The pheno analysis of $B \to K^{(*)}\mu^+\mu^-{}^\dagger$ decays in 2011+

†likewise, $B_s \to \Phi\mu^+\mu^-$

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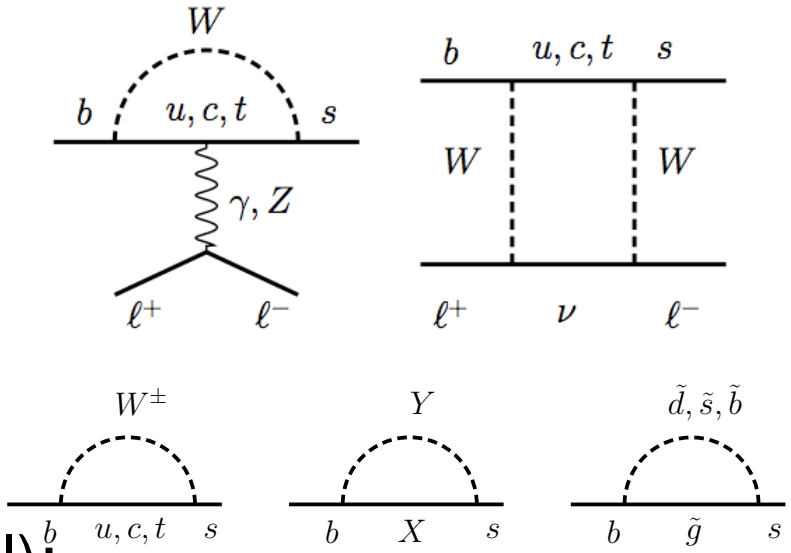
based on works with Christoph Bobeth and Danny van Dyk

Exclusive semileptonic FCNC $b \to s\mu^+\mu^-$ decays

$Br_{\rm SM} \sim 10^{-6} - 10^{-7}$



observed (at SM level):

$B \to K^{(*)}\mu^+\mu^-$ BaBar, Belle, CDF

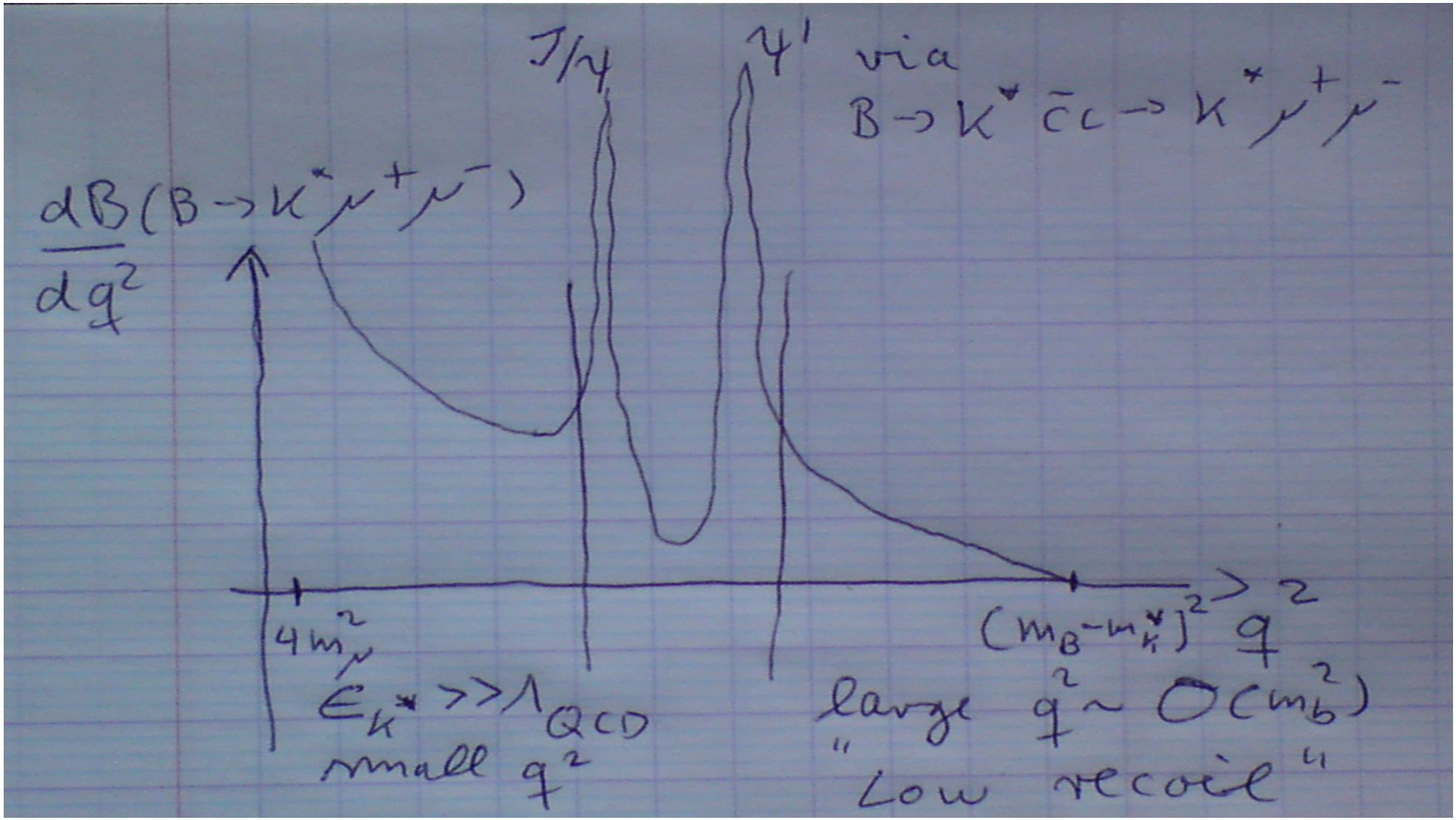
$B_s \to \Phi\mu^+\mu^-$ CDF 2011 1101.1028 [hep-ex]

$B^+ \to K^+\mu^+\mu^-$ LHCb ! La Thuile 2011, talk by A.Golutvin; 35 events in 37 pb^{-1}.

LHCb: $B \to K^*\mu^+\mu^-$ end of 2011: 1 fb^{-1} and order 10^3 events;

now: order 10^2 events per experiment.

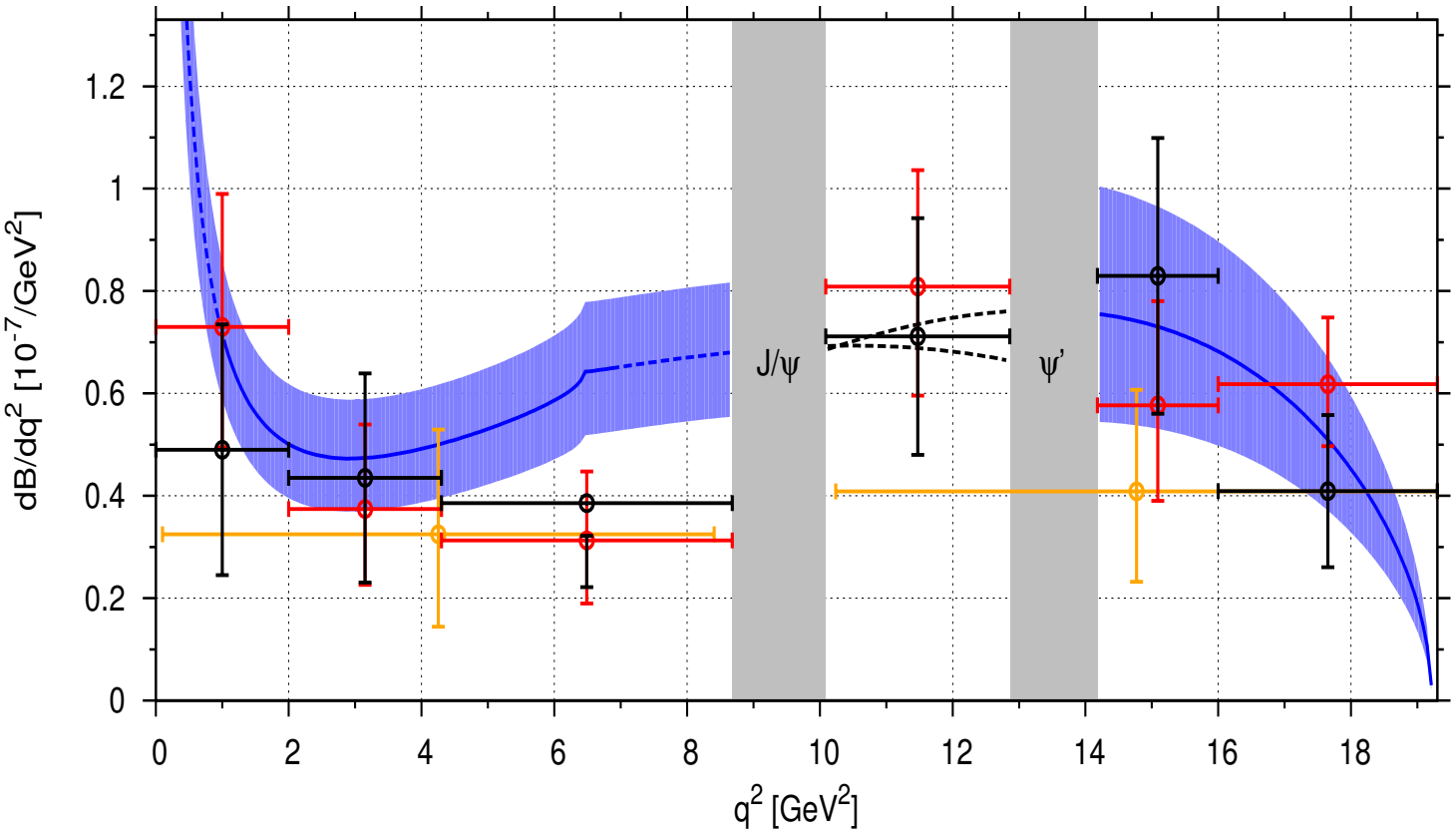
Dilepton Mass Spectra in $B \to K^* \mu^+ \mu^-$



Different TH for low q^2 (QCDF) and high q^2/low recoil. Binned data needed.

Today: Dilepton Mass Spectra in $B \to K^* \mu^+ \mu^-$

dBr/dq^2

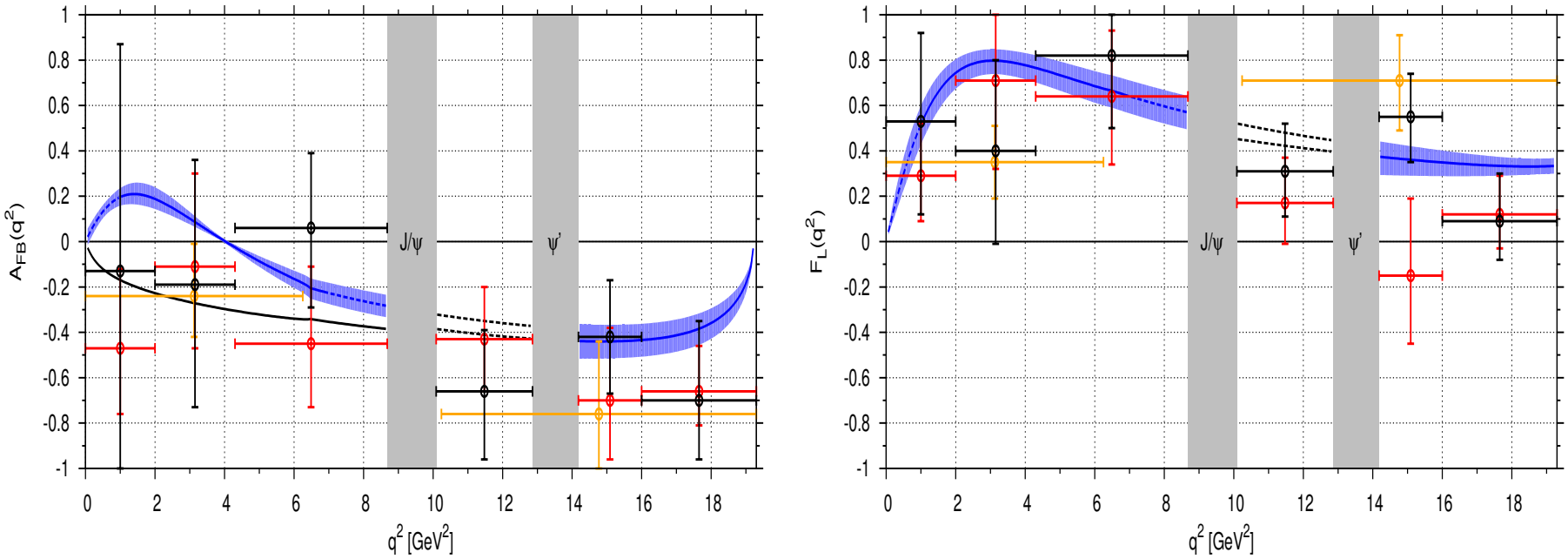


black: CDF'10 4.4fb^{-1}, gold: BaBar'08, red: Belle'09; blue: SM; $q^2 = m_{ll}^2$ Fig. from 1006.5013 [hep-ph]

Biggest source of TH uncertainty: the $B \to K^*$ form factors.

Today: Dilepton Mass Spectra in $B \to K^* \mu^+ \mu^-$

Forward-backward asymmetry $A_{\rm FB}$ and longitudinal K^* fraction F_L



black: CDF'10 4.4fb^{-1}, gold: BaBar'08, red: Belle'09; blue: SM; $q^2 = m_{ll}^2$ Fig. from 1006.5013 [hep-ph]

Sign of $A_{\rm FB}$ at large dilepton mass is SM-like. 0805.2525 [hep-ph]

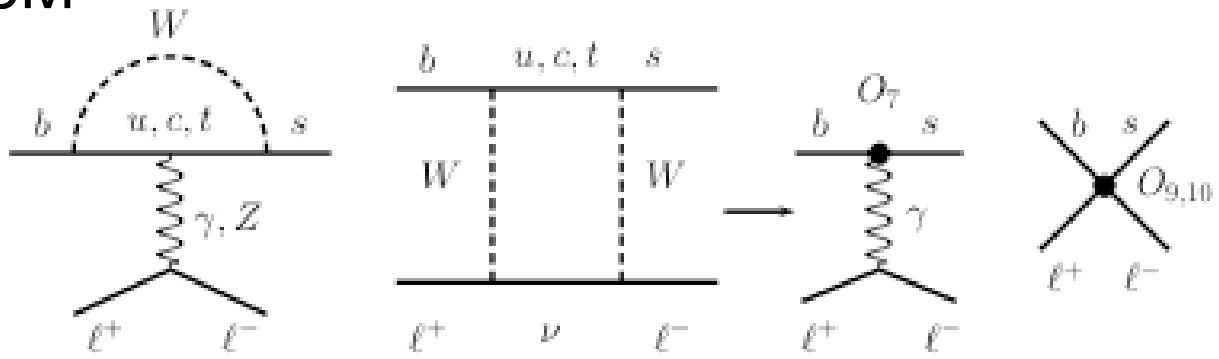
Sign/zero of $A_{\rm FB}$ at low dilepton mass?

Model-independent analysis of $b \to s l^+ l^-$

Test the SM and BSM with quantum loop effects using eff theory

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

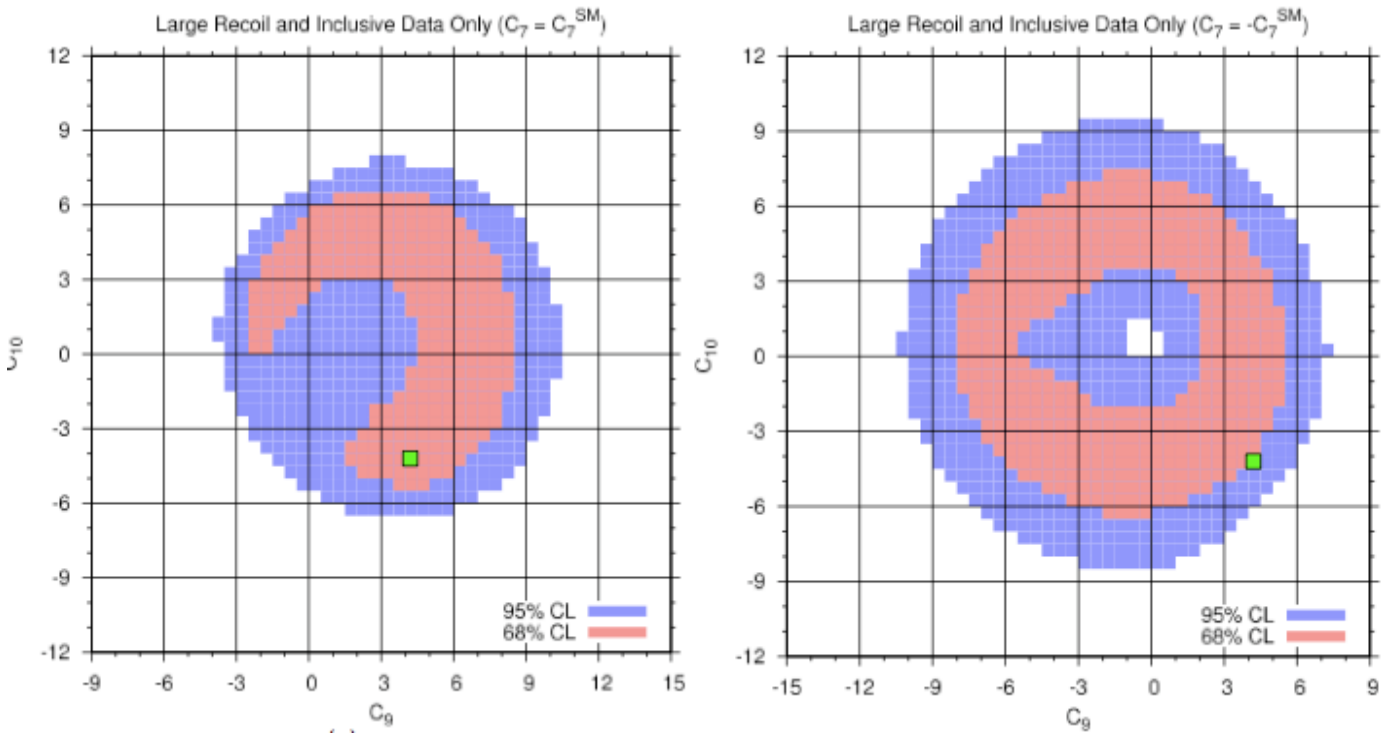
Diagrams in SM



4-Fermi-operators: $O_9 \sim \bar{s}_L \gamma_\mu b_L \bar{l} \gamma^\mu l$ $\quad$ $O_{10} \sim \bar{s}_L \gamma_\mu b_L \bar{l} \gamma^\mu \gamma_5 l$

Express observables thru Wilson coefficients C_7, C_9, C_{10} and extract the latter from data. Dipole coupling $|C_7|$ fixed by $Br(B \to X_s \gamma)$.

C_9-C_{10} Scans $B \to K^* l^+ l^-$ pre 2010

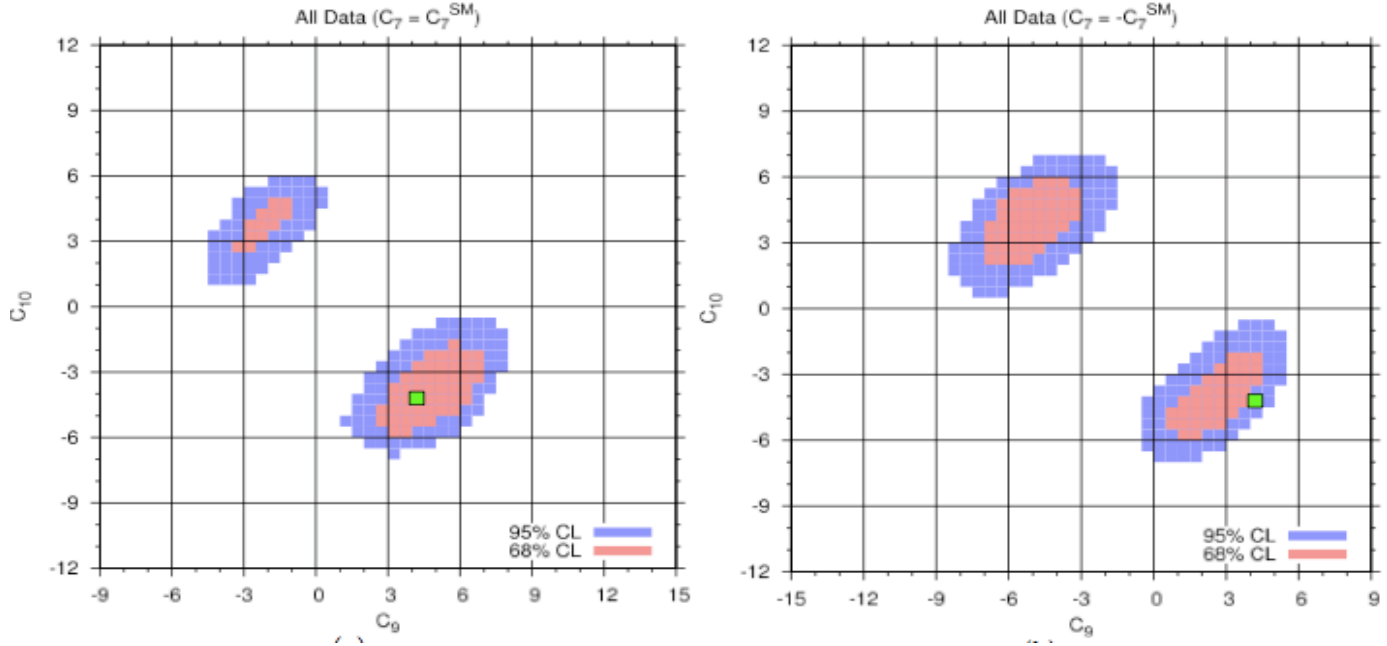


global fits to (real) $C_9\,, C_{10}$ for $C_7 = \pm C_7^{\rm SM}$; green box: SM value for $(C_9\,, C_{10})$

EOS project: http://project.het.physik.tu-dortmund.de/eos/ Fig. from 1006.5013 [hep-ph]

agreement with SM; order 1 BSM allowed.

Including low recoil data



global fits to (real) C_9, C_{10} for $C_7 = \pm C_7^{\rm SM}$; green box: SM value for (C_9, C_{10})
EOS project: http://project.het.physik.tu-dortmund.de/eos/ Bobeth, GH,vanDyk 1006.5013 [hep-ph]

agreement with SM; order 1 BSM allowed.

Gives $Br(B_s \to \mu^+\mu^-)$ within $[2 \times 10^{-11}, 1.0 \times 10^{-8}]$ (2σ).

2011+: IFF $A_{\rm FB}$ has zero, only 2 solutions with $C_i = \pm C_i^{\rm SM}$ remain.

Exploiting $B \to K^* l^+ l^-$ at low recoil further

OPE in $1/Q$, $Q = \{m_b, \sqrt{q^2}\}$ by Grinstein, Pirjol '04 with heavy quark FF relations $T_{1,2,3} \leftrightarrow V, A_{1,2}$ leads to simply transversity structure with universal short-distance C and form factor coefficients f_i

$$A_i \sim C \cdot f_i \qquad , \; i = 0, \perp, ||,$$

up to corrections of order $\alpha_s \Lambda / m_b$ and $(C_7/C_9)\Lambda/m_b$ (few percent).

Allows to design new observables which are Bobeth, GH,vanDyk 1006.5013, and '11

– independent of form factors ($H_T^{(2,3)}$)

– independent of short-distance coefficients and test the form factors

– independent of either ones and test the theoretical low recoil framework $H_T^{(1)}, H_T^{(2)}/H_T^{(3)}$

Exploiting $B \to K^* l^+ l^-$ at low recoil further

$$H_T^{(1)} = \frac{\mathrm{Re}(A_0^L A_\parallel^{L*} + A_0^{R*} A_\parallel^R)}{\sqrt{(|A_0^L|^2 + |A_0^R|^2)(|A_\parallel^L|^2 + |A_\parallel^R|^2)}} = \frac{\sqrt{2} J_4}{\sqrt{-J_2^c (2J_2^s - J_3)}},$$

$$H_T^{(2)} = \frac{\mathrm{Re}(A_0^L A_\perp^{L*} - A_0^{R*} A_\perp^R)}{\sqrt{(|A_0^L|^2 + |A_0^R|^2)(|A_\perp^L|^2 + |A_\perp^R|^2)}} = \frac{\beta_l J_5}{\sqrt{-2J_2^c (2J_2^s + J_3)}},$$

$$H_T^{(3)} = \frac{\mathrm{Re}(A_\parallel^L A_\perp^{L*} - A_\parallel^{R*} A_\perp^R)}{\sqrt{(|A_\parallel^L|^2 + |A_\parallel^R|^2)(|A_\perp^L|^2 + |A_\perp^R|^2)}} = \frac{\beta_l J_6}{2\sqrt{(2J_2^s)^2 - J_3^2}}.$$

Low recoil HQ-OPE: $H_T^{(1)} = 1, \qquad H_T^{(2)}/H_T^{(3)} = 1.$

Extract them from the $B \to K^*(\to K\pi)\mu^+\mu^-$ angular distribution.

Full Angular Analysis in $B \to V(\to PP)\mu^+\mu^-$

on-shell decaying V: $d\Gamma^4 \sim J dq^2 d\cos\Theta_l d\cos\Theta_{K^*} d\Phi$ hep-ph/9907386

$$
\begin{aligned}
J(q^2,\theta_l,\theta_{K^*},\phi) = {} & J_1^s \sin^2\theta_{K^*} + J_1^c \cos^2\theta_{K^*} + (J_2^s \sin^2\theta_{K^*} + J_2^c \cos^2\theta_{K^*})\cos 2\theta_l \\
& + J_3 \sin^2\theta_{K^*}\sin^2\theta_l \cos 2\phi + J_4 \sin 2\theta_{K^*}\sin 2\theta_l \cos\phi + J_5 \sin 2\theta_{K^*}\sin\theta_l \cos\phi \\
& + J_6 \sin^2\theta_{K^*}\cos\theta_l + J_7 \sin 2\theta_{K^*}\sin\theta_l \sin\phi \\
& + J_8 \sin 2\theta_{K^*}\sin 2\theta_l \sin\phi + J_9 \sin^2\theta_{K^*}\sin^2\theta_l \sin 2\phi, \qquad (2.3)
\end{aligned}
$$

$J_i = J_i(q^2)$ are functions of transversity amplitudes.

Θ_l: angle between l^- and $\bar{B}$ in dilepton CMS (warning: different conventions in literature)

Θ_{K^*}: angle between K and $\bar{B}$ in K^*-CMS

Φ: angle between normals of the $K\pi$ and l^+l^- plane

$\Gamma \sim J_1 - J_2/3$, $A_{\rm FB} \sim J_6$, $A_T^{(2)} \sim J_3$ hep-ph/0502060, $S_5 \sim J_5$ 0811.1214 [hep-ph]

Full Angular Analysis in $B \to V(\to PP)\mu^+\mu^-$

Several [hep-ph] groups working on angular analyses recently 0709.4174, 0805.2525, 0807.2589, 0811.1214, 1002.4310, 1005.0571, 1006.5013, 1008.2367, and counting ...

CP-asymmetries from angular distribution $A_i \propto J_i - \bar{J}_i$: SM: all doubly Cabbibo-suppressed and null tests of the SM.

A_3, A_9 vanish in SM by helicity conservation: sens. to RH currents
$A_3, A_9, (A_6)$ can be extracted from single-diff distribution in $\Phi(\Theta_l)$
$A_{7,8,9}$ T-odd: not suppressed by small strong phases; O(1) with BSM
$A_{5,6,8,9}$ CP-odd: can be extracted without tagging from $\Gamma + \bar{\Gamma}$; advantageous for $B_s, \bar{B}_s \to (\Phi \to K^+K^-)\mu^+\mu^-$.

T-odd versus T-even CP Asymmetries

A_7, A_8, A_9 are T-odd and can be order one with BSM. Tab. from 0805.2525

	generic NP	$C_{10}^{\rm NP}$ only	$C_{10}^{\prime\rm NP}$ only	$C_9^{\rm NP}$ only
$\langle A_{\rm CP}\rangle$	$[-0.12, 0.10]$	$[3, 8]\cdot 10^{-3}$	SM-like	$[-0.02, 0.02]$
$\langle A_3\rangle$	$[-0.08, 0.08]$	SM-like	SM-like	SM-like
$\langle A_4^D\rangle$	$[-0.04, 0.04]$	$[-4, -1]\cdot 10^{-3}$	$[-3, -1]\cdot 10^{-3}$	$[-0.01, 0.01]$
$\langle A_5^D\rangle$	$[-0.07, 0.07]$	$[-0.04, 0.04]$	$[-0.02, 0.04]$	$[5, 9]\cdot 10^{-3}$
$\langle A_6\rangle$	$[-0.13, 0.11]$	$[-0.05, 0.05]$	$[-9, -3]\cdot 10^{-3}$	SM-like
$\langle A_7^D\rangle$	$[-0.76, 0.76]$	$[-0.48, 0.48]$	$[-0.38, 0.38]$	SM-like
$\langle A_8^D\rangle$	$[-0.48, 0.48]$	$[2, 7]\cdot 10^{-3}$	$[-0.28, 0.28]$	$[-0.17, 0.17]$
$\langle A_9\rangle$	$[-0.62, 0.60]$	SM-like	$[-0.20, 0.20]$	SM-like
$\mathcal{B}(\bar{B}_s \to \bar{\mu}\mu)$	$< 1.4\cdot 10^{-8}$	$< 6.3\cdot 10^{-9}$	$< 1.3\cdot 10^{-8}$	SM

Summary

- It is fantastic to witness great advances in FCNC b-decays and respective tests of SM and BSM physics. After observing exclusive $b \to sll$ modes, first results of basic decay distributions and asymmetries are now available by several experiments. More involved and designed ones are accessible by angular analysis, promising for LHCb and Tevatron with muons; opportunity for electrons and neutrinos, also inclusive modes and if feasible taus, for super flavor factory.
- Lots of recent TH focus on angular distribution and their exploitation.

Summary

- New developments at low hadronic recoil in theory pheno+lattice greatly support exploitation of todays and tomorrows data. E.g., recent OPE study by Beylich et al 1101.5118 [hep-ph]; Preliminary unquenched lattice $B \to K^{(*)}$ form factors by Liu et al 1101.2726 [hep-ph].
- The large number of complementary observables accessible with $b \to s$ decays allows us to map out precisely the amount of CP violation, or BSM phenomena such as right-handed currents, or large scalar currents present at the TeV-scale.

Analysis workshop on $b \to sll$ at low recoil at DESY Hamburg June 15-17, 2011; please send email if you want to contribute.