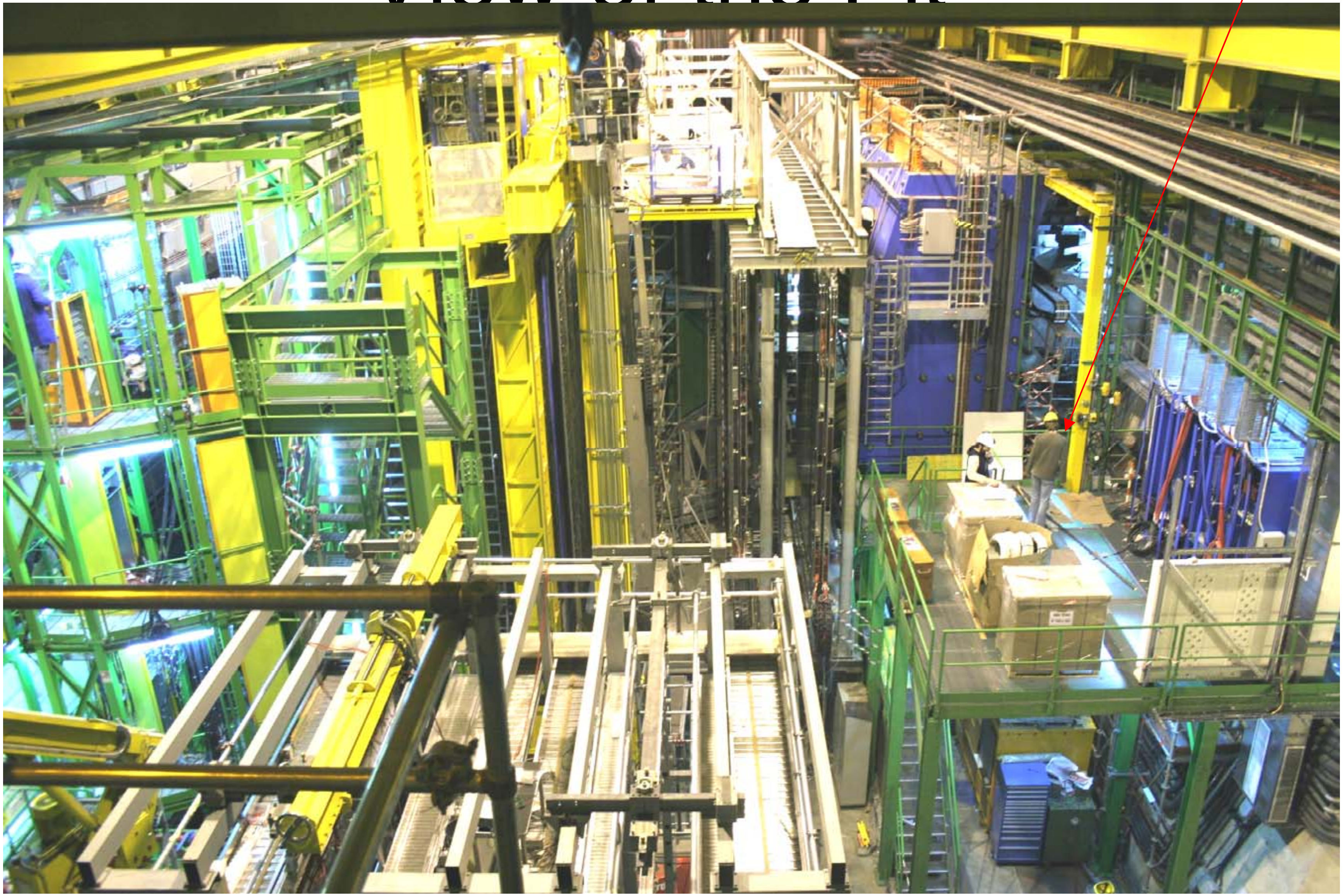
that theorists cannot cope with…

Example B-> X_s gamma versus B->K* gamma….Similarly for CPV observables

Prospects for improved exptal precision

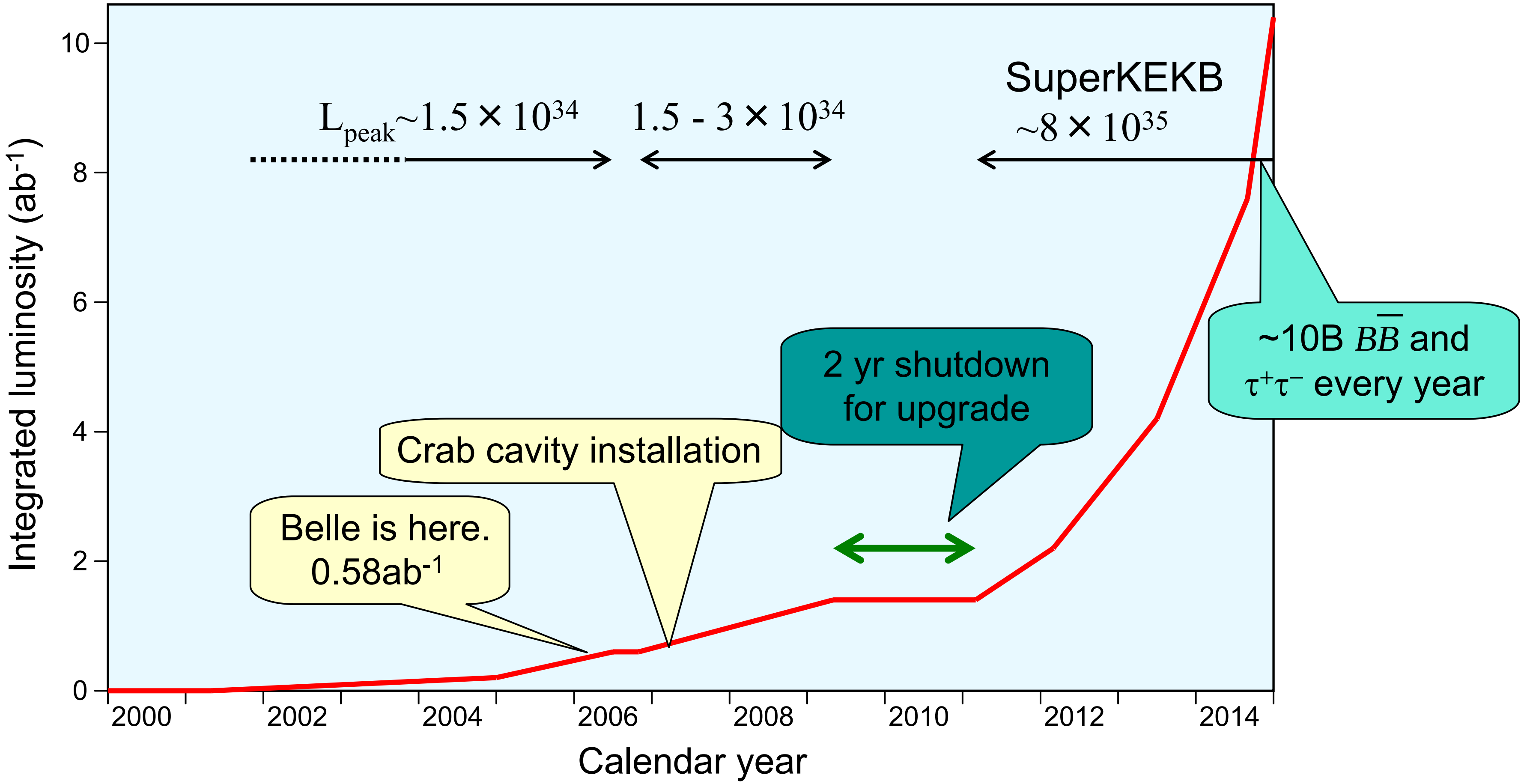
LHCb …(Sheldon Stone @CERN, Mar 07)

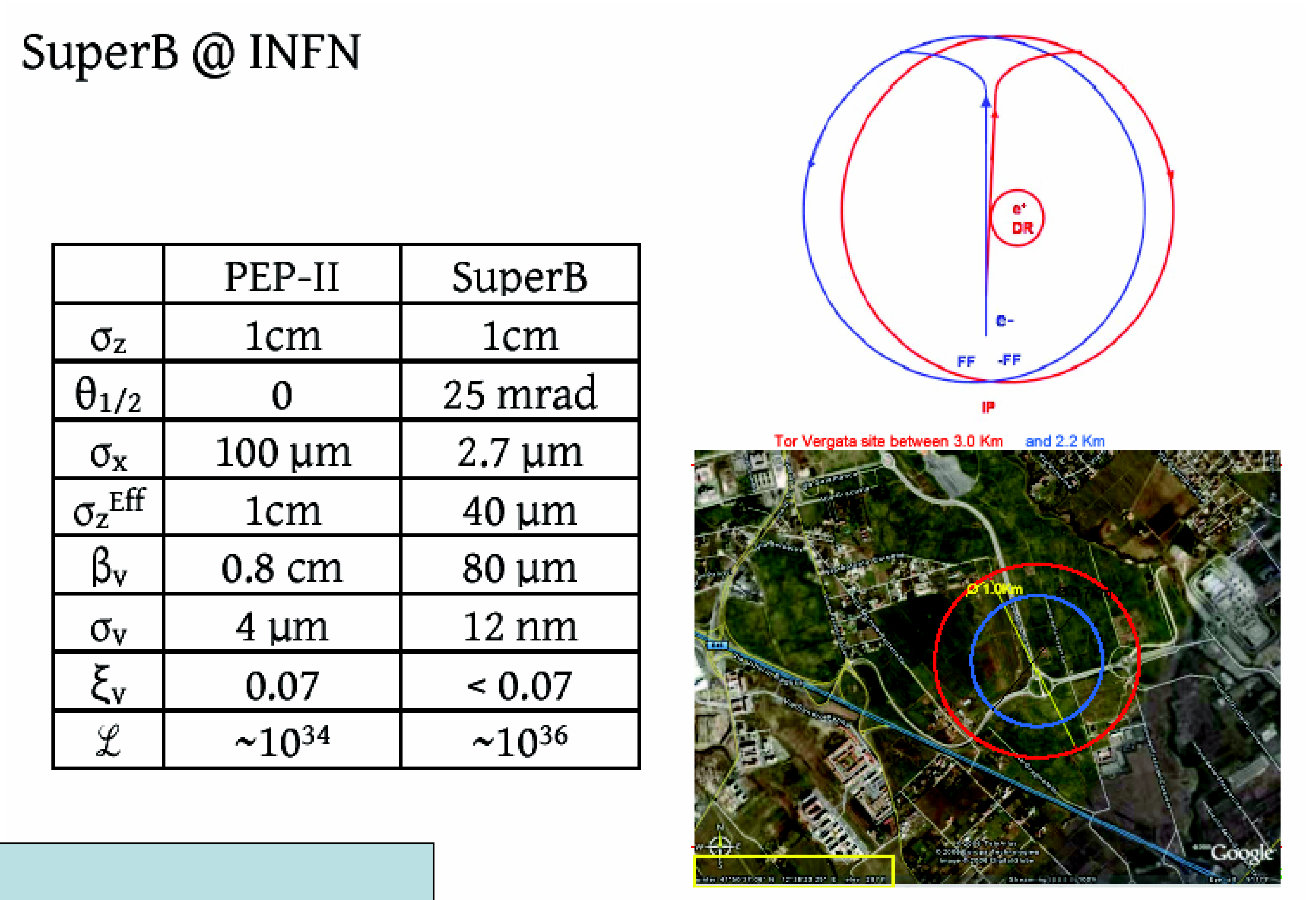
View of the Pit



Person

Proposed schedule





SuperB @ INFN

	PEP-II	SuperB
σ_z	1cm	1cm
$\theta_{1/2}$	0	25 mrad
σ_x	100 µm	2.7 µm
σ_z^{Eff}	1cm	40 µm
β_v	0.8 cm	80 µm
σ_v	4 µm	12 nm
ξ_v	0.07	< 0.07
$\mathcal{L}$	~10^{34}	~10^{36}

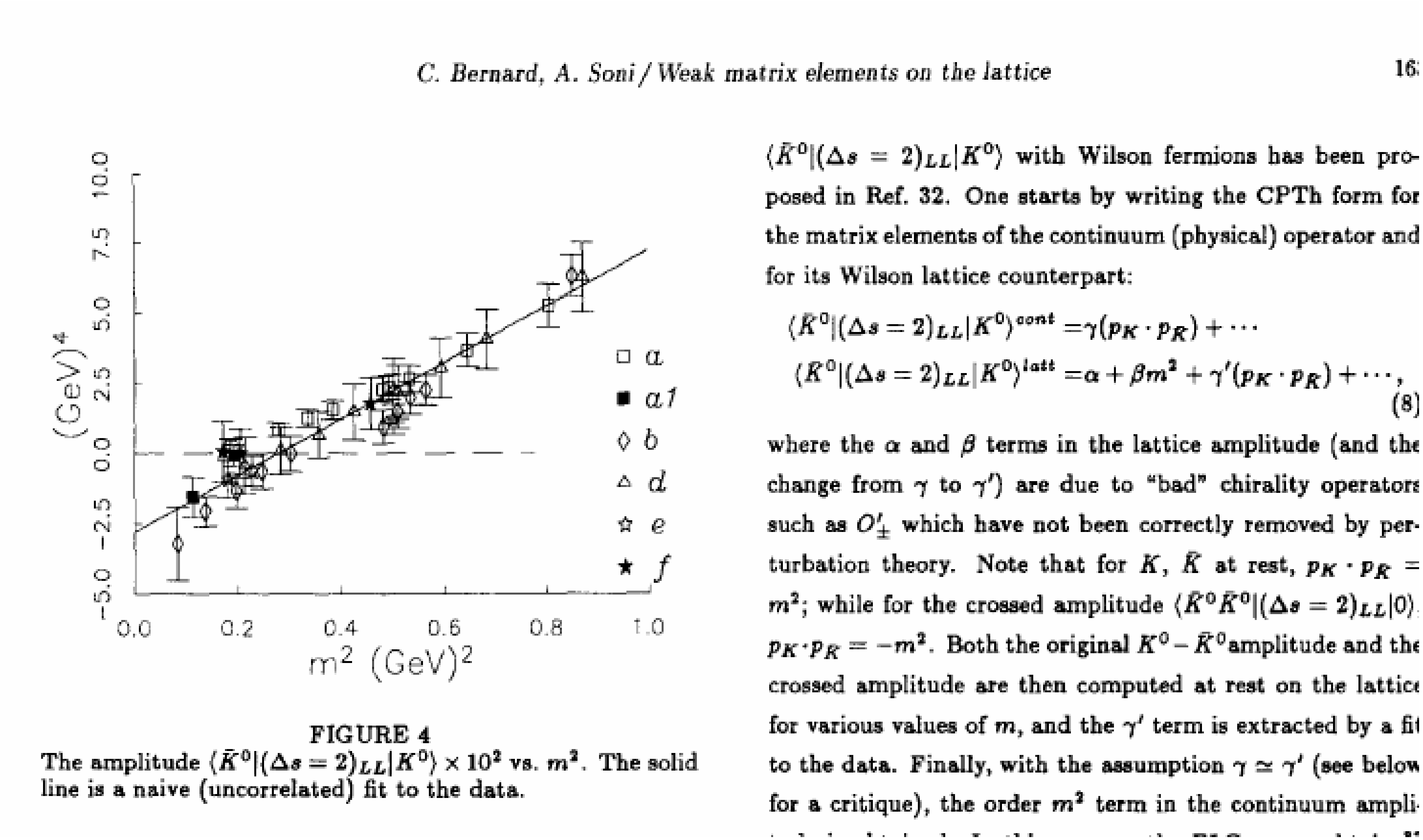
Aaron Roodman @DPF06

Prospects for improved lattice calculations

Note the unique role of B_K

Whereas B->ψK… (φ_1), B->ππ,πρ,ρρ (φ_2),
B->DK..(φ_3), with no theory input,
it is simply not possible to translate ε_K
on to the CKM-phase without theory input for B_K ; **B_K is indispensable for demonstrating that**
B & K CP have a common origin

~25 years of B_K



C. Bernard, A. Soni / Weak matrix elements on the lattice 16

FIGURE 4

The amplitude $\langle \bar{K}^0 | (\Delta s = 2)_{LL} | K^0 \rangle \times 10^2$ vs. m^2. The solid line is a naive (uncorrelated) fit to the data.

$\langle \bar{K}^0 | (\Delta s = 2)_{LL} | K^0 \rangle$ with Wilson fermions has been proposed in Ref. 32. One starts by writing the CPTh form for the matrix elements of the continuum (physical) operator and for its Wilson lattice counterpart:

$$\begin{aligned} \langle \bar{K}^0 | (\Delta s = 2)_{LL} | K^0 \rangle^{cont} &= \gamma (p_K \cdot p_{\bar{K}}) + \cdots \\ \langle \bar{K}^0 | (\Delta s = 2)_{LL} | K^0 \rangle^{latt} &= \alpha + \beta m^2 + \gamma' (p_K \cdot p_{\bar{K}}) + \cdots , \end{aligned} \tag{8}$$

where the α and β terms in the lattice amplitude (and the change from γ to γ') are due to "bad" chirality operators such as $O'_{\pm}$ which have not been correctly removed by perturbation theory. Note that for K, $\bar{K}$ at rest, $p_K \cdot p_{\bar{K}} = m^2$; while for the crossed amplitude $\langle \bar{K}^0 \bar{K}^0 | (\Delta s = 2)_{LL} | 0 \rangle$, $p_K \cdot p_{\bar{K}} = -m^2$. Both the original $K^0 - \bar{K}^0$ amplitude and the crossed amplitude are then computed at rest on the lattice for various values of m, and the γ' term is extracted by a fit to the data. Finally, with the assumption $\gamma \simeq \gamma'$ (see below for a critique), the order m^2 term in the continuum ampli-

Bernard & A.S.
Lattice ‘88

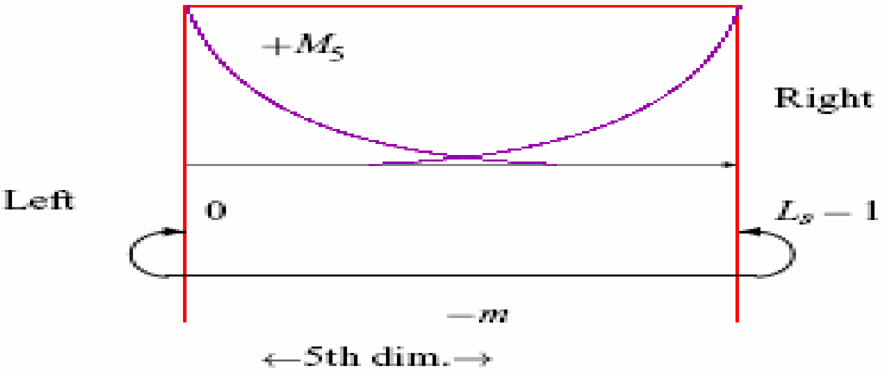
Chiral Symmetery & fine tuning

Accurate evaluation of O_{LL} requires precise knowledge of C's
-> SEARCHING FOR A NEEDLE IN A HAYSTACK

EXACT CHIRAL SYMMETRY ON THE LATTICE

Conventional fermions do not preserve chiral-flavor symmetry on the lattice (Nielsen - Ninomiya Theorem) ⇒ $\Delta S = 1$, $\Delta I = 1/2$ case mixing with lower dim. (power-divergent) operators & or mixing of 4-quark operators with wrong chirality ones makes lattice study of $K - \pi$ physics virtually impossible.

Domain Wall Fermions (Kaplan, Shamir, Narayanan and Neuberger)



Practical viability of DWF for QCD demonstrated (96-97) Tom Blum & A. S.

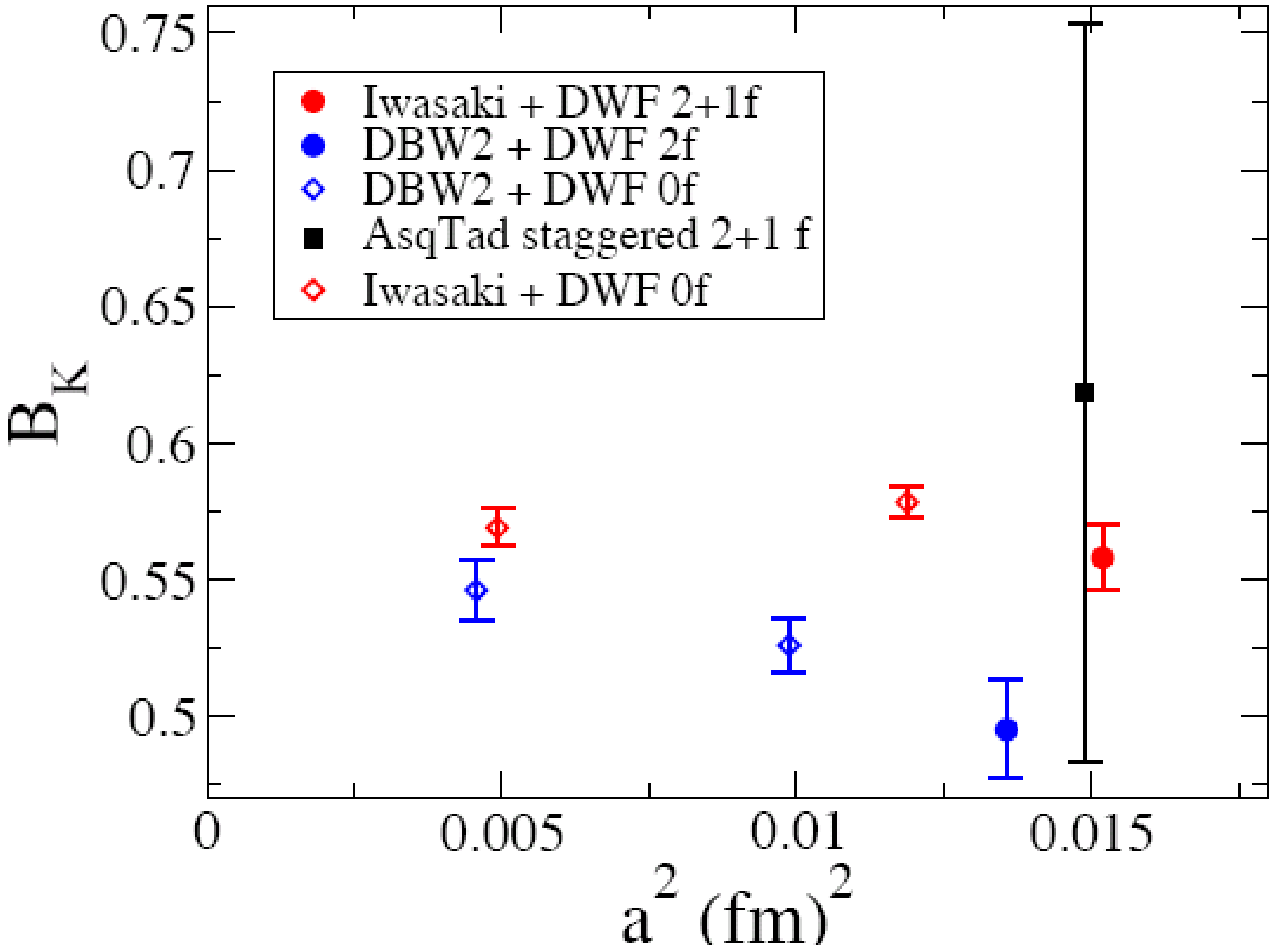
Chiral symmetry on the lattice, $a \neq 0$! Huge improvement

⇒ Now widespread use at BNL and elsewhere

RBC-UKQCD 2+1 dynamical DWQ,hep-ph/0702042

$$B_K^{\overline{\rm MS}}(2\ {\rm GeV}) \ = \ 0.524(10)(28)$$

PRL Jan25,08



New era in lattice accuracy

- Widespread use of chiral fermions (i.e. Domain wall or overlap) : respects important symmetries of the continuum theory.
- Dynamical (2+1) gauge configurations (no longer quenched)
- Use of SU(2)XSU(2)ChPT for chiral extrapolations (pioneered by RBC-UKQCD, hep-ph/0702042….):INCREASED PRECISION

Brief (~25 years) History of B_K

, ~’83 DGH use K^+ lifetime + LOChPT + SU(3)->
B_K ~0.33… no error estimate, no scale dependence….

~’84 Lattice method for WME born…many attempts & improvements for B_K evaluations

~’98 JLQCDstaggered B_K (2GeV)= 0.628(42)quenched(~110).

~’97 1st B_K with DWQ(T.Blum&A.S),0.628(47) quenched.

~’01 RBC B_K with DWQ, quenched=0.532(11) quenched

~’05 RBC , nf=2, dyn. DWQ, B_K =0.563(21)(39)(30)

~’06 Gimnez et al (HPQCD; stagg.) 2+1, B_K =0.618(18)(19)(30)(130)

~07,RBC-UKQCD DWQ 2+1 …..0.524(10)(28)

DWQ lower B_K -> requiring larger CKM-phase

~’08 Target 2+1 dyn. DWQ, B_K with total error 5%

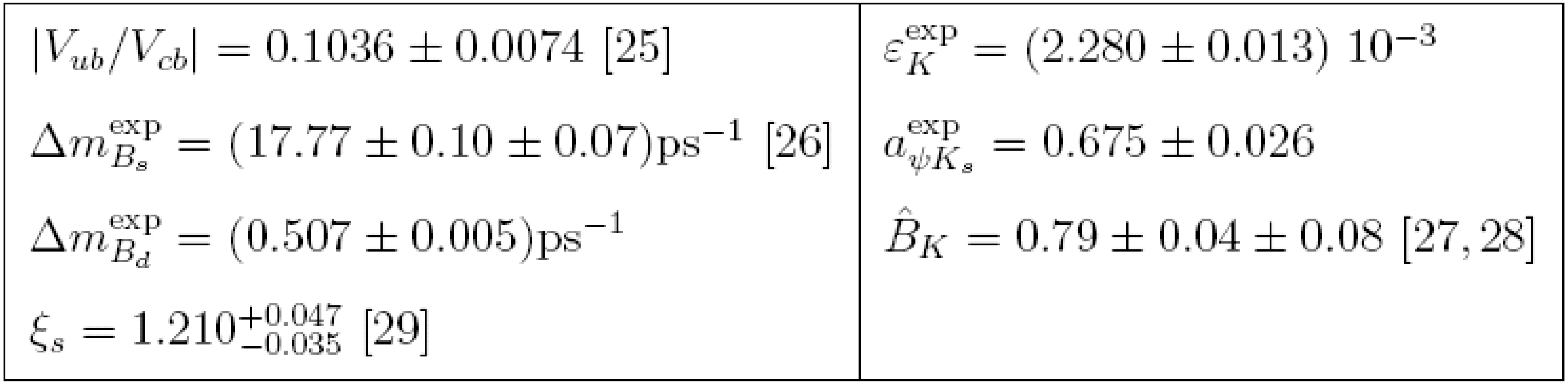
Emerging signs of New Physics

I. A tale of two numbers

Status('07) of fits to the UT

- CKMFitter group
  J.Charles et alhep-ph/0406184
- UTfit group
  M. Bona et al hep-ph/0606167
- E.Lunghi +A.S,arXiV.0707.0212

- Direct measurement(gold-plated)
  BELLE + BABAR (HFAG)
-



$\lvert V_{ub}/V_{cb}\rvert = 0.1036 \pm 0.0074$ [25]	$\varepsilon_K^{\mathrm{exp}} = (2.280 \pm 0.013)\ 10^{-3}$
$\Delta m_{B_s}^{\mathrm{exp}} = (17.77 \pm 0.10 \pm 0.07)\mathrm{ps}^{-1}$ [26]	$a_{\psi K_s}^{\mathrm{exp}} = 0.675 \pm 0.026$
$\Delta m_{B_d}^{\mathrm{exp}} = (0.507 \pm 0.005)\mathrm{ps}^{-1}$	$\hat{B}_K = 0.79 \pm 0.04 \pm 0.08$ [27, 28]
$\xi_s = 1.210^{+0.047}_{-0.035}$ [29]	

Table 1: Inputs that we use in the unitarity triangle fit.

Contrast '01 vs. '07 inputs:Drive for precision pays off

- '01 fit: '07 fit:

Lunghi+AS,arXiv.0707.0212

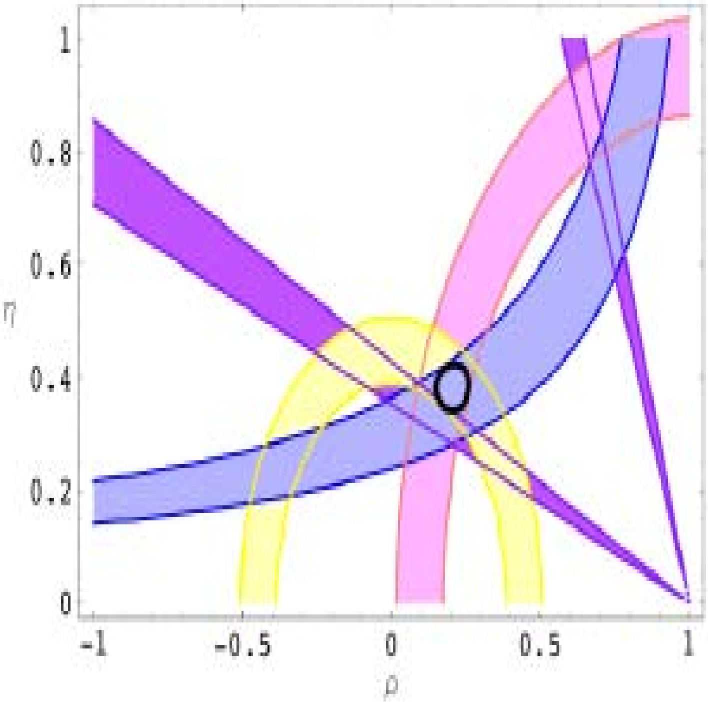
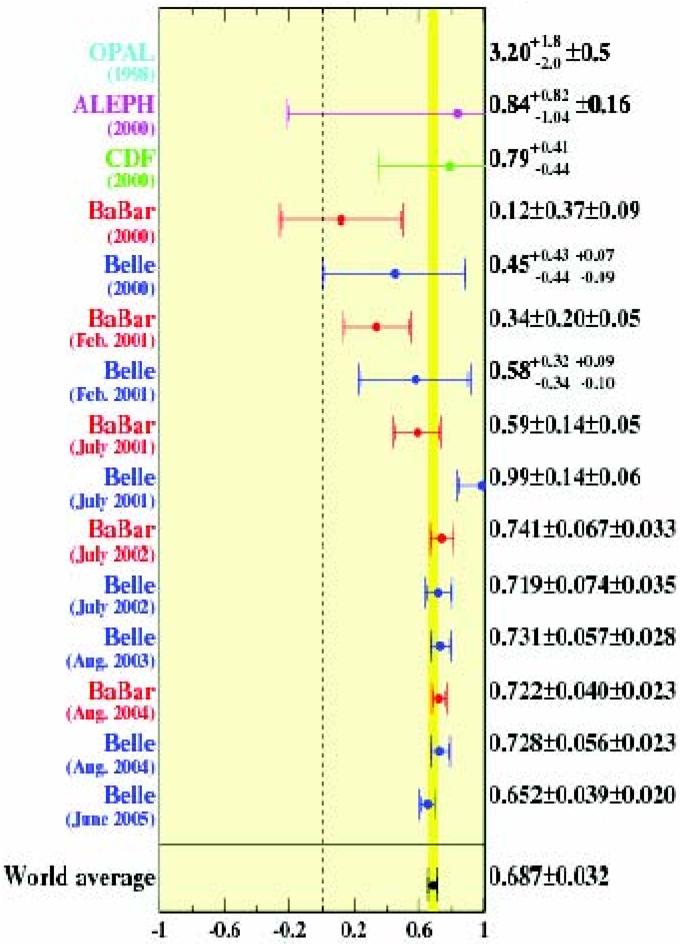


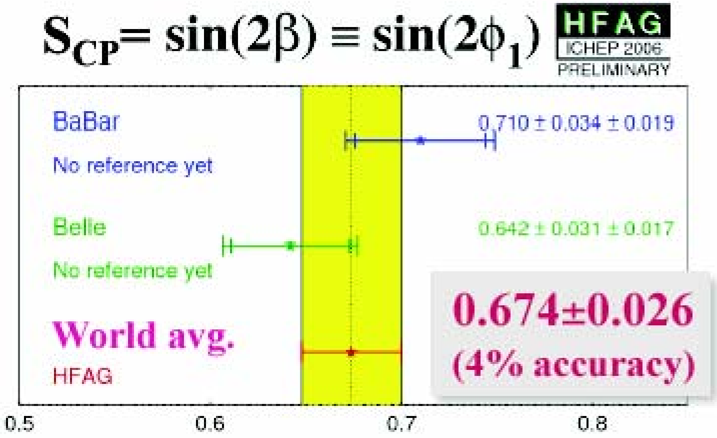
Figure 1: Unitarity triangle fit in the SM. The constraints from $|V_{ub}/V_{cb}|$, ε_K, $\Delta M_{B_s}/\Delta M_{B_d}$ are included in the fit; the region allowed by $a_{\psi K}$ is superimposed.

sin2β history (1998-2005)



2006 BaBar + Belle

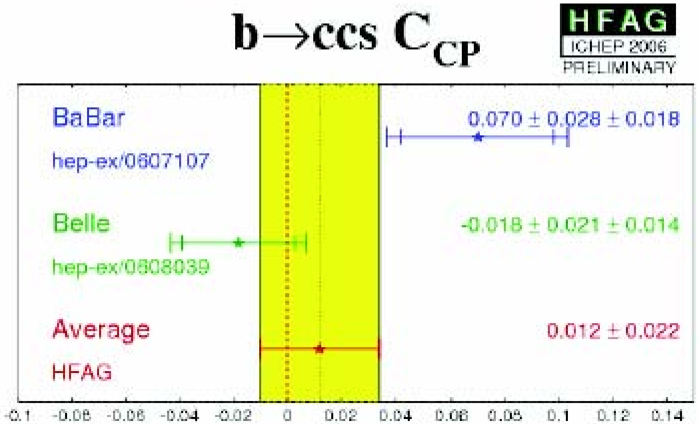
$S_{CP} = \sin(2\beta) \equiv \sin(2\phi_1)$



0.674±0.026

(4% accuracy)

$b \to ccs\ C_{CP}$

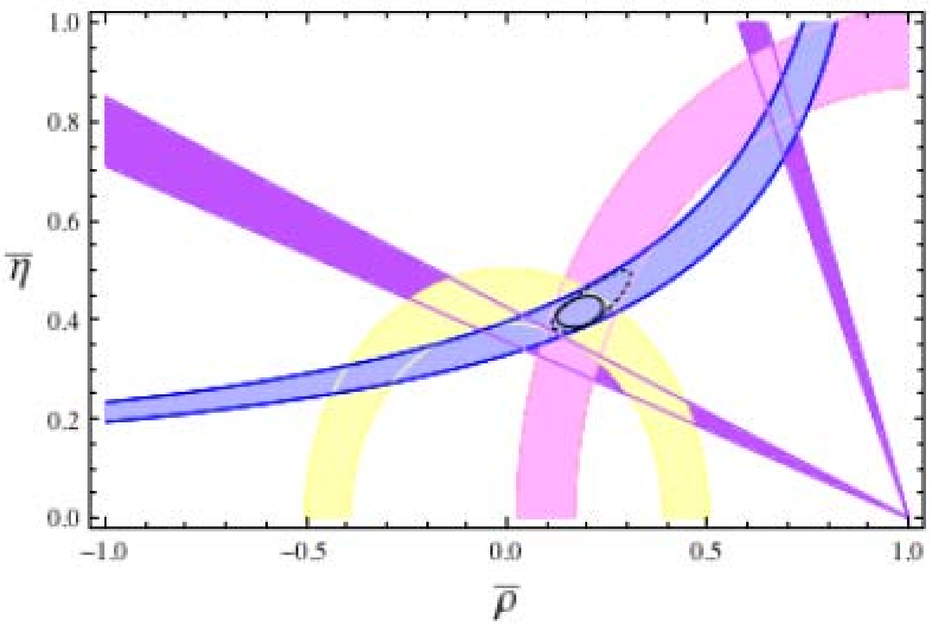


Continuing saga of Vub

- For past 2 years or so exclusive & inclusive ~small discrepancy:
- Exc ~ (3.7 +-.2+-.5)X10^{-3}
- Inc ~ (4.3 +-.2+-.3)X10^{-3}
- More recently (LP'07) Neubert suggests source is m_b extraction from b s gamma; disregarding that m_b shows incl. Vub quite consistent i.e. 3.98+-.15+-.30 X10^{-3}

-> ***Let's try NOT use Vub***

Leave out V_{ub}
Sin 2 β = 0.84+-.06



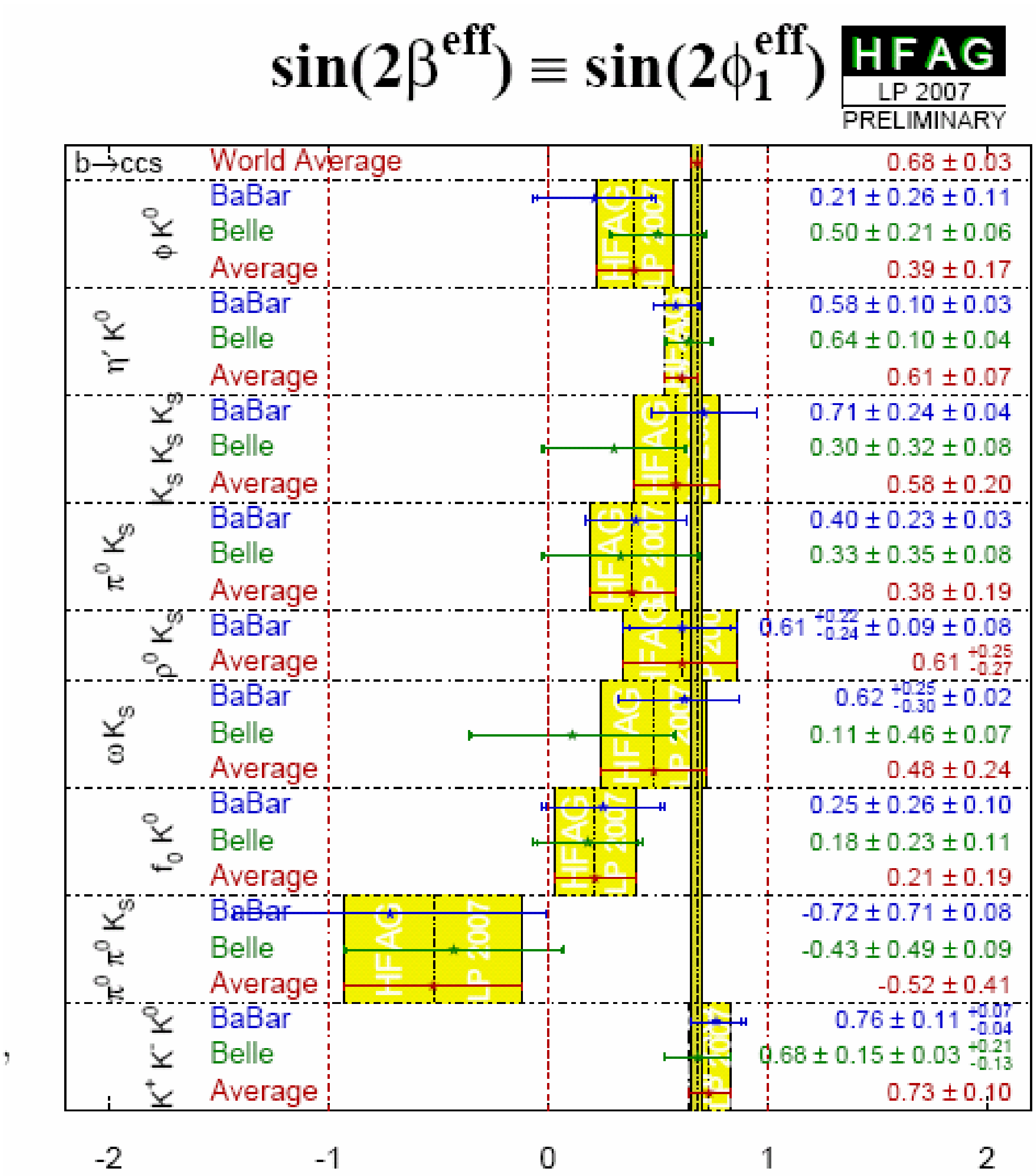
Unitarity triangle fit in the SM. The solid contour is obtained using the constraints
$\Delta M_{B_s}/\Delta M_{B_d}$ and $|V_{ub}/V_{cb}|$. The dashed contour shows the effect of excluding $|V_{ub}/V_{cb}|$
fit. The region allowed by $a_{\psi K}$ is superimposed.

Summary on 2 numbers

II. A tale of four numbers

- **Tantalizing (possible) signs of a BSM-CP-odd phase**

Grossman & Worah PLB’97;
London and A.S. PLB’97



$\sin(2\beta^{\rm eff}) \equiv \sin(2\phi_1^{\rm eff})$
HFAG
LP 2007
PRELIMINARY
b→ccs
World Average
0.68 ± 0.03
ϕK^0
BaBar
0.21 ± 0.26 ± 0.11
Belle
0.50 ± 0.21 ± 0.06
Average
0.39 ± 0.17
$\eta' K^0$
BaBar
0.58 ± 0.10 ± 0.03
Belle
0.64 ± 0.10 ± 0.04
Average
0.61 ± 0.07
$K_S K_S K_S$
BaBar
0.71 ± 0.24 ± 0.04
Belle
0.30 ± 0.32 ± 0.08
Average
0.58 ± 0.20
$\pi^0 K_S$
BaBar
0.40 ± 0.23 ± 0.03
Belle
0.33 ± 0.35 ± 0.08
Average
0.38 ± 0.19
$\rho^0 K_S$
BaBar
$0.61\ ^{+0.22}_{-0.24} \pm 0.09 \pm 0.08$
Average
$0.61\ ^{+0.25}_{-0.27}$
ωK_S
BaBar
$0.62\ ^{+0.25}_{-0.30} \pm 0.02$
Belle
0.11 ± 0.46 ± 0.07
Average
0.48 ± 0.24
$f_0 K^0$
BaBar
0.25 ± 0.26 ± 0.10
Belle
0.18 ± 0.23 ± 0.11
Average
0.21 ± 0.19
$\pi^0 \pi^0 K_S$
BaBar
-0.72 ± 0.71 ± 0.08
Belle
-0.43 ± 0.49 ± 0.09
Average
-0.52 ± 0.41
$K^+ K^- K^0$
BaBar
$0.76 \pm 0.11\ ^{+0.07}_{-0.04}$
Belle
$0.68 \pm 0.15 \pm 0.03\ ^{+0.21}_{-0.13}$
Average
0.73 ± 0.10
HFAG LP 2007
-2
-1
0
1
2

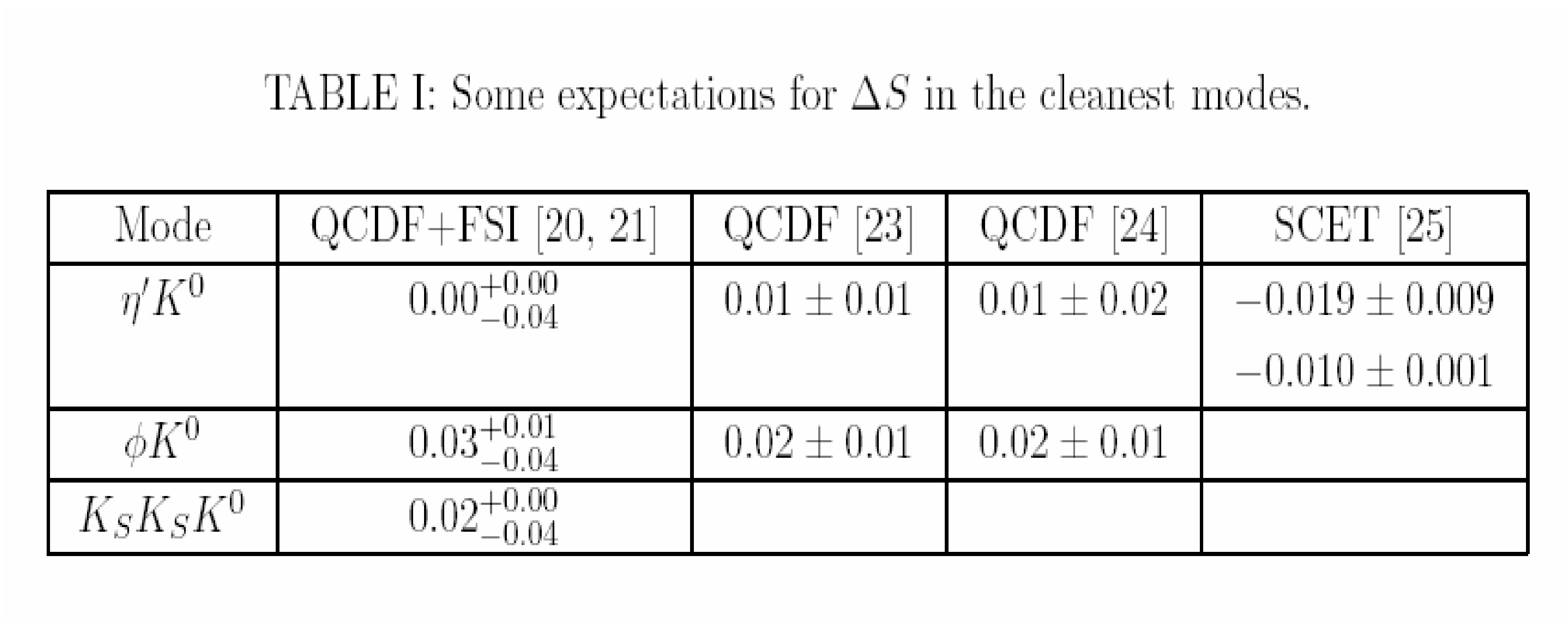


TABLE I: Some expectations for ΔS in the cleanest modes.

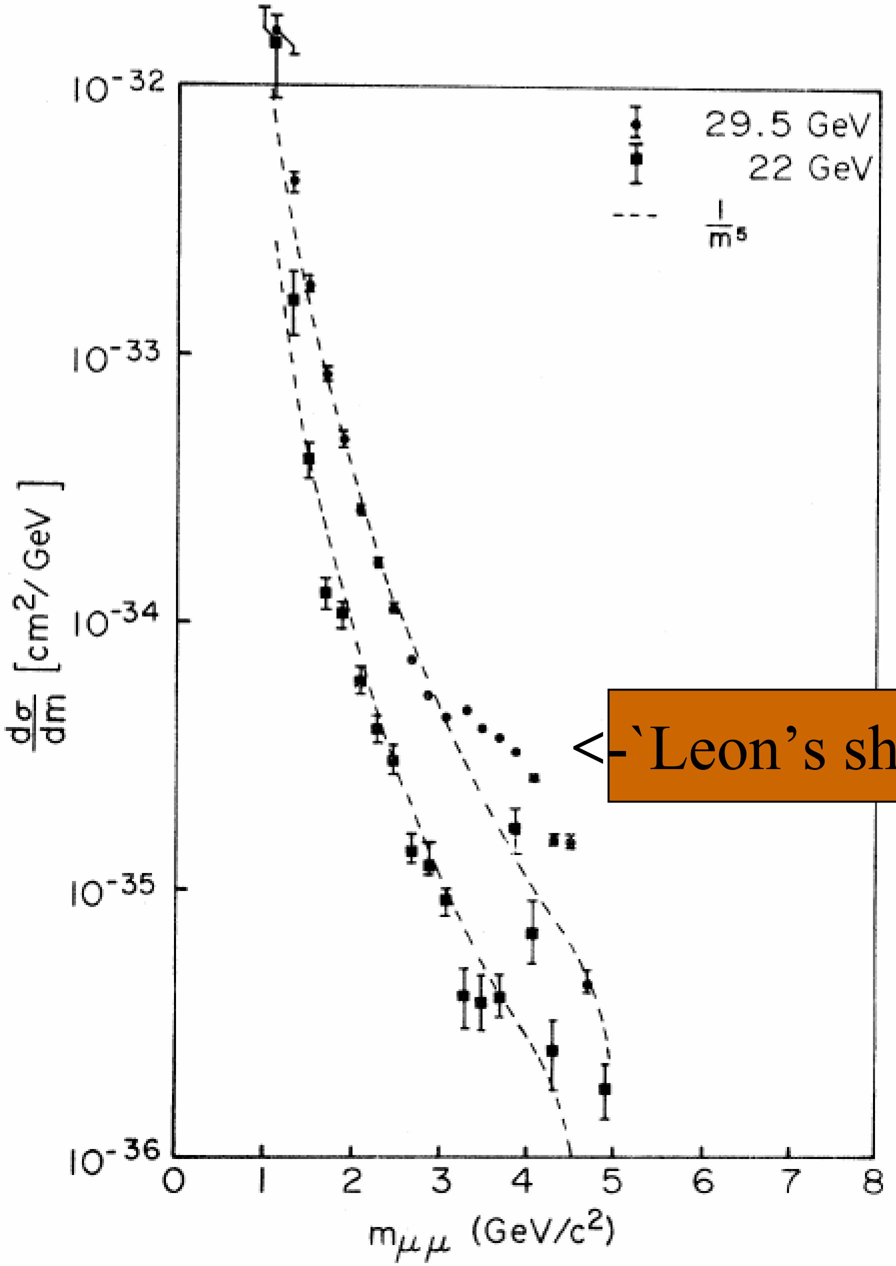
Mode	QCDF+FSI [20, 21]	QCDF [23]	QCDF [24]	SCET [25]
$\eta' K^0$	$0.00^{+0.00}_{-0.04}$	0.01 ± 0.01	0.01 ± 0.02	-0.019 ± 0.009 -0.010 ± 0.001
ϕK^0	$0.03^{+0.01}_{-0.04}$	0.02 ± 0.01	0.02 ± 0.01	
$K_S K_S K^0$	$0.02^{+0.00}_{-0.04}$			

CLEANEST MODES

Although, at the moment it is not a conclusive effect, it may well become a serious blunder on the part of our community to ignore it!

We can try learn some lessons from history.

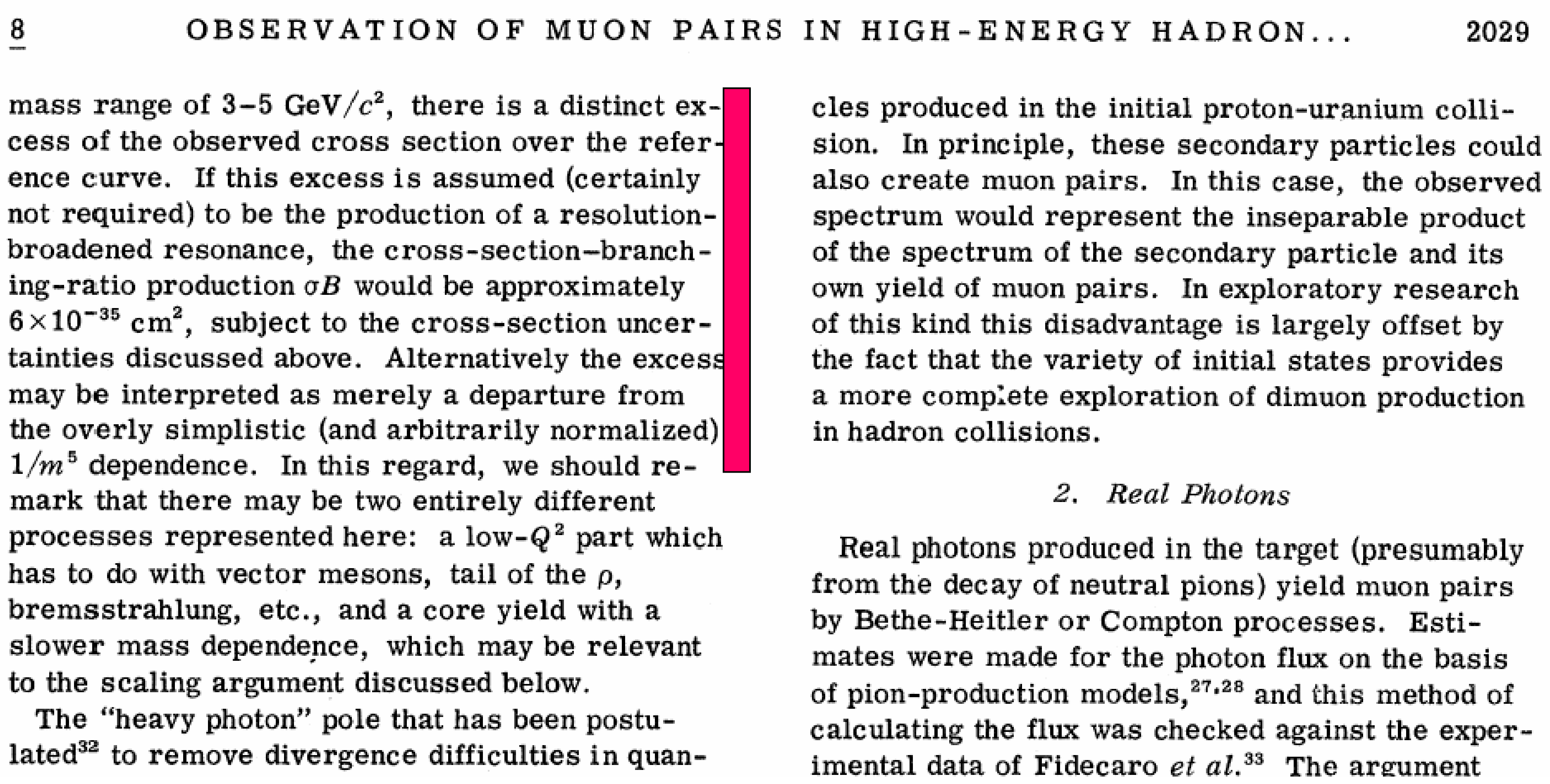
It is extremely important to understand that basically it is a very good test of the SM and it should be followed vigorously to a decisive conclusion ASAP.



<-`Leon’s shoulder

FIG. 15. Experimental cross sections at two energies compared with a simple $1/m^5$ continuum.

Christenson,Hicks,Lederman,Limon,Pope & Zavattini
PRD 8,2016 ‘72



mass range of 3–5 GeV/c^2, there is a distinct excess of the observed cross section over the reference curve. If this excess is assumed (certainly not required) to be the production of a resolution-broadened resonance, the cross-section–branching-ratio production σB would be approximately 6×10^{-35} cm^2, subject to the cross-section uncertainties discussed above. Alternatively the excess may be interpreted as merely a departure from the overly simplistic (and arbitrarily normalized) $1/m^5$ dependence. In this regard, we should remark that there may be two entirely different processes represented here: a low-Q^2 part which has to do with vector mesons, tail of the ρ, bremsstrahlung, etc., and a core yield with a slower mass dependence, which may be relevant to the scaling argument discussed below.

The “heavy photon” pole that has been postulated[32] to remove divergence difficulties in quan-

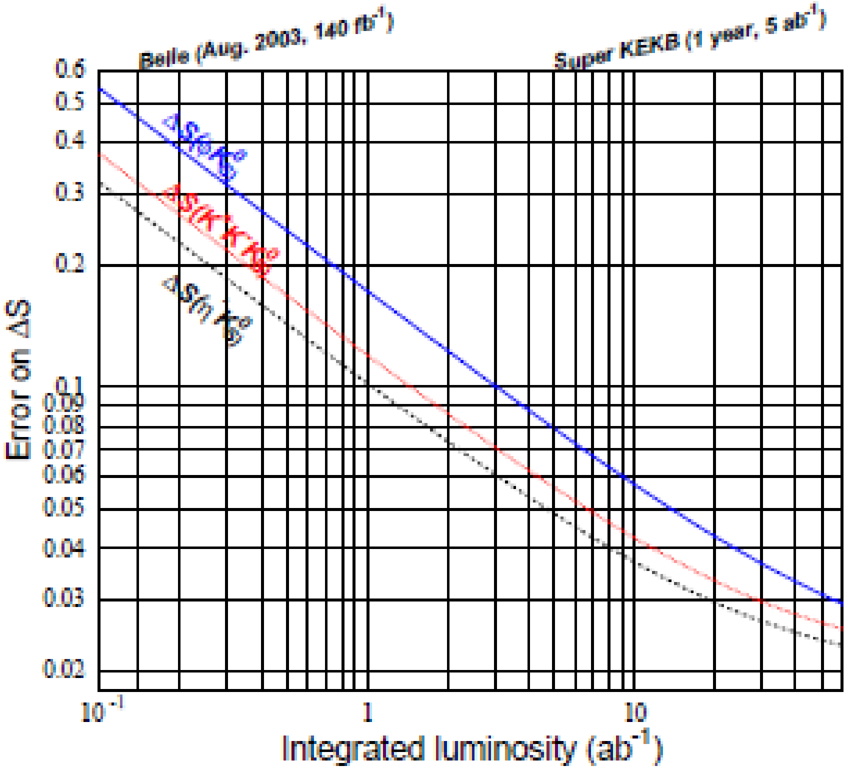
cles produced in the initial proton-uranium collision. In principle, these secondary particles could also create muon pairs. In this case, the observed spectrum would represent the inseparable product of the spectrum of the secondary particle and its own yield of muon pairs. In exploratory research of this kind this disadvantage is largely offset by the fact that the variety of initial states provides a more complete exploration of dimuon production in hadron collisions.

2. *Real Photons*

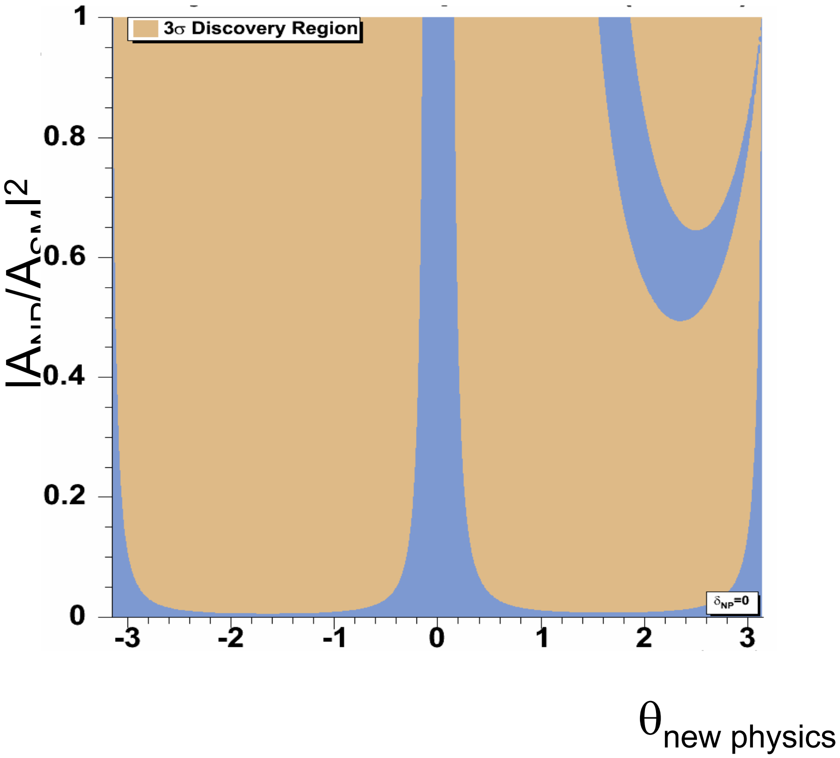
Real photons produced in the target (presumably from the decay of neutral pions) yield muon pairs by Bethe-Heitler or Compton processes. Estimates were made for the photon flux on the basis of pion-production models,[27,28] and this method of calculating the flux was checked against the experimental data of Fidecaro *et al.*[33] The argument

Sensitivity to new CP phases

Estimated error in the measurement of time dependent CP violation



Discovery region with 50 ab^{-1}



So far 3 numbers

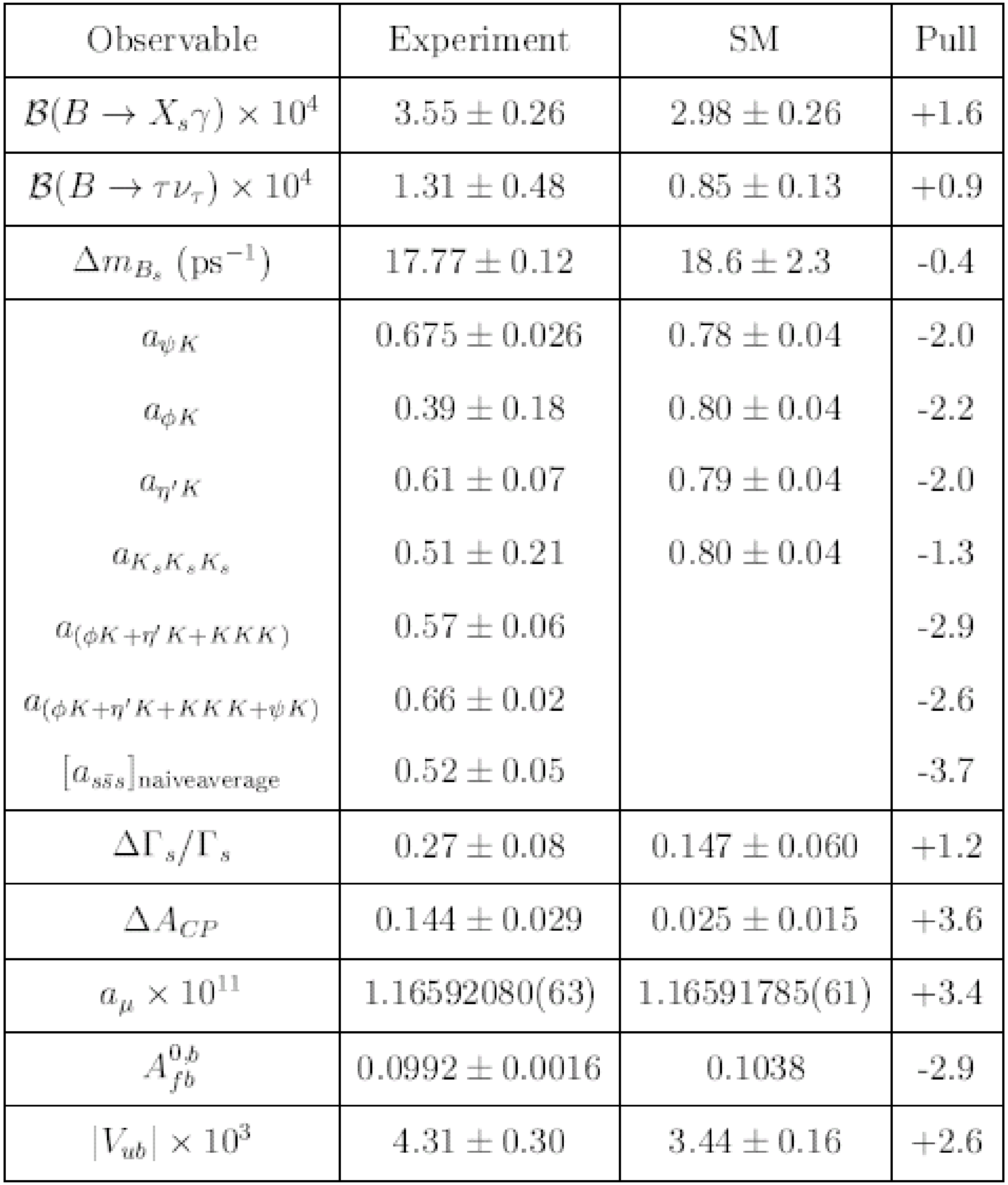
- I) Expt [ε_K , B-mixing, b->uev…] + Lattice WME -> $\sin 2\beta_{SM}$ =0.78+-.04
- II)BF measurements [B -> "ψ" K_S]=0.674+-0.026
- III) BF measurements [B-> (φ, η',3) K_S]=0.57+-.06
- ***-> Deviations 2.2(I-II) - 3(I-III) sigmas***

Last but quite significant #

Central Character:Penguin graph

PULL TABLE:Report Card on the health of the SM('07)

Lunghi+AS
arXiV.0707
0212

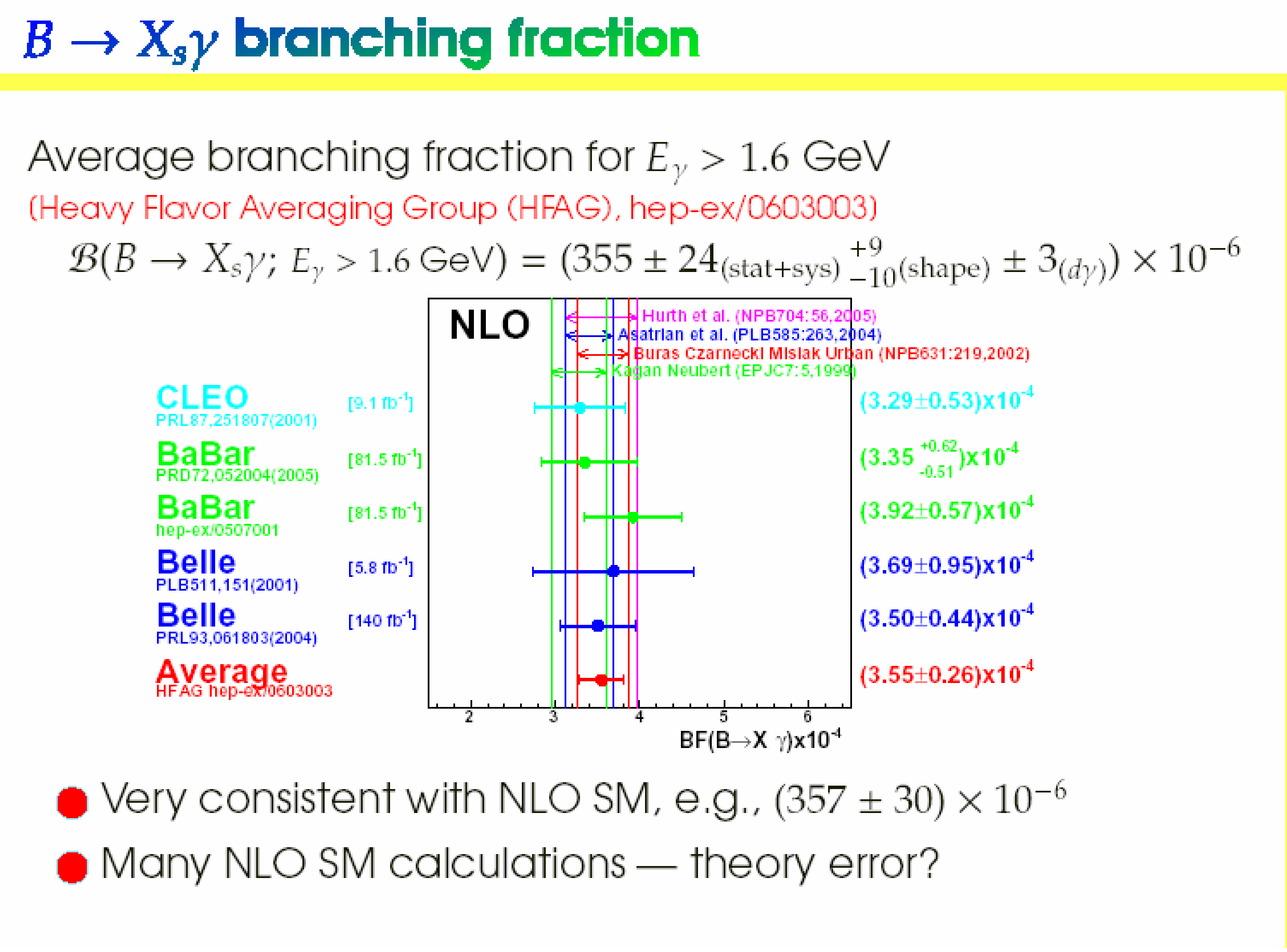


Observable	Experiment	SM	Pull
$\mathcal{B}(B \to X_s\gamma) \times 10^4$	3.55 ± 0.26	2.98 ± 0.26	+1.6
$\mathcal{B}(B \to \tau\nu_\tau) \times 10^4$	1.31 ± 0.48	0.85 ± 0.13	+0.9
Δm_{B_s} (ps^{-1})	17.77 ± 0.12	18.6 ± 2.3	-0.4
$a_{\psi K}$	0.675 ± 0.026	0.78 ± 0.04	-2.0
$a_{\phi K}$	0.39 ± 0.18	0.80 ± 0.04	-2.2
$a_{\eta' K}$	0.61 ± 0.07	0.79 ± 0.04	-2.0
$a_{K_s K_s K_s}$	0.51 ± 0.21	0.80 ± 0.04	-1.3
$a_{(\phi K + \eta' K + KKK)}$	0.57 ± 0.06		-2.9
$a_{(\phi K + \eta' K + KKK + \psi K)}$	0.66 ± 0.02		-2.6
$[a_{s\bar{s}s}]_{\rm naiveaverage}$	0.52 ± 0.05		-3.7
$\Delta\Gamma_s/\Gamma_s$	0.27 ± 0.08	0.147 ± 0.060	+1.2
ΔA_{CP}	0.144 ± 0.029	0.025 ± 0.015	+3.6
$a_\mu \times 10^{11}$	1.16592080(63)	1.16591785(61)	+3.4
$A_{fb}^{0,b}$	0.0992 ± 0.0016	0.1038	-2.9
$\lvert V_{ub}\rvert \times 10^3$	4.31 ± 0.30	3.44 ± 0.16	+2.6

Summary so far

- **The CKM-paradigm of CP violation accounts for the observed CP patterns to an accuracy of about 15%!**
- **Remarkably in the past few years several B-factories results exhibit 2 -3 σ deviations from the SM-CKM paradigm!!**

Some other notable effects



$B \to X_s\gamma$ branching fraction

Average branching fraction for $E_\gamma > 1.6$ GeV

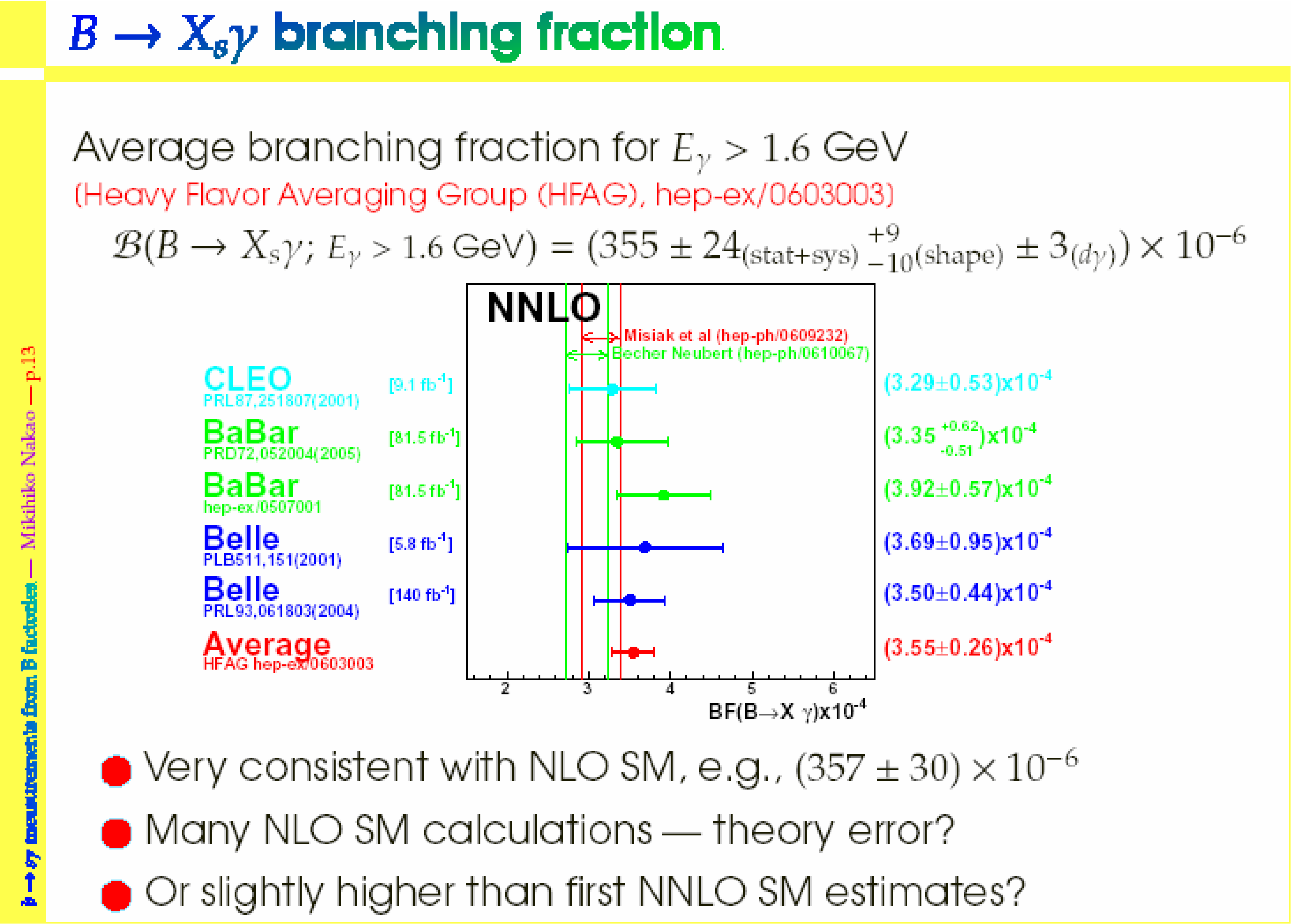
(Heavy Flavor Averaging Group (HFAG), hep-ex/0603003)

$$\mathcal{B}(B \to X_s\gamma;\ E_\gamma > 1.6\ \text{GeV}) = (355 \pm 24_{(\text{stat+sys})}\ {}^{+9}_{-10}{}_{(\text{shape})} \pm 3_{(d\gamma)}) \times 10^{-6}$$

CLEO PRL87,251807(2001)	[9.1 fb^{-1}]	$(3.29\pm0.53)\times10^{-4}$
BaBar PRD72,052004(2005)	[81.5 fb^{-1}]	$(3.35\,{}^{+0.62}_{-0.51})\times10^{-4}$
BaBar hep-ex/0507001	[81.5 fb^{-1}]	$(3.92\pm0.57)\times10^{-4}$
Belle PLB511,151(2001)	[5.8 fb^{-1}]	$(3.69\pm0.95)\times10^{-4}$
Belle PRL93,061803(2004)	[140 fb^{-1}]	$(3.50\pm0.44)\times10^{-4}$
Average HFAG hep-ex/0603003		$(3.55\pm0.26)\times10^{-4}$

- Very consistent with NLO SM, e.g., $(357 \pm 30) \times 10^{-6}$
- Many NLO SM calculations — theory error?

Mikihiko Nakao @ CKM06; c also Matthias Neubert



$B \to X_s\gamma$ branching fraction

Average branching fraction for $E_\gamma > 1.6$ GeV

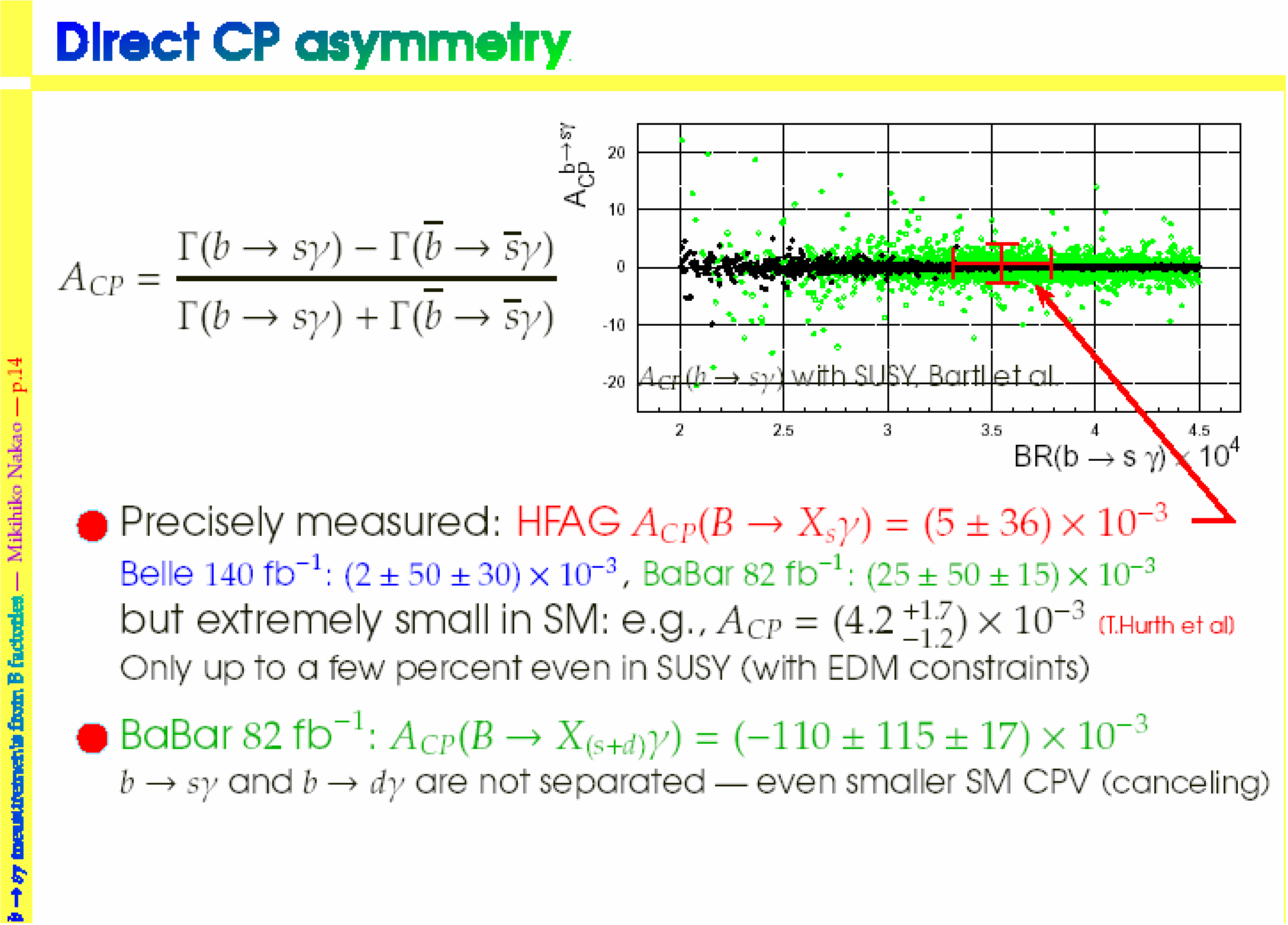
(Heavy Flavor Averaging Group (HFAG), hep-ex/0603003)

$$\mathcal{B}(B \to X_s\gamma;\, E_\gamma > 1.6\ \text{GeV}) = (355 \pm 24_{(\text{stat+sys})}\ {}^{+9}_{-10}{}_{(\text{shape})} \pm 3_{(d\gamma)}) \times 10^{-6}$$

- Very consistent with NLO SM, e.g., $(357 \pm 30) \times 10^{-6}$
- Many NLO SM calculations — theory error?
- Or slightly higher than first NNLO SM estimates?

$b \to s\gamma$ measurements from B factories — Mikihiko Nakao — p.13

Mikihiko Nakao @ CKM06 ; c also Matthias Neubert



Direct CP asymmetry

$$A_{CP} = \frac{\Gamma(b \to s\gamma) - \Gamma(\bar{b} \to \bar{s}\gamma)}{\Gamma(b \to s\gamma) + \Gamma(\bar{b} \to \bar{s}\gamma)}$$

- Precisely measured: HFAG $A_{CP}(B \to X_s\gamma) = (5 \pm 36) \times 10^{-3}$
  Belle 140 fb^{-1}: $(2 \pm 50 \pm 30) \times 10^{-3}$, BaBar 82 fb^{-1}: $(25 \pm 50 \pm 15) \times 10^{-3}$
  but extremely small in SM: e.g., $A_{CP} = (4.2\,^{+1.7}_{-1.2}) \times 10^{-3}$ (T.Hurth et al)
  Only up to a few percent even in SUSY (with EDM constraints)
- BaBar 82 fb^{-1}: $A_{CP}(B \to X_{(s+d)}\gamma) = (-110 \pm 115 \pm 17) \times 10^{-3}$
  $b \to s\gamma$ and $b \to d\gamma$ are not separated — even smaller SM CPV (canceling)

Mikihiko Nakao @ CKM06

WHODUNIT?

Honest answer &

- Don’t really know (too many possibilities…)
- But theoretically the most interesting possibility is that we may be witnessing

Dawning of the age of

“Warped Quantum Flavordynamics”

General characteristics of implied NP

- **At least one new CP-odd (largish) phase…should have interesting effects in e.g.**
- **New particle(s) with**
- **Numerous candidates: charged Higgs, heavier (4th family?) quarks, Z', KK/SUSY-partners…..**

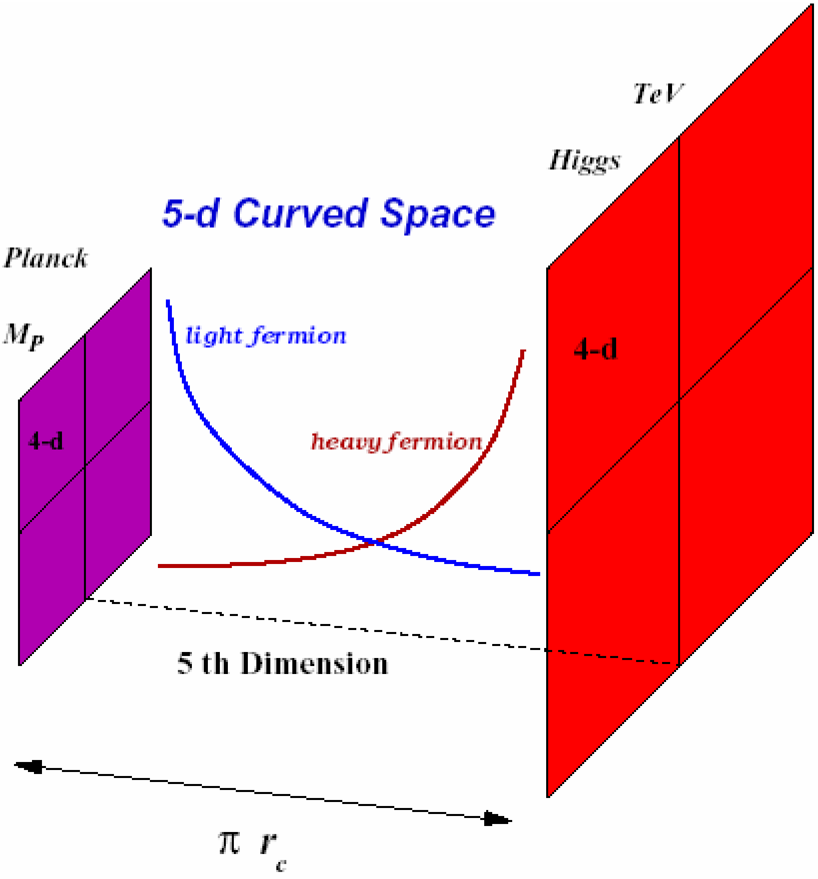


Figure 1: Warped geometry with flavor from fermion localization. The Higgs field resides on the TeV-brane. The size of the extra dimension is $\pi r_c \sim M_P^{-1}$.

Simultaneous resolution to hierarchy and flavor puzzles

Numerous other possibilities

- **1)2nd Higgs doublet…e.g. T2HDM**
- **2) another (4th) generation**
- **3) Z'**
- **4) SUSY**

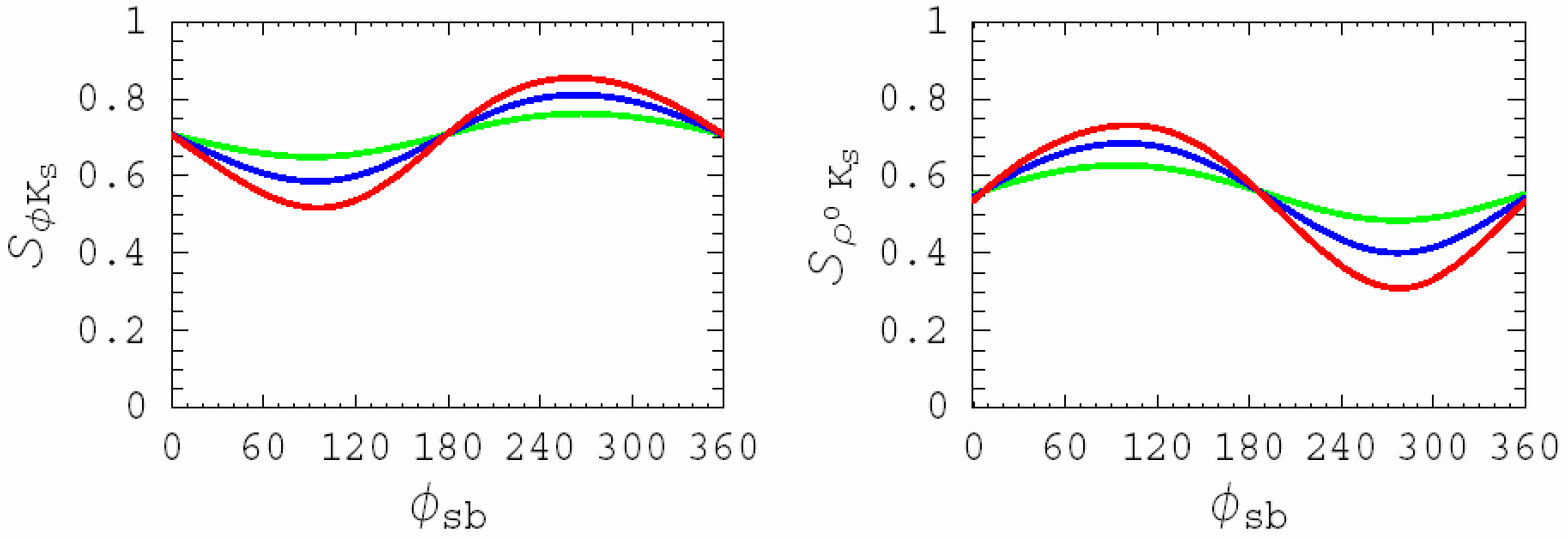
Revival of 4th Generation!

- Who needs it? May facilitate DEWSB
- Recall: 1) The Fourth family of quarks and leptons. Proceedings, 1st International Symposium, Santa Monica, USA, February 26-28, 1987.
  D.B. Cline, (ed.), A. Soni, (ed.) (UCLA) . 1987.
  New York, USA: Acad. Sci. (1987) 365 p. (Annals of the New York Academy of Sciences, 518).
- 2) The fourth family of quarks and leptons. Proceedings, 2nd International Symposium, Santa Monica, USA, February 23-25, 1989.
  D.B. Cline, (ed.), A. Soni, (ed.) (UCLA) . 1989.
  New York, USA: Acad. Sci. (1989) 500 p. (Annals of the New York Academy of Sciences, 578)

- Difficulties with precision tests ? May not be an obstacle
  (see Kribs, Tait et al)
- Additional CP-odd phases…mostly small effects but can have enhanced EWP
  can give rise to non-vanishing ΔS and $\Delta A_{K\pi}$ Important Implications for B_S especially
  $\sin 2\beta_s$ may be >> 1-2 degrees (which is the prediction in SM)
- Would be great news for LHCb and possibly for Tevatron
  as studies of TDCP &/or angular correlations in $B_S \to \psi\eta'$ (Φ); $D_S^{(*)} D_S^{(*)}$ ....
  could reveal this

Fourth Generation CP Violation Effect on $B \to K\pi$, ϕK and ρK in NLO PQCD

Wei-Shu Hou[1], Hsiang-nan Li[2,3], Satoshi Mishima[4], and Makiko Nagashima[5]



B-Factory Signals for a WED

(Agashe,Perez,Soni,hep-ph/0406101(PRL);0408134 (PRD)

- RS with a WARPED EXTRA DIMENSION (WED) provides an elegant solution to the HP
- In this framework, due to warped higher-dimensional spacetime, the mass scales (i.e. flavors) in an effective 4D description depend on location in ED. Thus, e.g. the light fermions are localized near the Plank brane where the effective cut-off is much higher than TeV so that FCNC's from HDO are greatly suppressed.. The top quark,on the other hand is localized on the TeV brane so that it gets a large 4D top Yukawa coupling.

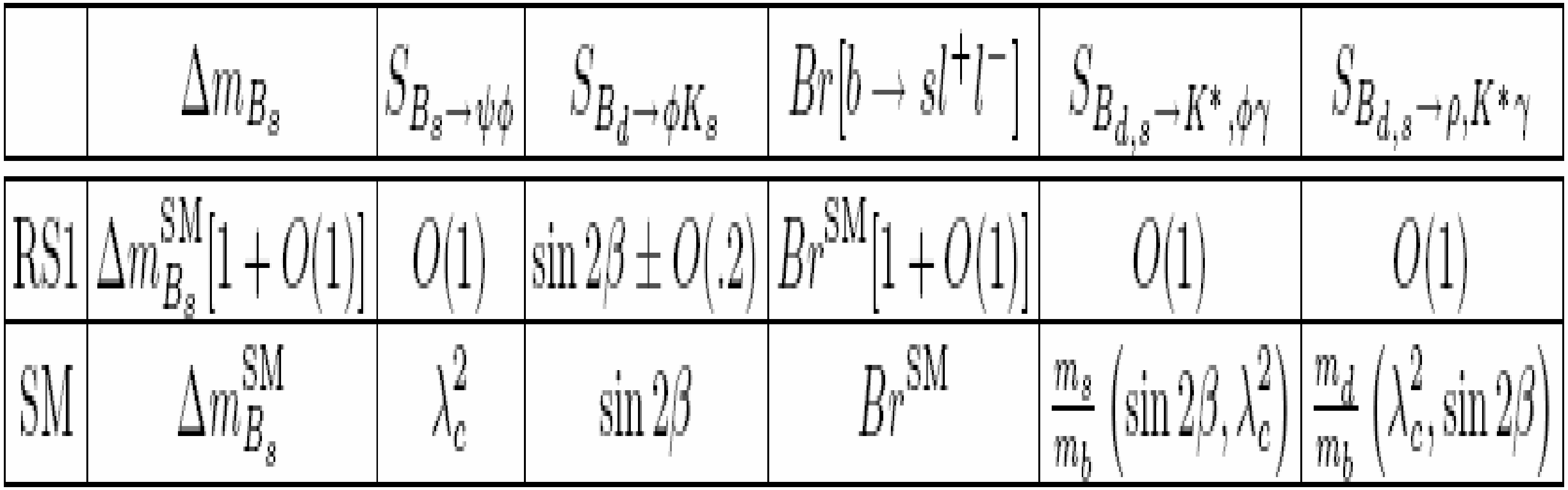
Key features of WED

- **Amielorating the Flavor Problem. This provides an understanding of hierarchy of fermion masses w/o hierarchies in fundamental 5D params. Thus "solving" the SM flavor problem.**

Flavor violations Most flavor-violating effects arise due to the violation of RS-GIM mechanism by the large top mass.

This originates from the fact that $(t,b)_L$ is localized on the TeV brane.

Contrasting B-Factory Signals from WED with those from SM



	Δm_{B_s}	$S_{B_s \to \psi\phi}$	$S_{B_d \to \phi K_s}$	$Br[b \to s l^+ l^-]$	$S_{B_{d,s} \to K^*,\phi\gamma}$	$S_{B_{d,s} \to \rho,K^*\gamma}$
RS1	$\Delta m_{B_s}^{SM}[1+O(1)]$	$O(1)$	$\sin 2\beta \pm O(.2)$	$Br^{SM}[1+O(1)]$	$O(1)$	$O(1)$
SM	$\Delta m_{B_s}^{SM}$	λ_c^2	$\sin 2\beta$	Br^{SM}	$\frac{m_s}{m_b}\left(\sin 2\beta, \lambda_c^2\right)$	$\frac{m_d}{m_b}\left(\lambda_c^2, \sin 2\beta\right)$

Recent warped models of hierarchy & flavor requiring further study for experimental implications

- Fitzpatrick, Perez and Randall, arXiV. 0710.1869
- Davoudiasl, Perez and Soni, arXiV: 0802.0203 (LRS@LHC)

.

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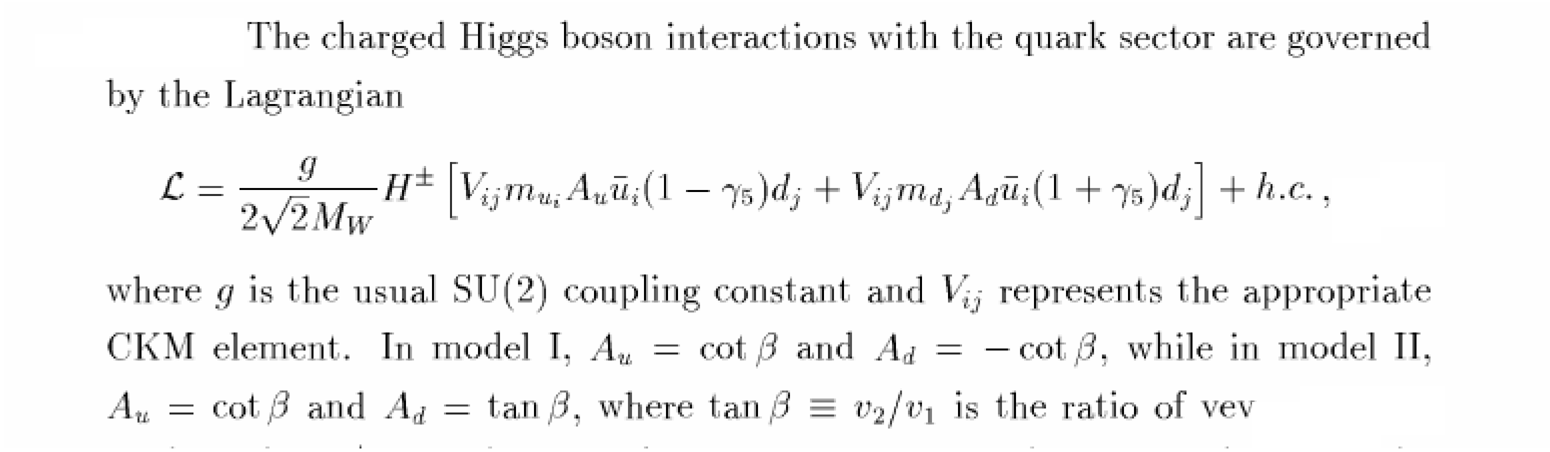
Two Higgs Doublet Models with Natural Flavor Conservation



The charged Higgs boson interactions with the quark sector are governed by the Lagrangian

$$\mathcal{L} = \frac{g}{2\sqrt{2}M_W} H^{\pm} \left[V_{ij} m_{u_i} A_u \bar{u}_i (1-\gamma_5) d_j + V_{ij} m_{d_j} A_d \bar{u}_i (1+\gamma_5) d_j \right] + h.c. \,,$$

where g is the usual SU(2) coupling constant and V_{ij} represents the appropriate CKM element. In model I, $A_u = \cot\beta$ and $A_d = -\cot\beta$, while in model II, $A_u = \cot\beta$ and $A_d = \tan\beta$, where $\tan\beta \equiv v_2/v_1$ is the ratio of vev

Part of SUSY

T2HDM: 2HiggsDM for the top quark

[see Das,Kao('96);Kirers,Wu,AS('99)…]

- **2nd doublet couples only to top (1st doublet**

to all else), so that with $V_2/V_1 >> 1$, natural

way to get a very heavy top

T2HDM Possibly disproves SUSY?

$$
\begin{aligned}
\mathcal{L}_Y = & -\bar{L}_L \phi_1 E l_R - \bar{Q}_L \phi_1 F d_R - \bar{Q}_L \tilde{\phi}_1 G \mathbf{1}^{(1)} u_R \\
& - \bar{Q}_L \tilde{\phi}_2 G \mathbf{1}^{(2)} u_R + \mathrm{H.c.},
\end{aligned}
$$

Here ϕ_1 are the two Higgs doublets; E, F and G are 3 X 3 Yukawa matrices giving masses respectively to the charged letptons, the down and up type quarks; $\mathbf{I}^{(1)} \equiv diag(1,1,0)$ and $\mathbf{I}^{(2)} \equiv diag(0,0,1)$ are the two orthogonal projectors onto the 1st two and third family respectively. Q_L and L_L are the usual left-handed quark and lepton doublets.

(b) T2HDM should be viewed as LEET that parametrizes through the yukawa interactions some high energy dynamics which generates the top quark mass as well as the weak scale...

(c) In addition to largish $\tan\beta$ the model has restrictive FCNC (since it belongs to type III) amongst only the up-type

H^{+-} phenomenology in T2HDM

H^{+-} interactions with U_R and D_L

$$\frac{g_2 m_c \tan\beta}{\sqrt{2} m_W} \begin{pmatrix} \xi'^* V_{td} & \xi'^* V_{ts} & \xi'^* V_{tb} \\ \xi^* V_{td} - V_{cd} & \xi^* V_{ts} - V_{cs} & \xi^* V_{tb} - V_{cb} \\ V_{td} \cot^2\beta/\epsilon_{ct} + \epsilon_{ct}\xi V_{cd} & V_{ts} \cot^2\beta/\epsilon_{ct} + \epsilon_{ct}\xi V_{cs} & V_{tb} \cot^2\beta/\epsilon_{ct} \end{pmatrix}$$

$$m_{H^\pm},\ \tan\beta,\ \xi = |\xi| e^{i\varphi_\xi}$$

$$|V_{ub}/V_{cb}|,\ \Delta M_{B_s}/\Delta M_{B_d},\ a_{\psi K},\ \varepsilon_K,\ B \to X_s\gamma,\ B \to \tau\nu$$

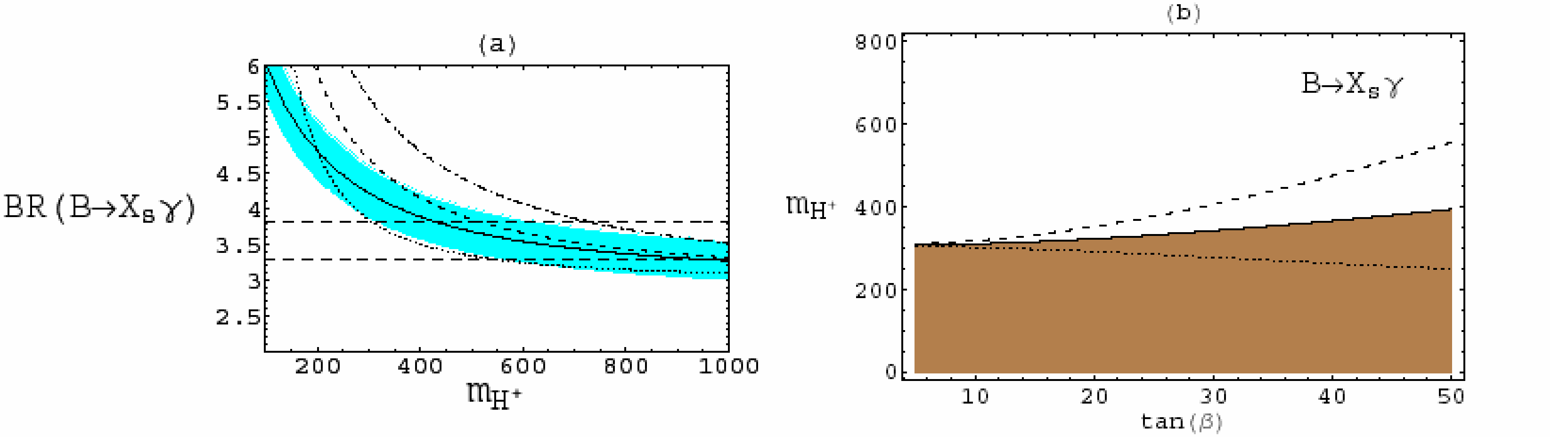


Figure 5: **Plot a.** $m_{H^\pm}$ dependence of the branching ratio $B \to X_s\gamma$ in units of 10^{-4}. Solid, dashed, dotted and dotted-dashed lines correspond to $(\tan\beta, \xi) = (10, 0)$, $(50, 0)$, $(50, 1)$ and $(50, -1)$, respectively. There is no appreciable dependence on ξ'. The two horizontal dashed lines are the experimental 68%C.L. allowed region. The blue region represents the theory uncertainty associated to the solid line (similar bands can be drown for the other cases). **Plot b.** Portion of the $(\tan\beta, m_{H^\pm})$ plane excluded at 68%C.L. by the $B \to X_s\gamma$ measurement. The shaded area corresponds to $\xi = 0$. The dotted and dashed lines show how this region changes for $\xi = 1$ and -1, respectively.

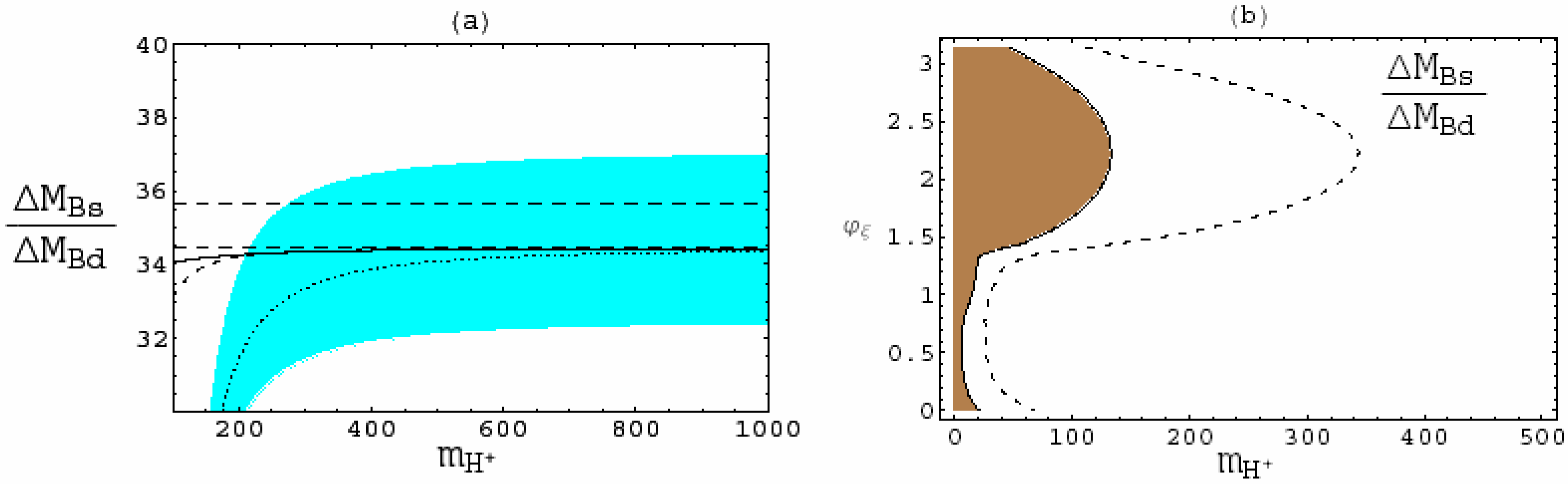
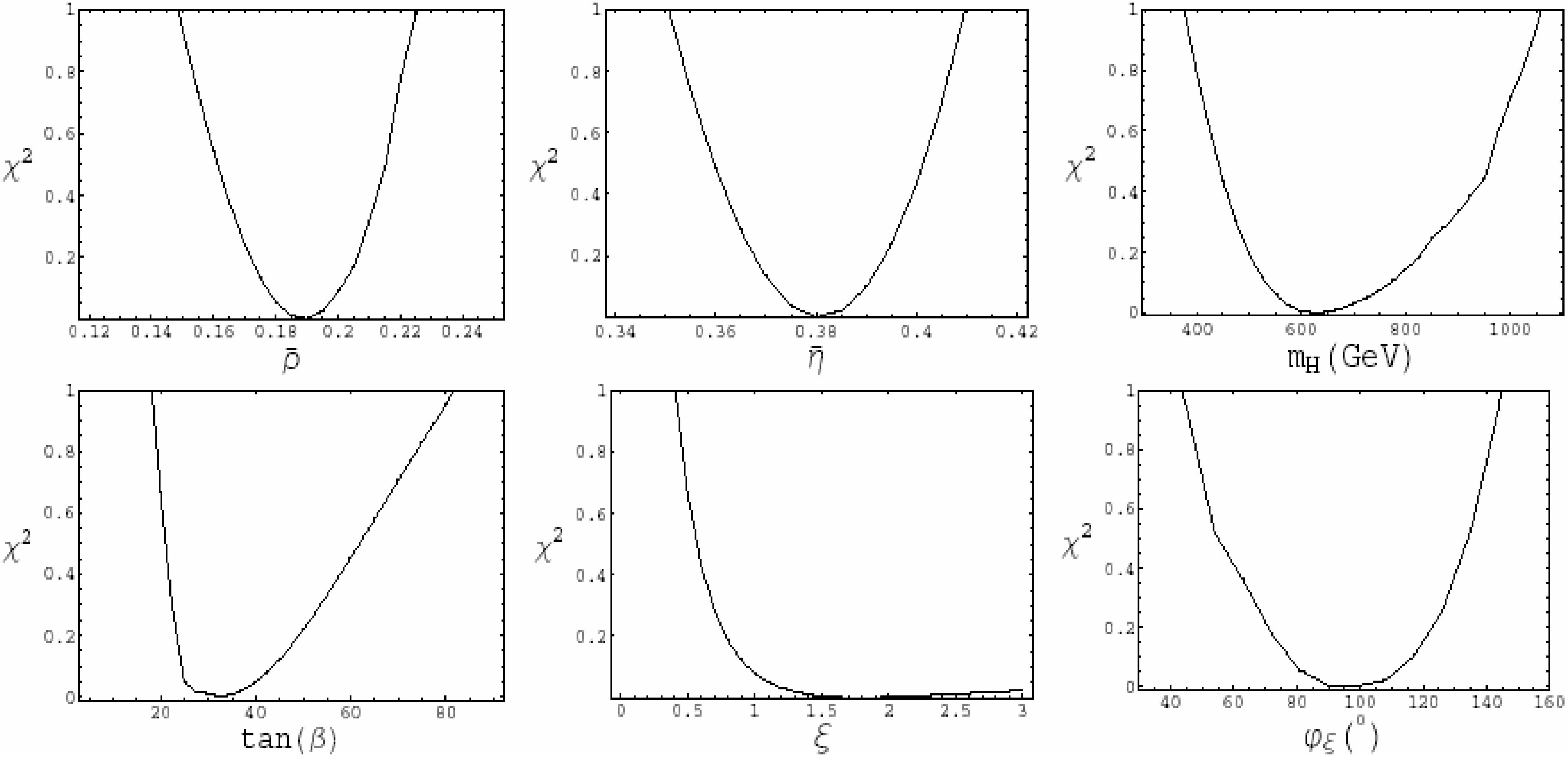


Figure 10: **Plot a.** $m_{H^\pm}$ dependence of the T2HDM contributions to $\Delta m_{B_{(s)}}/\Delta m_{B_{(d)}}$. See the caption in Fig. 9. **Plot b.** Excluded region in the $(\varphi_\xi, m_{H^\pm})$ plane. The solid and dashed contours correspond to $\tan\beta$ =30 and 50, respectively.


χ^2
1
0.8
0.6
0.4
0.2
0
0.12 0.14 0.16 0.18 0.2 0.22 0.24
$\bar{\rho}$
0.34 0.36 0.38 0.4 0.42
$\bar{\eta}$
400 600 800 1000
m_H (GeV)
20 40 60 80
tan(β)
0 0.5 1 1.5 2 2.5 3
ξ
40 60 80 100 120 140 160
φ_ξ (°)

DirectCP 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	≈ 0 to +0.6	≈ -16 to +4
Supergravity[*]	≈ -10 to +10	-(5 - 45) and (2
SUSY with squark mixing[+]	≈ -15 to +15	
SUSY with R-parity violation[+*]	≈ -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.

Can BF further stengthen these signs

- After all said & done expect from BF ~2/ab
- Need final #s for TDCP

Summary & Outlook

- Asym. B factories + Lattice : milestone in our understandig of CPV-> KM phase is the dominant contributor to observed CP, NP effects subdominant.
- Search for BSM-CP-odd phase imposes greater demands of precision on expt. & on theory
- As BF accumulated more data, ΔS, $\Delta A_{K\pi}$ tests of the CKM-paradigm became extremely tantalizing with ~2.5 -3.5σ deviations
- Urgent need for more accurate CKM physics from lattice
- Given that such effects occur quite naturally in most BSMs the expt. situation needs to be clarified at the highest priority.

- *-> SB(F)F should see an exciting –era!:*

New CP-odd phase (SBF); new particles 300GeV—few TeV…(LHC).

Importance of interplay between flavor & collider physics even in the LHC-era …