Testing WA and NP in charmless $B \to PP, PV$ with QCDF

– work in progress –

Christoph Bobeth, Martin Gorbahn and Stefan Vickers
TU Munich – Universe Cluster

Portoroz
2013

Motivation: Search for new physics (=NP)

In charmless hadronic B-decays:
$\Rightarrow$ "Loops" of $b \to s\, q\bar{q}$ transitions

- $B \to PP\,(= K\pi, K\eta^{(\prime)}, \ldots)$,
- $B \to PV\,(= K\rho, K\phi, K\omega, K^*\pi, \ldots)$,
- $B_s \to \ldots$

Motivation: Search for new physics (=NP)

In charmless hadronic B-decays:
$\Rightarrow$ "Loops" of $b \to s\, q\bar{q}$ transitions

- $B \to PP\,(= K\pi, K\eta^{(\prime)}, \ldots)$,
- $B \to PV\,(= K\rho, K\phi, K\omega, K^*\pi, \ldots)$,
- $B_s \to \ldots$

Final data set

@ Belle I

New data with high statistics

@ Belle II
@ LHCb (for charged final states)

Motivation: Search for new physics (=NP)

In charmless hadronic B-decays:
$\Rightarrow$ "Loops" of $b \to s\, q\bar{q}$ transitions

- $B \to PP\,(= K\pi, K\eta^{(\prime)}, \ldots)$,
- $B \to PV\,(= K\rho, K\phi, K\omega, K^*\pi, \ldots)$,
- $B_s \to \ldots$

Final data set

@ Belle I

New data with high statistics

@ Belle II
@ LHCb (for charged final states)

Theory beyond naive factorization:

- QCD Factorisation (=QCDF)
- SCET (I + II)

$\surd$ eff. coupl's in terms of NP pmr's
$\surd$ universal non-perturbative input

BUT: "QCD"-model-dependence
@ sub-leading order from end-point divergences (not yet resolved)

[$\Rightarrow$ comprehensive analysis Hofer/Scherer/Verrnazza arXiv:1011.6319]

B meson decays are a multi-scale problem . . .

. . . with hierarchical interaction scales

electroweak IA	$\gg$	ext. mom'a in B restframe	$\gg$	QCD-bound state effects
$M_W \approx 80$ GeV $M_Z \approx 91$ GeV		$M_B \approx 5$ GeV		$\Lambda_{\mathrm{QCD}} \approx 0.5$ GeV

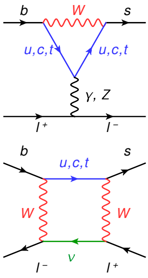
B meson decays are a multi-scale problem . . .

. . . with hierarchical interaction scales

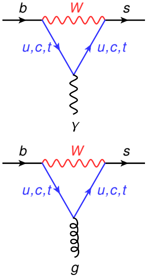
electroweak IA	$\gg$	ext. mom'a in *B* restframe
$M_W \approx 80$ GeV $M_Z \approx 91$ GeV		$M_B \approx 5$ GeV

$$\mathcal{L}_{\rm eff} \sim G_F\, V_{\rm CKM} \times \Big[\sum_{9,10} C_i^{\ell\bar\ell}\, \mathcal{O}_i^{\ell\bar\ell} + \sum_{7\gamma,\,8g} C_i\, \mathcal{O}_i + \text{CC} + (\text{QCD \& QED-peng}) \Big]$$

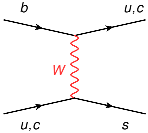
semi-leptonic



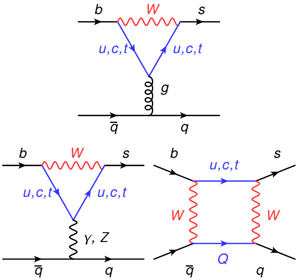
electro- & chromo-mgn



charged current



QCD & QED -penguin



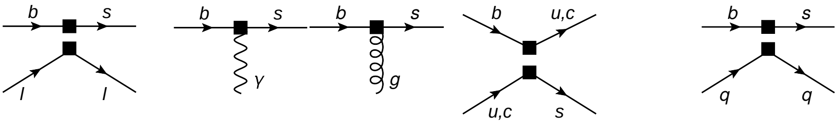
B meson decays are a multi-scale problem ...

... with hierarchical interaction scales

electroweak IA	$\gg$	ext. mom'a in B restframe
$M_W \approx 80$ GeV $M_Z \approx 91$ GeV		$M_B \approx 5$ GeV

$$\mathcal{L}_{\rm eff} \sim G_F\, V_{\rm CKM} \times \left[\sum_{9,10} C_i^{\ell\bar\ell}\, \mathcal{O}_i^{\ell\bar\ell} + \sum_{7\gamma,\,8g} C_i\, \mathcal{O}_i + \text{CC} + (\text{QCD \& QED-peng}) \right]$$

semi-leptonic | electro- & chromo-mgn | charged current | QCD & QED -penguin



$C_i =$ Wilson coefficients: contains short-dist. pmr's (heavy masses $M_t, \ldots$ – CKM factored out) and leading logarithmic QCD-corrections to all orders in α_s

$\Rightarrow$ in SM known up to next-to-next-to-leading order

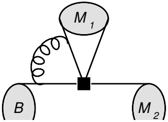
$\mathcal{O}_i =$ higher-dim. operators: flavour-changing coupling of light quarks and leptons

$B \to M_1 M_2$ matrix elements in QCDF

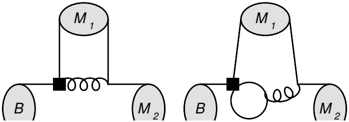
[Beneke/Buchalla/Neubert/Sachrajda hep-ph/0104110]

Different classes of diagrams can be calculated perturbatively due to large momentum transfers

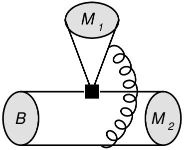
Vertex corrections



Penguin corrections



Hard spectator scattering (HS)



spectator quark not involved

perturbatively calculable

- "kernels": $T_{ij}^{I,II}$

non-perturbative quantities (sum rules, measurements, lattice)

- decay constants: f_{B,M_1,M_2}
- form factors: $F_j^{B\to M_1}$
- convolutions ($*$) of distribution amplitudes: Φ_{B,M_1,M_2}

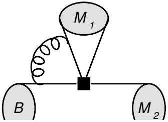
@ leading order in $\Lambda_{\rm QCD}/m_b$ expansion

$B \to M_1 M_2$ matrix elements in QCDF

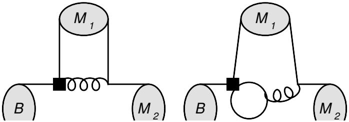
[Beneke/Buchalla/Neubert/Sachrajda hep-ph/0104110]

Different classes of diagrams can be calculated perturbatively due to large momentum transfers

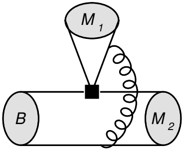
Vertex corrections



Penguin corrections



Hard spectator scattering (HS)



spectator quark not involved

$$\langle M_1 M_2 | \mathcal{O}_i | B \rangle = F_j^{B\to M_1} \, T_{ij}^{I} * f_{M_2} \Phi_{M_2} \quad +$$

perturbatively calculable

- "kernels": $T_{ij}^{I,II}$

non-perturbative quantities (sum rules, measurements, lattice)

- decay constants: f_{B,M_1,M_2}
- form factors: $F_j^{B\to M_1}$
- convolutions ($*$) of distribution amplitudes: Φ_{B,M_1,M_2}

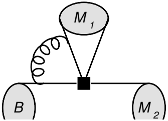
@ leading order in $\Lambda_{\mathrm{QCD}}/m_b$ expansion

$B \to M_1 M_2$ matrix elements in QCDF

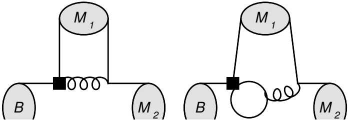
[Beneke/Buchalla/Neubert/Sachrajda hep-ph/0104110]

Different classes of diagrams can be calculated perturbatively due to large momentum transfers

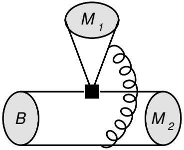
Vertex corrections



Penguin corrections



Hard spectator scattering (HS)



spectator quark not involved

$$\langle M_1 M_2 | \mathcal{O}_i | B \rangle = F_j^{B \to M_1} \, T_{ij}^{I} * f_{M_2} \Phi_{M_2} \quad + \quad T_{ij}^{II} * f_B \Phi_B * f_{M_1} \Phi_{M_1} * f_{M_2} \Phi_{M_2}$$

perturbatively calculable

- “kernels”: $T_{ij}^{I,II}$

non-perturbative quantities (sum rules, measurements, lattice)

- decay constants: f_{B,M_1,M_2}
- form factors: $F_j^{B \to M_1}$
- convolutions ($*$) of distribution amplitudes: Φ_{B,M_1,M_2}

@ leading order in $\Lambda_{\rm QCD}/m_b$ expansion

Endpoint divergences @ sub-leading order in $\Lambda_{\rm QCD}/m_b$

... arise in HS from higher twist LCDA's Φ_{m1}

$$\int_0^1 \frac{dy}{1-y}\Phi_{m1}(y)$$

$$\equiv \Phi_{m1}(1)\, X_H + \int_0^1 \frac{dy}{[1-y]_+}\Phi_{m1}(y)$$

with $\Phi_{m1}(y) \neq 0$ for $y \to 1$

$\Rightarrow$ phenomenological parameter of soft-gluon interaction with spectator quark

$$X_H \equiv (1+\rho_H)\ln\frac{m_b}{\Lambda_{\rm QCD}}, \qquad X_H, \rho_H \in \mathbb{C}$$

$\to$ for $\rho_H = 0 \Rightarrow X_H \approx \ln 10 \approx 2.3$

Endpoint divergences @ sub-leading order in $\Lambda_{\rm QCD}/m_b$

... arise in HS from higher twist LCDA's Φ_{m1}

$$\int_0^1 \frac{dy}{1-y}\Phi_{m1}(y)$$

$$\equiv \Phi_{m1}(1)\, X_H + \int_0^1 \frac{dy}{[1-y]_+}\Phi_{m1}(y)$$

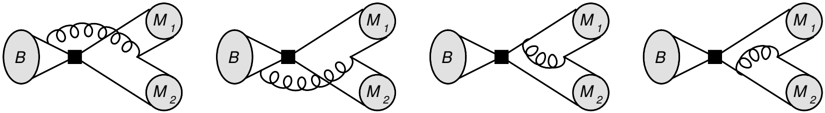
with $\Phi_{m1}(y) \neq 0$ for $y \to 1$

$\Rightarrow$ phenomenological parameter of soft-gluon interaction with spectator quark

$$X_H \equiv (1+\rho_H)\ln\frac{m_b}{\Lambda_{\rm QCD}}, \qquad X_H, \rho_H \in \mathbb{C}$$

$\to$ for $\rho_H = 0 \Rightarrow X_H \approx \ln 10 \approx 2.3$

... arise in weak annihilation (WA) = QCD & QED penguin operators



Endpoint divergences @ sub-leading order in $\Lambda_{\rm QCD}/m_b$

... arise in HS from higher twist LCDA's Φ_{m1}

$$\int_0^1 \frac{dy}{1-y}\Phi_{m1}(y)$$

$$\equiv \Phi_{m1}(1)\,X_H + \int_0^1 \frac{dy}{[1-y]_+}\Phi_{m1}(y)$$

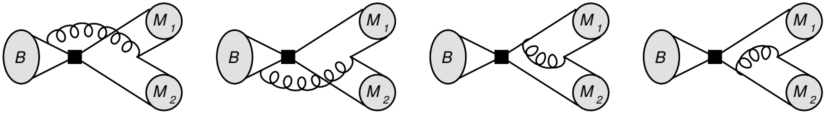
with $\Phi_{m1}(y) \neq 0$ for $y \to 1$

$\Rightarrow$ phenomenological parameter of soft-gluon interaction with spectator quark

$$X_H \equiv (1+\rho_H)\ln\frac{m_b}{\Lambda_{\rm QCD}}, \qquad X_H, \rho_H \in \mathbb{C}$$

$\to$ for $\rho_H = 0 \Rightarrow X_H \approx \ln 10 \approx 2.3$

... arise in weak annihilation (WA) = QCD & QED penguin operators



$\Rightarrow$ they are chirality-enhanced

$\Rightarrow$ in principle different for *initial* and *final* state radiation

$\Rightarrow$ also for 3 possible $\Gamma_1 \otimes \Gamma_2$:

$k=1$: $(V-A)\otimes(V-A)$, $k=2$: $(V-A)\otimes(V+A)$, $k=3$: $(-2)(S-P)\otimes(S+P)$

$\Rightarrow A_k^{(i,f)}$ with $A_1^f = A_2^f = 0$ and A_3^i negligible for $B \to PP$ [Beneke/Neubert hep-ph/0308039]

Endpoint divergences @ sub-leading order in $\Lambda_{\rm QCD}/m_b$

... arise in HS from higher twist LCDA's Φ_{m1}

$$\int_0^1 \frac{dy}{1-y}\Phi_{m1}(y)$$

$$\equiv \Phi_{m1}(1)\, X_H + \int_0^1 \frac{dy}{[1-y]_+}\Phi_{m1}(y)$$

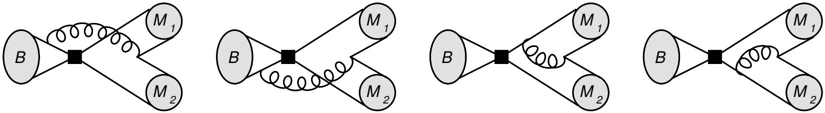
with $\Phi_{m1}(y) \neq 0$ for $y \to 1$

$\Rightarrow$ phenomenological parameter of soft-gluon interaction with spectator quark

$$X_H \equiv (1+\rho_H)\ln\frac{m_b}{\Lambda_{\rm QCD}}, \qquad X_H, \rho_H \in \mathbb{C}$$

$\to$ for $\rho_H = 0 \Rightarrow X_H \approx \ln 10 \approx 2.3$

... arise in weak annihilation (WA) = QCD & QED penguin operators



$A_k^{(i,f)}$ are divergent, however regularized by

$$\int_0^1 \frac{dy}{y} \to X_A, \qquad \int_0^1 dy\frac{\ln y}{y} \to -\frac{1}{2}(X_A)^2$$

X_A in principle different for each meson M_i, each $k = 1,2,3$, each process

... assuming isospin-symmetry single $X_{A,H}$ for each system $PP = (K\pi, \ldots)$, $PV = (K\rho, \ldots)$,

What are $X_{A,H}$???

. . . stand for something we do NOT know (yet)

. . . approximate that "something" in a to us "unknown" manner

- represent a strong phase → affect CP-asymmetries
- might be used to estimate the uncertainty due to our ignorance
- might be fitted from data to check with our naive expectations

What are $X_{A,H}$???

. . . stand for something we do NOT know (yet)

. . . approximate that “something” in a to us “unknown” manner

- represent a strong phase → affect CP-asymmetries
- might be used to estimate the uncertainty due to our ignorance
- might be fitted from data to check with our naive expectations

Can we still constrain New Physics in the presence of $X_{A,H}$???

What are $X_{A,H}$???

. . . stand for something we do NOT know (yet)

. . . approximate that "something" in a to us "unknown" manner

- represent a strong phase → affect CP-asymmetries
- might be used to estimate the uncertainty due to our ignorance
- might be fitted from data to check with our naive expectations

Can we still constrain New Physics in the presence of $X_{A,H}$???

In literature usually central values for $|\rho_{A,H}|$ and $\arg\rho_{A,H} = 0$ chosen and errors estimated from variation

$$\rho = |\rho| e^{i\phi} \qquad \text{with} \qquad |\rho| \in 1 \ldots 2 \text{ and } \phi \in [0, 2\pi]$$

We fit the $\rho_A \in \mathbb{C}$ with prior $|\rho_A| \leqslant 8$

Observables

Observables

CP-averaged branching ratios

$$\overline{Br}(B \to f) = \frac{1}{2}\left[Br\left(\bar{B} \to \bar{f}\right) + Br\left(B \to f\right)\right]$$

Direct CP-asymmetry

$$A_{\rm CP}(B \to f) = \frac{Br(\bar{B} \to \bar{f}) - Br(B \to f)}{Br(\bar{B} \to \bar{f}) + Br(B \to f)}$$

Mixing-induced CP-asymmetry

$$\frac{Br\left(\bar{B}(t) \to \bar{f}\right) - Br\left(B(t) \to f\right)}{Br\left(\bar{B}(t) \to \bar{f}\right) + Br\left(B(t) \to f\right)} = S \sin(\Delta M_B\, t) - C \cos(\Delta M_B\, t)$$

$$(A_{\rm CP} = -C)$$

Ratios of Br's

Here: errors determined from error propagation, BUT only experiments can account for common systematic uncertainties and should provide the errors on these ratios

$$R_n^B = \frac{1}{2}\frac{\overline{Br}(B^0 \to K^+\pi^-)}{\overline{Br}(B^0 \to K^0\pi^0)}$$

$$R_c^K = 2\frac{\tau_0}{\tau_-}\frac{\overline{Br}(B^+ \to K^+\pi^0)}{\overline{Br}(B^0 \to K^+\pi^-)}$$

$$R_c^\pi = \frac{\tau_0}{\tau_-}\frac{\overline{Br}(B^+ \to K^0\pi^+)}{\overline{Br}(B^0 \to K^+\pi^-)}$$

Differences of CP-asymmetries

$$\Delta A_{\rm CP}^- = A_{\rm CP}(B^- \to K^-\pi^0) - A_{\rm CP}(\bar{B}^0 \to K^-\pi^+)$$

$$\Delta A_{\rm CP}^0 = A_{\rm CP}(B^- \to \bar{K}^0\pi^-) - A_{\rm CP}(\bar{B}^0 \to \bar{K}^0\pi^0)$$

Experimental input from HFAG arXiv:1207.1158

$B \to PP$

$b \to s$			
$B \to K\pi$	$B \to K\eta'$	$B_s \to KK$	$B_s \to \pi\pi$
$K^0\pi^0$: Br, C, S	$K^0\eta'^0$: Br, C, S	K^+K^- : Br, C, S	$\pi^+\pi^-$: Br
$K^+\pi^-$: Br, C	$K^+\eta'^0$: Br, C		
$K^+\pi^0$: Br, C			
$K^0\pi^+$: Br, C			
$b \to d$			
$B \to KK$	$B \to \pi\pi$		
$K^0\bar{K}^0$: Br	$\pi^0\pi^+$: Br		
K^+K^- : Br			
K^+K^0 : Br, C			

$B \to PV$

$B \to K^*\pi$	$B \to K\rho$	$B \to K\phi$	$B \to K\omega$
$K^{*0}\pi^0$: Br, C	$K^0\rho^0$: Br, C, S	$K^0\phi^0$: Br, C, S	$K^0\omega^0$: Br, C, S
$K^{*+}\pi^-$: Br, C	$K^+\rho^-$: Br, C	$K^+\phi^0$: Br, C	$K^+\omega^0$: Br, C
$K^{*+}\pi^0$: Br, C	$K^+\rho^0$: Br, C		
$K^{*0}\pi^+$: Br, C	$K^0\rho^+$: Br, C		

SM Fits

All results are preliminary !!!

SM Fit for "ρ_A only"

Questions:

- can ρ_A be fitted separately for each $B \to M_1 M_2$ $(M_1 M_2 = K\pi, K\rho, \ldots)$ with current data?
- is the size of ρ_A consistent with naive expectations from QCDF?
- what are the preferred regions of *BR*'s and CP-asymmetries?
- what about composed observables R and $\Delta A_{\rm CP}$?

Assumptions:

- one ρ_A for each system $B \to M_1 M_2$ $(M_1 M_2 = K\pi, K\rho, \ldots)$ with current data?
- $\ldots$

SM Fit for "ρ_A only"

Questions:

- can ρ_A be fitted separately for each $B \to M_1 M_2$ ($M_1 M_2 = K\pi, K\rho, \ldots$) with current data?
- is the size of ρ_A consistent with naive expectations from QCDF?
- what are the preferred regions of BR's and CP-asymmetries?
- what about composed observables R and $\Delta A_{\rm CP}$?

Assumptions:

- one ρ_A for each system $B \to M_1 M_2$ ($M_1 M_2 = K\pi, K\rho, \ldots$) with current data?
- ...

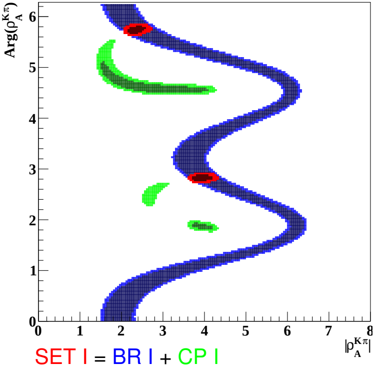
Use 2 sets of observables: for $M_1 M_2 = (K\pi,\ K\rho,\ K^*\pi)$

Set	Observables
Set I	$Br(B^- \to \bar{K}^0\pi^-)$, $Br(B^- \to K^-\pi^0)$, $Br(\bar{B}^0 \to K^-\pi^+)$, $Br(\bar{B}^0 \to \bar{K}^0\pi^0)$
	$A_{\rm CP}(B^- \to \bar{K}^0\pi^-)$, $A_{\rm CP}(B^- \to K^-\pi^0)$, $A_{\rm CP}(\bar{B}^0 \to K^-\pi^+)$, $A_{\rm CP}(\bar{B}^0 \to \bar{K}^0\pi^0)$
Set II	$Br(B^- \to \bar{K}^0\pi^-)$, R_n^B, R_c^K, R_c^π
	$A_{\rm CP}(B^- \to \bar{K}^0\pi^-)$, $A_{\rm CP}(\bar{B}^0 \to K^-\pi^+)$, $A_{\rm CP}(\bar{B}^0 \to \bar{K}^0\pi^0)$, $\Delta A_{\rm CP}^-$

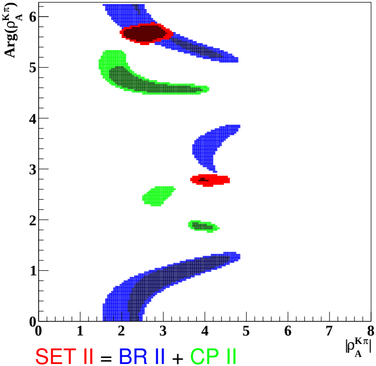
SM Fit $B \to K\pi$

$|\rho_A| - \arg(\rho_A)$

@ 95, 99 % CL



SET I = BR I + CP I



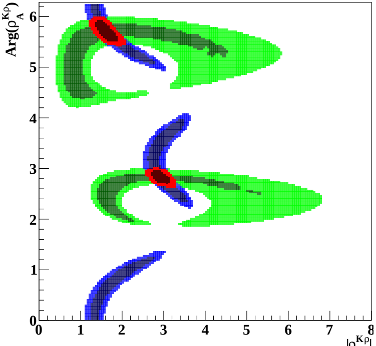
SET II = BR II + CP II

⇒ p-Value	21 %	0.5 %
⇒ Best-FP	(3.8, 2.8)	(2.2, 5.7)
⇒ Pull's @ BFP		
R_n^B	–	2.8σ
R_c^π	–	0.9σ
$C_{K^-\pi^0}/\Delta A_{\rm CP}^-$	2.3σ	2.8σ
$C_{\bar{K}^0\pi^-}$	1.6σ	1.4σ

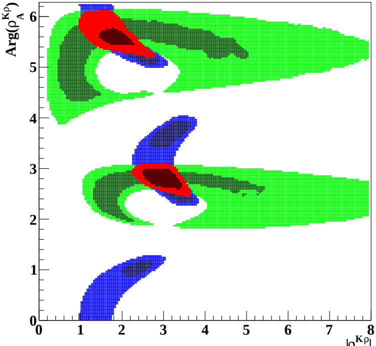
SM Fit $B \to K\rho$

$|\rho_A| - \arg(\rho_A)$

@ 68, 95 % CL



SET I = BR I + CP I



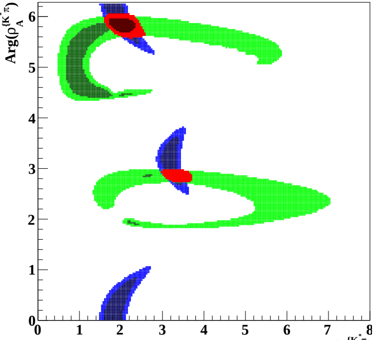
SET II = BR II + CP II

⇒ p-Value	100 %	98 %
⇒ Best-FP	(1.7, 5.6)	(3.2, 2.7)
⇒ Pull's @ BFP		
R_c^K	–	0.7σ
$C_{K^-\rho^+}$	0σ	0.2σ
$C_{\bar{K}^0\rho^-}$	0.7σ	0.7σ

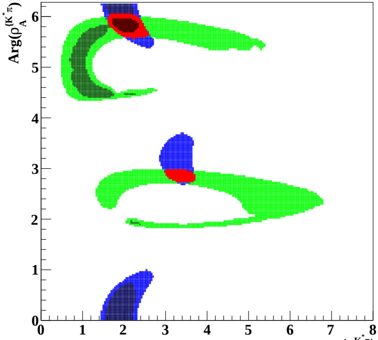
SM Fit $B \to K^*\pi$

$|\rho_A| - \arg(\rho_A)$

@ 68, 95 % CL



SET I = BR I + CP I

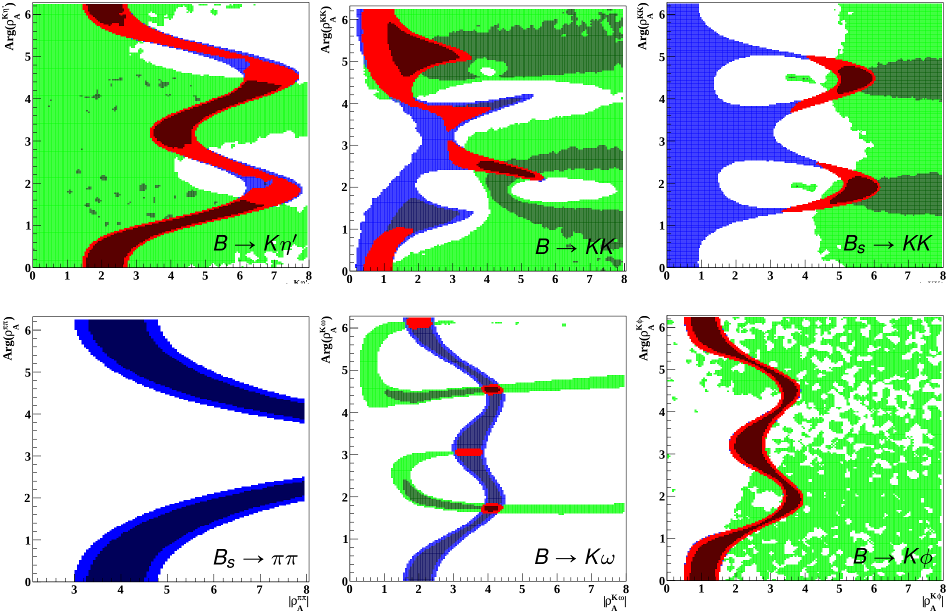


SET II = BR II + CP II

$\Rightarrow$ p-Value	98 %	89 %
$\Rightarrow$ Best-FP	(2.0, 5.9)	(1.8, 5.9)
$\Rightarrow$ Pull's @ BFP		
R_c^{K*}	–	0.9σ
R_c^{π}	–	0.6σ
$C_{\bar{K}*^0\pi^0}$	0.5σ	0.3σ
$C_{\bar{K}*^0\pi^-}$	1.0σ	1.0σ

SM Fit

$|\rho_A| - \arg(\rho_A)$ @ 68, 95 % CL



Summary SM Fits: "ρ_A only"

- only problems in $B \to K\pi$ system, fit is bad (p-value < 1 %) for BR Set II, pull values up to 2.8σ for $\Delta A_{\rm CP}^{-}$ and R_B^n
- BR's and CP-asymmetries give very complementary constraints
- Br's usually constrain $|\rho_A| < 8$ which is larger than used in previous literature, though in some cases $|\rho_A| < 4$ for $B \to K\rho, K\phi, K^*\pi$
- CP-asymmetries in $B \to K\pi, K\rho, K^*\pi$ ($B \to K\eta', KK,\ B_s \to \pi\pi$) prefer $\arg(\rho_A) \sim \pi$ or 2π $\to$ close to real !!! contrary to $B \to K\omega$ ($B_s \to KK$)
- pure weak annihilation $B_s \to \pi\pi$ allows also large $|\rho_A|$, but only one *Br*-measurement

New Physics fits

All results are preliminary !!!

Z-penguin scenario

Eff. Lagrangian @ high scale $\mu_W \sim M_W$

$$\mathcal{L}_{b\to sZ} = \mathcal{L}_{\rm SM} + \frac{G_F}{\sqrt{2}}\frac{e}{\pi^2} M_Z^2 c_W s_W V_{tb} V_{ts}^* \times \left[\bar{s}\,\gamma_\mu\,(Z_L P_L + Z_R P_R)\,b\right] Z^\mu \qquad \text{with} Z_L,\, Z_R \in \mathbb{C}$$

(in principle not 100% proper, might be gauge-dependent, depending on New Physics scenario)

Z-penguin scenario

Eff. Lagrangian @ high scale $\mu_W \sim M_W$

$$\mathcal{L}_{b\to sZ} = \mathcal{L}_{\rm SM} + \frac{G_F}{\sqrt{2}} \frac{e}{\pi^2} M_Z^2 c_W s_W V_{tb} V_{ts}^* \times \left[\bar{s} \gamma_\mu \left(Z_L P_L + Z_R P_R \right) b \right] Z^\mu \qquad \text{with} Z_L,\ Z_R \in \mathbb{C}$$

(in principle not 100% proper, might be gauge-dependent, depending on New Physics scenario)

Modification of QCD- & EW-penguin

$$C_3^{\rm NP}(\mu_W) = -\frac{\alpha_e}{6\pi} Z_L$$

$$C_7^{\rm NP}(\mu_W) = -\frac{2\alpha_e}{3\pi} s_W^2 Z_L$$

$$C_9^{\rm NP}(\mu_W) = +\frac{2\alpha_e}{3\pi} (1 - s_W^2) Z_L$$

Modification of $b \to s \ell^+ \ell^-$ Op's

$$C_{9,\ell\bar{\ell}}^{\rm NP}(\mu_W) = -(1 - 4 s_W^2) Z_L$$

$$C_{10,\ell\bar{\ell}}^{\rm NP}(\mu_W) = +Z_L$$

Z-penguin scenario

Eff. Lagrangian @ high scale $\mu_W \sim M_W$

$$\mathcal{L}_{b\to sZ} = \mathcal{L}_{\rm SM} + \frac{G_F}{\sqrt{2}}\frac{e}{\pi^2} M_Z^2 c_W s_W V_{tb} V_{ts}^* \times \left[\bar{s}\,\gamma_\mu \left(Z_L P_L + Z_R P_R\right) b\right] Z^\mu \qquad \text{with} Z_L,\; Z_R \in \mathbb{C}$$

(in principle not 100% proper, might be gauge-dependent, depending on New Physics scenario)

Modification of QCD- & EW-penguin

$$C_3^{\rm NP}(\mu_W) = -\frac{\alpha_e}{6\pi} Z_L$$

$$C_7^{\rm NP}(\mu_W) = -\frac{2\alpha_e}{3\pi} s_W^2 Z_L$$

$$C_9^{\rm NP}(\mu_W) = +\frac{2\alpha_e}{3\pi}(1 - s_W^2) Z_L$$

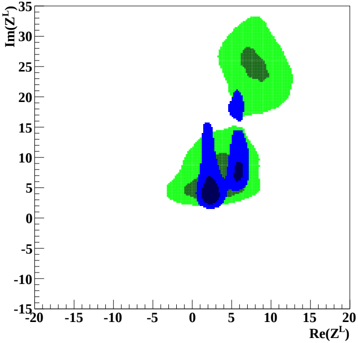
Modification of $b \to s\,\ell^+\ell^-$ Op's

$$C_{9,\ell\bar{\ell}}^{\rm NP}(\mu_W) = -(1 - 4s_W^2) Z_L$$

$$C_{10,\ell\bar{\ell}}^{\rm NP}(\mu_W) = +Z_L$$

Questions

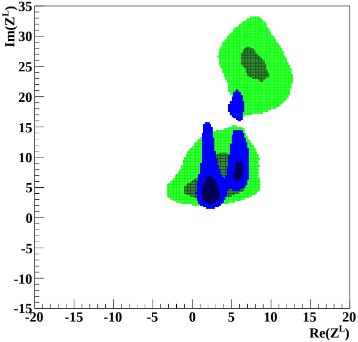
- fit for X_A still stable?
- can we fit for both: New Physics (Z_L) and QCD (ρ_A)?
- is there a strong correlation between Z_L and ρ_A?
- goodness-of-fit improved?
- what is the complementarity among $B \to M_1 M_2$ and $b \to s\,\ell^+\ell^-$?



$\Leftarrow$ $\boxed{\text{Re}(Z_L) \text{ vs } \text{Im}(Z_L)}$ @ 68, 95 % from

Set I (Br + C): $B \to K\pi$

Set II (Br, R + C, ΔA_{CP}): $B \to K\pi$



⇐ Re(Z_L) vs Im(Z_L) @ 68, 95 % from

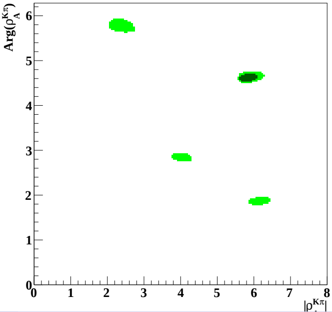
Set I (Br + C): $B \to K\pi$

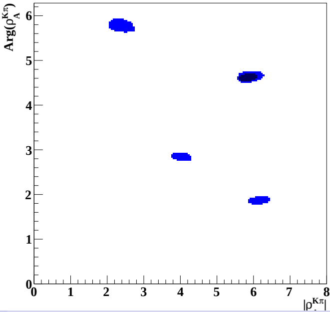
Set II (Br, R + C, $\Delta A_{\rm CP}$): $B \to K\pi$

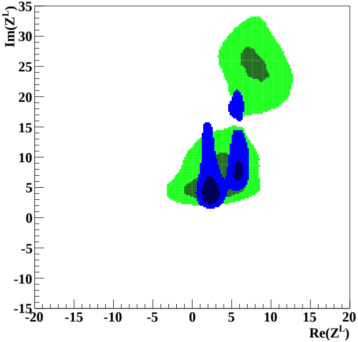
$|\rho_A^{K\pi}|$ vs $\arg(\rho_A^{K\pi})$ ⇒

@ 95, 99 %

Correlation between Z_L and $\rho_A^{K\pi}$ allows for additional solution compared







$\Leftarrow$ $\boxed{\mathrm{Re}(Z_L) \text{ vs } \mathrm{Im}(Z_L)}$ @ 68, 95 % from

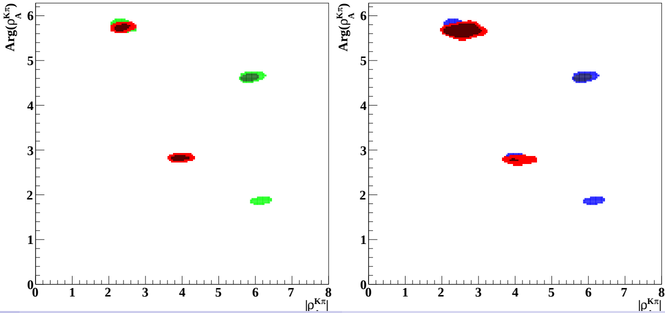
Set I (Br + C): $B \to K\pi$

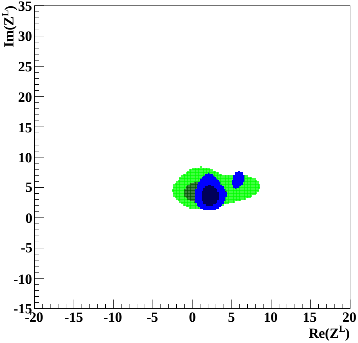
Set II (Br, R + C, ΔA_{CP}): $B \to K\pi$

$\boxed{|\rho_A^{K\pi}| \text{ vs } \arg(\rho_A^{K\pi})}$ $\Rightarrow$

@ 95, 99 %

Correlation between Z_L and $\rho_A^{K\pi}$ allows for additional solution compared to the SM





$\Leftarrow$ $\boxed{\mathrm{Re}(Z_L) \text{ vs } \mathrm{Im}(Z_L)}$ @ 68, 95 % from

Set I (Br + C): $B \to K\pi + K^*\pi + K\rho$

Set II (Br, R + C, $\Delta A_{\rm CP}$): $B \to K\pi + K^*\pi + K\rho$

Improved pull-values @ BF-point

Observable	Set I (SM)	Set II (SM)
R_n^B	–	0.5σ (2.3σ)
$C_{K^-\pi^0}/\Delta A_{\rm CP}^-$	0.3σ (2.3σ)	0.5σ (2.8σ)
$C_{K^0\pi^-}$	2.1σ (1.6σ)	0.0σ (1.4σ)

$\boxed{|\rho_A^{K\pi}| \text{ vs } \arg(\rho_A^{K\pi})}$ $\Rightarrow$

@ 95, 99 %

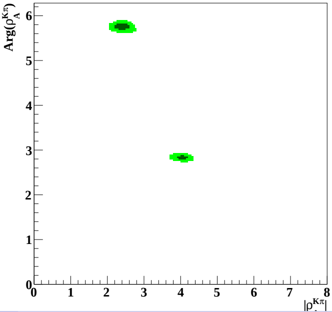
Adding more channels

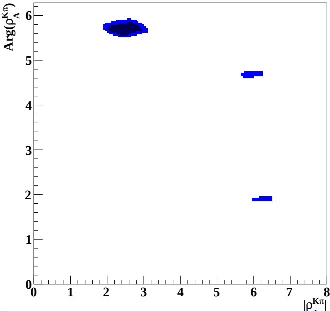
$\to$ high $|\rho_A^{K\pi}|$ unlikelier

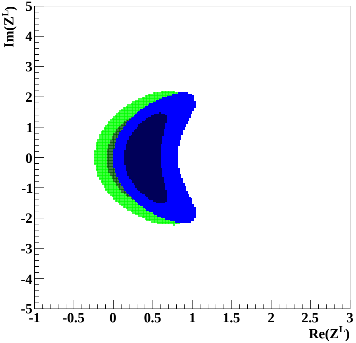
strong correlations

between $Z_L \leftrightarrow \rho_A^{M_1 M_2}$

get reduced







$\Leftarrow$ Re(Z_L) vs Im(Z_L) @ 68, 95 % from

$b \to s + (\gamma, \ell^+\ell^-)$

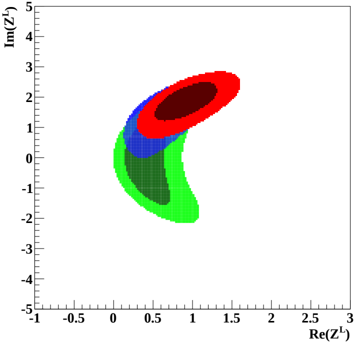
process	observable	experiment
$B \to K^*\gamma$	Br	Babar, Belle
$B \to K^*\ell^+\ell^-$	Br, $A_{\rm FB}$, F_L	Babar, Belle, CDF, LHCb
$B \to K\ell^+\ell^-$	Br	Babar, Belle, CDF (including LHCb$^{*)}$)

$^{*)}$ [LHCb Collaboration arXiv:1209.4284]

See talk A.Khodjamirian: discrepancy for $Br_{[1,6]\,\mathrm{GeV}^2} \cdot 10^7$:

LHCb: 1.21 ± 0.12 $\leftrightarrow$ SM: $1.76^{+0.60}_{-0.23}$

[Khodjamirian/Mannel/Wang arXiv:1211.0234]



$\Leftarrow$ Re(Z_L) vs Im(Z_L) @ 68, 95 % from

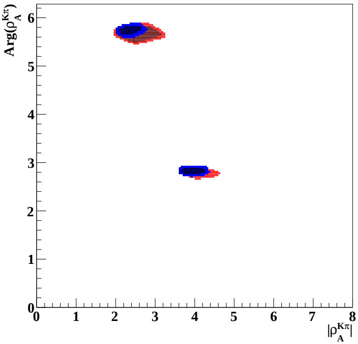
$b \to s + (\gamma, \ell^+\ell^-)$

$+B \to K\pi,\ K^*\pi,\ K\rho$

$\Rightarrow$ Set I (Br + C)

$\Rightarrow$ Set II (Br, R + C, ΔA_{CP})

$|\rho_A^{K\pi}|$ vs $\arg(\rho_A^{K\pi})$ @ 95, 99 % $\Rightarrow$



Observable	Set I (SM)	Set II (SM)
R_n^B	–	2.1σ (2.3σ)
$C_{K^-\pi^0}/\Delta A_{\text{CP}}^-$	1.7σ (2.3σ)	1.4σ (2.8σ)
$C_{K^0\pi^-}$	1.7σ (1.6σ)	1.8σ (1.4σ)

Summary

- pull-values in $B \to K\pi$ slightly better than in SM, even after including $b \to s + (\gamma,\, \ell^+\ell^-)$
- combination of several $B \to M_1 M_2$ give comparable Z_L, depending on Set of observables BR's vs. $R_{n,c}^{B,K,\pi}$
- correlation between Z_L and $\rho_A^{M_1 M_2}$ strongly reduced when combining several $B \to M_1 M_2$

More to do …

- implications of $\mathrm{Im}(Z_L) \neq 0$ on CP-asymmetries in $B \to K^* \ell^+\ell^-$
- repeat fit with hypothetical Belle II experimental uncertainties
- extend scenario $Z_L \to (Z_L,\, Z_R)$

$C_{7\gamma}$ & C_{8g} dipole operators

Eff. Lagrangian @ high scale $\mu_W \sim M_W$

$$\mathcal{L}_{b\to(s\gamma,\,sg)} = \mathcal{L}_{\rm SM} + \frac{4G_F}{\sqrt{2}}\frac{e}{16\pi^2} V_{tb}V_{ts}^* \times m_b\big[\,\bar{s}_\alpha\,\sigma^{\mu\nu}P_R b_\beta\,\big]\Big(C_{7\gamma}^{\rm NP}\delta_{\alpha\beta}F_{\mu\nu} + C_{8g}^{\rm NP}T^a_{\alpha\beta}G^a_{\mu\nu}\Big)$$

with $C_{7\gamma},\ C_{8g} \in \mathbb{C}$

$C_{7\gamma}$ & C_{8g} dipole operators

Eff. Lagrangian @ high scale $\mu_W \sim M_W$

$$\mathcal{L}_{b\to(s\gamma,\, sg)} = \mathcal{L}_{\text{SM}} + \frac{4G_F}{\sqrt{2}} \frac{e}{16\pi^2} V_{tb} V_{ts}^* \times m_b \left[\, \bar{s}_\alpha \, \sigma^{\mu\nu} P_R b_\beta \,\right] \left(C_{7\gamma}^{\text{NP}} \delta_{\alpha\beta} F_{\mu\nu} + C_{8g}^{\text{NP}} T^a_{\alpha\beta} G^a_{\mu\nu} \right)$$

with $C_{7\gamma},\ C_{8g} \in \mathbb{C}$

C_{8g} mixes into $C_{7\gamma}$

$$C_{7\gamma}^{\text{NP}}(\mu_b) = \eta^{\frac{16}{23}} C_{7\gamma}^{\text{NP}}(\mu_W) + \frac{4}{3}\left(\eta^{\frac{14}{23}} - \eta^{\frac{16}{23}}\right) C_{8g}^{\text{NP}}(\mu_W)$$

with $\eta = \alpha_s(\mu_W)/\alpha_s(\mu_b) \approx 0.5$

$\Rightarrow$ $C_{7\gamma}(\mu_b)$ strongly bound by $b \to s\gamma$

$\Rightarrow$ implies correlation between $C_{7\gamma}^{\text{NP}}(\mu_W)$ and $C_{8g}^{\text{NP}}(\mu_W)$

$\Rightarrow$ $C_{8g}^{\text{NP}}(\mu_W)$ is bound from $B \to M_1 M_2$ ($C_{7\gamma}^{\text{NP}}(\mu_W)$ only marginally)

$C_{7\gamma}$ & C_{8g} dipole operators

Eff. Lagrangian @ high scale $\mu_W \sim M_W$

$$\mathcal{L}_{b\to(s\gamma,\, sg)} = \mathcal{L}_{\rm SM} + \frac{4G_F}{\sqrt{2}}\,\frac{e}{16\pi^2} V_{tb} V_{ts}^* \times m_b \big[\, \bar{s}_\alpha\, \sigma^{\mu\nu} P_R b_\beta \,\big] \Big(C_{7\gamma}^{\rm NP} \delta_{\alpha\beta} F_{\mu\nu} + C_{8g}^{\rm NP} T^a_{\alpha\beta} G^a_{\mu\nu} \Big)$$

with $C_{7\gamma},\ C_{8g} \in \mathbb{C}$

C_{8g} mixes into $C_{7\gamma}$

$$C_{7\gamma}^{\rm NP}(\mu_b) = \eta^{\frac{16}{23}}\, C_{7\gamma}^{\rm NP}(\mu_W) + \frac{4}{3}\left(\eta^{\frac{14}{23}} - \eta^{\frac{16}{23}}\right) C_{8g}^{\rm NP}(\mu_W)$$

with $\eta = \alpha_s(\mu_W)/\alpha_s(\mu_b) \approx 0.5$

$\Rightarrow$ $C_{7\gamma}(\mu_b)$ strongly bound by $b \to s\gamma$

$\Rightarrow$ implies correlation between $C_{7\gamma}^{\rm NP}(\mu_W)$ and $C_{8g}^{\rm NP}(\mu_W)$

$\Rightarrow$ $C_{8g}^{\rm NP}(\mu_W)$ is bound from $B \to M_1 M_2$ ($C_{7\gamma}^{\rm NP}(\mu_W)$ only marginally)

Further constraint on $C_{8g}^{\rm NP}(\mu_W)$ from inclusive charmless

$$Br(B \to X_{\not c}) = Br(B \to X_s g) + \sum_{q=d,s;\,q'=u,d,s} Br(B \to q'\bar{q}' q)$$

$C_{7\gamma}$ & C_{8g} dipole operators

Individual modes $B \to K\pi,\ K\eta',\ K\phi,\ K^*\pi,\ KK$ and $B_s \to KK$ yield

$$\mathrm{Re}(C_{8g}) \in [-15, 15], \qquad\qquad \mathrm{Im}(C_{8g}) \in [-6, 6]$$

however, usually strong correlations with $\rho_A^{M_1 M_2}$ towards large values

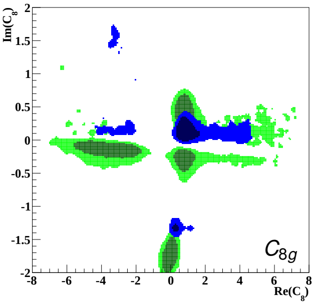
$C_{7\gamma}$ & C_{8g} dipole operators

Individual modes $B \to K\pi,\ K\eta',\ K\phi,\ K^*\pi,\ KK$ and $B_s \to KK$ yield

$$\mathrm{Re}(C_{8g}) \in [-15, 15], \qquad \mathrm{Im}(C_{8g}) \in [-6, 6]$$

however, usually strong correlations with $\rho_A^{M_1 M_2}$ towards large values

Combining $B \to (K\pi,\ K\eta',\ K\phi,\ K^*\pi)$ @ 95, 99 % CL



$C_{7\gamma}$ & C_{8g} dipole operators

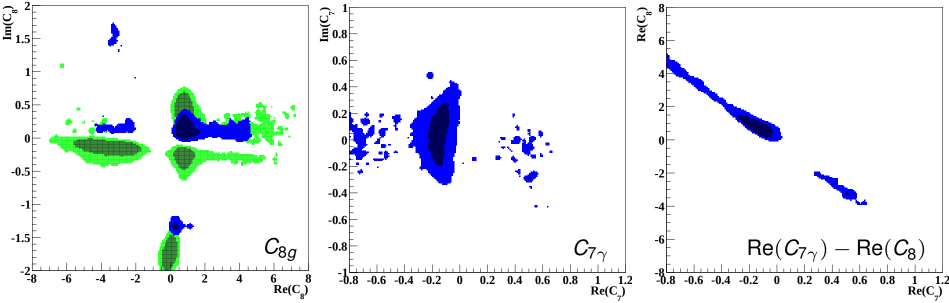
Individual modes $B \to K\pi,\ K\eta',\ K\phi,\ K^*\pi,\ KK$ and $B_s \to KK$ yield

$$\mathrm{Re}(C_{8g}) \in [-15, 15], \qquad \mathrm{Im}(C_{8g}) \in [-6, 6]$$

however, usually strong correlations with $\rho_A^{M_1 M_2}$ towards large values

Combining $B \to (K\pi,\ K\eta',\ K\phi,\ K^*\pi)$
and $b \to s\,(\gamma,\ \ell^+\ell^-) + B \to (K\pi,\ K\eta',\ K\phi,\ K^*\pi)$

@ 95, 99 % CL



$C_{7\gamma}$ & C_{8g} dipole operators

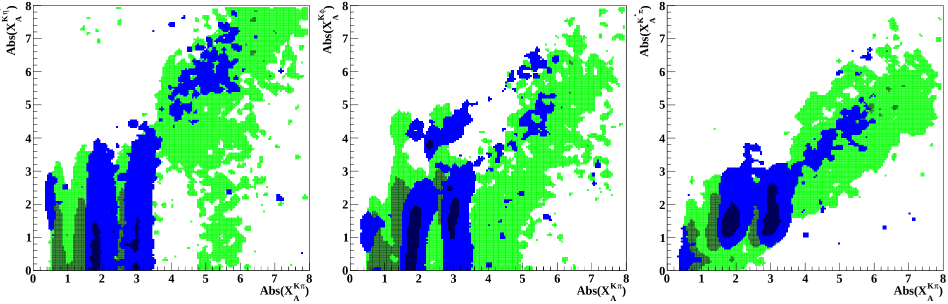
Individual modes $B \to K\pi,\ K\eta',\ K\phi,\ K^*\pi,\ KK$ and $B_s \to KK$ yield

$$\mathrm{Re}(C_{8g}) \in [-15, 15], \qquad \mathrm{Im}(C_{8g}) \in [-6, 6]$$

however, usually strong correlations with $\rho_A^{M_1 M_2}$ towards large values

Combining $B \to (K\pi,\ K\eta',\ K\phi,\ K^*\pi)$ @ 95, 99 % CL

and $b \to s\,(\gamma,\ \ell^+\ell^-) + B \to (K\pi,\ K\eta',\ K\phi,\ K^*\pi)$



$|\rho_A^{K\pi}| - |\rho_A^{K\eta'}|$ $\qquad$ $|\rho_A^{K\pi}| - |\rho_A^{K\phi}|$ $\qquad$ $|\rho_A^{K\pi}| - |\rho_A^{K^*\pi}|$

Summary

$B \to M_1 M_2$ interesting probes of New Physics

QCDF ideal tool, BUT endpoint divergences not understood yet

$\Rightarrow$ phenomenological pmr's $\rho_{A,H}$ @ sub-leading order in $m_b/\Lambda_{\rm QCD}$

Here: Infer ρ_A from data in SM

- $B \to K\pi$ data difficult to describe in SM (not only with QCDF)
- BR's yield usually $|\rho_A| \leqslant 8$ (in literature $|\rho_A| \sim 1 \ldots 2$)
- $\arg(\rho_A) \sim \pi$ or $\sim 2\pi$ suggests no large strong phases

and beyond

- combination of several $B \to M_1 M_2$ modes allow reduce correlation of NP-parameters and $\rho_A^{M_1 M_2}$
- present bounds from single $B \to M_1 M_2$ modes very weak $\to$ need their combination + complementary constraints

Reduced experimental uncertainties would be helpful &
On theory side: resolution to endpoint-divergences +
inclusion of NNLO α_s corrections at LO in $1/m_b$ in the future

Backup Slides

Fit method and treatment of theory uncertainties

Parameters of interest

$$\vec{\theta} = (C_i, \rho_{A,H}, \lambda_B)$$

Fit method and treatment of theory uncertainties

Parameters of interest

$$\vec{\theta} = (C_i, \rho_{A,H}, \lambda_B)$$

Nuisance parameters

$\vec{\nu}$

1) process-specific

   FF's, decay const's,
   LCDA pmr's,
   renorm. scales: $\mu_{b,0}$

2) general

   quark masses, CKM, . . .

Fit method and treatment of theory uncertainties

Parameters of interest

$$\vec{\theta} = (C_i, \rho_{A,H}, \lambda_B)$$

Nuisance parameters

$\vec{\nu}$

1) process-specific

FF's, decay const's,
LCDA pmr's,
renorm. scales: $\mu_{b,0}$

2) general

quark masses, CKM, ...

Observables

1) observables

$$O_i(\vec{\theta}, \vec{\nu})$$

depend usually on sub-set of $\vec{\theta}$ and $\vec{\nu}$

2) experimental data for each observable

$$\text{pdf}(O_i = o)$$

$\Rightarrow$ probability distribution of values o

Fit method and treatment of theory uncertainties

Parameters of interest

$$\vec{\theta} = (C_i, \rho_{A,H}, \lambda_B)$$

Nuisance parameters

$\vec{\nu}$

1) process-specific
   - FF's, decay const's,
   - LCDA pmr's,
   - renorm. scales: $\mu_{b,0}$
2) general
   - quark masses, CKM, ...

Observables

1) observables

$$O_i(\vec{\theta}, \vec{\nu})$$

depend usually on sub-set of $\vec{\theta}$ and $\vec{\nu}$

2) experimental data for each observable

$$\text{pdf}(O_i = o)$$

$\Rightarrow$ probability distribution of values o

Fit strategy: Put theory uncertainties in likelihood using RFit-scheme and ...

- sample $\vec{\theta}$-space (Markov Chains: BAT = Bayesian Analysis Tool)
- theory uncertainties of O_i due to $\vec{\nu}$ at each $(\vec{\theta})_a$:
  vary $\vec{\nu}$ in some ranges and combine uncertainties in quadrature $\Rightarrow \Delta_{i,\text{th}}[(\vec{\theta})_a]$
- use Bayesian method $\Rightarrow$ 68 & 95 % (CL or probability) regions of $\vec{\theta}$ with flat priors

Likelihood in Rfit scheme

Likelihood = product of pdf's of measurements O_i
$p[O_i = o_i]$ = probability of O_i having value o_i

$$\mathcal{L}(\vec{\theta}) = \prod_{i \in \text{data}} p\left[O_i = o_i(\vec{\theta})\right]$$

$$\to \exp\left[-\frac{1}{2} \sum_{i \in \text{data}} \left(\chi_i(\vec{\theta})\right)^2\right]$$

most O_i gaussian distributed

Likelihood in Rfit scheme

Likelihood = product of pdf's of measurements O_i
$p[O_i = o_i]$ = probability of O_i having value o_i

$$\mathcal{L}(\vec{\theta}) = \prod_{i \in \text{data}} p\left[O_i = o_i(\vec{\theta})\right]$$

$$\to \exp\left[-\frac{1}{2} \sum_{i \in \text{data}} \left(\chi_i(\vec{\theta})\right)^2\right]$$

most O_i gaussian distributed

$$\chi_i(\vec{\theta}) = \begin{cases} \frac{|O_{i,\mathrm{th}} - O_{i,\mathrm{exp}}| - \Delta^+_{i,\mathrm{th}}}{\sigma^-_{i,\mathrm{exp}}} & \text{if} \quad O_{i,\mathrm{exp}} \geqslant O_{i,\mathrm{th}} + \Delta^+_{i,\mathrm{th}} \\ \frac{|O_{i,\mathrm{th}} - O_{i,\mathrm{exp}}| - \Delta^+_{i,\mathrm{th}}}{\sigma^+_{i,\mathrm{exp}}} & \text{if} \quad O_{i,\mathrm{exp}} \leqslant O_{i,\mathrm{th}} - \Delta^-_{i,\mathrm{th}} \\ 0 & \text{else} \end{cases}$$

experimental measurement: $\left(O_{i,\mathrm{exp}}\right)^{+\sigma^+_{i,\mathrm{exp}}}_{-\sigma^-_{i,\mathrm{exp}}}$ theory prediction: $\left(O_{i,\mathrm{th}}\right)^{+\Delta^+_{i,\mathrm{th}}}_{-\Delta^-_{i,\mathrm{th}}}$

Likelihood in Rfit scheme

Likelihood = product of pdf's of measurements O_i

$p[O_i = o_i]$ = probability of O_i having value o_i

$$\mathcal{L}(\vec{\theta}) = \prod_{i \in \text{data}} p\left[O_i = o_i(\vec{\theta})\right]$$

most O_i gaussian distributed

$$\to \exp\left[-\frac{1}{2} \sum_{i \in \text{data}} \left(\chi_i(\vec{\theta})\right)^2\right]$$

$$\chi_i(\vec{\theta}) = \begin{cases} \dfrac{|O_{i,\text{th}} - O_{i,\text{exp}}| - \Delta^+_{i,\text{th}}}{\sigma^-_{i,\text{exp}}} & \text{if} \quad O_{i,\text{exp}} \geqslant O_{i,\text{th}} + \Delta^+_{i,\text{th}} \\ \dfrac{|O_{i,\text{th}} - O_{i,\text{exp}}| - \Delta^+_{i,\text{th}}}{\sigma^+_{i,\text{exp}}} & \text{if} \quad O_{i,\text{exp}} \leqslant O_{i,\text{th}} - \Delta^-_{i,\text{th}} \\ 0 & \text{else} \end{cases}$$

experimental measurement: $(O_{i,\text{exp}})^{+\sigma^+_{i,\text{exp}}}_{-\sigma^-_{i,\text{exp}}}$ theory prediction: $(O_{i,\text{th}})^{+\Delta^+_{i,\text{th}}}_{-\Delta^-_{i,\text{th}}}$

Theory uncertainties for O_i:

$$\Delta^\pm_{i,\text{th}} = \sqrt{\sum_a \left(\Delta^\pm_{i,a,\text{th}}\right)^2}$$

$\Rightarrow$ each $\nu_a \in (\nu_{a,\text{min}}, \nu_{a,\text{cen}}, \nu_{a,\text{max}})$:

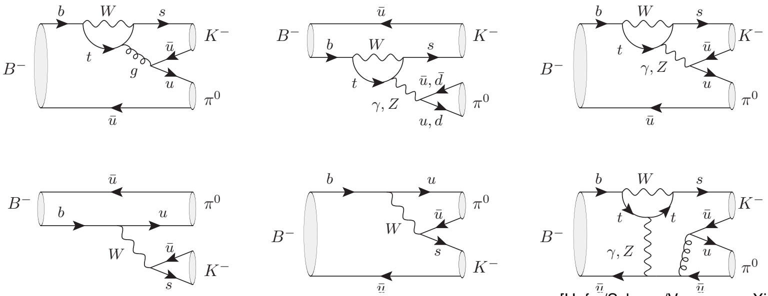
$$\Delta^+_{i,a,\text{th}} = o_i(\nu_{a,\text{max}}) - o_i(\nu_{a,\text{cen}}), \qquad \Delta^-_{i,a,\text{th}} = o_i(\nu_{a,\text{cen}}) - o_i(\nu_{a,\text{min}})$$

if $o_i(\nu_{a,\text{min}}) \leqslant o_i(\nu_{a,\text{cen}}) \leqslant o_i(\nu_{a,\text{max}})$, else ...

Topological amplitudes for example $B \to K\pi$

$B \to K\pi$ dominated by $P_{\rm QCD}$ penguins and polluted by ...

topologies	$\to$ suppression factor	
T = tree	CKM $\times 1/\alpha_s$	$r_{\rm T}$ =
C = col-sup tree	CKM $\times 1/N_c \times 1/\alpha_s$	$r_{\rm C}$ =
$P_{\rm EW}$ = EW peng	α_e/α_s	$r_{\rm EW}$ =
$P_{\rm EW}^C$ = col-sup EW peng	$\alpha_e/\alpha_s \times 1/N_c$	$r_{\rm EW}^C$ =
$PA_{\rm EW}$ = EW annihilation	$\alpha_e/\alpha_s \times \Lambda_{\rm QCD}/m_b$	$r_{\rm EW}^A$ =



[Hofer/Scherer/Vernazza arXiv:1011.6319]

Topological amplitudes for example $B \to K\pi$

$B \to K\pi$ dominated by $P_{\rm QCD}$ penguins and polluted by ...

topologies	$\to$ suppression factor	
$T =$ tree	CKM $\times 1/\alpha_s$	$r_{\rm T} \; =$
$C =$ col-sup tree	CKM $\times 1/N_c \times 1/\alpha_s$	$r_{\rm C} \; =$
$P_{\rm EW} =$ EW peng	α_e/α_s	$r_{\rm EW} =$
$P_{\rm EW}^C =$ col-sup EW peng	$\alpha_e/\alpha_s \times 1/N_c$	$r_{\rm EW}^C =$
$PA_{\rm EW} =$ EW annihilation	$\alpha_e/\alpha_s \times \Lambda_{\rm QCD}/m_b$	$r_{\rm EW}^A =$

In SM: using unitarity of CKM & factored out $\Rightarrow$ contains the weak phase

$$r_X = V_{CKM,X} \frac{\left\langle M_1 M_2 \middle| \sum_{a\in X} C_a \mathcal{O}_a \middle| B \right\rangle}{P_{\rm QCD}}, \qquad P_{\rm QCD} \sim V_{tb} V_{ts}^* \left\langle M_1 M_2 \middle| \sum_{a \in {\rm QCDpeng}} C_a \mathcal{O}_a \middle| B \right\rangle$$

with

$$V_{CKM,{\rm T}} = V_{CKM,{\rm C}} = V_{ub} V_{us}^*, \qquad V_{CKM,{\rm EW}} = V_{CKM,EWC} = V_{CKM,EWA} = V_{tb} V_{ts}^*$$

Topological amplitudes for example $B \to K\pi$

$B \to K\pi$ dominated by $P_{\rm QCD}$ penguins and polluted by ...

topologies	$\to$ suppression factor	
T = tree	CKM $\times 1/\alpha_s$	$r_{\rm T}$ =
C = col-sup tree	CKM $\times 1/N_c \times 1/\alpha_s$	$r_{\rm C}$ =
$P_{\rm EW}$ = EW peng	α_e/α_s	$r_{\rm EW}$ =
$P_{\rm EW}^C$ = col-sup EW peng	$\alpha_e/\alpha_s \times 1/N_c$	$r_{\rm EW}^C$ =
$PA_{\rm EW}$ = EW annihilation	$\alpha_e/\alpha_s \times \Lambda_{\rm QCD}/m_b$	$r_{\rm EW}^A$ =

Expanding the amplitude ...

$$A(B^- \to \bar{K}^0\pi^-) \sim P_{\rm QCD}\left(1 - \frac{1}{3}r_{\rm EW}^C + \frac{2}{3}r_{\rm EW}^A\right)$$

$$\sqrt{2}A(B^- \to K^-\pi^0) \sim P_{\rm QCD}\left(1 + r_{\rm EW} + \frac{2}{3}r_{\rm EW}^C + \frac{2}{3}r_{\rm EW}^A - (r_{\rm T} + r_{\rm C})e^{-i\gamma}\right)$$

$$A(\bar{B}^0 \to K^-\pi^+) \sim P_{\rm QCD}\left(1 + \frac{2}{3}r_{\rm EW}^C - \frac{1}{3}r_{\rm EW}^A - r_{\rm T}e^{-i\gamma}\right)$$

$$\sqrt{2}A(\bar{B}^0 \to \bar{K}^0\pi^0) \sim P_{\rm QCD}\left(1 - r_{\rm EW} - \frac{1}{3}r_{\rm EW}^C - \frac{1}{3}r_{\rm EW}^A + r_{\rm C}e^{-i\gamma}\right)$$

Topological amplitudes for example $B \to K\pi$

$B \to K\pi$ dominated by $P_{\rm QCD}$ penguins and polluted by . . .

topologies	$\to$ suppression factor	
$T =$ tree	CKM $\times 1/\alpha_s$	$r_{\rm T} \;=$
$C =$ col-sup tree	CKM $\times 1/N_c \times 1/\alpha_s$	$r_{\rm C} \;=$
$P_{\rm EW} =$ EW peng	α_e/α_s	$r_{\rm EW} =$
$P_{\rm EW}^C =$ col-sup EW peng	$\alpha_e/\alpha_s \times 1/N_c$	$r_{\rm EW}^C =$
$PA_{\rm EW} =$ EW annihilation	$\alpha_e/\alpha_s \times \Lambda_{\rm QCD}/m_b$	$r_{\rm EW}^A =$

Very popular: each topological amplitude parametrised

$$r_a = |r_a| e^{i\phi_a}$$

and fitted from experiment (with additional assumptions to reduce number of parameters)

However, in QCDF they can be calculated...

Topological amplitudes for example $B \to K\pi$ [Hofer/Scherer/Vernazza arXiv:1011.6319]

$B \to K\pi$ dominated by $P_{\rm QCD}$ penguins and polluted by ...

topologies	→	suppression factor	→	QCDF
T = tree		CKM $\times 1/\alpha_s$		$r_{\rm T} = 0.17^{+0.07}_{-0.06} + i\,0.03^{+0.03}_{-0.10}$
C = col-sup tree		CKM $\times 1/N_c \times 1/\alpha_s$		$r_{\rm C} = 0.07^{+0.04}_{-0.06} - i\,0.01^{+0.03}_{-0.05}$
$P_{\rm EW}$ = EW peng		α_e/α_s		$r_{\rm EW} = 0.13^{+0.05}_{-0.05} + i\,0.02^{+0.02}_{-0.07}$
$P^C_{\rm EW}$ = col-sup EW peng		$\alpha_e/\alpha_s \times 1/N_c$		$r^C_{\rm EW} = 0.04^{+0.02}_{-0.03} - i\,0.01^{+0.02}_{-0.03}$
$PA_{\rm EW}$ = EW annihilation		$\alpha_e/\alpha_s \times \Lambda_{\rm QCD}/m_b$		$r^A_{\rm EW} = 0.007^{+0.002}_{-0.010} - i\,0.004^{+0.011}_{-0.003}$

Very popular: each topological amplitude parametrised

$$r_a = |r_a| e^{i\phi_a}$$

and fitted from experiment (with additional assumptions to reduce number of parameters)

However, in QCDF they can be calculated...

Observables and topological amplitudes

[Hofer/Scherer/Vernazza arXiv:1011.6319]

$B \to K\pi$ dominated by $P_{\rm QCD}$ penguins and polluted by $r_i \equiv P_i/P_{\rm QCD}$ ...

i =topologies	→ suppression factor	→ expansion parameter
$T =$ tree	CKM $\times 1/\alpha_s$	$r_{\rm T} = 0.17^{+0.07}_{-0.06} + i\,0.03^{+0.03}_{-0.10}$
$C =$ col-sup tree	CKM $\times 1/N_c \times 1/\alpha_s$	$r_{\rm C} = 0.07^{+0.04}_{-0.06} - i\,0.01^{+0.03}_{-0.05}$
$P_{\rm EW} =$ EW peng	α_e/α_s	$r_{\rm EW} = 0.13^{+0.05}_{-0.05} + i\,0.02^{+0.02}_{-0.07}$
$P^C_{\rm EW} =$ col-sup EW peng	$\alpha_e/\alpha_s \times 1/N_c$	$r^C_{\rm EW} = 0.04^{+0.02}_{-0.03} - i\,0.01^{+0.02}_{-0.03}$
$PA_{\rm EW} =$ EW annihilation	$\alpha_e/\alpha_s \times \Lambda_{\rm QCD}/m_b$	$r^A_{\rm EW} = 0.007^{+0.002}_{-0.010} - i\,0.004^{+0.011}_{-0.003}$

Observables and topological amplitudes

[Hofer/Scherer/Vernazza arXiv:1011.6319]

$B \to K\pi$ dominated by $P_{\rm QCD}$ penguins and polluted by $r_i \equiv P_i/P_{\rm QCD}$ ...

i =topologies	→ suppression factor	→ expansion parameter
$T =$ tree	CKM $\times 1/\alpha_s$	$r_{\rm T} = 0.17^{+0.07}_{-0.06} + i\,0.03^{+0.03}_{-0.10}$
$C =$ col-sup tree	CKM $\times 1/N_c \times 1/\alpha_s$	$r_{\rm C} = 0.07^{+0.04}_{-0.06} - i\,0.01^{+0.03}_{-0.05}$
$P_{\rm EW} =$ EW peng	α_e/α_s	$r_{\rm EW} = 0.13^{+0.05}_{-0.05} + i\,0.02^{+0.02}_{-0.07}$
$P^C_{\rm EW} =$ col-sup EW peng	$\alpha_e/\alpha_s \times 1/N_c$	$r^C_{\rm EW} = 0.04^{+0.02}_{-0.03} - i\,0.01^{+0.02}_{-0.03}$
$PA_{\rm EW} =$ EW annihilation	$\alpha_e/\alpha_s \times \Lambda_{\rm QCD}/m_b$	$r^A_{\rm EW} = 0.007^{+0.002}_{-0.010} - i\,0.004^{+0.011}_{-0.003}$

CP-asymmetries ...

$$A_{\rm CP}(B^- \to K^-\pi^0) \sim -2\,{\rm Im}\,(r_{\rm T} + r_{\rm C})\sin\gamma$$

$$A_{\rm CP}(\bar{B}^0 \to K^-\pi^+) \sim -2\,{\rm Im}\,(r_{\rm T})\sin\gamma$$

$$\Delta A^-_{\rm CP} \sim -2\,{\rm Im}\,(r_{\rm C})\sin\gamma$$

QCDF predicts small $r_{\rm C}$

Observables and topological amplitudes

[Hofer/Scherer/Vernazza arXiv:1011.6319]

$B \to K\pi$ dominated by $P_{\rm QCD}$ penguins and polluted by $r_i \equiv P_i/P_{\rm QCD}$ ...

i =topologies	$\to$ suppression factor	$\to$ expansion parameter
T = tree	CKM $\times 1/\alpha_s$	$r_{\rm T} = 0.17^{+0.07}_{-0.06} + i\,0.03^{+0.03}_{-0.10}$
C = col-sup tree	CKM $\times 1/N_c \times 1/\alpha_s$	$r_{\rm C} = 0.07^{+0.04}_{-0.06} - i\,0.01^{+0.03}_{-0.05}$
$P_{\rm EW}$ = EW peng	α_e/α_s	$r_{\rm EW} = 0.13^{+0.05}_{-0.05} + i\,0.02^{+0.02}_{-0.07}$
$P^C_{\rm EW}$ = col-sup EW peng	$\alpha_e/\alpha_s \times 1/N_c$	$r^C_{\rm EW} = 0.04^{+0.02}_{-0.03} - i\,0.01^{+0.02}_{-0.03}$
$PA_{\rm EW}$ = EW annihilation	$\alpha_e/\alpha_s \times \Lambda_{\rm QCD}/m_b$	$r^A_{\rm EW} = 0.007^{+0.002}_{-0.010} - i\,0.004^{+0.011}_{-0.003}$

CP-asymmetries ...

$$A_{\rm CP}(B^- \to K^-\pi^0) \sim -2\,{\rm Im}\,(r_{\rm T} + r_{\rm C})\sin\gamma + 2\,{\rm Im}\left(\tilde r_{\rm EW} + \frac{2}{3}\tilde r^C_{\rm EW} + \frac{2}{3}\tilde r^A_{\rm EW}\right)\sin\delta$$

$$A_{\rm CP}(\bar B^0 \to K^-\pi^+) \sim -2\,{\rm Im}\,(r_{\rm T})\sin\gamma + 2\,{\rm Im}\left(\frac{2}{3}\tilde r^C_{\rm EW} - \frac{1}{3}\tilde r^A_{\rm EW}\right)\sin\delta$$

$$\Delta A^-_{\rm CP} \sim -2\,{\rm Im}\,(r_{\rm C})\sin\gamma + 2\,{\rm Im}\left(\tilde r_{\rm EW} + \tilde r^A_{\rm EW}\right)\sin\delta$$

QCDF predicts small $r_{\rm C}$, BUT in the presence of New physics $r^{(C,A)}_{\rm EW} \to r^{(C,A)}_{\rm EW} + \tilde r^{(C,A)}_{\rm EW}\, e^{-i\delta}$

Observables and topological amplitudes

[Hofer/Scherer/Vernazza arXiv:1011.6319]

$B \to K\pi$ dominated by $P_{\rm QCD}$ penguins and polluted by $r_i \equiv P_i/P_{\rm QCD}$ ...

i =topologies	$\to$ suppression factor	$\to$ expansion parameter
$T =$ tree	CKM $\times 1/\alpha_s$	$r_{\rm T} = 0.17^{+0.07}_{-0.06} + i\,0.03^{+0.03}_{-0.10}$
$C =$ col-sup tree	CKM $\times 1/N_c \times 1/\alpha_s$	$r_{\rm C} = 0.07^{+0.04}_{-0.06} - i\,0.01^{+0.03}_{-0.05}$
$P_{\rm EW} =$ EW peng	α_e/α_s	$r_{\rm EW} = 0.13^{+0.05}_{-0.05} + i\,0.02^{+0.02}_{-0.07}$
$P_{\rm EW}^C =$ col-sup EW peng	$\alpha_e/\alpha_s \times 1/N_c$	$r_{\rm EW}^C = 0.04^{+0.02}_{-0.03} - i\,0.01^{+0.02}_{-0.03}$
$PA_{\rm EW} =$ EW annihilation	$\alpha_e/\alpha_s \times \Lambda_{\rm QCD}/m_b$	$r_{\rm EW}^A = 0.007^{+0.002}_{-0.010} - i\,0.004^{+0.011}_{-0.003}$

Ratios ...

$$R_n^B \sim 1 + 2\,\mathrm{Re}\left(r_{\rm EW} + r_{\rm EW}^C\right) - 2\,\mathrm{Re}\,(r_{\rm T} + r_{\rm C})\cos\gamma$$

$$R_c^K \sim 1 + 2\,\mathrm{Re}\,(r_{\rm EW}) - 2\,\mathrm{Re}\,(r_{\rm C})\cos\gamma$$

$$R_c^\pi \sim 1 - 2\,\mathrm{Re}\left(r_{\rm EW}^C\right) + 2\,\mathrm{Re}\,(r_{\rm T})\cos\gamma$$

Observables and topological amplitudes

[Hofer/Scherer/Vernazza arXiv:1011.6319]

$B \to K\pi$ dominated by $P_{\rm QCD}$ penguins and polluted by $r_i \equiv P_i/P_{\rm QCD}$ ...

i =topologies	→ suppression factor	→ expansion parameter
T = tree	CKM $\times 1/\alpha_s$	$r_{\rm T} = 0.17^{+0.07}_{-0.06} + i\,0.03^{+0.03}_{-0.10}$
C = col-sup tree	CKM $\times 1/N_c \times 1/\alpha_s$	$r_{\rm C} = 0.07^{+0.04}_{-0.06} - i\,0.01^{+0.03}_{-0.05}$
$P_{\rm EW}$ = EW peng	α_e/α_s	$r_{\rm EW} = 0.13^{+0.05}_{-0.05} + i\,0.02^{+0.02}_{-0.07}$
$P^C_{\rm EW}$ = col-sup EW peng	$\alpha_e/\alpha_s \times 1/N_c$	$r^C_{\rm EW} = 0.04^{+0.02}_{-0.03} - i\,0.01^{+0.02}_{-0.03}$
$PA_{\rm EW}$ = EW annihilation	$\alpha_e/\alpha_s \times \Lambda_{\rm QCD}/m_b$	$r^A_{\rm EW} = 0.007^{+0.002}_{-0.010} - i\,0.004^{+0.011}_{-0.003}$

Ratios ...

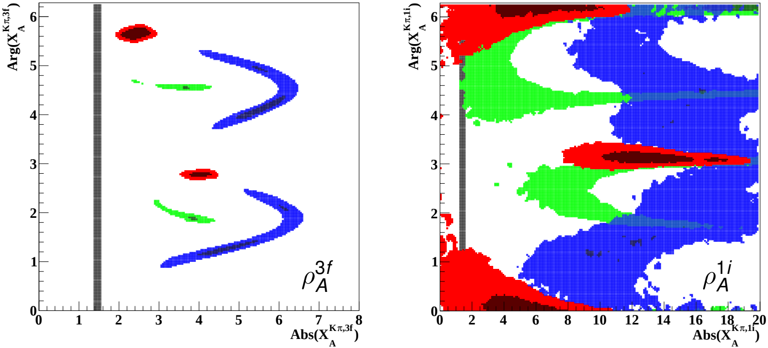
$$R^B_n \sim 1 + 2\,\mathrm{Re}\left(r_{\rm EW} + r^C_{\rm EW}\right) - 2\,\mathrm{Re}\,(r_{\rm T} + r_{\rm C})\cos\gamma$$

$$R^K_c \sim 1 + 2\,\mathrm{Re}\,(r_{\rm EW}) - 2\,\mathrm{Re}\,(r_{\rm C})\cos\gamma$$

$$R^\pi_c \sim 1 - 2\,\mathrm{Re}\left(r^C_{\rm EW}\right) + 2\,\mathrm{Re}\,(r_{\rm T})\cos\gamma$$

in the presence of New physics: $\mathrm{Re}\left(r^{(C)}_{\rm EW}\right) \to \mathrm{Re}\left(r^{(C,A)}_{\rm EW}\right) + \mathrm{Re}\left(\tilde{r}^{(C,A)}_{\rm EW}\right)\cos\delta$

Extending SM Fits for $B \to K\pi$: A) “several ρ_A”



⇒ Fit 2 annihilation contributions: ρ_A^{3f} and ρ_A^{1i}: using comb = BR-Set II + CP-Set II

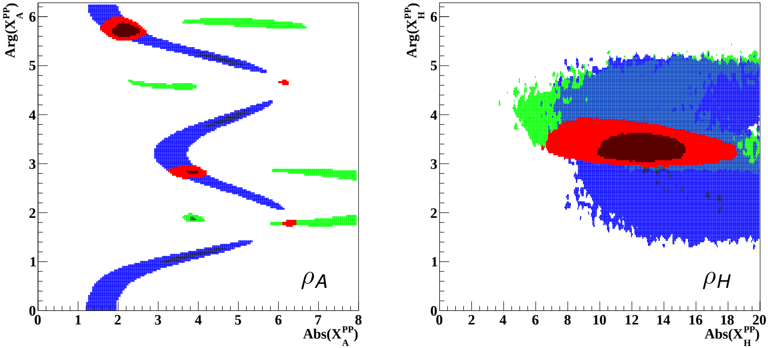
p-Value: 0.4 % (before 0.7 %)

Best-FP for $\rho_A^{1i} = (18.3, 3.1)$

⇒ ρ_A^{3f} takes role of ρ_A

⇒ ρ_A^{1i} weakly constrained: Br's prefer $8 \leqslant |\rho_A^{1i}| \leqslant 20$

Extending SM Fits for $B \to K\pi$: B) "ρ_A and ρ_H"



$\Rightarrow$ Fit both ρ_A and ρ_H: using comb = BR-Set II + CP-Set II @ 68, 95 % CL

with prior $|\rho_H| \leqslant 20$

p-Value: 81 % (before 0.7 %) $\Rightarrow$ good fit

Best-FP for $\rho_A = (2.6, 5.7)$ and $\rho_H = (12.1, 3.0)$

$\Rightarrow |\rho_A| \leqslant 4$

$\Rightarrow$ BUT large $8 \leqslant |\rho_H|$