Selected topics in B physics for Super-B

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To do list for Super-B

- B_d Physics:
  - $\sin 2\beta$ tensions†
  - radiative and semileptonic rare decays:
    - inclusive: $B \to X_s\gamma$ and $B \to X_s l^+ l^-$
    - exclusive: $B \to K^{(*)}\gamma$ and $B \to K^{(*)} l^+ l^-$
    - angular distributions in $B \to K^* l^+ l^-$ decays†
    - $b \to s$ penguin transitions: Large difference $A^{dir}(B^0 \to K^+\pi^-) - A^{dir}(B^+ \to K^+\pi^0)$
      - Exp: $(14.4 \pm 2.9)\%$
      - QCDF: $(2.2 \pm 2.4)\%$
- B_s Physics
  - $\sin\phi_s$ determinations †
  - $B_s \to \gamma\gamma$
  - $b \to s$ penguin transitions (non-leptonic †, ...)
- Wilson coefficient correlations, the new UT plane.†

I. B_d Physics: sin 2β

Three different ways of determining $S = \sin 2\beta$:

- S^{SM} predicted by SM from UT fit. How?

From time-dependent CP asymmetry:

- $S_{eff}^{c\bar{c}s}$ measured from golden mode $B \to J/\Psi K^0$ (tree level dominated $b \to c\bar{c}s$)
- S_{eff}^{s} penguin dominated decays governed by $b \to s$ transitions.

Expected sensitivites at Super-B

- Experimental inputs for the determination of SM sin 2β from UT fit (Soni/Lunghi):

$$\epsilon_K, \Delta M_s/\Delta M_d, \gamma \quad \text{and} \quad \mathrm{BR}(B \to \tau\nu)$$

- Lattice inputs: $\hat{B}_K$, $\xi = f_{B_s}\hat{B}_s^{1/2}/f_B\hat{B}_d^{1/2}$, $f_{B_s}\hat{B}_s^{1/2}$ and $\hat{B}_d$ (but not f_B)

$\lvert V_{cb}\rvert_{\rm excl} = (39.0 \pm 1.2)10^{-3}$	$\eta_1 = 1.51 \pm 0.24$
$\lvert V_{cb}\rvert_{\rm incl} = (41.31 \pm 0.76)10^{-3}$	$\eta_2 = 0.5765 \pm 0.0065$
$\lvert V_{cb}\rvert_{\rm tot} = (40.43 \pm 0.86)10^{-3}$	$\eta_3 = 0.494 \pm 0.046$
$\lvert V_{ub}\rvert_{\rm excl} = (29.7 \pm 3.1)10^{-4}$	$\eta_B = 0.551 \pm 0.007$
$\lvert V_{ub}\rvert_{\rm incl} = (40.1 \pm 2.7 \pm 4.0)10^{-4}$	$\xi = 1.23 \pm 0.04$
$\lvert V_{ub}\rvert_{\rm tot} = (32.7 \pm 4.7)10^{-4}$	$\lambda = 0.2255 \pm 0.0007$
$\Delta m_{B_d} = (0.507 \pm 0.005)\ \mathrm{ps}^{-1}$	$\alpha = (89.5 \pm 4.3)^{\rm o}$
$\Delta m_{B_s} = (17.77 \pm 0.12)\ \mathrm{ps}^{-1}$	$\kappa_\varepsilon = 0.94 \pm 0.02$
$S_{\psi K_S} = 0.668 \pm 0.023$	$\gamma = (74 \pm 11)^{\rm o}$
$m_c(m_c) = (1.268 \pm 0.009)\ \mathrm{GeV}$	$\hat{B}_K = 0.740 \pm 0.025$
$m_{t,pole} = (172.4 \pm 1.2)\ \mathrm{GeV}$	$f_K = (155.8 \pm 1.7)\ \mathrm{MeV}$
$f_{B_s}\sqrt{\hat{B}_s} = (276 \pm 19)\ \mathrm{MeV}$	$\varepsilon_K = (2.229 \pm 0.012)10^{-3}$
$f_B = (208 \pm 8)\ \mathrm{MeV}$	$\hat{B}_d = 1.26 \pm 0.10$
$\mathcal{B}_{B\to\tau\nu} = (1.68 \pm 0.31) \times 10^{-4}$	

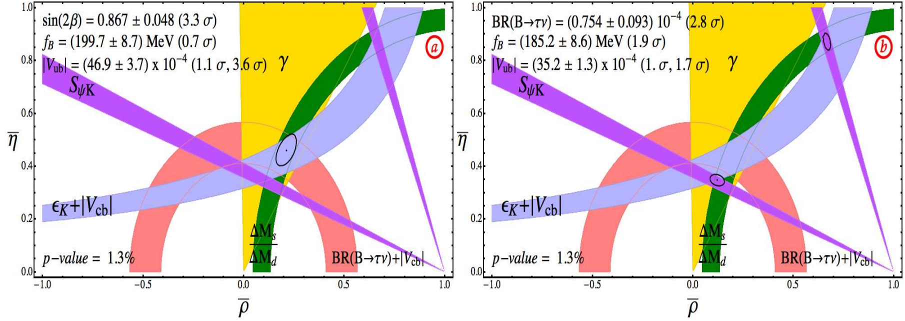
Experimental measurement $\sin 2\beta = 0.668 \pm 0.023$ ($S^{c\bar{c}s}_{eff}$)

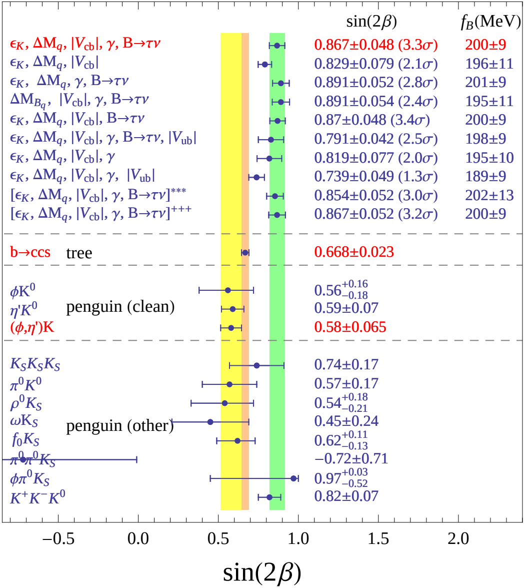
Result of the fit

a) $\sin 2\beta = 0.867 \pm 0.048$ (S^{SM}) deviates 3.3σ, f_B (good agreement) and $|V_{ub}|$ deviates (1.1σ incl. 3.6σ excl.) using as extra input $|V_{cb}|$. Conclusion: I. No large NP contributions to tree $B \to \tau\nu$ decay due to good f_B. II. Dominant effect of NP in $\sin 2\beta$

b) $BR(B \to \tau\nu)$ substituted by $\sin 2\beta$ measured ($S^{c\bar{c}s}_{eff}$). $BR(B \to \tau\nu)$ deviates ~ 3 sigmas and f_B by ~ 2 sigmas. Reinforces that $\sin 2\beta$ measured is inconsistent with SM.

c) Using only $\epsilon_K, \Delta M_s/\Delta M_d, |V_{cb}|$ and NOT $BR(B \to \tau\nu)$ the fit for $\sin 2\beta = 0.829 \pm 0.079$ deviates 2.1 sigmas. Thus NP in $BR(B \to \tau\nu)$ does not solve the tension.





- Different $\sin 2\beta$ determinations
- $|V_{ub}|$ inclusive and exclusive conflict limited use recommended
  - V_{ub} from exclusive (lattice determination of semileptonic form factor problematic).
  - exclusive modes are sensitive to NP that are blind to inclusive.
- S^s_{eff} (penguin dominated) central values are systematically lower (but less) than $S^{c\bar{c}s}_{eff}$: NP in the mixing and in penguin transition.
- This also possibly seen in CP asymmetry difference of $b \to s$ transition: $B^0 \to K^+\pi^-$ versus $B^+ \to K^+\pi^0$.

Current experimental precision of $S_{eff}^{c\bar{c}s}$ (first), S_{eff}^{s} (second block $b \to s$) and S_{eff}^{d} (third block $b \to d$) and **predicted** at Super-B (taken from Super-B report 2010)

Mode	Current Precision			Predicted Precision ($75\ ab^{-1}$)			Discovery Pot.	
	Stat.	Syst.	ΔS^f(Th.)	Stat.	Syst.	ΔS^f(Th.)	3σ	5σ
$J/\psi K_S^0$	0.022	0.010	0 ± 0.01	0.002	0.005	0 ± 0.001	0.02	0.03
$\eta' K_S^0$	0.08	0.02	0.015 ± 0.015	0.006	0.005	0.015 ± 0.015	0.05	0.08
$\phi K_S^0 \pi^0$	0.28	0.01	–	0.020	0.010	–	–	–
$f_0 K_S^0$	0.18	0.04	0 ± 0.02	0.012	0.003	0 ± 0.02	0.07	0.12
$K_S^0 K_S^0 K_S^0$	0.19	0.03	0.02 ± 0.01	0.015	0.020	0.02 ± 0.01	0.08	0.14
ϕK_S^0	0.26	0.03	0.03 ± 0.02	0.020	0.005	0.03 ± 0.02	0.09	0.14
$\pi^0 K_S^0$	0.20	0.03	0.09 ± 0.07	0.015	0.015	0.09 ± 0.07	0.21	0.34
ωK_S^0	0.28	0.02	0.1 ± 0.1	0.020	0.005	0.1 ± 0.1	0.31	0.51
$K^+ K^- K_S^0$	0.08	0.03	0.05 ± 0.05	0.006	0.005	0.05 ± 0.05	0.15	0.26
$\pi^0 \pi^0 K_S^0$	0.71	0.08	–	0.038	0.045	–	–	–
ρK_S^0	0.28	0.07	-0.13 ± 0.16	0.020	0.017	-0.13 ± 0.16	0.41	0.69
$J/\psi \pi^0$	0.21	0.04	–	0.016	0.005	–	–	–
$D^{*+} D^{*-}$	0.16	0.03	–	0.012	0.017	–	–	–
$D^+ D^-$	0.36	0.05	–	0.027	0.008	–	–	–

Few processes contain a richer phenomenology than the $b \to s$ semileptonic exclusive decay $B \to K^* l^+ l^-$. **Observables**:

- Forward-Backward asymmetry

$$A_{\rm FB} = \frac{1}{d\Gamma/dq^2}\left(\int_0^1 d(\cos\theta)\,\frac{d^2\Gamma[B \to K^*\ell^+\ell^-]}{dsd\cos\theta} - \int_{-1}^0 d(\cos\theta)\,\frac{d^2\Gamma[B \to K^*\ell^+\ell^-]}{dsd\cos\theta}\right)$$

  and its zero.

- Isospin asymmetry

$$A_I = \frac{d\Gamma[B^0 \to K^{*0}\ell^+\ell^-]/ds - d\Gamma[B^\pm \to K^{*\pm}\ell^+\ell^-]/ds}{d\Gamma[B^0 \to K^{*0}\ell^+\ell^-]/ds + d\Gamma[B^\pm \to K^{*\pm}\ell^+\ell^-]/ds}$$

- K^* spin/helicity amplitude observables of the 4-body decay used to construct **QCD-protected** $\mathbf{A_T^{(i)}}$

Main goal: Identify signals of specific NP models in the flavor sector to complement direct research.

Condition: Construct the best (less QCD uncertainties) observables. How?

The effective Hamiltonian describing the $b \to s l^+ l^-$ transition

$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_{i=1}^{10} [C_i(\mu)\mathcal{O}_i(\mu) + C_i'(\mu)\mathcal{O}_i'(\mu)],$$

where $C_i^{(\prime)}(\mu)$ and $\mathcal{O}_i^{(\prime)}(\mu)$ are the Wilson coefficients and local operators respectively.

In our subsequent analysis, we concentrate on

$$\mathcal{O}_7 = \frac{e}{16\pi^2} m_b (\bar{s}\sigma_{\mu\nu} P_R b) F^{\mu\nu}, \quad \mathcal{O}_9 = \frac{e^2}{16\pi^2} (\bar{s}\gamma_\mu P_L b)(\bar{l}\gamma^\mu l),$$
$$\mathcal{O}_{10} = \frac{e^2}{16\pi^2} (\bar{s}\gamma_\mu P_L b)(\bar{l}\gamma^\mu \gamma_5 l),$$

where $P_{L,R} = (1 \mp \gamma_5)/2$ and primed operators

$$\mathcal{O}_7' = \frac{e}{16\pi^2} m_b (\bar{s}\sigma_{\mu\nu} P_L b) F^{\mu\nu}, \quad \mathcal{O}_9' = \frac{e^2}{16\pi^2} (\bar{s}\gamma_\mu P_R b)(\bar{l}\gamma^\mu l),$$
$$\mathcal{O}_{10}' = \frac{e^2}{16\pi^2} (\bar{s}\gamma_\mu P_R b)(\bar{l}\gamma^\mu \gamma_5 l),$$

Description of the Method for $B \to K^*(\to K\pi)l^+l^-$

The steps of the present method are

- **Construction** of a quantity using spin or helicity amplitudes as the milestones.
  - **Maximize** sensitivity to certain type of New Physics
  - **Minimize** dependence on hadronic uncertainties (soft form factors).
- **Identification** of all **symmetries** of the distribution.
- Check that the quantity **fulfills** all the symmetries $\Rightarrow$ Observables.
- **Express** the observable in terms of the coefficients of the distribution using symmetries and explicit solution.
- **Find hidden correlations** (dependencies) between the coefficients of the distribution.
  - Stability of fit and extra experimental checks.

Differential decay distributions

The decay $\mathbf{\bar{B}_d} \to \mathbf{\bar{K}^{*0}}(\to \mathbf{K^-}\pi^+)\mathbf{l^+l^-}$ with the K^{*0} on the mass shell is described by s and three angles $\theta_{\mathbf{l}}$, $\theta_{\mathbf{K}}$ and ϕ

$$\frac{d^4\Gamma}{dq^2\, d\cos\theta_l\, d\cos\theta_K\, d\phi} = \frac{9}{32\pi} J(q^2, \theta_l, \theta_K, \phi)$$

- $q^2 = s$ square of the lepton-pair invariant mass.
- θ_l angle between $\vec{p_{l^+}}$ in l^+l^- rest frame and dilepton's direction in rest frame of $\bar{B}_d$
- θ_K angle between $\vec{p_{K^-}}$ in the $\bar{K}^{*0}$ rest frame and direction of the $\bar{K}^{*0}$ in rest frame of $\bar{B}_d$
- ϕ angle between the planes defined by the two leptons and the $K - \pi$ planes.

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$$J(q^2, \theta_l, \theta_K, \phi) =$$
$$J_{1s}\sin^2\theta_K + J_{1c}\cos^2\theta_K + (J_{2s}\sin^2\theta_K + J_{2c}\cos^2\theta_K)\cos 2\theta_l + J_3\sin^2\theta_K\sin^2\theta_l\cos 2\phi$$
$$+J_4\sin 2\theta_K\sin 2\theta_l\cos\phi + J_5\sin 2\theta_K\sin\theta_l\cos\phi + (J_{6s}\sin^2\theta_K + J_{6c}\cos^2\theta_K)\cos\theta_l$$
$$+J_7\sin 2\theta_K\sin\theta_l\sin\phi + J_8\sin 2\theta_K\sin 2\theta_l\sin\phi + J_9\sin^2\theta_K\sin^2\theta_l\sin 2\phi\,.$$

$$J_{1s} = \frac{(2+\beta_\ell^2)}{4}\left[|A_\perp^L|^2 + |A_\|^L|^2 + (L\to R)\right] + \frac{4m_\ell^2}{q^2}\mathrm{Re}\left(A_\perp^L A_\perp^{R\,*} + A_\|^L A_\|^{R*}\right),$$

$$J_{1c} = |A_0^L|^2 + |A_0^R|^2 + \frac{4m_\ell^2}{q^2}\left[|A_t|^2 + 2\mathrm{Re}(A_0^L A_0^{R*})\right] + \beta_\ell^2|A_S|^2,$$

$$J_{2s} = \frac{\beta_\ell^2}{4}\left[|A_\perp^L|^2 + |A_\|^L|^2 + (L\to R)\right], \quad J_{2c} = -\beta_\ell^2\left[|A_0^L|^2 + (L\to R)\right],$$

$$J_3 = \frac{1}{2}\beta_\ell^2\left[|A_\perp^L|^2 - |A_\|^L|^2 + (L\to R)\right], \quad J_4 = \frac{1}{\sqrt{2}}\beta_\ell^2\left[\mathrm{Re}(A_0^L A_\|^{L\,*}) + (L\to R)\right],$$

$$J_5 = \sqrt{2}\beta_\ell\left[\mathrm{Re}(A_0^L A_\perp^{L\,*}) - (L\to R) - \frac{m_\ell}{\sqrt{q^2}}\mathrm{Re}(A_\|^L A_S^* + A_\|^R A_S^*)\right],$$

$$J_{6s} = 2\beta_\ell\left[\mathrm{Re}(A_\|^L A_\perp^{L\,*}) - (L\to R)\right], \quad J_{6c} = 4\beta_\ell\frac{m_\ell}{\sqrt{q^2}}\mathrm{Re}\left[A_0^L A_S^* + (L\to R)\right],$$

$$J_7 = \sqrt{2}\beta_\ell\left[\mathrm{Im}(A_0^L A_\|^{L\,*}) - (L\to R) + \frac{m_\ell}{\sqrt{q^2}}\mathrm{Im}(A_\perp^L A_S^* + A_\perp^R A_S^*)\right],$$

$$J_8 = \frac{1}{\sqrt{2}}\beta_\ell^2\left[\mathrm{Im}(A_0^L A_\perp^{L\,*}) + (L\to R)\right], \quad J_9 = \beta_\ell^2\left[\mathrm{Im}(A_\|^{L\,*} A_\perp^L) + (L\to R)\right]$$

SCALARS: We have 8 complex amplitudes ($A_{\perp,||,0,(L,R)S,t}$) and 12 experimental inputs

NO SCALARS: We have 7 complex amplitudes ($A_{\perp,||,0,(L,R)}, t$) and 11 experimental inputs

Symmetries of the distribution

Experimental (J_i) $\leftrightarrow$ theoretical (A_i) degrees of freedom

$$\mathbf{n_C - n_d = 2n_A - n_s}$$

- $\mathbf{n_C}$: # coefficients of differential distribution: J_i
- $\mathbf{n_d}$: # relations between J_i
- $\mathbf{n_A}$: # spin amplitudes
- $\mathbf{n_s}$: # symmetries of the distribution

Case: **Massless leptons with no scalars: ML-NS**

$\mathbf{n_C = 11}$, $\mathbf{n_d = 3}$ ($J_{1s} = 3J_{2s}$, $J_{1c} = -J_{2c}$ and a **third relation**),

$$\Updownarrow$$

$\mathbf{n_A = 6}$ (spin amplitudes), $\mathbf{n_s = 4}$ **symmetries**.

What is this third relation and which are those symmetries?

Counting symmetries

Infinitesimal symmetry transformation of the distribution

$$\mathbf{A}' = \mathbf{A} + \delta\mathbf{S}\ .$$

$$\vec{A} \;=\; \Big(\mathrm{Re}(A_\perp^L), \mathrm{Im}(A_\perp^L), \mathrm{Re}(A_\|^L), \mathrm{Im}(A_\|^L), \mathrm{Re}(A_0^L), \mathrm{Im}(A_0^L),$$
$$\mathrm{Re}(A_\perp^R), \mathrm{Im}(A_\perp^R), \mathrm{Re}(A_\|^R), \mathrm{Im}(A_\|^R), \mathrm{Re}(A_0^R), \mathrm{Im}(A_0^R)\Big)$$

S represents a symmetry of the distribution if and only if

$$\forall i \in (J_{1s} ... J_9) : \vec{\nabla}(J_i) \perp \mathbf{S}\ .$$

n independent infinitesimal symmetries $\leftrightarrow$
n linearly independent vectors $\mathbf{S}_j$ with $j = 1, ..n$.

$\Rightarrow$ In the masless case $\mathbf{n} = \mathbf{4}$

From infinitesimal to continuous symmetry.

The differential distribution is invariant under $n = 4$ independent symmetry transformations of the amplitudes:

- 1. An independent phase transformation of L-amplitudes

$$A'_{\perp L} = e^{i\phi_L} A_{\perp L}, \qquad A'_{\| L} = e^{i\phi_L} A_{\| L}, \qquad A'_{0L} = e^{i\phi_L} A_{0L},$$

- 2. An independent phase transformation of the R-amplitudes,

$$A'_{\perp R} = e^{i\phi_R} A_{\perp R}, \qquad A'_{\| R} = e^{i\phi_R} A_{\| R}, \qquad A'_{0R} = e^{i\phi_R} A_{0R},$$

- 3. A first continuous $L \leftrightarrow R$ rotation (I)

$$\begin{aligned}
A'_{\perp L} &= +\cos\theta A_{\perp L} + \sin\theta A^*_{\perp R} \quad A'_{\perp R} = -\sin\theta A^*_{\perp L} + \cos\theta A_{\perp R} \\
A'_{\| L} &= +\cos\theta A_{\| L} - \sin\theta A^*_{\| R} \quad A'_{\| R} = +\sin\theta A^*_{\| L} + \cos\theta A_{\| R} \\
A'_{0L} &= +\cos\theta A_{0L} - \sin\theta A^*_{0R} \quad A'_{0R} = +\sin\theta A^*_{0L} + \cos\theta A_{0R}
\end{aligned}$$

- 4. A second continuous $L \leftrightarrow R$ transformation (II)

$$\begin{aligned} A'_{\perp L} &= +\cosh\bar\theta A_{\perp L} + \sinh\bar\theta A^*_{\perp R} \quad A'_{\perp R} = -\sinh\bar\theta A^*_{\perp L} + \cosh\bar\theta A_{\perp R} \\ A'_{\parallel L} &= +\cosh\bar\theta A_{\parallel L} - \sinh\bar\theta A^*_{\parallel R} \quad A'_{\parallel R} = +\sinh\bar\theta A^*_{\parallel L} + \cosh\bar\theta A_{\parallel R} \\ A'_{0L} &= +\cosh\bar\theta A_{0L} - \sinh\bar\theta A^*_{0R} \quad A'_{0R} = +\sinh\bar\theta A^*_{0L} + \cosh\bar\theta A_{0R} \end{aligned}$$

$$\bar\theta = \mathbf{i}\,\theta'$$

Any quantity constructed out of A has to fulfill all symmetries of the distribution

Consequence: The quantity $A_T^{(1)} = -2\frac{\mathrm{Re}(A_\parallel A_\perp^*)}{|A_\perp|^2+|A_\parallel|^2}$ is not invariant under 3 and 4 $\Rightarrow$ it cannot be extracted from angular distribution.

A bit more on symmetries

Define

$$n_1 = (A_\parallel^L, A_\parallel^{R^*}) \qquad m_1 = (H_{+1}^L, {H_{-1}^R}^*)$$
$$n_2 = (A_\perp^L, -A_\perp^{R^*}) \qquad \text{or} \qquad m_2 = (H_{-1}^L, {H_{+1}^R}^*)$$
$$n_3 = (A_0^L, A_0^{R^*}) \qquad m_3 = (H_0^L, H_0^{R^*})$$

Spin amplitudes — Helicity amplitudes

All physical information of the distribution encoded in 3 moduli + 3 relative angles (complex) - 1 constrain (**third relation)**.

$$|n_1|^2 = \frac{2}{3}J_{1s} - J_3\,, \qquad |n_2|^2 = \frac{2}{3}J_{1s} + J_3\,, \qquad |n_3|^2 = J_{1c}$$
$$n_1 \cdot n_2 = \frac{J_{6s}}{2} - iJ_9\,, \qquad n_1 \cdot n_3 = \sqrt{2}J_4 - i\frac{J_7}{\sqrt{2}}\,, \qquad n_2 \cdot n_3 = \frac{J_5}{\sqrt{2}} - i\sqrt{2}J_8$$

Interpretation of the symmetry: moduli and complex scalar products kept invariant.

What do we learn/gain out of those symmetries?

- **Identify** the conditions to construct observables out of spin amplitudes.
- **Solve** the system of A's in terms of J's.
- **Stability and convergence of the fit** by identifying all hidden correlations inside the distribution.
- Identify a **non-linear and non-trivial correlation** (third relation) between the coefficients of the angular distribution.
- Moreover, this is a more general view of angular distributions **reinterpreted** in terms of moduli and angle between certain complex vectors.

Explicit solution and New non-trivial relation

We can solve the system of A's in terms of J's:

- Global phase symmetry L (1) $\Rightarrow \phi_L$ such that $\mathrm{Im}A_\|^L = 0$
- Global phase symmetry R (2) $\Rightarrow \phi_R$ such that $\mathrm{Im}A_\|^R = 0$ (simplicity)
- Continuous $L \leftrightarrow R$ rotation (3) $\Rightarrow \theta$ such that $\mathrm{Re}A_\|^R = 0$

This implies $n_1 = \left(0, A_\|^R\right)$ with $\mathrm{Im}A_\|^R = 0$. The system is then easily solved

Amp.	LEFT	RIGHT
$A_\perp$	$\left[\|n_2\|^2 - \frac{\|(n_1.n_2)\|^2}{\|n_1\|^2}\right]^{\frac{1}{2}} e^{i\phi^L_\perp} = \left[\frac{\frac{4}{9}J_{1s}^2 - J_3^2 - \frac{1}{4}J_{6s}^2 - J_9^2}{\frac{2}{3}J_{1s} - J_3}\right]^{\frac{1}{2}} e^{i\phi^L_\perp}$	$-\frac{n_1.n_2}{\sqrt{\|n_1\|^2}} = -\frac{(J_{6s} - 2iJ_9)}{2\sqrt{\frac{2}{3}J_{1s} - J_3}}$,
$A_\|$	0	$\sqrt{\|n_1\|^2} = \sqrt{\frac{2}{3}J_{1s} - J_3}$
A_0	$\left[\|n_3\|^2 - \frac{\|(n_1.n_3)\|^2}{\|n_1\|^2}\right]^{\frac{1}{2}} e^{i\phi^L_0} = \left[\frac{J_{1c}\left(\frac{2}{3}J_{1s} - J_3\right) - 2J_4^2 - \frac{1}{2}J_7^2}{\frac{2}{3}J_{1s} - J_3}\right]^{\frac{1}{2}} e^{i\phi^L_0}$	$\frac{n_1.n_3}{\sqrt{\|n_1\|^2}} = \frac{2J_4 - iJ_7}{\sqrt{\frac{4}{3}J_{1s} - 2J_3}}$

BUT, there is a last equation

$$e^{i(\phi_\perp^{\mathbf{L}}-\phi_{\mathbf{0}}^{\mathbf{L}})} = \frac{(n_2\cdot n_3)|n_1|^2-(n_2\cdot n_1)(n_1\cdot n_3)}{\left([|n_1|^2|n_2|^2-|(n_2\cdot n_1)|^2)\left(|n_1|^2|n_3|^2-|(n_3\cdot n_1)|^2\right)\right]^{1/2}}$$
$$= \frac{J_5\left(\frac{2}{3}J_{1s}-J_3\right)-J_4J_{6s}-J_7J_9-i\left(\frac{4}{3}J_{1s}J_8-2J_3J_8+2J_4J_9-\frac{1}{2}J_{6s}J_7\right)}{\left[2\left(\frac{4}{9}J_{1s}^2-J_3^2-\frac{1}{4}J_{6s}^2-J_9^2\right)\left(J_{1c}\left(\frac{2}{3}J_{1s}-J_3\right)-2J_4^2-\frac{1}{2}J_7^2\right)\right]^{1/2}}.$$

Remarks:

a) Condition of the L.H.S. being a phase $\Rightarrow$ the non-trivial new relation:

$$-\mathbf{J_{2c}} = 6\,\frac{(2J_{1s}+3J_3)\left(4J_4^2+J_7^2\right)+(2J_{1s}-3J_3)\left(J_5^2+4J_8^2\right)}{16J_{1s}^2-9\left(4J_3^2+J_{6s}^2+4J_9^2\right)} - 36\,\frac{J_{6s}(J_4J_5+J_7J_8)+J_9(J_5J_7-4J_4J_8)}{16J_{1s}^2-9\left(4J_3^2+J_{6s}^2+4J_9^2\right)}$$

True in massless leptons case with and without scalars.
Not fulfilled for massive leptons with scalars.
Large deviations $\Rightarrow$ most probably experimental problem with data.

b) 4th symmetry manifest in the freedom to chose $\phi_\perp^{\mathbf{L}}$ or $\phi_{\mathbf{0}}^{\mathbf{L}}=0$

More general cases

The discussion of the differential symmetries can be generalised to:

a) **Massless leptons with scalars**: $\mathbf{n_C = 11, n_d = 2, n_A = 7, n_s = 5}$

- Amplitudes ML-NS + scalar amplitude A_S: Seven amplitudes.
- Four explicit symmetries and

$$A_S^{'} = e^{i\phi_S} A_S$$

The phase of A_S cannot be determined.

b) **Massive leptons without scalars**: $\mathbf{n_C = 11, n_d = 1, n_A = 7, n_s = 4}$

- Amplitudes ML-NS + A_t: Seven amplitudes
- Symmetries:
  - One global phase transformation $\phi_L = \phi_R$.
  - Two continuous LR symmetries are broken.
  - A new symmetry concerning the phase of A_t given as:

$$A_t^{'} = e^{i\phi_t} A_t$$

Four symmetries of differential distribution required.

c) **Massive leptons with scalars**: $\mathbf{n_C = 12, n_d = 0, n_A = 8, n_s = 4}$

- Amplitudes: ML-NS $+A_s+A_t$: Eight amplitudes.
- Coefficients of the distribution 12: ML-NS $+J_{6c}$.
- Symmetries:
  - The global phase transformation, $\phi_L = \phi_R$.
  - The phase transformation of A_t in b) is valid.

In this case, there is NO dependency between J's, and four symmetries of the differential form required.

Case	Coefficients	Dependencies	Amplitudes	Symmetries
$m_l = 0,\ A_S = 0$	11	3	6	4 (4)
$m_l = 0,\ A_S <> 0$	11	2	7	5 (5)
$m_l > 0,\ A_S = 0$	11	1	7	4 (2)
$m_l > 0,\ A_S <> 0$	12	0	8	4 (2)

Remind: $\mathbf{n_C - n_d = 2n_A - n_s}$

Construction of Observables: $A_T^{(i)}$ i=2,3,4,5

Theory framework: NLO QCDF including Λ/m_b corrections.

Spin amplitudes $A_{\perp L,R}, A_{\| L,R}, A_{0L,R}$ are functions:

- $B \to K^*$ Form factors: $A_{0,1,2}(s)$, $V(s)$, $T_{1,2,3}(s)$.
- Wilson Coefficients: $\mathcal{C}_7^{(\text{eff})}, \mathcal{C}_7^{\prime(\text{eff})}, \mathcal{C}_9^{(\text{eff})}, \mathcal{C}_{10}$

$$\begin{aligned}
\mathbf{A}_{\perp \mathbf{L},\mathbf{R}} &= N\sqrt{2}\lambda^{1/2}\left[(\mathcal{C}_9^{(\text{eff})} \mp \mathcal{C}_{10})\frac{V(q^2)}{m_B + m_K^*} + \frac{2m_b}{q^2}(\mathcal{C}_7^{(\text{eff})} + \mathcal{C}_7^{\prime(\text{eff})})T_1(q^2)\right] \\
\mathbf{A}_{\| \mathbf{L},\mathbf{R}} &= -N\sqrt{2}(m_B^2 - m_{K^*}^2)\left[(\mathcal{C}_9^{(\text{eff})} \mp \mathcal{C}_{10})\frac{A_1(q^2)}{m_B - m_{K^*}} + \frac{2m_b}{q^2}(\mathcal{C}_7^{(\text{eff})} - \mathcal{C}_7^{\prime(\text{eff})})T_2(q^2)\right], \\
\mathbf{A}_{0\mathbf{L},\mathbf{R}} &= -\frac{N}{2m_{K^*}\sqrt{q^2}} \times \left[(\mathcal{C}_9^{(\text{eff})} \mp \mathcal{C}_{10})\left\{(m_B^2 - m_{K^*}^2 - q^2)(m_B + m_{K^*})A_1(q^2) - \right.\right. \\
&\left. -\lambda\frac{A_2(q^2)}{m_B + m_{K^*}}\right\} + 2m_b(\mathcal{C}_7^{(\text{eff})} - \mathcal{C}_7^{\prime(\text{eff})})\left\{(m_B^2 + 3m_{K^*}^2 - q^2)T_2(q^2) - \right. \\
&\left.\left. -\frac{\lambda}{m_B^2 - m_{K^*}^2}T_3(q^2)\right\}\right],
\end{aligned}$$

HOW to deal with the form factors? Two alternatives:

- **Framework of QCDF at LO+α_s-NLO+Λ/m_b corrections.**
  Egede et al '08 and '10
- Mix QCD LCSR FF (LO) + α_s-QCDF NLO (neglect Λ/m_b).
  Altmannshofer et al. '08

All FF (V, A_i, T_i) in the limit $m_B \to \infty$ and $E_K^* \to \infty \Rightarrow \xi_\perp(\mathbf{E_K^*}),\ \xi_\parallel(\mathbf{E_K^*})$

$$A_1(s) = \frac{2E_{K^*}}{m_B + m_{K^*}}\xi_\perp(\mathbf{E_{K^*}}), \qquad A_2(s) = \frac{m_B}{m_B - m_{K^*}}\left[\xi_\perp(\mathbf{E_{K^*}}) - \xi_\parallel(\mathbf{E_{K^*}})\right],$$

$$A_0(s) = \frac{E_{K^*}}{m_{K^*}}\xi_\parallel(\mathbf{E_{K^*}}), \qquad V(s) = \frac{m_B + m_{K^*}}{m_B}\xi_\perp(\mathbf{E_{K^*}}),$$

$$T_1(s) = \xi_\perp(\mathbf{E_{K^*}}), \quad T_2(s) = \frac{2E_{K^*}}{m_B}\xi_\perp(\mathbf{E_{K^*}}), \quad T_3(s) = \xi_\perp(\mathbf{E_{K^*}}) - \xi_\parallel(\mathbf{E_{K^*}}).$$

In this limit spin amplitudes reduce to a very simple form:

$$\mathbf{A}_{\perp \mathbf{L},\mathbf{R}} = \sqrt{2} N m_B (1-\hat{s}) \left[(\mathcal{C}_9^{(\mathrm{eff})} \mp \mathcal{C}_{10}) + \frac{2\hat{m}_b}{\hat{s}} (\mathcal{C}_7^{(\mathrm{eff})} + \mathcal{C}_7^{\prime(\mathrm{eff})}) \right] \xi_\perp(E_{K^*}),$$

$$\mathbf{A}_{\parallel \mathbf{L},\mathbf{R}} = -\sqrt{2} N m_B (1-\hat{s}) \left[(\mathcal{C}_9^{(\mathrm{eff})} \mp \mathcal{C}_{10}) + \frac{2\hat{m}_b}{\hat{s}} (\mathcal{C}_7^{(\mathrm{eff})} - \mathcal{C}_7^{\prime(\mathrm{eff})}) \right] \xi_\perp(E_{K^*}),$$

$$\mathbf{A}_{\mathbf{0L},\mathbf{R}} = -\frac{N m_B}{2\hat{m}_{K^*}\sqrt{\hat{s}}} (1-\hat{s})^2 \left[(\mathcal{C}_9^{(\mathrm{eff})} \mp \mathcal{C}_{10}) + 2\hat{m}_b (\mathcal{C}_7^{(\mathrm{eff})} - \mathcal{C}_7^{\prime(\mathrm{eff})}) \right] \xi_\parallel(E_{K^*}),$$

- Corrections to FF relations:
  - order α_s in QCDF at NLO (factor. and non-factor.)
  - $\mathbf{\Lambda/m_b}$ breaking contributions: order 5 and 10%.

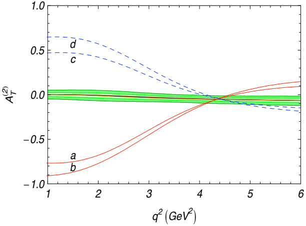
EXAMPLE Transverse Asymmetries: A_T^2

Definition

Kruger,J.M. '05

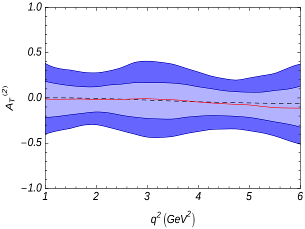
$$A_T^2 = \frac{|A_\perp|^2 - |A_\parallel|^2}{|A_\perp|^2 + |A_\parallel|^2} = -2\frac{\mathrm{Re}H_+^* H_-}{|H_+|^2 + |H_-|^2}$$

- Physics Sensitivity: Deviation from SM left-handed structure: $A_T^2\Big|_{SM} \sim 0$.
- Cleanliness: Soft form factor ($\xi_\perp(0)$) dependence cancel exactly at LO and very mild dependence at NLO.
- Domain: Low-Region $1 \leq q^2 \leq 6\ \mathrm{GeV}^2$ (High region, see G. Hiller et al.)



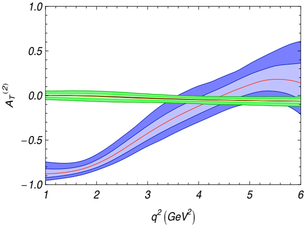
Theoretical sensitivity

Λ/m_b: light(dark) green $\pm 5\%$ ($\pm 10\%$)



Exper. sensitivity SM ($10\mathrm{fb}^{-1}$)

light(dark) blue 1σ (2σ)



Exper. SUSY sens.

(Egede et al. 08)

Understanding A_T^2

In the large E_K^* and m_B limit (only C_7')

$$A_T^2 \sim 4\mathcal{C}_7^{\prime(\text{eff})}\frac{m_b M_B}{s}\frac{\Delta_- + \Delta_+^*}{2C_{10}^2 + |\Delta_-|^2 + |\Delta_+|^2}$$

$$\Delta_\pm = \mathcal{C}_9^{\text{eff}} + 2\frac{m_b M_B}{s}(\mathcal{C}_7^{(\text{eff})} \pm \mathcal{C}_7^{\prime(\text{eff})})$$

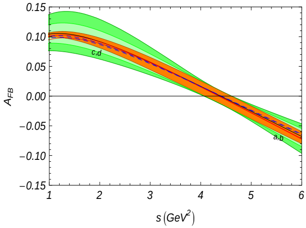
BUT

$$\Delta_+ + \Delta_-^* = 2\mathcal{C}_9^{\text{eff}} + 4\frac{m_b M_B}{s}(\mathcal{C}_7^{(\text{eff})})$$

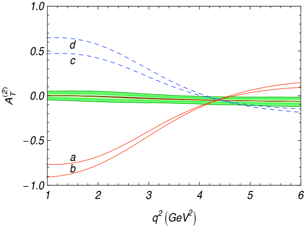
- Enhance sensitivity to $\mathcal{C}_7^{\prime(\text{eff})}$ (modulus+sign) at low s ($1 < s < 2\,\text{GeV}^2$) and 1/s-slope:

$$\underline{\mathbf{A_{FB}}} = \frac{3}{2}\frac{\mathrm{Re}(A_{\|L}A_{\perp L}^*) - \mathrm{Re}(A_{\|R}A_{\perp R}^*)}{|A_0|^2 + |A_\||^2 + |A_\perp|^2} \quad \textbf{versus} \quad \underline{\mathbf{A_T^2}} = \frac{|A_\perp|^2 - |A_\||^2}{|A_\perp|^2 + |A_\||^2}$$

Only FF protection at q_0^2
q_0^2 at LO (and NLO)



FF protection from $1 < q^2 < 6\,\text{GeV}^2$
SAME q_0^2 at LO (and NLO) ($C_7' \neq 0$)



Understanding A_T^2

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$$\Delta_\pm = \mathcal{C}_9^{\mathrm{eff}} + 2\frac{m_b M_B}{s}(\mathcal{C}_7^{(\mathrm{eff})} \pm \mathcal{C}_7^{\prime(\mathrm{eff})})$$

BUT

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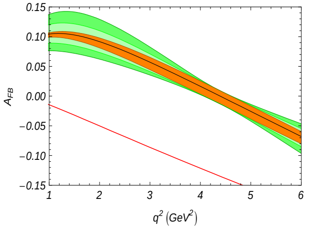
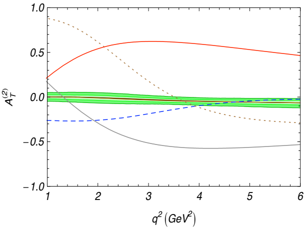
$$\underline{\mathbf{A_{FB}}} = \frac{3}{2}\frac{\mathrm{Re}(A_{\parallel L}A_{\perp L}^*) - \mathrm{Re}(A_{\parallel R}A_{\perp R}^*)}{|A_0|^2 + |A_\parallel|^2 + |A_\perp|^2} \quad \textbf{versus} \quad \underline{\mathbf{A_T^2}} = \frac{|A_\perp|^2 - |A_\parallel|^2}{|A_\perp|^2 + |A_\parallel|^2}$$

Only FF protection at q_0^2
q_0^2 at LO + **Absence of zero**

FF protection from $1 < q^2 < 6\,\mathrm{GeV}^2$
SAME q_0^2 at LO+ **Absence of zero**





Understanding A_T^2

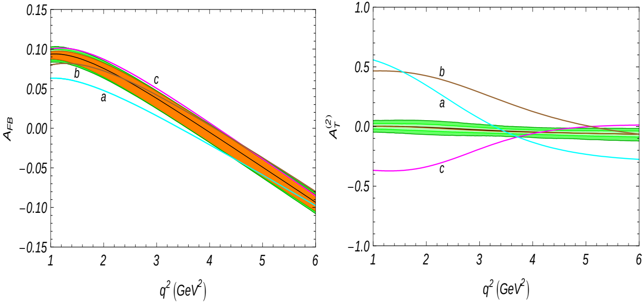
- A_T^2: CP violating phase (O_7') sensitivity BETTER than CP violating observables

$$\underline{\mathbf{A_{FB}}} = \frac{3}{2}\frac{\mathrm{Re}(A_{\parallel L}A^*_{\perp L}) - \mathrm{Re}(A_{\parallel R}A^*_{\perp R})}{|A_0|^2+|A_\parallel|^2+|A_\perp|^2} \quad \textbf{versus} \quad \underline{\mathbf{A_T^2}} = \frac{|A_\perp|^2 - |A_\parallel|^2}{|A_\perp|^2+|A_\parallel|^2}$$

A_{FB}: **Mild** sensitivity to C_7' mod+phase A_T^2: **Strong** sensitivity to C_7' mod+phase

$$\mathrm{Num}(A_{FB}) \sim \frac{2m_b M_B}{q^2} C_7^{eff} + C_9 + \frac{2m_b M_B}{q^2}|C_7^{NP}| \cos \phi_7^{NP}$$

$$\mathrm{Num}(A_T^2) = \frac{4m_b M_B}{q^2}\left[\left(\frac{2m_b M_B}{q^2} C_7^{eff} + C_9\right)|C_7'| \cos \phi_7' + \frac{2m_b M_B}{q^2}|C_7'||C_7^{NP}| \cos(\phi_7' - \phi_7^{NP})\right]$$

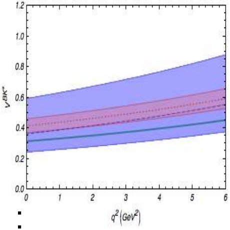


$C_7^{NP} e^{i\phi_7^{NP}}$	$C_7' e^{i\phi_7'}$
$0.26e^{-i\frac{7\pi}{16}}$	$0.2e^{i\pi}(a)$
$0.07e^{i\frac{3\pi}{5}}$	$0.3e^{i\frac{3\pi}{5}}(b)$
$0.03e^{i\pi}$	$0.07(c)$

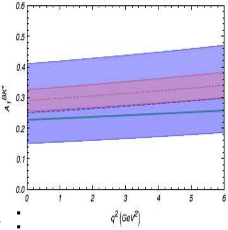
How solid are these predictions under FF changes?

A_T^2 is function of form factors: V, A_1, T_1 and $T_2 \Rightarrow \xi_\perp$.

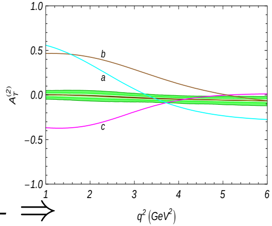
V:



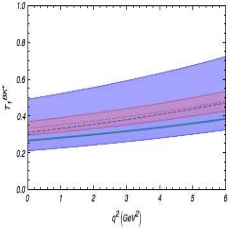
A_1 :



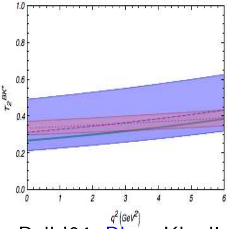
A_T^2 with Ball '98



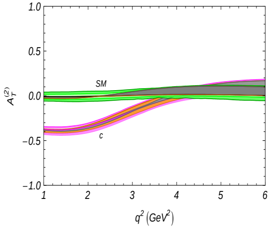
T_1 :



T_2 :



$A_T^2 \Rightarrow$



Green: Egede'10, Magenta: Ball '04, Blue: Khodjamirian '10

A_T^2 with Khodjamirian '10

Other sensitivities of A_T^2 : O'_{10}

A_T^2 may serve also as an excellent test of O'_{10} if ONLY switched on.
In the limit $m_b \to \infty, E_K^* \to \infty$

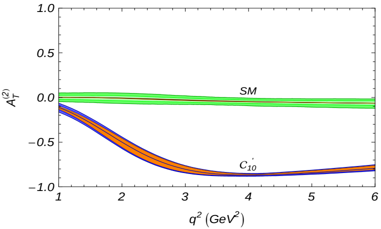
$$A_T^2 = \frac{2 C_{10} C'_{10} \cos\phi'_{10}}{C_{10}^2 + |C'_{10}|^2 + (2 m_b M_B C_7/q^2 + C_9)^2}$$

- A_T^2 shows a linear dependence on C'_{10} like for $C_7^{eff\,\prime}$
- But the q^2-dependence is different:
    - It does not show up a ZERO
    - Maximal around the standard minima of the A_{FB}.

A combined analysis with $A_T^{(3,4)}$ and A_T^5 allow to disentangle different WC.

Green $\to$ SM
Orange/Blue $\to$ $C'_{10} = 3e^{i\pi/8}$

All uncertainties included



A new example: A_T^5

Definition:

$$A_T^{(5)} = \frac{|A_\|^{R*} A_\perp^L + A_\|^L A_\perp^{R*}|}{|A_\||^2 + |A_\perp|^2}$$

a) It probes spin amplitudes $A_\perp$ and $A_\|$ differently from A_T^2.

b) No angular coefficient mixes L/R with $\perp/\|$ simultaneously.

c) In the large recoil limit

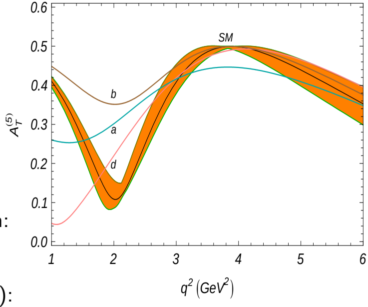
$$A_T^{(5)}\Big|_{SM} = \frac{\left|-C_{10}^2 + (2m_b M_B C_7^{eff}/q^2 + C_9^{eff})^2\right|}{2\left[C_{10}^2 + (2m_b M_B C_7^{eff}/q^2 + C_9^{eff})^2\right]},$$

Minimum at LO of $A_T^5 \Rightarrow$ **NEW** relation:

$$C_{10}^2 = (2m_b M_B C_7^{eff}/q_1^2 + C_9^{eff})^2$$

Maximum at LO of $A_T^5 \Rightarrow$ by **OLD** (A_{FB}-zero) relation:

$$-C_9^{eff} = 2m_b M_B C_7^{eff}/q_0^2$$



d) Expresion in terms of J's (using explicit solution):

$$A_T^{(5)}\Big|_{m_\ell=0} = \frac{\sqrt{16 J_1^{s\,2} - 9 J_6^{s\,2} - 36(J_3^2 + J_9^2)}}{8 J_1^s}.$$

A_T^5 sensitivities

C_7' sensitivity weaker, BUT dependence on C_9, C_{10} and C_{10}' is transparent.
At large recoil in presence of O_{10}', O_7, O_9, O_{10}

$$A_T^{(5)}\Big|_{10'} = \frac{\left| -C_{10}^2 + |C_{10}'|^2 + \left(2m_b M_B C_7^{eff}/q^2 + C_9^{eff}\right)^2 \right|}{2\left[C_{10}^2 + |C_{10}'|^2 + \left(2m_b M_B C_7^{eff}/q^2 + C_9^{eff}\right)^2\right]}$$

a) **Maximum (LO)** in SM when $2m_b M_B C_7^{eff}/q_0^2 + C_9^{eff} = 0$ and $C_{10}' = 0$ then $A_T^5\Big|_{max} = \frac{1}{2}$ (True for NLO also).

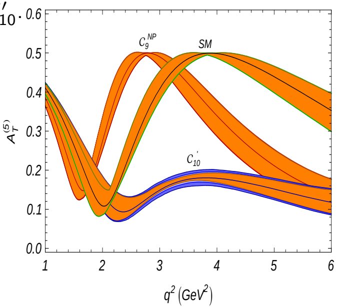
b) **Maximum** moves also by NP contributions from C_7^{eff} or C_9^{eff} like A_{FB}.

c) **Minimum (LO)** moves by NP contribution from C_{10}'.

$$|C_{10}'|^2 = C_{10}^2 - (2m_b M_B C_7^{eff}/q^2 + C_9^{eff})^2$$

d) If only O_{10}' turn on and $C_{10}' < C_{10}$

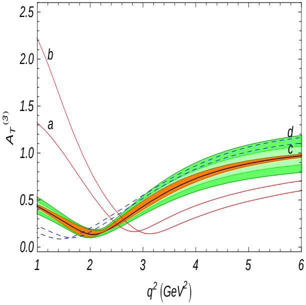
$$\frac{\text{Distance between SM maximum and NP } (O_{10}') \text{ maximum:}}{|C_{10}'^{NP}|^2/(C_{10}^2 + |C_{10}'^{NP}|^2)}$$



Open **longitudinal spin amplitude** A_0 sensitivity in a protected way.

$$A_T^3 = \frac{|A_{0L}A^*_{\parallel L} + A^*_{0R}A_{\parallel R}|}{\sqrt{|A_0|^2|A_\perp|^2}} \qquad \text{and} \qquad A_T^4 = \frac{|A_{0L}A^*_{\perp L} - A^*_{0R}A_{\perp R}|}{|A_{0L}A^*_{\parallel L} + A^*_{0R}A_{\parallel R}|}$$

- Invariant under massless symmetries and high experimental resolution.
- Constructed to cancel both $\xi_\perp(0)$ and $\xi_\parallel(0)$ dependence at LO.
- Offer different sensitivity to $\mathcal{C}_7^{\prime(\mathrm{eff})}$, C_9^{eff} and C_{10}:



- $\mathbf{A_T^3}$ at LO its **minimum** determines a relation:

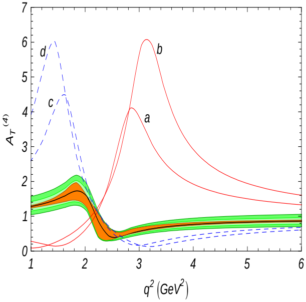
$$C_{10}^2 = -(C_9^{eff} + 2\frac{m_b}{M_B}(C_7^{eff} - C_7^{eff\prime}))(C_9^{eff} + 2\frac{m_b M_B}{q^2}(C_7^{eff} - C_7^{eff\prime}))$$

- Restrict analysis to the low-dilepton mass region $1 \leq s \leq 6$ GeV^2.

Open **longitudinal spin amplitude** A_0 sensitivity in a protected way.

$$A_T^3 = \frac{|A_{0L}A^*_{\|L} + A^*_{0R}A_{\|R}|}{\sqrt{|A_0|^2|A_\perp|^2}} \qquad \text{and} \qquad A_T^4 = \frac{|A_{0L}A^*_{\perp L} - A^*_{0R}A_{\perp R}|}{|A_{0L}A^*_{\|L} + A^*_{0R}A_{\|R}|}$$

- Invariant under massless symmetries and high experimental resolution.
- Constructed to cancel both $\xi_\perp(0)$ and $\xi_\|(0)$ dependence at LO.
- Offer different sensitivity to $\mathcal{C}_7^{\prime(\mathrm{eff})}$, C_9^{eff} and C_{10}:



- A_T^3 at LO its **minimum** determines a relation:

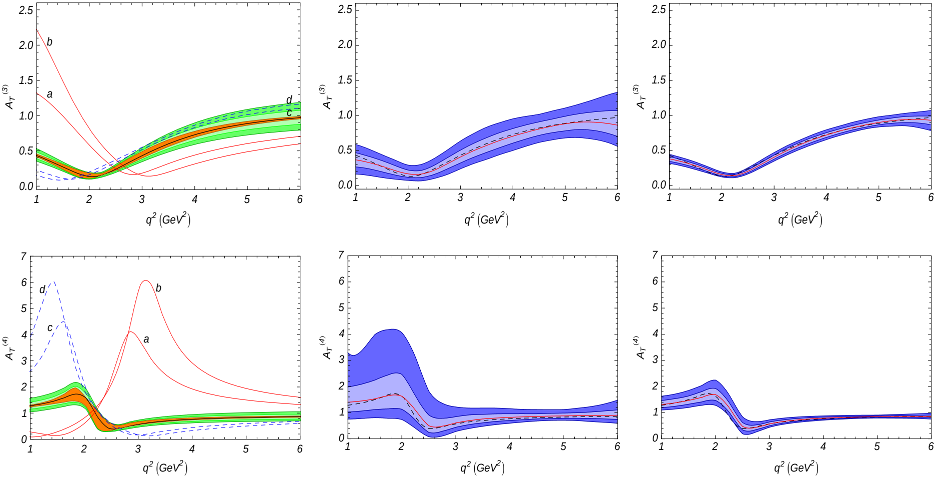
$$C_{10}^2 = -(C_9^{eff} + 2\frac{m_b}{M_B}(C_7^{eff} - C_7^{eff\prime}))(C_9^{eff} + 2\frac{m_b M_B}{q^2}(C_7^{eff} - C_7^{eff\prime}))$$

- $\mathbf{A_T^4}$ at LO its **minimum** determines a relation:

$$C_9^{eff} = -\frac{m_b}{M_B}(C_7^{eff} - C_7^{eff\prime}) - \frac{m_b M_B}{q^2}(C_7^{eff} + C_7^{eff\prime})$$

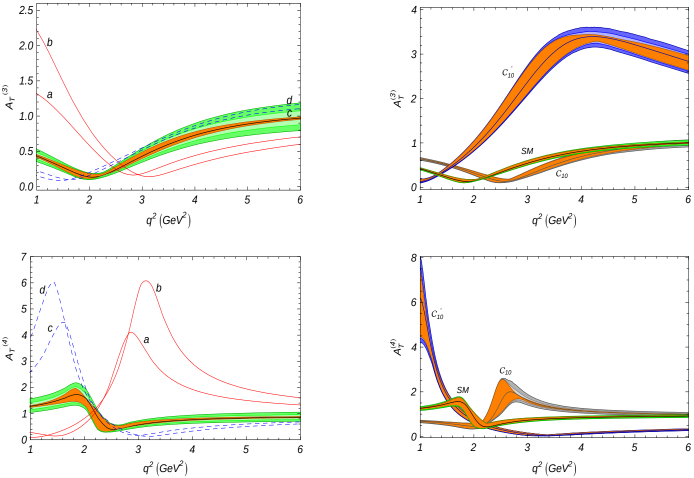
- $\mathbf{A_T^4}$ its **maximum** is related to the **minimum** of A_T^3

- Restrict analysis to the low-dilepton mass region $1 \le s \le 6$ GeV^2.



- Large-gluino scenario (a,b) with $\delta > 0$ clear at low-s region for A_T^3 and large-s for A_T^4
- Low-gluino scenario (c,d) with $\delta < 0$ clear at low-s region for A_T^4

Egede, Reece, Hurth, J.M, Ramon '08 update+Exper. sensitivity with $10/100\ \mathrm{fb}^{-1}$



- A_T^3 large sensitivity to $\mathcal{O}'_{10}$ like in A_T^5
- A_T^4 stronger sensitivity to $\mathcal{O}_{10}$

Egede, Reece, Hurth, J.M, Ramon '10 update

III. Precision Flavour dynamics: $\sin\phi_s$ ($B_s^0 - \bar{B}_s^0$ weak mixing phase)

Tevatron have been measuring CP asymmetry of $B_s \to \psi\phi$ ($\sin\phi_s$) and dimuon charge asymmetry:

$$A_{sl}^b = \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}}$$

N_b^{++} number of events with two b-hadrons decaying into $\mu^+\mu^+X$. Both semileptonic B_d and B_s can contribute. Relation with asymmetries

$$a_{sl}^q = \frac{\Gamma(\bar{B}_q \to \mu^+ X) - \Gamma(B_q \to \mu^- X)}{\Gamma(\bar{B}_q \to \mu^+ X) - \Gamma(B_q \to \mu^- X)} = \frac{\Delta\Gamma}{\Delta M_q}\tan\phi_q \qquad \phi_q = arg\left(-\frac{M_{12}}{\Gamma_{12}}\right)$$

is $A_{sl}^b = (0.506 \pm 0.043)a_{sl}^d + (0.49 \pm 0.043)a_{sl}^s$
D0 announced a large dimuon charge asymmetry in B-decays up to 3.2σ with respect to the tiny SM prediction.
Direct measurement of a_{sl}^d is in good agreement with SM $\Rightarrow$ the value obtained for a_{sl}^s from A_{sl}^b (D0) is much larger than SM prediction by $\sim 2\sigma$. • CDF has also measured A_{sl}^b with larger errors. • Direct measurement of a_{sl}^s from $D0$ $(-(1.7 \pm 9.1^{1.4}_{-1.5})10^{-3})$. Still an average value of a_{sl}^s from CDF-D0 is 2.5 σ away from SM.

Concerning $\sin\phi_s$: Latest result (6.1 fb^{-1} luminosity)

- D0: Deviation from SM of 2σ (increase with respect to previous 1.8σ)
- CDF: Deviation from SM of 0.8σ (downward shift from previous 1.8σ).

Situation unclear, other measurements required....

Non leptonic B decays in QCDF suffers from IR divergences:.

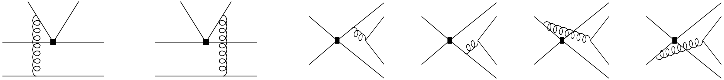
- Hard spectator-scattering:

$$H_i(M_1 M_2) \quad = \quad C\int_0^1 dx \int_0^1 dy \left[\frac{\Phi_{M_2}(x)\Phi_{M_1}(y)}{\bar{x}\bar{y}} + r_\chi^{M_1}\,\frac{\Phi_{M_2}(x)\Phi_{m_1}(y)}{x\bar{y}}\right],$$

second term (formally of order Λ/m_b) diverges when $y \to 1$.

- Weak annihilation also exhibit endpoint IR divergences.

$$\begin{aligned} A_1^i = \pi\alpha_s \quad & \int_0^1 dxdy\, \left\{\Phi_{M_2}(x)\,\Phi_{M_1}(y)\left[\frac{1}{y(1-x\bar{y})}\right.\right. \\ + \quad & \left.\left. \frac{1}{\bar{x}^2 y}\right] + r_\chi^{M_1} r_\chi^{M_2}\,\Phi_{m_2}(x)\,\Phi_{m_1}(y)\,\frac{2}{\bar{x}y}\right\}. \end{aligned}$$



Hard Scattering and Weak Annihilation

Both divergences modeled in the same way in QCDF:

$$\int_0^1 \frac{dy}{\bar{y}} \Phi_{m_1}(y) \equiv \Phi_{m_1}(1)\, X_{H,A}^{M_1} + r,$$

with r a finite piece and $X_{H,A} = (1 + \rho_{H,A}) \ln(m_b/\Lambda)$.

Amplitude for a B-decay into two mesons:

$$A(\bar{B}_q \to M\bar{M}) = \lambda_u^{(q)} T_M^q + \lambda_c^{(q)} P_M^q \,, \qquad \lambda_p^{(q)} = V_{pb} V_{pq}^*$$

Keypoint: For certain processes the structure of the IR divergences at NLO in QCDF is the same for both pieces.

Consequence: This allows to identify an IR safe quantity **at this order**, defined by $\Delta = T - P$.

Remark: This quantity Δ can be directly related to observables leading to a set of sum rules that can be translated into predictions for the UT angles.

EXAMPLES

- $B \to PP$: Δ was first calculated for $B_{s,d} \to K^0 \bar{K}^0$ (DMV)
- $B \to VV$: One Δ for each helicity amplitudes. Longitudinal is leading in a naive power counting in Λ/m_b.

Longitudinal Δ of $B_d \to K^{*0}\bar{K}^{*0}$ ($B_s \to K^{*0}\bar{K}^{*0}$) and $B_s \to \phi\phi$:

$$|\Delta^d_{K^*K^*}| = A^{d,0}_{K^*K^*} \frac{C_F \alpha_s}{4\pi N_c} C_1 \, |\bar{G}_{K^*}(s_c) - \bar{G}_{K^*}(0)| = (1.85 \pm 0.79) \times 10^{-7}\mathrm{GeV}$$

$$|\Delta^s_{K^*K^*}| = A^{s,0}_{K^*K^*} \frac{C_F \alpha_s}{4\pi N_c} C_1 \, |\bar{G}_{K^*}(s_c) - \bar{G}_{K^*}(0)| = (1.62 \pm 0.69) \times 10^{-7}\mathrm{GeV}$$

$$|\Delta^s_{\phi\phi}| = A^{s,0}_{\phi\phi} \frac{C_F \alpha_s}{4\pi N_c} C_1 \, |\bar{G}_{\phi}(s_c) - \bar{G}_{\phi}(0)| = (2.06 \pm 2.24) \times 10^{-7}\mathrm{GeV}$$

where $\bar{G}_V \equiv G_V - r_\chi^V \hat{G}_V$ are the usual penguin functions and $A^{q,0}_{V_1 V_2}$ are the naive factorization factors.

Strategies to measure $\sin \phi_s$ based on Δ

First Strategy:

General, it applies to any $B \to PP, VV$ decay. It allows to perform a test on the SM value of ϕ_s.

- We will focus here on two cases:

  1. B_s decay through a $b \to s$ process, e.g. $B_s \to K^{*0}\bar{K}^{*0}, \phi\phi$
  2. B_s decay through a $b \to d$ process, e.g. $B_s \to \phi\bar{K}^{*0}$ (with a subsequent decay into a CP eigenstate)

I. **Experimental inputs**: longitudinal branching ratio and $A_{\Delta\Gamma}$ asymmetry of a B_s meson decaying through a $b \to d$ or $b \to s$ process (from the untagged rate):

$$\mathrm{BR}^{long} = (N \times f_0 + \bar{N} \times \bar{f}_0) \quad \text{where} \quad \bar{f}_0 = \frac{|\bar{A}_0|^2}{|\bar{A}_0|^2 + |\bar{A}_+|^2 + |\bar{A}_-|^2} = \frac{|\bar{A}_0|^2}{\bar{T}}$$

$$\Gamma^L(B^0(t) \to f) + \bar{\Gamma}^L(\bar{B}^0(t) \to f) = R_L e^{-\Gamma_L t} + R_H e^{-\Gamma_H t}$$

$$A_{\Delta\Gamma}^{long} = \frac{R_H/R_L - 1}{R_H/R_L + 1} \quad \text{and} \quad |A_{dir}|^2 + |A_{mix}|^2 + |A_{\Delta\Gamma}|^2 = 1$$

.

Notice that $\bar{T}/T = \bar{N}/N$, where $N(\bar{N})$ are the corresponding number of events with a $B(\bar{B})$ respectively

II. **Theory inputs**:

- longitudinal Δ (already computed for different decays) and
- combination of CKM elements.

III. **Main results**:

$$\sin^2\beta_s = \frac{\widetilde{BR}}{2|\lambda_c^{(D)}|^2|\Delta|^2}\,(1 - A_{\Delta\Gamma})$$

$$\sin^2(\beta_s+\gamma) = \frac{\widetilde{BR}}{2|\lambda_u^{(D)}|^2|\Delta|^2}\,(1 - A_{\Delta\Gamma})$$

Conclusion:

1. Direct test of the weak mixing angle ϕ_s with only **one** single theoretical input: the corresponding Δ of the process with an untagged rate (not tagging required).
2. Enough to test β_s but also γ.

Second Strategy:

This strategy is the most theoretically driven. It focus on the golden mode $B_s \to K^{0*}\bar{K}^{0*}$
Assumption: no sizeable NP in the $B_d \to K^{0*}\bar{K}^{0*}$ U-spin related decay.
The steps to follow here are:

- Relate the hadronic parameters of both processes (B_s and B_d):

$$P^s_{K^*K^*} = f\, P^d_{K^*K^*}(1+\delta^P_{K^*K^*})$$

$$T^s_{K^*K^*} = f\, T^d_{K^*K^*}(1+\delta^T_{K^*K^*})$$

  computing factorizable

$$f = m^2_{B_s} A_0^{B_s \to K^*} / m^2_B A_0^{B \to K^*} = 0.88 \pm 0.19$$

  and non-factorizable SU(3) breaking parameters:

$$|\delta^P_{K^*K^*}| \leq 0.12\ , \qquad |\delta^T_{K^*K^*}| \leq 0.15$$

- Main inputs: $BR^{long}(B_d \to K^{0*}\bar{K}^{0*})$, Δ_{K*K*} together with $A_{dir}^{long}(B_d \to K^{0*}\bar{K}^{0*})$

- Prediction in the SM for the corresponding B_s observables:

$$
\begin{aligned}
\frac{BR^{long}(B_s \to K^{*0}\bar{K}^{*0})}{BR^{long}(B_d \to K^{*0}\bar{K}^{*0})} &= 17 \pm 6 \\
A_{dir}^{long}(B_s \to K^{*0}\bar{K}^{*0}) &= 0.000 \pm 0.014 \\
A_{mix}^{long}(B_s \to K^{*0}\bar{K}^{*0}) &= 0.004 \pm 0.018
\end{aligned}
$$

- A measurement of $A_{mix}^{long}(B_s \to K^{0*}\bar{K}^{0*})$ allow to extract the weak mixing angle ϕ_s even in presence of New Physics in the mixing including all penguin pollution.

Correlation between A_{mix}^{long} and ϕ_s. The extraction of ϕ_s from this plot is possible even in the presence of New Physics under the condition that there are only New Physics contributions in $\Delta B = 2$ but not large New Physics effects in $\Delta B = 1$ FCNC amplitudes.

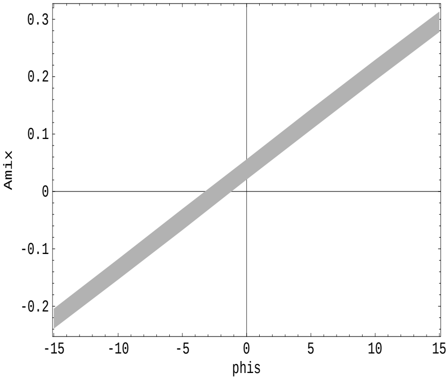


Figure: $\mathcal{A}_{mix}^{long}(B_s \to K^{0*}\bar{K}^{0*})$ versus ϕ_s.

Conclusions

- Possible $\sin 2\beta$ tensions can be very clearly clarified at Super-B.
- We have **completed the method** to construct QCD-protected observables A_T^i based on the exclusive 4-body B-meson decay $\bar{B}_d \to \bar{K}^{*0}(\to K\pi)l^+l^-$ in the low dilepton mass region.
- While the coefficients of the distribution J_i cannot be predicted with high accuracy if realistic form factor errors are taken. On the contrary A_T^i are very robust, precise and very sensitive to NP.
- We have **explored the NP sensitivities** of A_T^2, A_T^3, A_T^4 and the new A_T^5. Their combined analysis together with A_{FB} will help in disentangling NP contributions to each Wilson coefficient.
- A_T^2 emerges as an improved version of A_{FB}. Contains all A_{FB} physics, it is much more sensitive to NP and it is QCD protected in **all region** and not only in one point.
- New proposal to test B_s mixing angle with no tagging, using $B_s \to VV, PP$ decays and one very solid theoretical input Δ.

Hints
Of
New Physics??

Hint number 1: CP asymmetries in B→π K

"Large" difference of CP asymmetries in B→πK in charged and neutral mode:

$$A_{\rm CP}(B^0 \to K^+\pi^-) = -0.097(12)\,,\; A_{\rm CP}(B^+ \to K^+\pi^0) = 0.050(25)$$
$$\Rightarrow \quad \Delta A_{\rm CP} \neq 0 \;\; @ 5.3\sigma\,,$$

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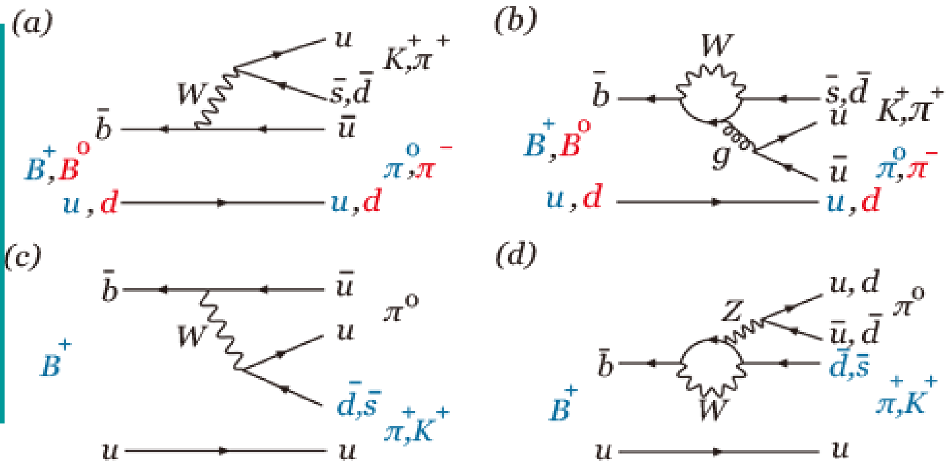
Nature 452 (08) 332

- Loop dominated decay sensitive to NP (b→s transition).
- Previously "B→πK puzzle" between ratios of charged and neutral BR.

$$A(B^0 \to K^+\pi^-) = -Te^{i\gamma} - P$$
$$\sqrt{2}\,A(B^+ \to K^+\pi^0) = -(T + C + \boxed{A})e^{i\gamma} - P - P_{EW}$$

P is dominant QCD penguin but also Penguin annihilation.

- C Color and Cabibbo suppressed tree
- P_{EW} electroweak penguins (sensitive to New Physics).
- A annihilation-tree (exp. small, difficult to estimate)



I. Crude Estimate of hierarchies:

$|P| : |T|, |P_{EW}| : |C| \approx 1 : \lambda : \lambda^2$ with $\lambda \approx 0.2$ (and $A \propto \phi_B$) ➡ $A_{CP} \propto \lambda \times \delta$

II. Flavour symmetries only (errors too large to arrive to any conclusion).

III. SM prediction in QCD Factorization:

CKM HADRONIC PAR.

$$A_{CP}(B^- \to K^- \pi^0) = \left(7.1^{+1.7+2.0+0.8+9.0}_{-1.8-2.0-0.6-9.7}\right)\%$$

$$A_{CP}(\bar{B}^0 \to K^- \pi^-) = \left(4.5^{+1.1+2.2+0.5+8.7}_{-1.1-2.5-0.6-9.5}\right)\%$$

Large correlation of uncertainties imply important cancellations:

$$\Delta A_{CP} = A_{CP}(B^- \to K^- \pi^0) - A_{CP}(\bar{B}^0 \to K^- \pi^+) = (2.5 \pm 1.5)\%$$ (limit QCDF)

$$\Delta A_{CP}^{\exp} = (14.4 \pm 2.9)\%$$ ➡ 3.5σ

• Moreover this problem is correlated to $S_{\pi 0KS}$ in QCDF (predicts $\epsilon_T \approx \epsilon_{3/2}$):

$$R_c - R_n \simeq 2\,\epsilon_{3/2}\left(\epsilon_T - \epsilon_{3/2}\left(1 - q^2\right)\right) + \mathcal{O}(\lambda^3),$$

$$\Delta A \simeq C_{\pi^0 K_S^0} \simeq 2\left(\epsilon_T \sin\phi_T - \epsilon_{3/2} \sin\phi_{3/2}\right) + \mathcal{O}(\lambda^3),$$

$$S_{\pi^0 K_S^0} \simeq -\sin 2\beta + 2\cos 2\beta\left(\epsilon_T - \epsilon_{3/2}\right) + \mathcal{O}(\lambda^2)$$

if strong phases tuned to solve ΔA_{CP} ⟷ $S_{\pi 0KS}$ would show 2σ dev.

Hint number 2: $B \to K^*(\to K\pi)l^+l^-$

Lunghi&Matias 07, **arXiv:0804.4412** [hep-ex]
Kruger&Matias 05 , **arXiv:0807.4119** [hep-ex]
Feldmann&Matias 03

Longitudinal K polarization*: **1.5σ**

$$F_L(s) = \frac{|A_0|^2}{|A_0|^2+|A_{\parallel}|^2+|A_{\perp}|^2}$$

F_L^{exp}= 0.35 ± 0.16 ($4m_{\mu}^2 < q^2 < 6.2\,\mathrm{GeV}^2$)
F_L^{theory}= 0.67± 0.08

Isospin asymmetry: **3.2σ**

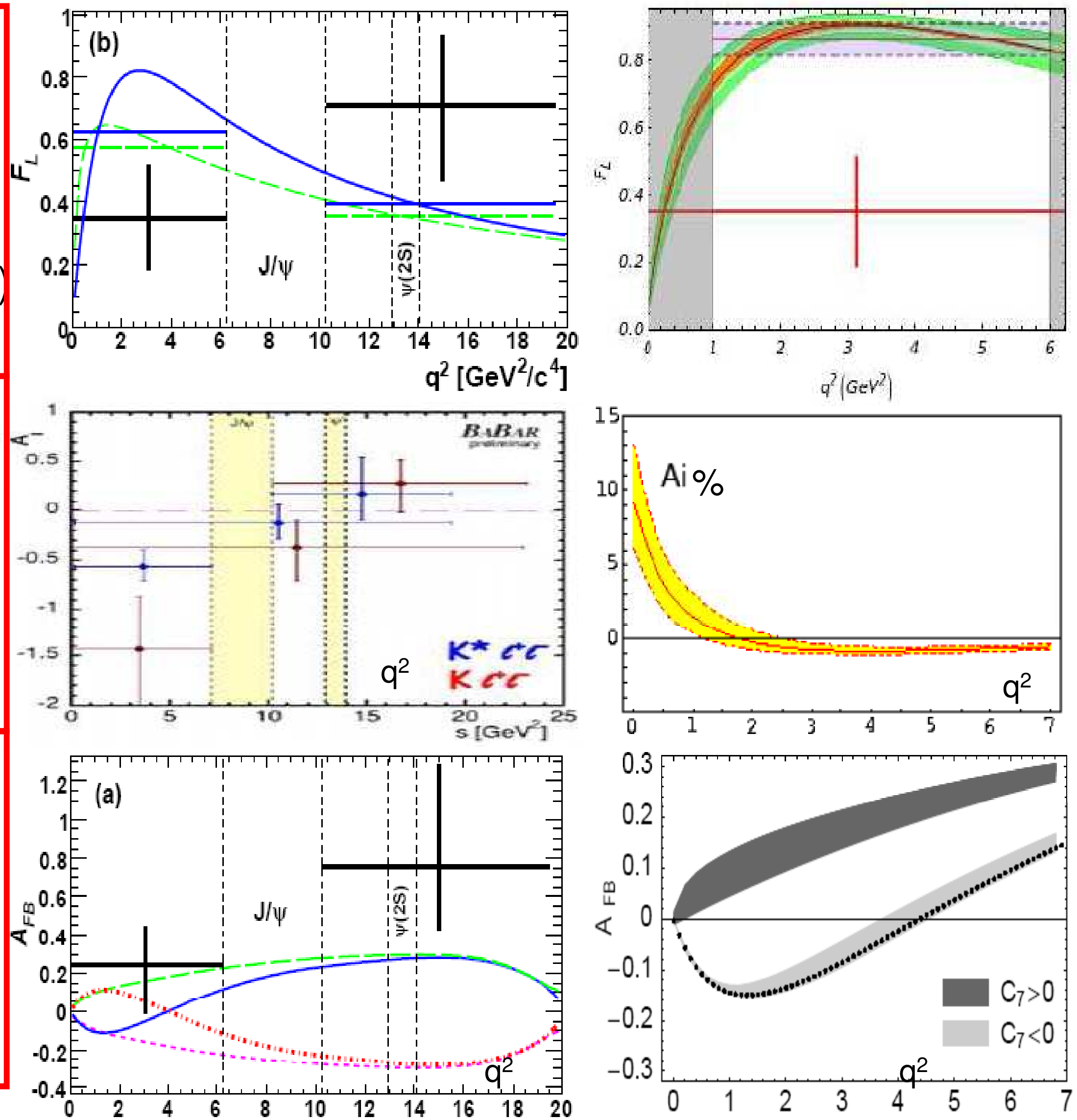
$$A_I = \frac{d\Gamma[B^0 \to K^{*0}\ell^+\ell^-]/ds - d\Gamma[B^\pm \to K^{*\pm}\ell^+\ell^-]/ds}{d\Gamma[B^0 \to K^{*0}\ell^+\ell^-]/ds + d\Gamma[B^\pm \to K^{*\pm}\ell^+\ell^-]/ds}$$

A_I^{exp}=-0.56±0.17, but at q^2=0 agrees
A_I^{theory}=-0.005±0.020

Forward-Backward asymmetry:

$$\frac{dA_{FB}}{dq^2} \equiv \frac{1}{d\Gamma/dq^2}\left(\int_0^1 d(\cos\theta)\frac{d^2\Gamma[B\to K^*\ell^+\ell^-]}{dq^2 d\cos\theta} - \int_{-1}^0 d(\cos\theta)\frac{d^2\Gamma[B\to K^*\ell^+\ell^-]}{dq^2 d\cos\theta}\right)$$

Flipped sign solution favored

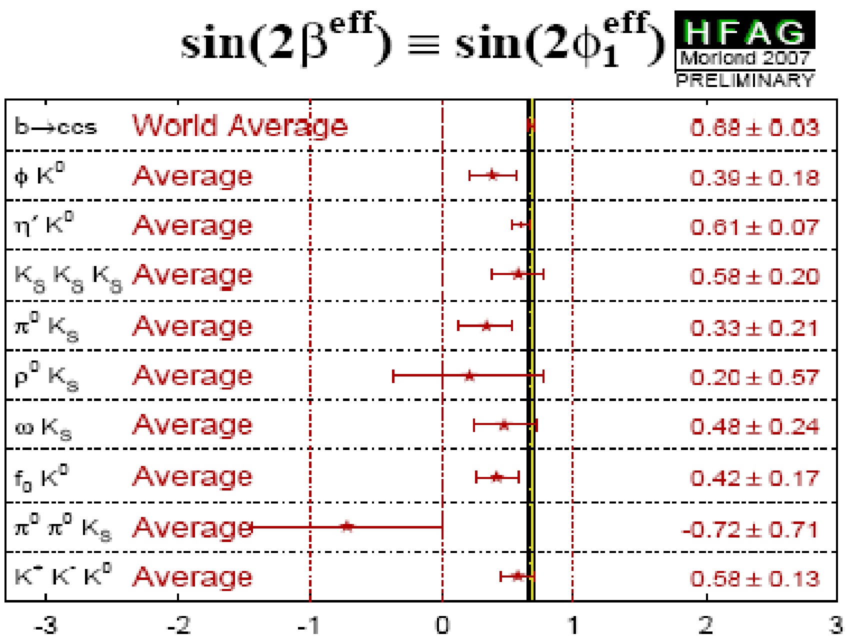


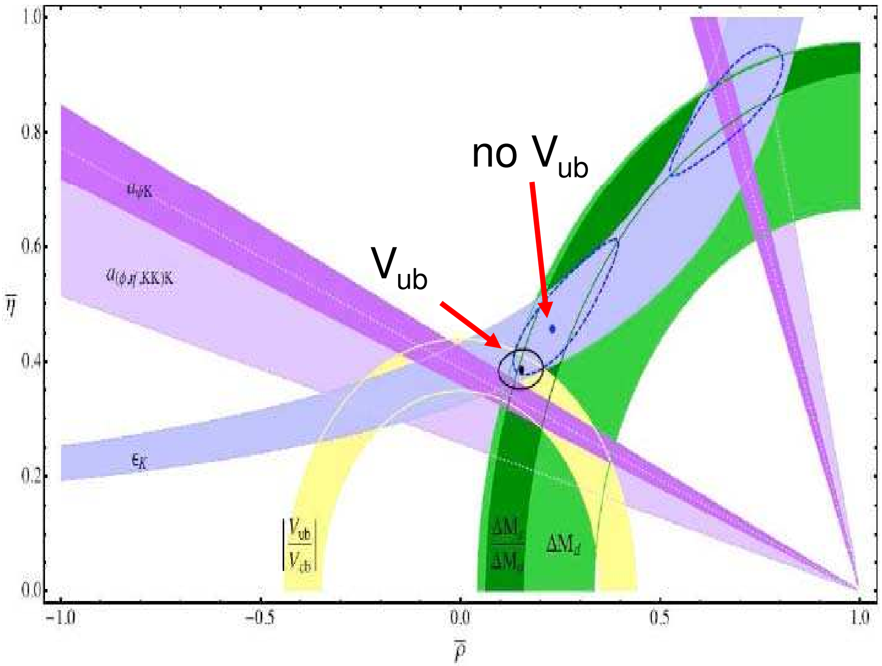
Hint number 3: $b \to s\bar{s}s$ versus $b \to c\bar{c}s$ and $\sin 2\beta$

- Prediction for $\sin 2\beta$ using ϵ_K, $\Delta M_{Bs}/\Delta M_{Bd}$ without V_{ub}(B_K, ξ_s): Lunghi&Soni 08

$$\sin(2\beta)^{\text{prediction}}_{\text{no}V_{ub}} = 0.87 \pm 0.09$$
$$\sin(2\beta)_{\psi K_S} = 0.681 \pm 0.025 \quad (2.1\sigma)$$
$$\sin(2\beta)_{(\phi,\eta',K_SK_S)K_S} = 0.58 \pm 0.06 \quad (2.7\sigma)$$

- $b \to s$ penguin dominated decays are systematically lower than $B \to \psi K_s$





mode	experiment	no V_{ub}	with V_{ub}
$a_{\psi K_S}$	0.681 ± 0.025	$2.1\,\sigma$	$1.7\,\sigma$
$a_{\phi K_S}$	0.39 ± 0.17	$2.5\,\sigma$	$2.1\,\sigma$
$a_{\eta' K_S}$	0.61 ± 0.07	$2.3\,\sigma$	$1.8\,\sigma$
$a_{K_SK_SK_S}$	0.58 ± 0.20	$1.4\,\sigma$	$0.9\,\sigma$
$a_{(\phi+\eta'+K_SK_S)K_S}$	0.58 ± 0.06	$2.7\,\sigma$	$2.5\,\sigma$
$a_{(\psi+\phi+\eta'+K_SK_S)K_S}$	0.66 ± 0.024	$2.3\,\sigma$	$2.1\,\sigma$

Hint number 4: **UT** claims first evidence of NP in b→s transitions.

Observables:

$$\Delta m_s = |A_s^{\rm full}| = C_{B_s} (\Delta m_s)^{\rm SM}$$

$$2\phi_s = -\arg A_s^{\rm full} = 2(\beta_s - \phi_{B_s})$$

$$A_{\rm SL}^s \equiv \frac{\Gamma(\bar B_s \to \ell^+ X) - \Gamma(B_s \to \ell^- X)}{\Gamma(\bar B_s \to \ell^+ X) + \Gamma(B_s \to \ell^- X)} = {\rm Im}\left(\frac{\Gamma_{12}^s}{A_s^{\rm full}}\right)$$

$$A_{\rm SL}^{\mu\mu} = \frac{f_d \chi_{d0} A_{\rm SL}^d + f_s \chi_{s0} A_{\rm SL}^s}{f_d \chi_{d0} + f_s \chi_{s0}}$$

$$A_{SL}^{s} = \frac{N(\mu^+ D_s^-) - N(\mu^- D_s^+)}{N(\mu^+ D_s^-) + N(\mu^- D_s^+)}$$

$$A_{SL}^{\mu\mu} = \frac{N(\mu^+\mu^+) - N(\mu^-\mu^-)}{N(\mu^+\mu^+) + N(\mu^-\mu^-)}$$

Theory:

$$C_{B_s} e^{2i\phi_{B_s}} = \frac{\langle B_s|H_{eff}^{full}|\bar B_s\rangle}{\langle B_s|H_{eff}^{SM}|\bar B_s\rangle} = 1 + \left(A_s^{NP}/A_s^{SM}\right) e^{2i\phi^{NP}}$$

$$\beta_s = \arg\left(-\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right) \approx 1^0$$

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Data:

Δm_s [ps^{-1}]	17.77 ± 0.12
$A_{\rm SL}^s \times 10^2$	2.45 ± 1.96
$A_{\rm SL}^{\mu\mu} \times 10^3$	-4.3 ± 3.0
$\tau_{B_s}^{\rm FS}$ [ps]	1.461 ± 0.032

Angular analysis of $B_s \to J/\psi\phi$ from CDF and D0 → $\Delta\Gamma_s$ and ϕ_s.

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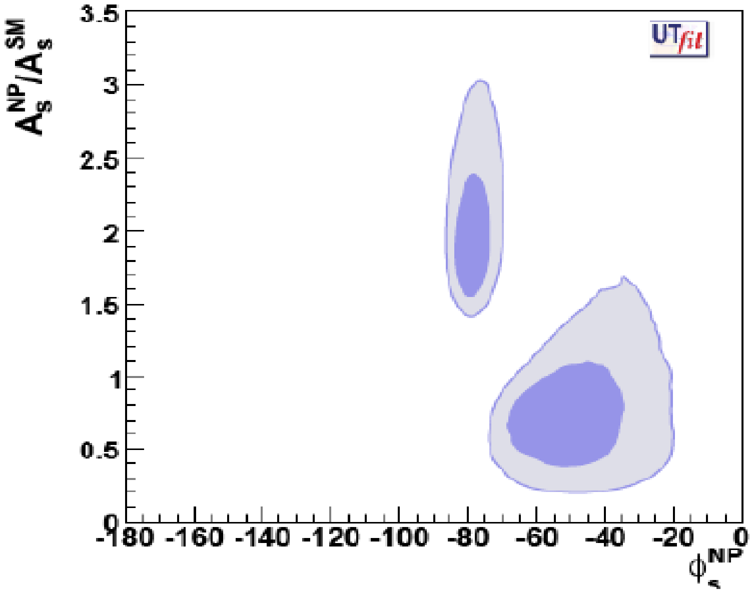
FIT RESULT:



The two solutions for ϕ_s correspond to two regions for A_s^{NP} and ϕ_s^{NP}:

$A_s^{NP}/A_s^{SM}=0.7\pm0.4$ & $\phi_{NP}=-50\pm10$

$A_s^{NP}/A_s^{SM}=1.9\pm0.1$ & $\phi_{NP}=-80\pm3$

Requires NP with new sources of CP violation!

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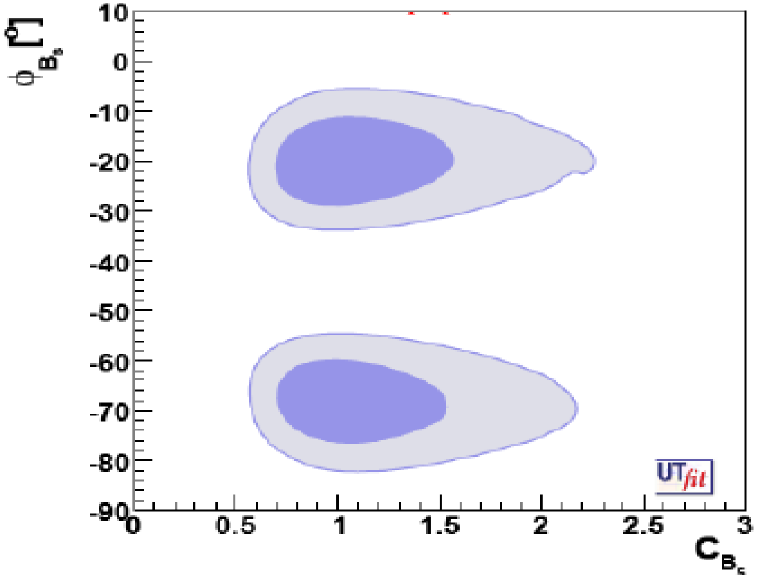
UTfit: Silvestrini&Ciuchini&al. 08



UTfit: ϕ_{Bs}= -19.9(5.6)^0
(trying to avoid D0 data assumption on strong phases) : 3.7σ

Recent D0 update (without assumption)
UTfit: ϕ_{Bs}= -18(7)^0 : 2.7σ

** **$B_s \to K^{0*}\overline{K^{0}}{}^{*}$ golden mode to extract ϕ_s** Descotes&Matias&Virto 07

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