

LHCb - TH workshop

(NP) mixing angles from hadronic penguin decays:

- In the presence of NP
- Hadronic corrections & Theoretically Clean
- As simple as possible

- + Status
- + LHCb expect

SM prediction for $B_q \rightarrow K^* K^*$

+ Recent LHCb measurement

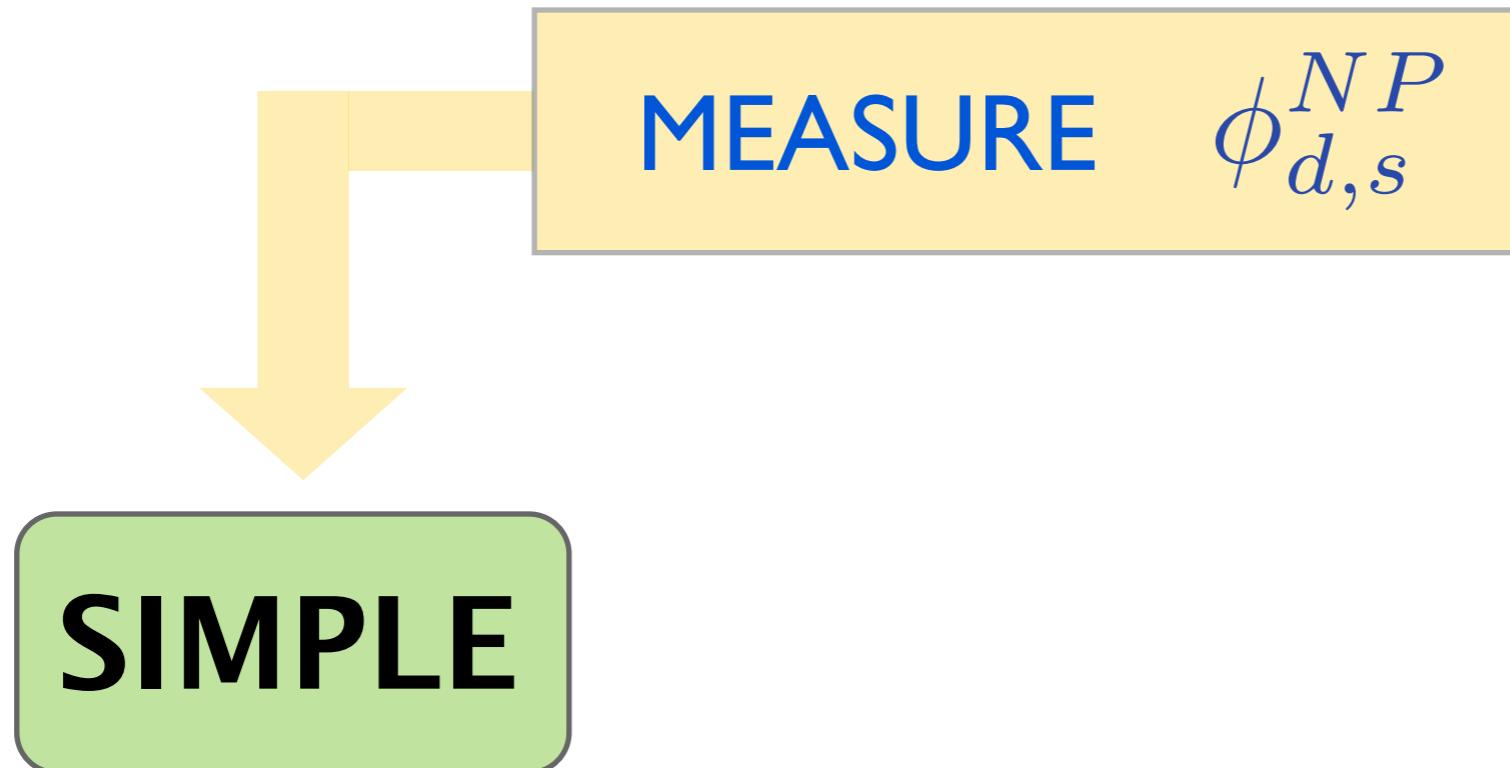
Measuring NP

OBJECTIVE:

MEASURE $\phi_{d,s}^{NP}$

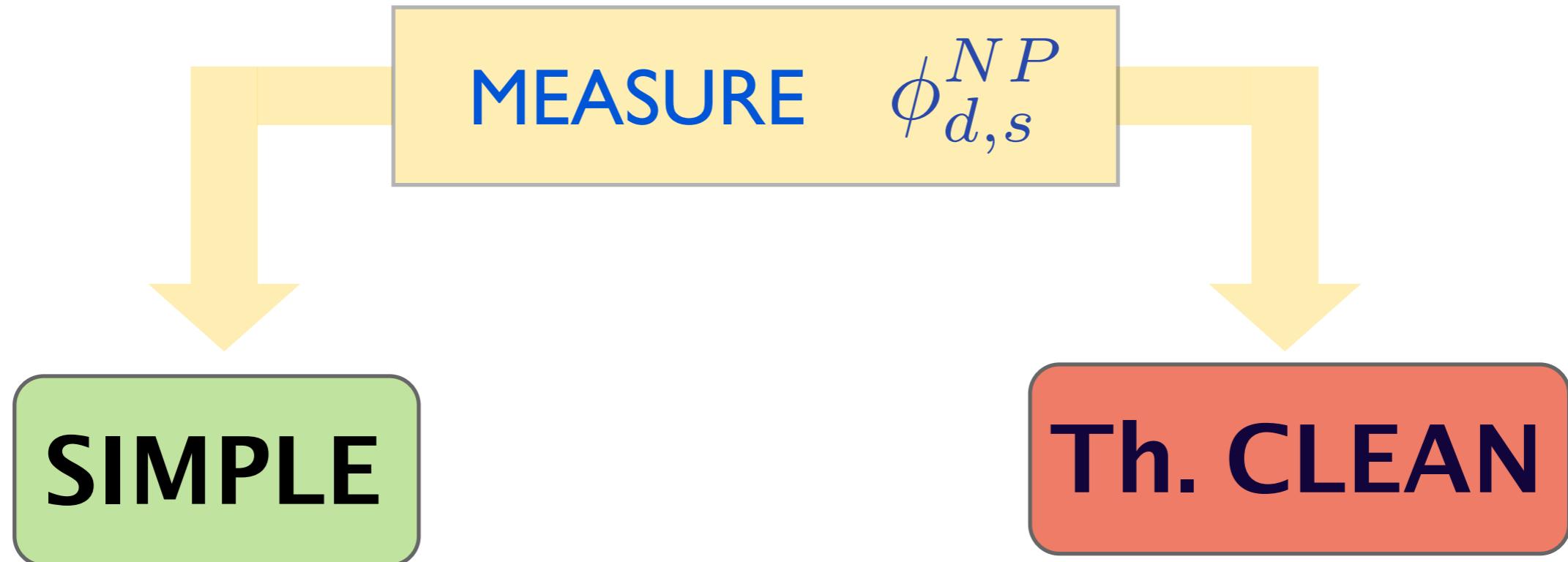
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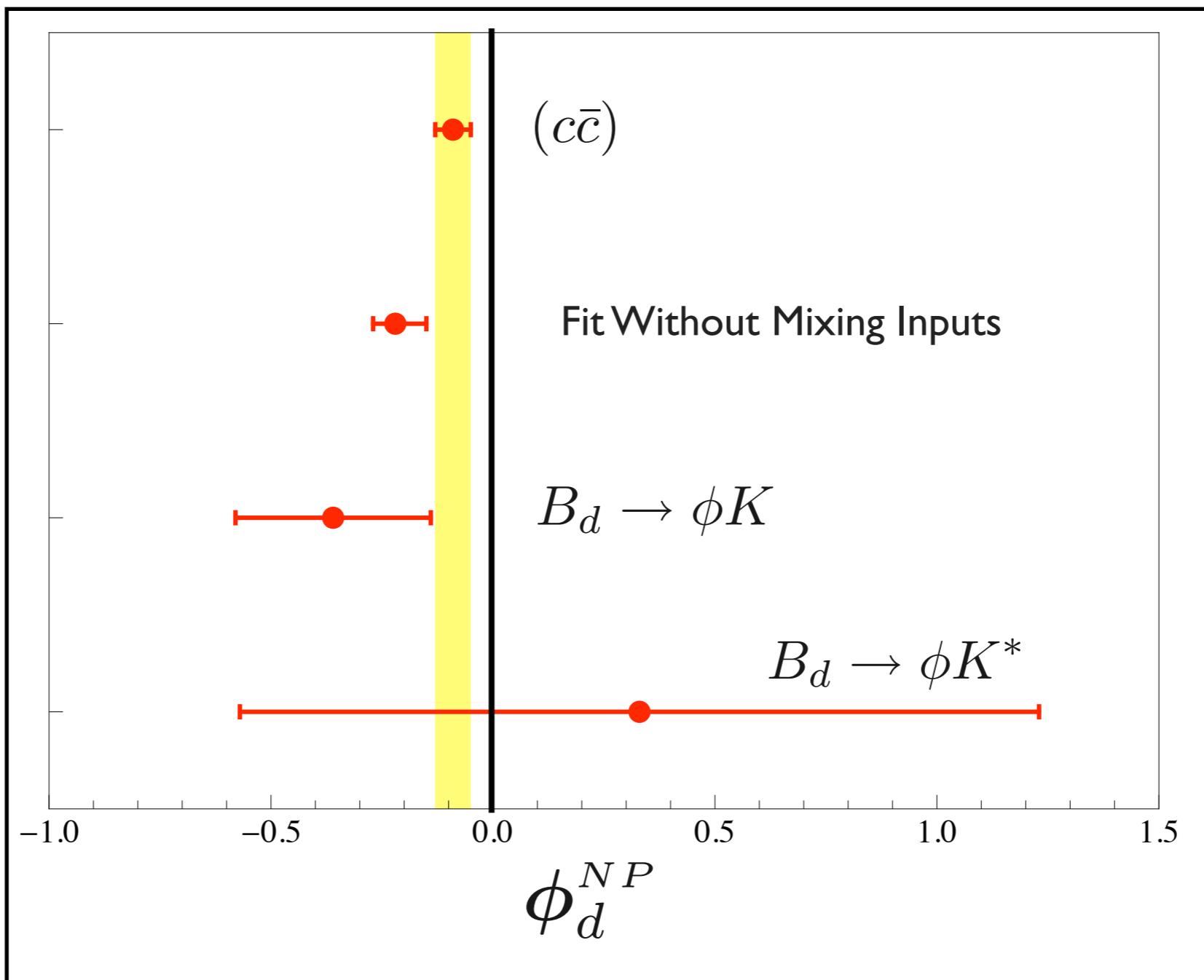


Measuring NP

OBJECTIVE:



Anticipated Results:



S. DESCOTES-GENON, J. MATIAS, J. VIRTO

Amplitude for hadronic B decay:

$$B_Q \rightarrow M_1 M_2 \quad (b \rightarrow q)$$

$$A(\bar{B}_Q \rightarrow M_1 M_2) = -\lambda_u^{(q)} T - \lambda_c^{(q)} P$$

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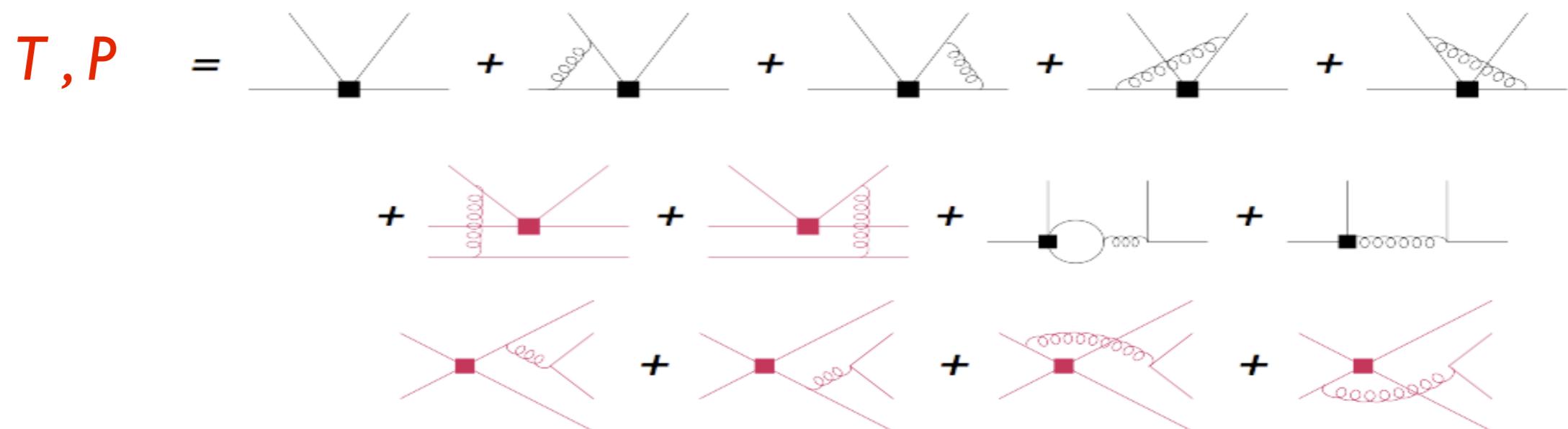
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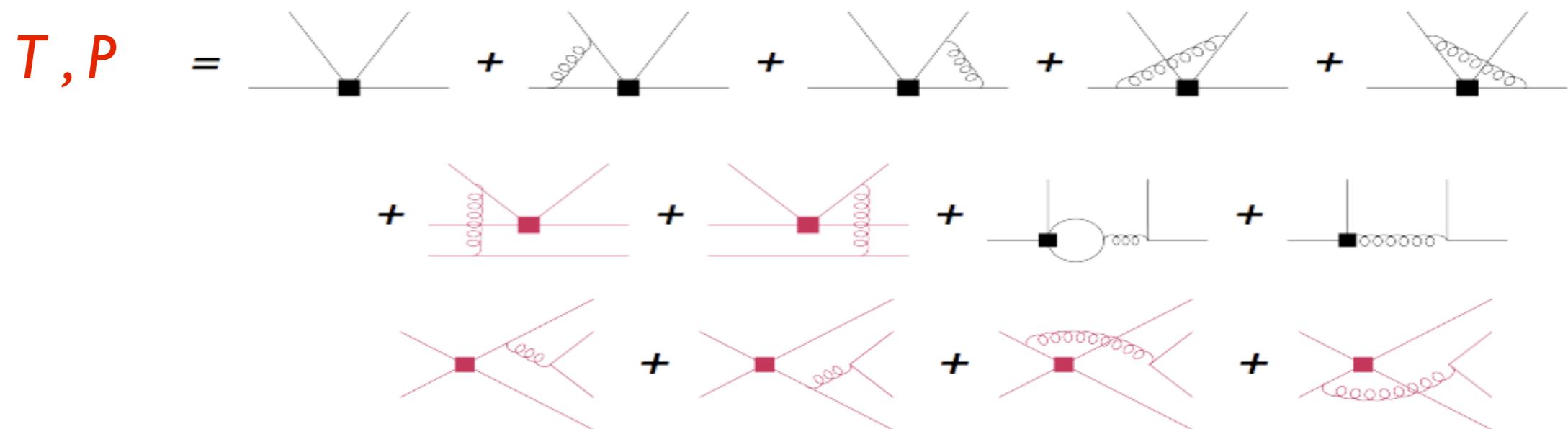
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HME from QCD Factorization:



IR (end-point) divergencies:

The diagram shows two diagrams for the analysis of IR divergencies. The left diagram shows a quark loop with a gluon insertion, and the right diagram shows a quark loop with two gluons. These diagrams are followed by a plus sign and the equation $\supset \int_0^1 \frac{dy}{\bar{y}} \Phi_{m_1}(y) = \Phi_{m_1}(1) X_H^{M_1} + \text{finite}$.

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KEY IDEA: Descotes-Genon, Matias, Virto, Phys.Rev.Lett. 97 (2006) 061801

$$\Delta \equiv T - P \quad \text{is FREE from IR divergencies*}$$

* For a list of selected penguin decays (see later)

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$$\Delta \equiv T - P \quad \text{is FREE from IR divergencies*}$$

If we can use Δ as the ONLY theoretical input
we obtain more RELIABLE and PRECISE
predictions

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List of selected penguin decays

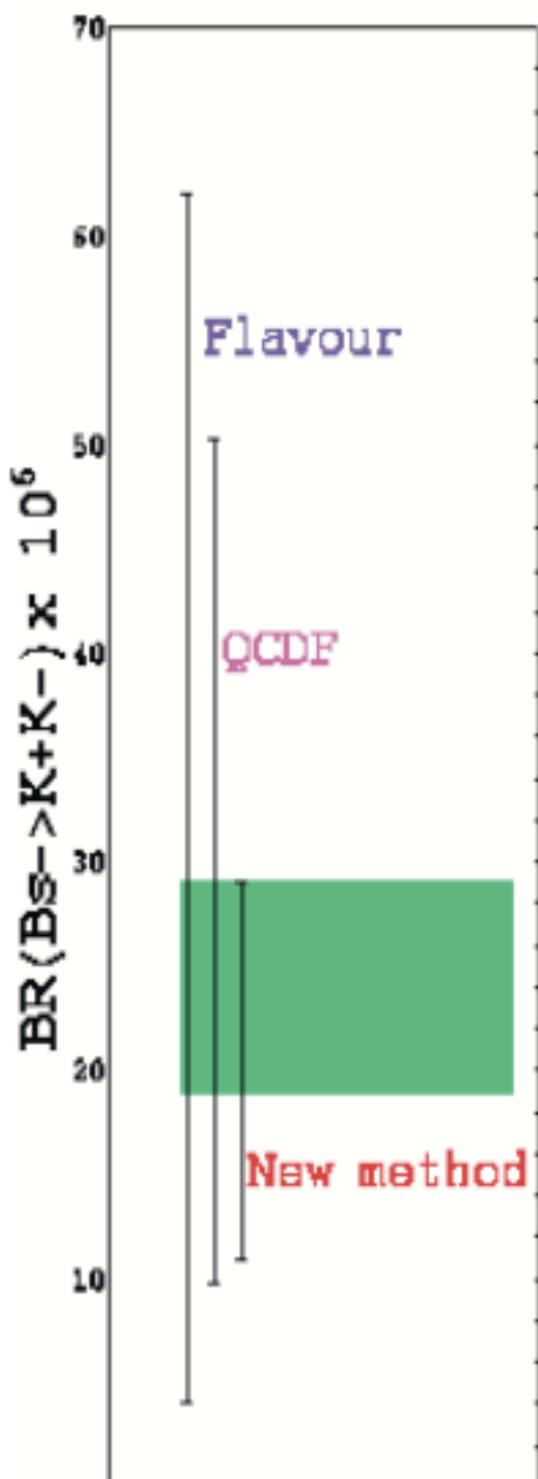
Channel	$ \Delta (10^{-7} \text{ GeV})$
$B_d \rightarrow KK$	(3.23 ± 1.16)
$B_s \rightarrow KK$	(3.05 ± 1.11)
$B_d \rightarrow \phi K$	(2.32 ± 1.00)
$B_d \rightarrow K^* K^*$	(1.85 ± 0.93)
$B_s \rightarrow K^* K^*$	(1.62 ± 0.81)
$B_d \rightarrow \phi K^*$	(1.92 ± 1.03)
$B_s \rightarrow \phi K^*$	(1.87 ± 0.94)
$B_s \rightarrow \phi \phi$	(3.86 ± 2.09)

- Our method was used to predict BR's and Asymmetries in $B_s \rightarrow K^+ K^-$ and $B_s \rightarrow K^0 \bar{K}^0$.

(Descotes-Genon, Matias, Virto, *Phys.Rev.Lett* 97 061801 (2006))

The outcome was quite promising.

- SU(3) methods suffer from large experimental uncertainties and cannot estimate SU(3)-breaking.
- QCDF has trouble with chirally enhanced $1/m_b$ suppressed contributions, which have to be modelled and introduce huge uncertainties.



EQUATION:

$$B_Q \rightarrow M_1 M_2 \ (b \rightarrow q)$$

$$\Phi_{Qq} = 2\beta_Q - 2\beta_q + \phi_Q^{\text{NP}}$$

(= ϕ^{NP} if $Q=q$)

$$2g_{ps}|\Delta|^2|\lambda_c^{(q)}|^2 \sin^2 \beta_q$$

$$= BR(1 - \eta_f \sin \Phi_{Qq} A_{\text{mix}} + \eta_f \cos \Phi_{Qq} A_{\Delta\Gamma})$$

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Theory

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OUTPUT

FORMULA:

$$\Phi_{Qq} = 2\beta_Q - 2\beta_q + \phi_Q^{\text{NP}}$$

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$$= BR(1 - \eta_f \sin \Phi_{Qq} A_{\text{mix}} + \eta_f \cos \Phi_{Qq} A_{\Delta\Gamma})$$



$$\sin \Phi_{Qq} = z \eta_f \hat{A}_{\text{mix}} \pm \sqrt{1 - z^2} \eta_f \hat{A}_{\Delta\Gamma}$$

$$\hat{A}_{\text{mix}}^2 + \hat{A}_{\Delta\Gamma}^2 = 1$$

Where: {

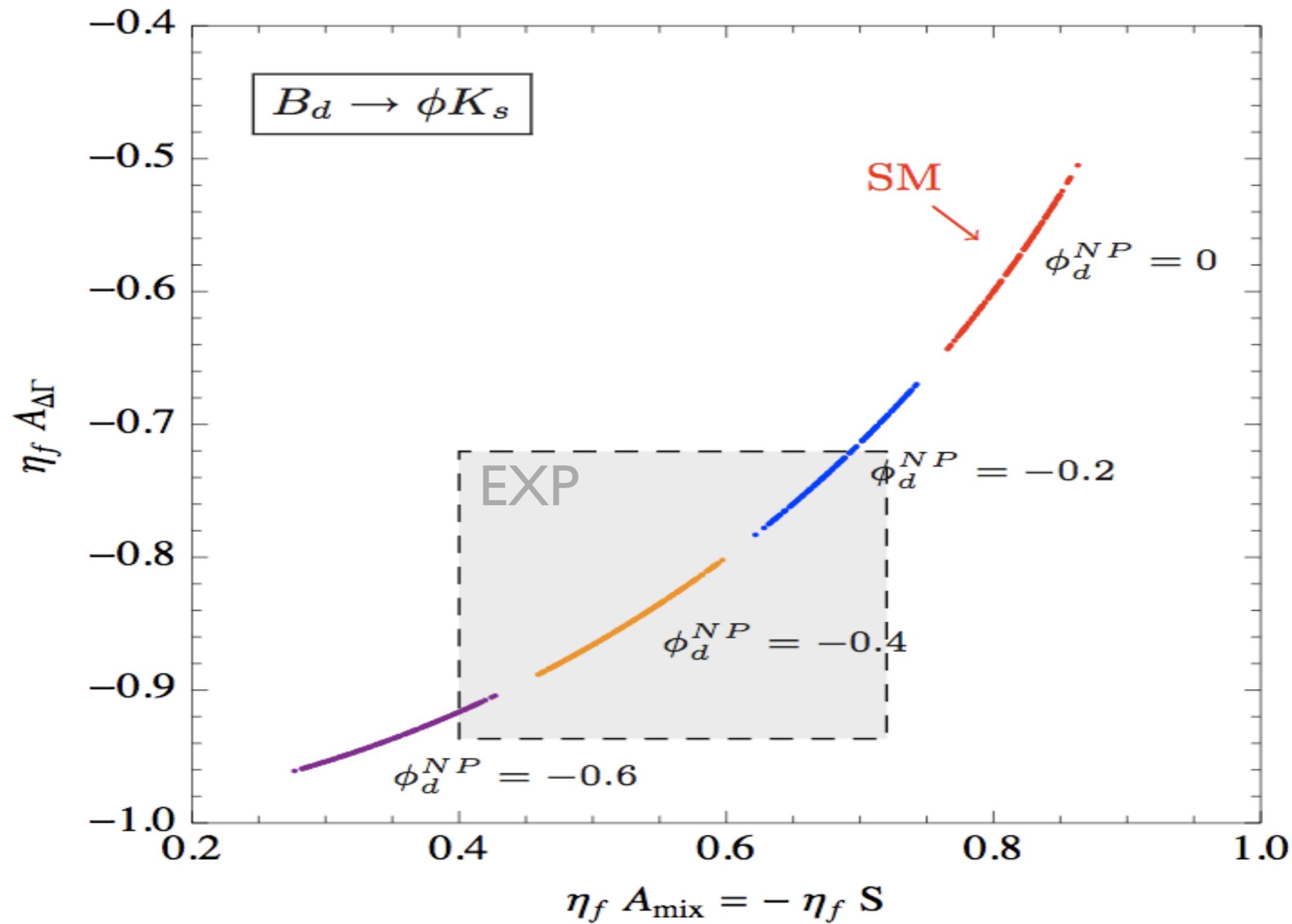
$$\hat{A}_{xxx} = A_{xxx}/\sqrt{1 - A_{dir}^2}$$

$$z = (1 - C)/\sqrt{1 - A_{dir}^2}$$

$$C = \frac{2 g_{ps} |\lambda_c|^2 \sin^2 \beta_q |\Delta|^2}{BR}$$

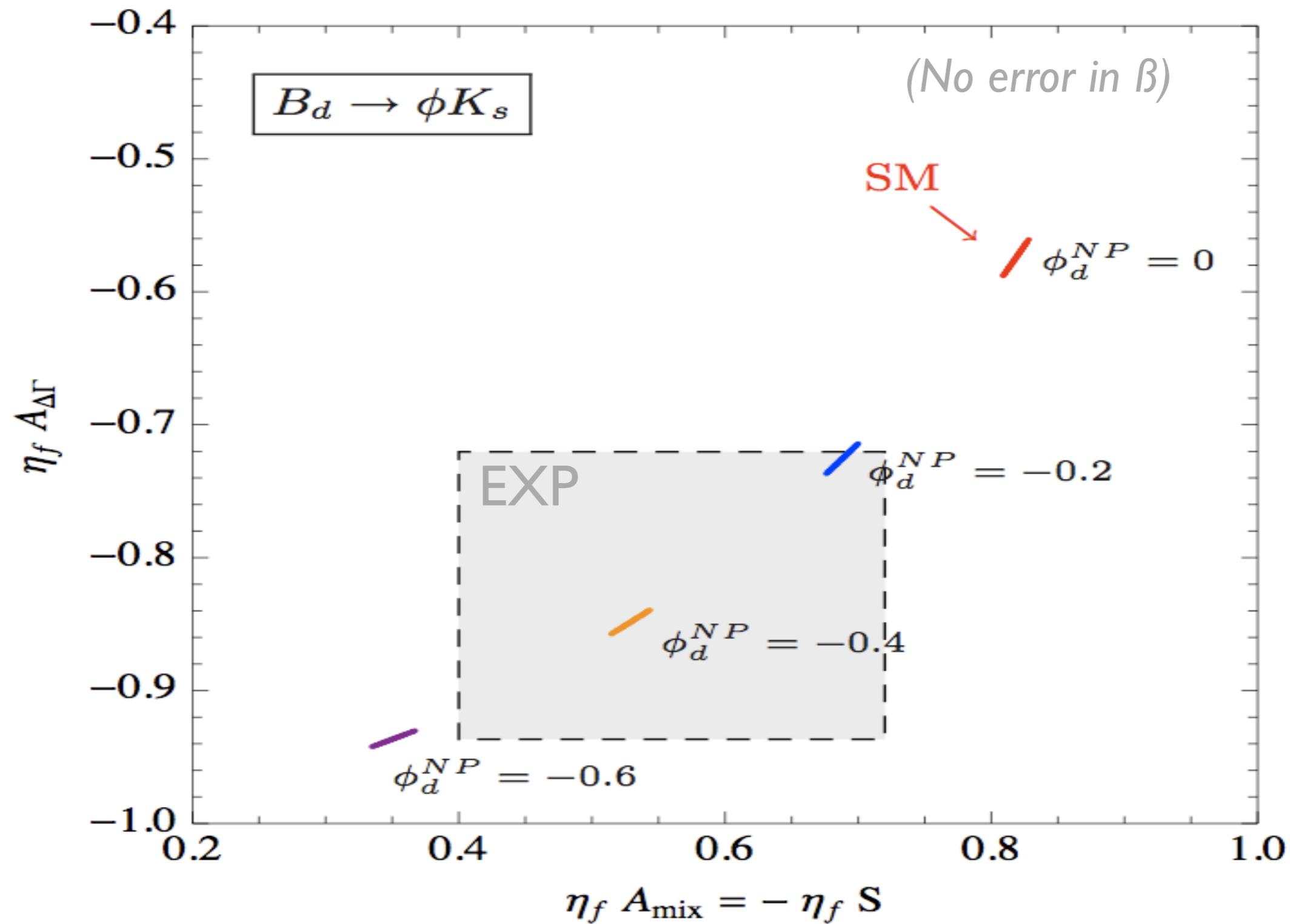
Channel	$ \Delta (10^{-7} \text{ GeV})$	$C \times BR (10^{-9} \text{ GeV}^2)$
$B_d \rightarrow KK$	(3.23 ± 1.16)	(29.8 ± 21.9)
$B_s \rightarrow KK$	(3.05 ± 1.11)	(1.21 ± 0.89)
$B_d \rightarrow \phi K$	(2.32 ± 1.00)	(0.74 ± 0.64)
$B_d \rightarrow K^* K^*$	(1.85 ± 0.93)	(9.37 ± 9.53)
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$B_s \rightarrow \phi K^*$	(1.87 ± 0.94)	(8.80 ± 8.96)
$B_s \rightarrow \phi \phi$	(3.86 ± 2.09)	(0.92 ± 1.00)

EXAMPLE I: $B \rightarrow VP$



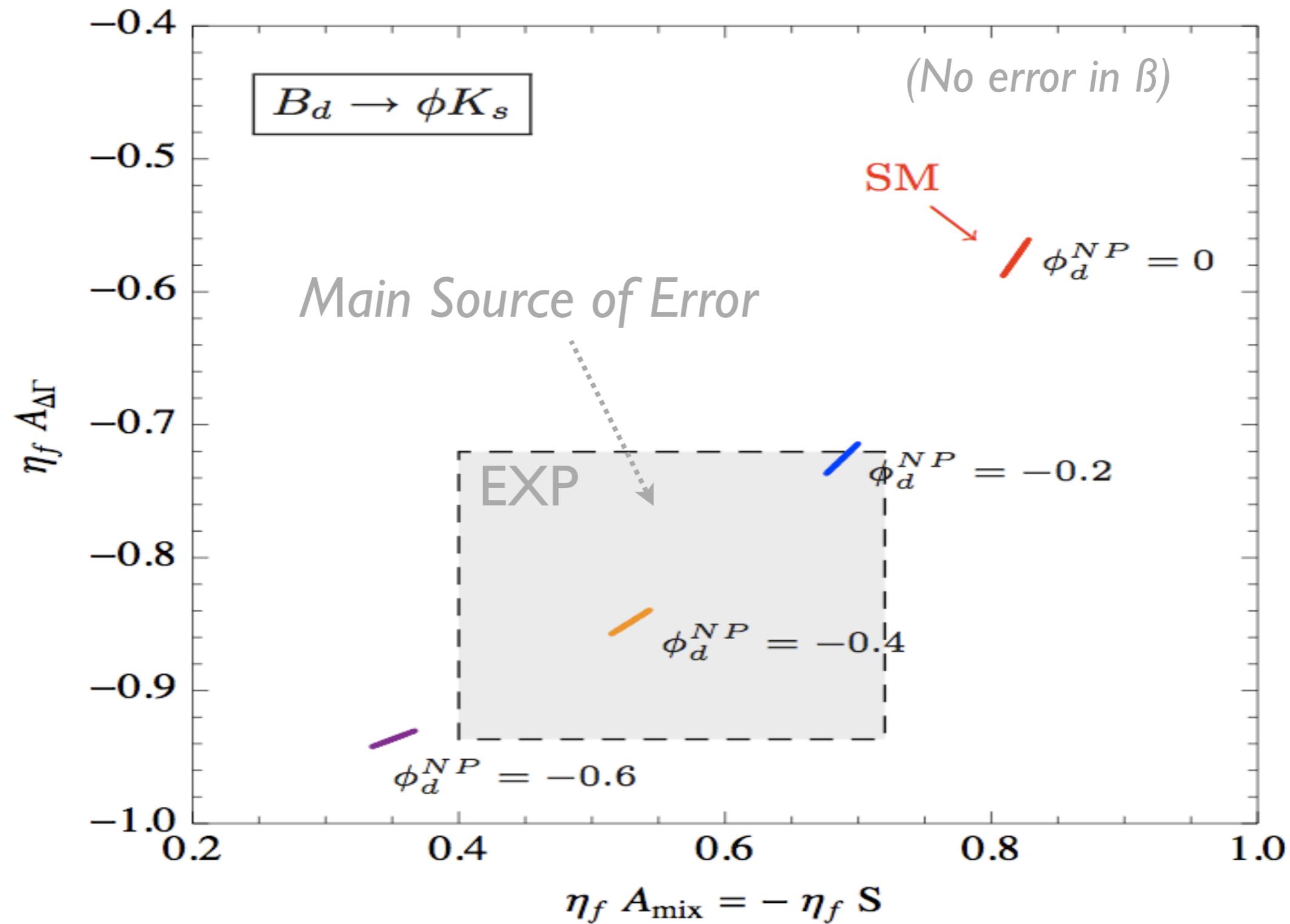
$$\phi_{d, \text{aver}}^{NP} = -0.36 \pm 0.22$$

EXAMPLE I: $B \rightarrow VP$



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EXAMPLE I: $B \rightarrow VP$

LHCb expectations: $(B_d \rightarrow \phi K_S)$

2/fb: $\sigma_S \sim 0.23$ (@14 TeV)

Xie, LHCb-2007-130

10/fb: $\sigma_S \sim 0.10$

Extrapolation:

$$N_{\text{sig}} = L_{\text{int}} \times \sigma_{b\bar{b}} \times 2 \times f_d \times BR^{\text{vis}} \times \epsilon_{\text{sig}}^{\text{tot}}$$

$$\sigma_{b\bar{b}}(14 \text{ TeV}) = 500 \mu b, \sigma_{b\bar{b}}(7 \text{ TeV}) = 75.3 \mu b$$

CERN-PH-EP-2010-029

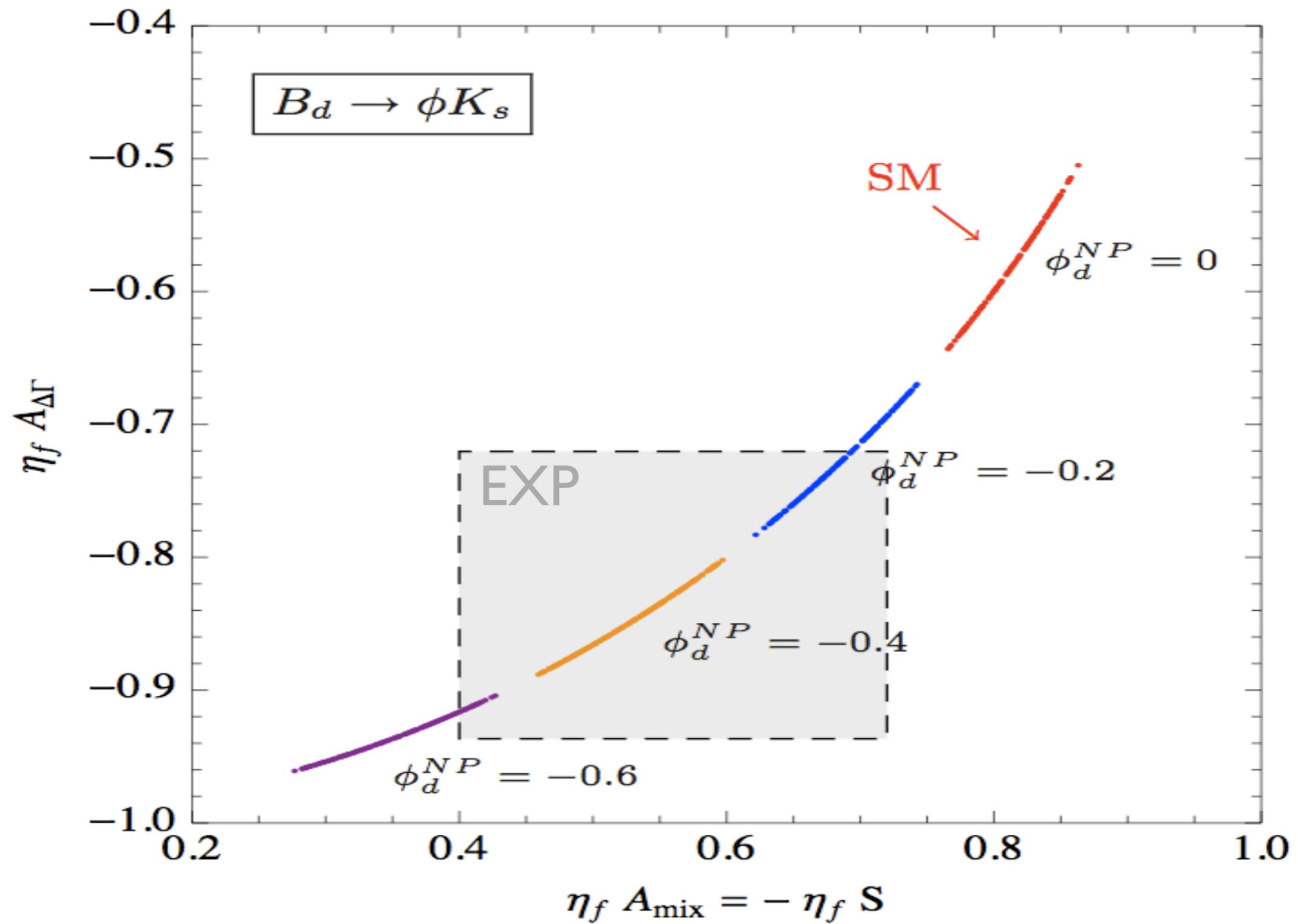
10/fb: $\sigma_S \sim 0.16$ $\Delta BR \sim 0.19$

100/fb: $\sigma_S \sim 0.05$ $\Delta BR \sim 0.06$

(Assuming the error is dominated by statistics)

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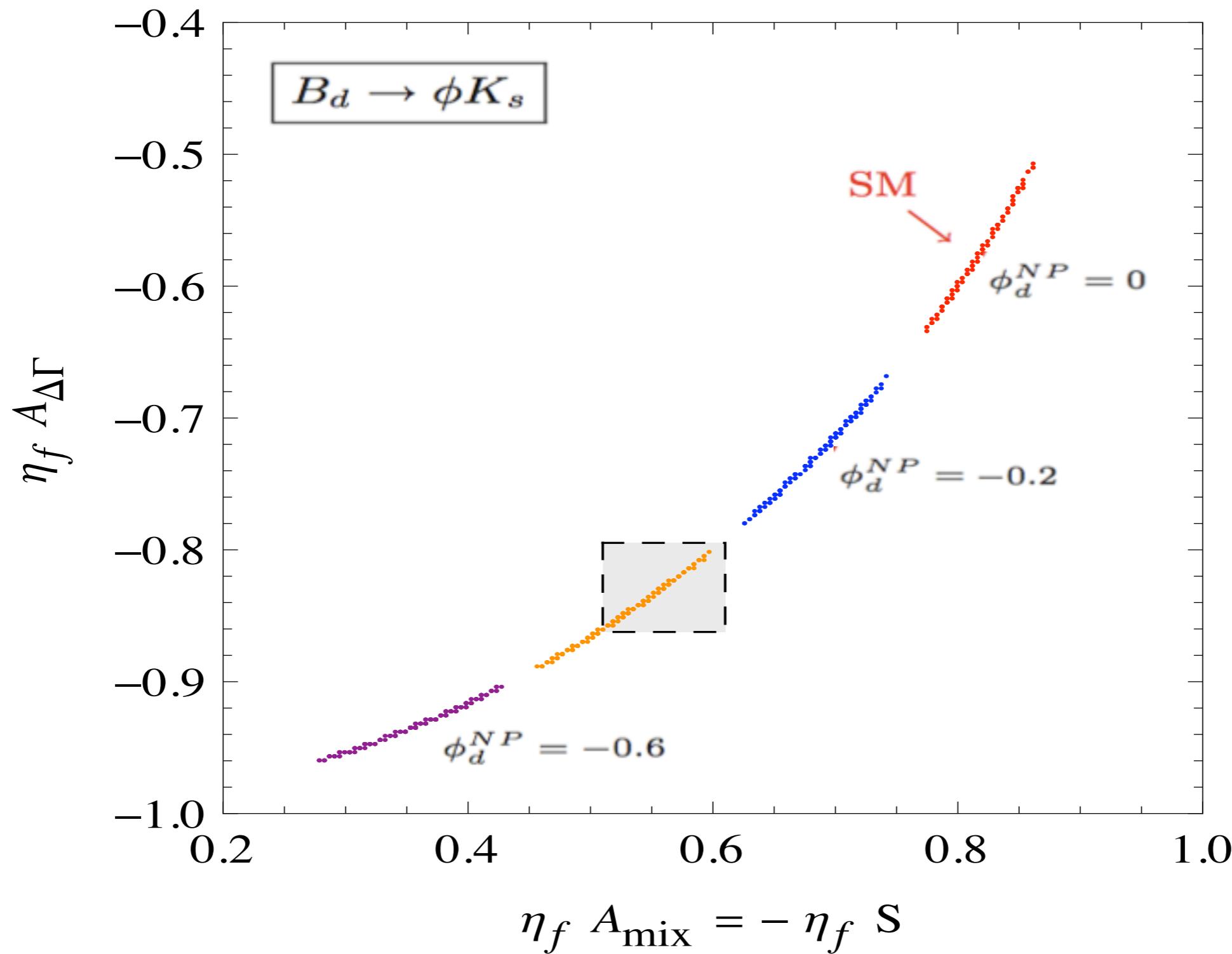
LHCb 10/fb



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EXAMPLE I: $B \rightarrow VP$

LHCb 100/fb



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EXAMPLE 2: $B \rightarrow VV$

Longitudinal Observables:

$$BR^{\text{long}} = g_{ps} \frac{|A_0|^2 + |\bar{A}_0|^2}{2} \quad A_{dir}^{\text{long}} = \frac{|A_0|^2 - |\bar{A}_0|^2}{|A_0|^2 + |\bar{A}_0|^2}$$
$$A_{\Delta\Gamma}^{\text{long}} + iA_{mix}^{\text{long}} = -2\eta \frac{e^{-i\phi_Q} A_0^* \bar{A}_0}{|A_0|^2 + |\bar{A}_0|^2}$$

How do we get these from experiment?

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Quantities extracted in the angular analysis:

$$BR = \frac{1}{2} \frac{1}{\Gamma_{\text{total}}} (\bar{\Gamma} + \Gamma) , \quad \mathcal{A}_{CP} = \frac{\bar{\Gamma} - \Gamma}{\bar{\Gamma} + \Gamma} ,$$

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Dictionary:

$$\left\{ \begin{array}{l} BR^{\text{long}} = BR \cdot f_L \cdot [1 + \mathcal{A}_{CP}^0 \cdot \mathcal{A}_{CP}] , \\ A_{\text{dir}}^{\text{long}} = -\frac{\mathcal{A}_{CP}^0 + \mathcal{A}_{CP}}{1 + \mathcal{A}_{CP}^0 \cdot \mathcal{A}_{CP}} , \\ A_{\text{mix}}^{\text{long}} = \eta \sqrt{1 - (A_{\text{dir}}^{\text{long}})^2} \sin(2\beta + \arg(A_0/\bar{A}_0)) , \\ A_{\Delta\Gamma}^{\text{long}} = -\eta \sqrt{1 - (A_{\text{dir}}^{\text{long}})^2} \cos(2\beta + \arg(A_0/\bar{A}_0)) \end{array} \right.$$

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Example: $B_d \rightarrow \phi K^*$

$$\begin{aligned} BR &= (9.8 \pm 0.7) \cdot 10^{-6}, & \mathcal{A}_{CP} &= 0.01 \pm 0.05, \\ f_L &= 0.48 \pm 0.03, & \mathcal{A}_{CP}^0 &= 0.04 \pm 0.06, \\ \Delta\phi_0 &= 0.28, \pm 0.42 & \Delta\delta_0 &= 0.27 \pm 0.16. \end{aligned}$$

(Babar&Belle)

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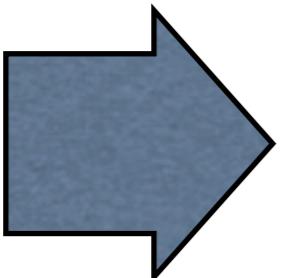
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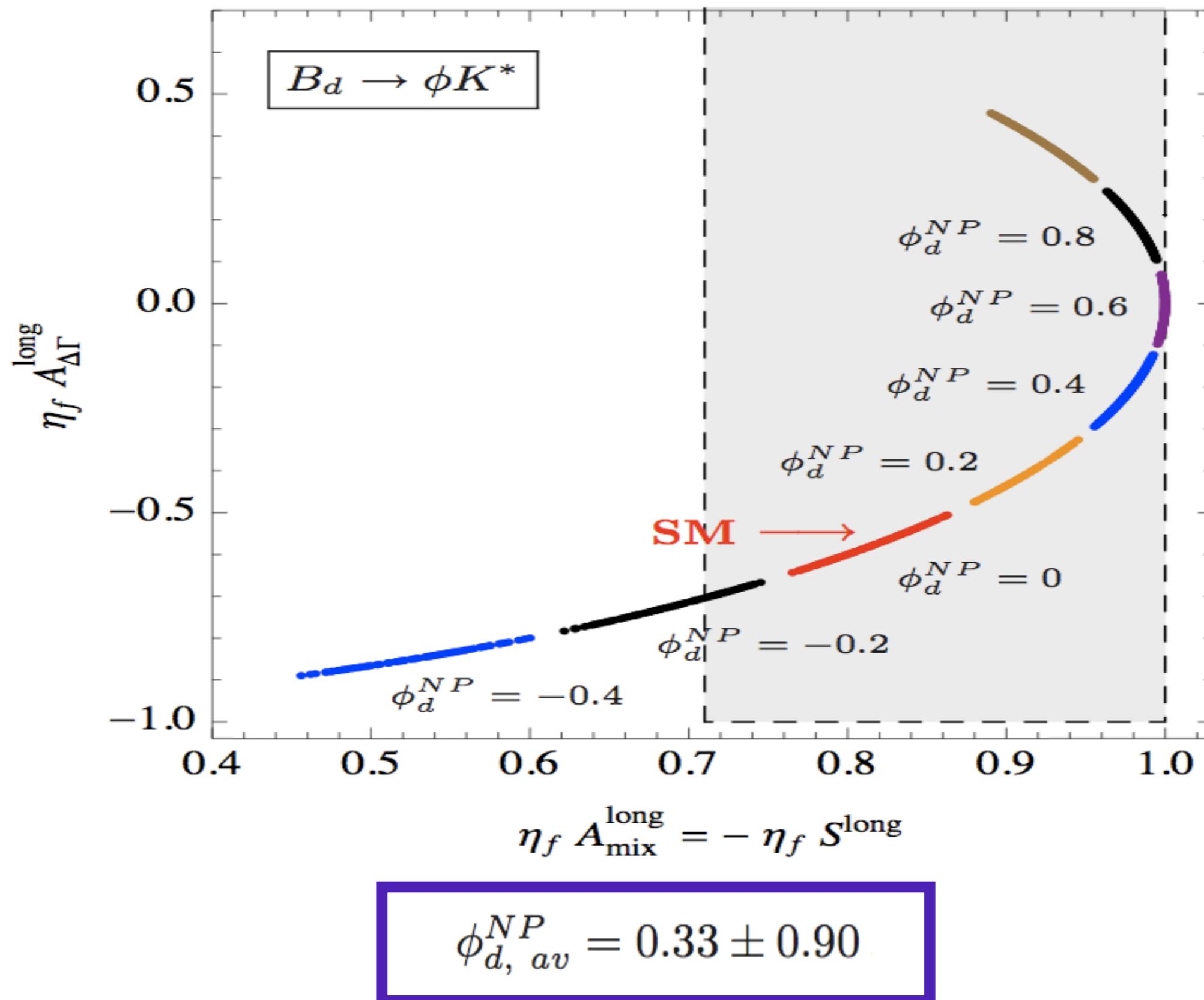


$$\begin{aligned} BR^{\text{long}} &= (4.7 \pm 0.4) \cdot 10^{-6}, \\ A_{\text{dir}}^{\text{long}} &= -0.05 \pm 0.08, \\ A_{\text{mix}}^{\text{long}} &= 0.96 \pm 0.25, \\ A_{\Delta\Gamma}^{\text{long}} &= \pm(0.27 \pm 0.86). \end{aligned}$$

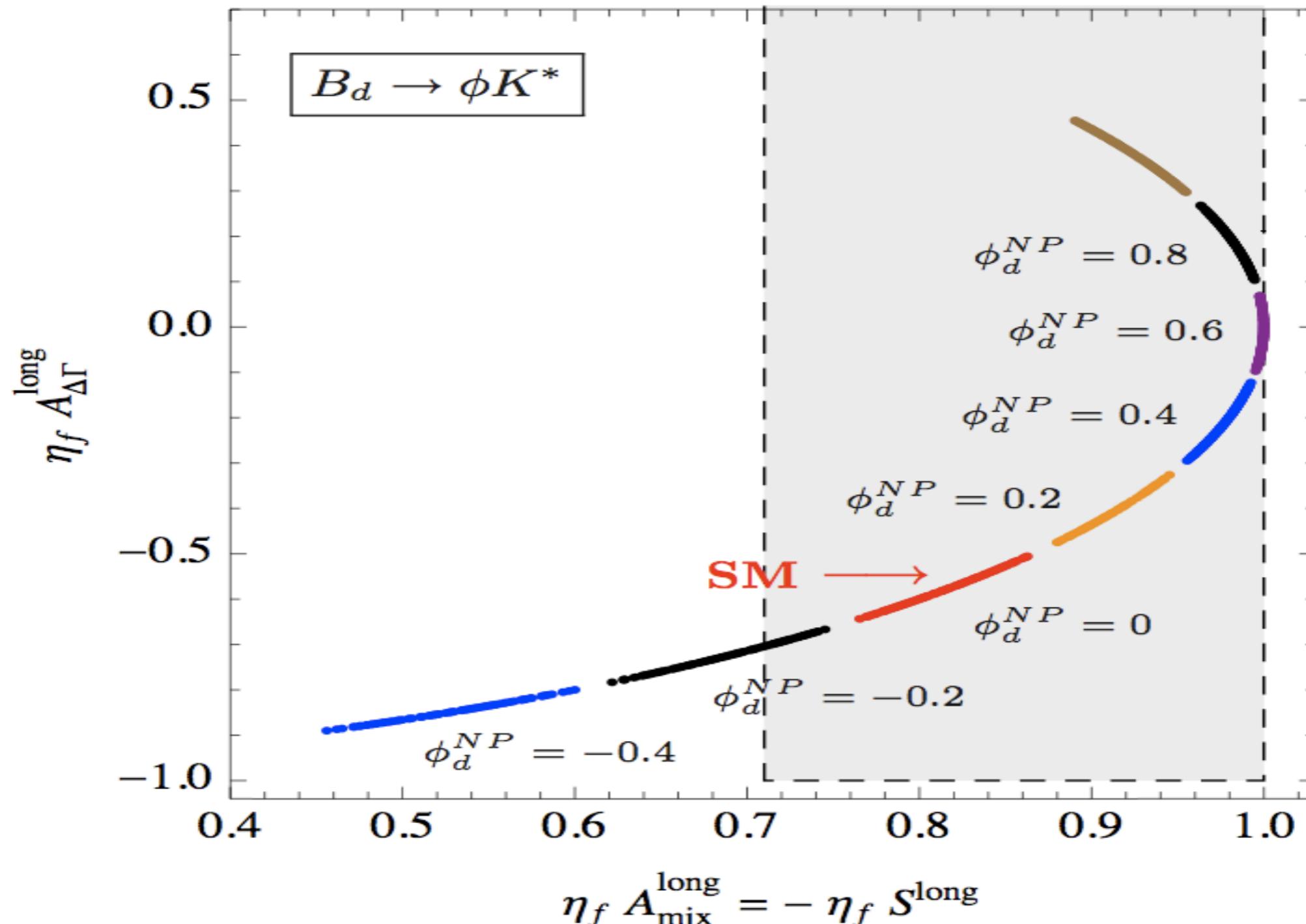
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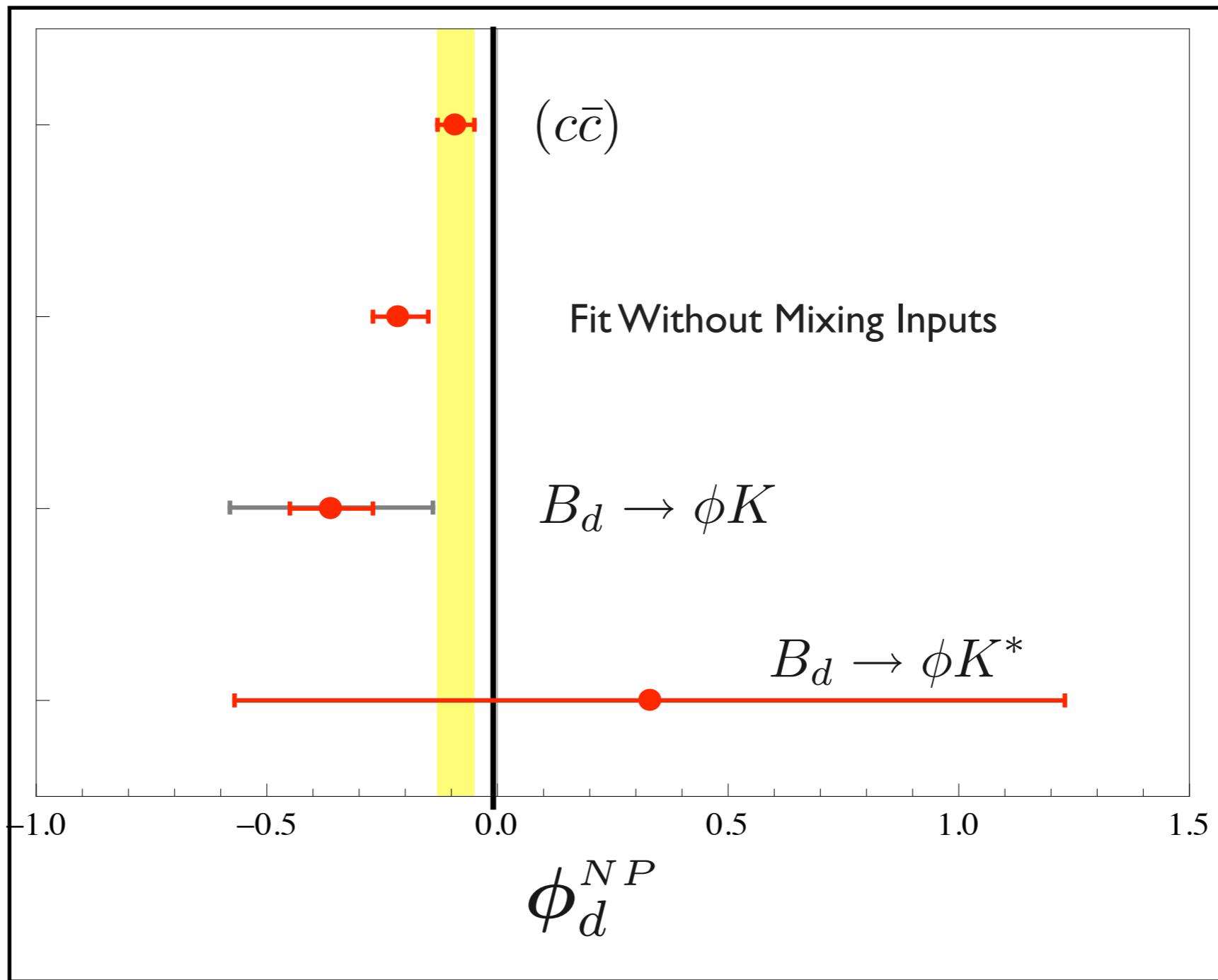
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What can LHCb do at 10/fb?

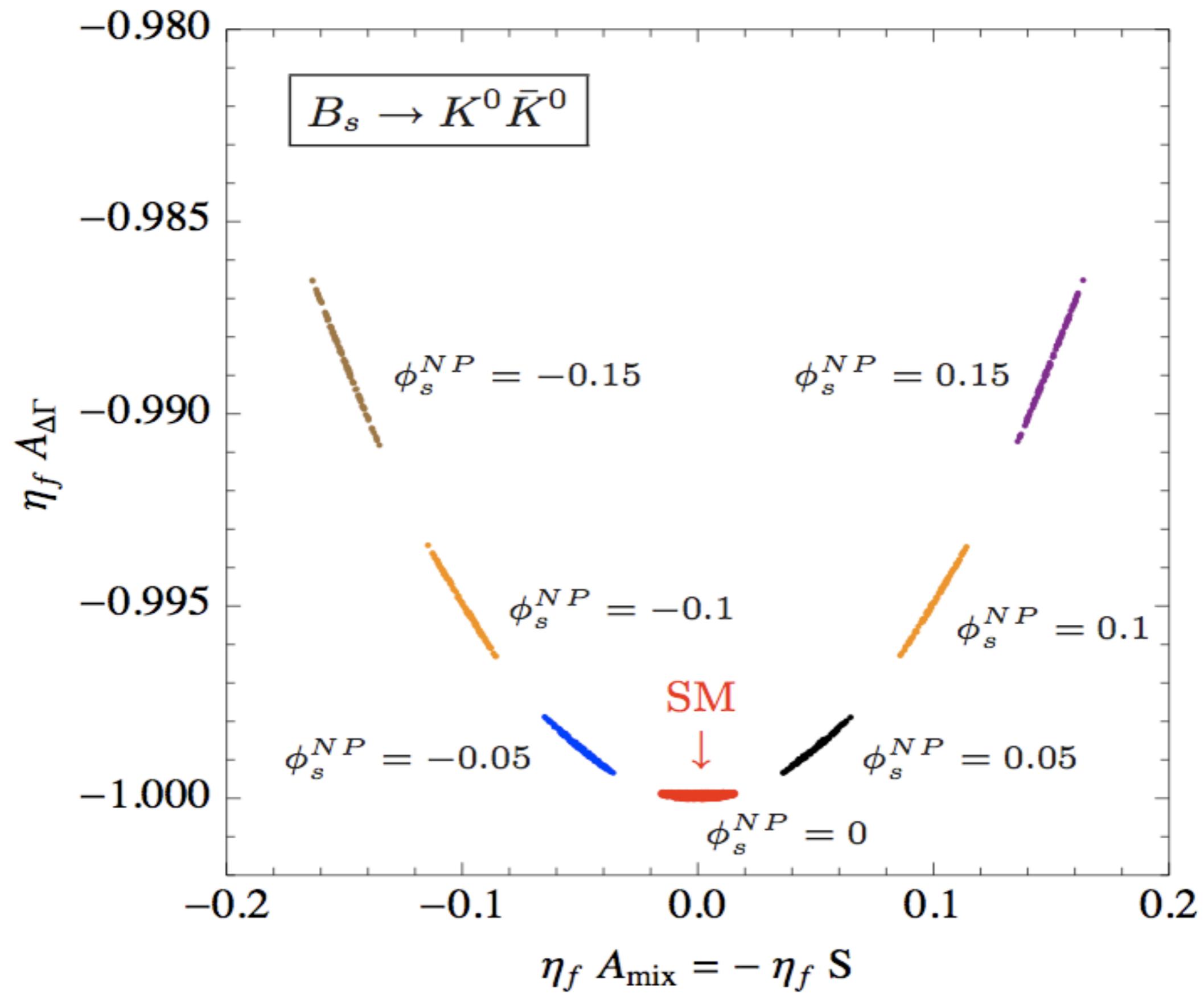


$$+ \begin{cases} B_d \rightarrow K^0 \bar{K}^0 \\ B_d \rightarrow K^{0*} \bar{K}^{0*} \end{cases}$$

+

The same for ϕ_s^{NP}

EXAMPLE 3: $B \rightarrow PP$



EXTRA: Rsd

With our method we can also give a SM prediction for Rsd:

$$R_{sd} \equiv \frac{BR^{\text{long}}(B_s \rightarrow K^{*0} \bar{K}^{*0})}{BR^{\text{long}}(B_d \rightarrow K^{*0} \bar{K}^{*0})}$$

$$\mathbf{R}_{sd}^{\text{DMV}} = 16.4 \pm 5.2$$

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LHCb Direct Meas. $R_{sd}^{\text{exp-I}} = (8.1 \pm 3.3) \times \left(\frac{f_L(B_s)}{0.31} \right) = 8.1 \pm 4.7$

LHCb with D π $R_{sd}^{\text{exp-II}} = (7.6 \pm 3.2) \times \left(\frac{f_L(B_s)}{0.31} \right) = 7.6 \pm 4.5$

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-Extrapolating Stat. Error at LHCb with 10/fb (Only Bs!!): $\sigma(R_{sd}) \sim 3.2$



SUMMARY

Theoretically CLEAN hadronic quantity:

$$\Delta \equiv T - P$$

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For any NP affecting only the MIXING:

$$2g_{ps}|\Delta|^2 |\lambda_c^{(q)}|^2 \sin^2 \beta_q$$

$$= BR(1 - \eta_f \sin \Phi_{Qq} A_{\text{mix}} + \eta_f \cos \Phi_{Qq} A_{\Delta\Gamma})$$

$$\sin \Phi_{Qq} = z \eta_f \hat{A}_{\text{mix}} \pm \sqrt{1-z^2} \eta_f \hat{A}_{\Delta\Gamma}$$

EXACT FORMULA

Theoretically CLEAN hadronic quantity:

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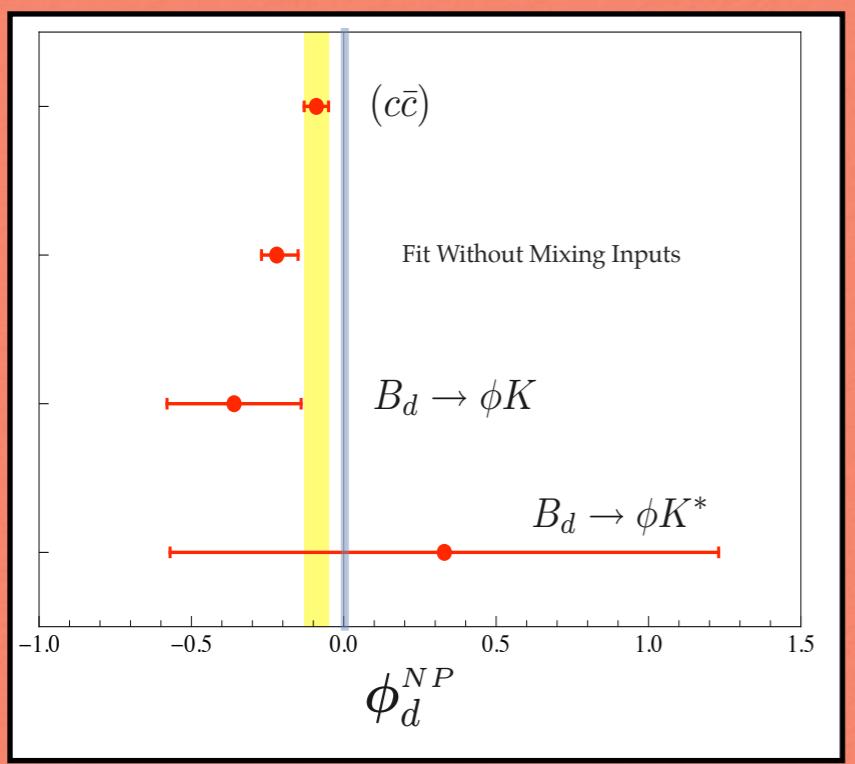
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EXACT FORMULA

Results:



Theoretically CLEAN hadronic quantity: $\Delta \equiv T - P$

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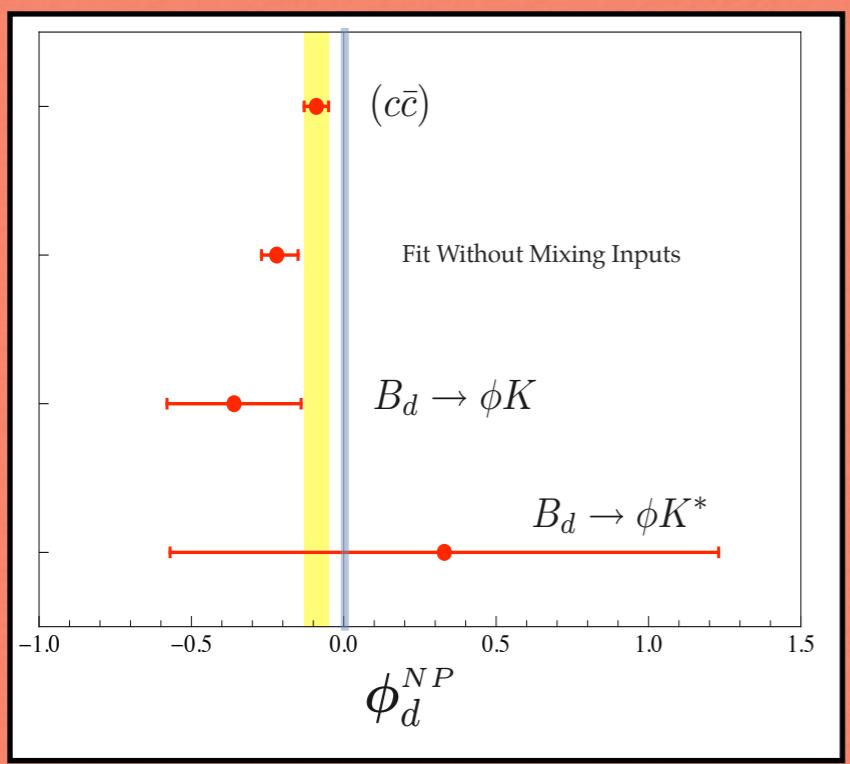
$$2g_{ps}|\Delta|^2 |\lambda_c^{(q)}|^2 \sin^2 \beta_q$$

$$= BR(1 - \eta_f \sin \Phi_{Qq} A_{\text{mix}} + \eta_f \cos \Phi_{Qq} A_{\Delta\Gamma})$$

$$\sin \Phi_{Qq} = z \eta_f \hat{A}_{\text{mix}} \pm \sqrt{1-z^2} \eta_f \hat{A}_{\Delta\Gamma}$$

EXACT FORMULA

Results:



Objectives: Complete the list of Decays

The same for ϕ_s^{NP}

SUMMARY

Theoretically CLEAN hadronic quantity: $\Delta \equiv T - P$

For any NP affecting only the MIXING:

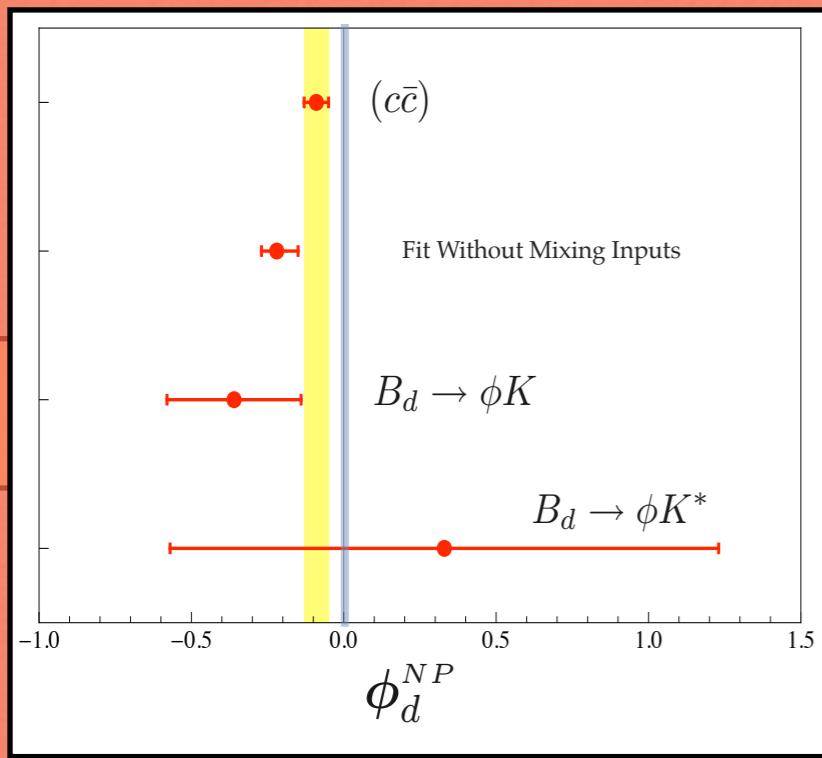
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EXACT FORMULA

Results:



Objectives: Complete the list of Decays

The same for ϕ_s^{NP}

Results for $B_s^- \rightarrow K^{0*} \bar{K}^{0*}$

$$R_{sd}^{\text{DMV}} = 16.4 \pm 5.2$$

$$R_{sd}^{\text{QCDF}} = 13.8 \pm 19.2$$

LHCb ---> very soon