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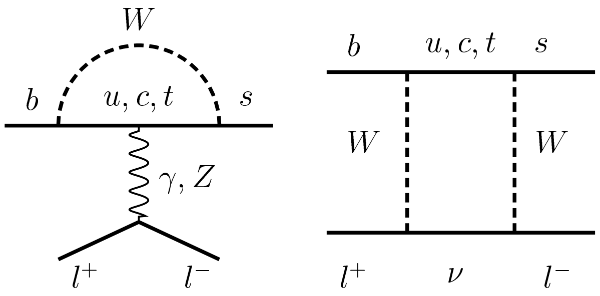
V_{xb} and V_{tx} - Workshop, SLAC, December 4-6, 2002

- *introduction: $\mathcal{H}_{eff}$ primer, the coefficients $C_{7,8,9,10}$*
- *status of inclusive $b \to s\ell^+\ell^-$ decays, $\ell = e, \mu$*
- *theoretical uncertainties in $\mathcal{B}(b \to s\ell^+\ell^-)$*
- *forward-backward asymmetry $A_{FB}(b \to s\ell^+\ell^-)$*

structures in SM



organization of α_s-corrections with effective theory $m_b \ll m_W, m_t$

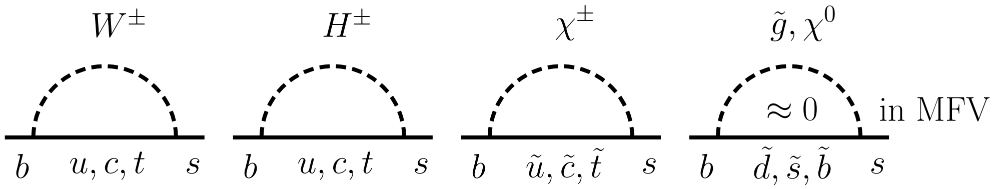
$\mathcal{H}_{eff} = -4G_F/\sqrt{2}V_{tb}V_{ts}^* \sum C_i O_i$ drop $V_{ub}V_{us}^* \sim \lambda^4 \ll V_{tb}V_{ts}^* \sim \lambda^2$

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

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

$C_i^{SM}(m_W) = C_i(m_t^2/m_W^2)$; $C_i(m_{weak})$ to $C_i(m_b)$ with RGE methods

new physics in Wilson coefficients $C_i = C_i^{SM} + C_i^{NP}$ e.g. FCNC in SUSY



⋆⋆⋆ 2001 first observation of exclusive decay ⋆⋆⋆

$\mathcal{B}(B \to K\ell^+\ell^-)_{SM} = 0.35 \pm 0.12 \cdot 10^{-6}$ NNLO hep-ph/0112300

$\mathcal{B}(B \to K\ell^+\ell^-) = 0.58^{+0.17}_{-0.15} \pm 0.06 \cdot 10^{-6}$ Belle prelim. ICHEP 2002

$\mathcal{B}(B \to K\ell^+\ell^-) = 0.78^{+0.24+0.11}_{-0.20-0.18} \cdot 10^{-6}$ BaBar prelim. ICHEP 2002

$\mathcal{B}(B \to K^*\mu^+\mu^-)_{SM} = 1.19 \pm 0.39 \cdot 10^{-6}$ NNLO hep-ph/0112300

$\mathcal{B}(B \to K^*e^+e^-)_{SM} = 1.58 \pm 0.49 \cdot 10^{-6}$ NNLO hep-ph/0112300

$\mathcal{B}(B \to K^*\ell^+\ell^-) < 1.4 \cdot 10^{-6}$ @ 90%C.L. Belle prelim. ICHEP 2002

$\mathcal{B}(B \to K^*\ell^+\ell^-) < 3.0 \cdot 10^{-6}$ @ 90%C.L. BaBar prelim. ICHEP 2002

inclusive mode	Br_{exp} Belle prelim'02	signif.	Br_{SM} NNLO hep-ph/0112300
$B \to X_s\mu^+\mu^-$	$7.9 \pm 2.1^{+2.0}_{-1.5} \cdot 10^{-6}$	4.7σ	$4.15 \pm 0.70 \cdot 10^{-6}$
$B \to X_s e^+e^-$	$5.0 \pm 2.3^{+1.2}_{-1.1} \cdot 10^{-6}$	3.4σ	$6.89 \pm 1.01 \cdot 10^{-6}$
$B \to X_s\ell^+\ell^-$	$6.1 \pm 1.4^{+1.3}_{-1.1} \cdot 10^{-6}$	5.4σ	

C_9 is special: O_2 admixture at 1-loop without α_s-corr, so $C_9 \propto \frac{1}{\alpha_s} + \ldots$
NNLO in $b \to s\ell^+\ell^-$ corresponds to NLO in $b \to s\gamma$

NNLO complete for low dilepton inv mass $\hat{s} < 4\hat{m}_c^2$

$$C_i^{eff} = \left[1 + \frac{\alpha_s}{\pi}\omega_i(\hat{s})\right]\left[C_i + \ldots\right] + \frac{\alpha_s}{4\pi} C_j F_{ij}(\hat{s})$$

F_{ij}: virtual corrections

ω_i: correction of matrix element of O_i includes bremsstrahlung

$$\frac{d\Gamma(B \to X_s\ell^+\ell^-)}{d\hat{s}} = \left(\frac{\alpha_{em}}{4\pi}\right)^2 \frac{G_F^2 m_{b,pole}^5 \left|V_{ts}^* V_{tb}\right|^2}{48\pi^3}(1-\hat{s})^2 \left[(1+2\hat{s})\left(\left|C_9^{eff}\right|^2 + \left|C_{10}^{eff}\right|^2\right) f_1(\hat{s}) + 4(1+2/\hat{s})\left|C_7^{eff}\right|^2 f_2(\hat{s}) + 12\mathrm{Re}\left(C_7^{eff} C_9^{eff*}\right) f_3(\hat{s}) + f_c(\hat{s})\right]$$

includes $1/m_c$,$1/m_b$ hqet corrections $\lambda_1 = -0.2\mathrm{GeV}^2$, $\lambda_2 = +0.12\mathrm{GeV}^2$

$$f_i(\hat{s}) = 1 + \frac{\lambda_1}{2m_b^2} + \frac{\mathcal{O}(\lambda_2)}{m_b^2} \quad f_c(\hat{s}) \propto \frac{\lambda_2}{m_c^2} C_2 \left[C_9^{eff*}(2+\hat{s}) + C_7^{eff*}\frac{1+6\hat{s}-\hat{s}^2}{\hat{s}}\right]$$

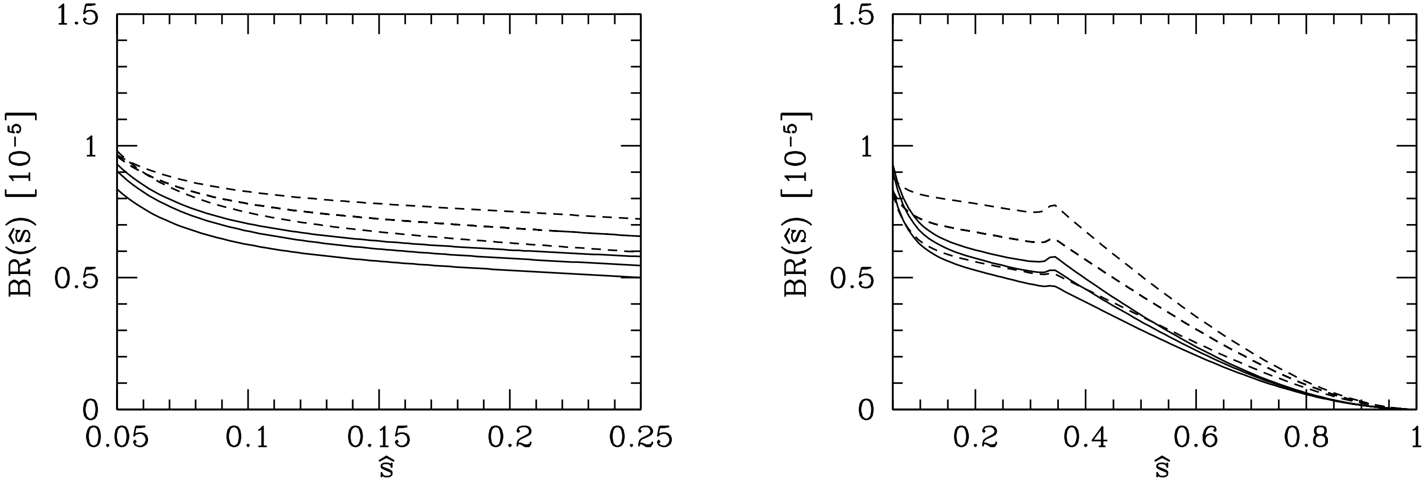
$b \to s\ell^+\ell^-$ at NNLO precision

left figure NLO dashed vs NNLO solid for renorm scale

$\mu = m_b/2$(lowest)$, m_b, 2m_b$

NLO $\to$ NNLO: μ dependence decreased from $\pm 13\%$ to $\pm 6.5\%$

NLO $\to$ NNLO: branching ratio for $B \to X_s \ell^+\ell^-$ decreased by 12% (electrons) 20% (muons)



right figure partially NNLO ($F_{ij} = 0$) dashed, full NNLO solid

$b \to s\ell^+\ell^-$ at NNLO precision, prospects

inclusive decays @NNLO hep-ph/0112300

errors $m_b/2 < \mu < 2m_b$ $m_t^{pole} = (173.8 \pm 5)$ GeV $m_c/m_b = 0.29 \pm 0.04$

$\mathcal{B}(B \to X_s e^+e^-)_{SM} = 6.89 \pm 0.37 \pm 0.25 \pm 0.91 \cdot 10^{-6}$ $\quad \delta\mathcal{B}_{X_s ee} = \pm 15\%$

$\mathcal{B}(B \to X_s \mu^+\mu^-)_{SM} = 4.15 \pm 0.27 \pm 0.21 \pm 0.62 \cdot 10^{-6}$ $\quad \delta\mathcal{B}_{X_s \mu\mu} = \pm 17\%$

prospects at B-factories hep-ex/0112041

year	summer 2002	2005	2008
$\mathcal{L}[fb^{-1}/y]$	100	500	1000
yield $b \to se^+e^-(\mu^+\mu^-)$	73 (57)	365 (280)	728 (565)
$\sigma(stat)[\%]$	17 (19)	7 (9)	5 (6)
$\sigma(sys)[\%]$	10 (17)	7 (12)	6 (10)

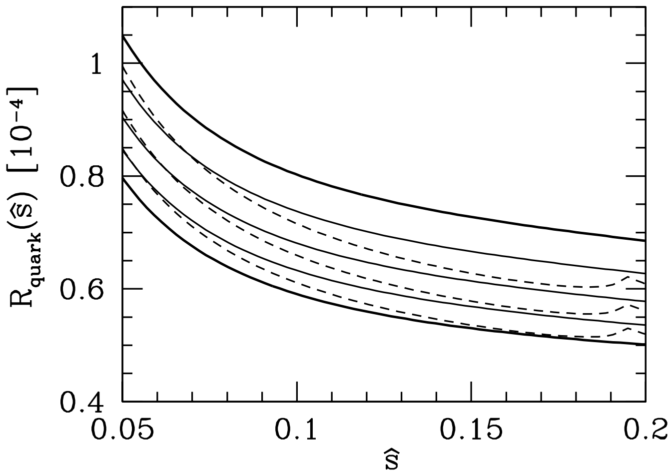
charm mass effects in $b \to s\gamma, s\ell^+\ell^-$

2 sources: in rare decay itself and from normalization to $\Gamma(b \to c\ell^- \bar\nu_\ell)$
$Br(b \to s\ell^+\ell^-) = B_{sl}\Gamma(b \to s\ell^+\ell^-)/\Gamma_{sl}$
study parametric dependence in rates $z = m_c/m_b$ as $\triangle(z) = \frac{\Gamma(z)-\Gamma(0.29)}{\Gamma(0.29)}$
then approx. linear $\triangle(z) \approx (0.29 - z)/0.02\ \epsilon$

	ϵ
$b \to s\ell^+\ell^-$	1%
$b \to s\gamma$	3%
$b \to c\ell^-\bar\nu_\ell$	8%

differences $b \to s\ell^+\ell^-$ vs $b \to s\gamma$ 1) m_c already at 1-loop 2) parametric dependence on $z = m_c/m_b$ smaller 3) less crucial in 2002: experimental error far (~ 2005 ?) 4) richer final state: in asymmetries normalization $\Gamma(b \to c\ell^-\bar\nu_\ell)$ drops out plot of branching ratio of $b \to s\ell^+\ell^-$ from hep-ph/0204341

solid:$m_c/m_b = 0.33$ (upper most) $m_c/m_b = 0.31, 0.29, 0.27, 0.25$ in both semileptonic decays; dashed: pole mass $m_c/m_b = 0.31, 0.29, 0.27$ in Γ_{sl},$\bar{m}_c/m_b = 0.22$ in rare decay $m_c/m_b = 0.29 \pm 0.04$ conservative



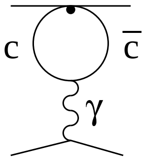
exclusive $B \to K, K^*\ell^+\ell^-$ decays: normalize to life time $\delta\tau(B) = 1\%$

normalize inclusive to $\tau(B)$? $\Gamma(b \to s\ell^+\ell^-) \sim m_b^5 |V_{tb}V_{ts}^*|^2$

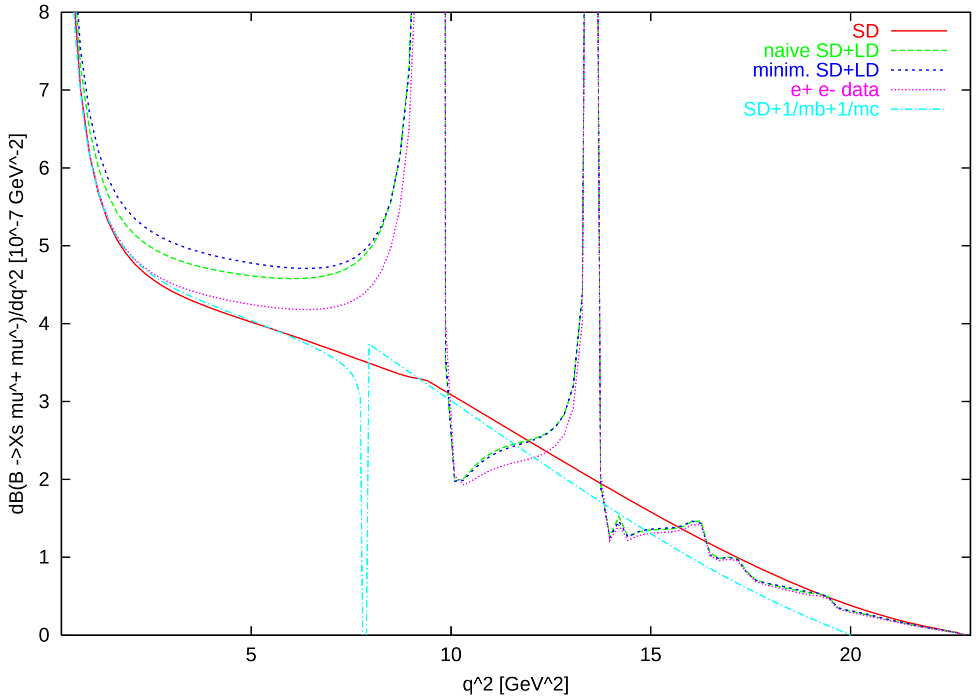
from m_b: $\delta\Gamma \simeq 5\delta m_b \simeq 10\%$ for $m_b^{1S} = 4.7 \pm 0.1$GeV will improve

charmonium effects in $b \to s\ell^+\ell^-$ decays

BGD from $b \to s(c\bar{c}) \to s\ell^+\ell^-$ peaks near $q^2 \sim m^2_{J/\Psi}, m^2_{\Psi'}, m^2_{\Psi''}...$



not captured by perturbation theory, add Breit-Wigner



cuts in q^2 required; double counting? leakage away from resonances?

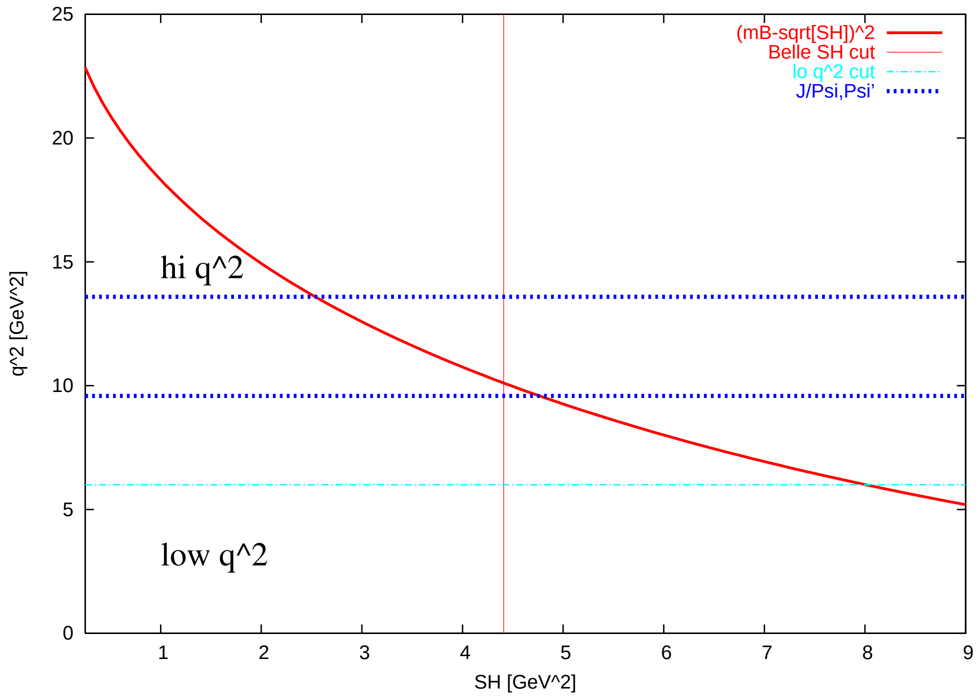
$e^+e^- \to hadrons$ data (pink) supported by $1/m_c$ expansion (light blue)

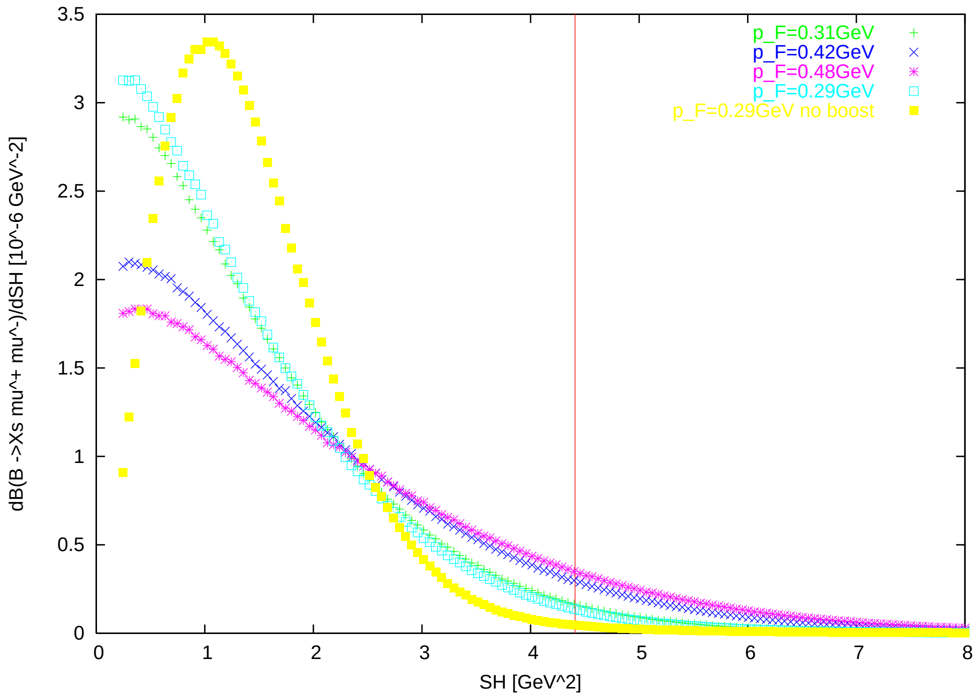
ok below charm threshold – rely on factorization

hadronic invariant mass cuts

Belle'02 $b \to s\ell^+\ell^-$ analysis $m_{X_s} < 2.1$ GeV $\qquad$ m_{X_s}-spectrum:

bremsstrahlung and Fermi motion (b-quark moves in B-meson with p_F)





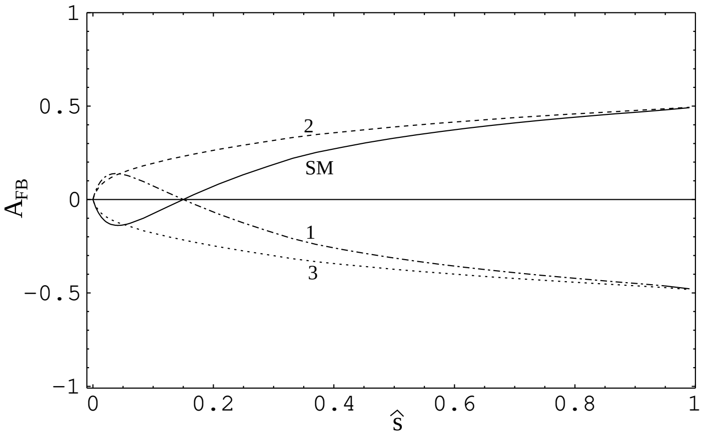
efficiency in Fermi mo $\left(\int_{m_K}^{2.1GeV} dX_s \frac{dBr}{dX_s}\right)/Br = 93 \pm 4\%$ hep-ph/9807418

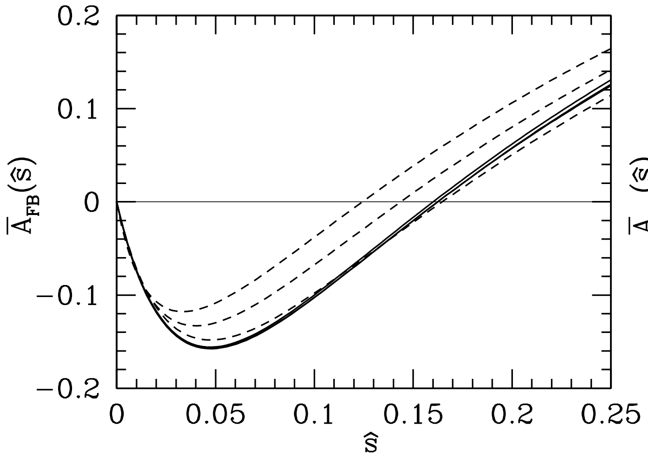
fit $\bar{B} \to X_s\gamma$ photon spectrum by CLEO hep-ex/0108032: $p_F = 410$ MeV

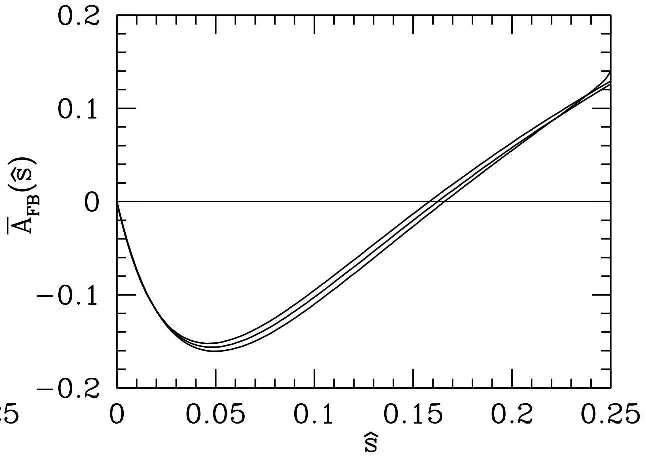
forward backward asymmetry in $b \to s\ell^+\ell^-$

asymmetry between N(forward) and N(backward) scattered ℓ^- in dilepton CMS w.r.t. B-meson $A_{FB}(\hat{s}) \sim C_{10}\left[C_7 + \beta(\hat{s})Re(C_9)\right]$

- SM or $C_7 < 0$ A_{FB} has zero in low q^2 $\hat{s}_{SM}^{NNLL} = 0.162 \pm 0.002(8)$
- $C_7 > 0$ NO zero (curve 2) e.g. MFV MSSM
- C_{10} non-SM curve 3 or 1 or flat $A_{FB}(\hat{s}) \sim 0$ possible !







mid fig solid NNLO vs dashed NLO for $\mu = m_b/2, m_b, 2m_b$,$m_c/m_b = 0.29$
right fig NNLO $\mu = m_b$, $m_c/m_b = 0.29 \pm 0.04$ hep-ph/0209006

summary

- $b \to s\ell^+\ell^-$ complement $b \to s\gamma$ decays: Z-penguin and box
- $\mathcal{B}(b \to s\ell^+\ell^-)$ known to NNLO at low q^2
- important theory uncertainties in $\mathcal{B}(b \to s\ell^+\ell^-)$
  - charm: $c\bar{c}$ resonances and normalization Γ_{sl} induced
  - B bound state effects: near $q^2 \approx q^2_{max}$ and if Br with hadronic mass cut required
- very clean observable A_{FB} at NNLO; shape, zero in low q^2 region

  $\hat{s}_{SM}^{NNLL} = 0.162 \pm 1\% \pm 3\%$

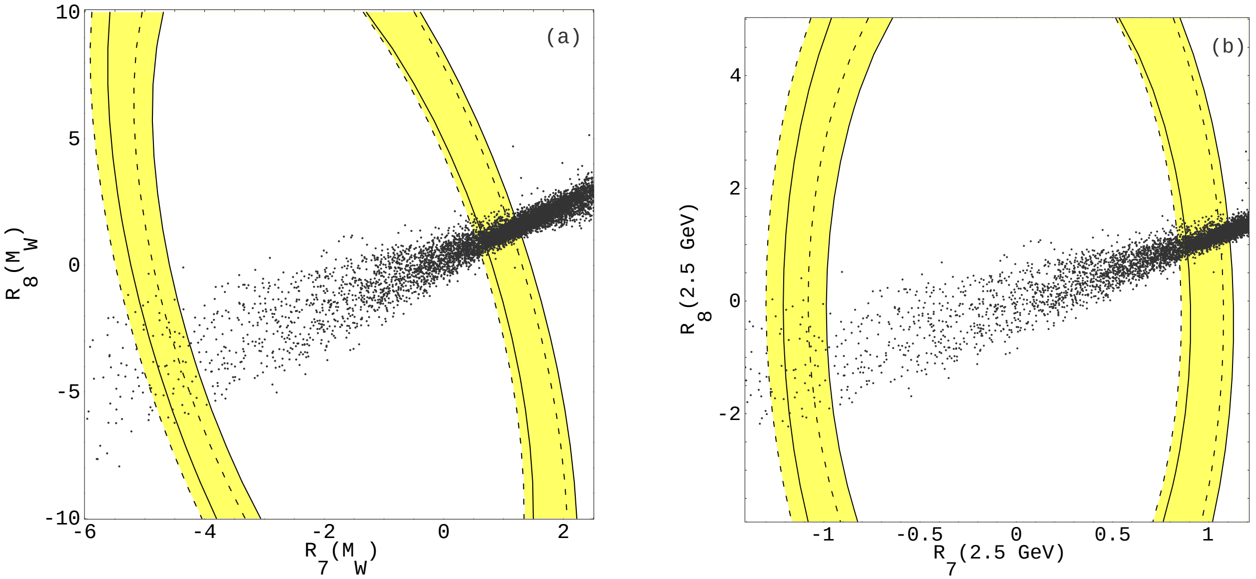
  for $m_b/2 \leq \mu \leq m_b$, $m_c/m_b = 0.29 \pm 0.04$

back up slides

model independent analysis with $\mathcal{H}_{eff}$ C_7, C_8 eff. $bs\gamma, bsg$ couplings

$O_7 \propto \bar{s}_L \sigma_{\mu\nu} b_R F^{\mu\nu}$, $O_8 \propto \bar{s}_L \sigma_{\mu\nu} b_R G^{\mu\nu}$ $\mathcal{B}(b \to s\gamma)_{LO} \sim |C_7(m_b)|^2$

ratios $R(\mu) \equiv \frac{C^{SM}(\mu)+C^{NP}(\mu)}{C^{SM}(\mu)}$ NLO update @90%C.L. hep-ph/0112300



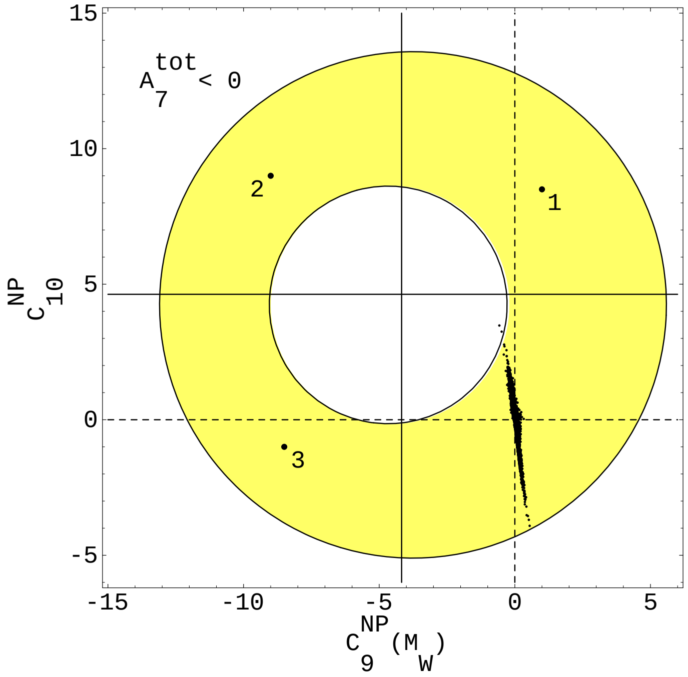
theory errors μ and charm mass solid:pole, dashed:$\overline{\mathrm{MS}}$ prospects: 2005

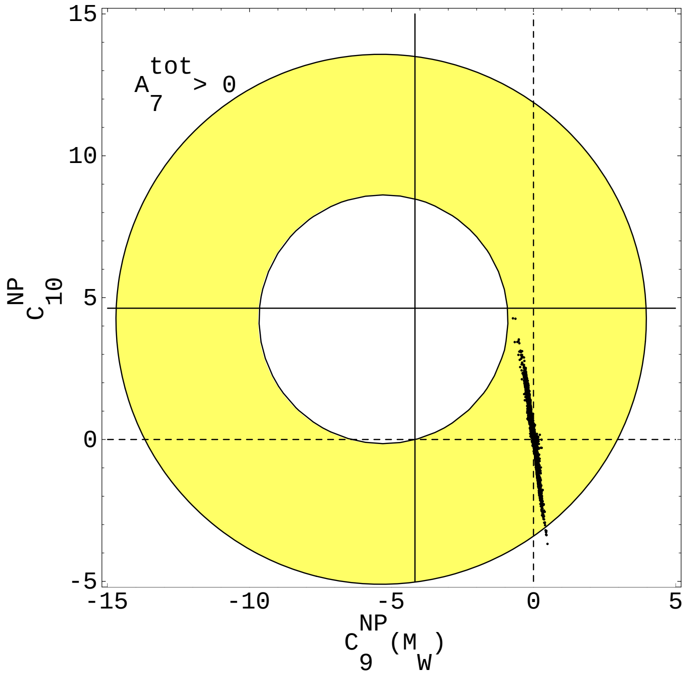
B-factories have $500 fb^{-1}$, $\sigma(stat, sys)_{b \to s\gamma} = 1.8\%, 3\%$ hep-ex/0112041

model independent analysis $b \to s\ell^+\ell^-, s\gamma$

SM: $C_9(m_W) = 2.04$, $C_{10} = -4.59$, $C_7 < 0$ hep-ph/0112300

@ 90% C.L. incl data on $B \to K\mu^+\mu^-$,$B \to X_s e^+e^-$ and $b \to s\gamma$





$|C_{10}| \lesssim 2|C_{10}^{SM}|$ bound on sZb-penguins, contrib. also to $b \to s\bar{q}q, b \to s\bar{\nu}\nu$

scatter plot: non MFV scenario, with up-squark mixing $\delta^U_{23,LL}, \delta^U_{23,LR}$