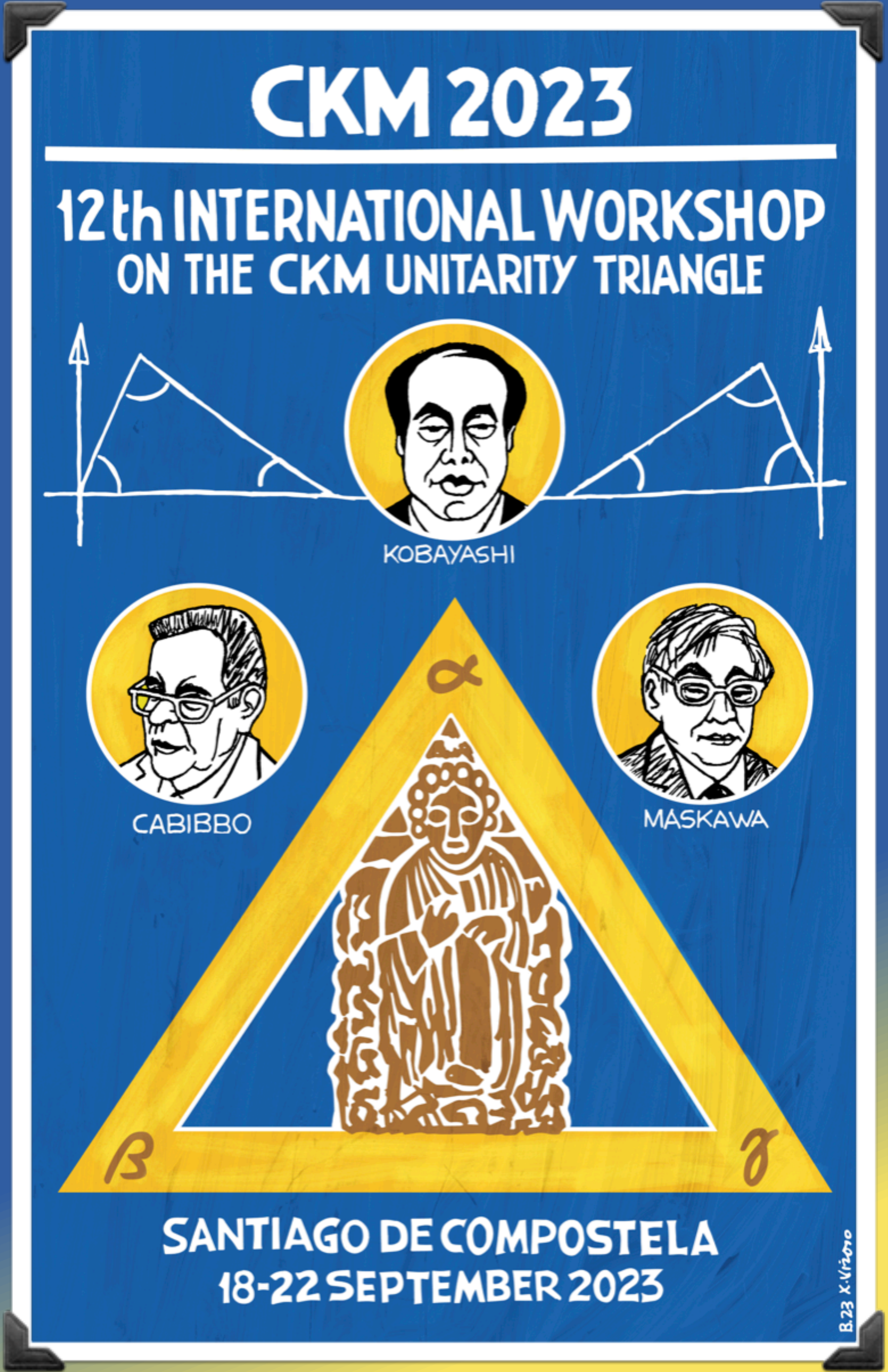

New Physics in $B_q - \bar{B}_q$ Mixing in connection with CKM angle γ

The talk is based on:

Journal of Physics G: Nuclear and Particle Physics,
Volume 50, Number 4
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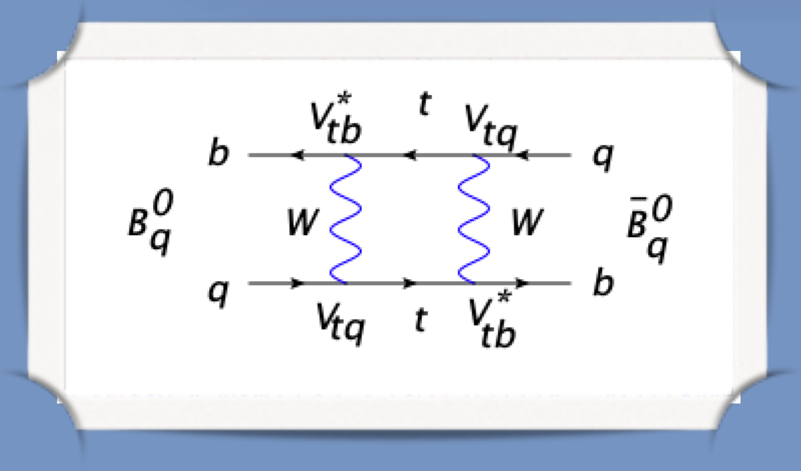
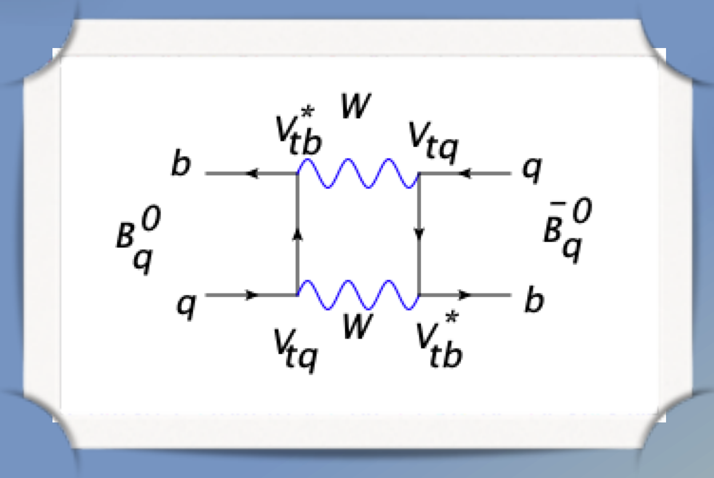
Theoretical Particle Physics Group

Center for Particle Physics Siegen
Universität Siegen
Nikhef

Introduction

Neutral Meson Mixing





Important quantities

ϕ_d and ϕ_s mixing phases

$$\boxed{|B_q(t)\rangle = a(t)|B_q^0\rangle + b(t)|\overline{B_q^0}\rangle}$$

Schrödinger equation → Mass eigenstates

Time-dependent decay rates:
characterised by
mass difference ΔM_q

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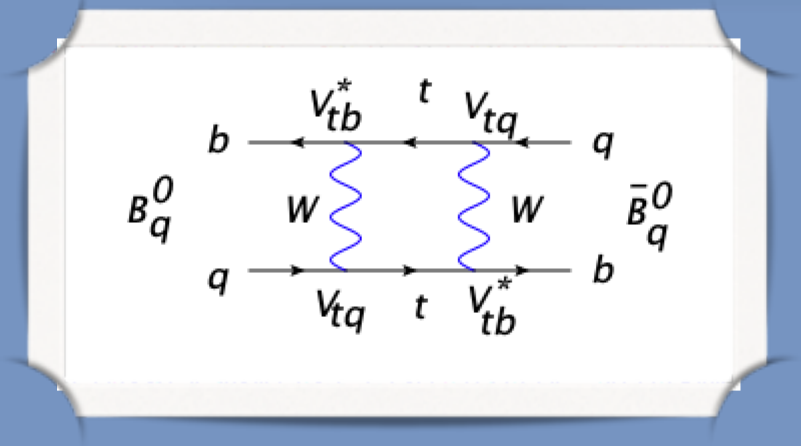

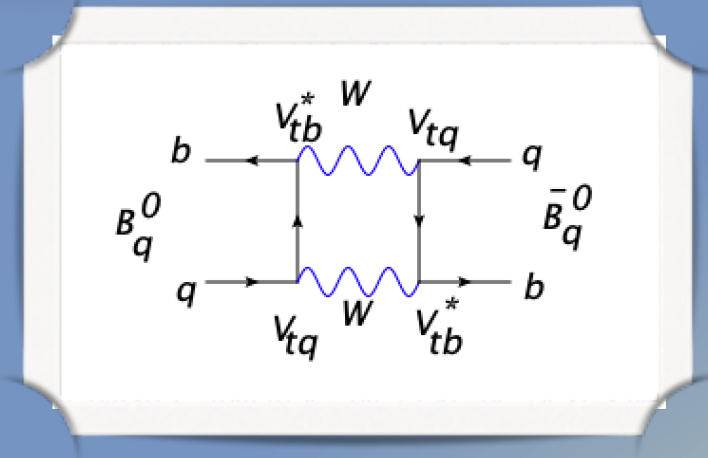

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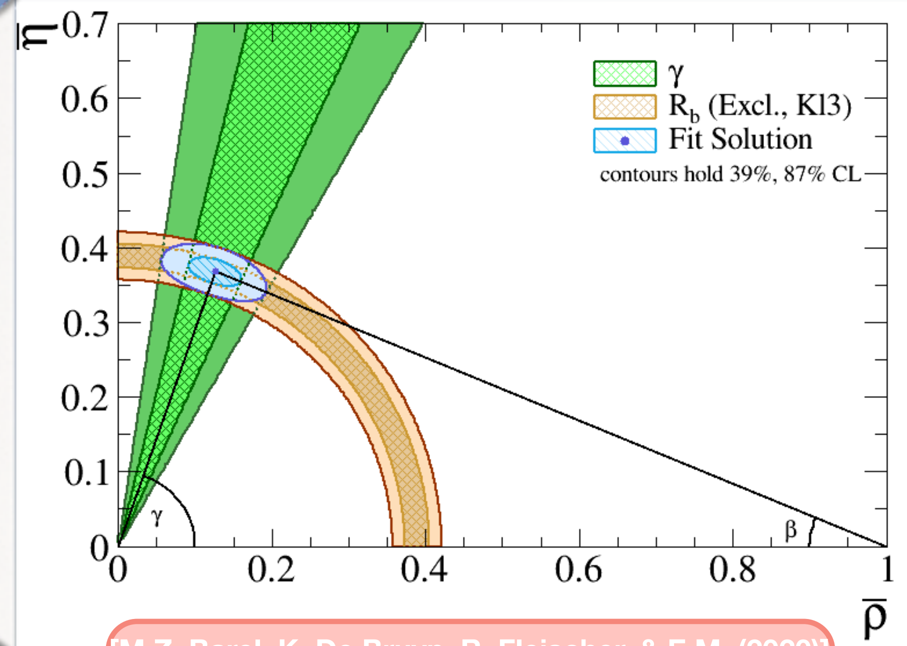
Unitarity Triangle



[M.Z. Barel, K. De Bruyn, R. Fleischer, & E.M. (2020)]

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Wolfenstein parameters

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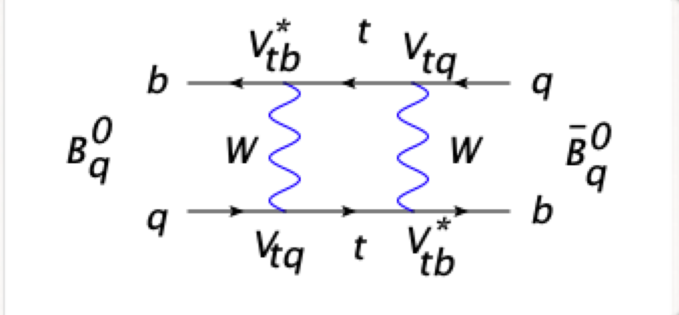

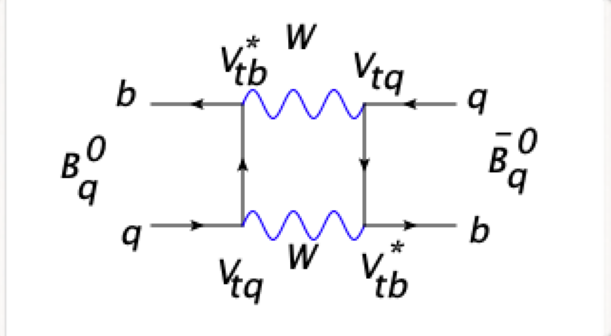

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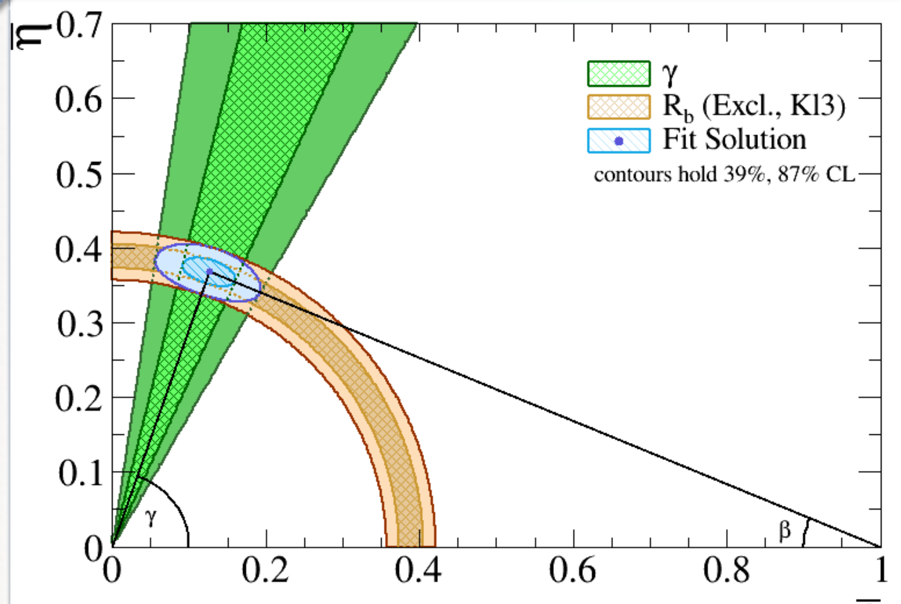

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determined from decays
that proceed only via tree topologies

We will focus on the following topics

- UT determination
- Special attention: to determination of CKM input parameters

- Constraining the New Physics parameters of $B_q^0 - \bar{B}_q^0$ mixing

- Application in the analysis of rare leptonic decays
- Minimising CKM parameters impact in NP searches

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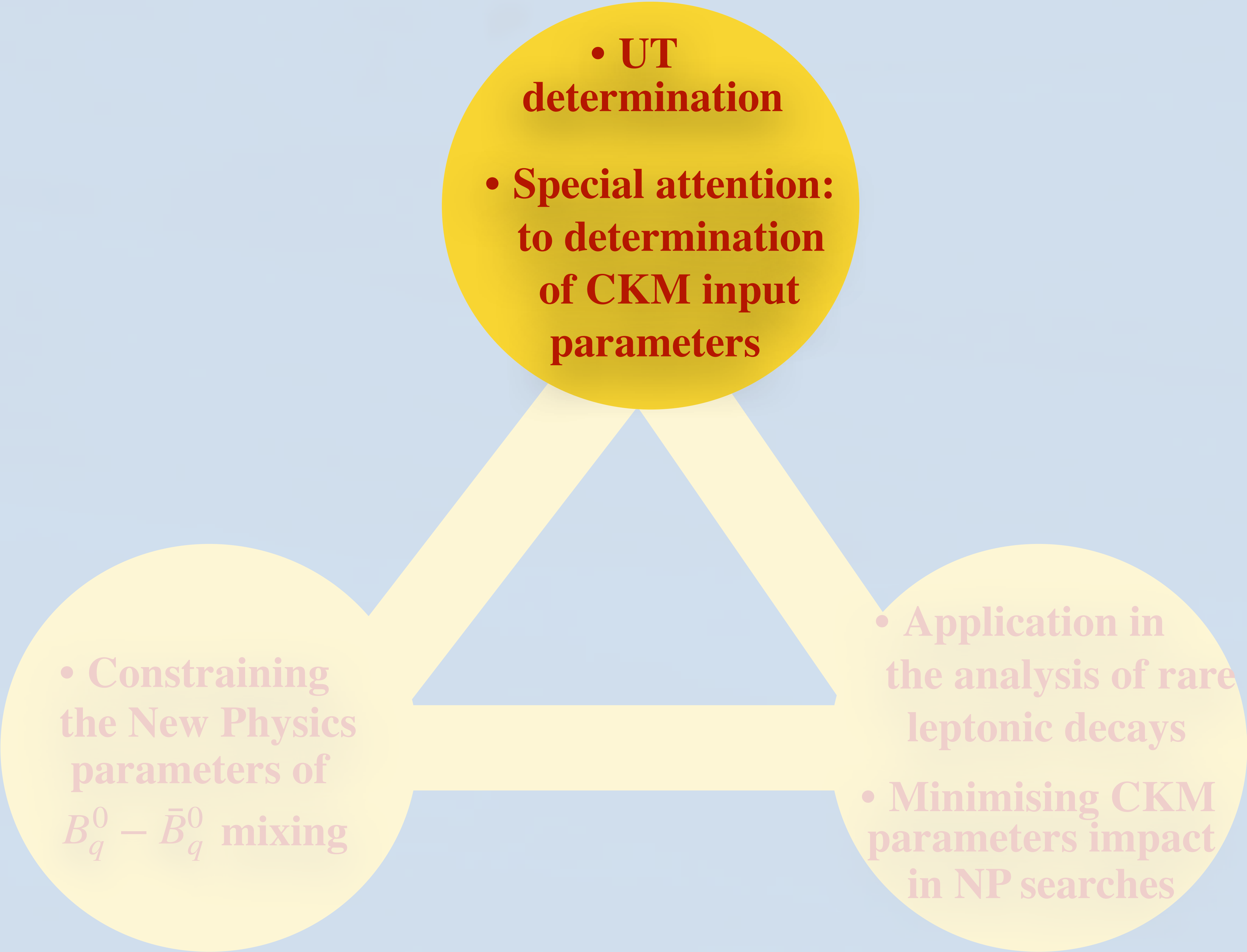

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$\boxed{\text{sensitivity to } \gamma}$ → $\boxed{\text{from direct CP violation}}$

$$\left.\right\} \quad \boxed{\gamma_{B\to DK} = (64.9 \pm 4.5)^\circ}$$

LHCb [2110.02350]

assume
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input $\phi_s = -0.052 \pm 0.020 = (-3.0 \pm 1.1)^\circ$

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[R. Fleischer and E.M. (2021)]

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Performing Penguin Fit

SU(3) relation → $a' e^{i\theta'} = a e^{i\theta}$ **penguin parameters**

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[S. Faller, M. Jung, R. Fleischer & T. Mannel (2009)]
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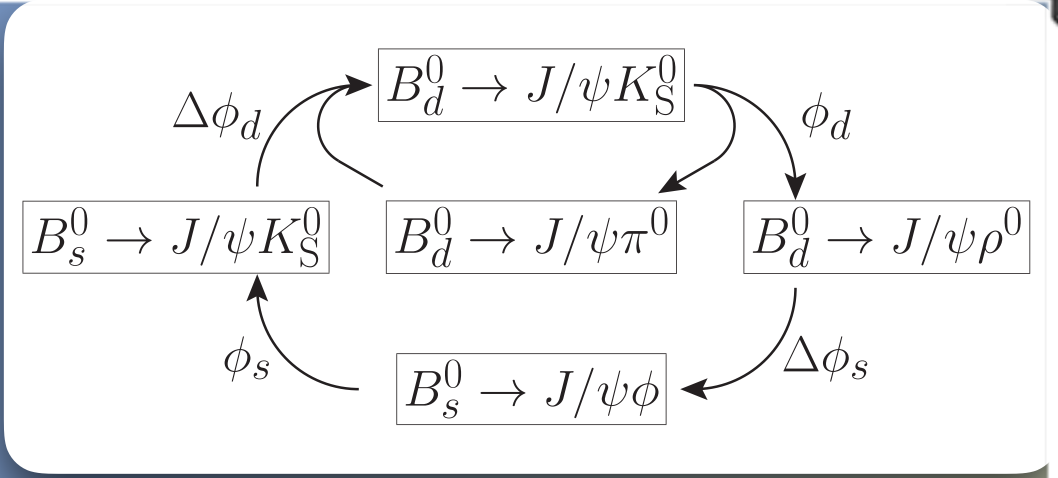

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Control channels:
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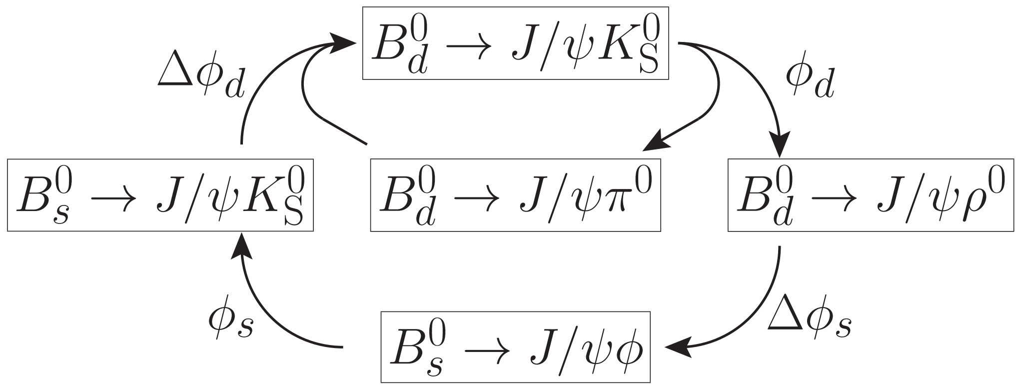

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$$a = 0.12^{+0.17}_{-0.11}\,, \qquad \theta = \left(185^{+50}_{-43}\right)^\circ\,, \qquad \phi_d = \left(45.4^{+1.3}_{-1.1}\right)^\circ$$

$$a_V = 0.053^{+0.084}_{-0.041}\,, \qquad \theta_V = \left(310^{+\ 41}_{-109}\right)^\circ\,, \qquad \phi_s = (-3.0 \pm 1.1)^\circ$$

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$$\phi_s^{\text{eff}} = -0.049 \pm 0.017 = (-2.81 \pm 0.97)^\circ$$

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The effective mixing angle determined from $B_s^0 \to J/\psi \phi$

Updating [J. Phys. G: Nucl. Part. Phys. 48 (2021) 065002]

using new LHCb [2308.01468] **full Run 2 data**

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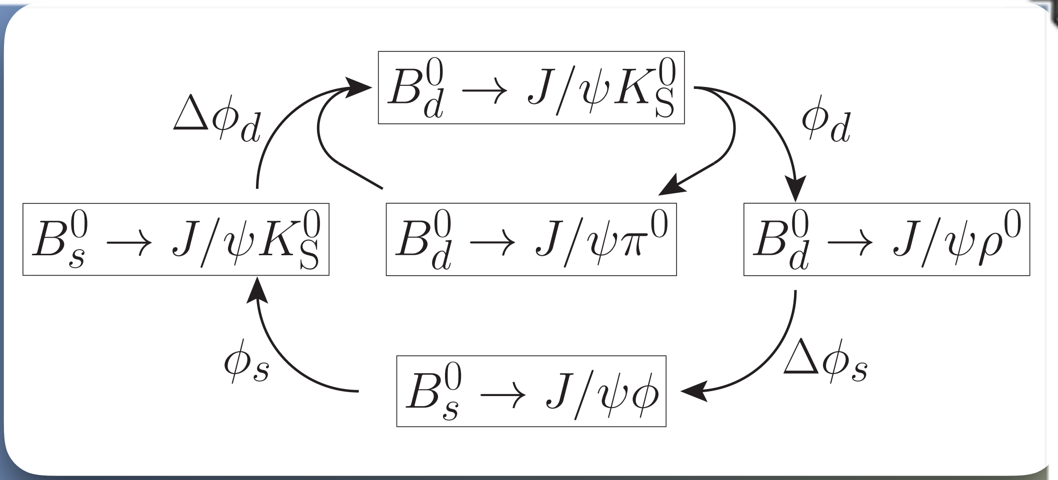

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The effective mixing angle determined from $B_d^0 \to J/\psi K_S$

and the corresponding CP asymmetries

Updating [J. Phys. G: Nucl. Part. Phys. 48 (2021) 065002]

using new LHCb [LHCb-PAPER-2023-013] **and Belle II** [2302.12898] **data**

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Using ϕ_d the UT angle α is converted into γ

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$$\lambda \equiv |V_{us}|, |V_{ub}| \text{ and } |V_{cb}|$$

$$|V_{us}| = 0.22309 \pm 0.00056$$

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Tensions between inclusive and exclusive determinations of V_{ub} and V_{cb}

HFLAV(2022), arXiv:2107.00604 arXiv:0707.2493

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HFLAV(2022)

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$$|V_{cb}|_{\text{incl}} = (42.16 \pm 0.50) \times 10^{-3}$$

$$|V_{cb}|_{\text{excl}} = (39.10 \pm 0.50) \times 10^{-3}$$

HFLAV(2022)

$$R_{b,\text{incl}} = 0.434 \pm 0.018$$

$$R_{b,\text{excl}} = 0.392 \pm 0.014$$

In the literature → Third possibility

hybrid combination

of exclusive $|V_{ub}|$ with inclusive $|V_{cb}|$

$$R_b(|V_{ub}^{\text{excl}}|, |V_{cb}^{\text{incl}}|) = 0.364 \pm 0.013$$

How can we determine the Unitarity Triangle Apex?

1) Utilising γ and R_b

i) Obtaining the value of γ

Average →

$$\gamma_{\rm avg} = (68.2 \pm 3.3)^\circ$$

ii) Obtaining the value of R_b

→ **tensions** between various theoretical & experimental approaches

$$R_b \equiv \left(1 - \frac{\lambda^2}{2}\right) \frac{1}{\lambda} \left|\frac{V_{ub}}{V_{cb}}\right| = \sqrt{\bar\rho^{\,2} + \bar\eta^{\,2}}$$

$$\lambda \equiv |V_{us}|, |V_{ub}| \text{ and } |V_{cb}|$$

$$|V_{us}| = 0.22309 \pm 0.00056$$

Tensions between inclusive and exclusive determinations of V_{ub} and V_{cb} → **Important to study inclusive and exclusive case separately**

HFLAV(2022), arXiv:2107.00604 arXiv:0707.2493

$$|V_{ub}|_{\rm incl} = (4.19 \pm 0.17) \times 10^{-3}$$

$$|V_{ub}|_{\rm excl} = (3.51 \pm 0.12) \times 10^{-3}$$

HFLAV(2022)

HFLAV(2022), arXiv:2107.00604

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In the literature → Third possibility **hybrid combination** of exclusive $|V_{ub}|$ with inclusive $|V_{cb}|$

$$R_b(|V_{ub}^{\rm excl}|, |V_{cb}^{\rm incl}|) = 0.364 \pm 0.013$$

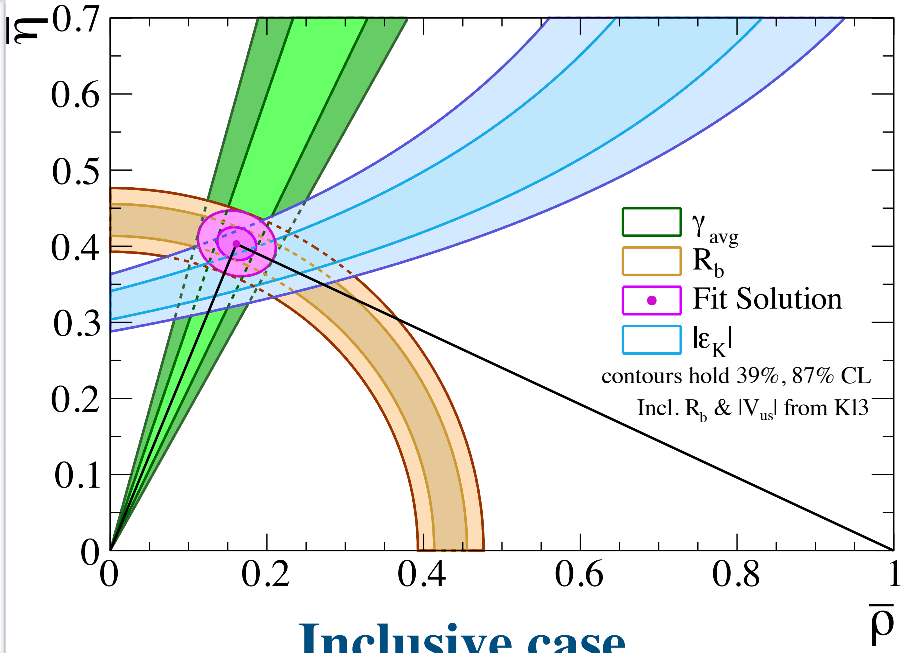
For completeness, the other mixed option

$$R_b(|V_{ub}^{\rm incl}|, |V_{cb}^{\rm excl}|) = 0.468 \pm 0.020$$

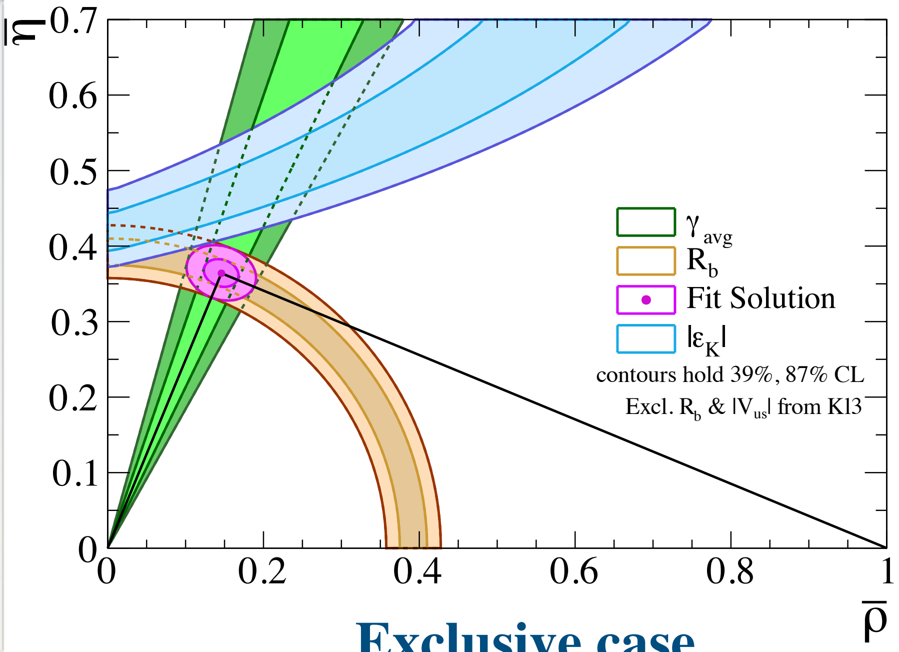
Unitarity Triangle Apex Determination

- Making a fit to γ and R_b

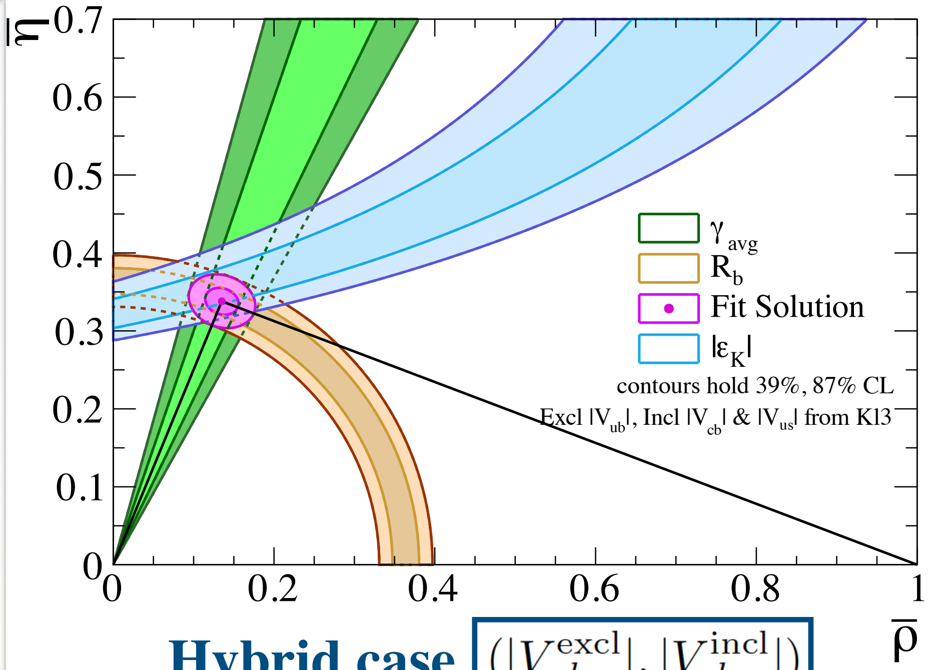
Incl	$\bar{\rho} = 0.161 \pm 0.025\,,$	$\bar{\eta} = 0.403 \pm 0.022$
Excl	$\bar{\rho} = 0.146 \pm 0.022\,,$	$\bar{\eta} = 0.364 \pm 0.018$
$(\lvert V_{ub}^{\text{excl}}\rvert, \lvert V_{cb}^{\text{incl}}\rvert)$	$\bar{\rho} = 0.135 \pm 0.021\,,$	$\bar{\eta} = 0.338 \pm 0.017$
$(\lvert V_{ub}^{\text{incl}}\rvert, \lvert V_{cb}^{\text{excl}}\rvert)$	$\bar{\rho} = 0.174 \pm 0.027\,,$	$\bar{\eta} = 0.435 \pm 0.023$



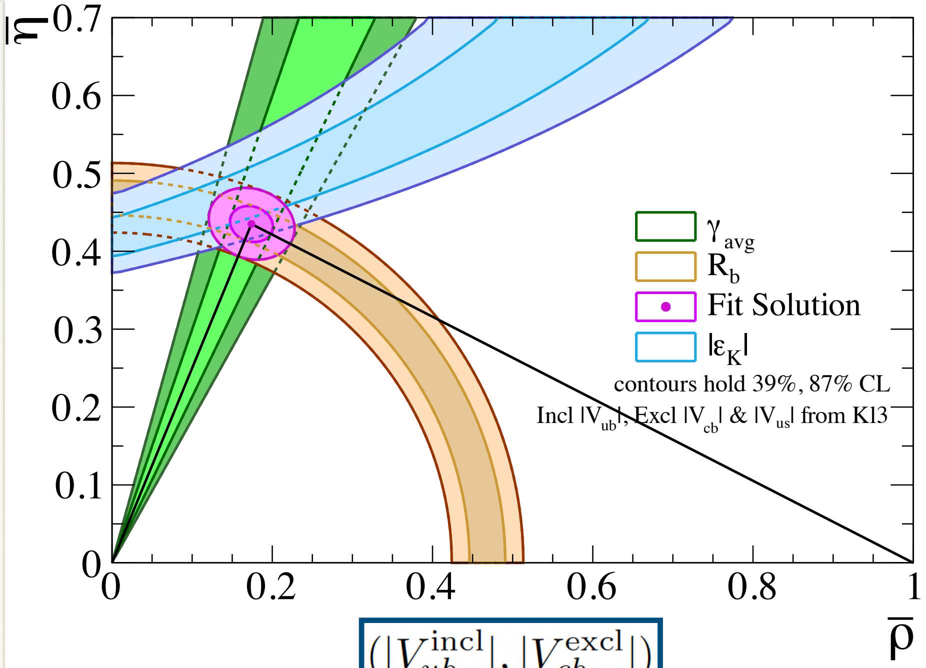
Inclusive case



Exclusive case



Hybrid case $(\lvert V_{ub}^{\text{excl}}\rvert, \lvert V_{cb}^{\text{incl}}\rvert)$



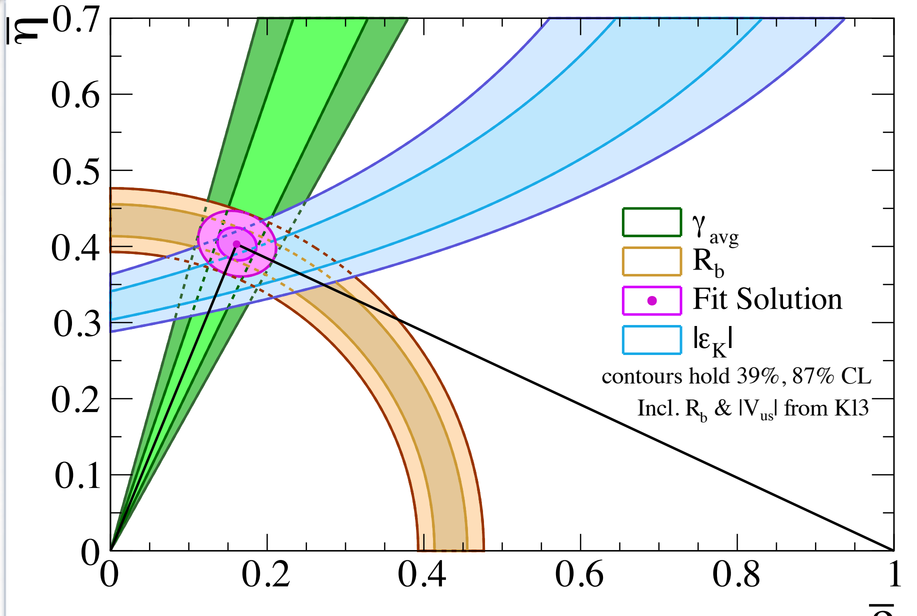
$(\lvert V_{ub}^{\text{incl}}\rvert, \lvert V_{cb}^{\text{excl}}\rvert)$

Unitarity Triangle Apex Determination

▹ Making a fit to γ and R_b

arXiv:1911.06822

$$|\varepsilon_K| = \frac{G_F^2 m_W^2 m_K f_K^2}{6\sqrt{2}\pi^2 \Delta m_K} \kappa_\varepsilon \hat{B}_K |V_{cb}|^2 \lambda^2 \bar{\eta} \left[|V_{cb}|^2 (1-\bar{\rho})\, \eta_{tt}^{\mathrm{EW}} \eta_{tt}\, \mathcal{S}(x_t) - \eta_{ut}\, \mathcal{S}(x_c, x_t) \right]$$



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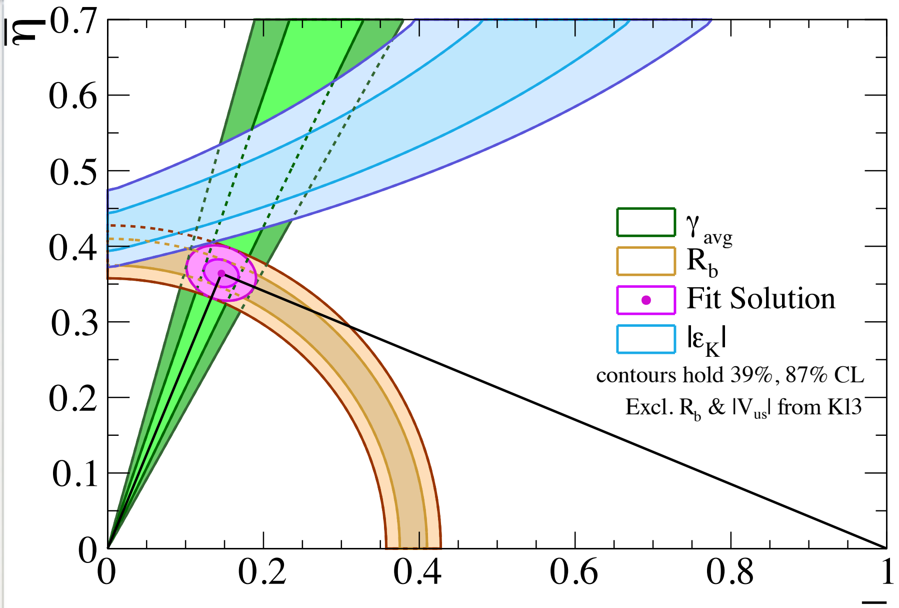

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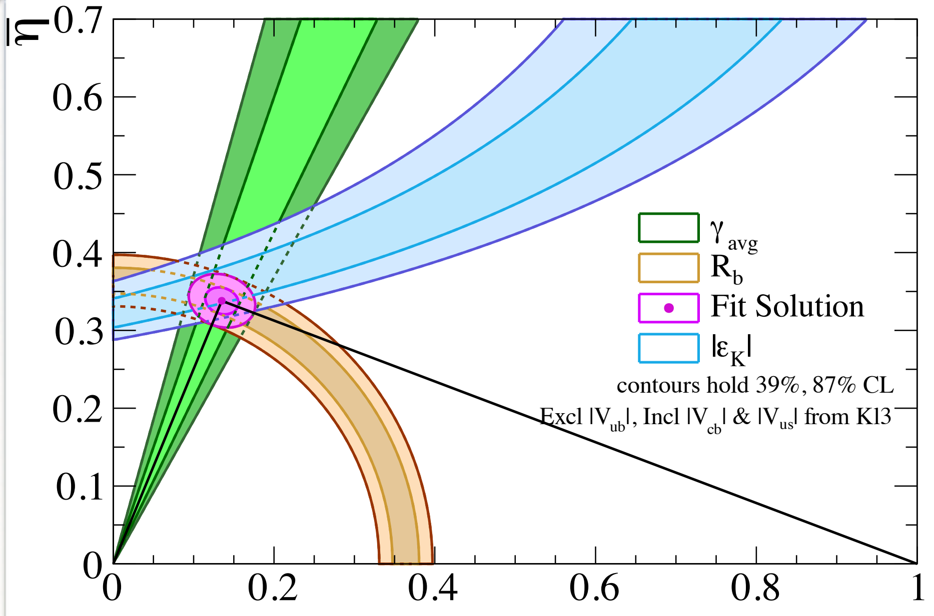
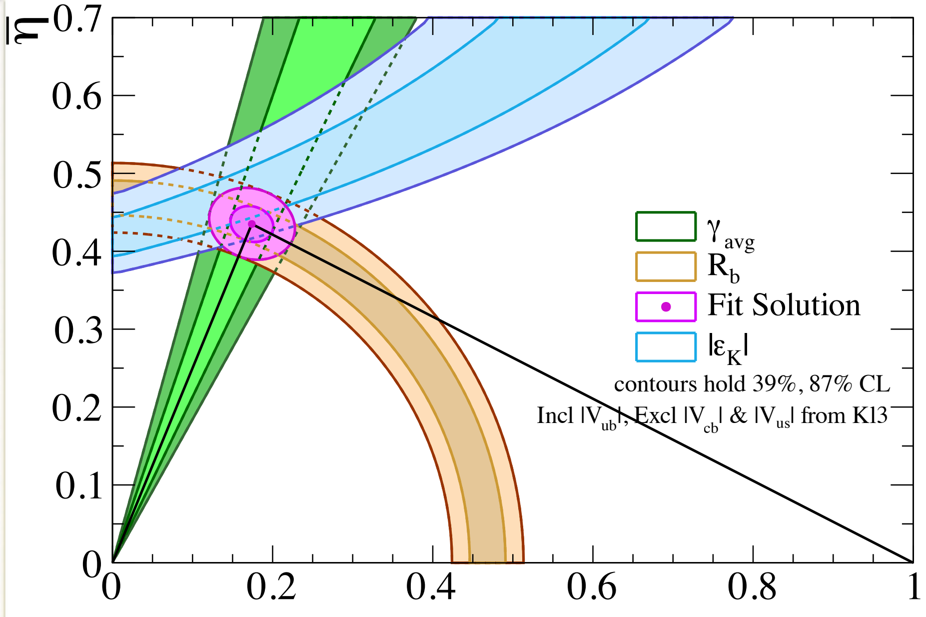


Hybrid case $\boxed{(|V_{ub}^{\mathrm{excl}}|, |V_{cb}^{\mathrm{incl}}|)}$



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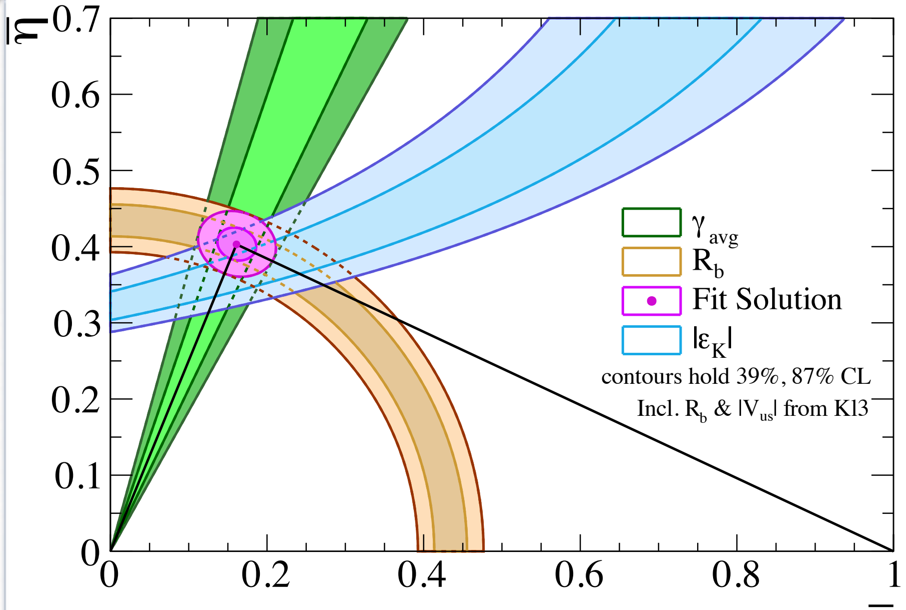

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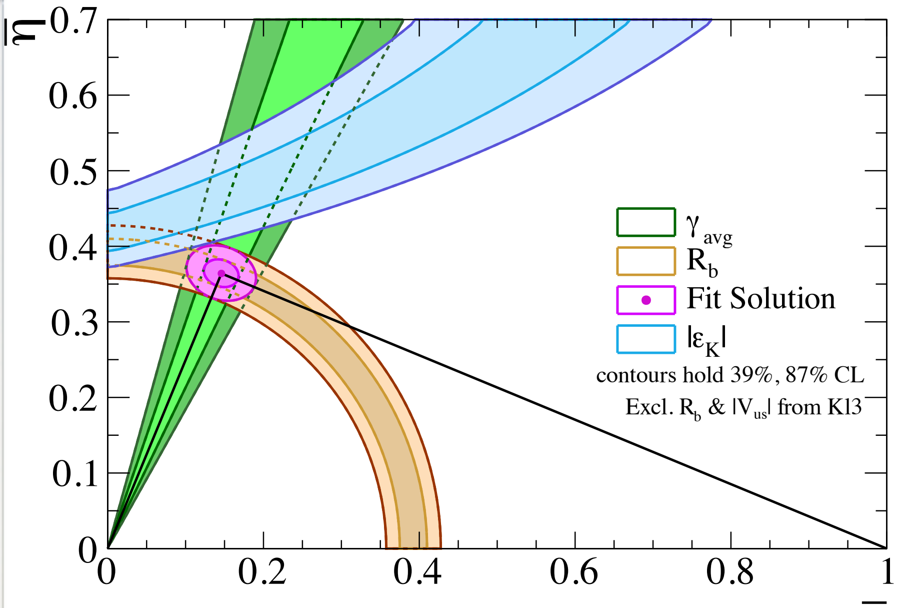
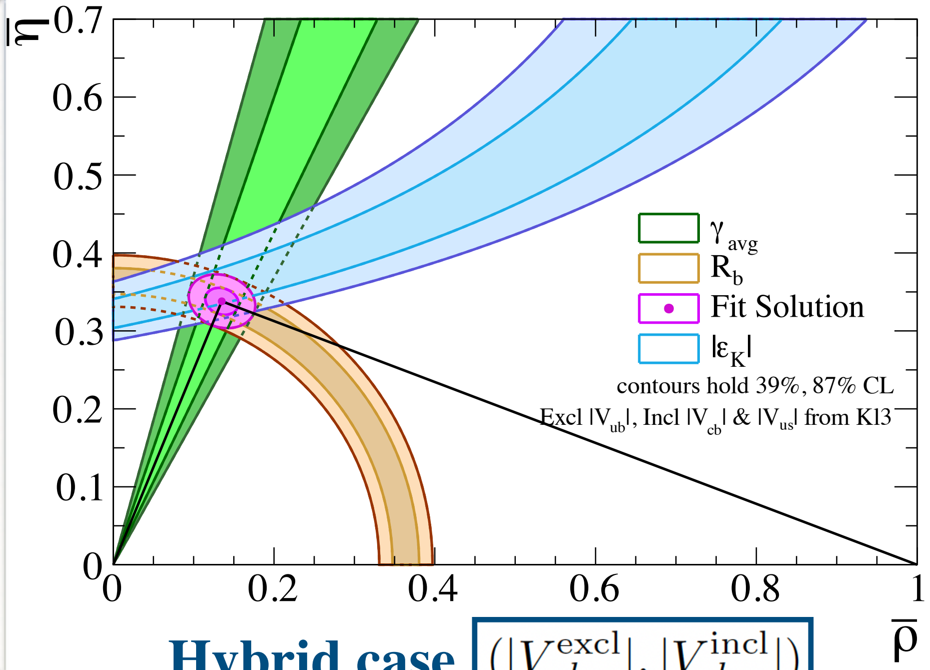
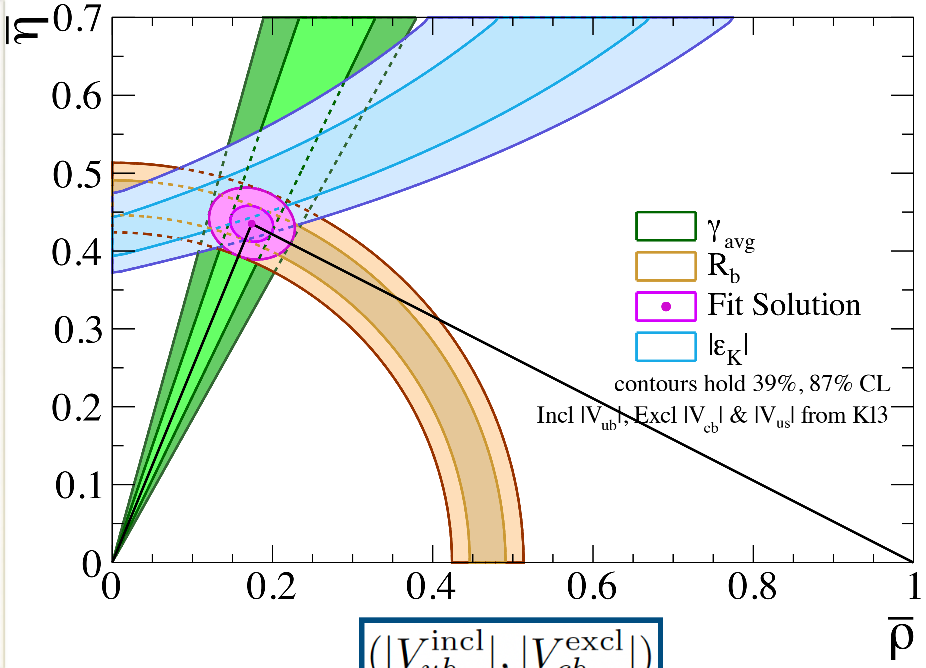


Exclusive case



Hybrid case $(|V_{ub}^{\mathrm{excl}}|, |V_{cb}^{\mathrm{incl}}|)$



$(|V_{ub}^{\mathrm{incl}}|, |V_{cb}^{\mathrm{excl}}|)$

Unitarity Triangle Apex Determination

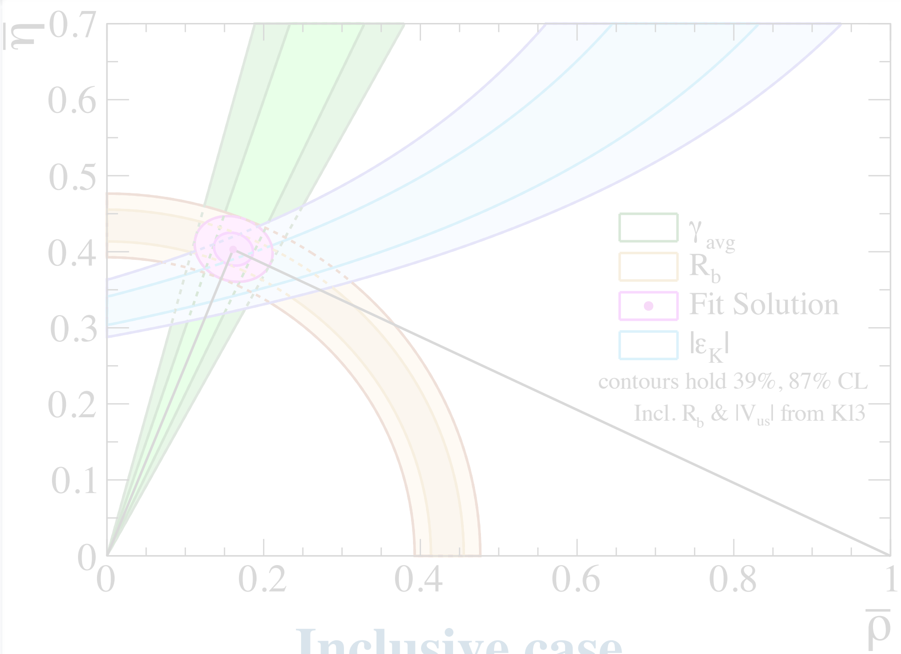
Making a fit to γ and R_b

$|\varepsilon_K| = \frac{G_F^2 m_W^2}{6\sqrt{2}\pi}$ … $x_c, x_t)]$

1.06822

Strong dependence of value of $|V_{cb}|$

In the future: it could help to understand the inclusive-exclusive puzzle, if NP in kaon can be controlled/ignored



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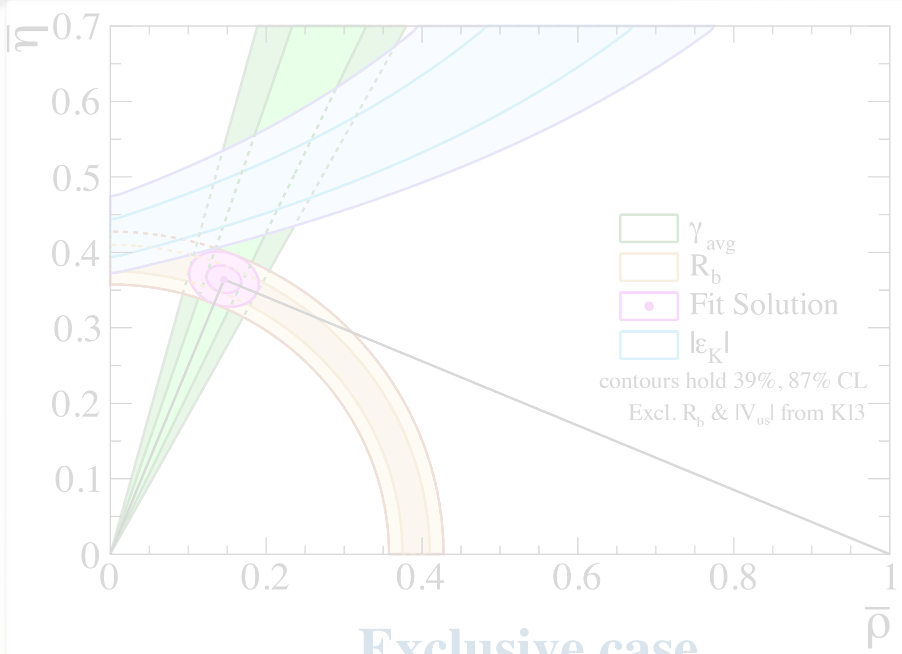
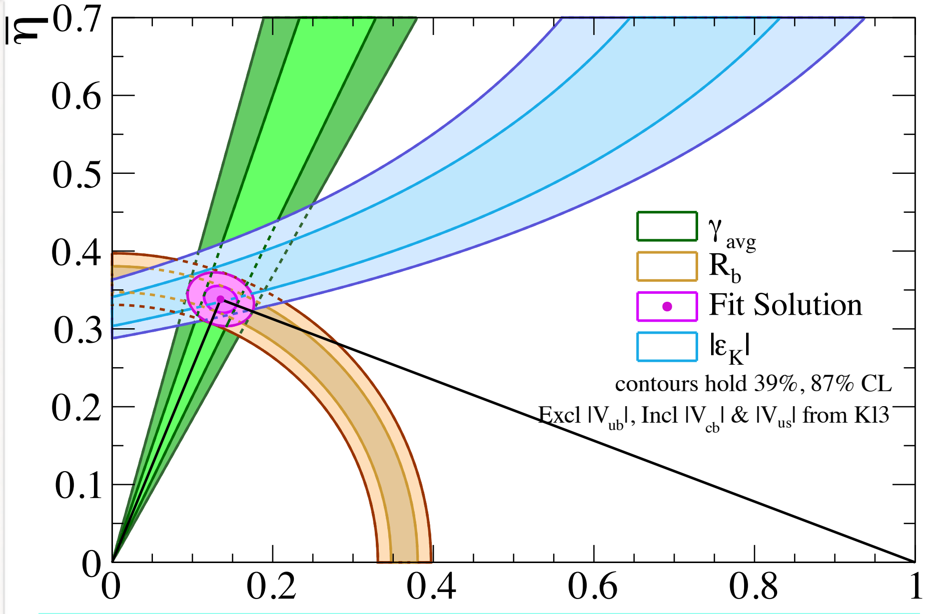
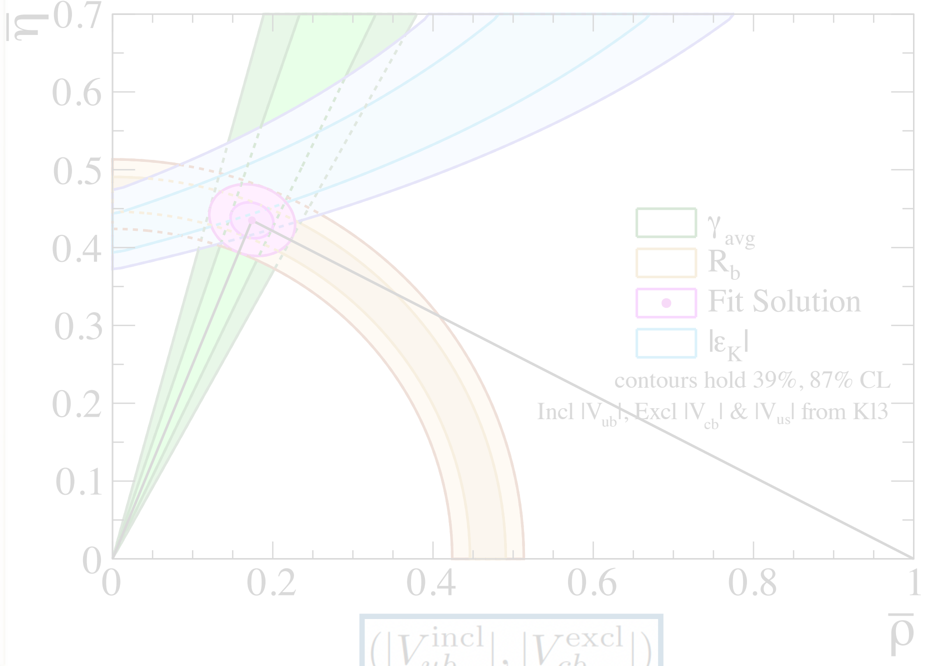


Exclusive case



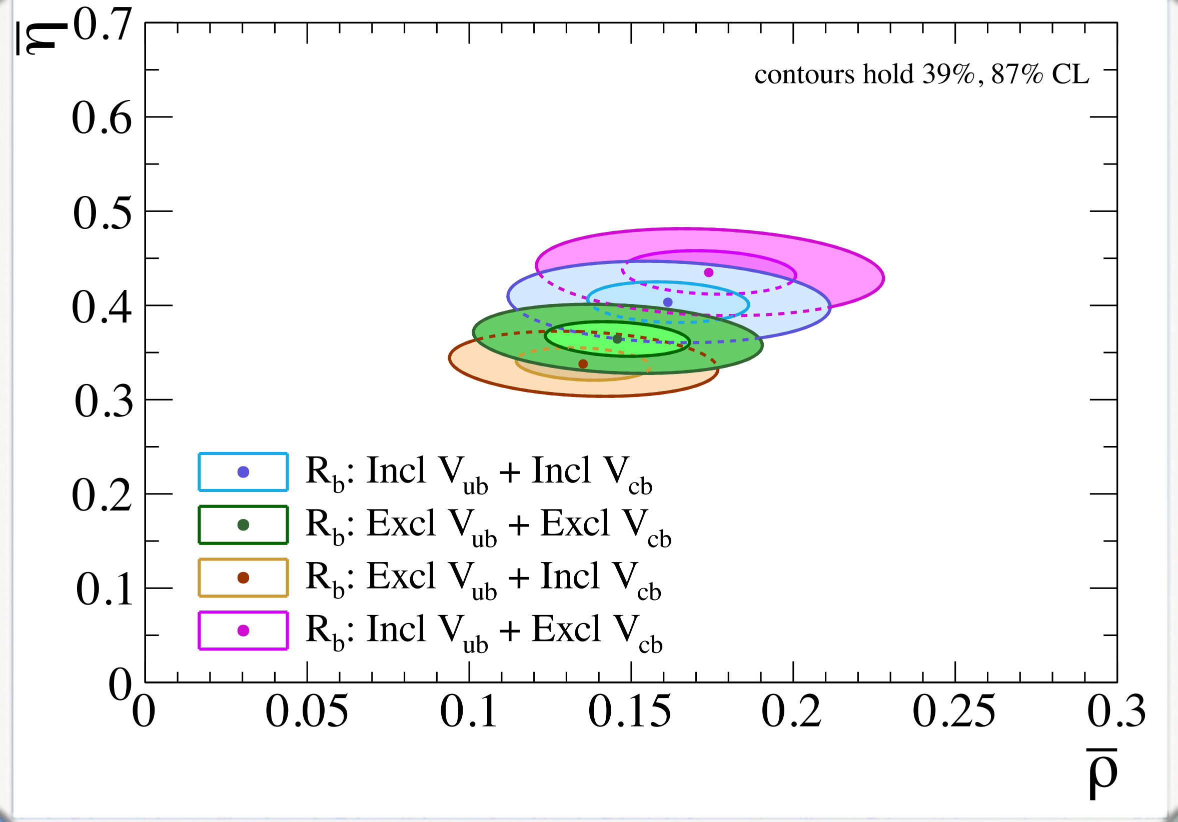
Most consistent picture of UT apex



$(|V_{ub}^{incl}|, |V_{cb}^{excl}|)$

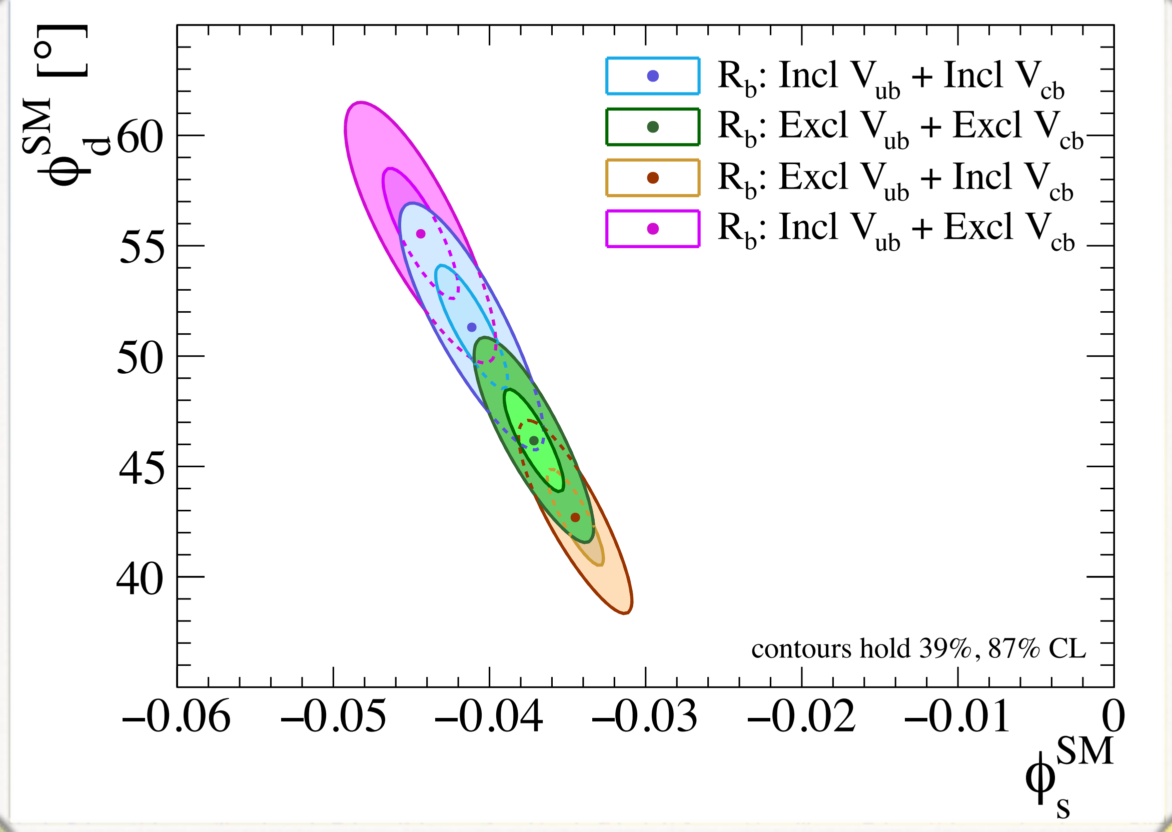
Unitarity Triangle Apex Determination

- Making a fit to γ and R_b



Contours for the coordinates of the UT apex for all four cases

Following from these UT fit results, we present the contours for the SM predictions of the mixing phases



$$
\begin{aligned}
\text{Incl} \quad & \phi_s^{\rm SM} = -0.0411 \pm 0.0023 = (-2.36 \pm 0.13)^\circ \,, \quad \phi_d^{\rm SM} = (51.3 \pm 2.8)^\circ \\
\text{Excl} \quad & \phi_s^{\rm SM} = -0.0372 \pm 0.0018 = (-2.13 \pm 0.11)^\circ \,, \quad \phi_d^{\rm SM} = (46.2 \pm 2.3)^\circ \\
(|V_{ub}^{\rm excl}|, |V_{cb}^{\rm incl}|) \quad & \phi_s^{\rm SM} = -0.0345 \pm 0.0017 = (-1.98 \pm 0.10)^\circ \,, \quad \phi_d^{\rm SM} = (42.7 \pm 2.2)^\circ \\
(|V_{ub}^{\rm incl}|, |V_{cb}^{\rm excl}|) \quad & \phi_s^{\rm SM} = -0.0444 \pm 0.0024 = (-2.54 \pm 0.14)^\circ \,, \quad \phi_d^{\rm SM} = (55.5 \pm 2.9)^\circ
\end{aligned}
$$

How can we determine the Unitarity Triangle Apex?

2) Utilising Mixing and R_b - without γ

How can we determine the Unitarity Triangle Apex?

2) Utilising Mixing and R_b - without γ

assume Δm_s^{SM} Δm_d^{SM}

- **The UT side R_t is defined as:**

$$R_t \equiv \left|\frac{V_{td}V_{tb}}{V_{cd}V_{cb}}\right| = \sqrt{(1-\bar\rho)^2+\bar\eta^{\,2}} = \frac{1}{\lambda}\left|\frac{V_{td}}{V_{ts}}\right|\left[1-\frac{\lambda^2}{2}\left(1-2\bar\rho\right)\right]+\mathcal{O}\left(\lambda^4\right)$$

$$\left|\frac{V_{td}}{V_{ts}}\right| = \xi\sqrt{\frac{m_{B_s}\Delta m_d^{\mathrm{SM}}}{m_{B_d}\Delta m_s^{\mathrm{SM}}}}$$

lattice

$$\xi \equiv \frac{f_{B_s}\sqrt{\hat B_{B_s}}}{f_{B_d}\sqrt{\hat B_{B_d}}}$$

FLAG(2021), arXiv:1907.01025

$$\xi = 1.212 \pm 0.016$$

$$\left|\frac{V_{td}}{V_{ts}}\right| = 0.2063 \pm 0.0004 \pm 0.0027$$

→ **due to lattice input**

due to experiment

How can we determine the Unitarity Triangle Apex?

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due to experiment

Incl	$\Delta m_d^{\rm SM} = (0.511 \pm 0.040)\ {\rm ps}^{-1}$,	$\Delta m_s^{\rm SM} = (17.23 \pm 0.87)\ {\rm ps}^{-1}$
Excl	$\Delta m_d^{\rm SM} = (0.438 \pm 0.033)\ {\rm ps}^{-1}$,	$\Delta m_s^{\rm SM} = (14.80 \pm 0.76)\ {\rm ps}^{-1}$
$(\lvert V_{ub}^{\rm excl}\rvert, \lvert V_{cb}^{\rm incl}\rvert)$	$\Delta m_d^{\rm SM} = (0.509 \pm 0.037)\ {\rm ps}^{-1}$,	$\Delta m_s^{\rm SM} = (17.19 \pm 0.87)\ {\rm ps}^{-1}$
$(\lvert V_{ub}^{\rm incl}\rvert, \lvert V_{cb}^{\rm excl}\rvert)$	$\Delta m_d^{\rm SM} = (0.442 \pm 0.036)\ {\rm ps}^{-1}$,	$\Delta m_s^{\rm SM} = (14.84 \pm 0.76)\ {\rm ps}^{-1}$

fit to the sides R_b and R_t

Incl, $K\ell3$	$\bar\rho = 0.180 \pm 0.014$,	$\bar\eta = 0.395 \pm 0.020$
Excl, $K\ell3$	$\bar\rho = 0.163 \pm 0.013$,	$\bar\eta = 0.357 \pm 0.017$
Hybrid, $K\ell3$	$\bar\rho = 0.153 \pm 0.013$,	$\bar\eta = 0.330 \pm 0.016$

scenarios with γ are a factor 2 less precise than the scenarios without γ

How can we determine the Unitarity Triangle Apex?

2) Utilising Mixing and R_b - without γ

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lattice

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$$\xi = 1.212 \pm 0.016$$

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→ due to lattice input

due to experiment

fit to the sides R_b and R_t

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↓

scenarios with γ are a factor 2 less precise than the scenarios without γ

✻ UT apex determination through R_b and R_t is more precise

✻ R_t determined assuming SM Δm_d and Δm_s

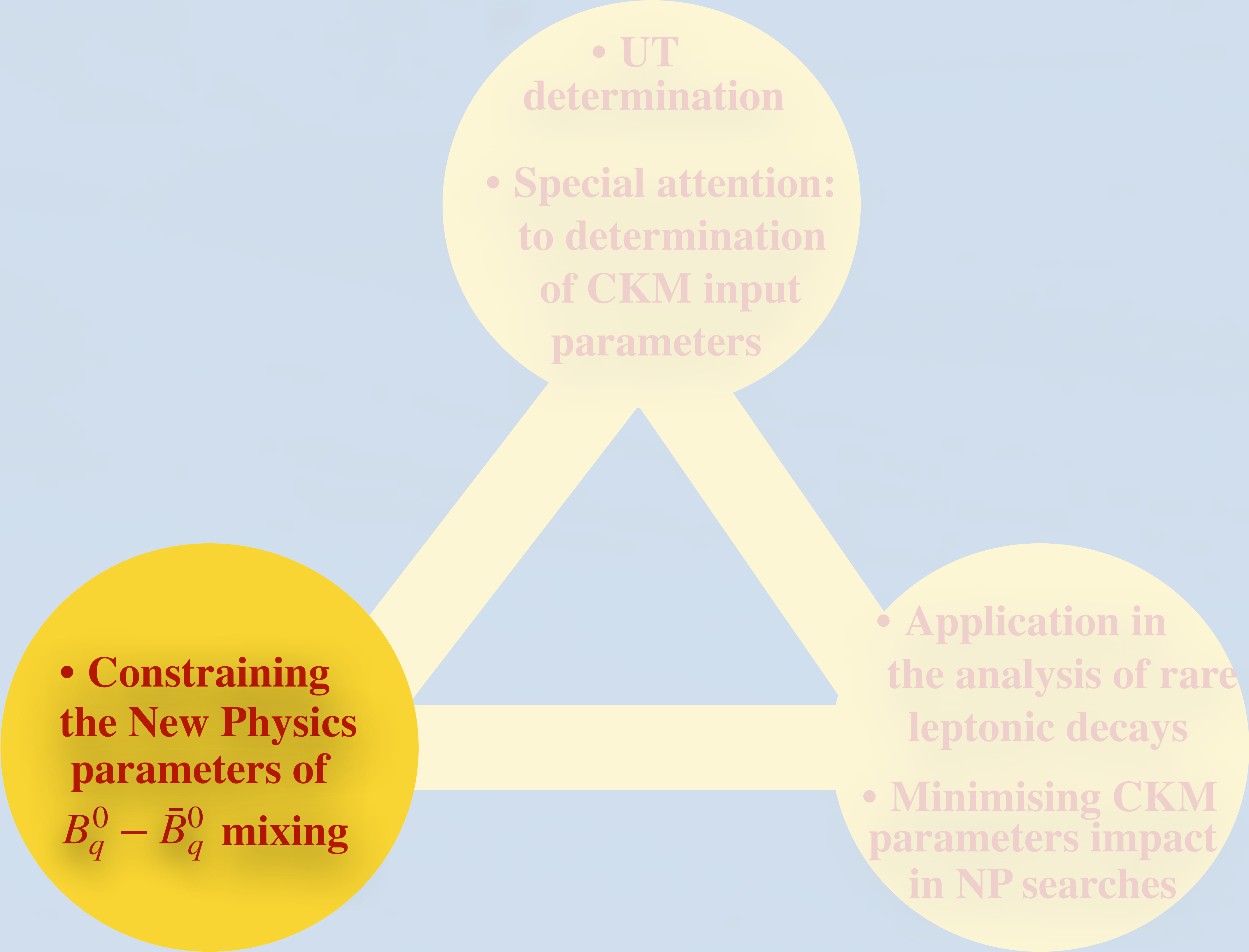
↓

ignores possible NP in $B_q^0 - \bar B_q^0$ mixing

- NP will contaminate R_t determination

✻ To determine NP in $B_q^0 - \bar B_q^0$ mixing in a general scenario: UT apex determination through R_b and γ

We will focus on the following topics



- UT determination
- Special attention: to determination of CKM input parameters

- Constraining the New Physics parameters of $B_q^0 - \bar{B}_q^0$ mixing

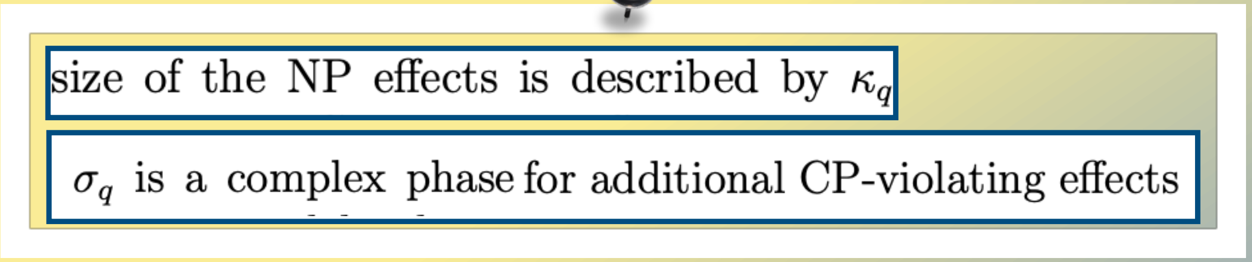
- Application in the analysis of rare leptonic decays
- Minimising CKM parameters impact in NP searches

Introducing NP Parameters

$$\Delta m_q = \Delta m_q^{\mathrm{SM}} \left(1 + \kappa_q e^{i\sigma_q}\right)$$

$$\phi_q = \phi_q^{\mathrm{SM}} + \phi_q^{\mathrm{NP}} = \phi_q^{\mathrm{SM}} + \arg\left(1 + \kappa_q e^{i\sigma_q}\right)$$

Model independent parametrization



size of the NP effects is described by κ_q

σ_q is a complex phase for additional CP-violating effects

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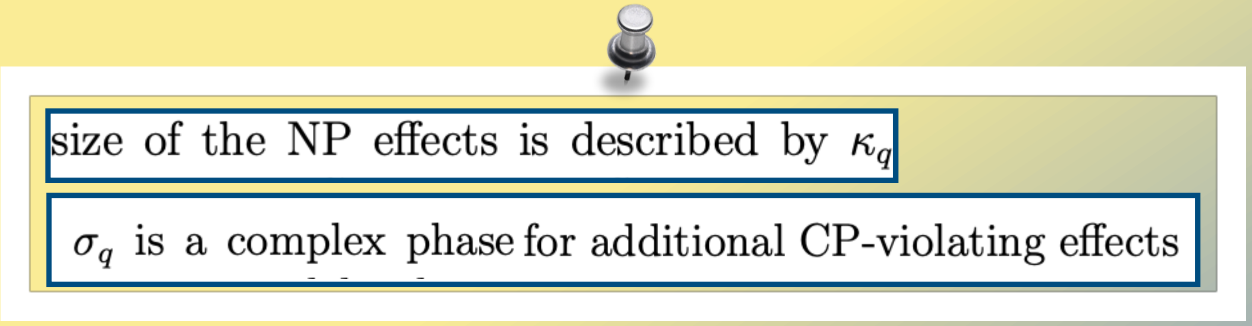

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We explore 2 different NP scenarios

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We explore 2 different NP scenarios

Scenario I → most general case

utilise UT apex determination for the SM predictions of Δm_q and ϕ_q

↓

NP parameters (κ_d, σ_d) and (κ_s, σ_s) independently from each other

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Scenario II

we consider NP contributions are equal in the B_d and the B_s systems

FUNP

↓

UT apex determination that only relies on R_b and mixing parameters without information on γ.

↓

NP in γ will not affect the results

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↓

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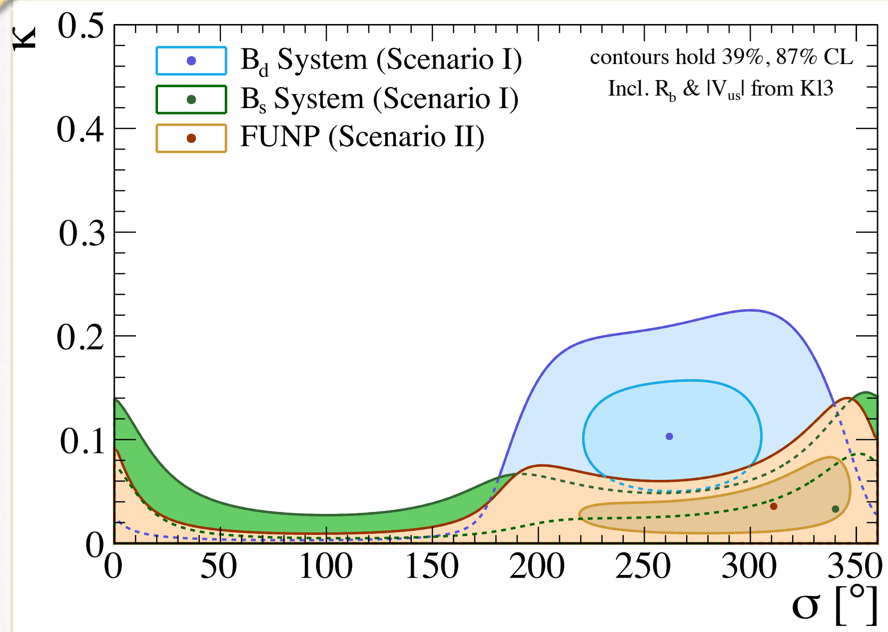
Comparing FUNP with Scenario I

test of FUNP assumption

Impact of the assumptions on the constraints on parameters space of NP in mixing

Comparison between Scenarios I and II for $\varkappa_q$ and σ_q



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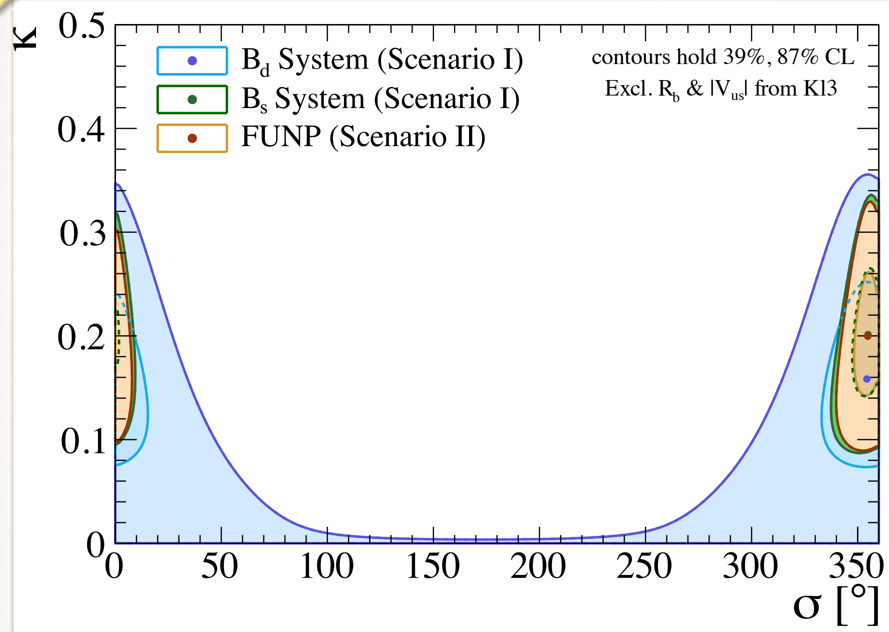
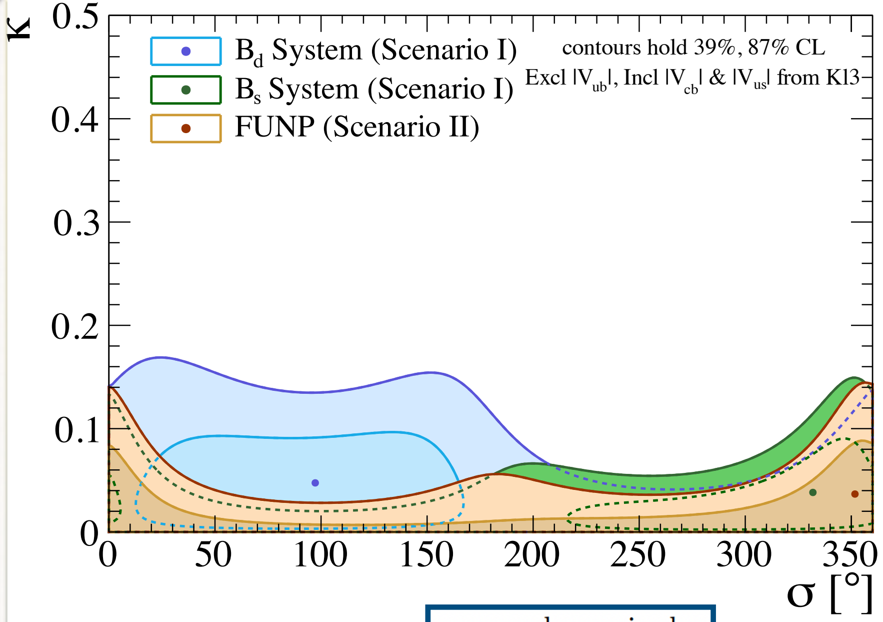
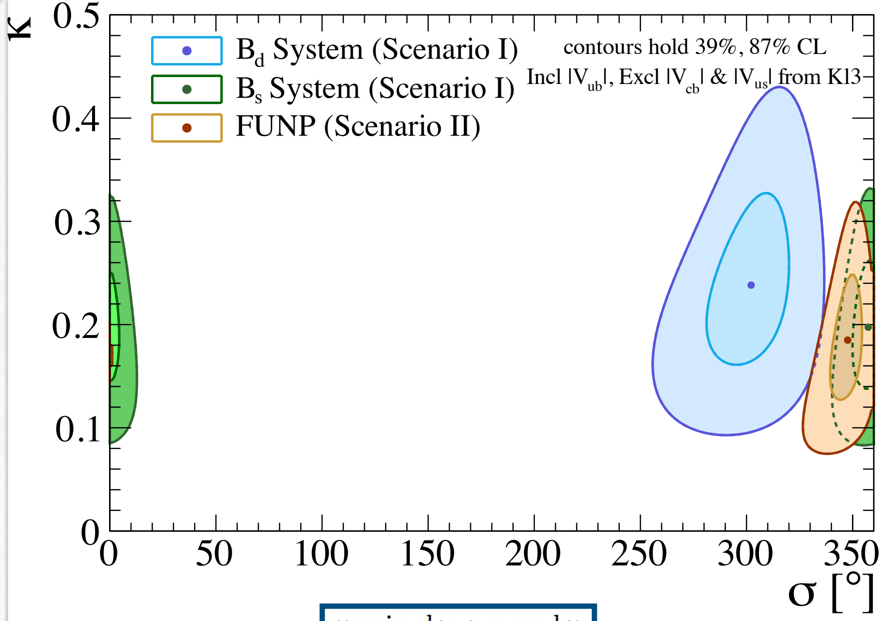


Exclusive case

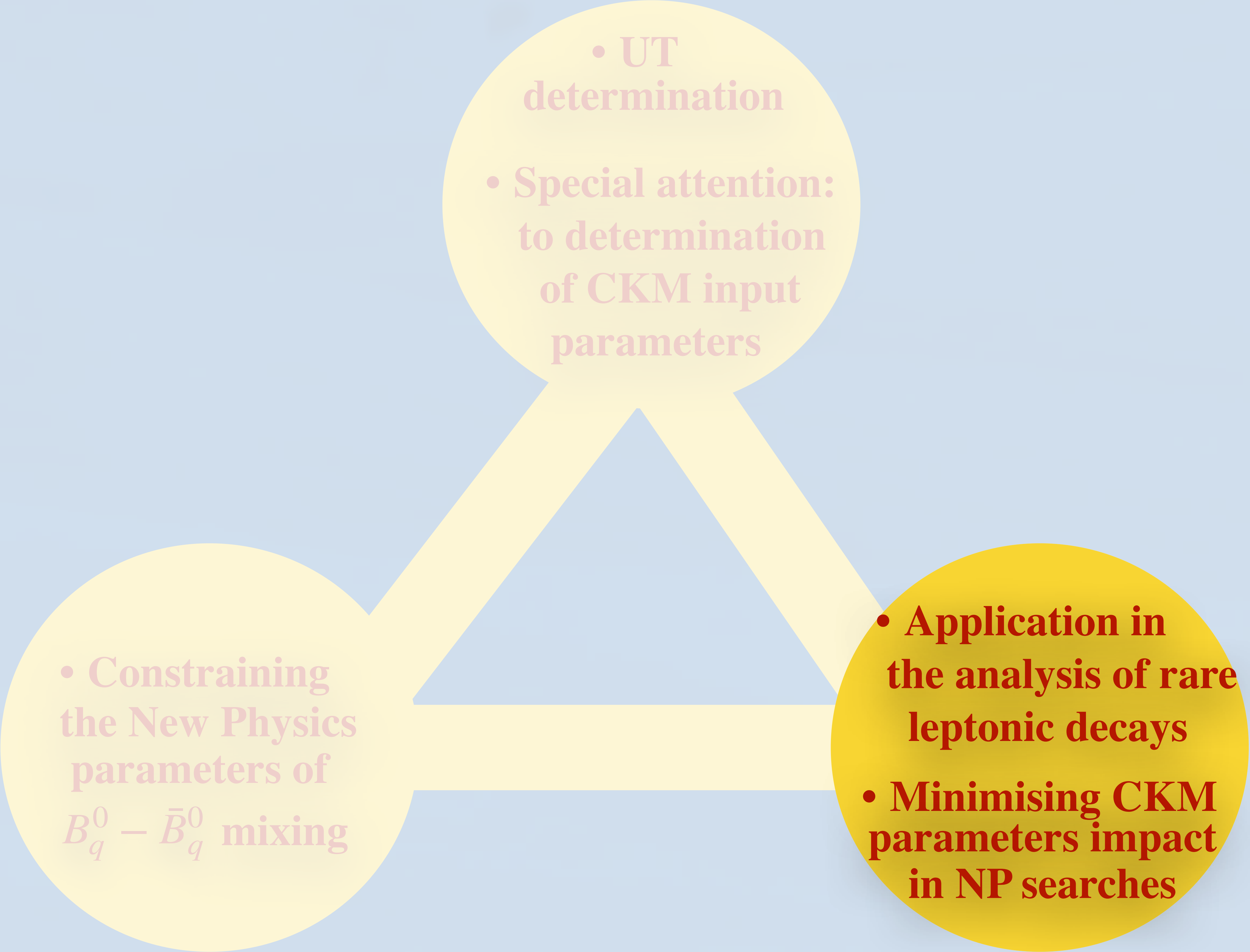


Hybrid case $(|V_{ub}^{\mathrm{excl}}|, |V_{cb}^{\mathrm{incl}}|)$



$(|V_{ub}^{\mathrm{incl}}|, |V_{cb}^{\mathrm{excl}}|)$

We will focus on the following topics



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Determining NP in $B_s^0 \rightarrow \mu^+\mu^-$

NP can modify its branching ratio

(Pseudo-)Scalar

$B_s^0 - \bar{B}_s^0$ mixing

The measured branching ratio:

$$\bar{\mathcal{B}}(B_s \to \mu^+\mu^-) = \bar{\mathcal{B}}(B_s \to \mu^+\mu^-)^{\mathrm{SM}} \times \frac{1 + \mathcal{A}^{\mu\mu}_{\Delta\Gamma_s} y_s}{1 + y_s} \left(|P^s_{\mu\mu}|^2 + |S^s_{\mu\mu}|^2\right)$$

$\mathcal{A}^{\mu\mu}_{\Delta\Gamma_s}$ depends on $P^s_{\mu\mu} \equiv |P^s_{\mu\mu}| e^{i\varphi_P}$, $S^s_{\mu\mu} \equiv |S^s_{\mu\mu}| e^{i\varphi_S}$ and ϕ_s^{NP}

$$\mathcal{A}^{\mu\mu}_{\Delta\Gamma} = \frac{|P^s_{\mu\mu}|^2 \cos(2\varphi_P - \phi_s^{\mathrm{NP}}) - |S^s_{\mu\mu}|^2 \cos(2\varphi_S - \phi_s^{\mathrm{NP}})}{|P^s_{\mu\mu}|^2 + |S^s_{\mu\mu}|^2}$$

In SM

$$P^{s,\mathrm{SM}}_{\mu\mu} = 1$$

$$S^{s,\mathrm{SM}}_{\mu\mu} = 0$$

Determining NP in $B_s^0 \to \mu^+\mu^-$

NP can modify its branching ratio

(Pseudo-)Scalar

$B_s^0 - \bar{B}_s^0$ **mixing**

The measured branching ratio:

$$\bar{\mathcal{B}}(B_s \to \mu^+\mu^-) = \bar{\mathcal{B}}(B_s \to \mu^+\mu^-)^{\rm SM} \times \frac{1 + \mathcal{A}^{\mu\mu}_{\Delta\Gamma_s} y_s}{1 + y_s} \left(|P^s_{\mu\mu}|^2 + |S^s_{\mu\mu}|^2\right)$$

$\mathcal{A}^{\mu\mu}_{\Delta\Gamma_s}$ depends on $P^s_{\mu\mu} \equiv |P^s_{\mu\mu}|e^{i\varphi_P}$, $S^s_{\mu\mu} \equiv |S^s_{\mu\mu}|e^{i\varphi_S}$ and $\phi_s^{\rm NP}$

$$\mathcal{A}^{\mu\mu}_{\Delta\Gamma} = \frac{|P^s_{\mu\mu}|^2 \cos(2\varphi_P - \phi_s^{\rm NP}) - |S^s_{\mu\mu}|^2 \cos(2\varphi_S - \phi_s^{\rm NP})}{|P^s_{\mu\mu}|^2 + |S^s_{\mu\mu}|^2}$$

In SM

$P^{s,{\rm SM}}_{\mu\mu} = 1$

$S^{s,{\rm SM}}_{\mu\mu} = 0$

Comparing

Incl, $K\ell3$	$\bar{\mathcal{B}}(B_s \to \mu^+\mu^-) = (3.81 \pm 0.11) \times 10^{-9}$,
Excl, $K\ell3$	$\bar{\mathcal{B}}(B_s \to \mu^+\mu^-) = (3.27 \pm 0.10) \times 10^{-9}$,
Hybrid, $K\ell3$	$\bar{\mathcal{B}}(B_s \to \mu^+\mu^-) = (3.80 \pm 0.10) \times 10^{-9}$.

with $\bar{\mathcal{B}}(B_s \to \mu^+\mu^-) = (2.85^{+0.34}_{-0.31}) \times 10^{-9}$

arXiv:1204.1737

We constrain the parameters $|P^s|$ and $|S^s|$

We assume NP phases for the pseudo-scalar and scalar contributions are zero $\varphi_P = \varphi_S = 0$

Determining NP in $B_s^0 \to \mu^+\mu^-$

NP can modify its branching ratio

(Pseudo-)Scalar

$B_s^0 - \bar{B}_s^0$ **mixing**

The measured branching ratio:

$$\bar{\mathcal{B}}(B_s \to \mu^+\mu^-) = \bar{\mathcal{B}}(B_s \to \mu^+\mu^-)^{\rm SM} \times \frac{1 + \mathcal{A}^{\mu\mu}_{\Delta\Gamma_s} y_s}{1 + y_s} \left(|P^s_{\mu\mu}|^2 + |S^s_{\mu\mu}|^2\right)$$

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In SM

$$P^{s,\rm SM}_{\mu\mu} = 1$$

$$S^{s,\rm SM}_{\mu\mu} = 0$$

Comparing

Incl, $K\ell 3$	$\bar{\mathcal{B}}(B_s \to \mu^+\mu^-) = (3.81 \pm 0.11) \times 10^{-9}$,
Excl, $K\ell 3$	$\bar{\mathcal{B}}(B_s \to \mu^+\mu^-) = (3.27 \pm 0.10) \times 10^{-9}$,
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with $\bar{\mathcal{B}}(B_s \to \mu^+\mu^-) = (2.85^{+0.34}_{-0.31}) \times 10^{-9}$

arXiv:1204.1737

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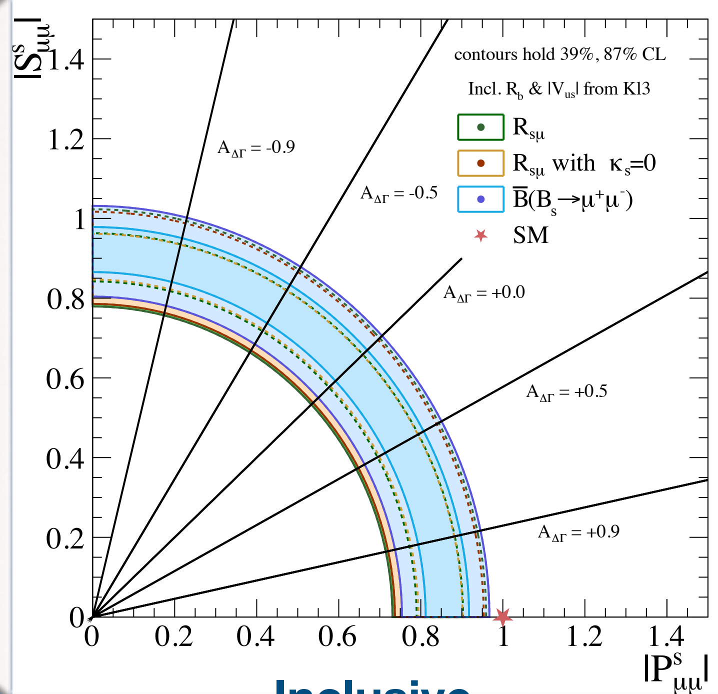
We assume NP phases for the pseudo-scalar and scalar contributions are zero $\varphi_P = \varphi_S = 0$



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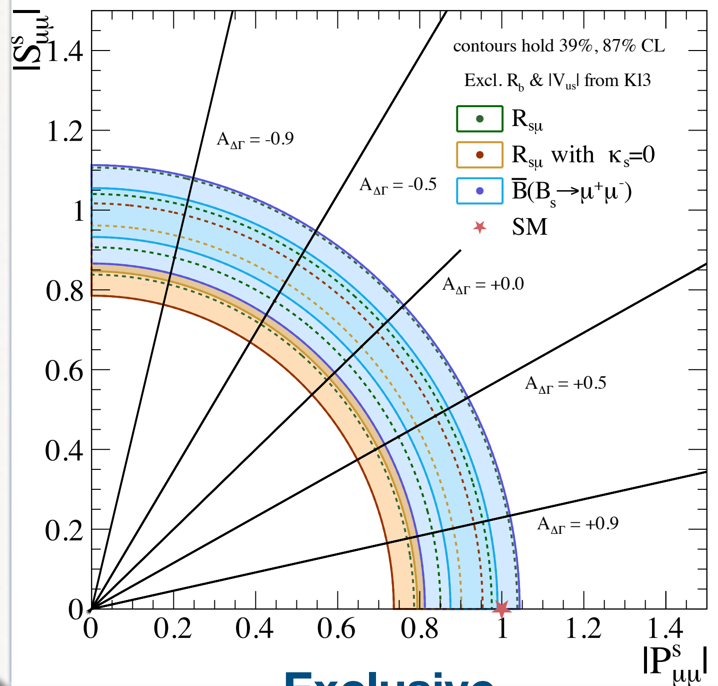

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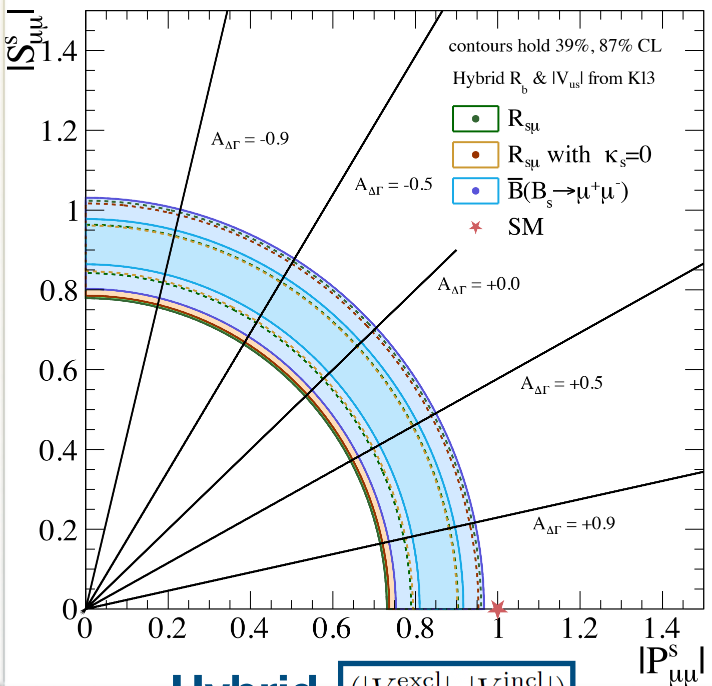

Hybrid $(|V_{ub}^{\rm excl}|, |V_{cb}^{\rm incl}|)$

Determining NP in $B_s^0 \to \mu^+\mu^-$

NP can modify its branching ratio

(Pseudo-)Scalar $B_s^0 - \bar{B}_s^0$ **mixing**

The measured branching ratio:

$$\bar{\mathcal{B}}(B_s \to \mu^+\mu^-) = \bar{\mathcal{B}}(B_s \to \mu^+\mu^-)^{\rm SM} \times \frac{1 + \mathcal{A}^{\mu\mu}_{\Delta\Gamma_s} y_s}{1 + y_s} \left(|P^s_{\mu\mu}|^2 + |S^s_{\mu\mu}|^2\right)$$

$\mathcal{A}^{\mu\mu}_{\Delta\Gamma_s}$ depends on $P^s_{\mu\mu} \equiv |P^s_{\mu\mu}| e^{i\varphi_P}$, $S^s_{\mu\mu} \equiv |S^s_{\mu\mu}| e^{i\varphi_S}$ and $\phi_s^{\rm NP}$

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In SM

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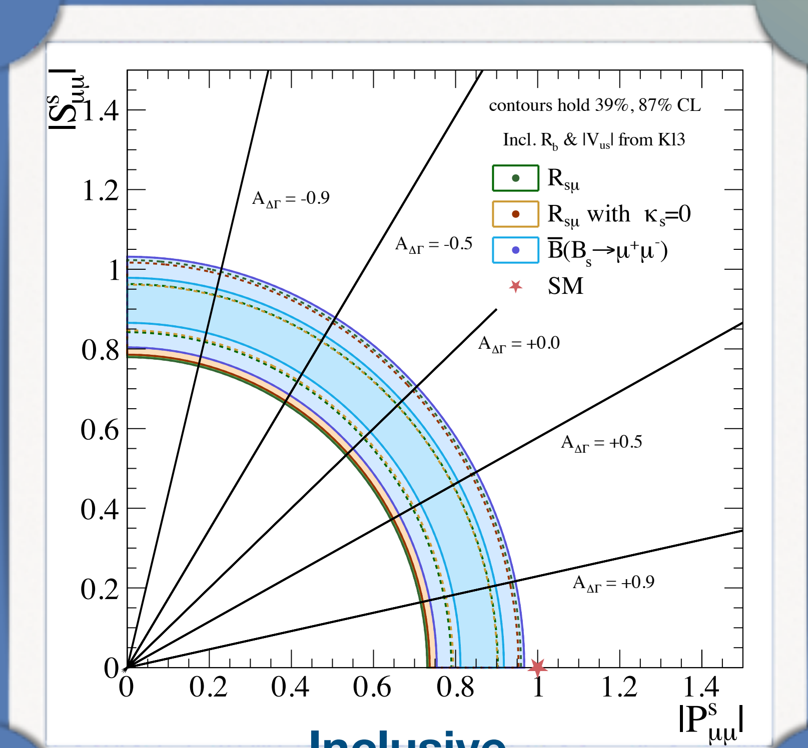

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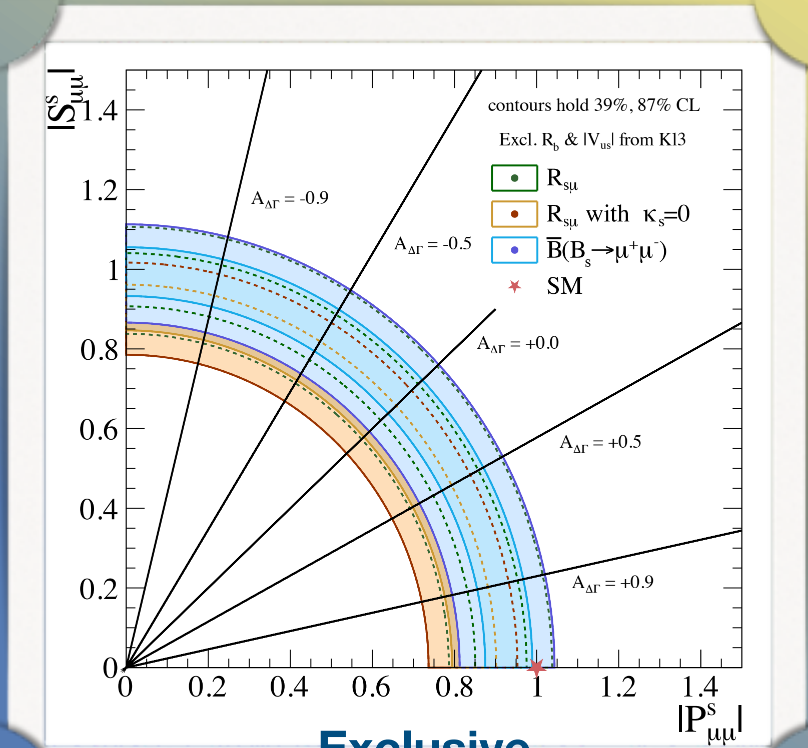

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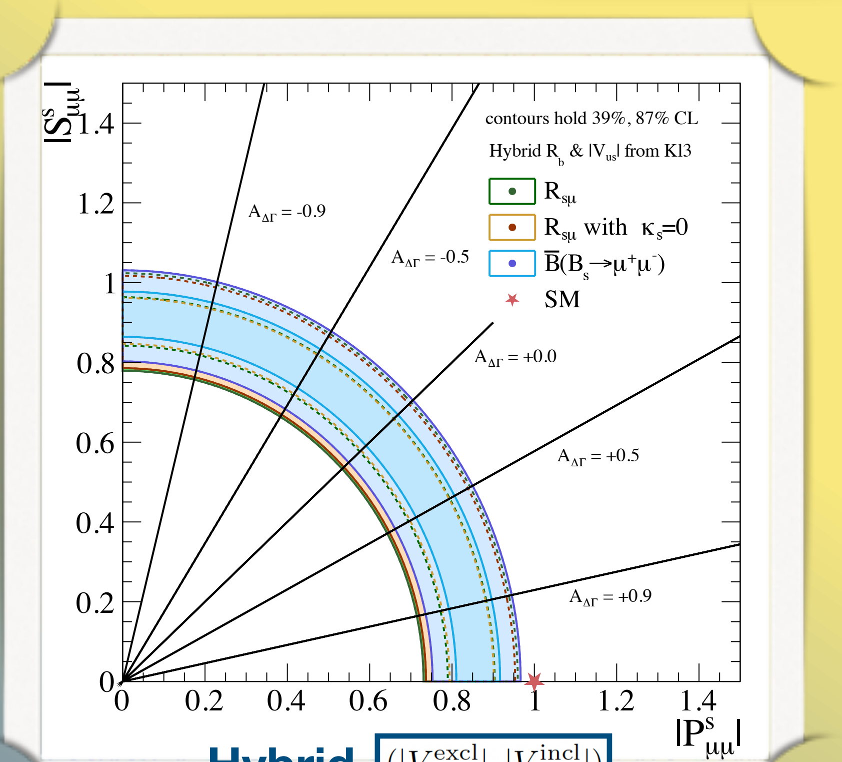


Hybrid $(|V_{ub}^{\rm excl}|, |V_{cb}^{\rm incl}|)$

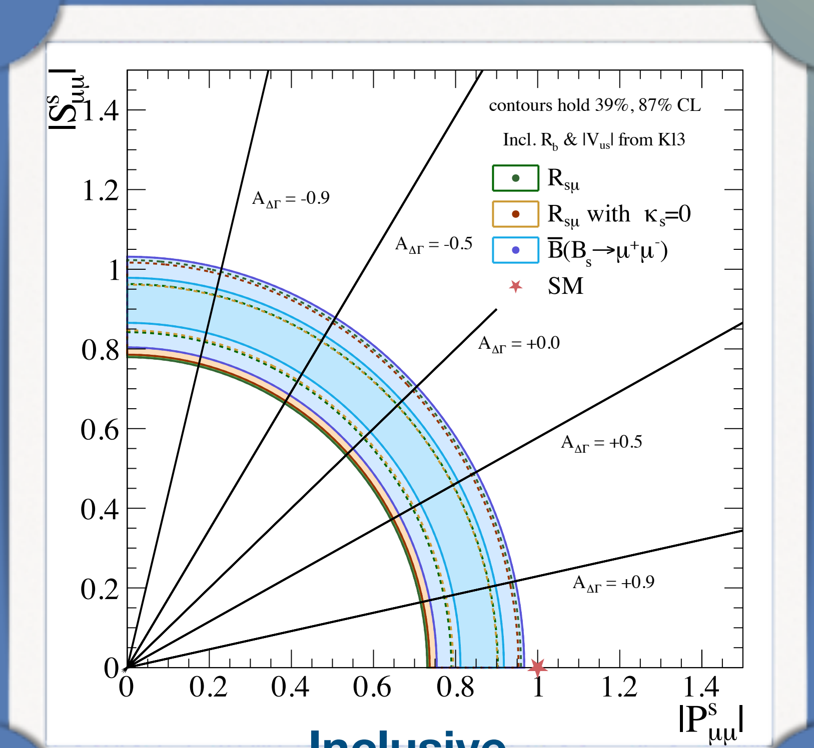
Comparing blue contours:
dependence of the NP searches with $B(B_s \to \mu^+\mu^-)$ on the CKM matrix element $|V_{cb}|$ and the UT apex

Determining NP in $B_s^0 \to \mu^+\mu^-$

NP can modify its branching ratio

(Pseudo-)Scalar

$B_s^0 - \bar{B}_s^0$ **mixing**



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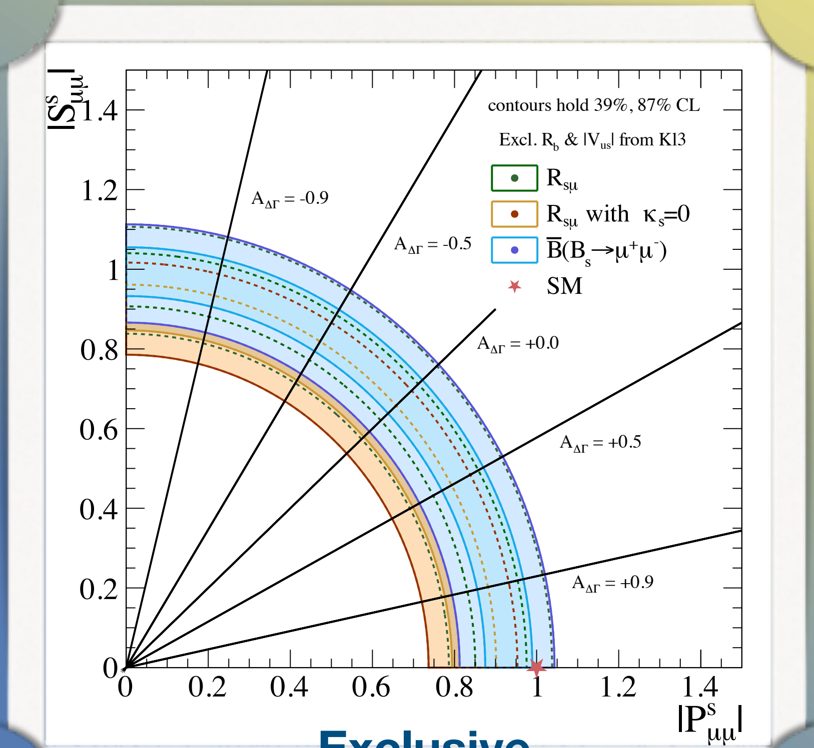

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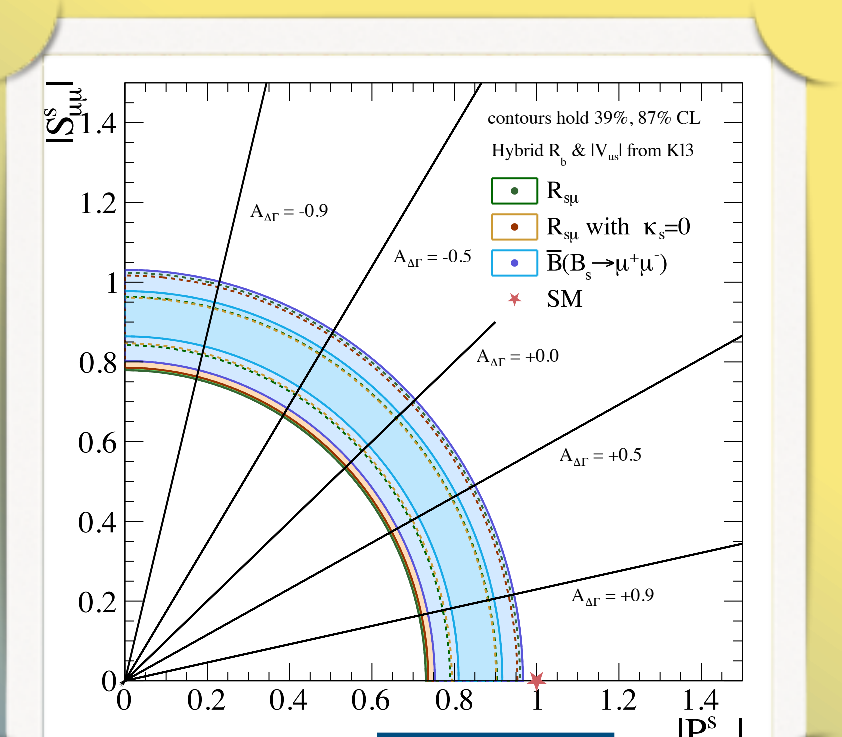


Hybrid $\boxed{(|V_{ub}^{\mathrm{excl}}|, |V_{cb}^{\mathrm{incl}}|)}$

We can minimise this dependence, creating the following ratio $R_{s\mu}$

Determining NP in $B_s^0 \to \mu^+\mu^-$

NP can modify its branching ratio

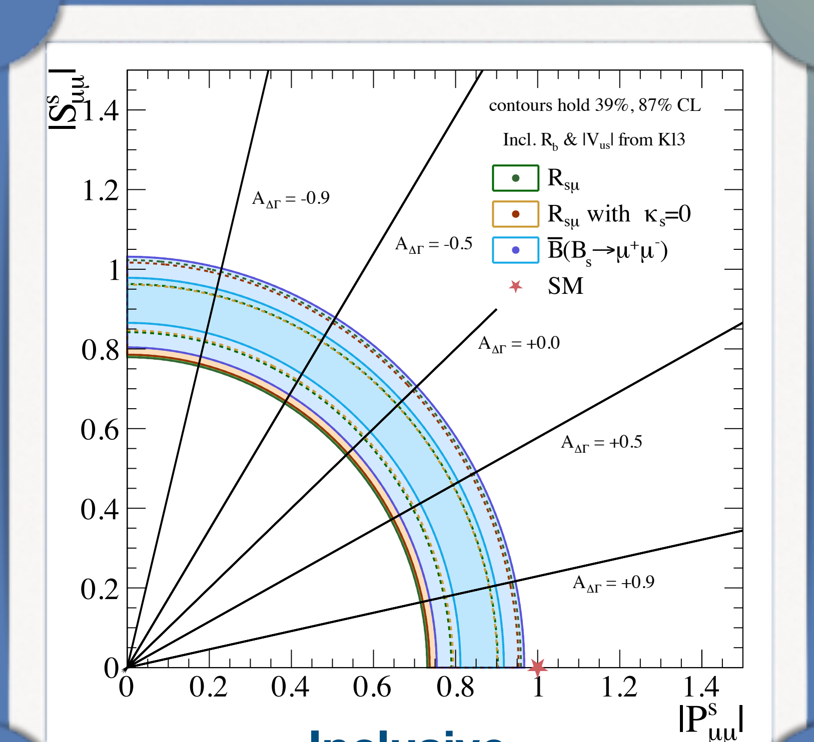
(Pseudo-)Scalar

$B_s^0 - \bar{B}_s^0$ mixing

arXiv:hep-ph/0303060
arXiv:2104.09521
arXiv:2109.11032

$$\mathcal{R}_{s\mu} \equiv \left| \frac{\bar{\mathcal{B}}(B_s \to \mu^+\mu^-)}{\Delta m_s} \right|$$

CKM elements drop out in the SM ratio



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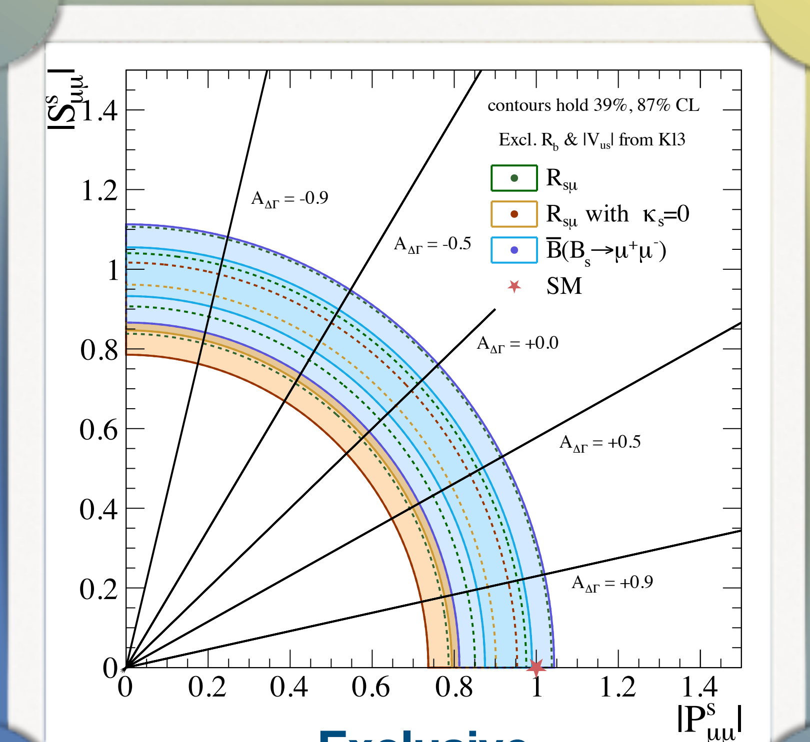

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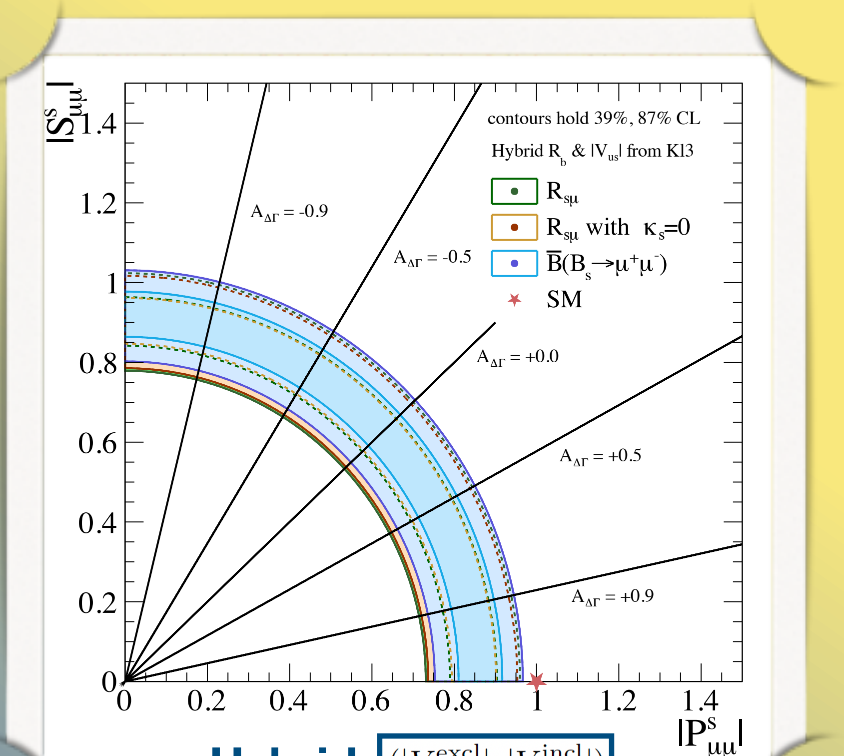

Hybrid $(|V_{ub}^{\rm excl}|, |V_{cb}^{\rm incl}|)$

We can minimise this dependence, creating the following ratio $R_{s\mu}$

Determining NP in $B_s^0 \to \mu^+\mu^-$

NP can modify its branching ratio

(Pseudo-)Scalar

$B_s^0 - \bar{B}_s^0$ mixing

arXiv:hep-ph/0303060
arXiv:2104.09521
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$$\mathcal{R}_{s\mu} \equiv \left| \frac{\bar{\mathcal{B}}(B_s \to \mu^+\mu^-)}{\Delta m_s} \right|$$

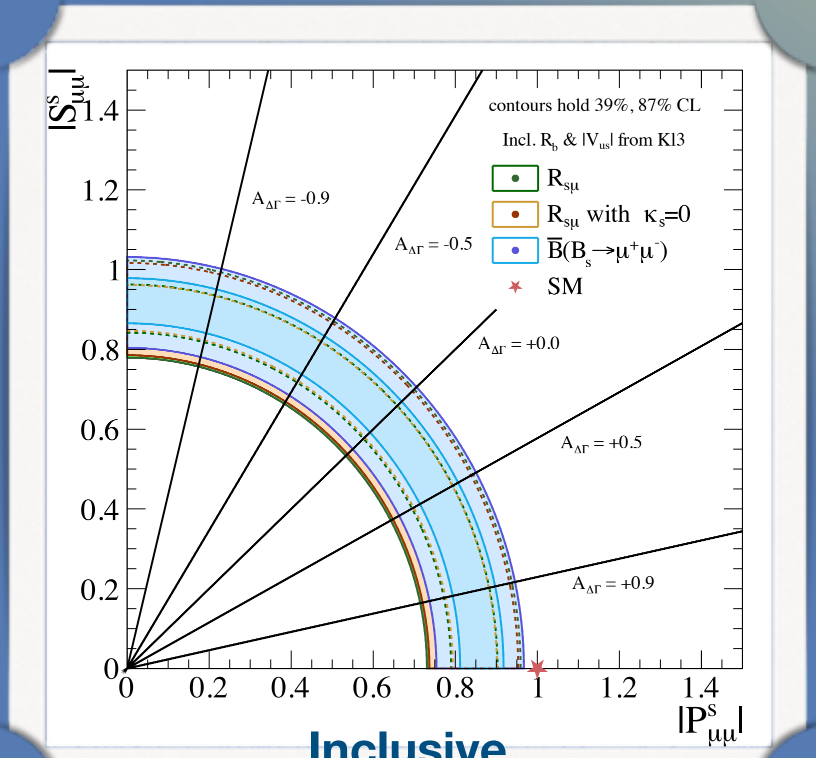
CKM elements drop out in the SM ratio

Including NP effects in both $B(B_s \to \mu^+\mu^-)$ and Δm_s we get the generalised expression

$$\mathcal{R}_{s\mu} = \mathcal{R}_{s\mu}^{\rm SM} \times \frac{1 + \mathcal{A}_{\Delta\Gamma_s}^{\mu\mu} y_s}{1 + y_s} \frac{|P_{\mu\mu}^s|^2 + |S_{\mu\mu}^s|^2}{\sqrt{1 + 2\kappa_s \cos\sigma_s + \kappa_s^2}} \, .$$

$$\mathcal{R}_{s\mu}^{\rm SM} = \frac{\tau_{B_s}}{1 - y_s} \frac{3G_{\rm F}^2 m_W^2 \sin^4\theta_W}{4\pi^3} \frac{|C_{10}^{\rm SM}|^2}{S_0(x_t)\eta_{2B}\hat{B}_{B_s}} m_\mu^2 \sqrt{1 - 4\frac{m_\mu^2}{m_{B_s}^2}}$$

introduces a dependence on the CKM matrix elements through the NP parameters ($\varkappa_S$, σ_S)



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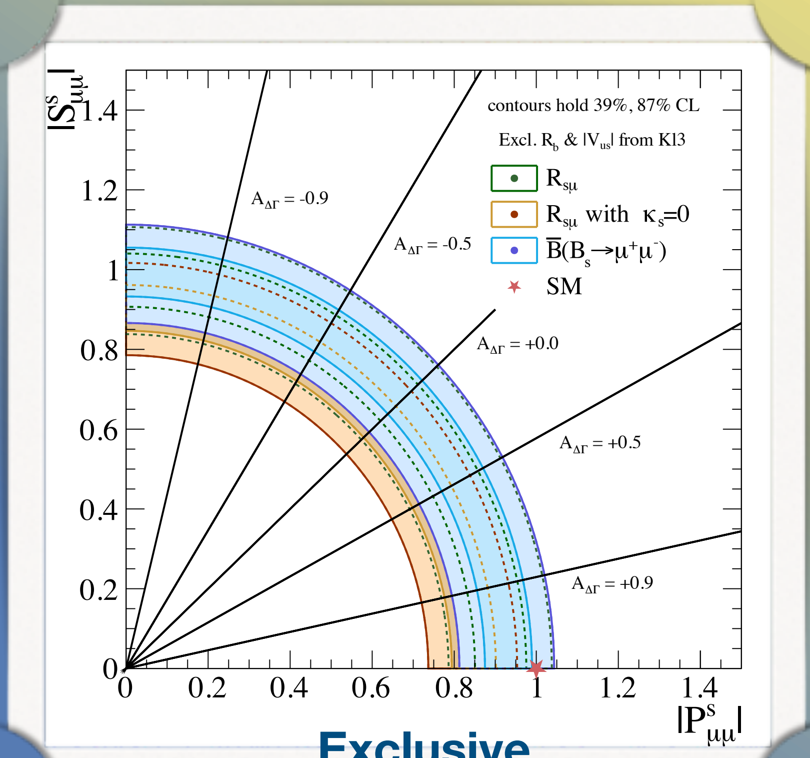

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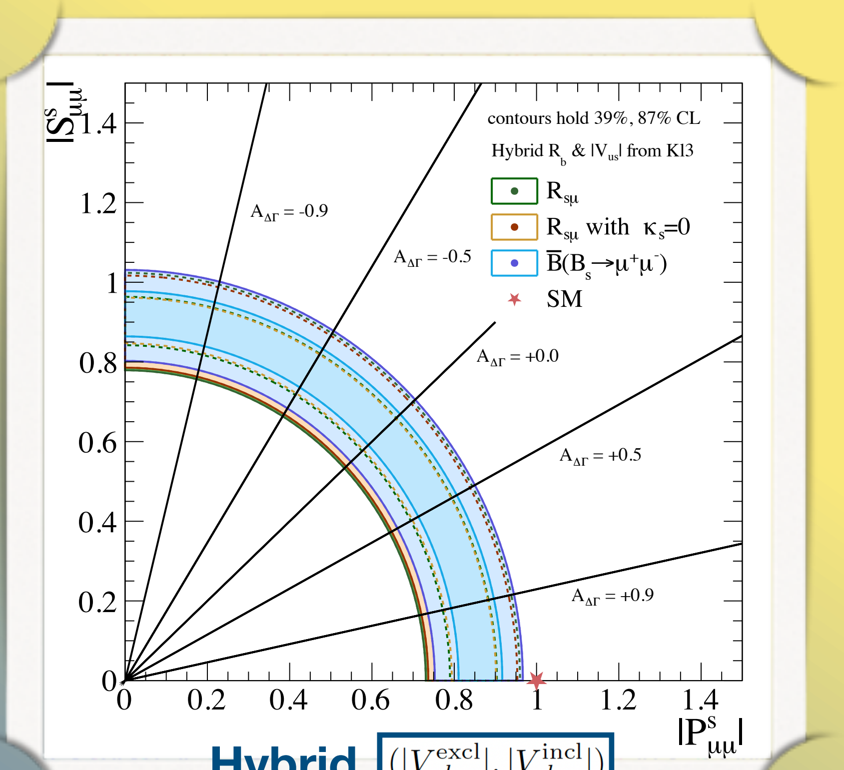


Hybrid $(|V_{ub}^{\rm excl}|, |V_{cb}^{\rm incl}|)$

We can minimise this dependence, creating the following ratio $R_{s\mu}$

Determining NP in $B_s^0 \to \mu^+\mu^-$

NP can modify its branching ratio

(Pseudo-)Scalar

$B_s^0 - \bar{B}_s^0$ mixing

arXiv:hep-ph/0303060
arXiv:2104.09521
arXiv:2109.11032

$$\mathcal{R}_{s\mu} \equiv \left| \frac{\bar{\mathcal{B}}(B_s \to \mu^+\mu^-)}{\Delta m_s} \right|$$

CKM elements drop out in the SM ratio

Including NP effects in both $B(B_s \to \mu^+\mu^-)$ and Δm_s we get the generalised expression

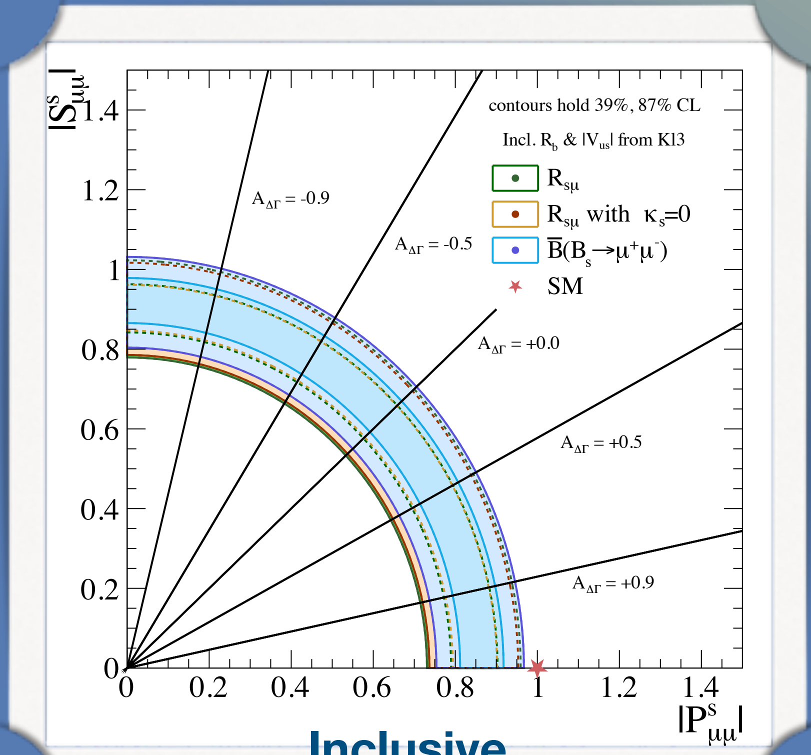
$$\mathcal{R}_{s\mu} = (1.60 \pm 0.19) \times 10^{-10}$$

Comparing with the SM, we obtain extra contours

$$\mathcal{R}_{s\mu}^{\rm SM} = \frac{\tau_{B_s}}{1-y_s} \frac{3G_{\rm F}^2 m_W^2 \sin^4\theta_W}{4\pi^3} \frac{|C_{10}^{\rm SM}|^2}{S_0(x_t)\eta_{2B}\hat{B}_{B_s}} m_\mu^2 \sqrt{1 - 4\frac{m_\mu^2}{m_{B_s}^2}}$$

$$\mathcal{R}_{s\mu}^{\rm SM} = (2.22 \pm 0.10) \times 10^{-10}\ {\rm ps}$$

introduces a dependence on the CKM matrix elements through the NP parameters ($\varkappa_S$, σ_S)



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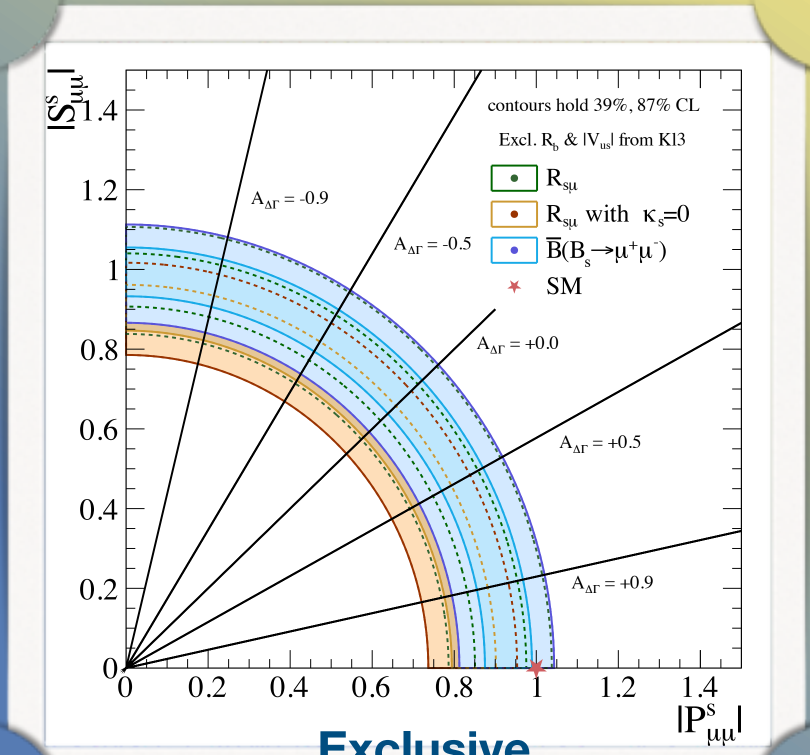

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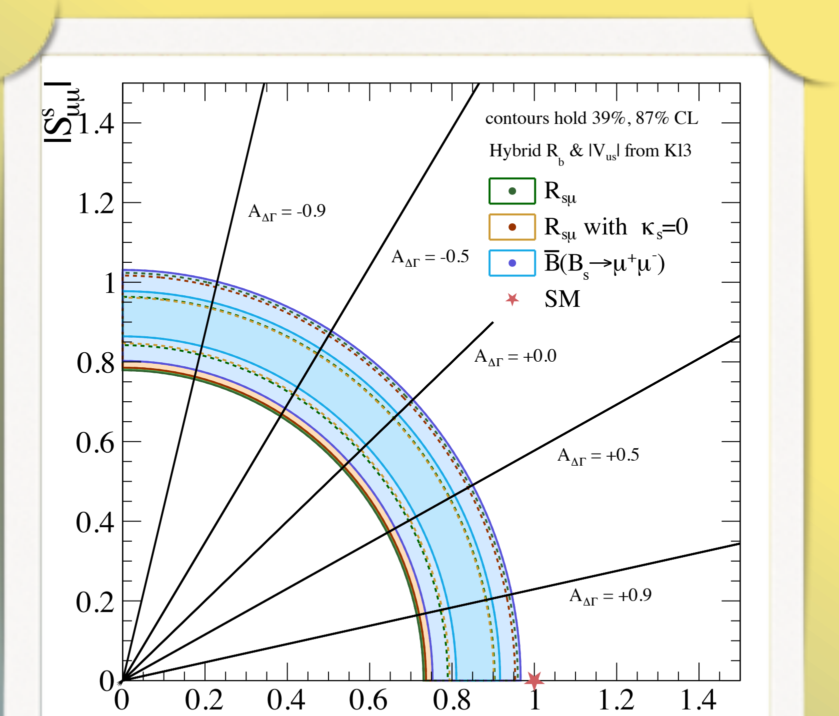
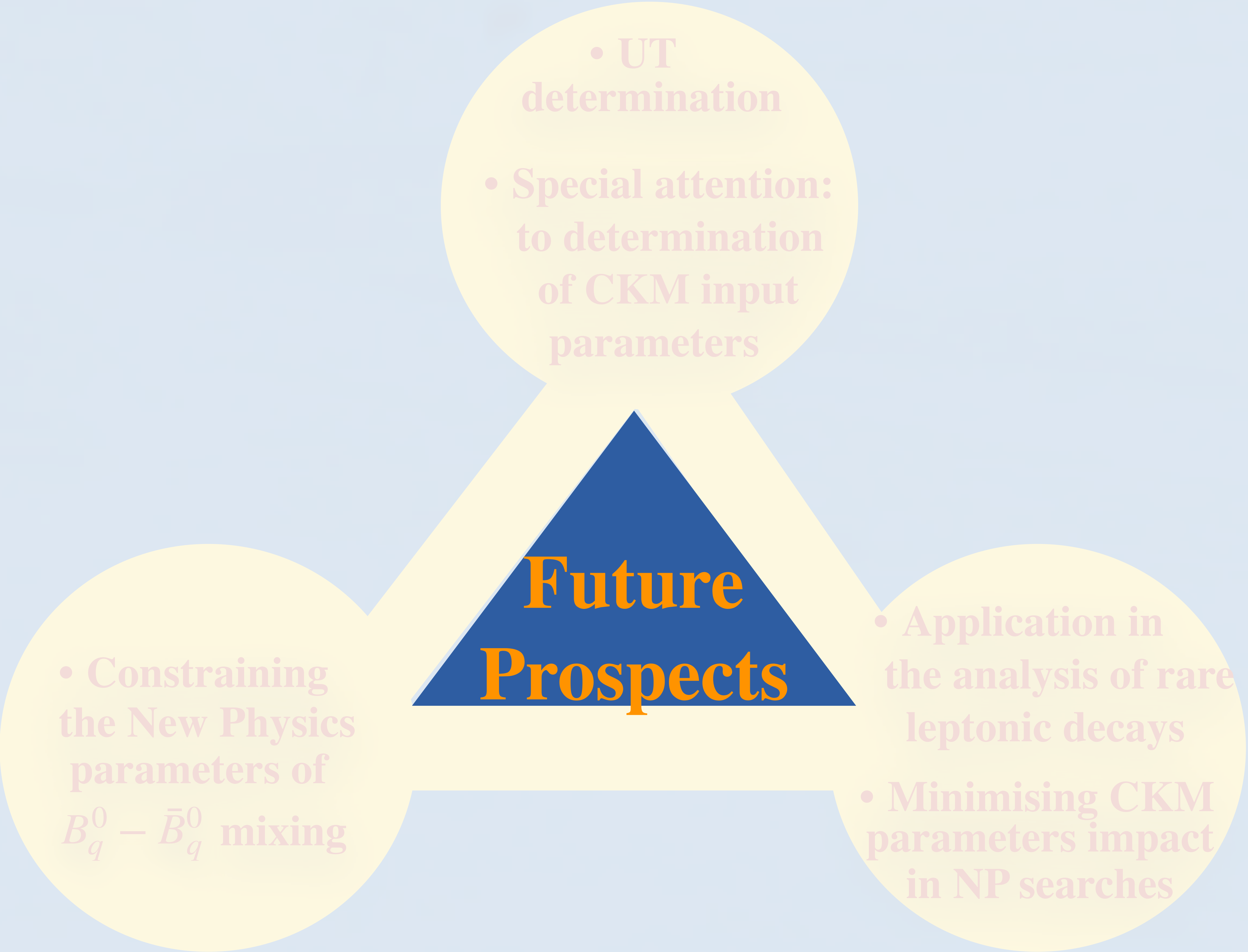


Hybrid $(|V_{ub}^{\rm excl}|, |V_{cb}^{\rm incl}|)$

We can minimise this dependence, creating the following ratio $R_{s\mu}$

We will focus on the following topics



Future Prospects

- UT determination
- Special attention: to determination of CKM input parameters

- Constraining the New Physics parameters of $B_q^0 - \bar{B}_q^0$ mixing

- Application in the analysis of rare leptonic decays
- Minimising CKM parameters impact in NP searches

Improved Precision on $\varkappa_q$ and σ_q

We assume a hypothetical reduction of 50%
in the uncertainty on:

- the CKM matrix element $|V_{cb}|$,
- the lattice calculations,
- the UT apex

In the B_d-system: apex plays a limiting factor

progress on UT apex has to be made

In the B_s-system: we do not have this situation

↓

Hints of NP in $B_d^0 - \bar{B}_d^0$ mixing:
less promising than the B_s-meson
due to small $\varkappa_d$ we find with current data

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NP in γ

Improved precision on the input measurements: discrepancies between the γ determinations

Averaging over both results would then no longer be justified - UT should be revisited

Independent info from additional observables: necessary to resolve the situation

Exciting new opportunities for NP searches, both in
γ itself and in $B_q^0 - \bar{B}_q^0$ mixing:strongly correlated with the coordinates of the UT apex

Improved Precision on $\varkappa_q$ and σ_q

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Exciting new opportunities for NP searches, both in
γ itself and in $B_q^0 - \bar{B}_q^0$ mixing:strongly correlated with the coordinates of the UT apex

Opportunities for $B(B_q \to \mu^+\mu^-)$

1) Ratio of branching fractions between $B_d^0 \to \mu^+\mu^-$ and $B_s^0 \to \mu^+\mu^-$
⟶ alternative way to determine the UT side R_t

2) Another useful application for the ratio of branching fractions between $B_d^0 \to \mu^+\mu^-$ and $B_s^0 \to \mu^+\mu^-$

Improved Precision on $\varkappa_q$ and σ_q

We assume a hypothetical reduction of 50%
in the uncertainty on:

- the CKM matrix element $|V_{cb}|$,
- the lattice calculations,
- the UT apex

In the B_d-system: apex plays a limiting factor
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Opportunities for $B(B_q \to \mu^+\mu^-)$

1) Ratio of branching fractions between $B_d^0 \to$

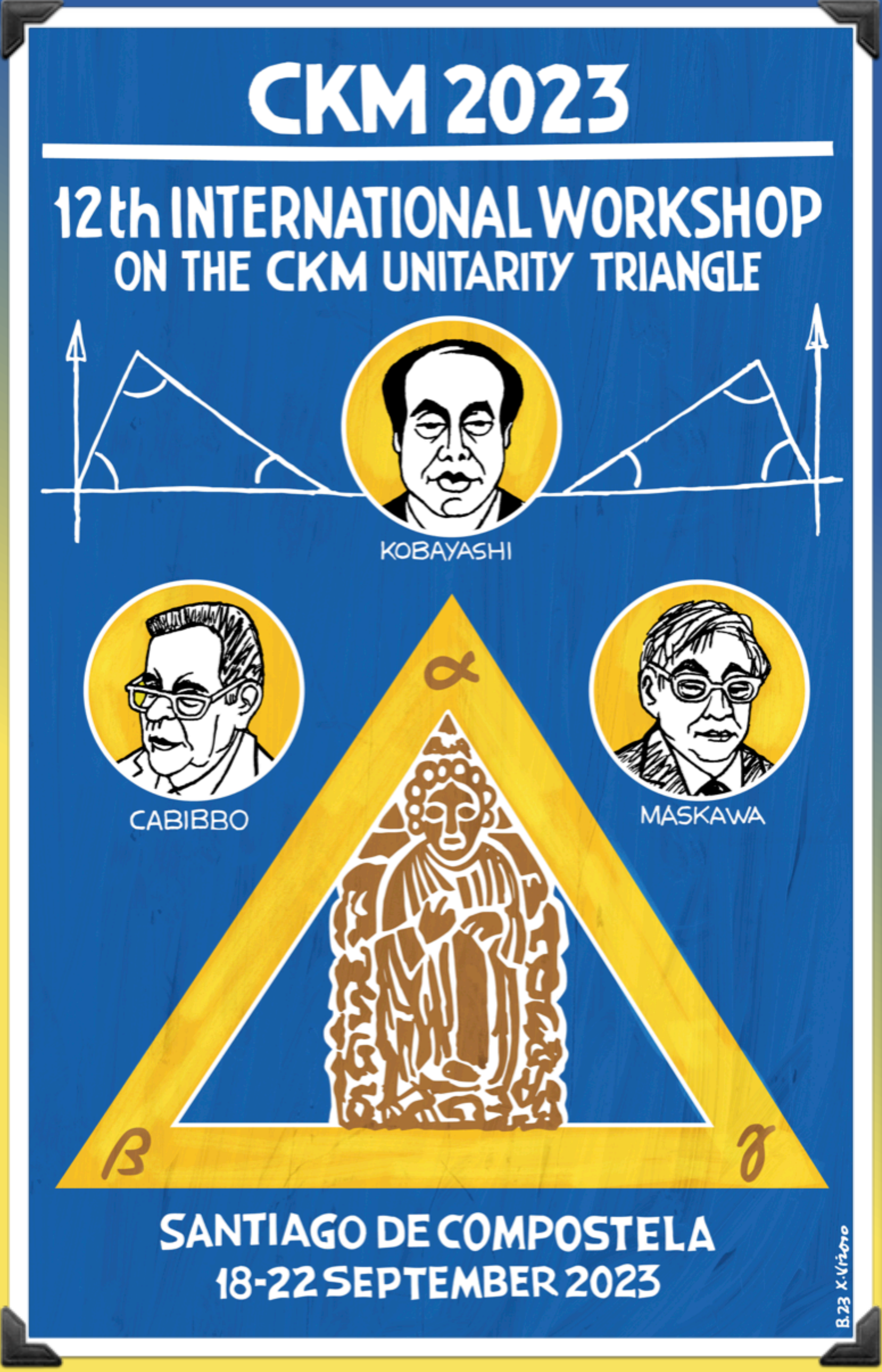
⟶ alternative way to determine the UT

2) Another useful application for the ratio of b

$$U^{ds}_{\mu\mu} \equiv \sqrt{\frac{|P^d_{\mu\mu}|^2 + |S^d_{\mu\mu}|^2}{|P^s_{\mu\mu}|^2 + |S^s_{\mu\mu}|^2}} \,,$$

more powerful test of the SM, where $U^{ds}_{\mu\mu} = 1$

$$= \left[\frac{\tau_{B_s}}{\tau_{B_d}} \frac{1-y_d^2}{1-y_s^2} \frac{1+\mathcal{A}^d_{\Delta\Gamma} y_d}{1+\mathcal{A}^s_{\Delta\Gamma} y_s} \frac{\sqrt{m^2_{B_s} - 4m^2_\mu}}{\sqrt{m^2_{B_d} - 4m^2_\mu}} \left(\frac{f_{B_s}}{f_{B_d}}\right)^2 \left|\frac{V_{ts}}{V_{td}}\right|^2 \frac{\bar{\mathcal{B}}(B_d \to \mu^+\mu^-)}{\bar{\mathcal{B}}(B_s \to \mu^+\mu^-)} \right]^{1/2} .$$



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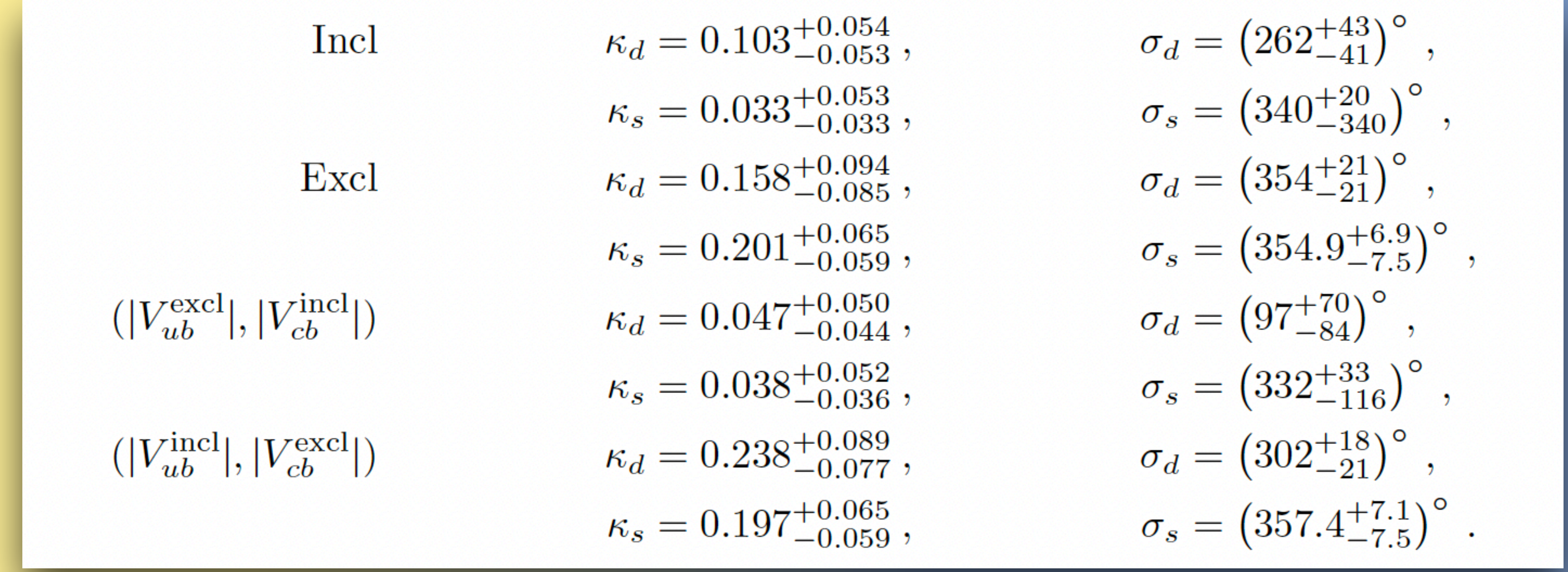
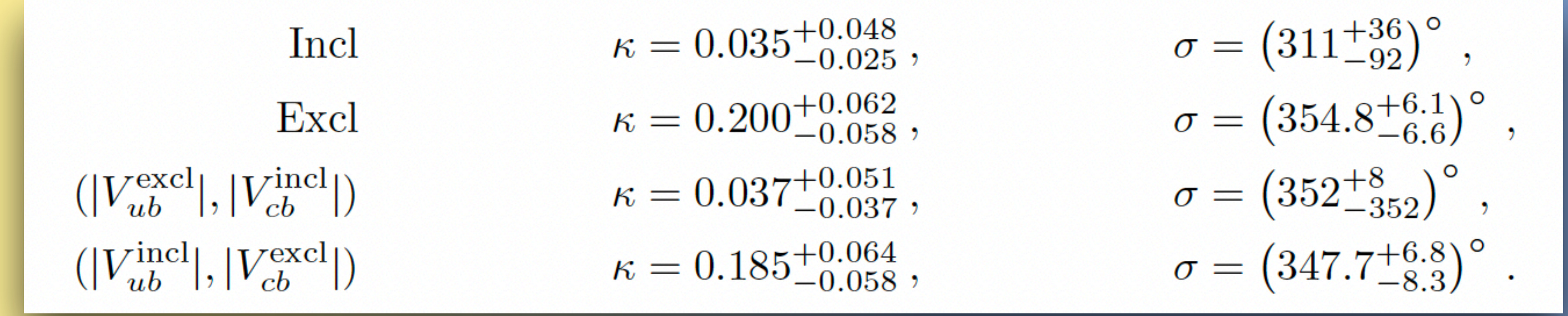
Fit results

NP Scenario I



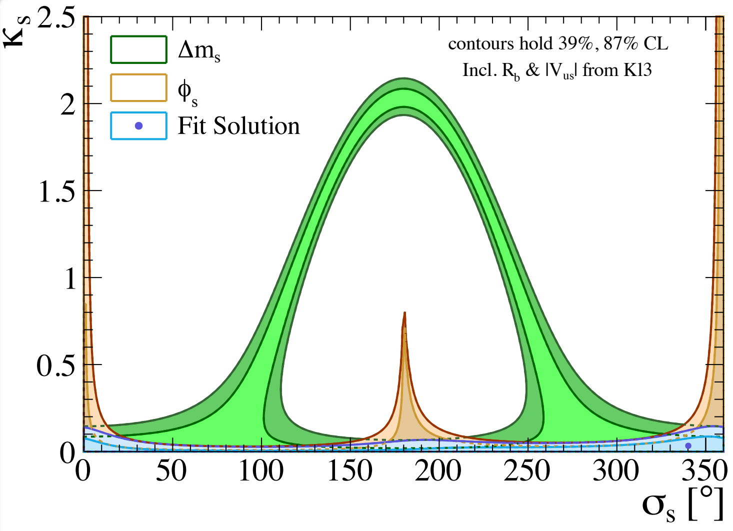
Incl	$\kappa_d = 0.103^{+0.054}_{-0.053}$,	$\sigma_d = \left(262^{+43}_{-41}\right)^\circ$,
	$\kappa_s = 0.033^{+0.053}_{-0.033}$,	$\sigma_s = \left(340^{+20}_{-340}\right)^\circ$,
Excl	$\kappa_d = 0.158^{+0.094}_{-0.085}$,	$\sigma_d = \left(354^{+21}_{-21}\right)^\circ$,
	$\kappa_s = 0.201^{+0.065}_{-0.059}$,	$\sigma_s = \left(354.9^{+6.9}_{-7.5}\right)^\circ$,
$(\lvert V_{ub}^{\rm excl}\rvert, \lvert V_{cb}^{\rm incl}\rvert)$	$\kappa_d = 0.047^{+0.050}_{-0.044}$,	$\sigma_d = \left(97^{+70}_{-84}\right)^\circ$,
	$\kappa_s = 0.038^{+0.052}_{-0.036}$,	$\sigma_s = \left(332^{+33}_{-116}\right)^\circ$,
$(\lvert V_{ub}^{\rm incl}\rvert, \lvert V_{cb}^{\rm excl}\rvert)$	$\kappa_d = 0.238^{+0.089}_{-0.077}$,	$\sigma_d = \left(302^{+18}_{-21}\right)^\circ$,
	$\kappa_s = 0.197^{+0.065}_{-0.059}$,	$\sigma_s = \left(357.4^{+7.1}_{-7.5}\right)^\circ$.

NP Scenario II

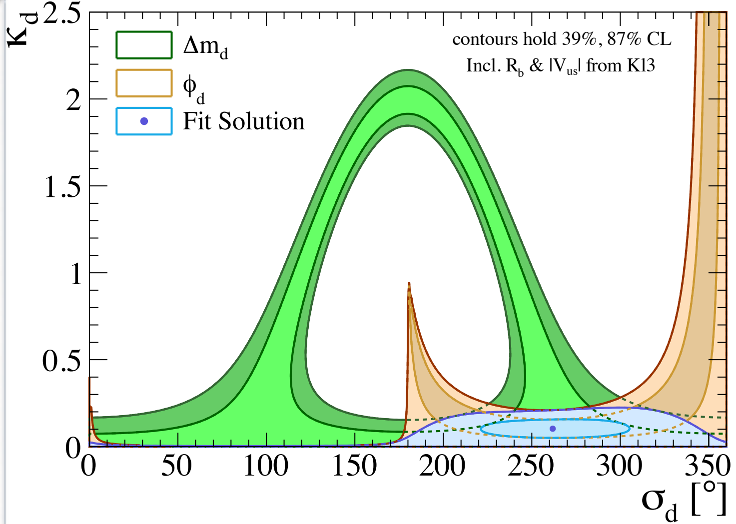


Incl	$\kappa = 0.035^{+0.048}_{-0.025}$,	$\sigma = \left(311^{+36}_{-92}\right)^\circ$,
Excl	$\kappa = 0.200^{+0.062}_{-0.058}$,	$\sigma = \left(354.8^{+6.1}_{-6.6}\right)^\circ$,
$(\lvert V_{ub}^{\rm excl}\rvert, \lvert V_{cb}^{\rm incl}\rvert)$	$\kappa = 0.037^{+0.051}_{-0.037}$,	$\sigma = \left(352^{+8}_{-352}\right)^\circ$,
$(\lvert V_{ub}^{\rm incl}\rvert, \lvert V_{cb}^{\rm excl}\rvert)$	$\kappa = 0.185^{+0.064}_{-0.058}$,	$\sigma = \left(347.7^{+6.8}_{-8.3}\right)^\circ$.

Fit results - Scenario I



Inclusive



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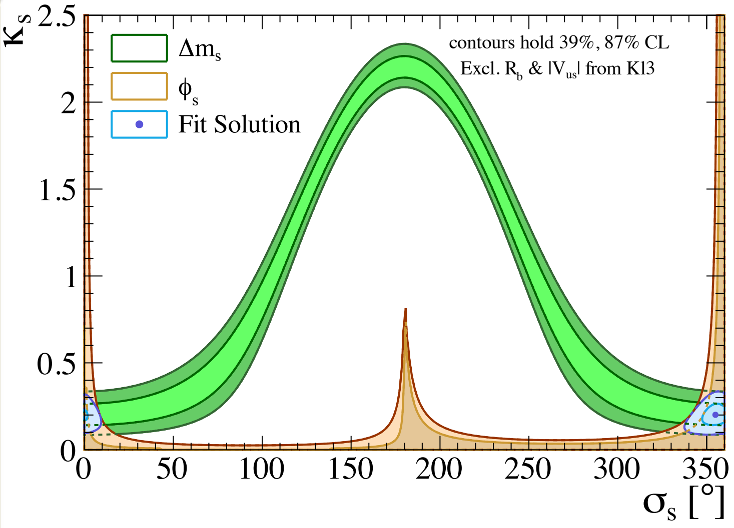

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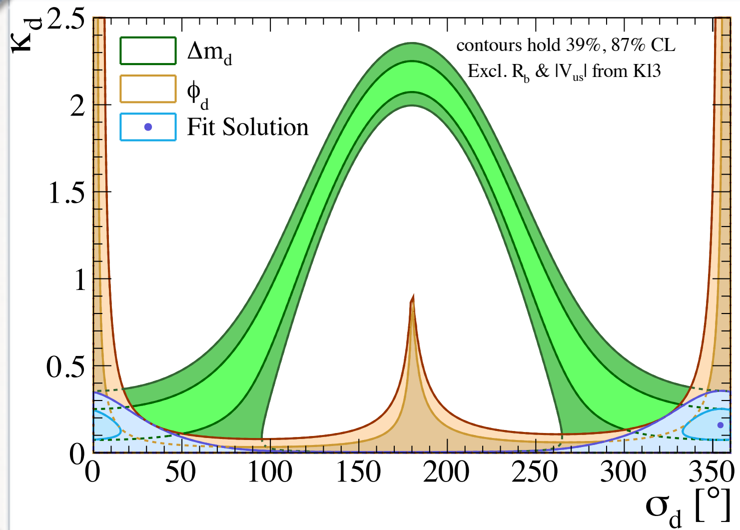

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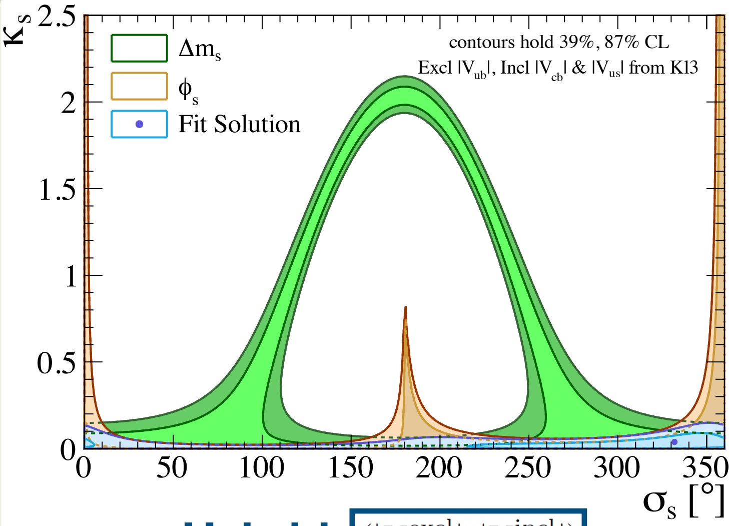
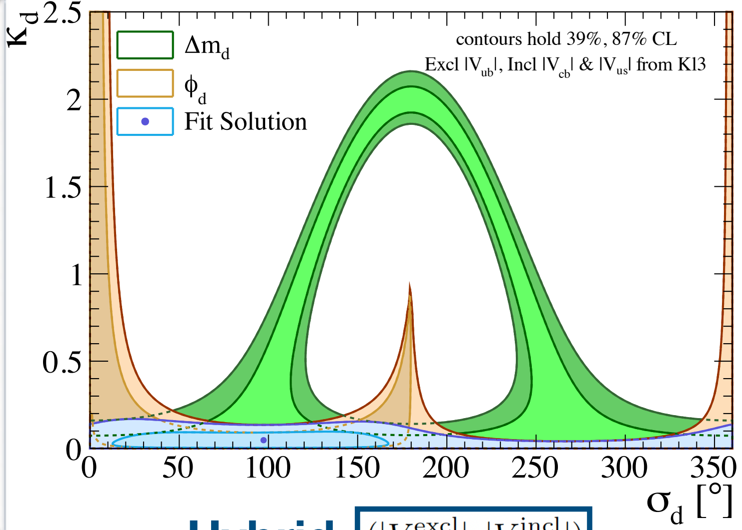


Hybrid $(|V_{ub}^{\rm excl}|, |V_{cb}^{\rm incl}|)$



Hybrid $(|V_{ub}^{\rm excl}|, |V_{cb}^{\rm incl}|)$