FLAVOR PHYSICS PHENO

–Where are we in Flavor Physics?

–Directions, Tasks, Needs

–A recent Fit analysis

–Outlook

Gudrun Hiller, CERN and Dortmund

Flavor physics originates from the generational structure of known fundamental matter $\psi \to \psi_i$, $i = 1, 2, 3$, with lives in the same representation of the SM gauge group:

$$SU(3)_C \times SU(2)_L \times U(1)_Y \to SU(3)_C \times U(1)_{em}$$

The Yukawa matrices $Y_{u,d,e}$ are the sole sources of flavor in the SM:

$$\mathcal{L}_{\rm SM} = \sum_{\psi=Q,U,D,L,E} \bar{\psi}_i i \not{D} \psi_i$$

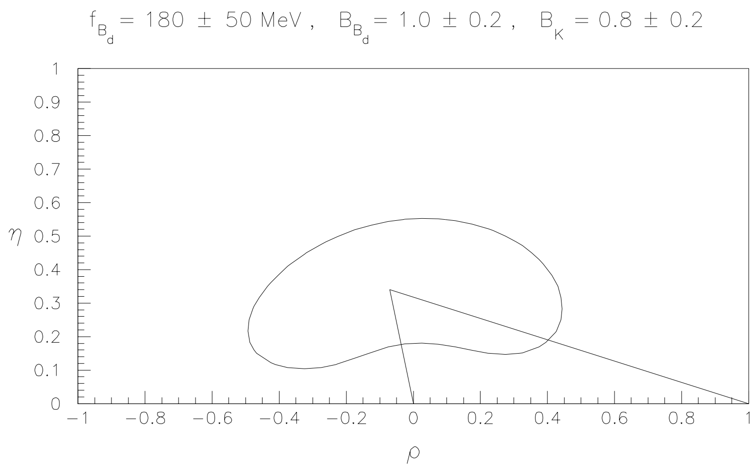
$$-\bar{Q}_i (Y_u)_{ij} \Phi^C U_j - \bar{Q}_i (Y_d)_{ij} \Phi D_j - \bar{L}_i (Y_e)_{ij} \Phi E_j$$

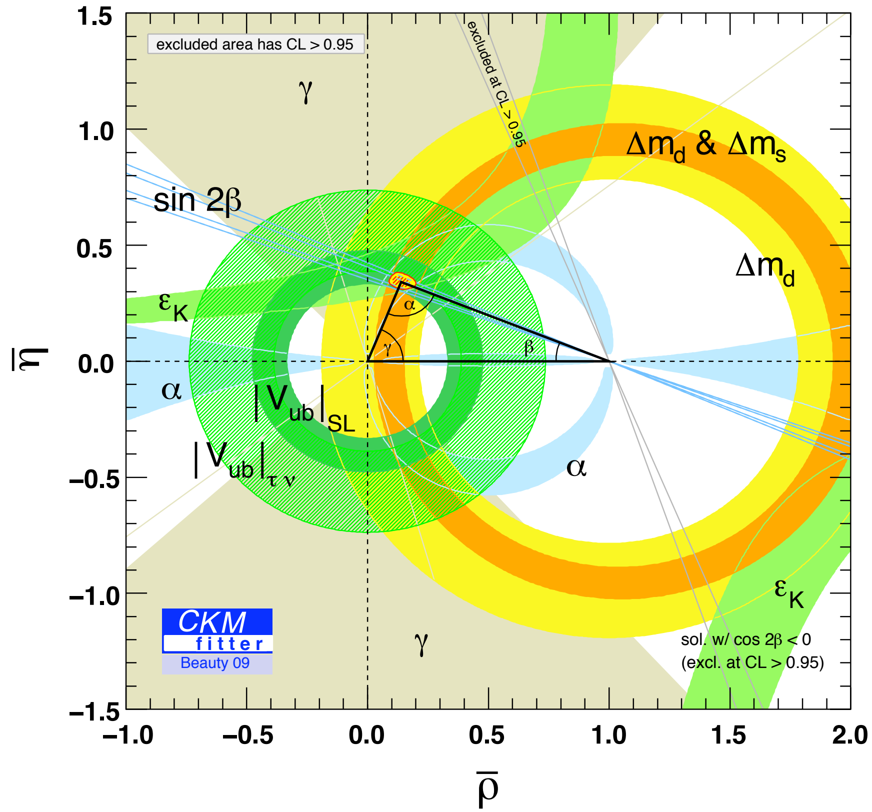
$$+\mathcal{L}_{higgs} + \mathcal{L}_{gauge}$$

This set-up predicts correlations and CP-violation.

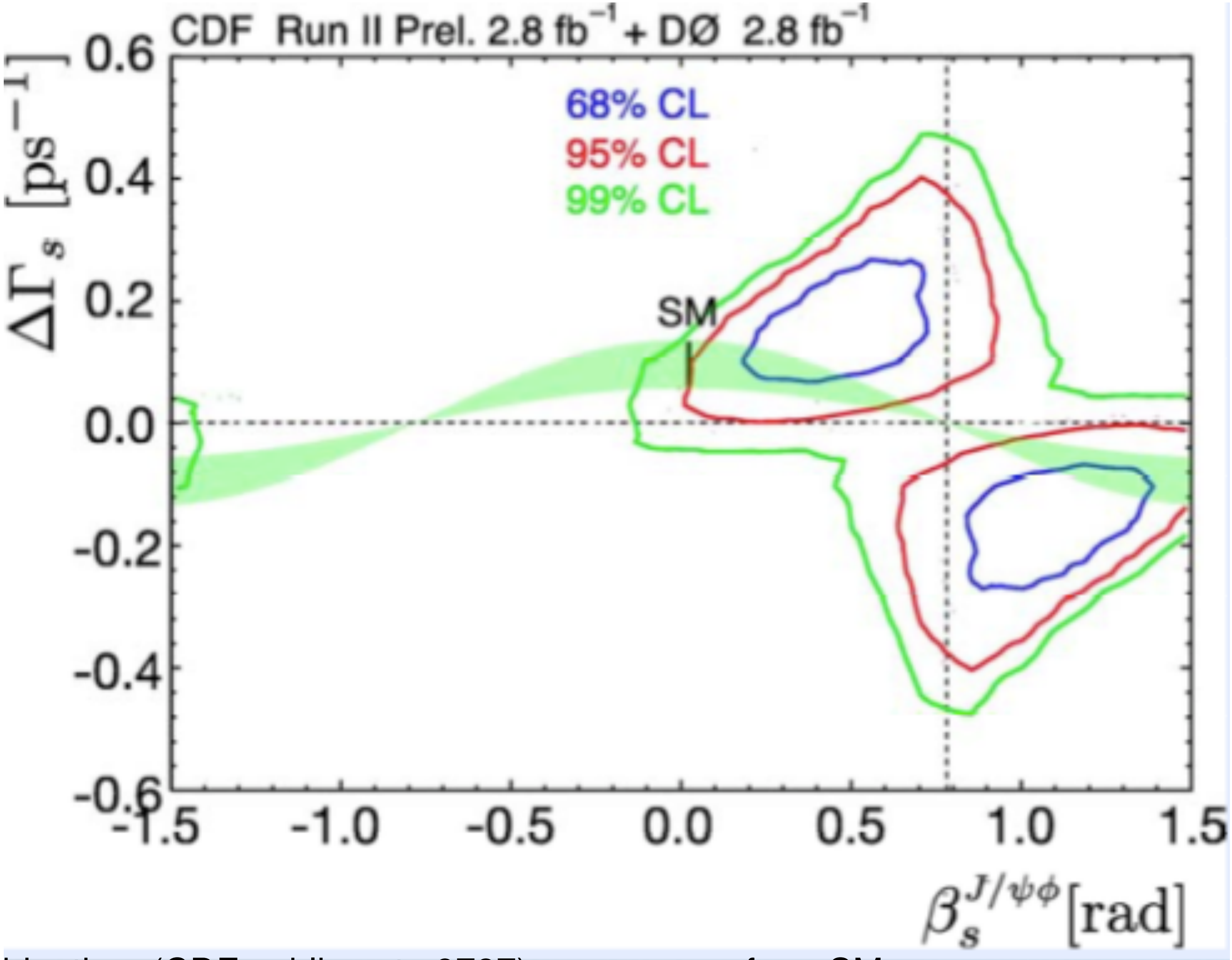
The Flavor of the Quarks/CKM 1995 vs today

The CKM-picture of flavor and CP violation is currently consistent with all – and quite different – laboratory observations, although some tensions exist.



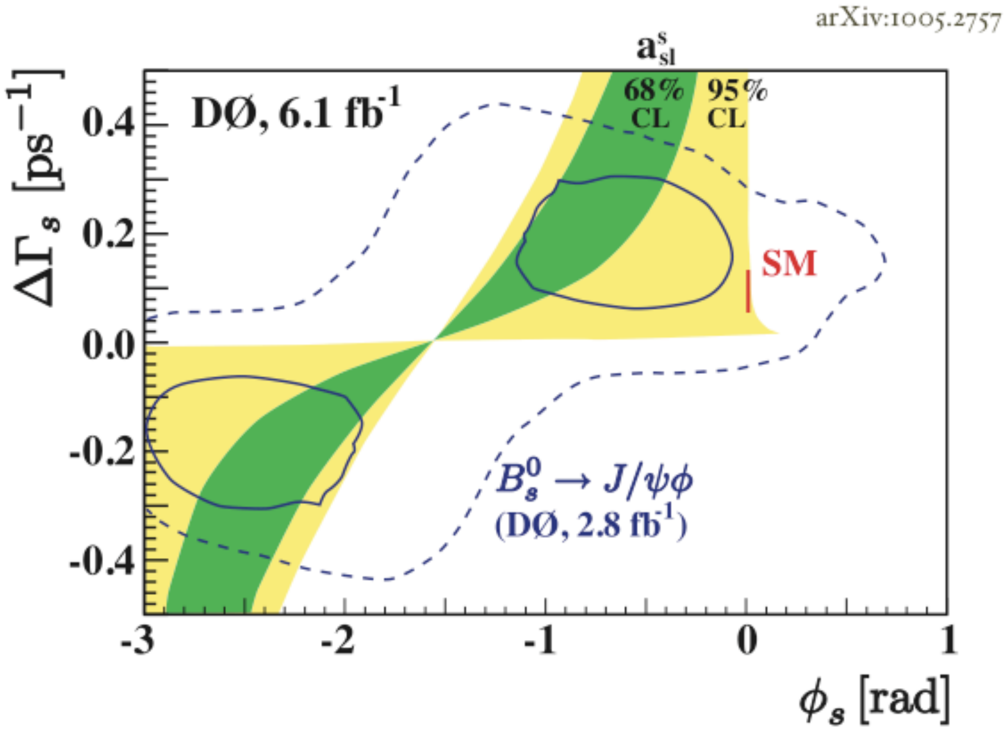


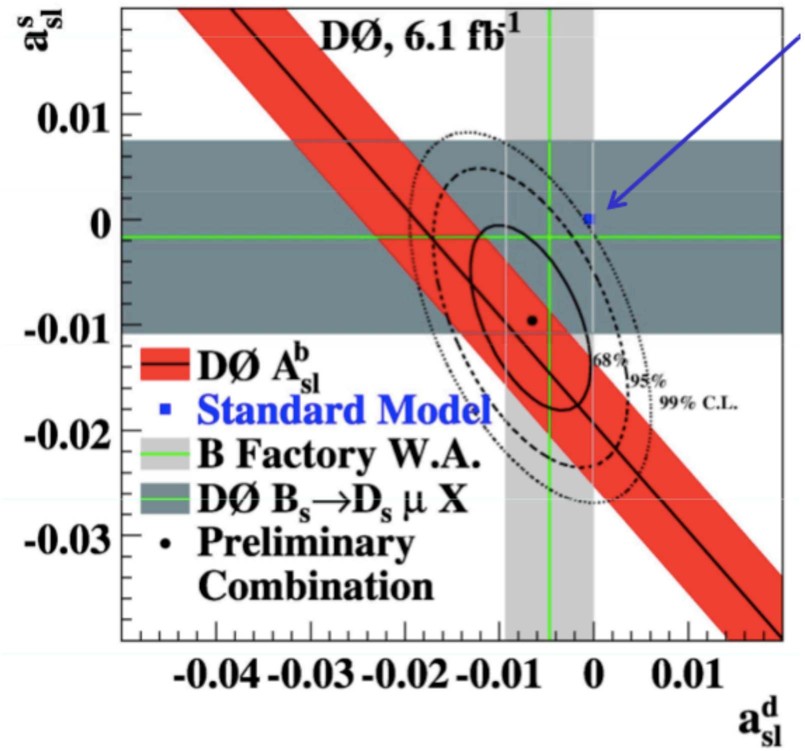
Data on $B_s, \bar{B}_s \to J/\Psi\Phi$; beginning of 2010



Tevatron combination; (CDF public note 9787); 2.12σ away from SM

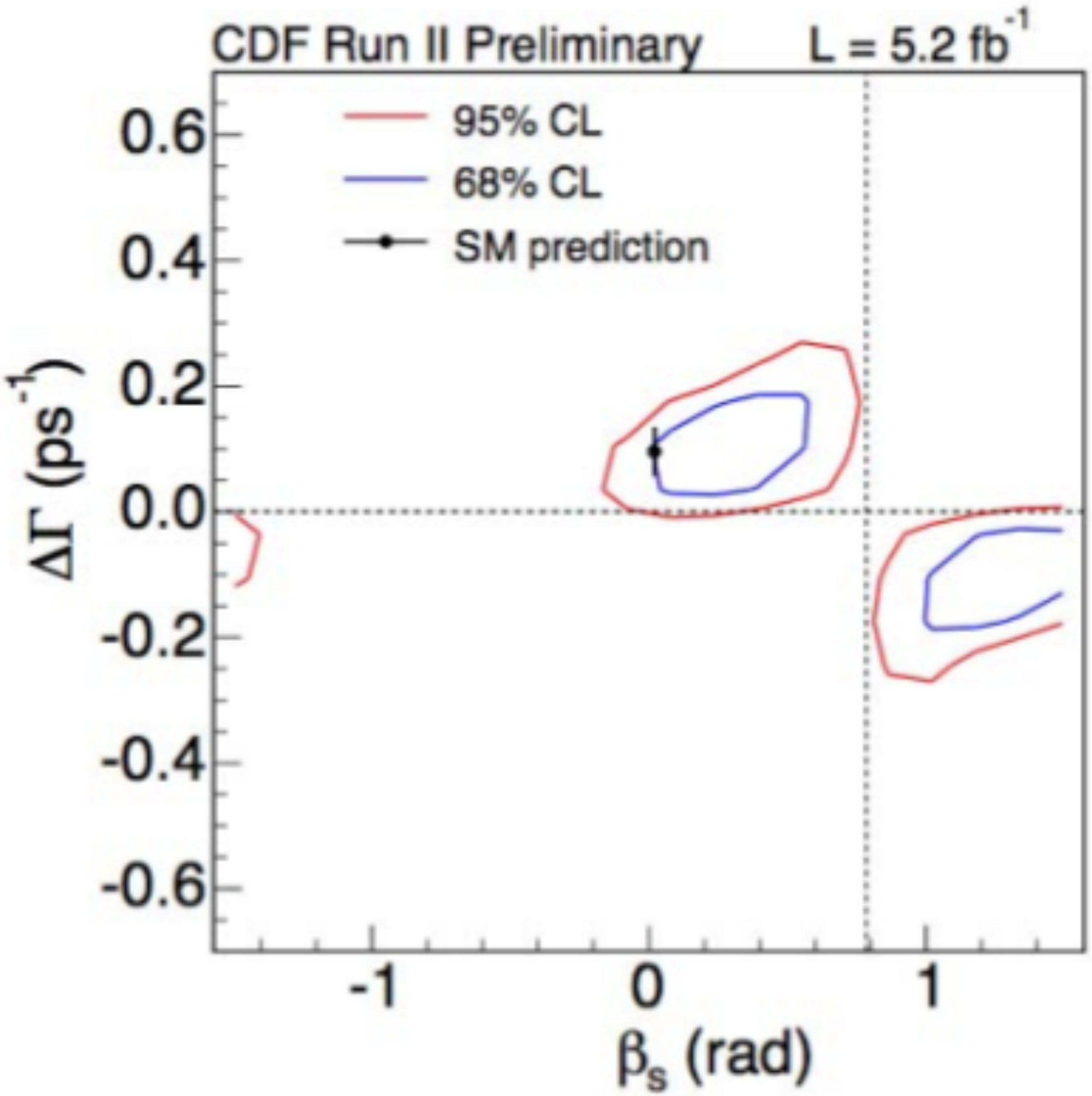
Another way of Measuring the $B_s\bar{B}_s$ phase





D0, $\Phi_s = -2\beta_s$; $A_{sl} = 0.506\, A_{sl}^d + 0.494\, A_{sl}^s$; left: used $A_{sl}^{d\,exp}$

New CDF Data on $B_s, \bar{B}_s \to J/\Psi\Phi$; FPCP 2010



Talk by Oakes, FPCP 2010; at 68% CL β_s is in $[0, 0.5]$ or $[1.1, 1.5]$

Modulo "hints" all hadronic flavor changing data are currently ok with the SM within uncertainties.

Different sectors and different couplings probed:

$s \to d$: $K^0 - \bar{K}^0$, $K \to \pi\nu\bar{\nu}$

$c \to u$: $D^0 - \bar{D}^0$ (first data on FCNC in up-sector)

$b \to d$: $B^0 - \bar{B}^0$, $B \to \rho\gamma$, $b \to d\gamma$ ($B \to \pi ll$ close)

$b \to s$: $B_s - \bar{B}_s$, $b \to s\gamma$, $B \to K_s\pi^0\gamma$, $b \to sll$, $B \to K^{(*)}ll$ (precision, angular observables starting), $B_s \to \mu\mu$ (bound improving)

$t \to c, u$: not observed

Probing Physics at Highest Energies with Flavor

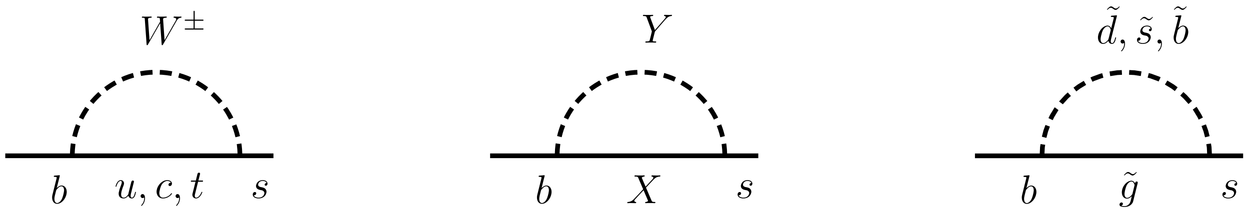
Assuming no specific flavor structure, New Physics sets in where?

$$\mathcal{A}_{\rm SM}^{\Delta f=2} \sim \frac{g^4}{16\pi^2} \cdot V_{\rm CKM}^4 \cdot 1/m_W^2 \cdot \delta f$$
$$\mathcal{A}_{\rm NP}^{\Delta f=2} \sim 1/\Lambda_{\rm NP}^2$$

	$K^0\bar{K}^0$	$D^0\bar{D}^0$	$B_d^0\bar{B}_d^0$	$B_s^0\bar{B}_s^0$
$\Lambda_{\rm NP}$ [TeV]	$2 \cdot 10^5$	$5 \cdot 10^3$	$2 \cdot 10^3$	$3 \cdot 10^2$

Table 1: The lower bounds on the scale of new physics from FCNC mixing data in TeV for arbitrary new physics at 95 % C.L.

Numbers from Bona et al, '07



The absence of O(1) New Physics observations in FCNC-processes implies that physics at theTeV-scale has non-generic flavor properties.

In particular, suppression mechanisms of similar power as CKM and GIM, which are built-in in the SM, need to be at work.

Minimal Flavor Violation (MFV)

A model-independent framework, which passes all current flavor-tests, is to assume that flavor is broken only through the Yukawa matrices, as in the SM.

This is termed minimal flavor violation.

Very predictive framework (CPX, RH currents, splitting & mixing of SM partners)

As in the SM, the origin of flavor is not addressed.

MFV model-independent: Chivukula, Georgi ’87, Ali, London ’99, Buras^2 ’00

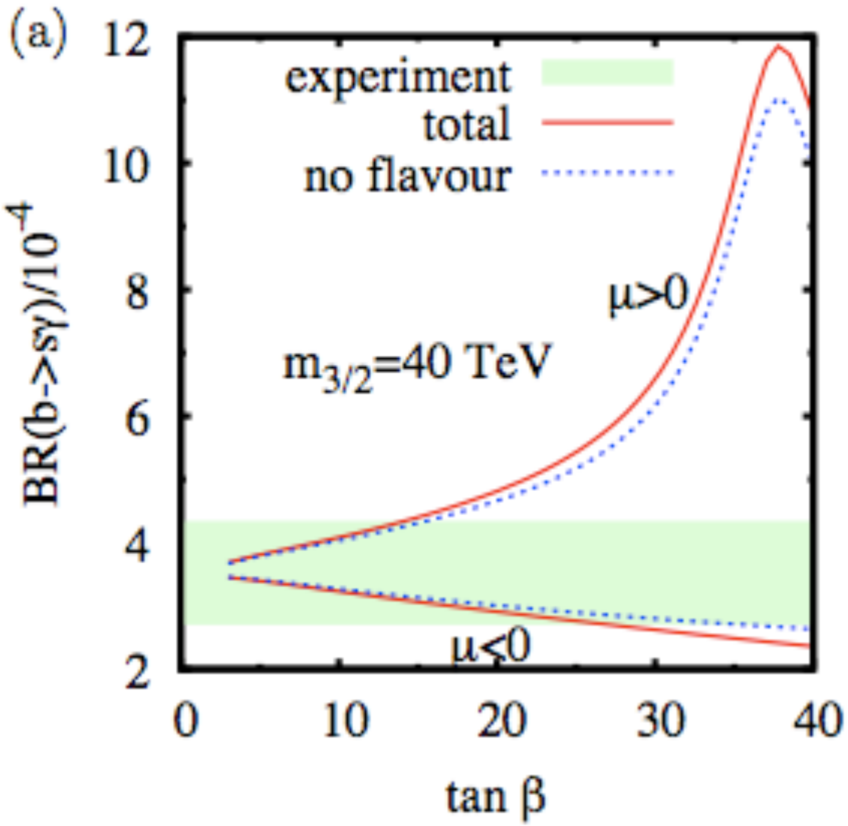
MFV-SUSY: d’Ambrosio, Giudice, Isidori, Strumia ’02

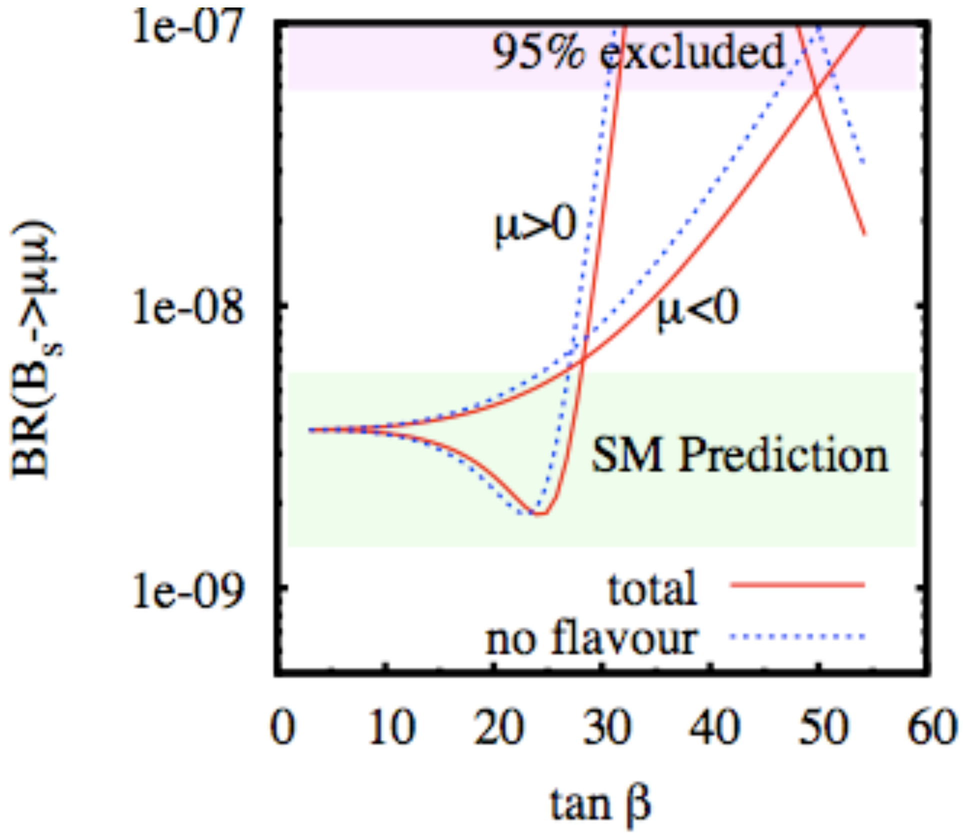
MFV variants, extensions: Agashe, Papucci, Perez, Pirjol ’05, Feldmann, Mannel ’08, Kagan, Perez, Volansky, Zupan ’09

Predictivity and large Effects in FCNC loops

* Predictive $\mathcal{O}(1)$ effects within MFV models if $\tan\beta$ largish. many works

Here, AMSB ($m_{3/2} = 40$ TeV) Figs from 0902.4880 [hep-ph]





* Different decays are complementary

$$Y_u \sim \begin{pmatrix} 10^{-5} & -0.002 & 0.008 + i\,0.003 \\ 10^{-6} & 0.007 & -0.04 \\ 10^{-8} + i\,10^{-7} & 0.0003 & 0.94 \end{pmatrix}$$

$$Y_d \sim \text{diag}\left(10^{-5}, 5 \cdot 10^{-4}, 0.025\right) \quad (\cdot \frac{\langle H_u \rangle}{\langle H_d \rangle})$$

$$Y_e \sim \text{diag}\left(10^{-6}, 6 \cdot 10^{-4}, 0.01\right) \quad (\cdot \frac{\langle H_u \rangle}{\langle H_d \rangle})$$

Very peculiar pattern.

Observables & Models

Observables:

– precision CKM studies; ”SM input”, sides and angles, consistency

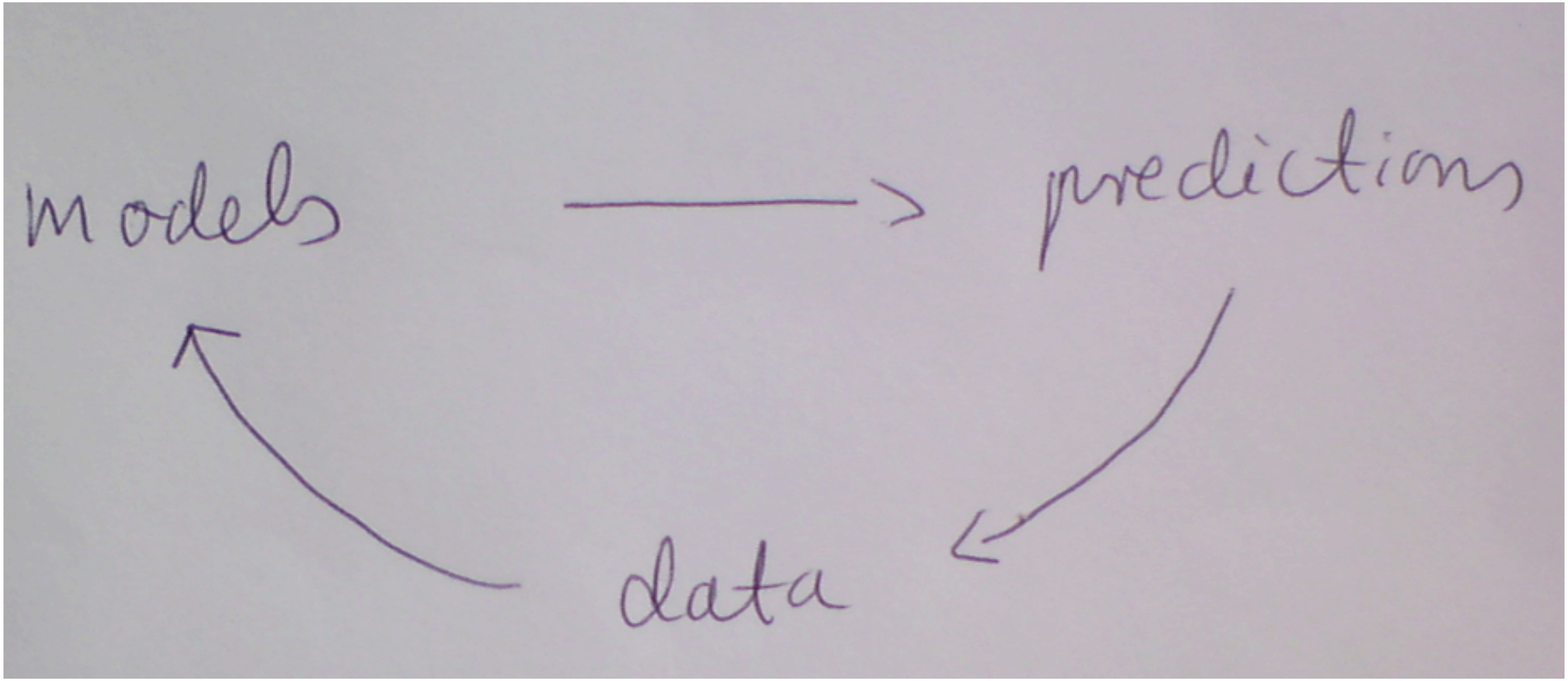
– FCNCs; discovery modes; probe new physics flavor (MFV vs non-MFV)

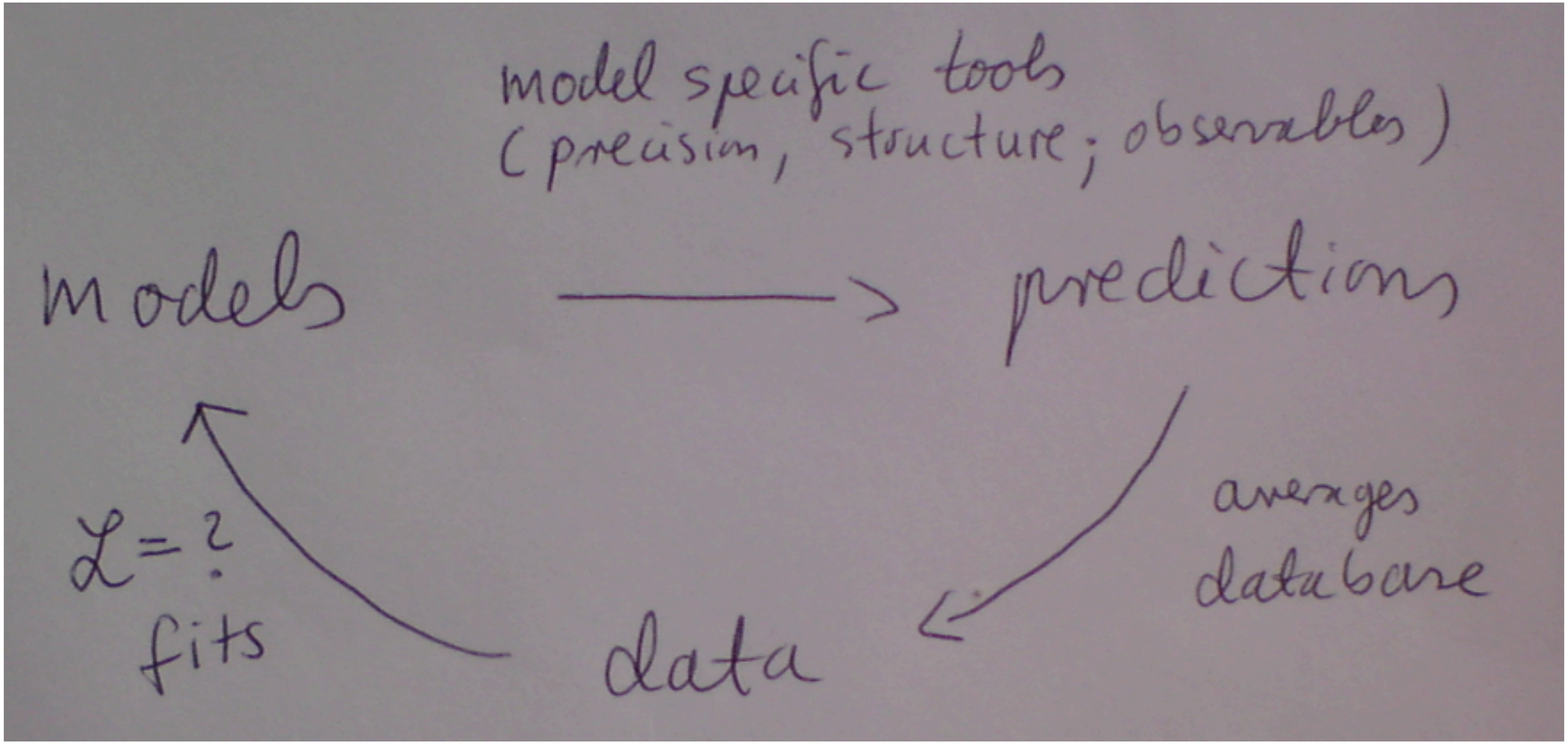
– high p_T; probe new physics flavor (MFV vs non-MFV); generational pattern of SM-partners

Models:

– Flavor aspects of (new) proposals; precision

– Explaining flavor (family symmetries, anarchy, textures,...)


models
predictions
data



Fit codes, averages, model-specific tools

besides standard LHC/collider tools

Fit codes, averages, model-specific tools in flavor, a very incomplete list

not every code publicly available

Fits: CKM: CKMfitter, UTfitter

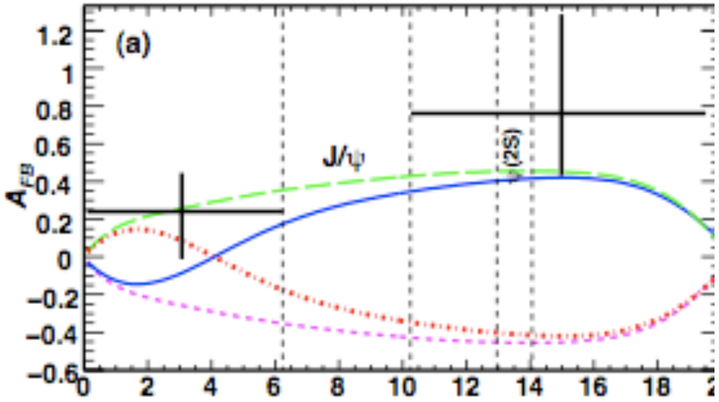
Averages: HFAG, PDG

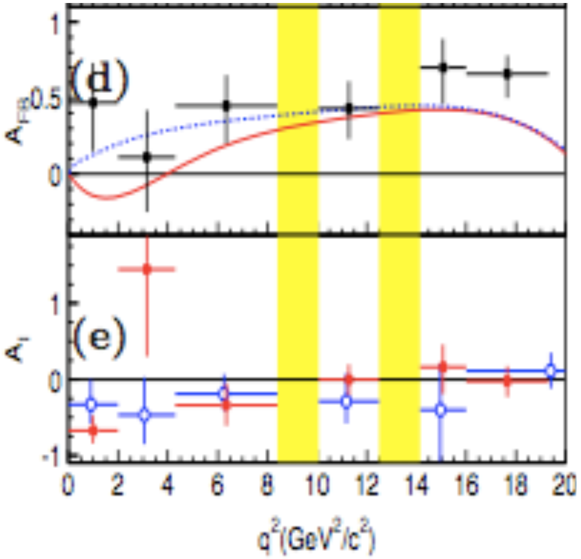
SUSY: softsusy, superiso

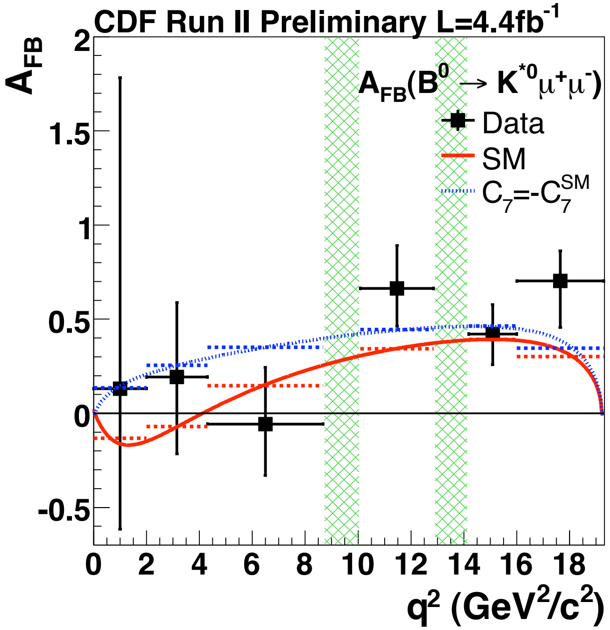
$\Delta b = 1$ model-independent analysis

SM-like A_{FB} in $B \to K^* l^+ l^-$?

left: BaBar: 0804.4412 [hep-ex], mid: Belle 0904.0770 [hep-ex], right: CDF public note 10047 (January 2010)

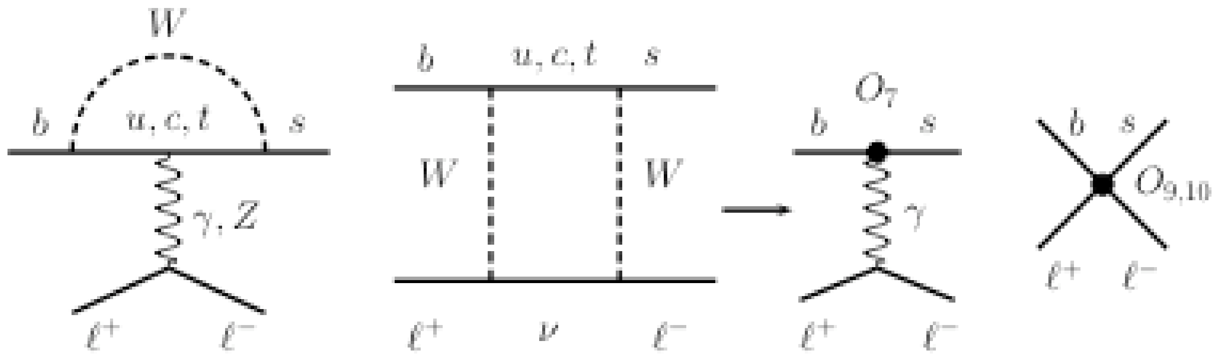






sign/zero of A_{FB} at low dilepton mass?

sign of A_{FB} at large dilepton mass SM-like 0805.2525 [hep-ph]



$$\mathcal{H}_{\text{eff}} = -4\frac{G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum C_i(\mu) O_i(\mu)$$

dipole operators $O_7 \propto \bar{s}_L \sigma_{\mu\nu} b_R F^{\mu\nu}$ $\quad O_8 \propto \bar{s}_L \sigma_{\mu\nu} b_R G^{\mu\nu}$

4-Fermi operators $O_9 \propto (\bar{s}_L \gamma_\mu b_L)(\bar{\ell}\gamma^\mu \ell)$ $\quad O_{10} \propto (\bar{s}_L \gamma_\mu b_L)(\bar{\ell}\gamma^\mu \gamma_5 \ell)$

New Physics (NP) in $C_i = C_i^{SM} + C_i^{NP}$ or new operators.

model-independent analysis: Br‘s, $A_{CP}, A_{FB} = f(C_i) \to$ fit! hep-ph/9408213

Example: $\mathcal{B}(b \to s\gamma) \sim |C_7|^2$.

Effective couplings $b \to sll$ list

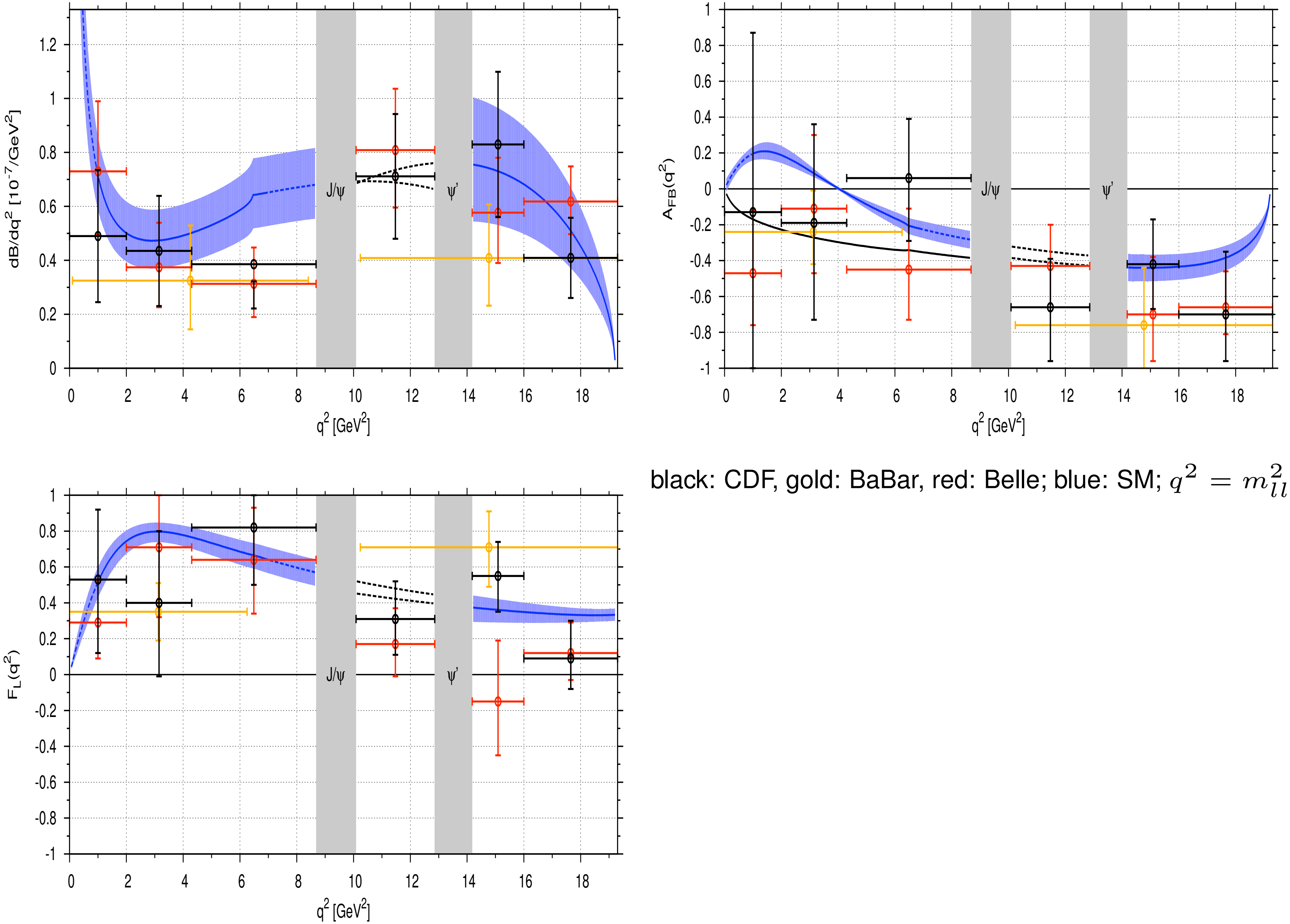
Wilson coefficient	description	SM	enhancement in models
$C_{1,2}$	charged current	YES	
$C_{3,..,6}$	QCD penguins	YES	SUSY
$C_{7,8}$	γ, g-dipole	YES	SUSY, large $\tan\beta$
$C_{9,10}$	(axial-)vector	YES	SUSY
$C_{S,P}$	(pseudo-)scalar	$\sim m_l m_b/m_W^2$	SUSY, large $\tan\beta$, R-parity viol.
$C'_{S,P}$	(pseudo-)scalar flipped	$\sim m_l m_s/m_W^2$	SUSY, R-parity viol.
$C'_{3,..,6}$	QCD peng. flipped	$\sim m_s/m_b$	SUSY
$C'_{7,8}$	γ, g-dipole flipped	$\sim m_s/m_b$	SUSY, esp. large $\tan\beta$
$C'_{9,10}$	(axial-)vector flipped	$\sim m_s/m_b$	SUSY
$C_{T,T5}$	tensor	negligible	leptoquarks

$O_S \propto (\bar{s}_L b_R)(\bar{\ell}\ell)$, $O_P \propto (\bar{s}_L b_R)(\bar{\ell}\gamma_5\ell)$, $O'_S \propto (\bar{s}_R b_L)(\bar{\ell}\ell)$, ... 0911.4054 [hep-ph]

with BSM CP violation: C_i complex; ℓ flavor dependence possible

A full model-independent analysis with all allowed op's is not tractable. Stay within MFV, or take guidance from BSM.

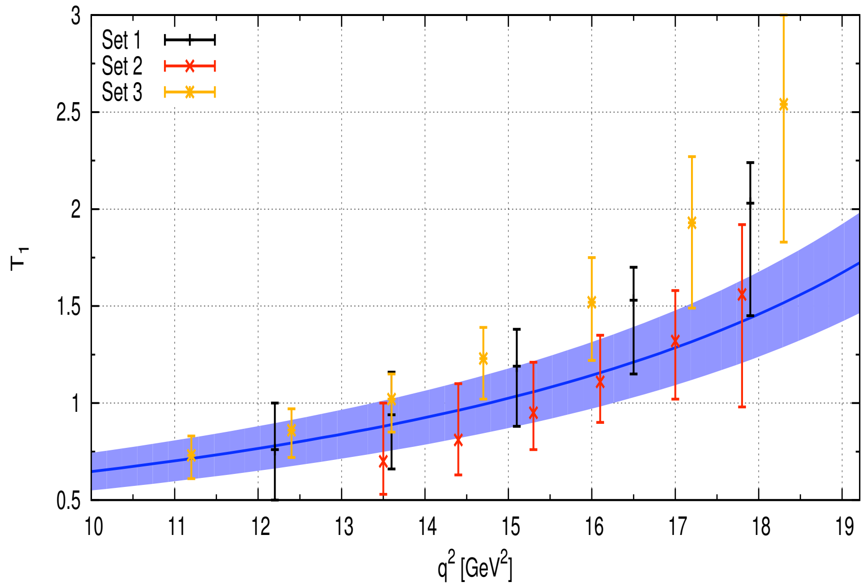
SM testing with $B \to K^* l^+ l^-$ 2010 Bobeth, GH,vanDyk ’10



black: CDF, gold: BaBar, red: Belle; blue: SM; $q^2 = m_{ll}^2$

Benefits of $B \to K^* l^+ l^-$ at low recoil

Biggest TH uncertainty from $B \to K^*$ form factors 1006.5013 [hep-ph]



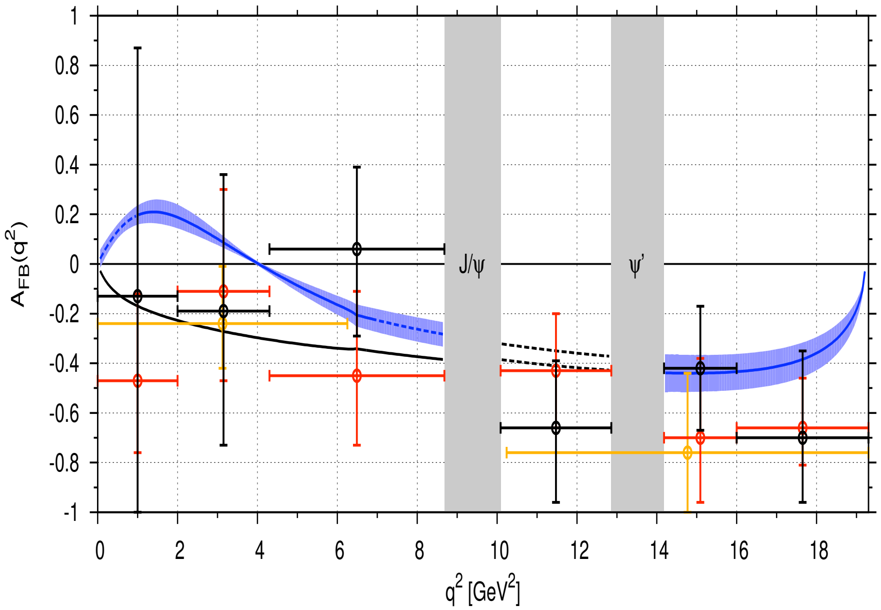
lattice (quenched), only T_1, T_2 BLM hep-ph/0611295 vs light cone sum rule fit extrapolated BZ hep-ph/0412079

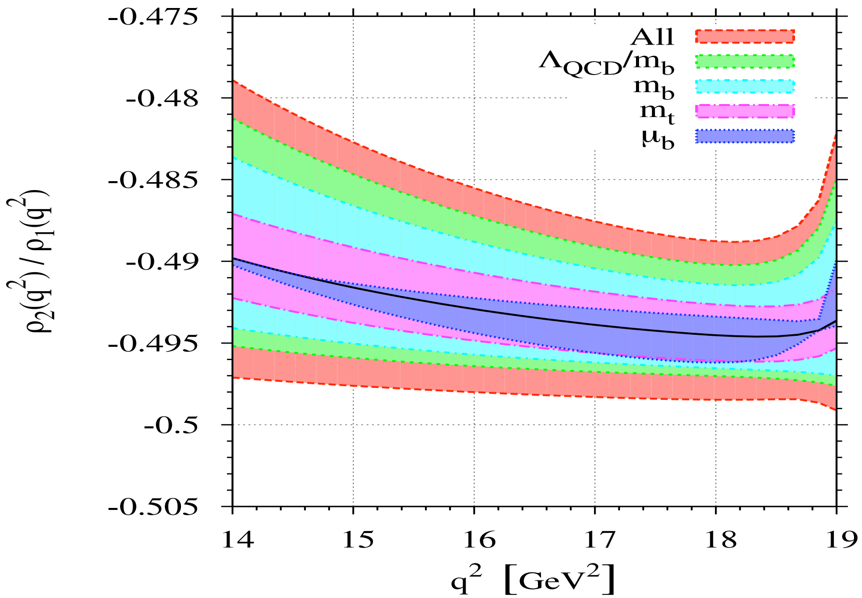
Precision tests with $B \to K^* l^+ l^-$ at low recoil

Heavy quark FF relations at low recoil and OPE in $1/\sqrt{q^2}$ GP hep-ph/0404250

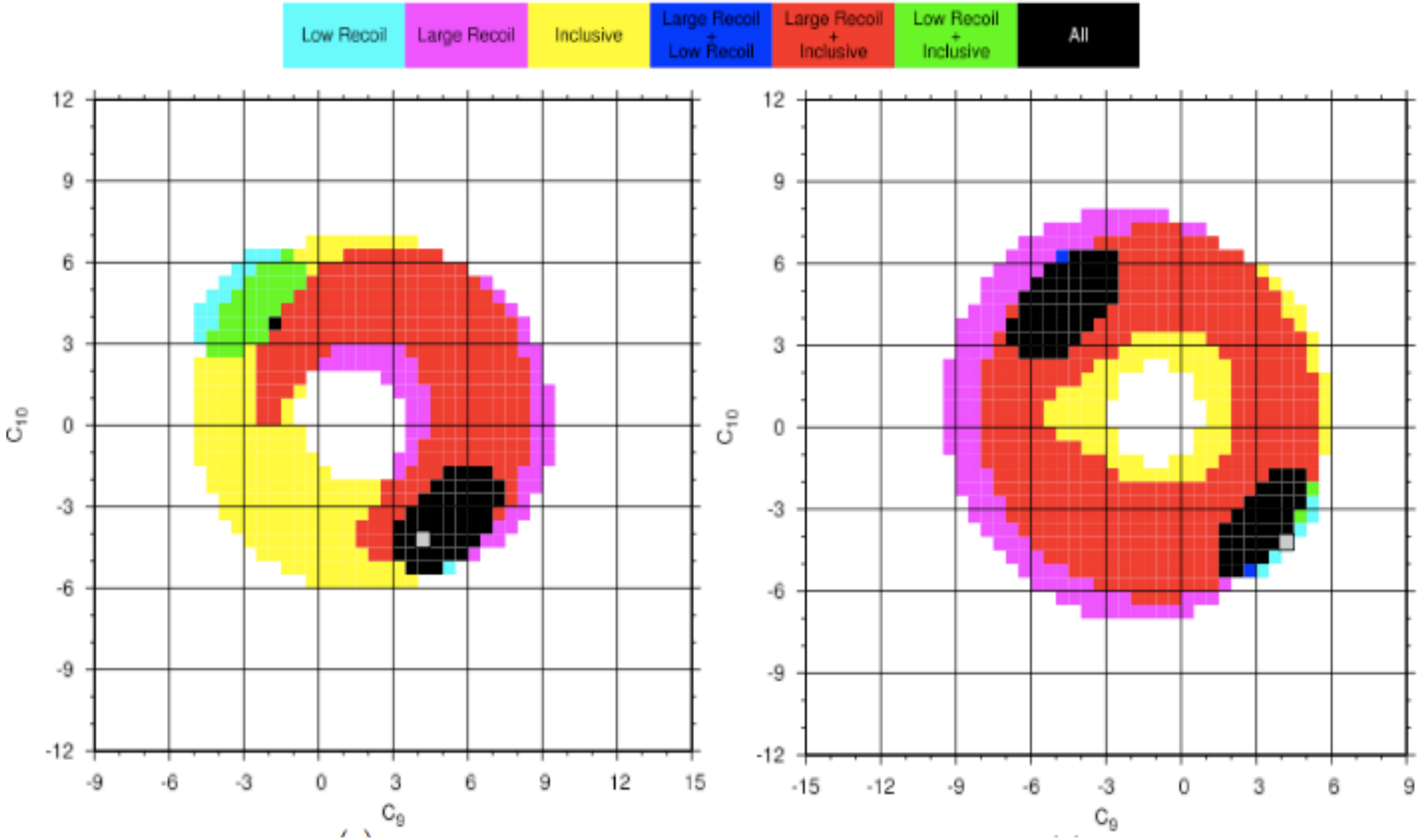
Leads to simplified transversity structure in $B \to K^* l^+ l^-$, and only 2 independent combinations of short-distance couplings!

Allows to define new FF-free observables and those who are only dependent on the FFs. 1006.5013 [hep-ph]





C_i-Constraints 2010

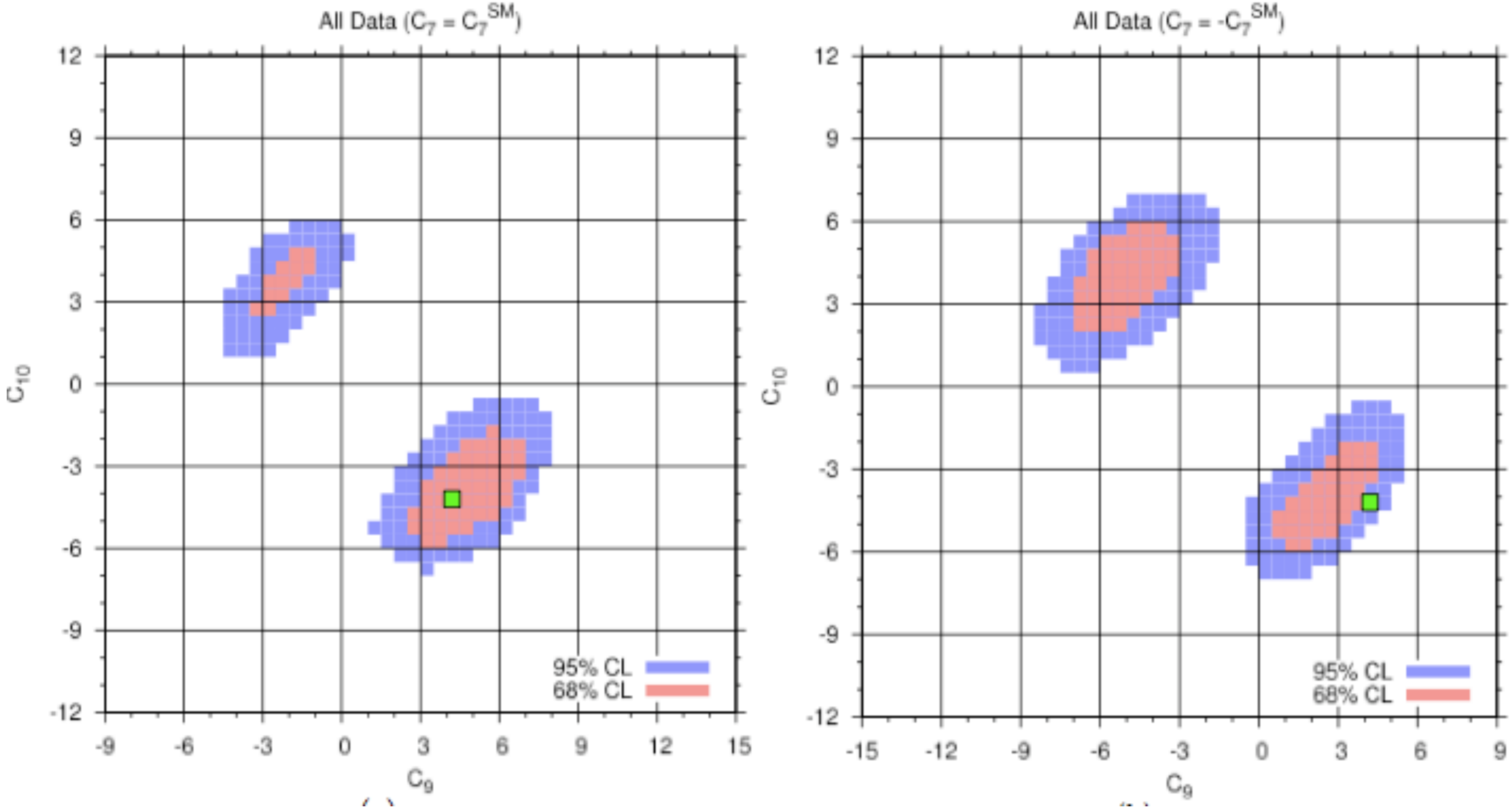


68 % CL regions for (real) C_9, C_{10} for $C_7 = +C_7^{SM}$ (left),$C_7 = -C_7^{SM}$ (right) 1006.5013 [hep-ph]

SM: $C_9 = +4.2$, $C_{10} = -4.2$

MFV MSSM: No O(1) deviations from $C_{9,10}$ in SM. hep-ph/9910221

Global $C_{9,10}$-Fits 2010



green box: SM value for (C_9, C_{10}) Consistent with SM; 4-fold ambiguity. Reduces to 2-fold if A_{FB} zero is seen (or not); last ambiguity requires precision study 1006.5013 [hep-ph] Plans to make code publicly available –stay tuned

Summary

- Flavor physics enters next stage with SM parameters becoming precision input.
- Rare decays: precision studies beginning; promising for LHC(b) nearer term: $\arg(B_s - \bar{B}_s)$, $B_s \to \mu\mu$, A_{FB}+ more
- Flavor and the LHC: is the TeV-scale MFV or non-MFV? – map out flavor quantum numbers of SM-partners related to EWKSB at $\mathcal{O}(\mathrm{TeV})$
- The observation of non-MFV couplings could point towards the origin of generational mixing and hierarchies, i.e., flavor.