B theory overview

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UNIVERSITÉ PARIS SUD
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Outline

- ★ Introduction: Flavour physics as a window to new physics
- ★ New physics search in b-> d transition
- ★ New physics search in b-> s transitions
- ★ Searching new physics in b->sγ processes
- ★ Conclusions

Introduction:

Flavour Physics as a window to physics beyond the SM

Flavour Physics in SM

In SM, the difference between mass and interaction basis explains, the GIM mechanism, the CP Violation! Very concise!

$$\mathcal{L}_Y = \sum_{ij} Y^u_{ij} \overline{Q_{iL}} \begin{pmatrix} \phi^0 \\ \phi^- \end{pmatrix} u_{jR} + \sum_{ij} Y^d_{ij} \overline{Q_{iL}} \begin{pmatrix} -\phi^{-\dagger} \\ \phi^{0\dagger} \end{pmatrix} d_{jR} + h.c.$$

Yukawa coupling

Glashow, Illiopolous, Maiani '70

$$(U^u_{L,R})^\dagger U^u_{L,R} \equiv \mathbf{1}, \quad (U^d_{L,R})^\dagger U^d_{L,R} \equiv \mathbf{1}$$

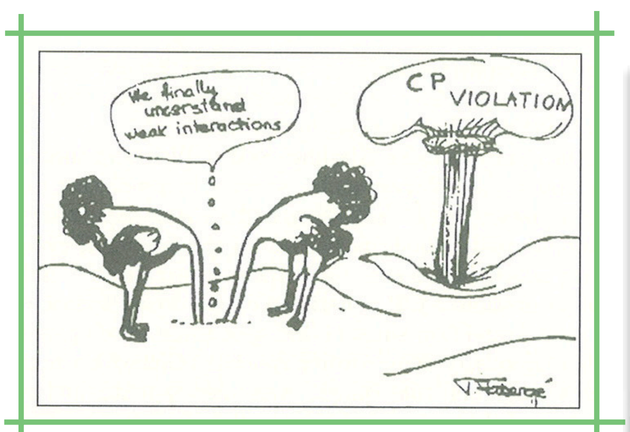
Neutral current: GIM mechanism!

Cabibbo '63
Kobayashi, Maskawa '73

$$(U^u_L)^\dagger U^d_L \equiv V_{\rm CKM}$$

Charged current:
CKM matrix
Origin of CP Violation!

Cronin, Fitch, Christenson,Turlay '64



- Simple explanation of flavour physics up to now! Hundreds of observables (including dozens of CPV) are explained by this single matrix.

Flavour Physics beyond SM

The indirect search of new physics through quantum loop effect: very powerful tool to search for new physics signal!

- Such a simple picture does not exist in most of the extensions of SM: suppression of the FCNC is not automatic and also unwanted CP violation parameters appear.
  N.B.: SM also has an "unwanted" CP parameter (strong CP problem).

SUSY: Quark and Squark mass matrices can not be diagonalized at the same time ---> many unwanted FCNC and CP violation

Mutli-Higgs model, Left-Right symmetric model: Many Higgs appearing in this model ---> tree level FCNC

Warped extra-dimension with flavour in bulk: Natural FCNC suppression though, K-K mixing is still too large due to the chiral enhancement

- In reverse, new physics models predict naturally deviation of SM in flavour and CP violating phenomena.
- But then, what is the indication of the non-appearance of new physics? And where/how to search now?

Flavour Physics beyond SM

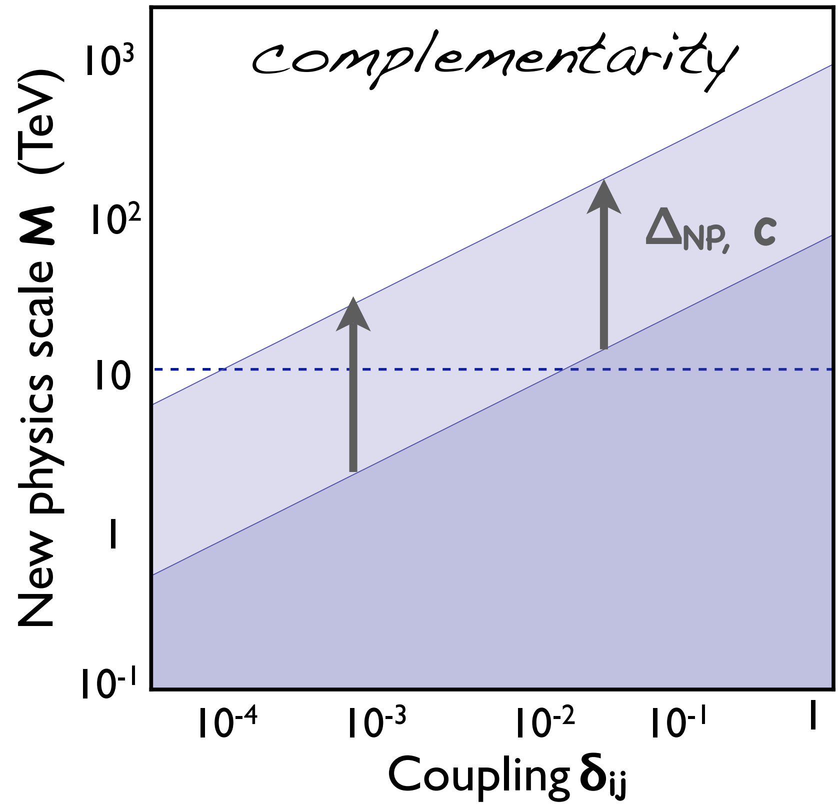
Discovery of New Physics

Energy Frontier?

Intensity Frontier?

Δ_{NP} = Deviation from SM
= [exp.]−[SM prediction] > $c(\delta_{ij})/M_{NP}$

flavour coupling δ_{ij}, new physics scale M_{NP}



☞Increasing the sensitivity to NP in indirect search?

- Reduce experimental error (---> high luminosity!)
- Reduce theoretical error (---> hadronic effect!)
- Find observable which is more sensitive (---> new ideas!)

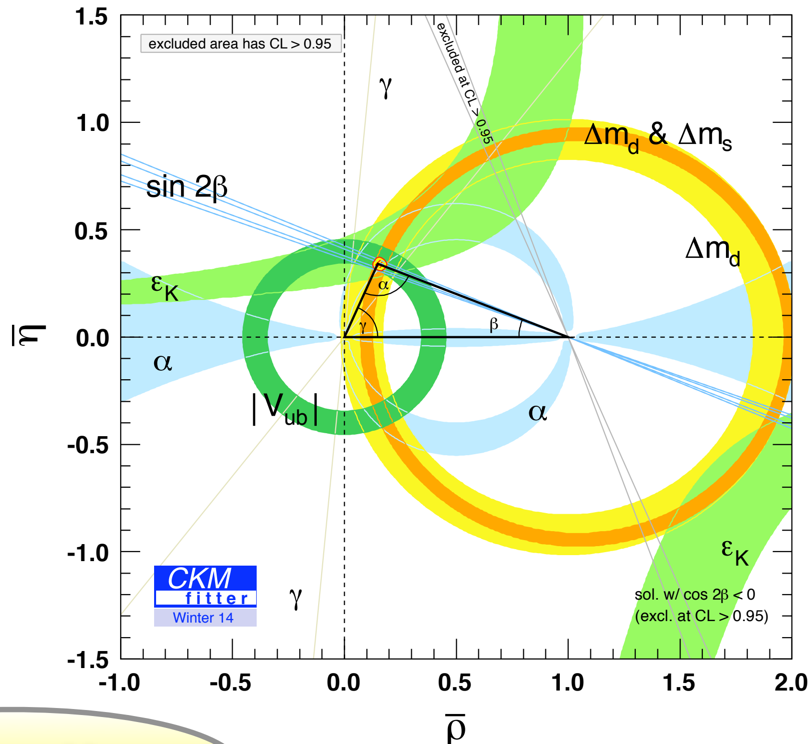
New physics search in b->d transition:

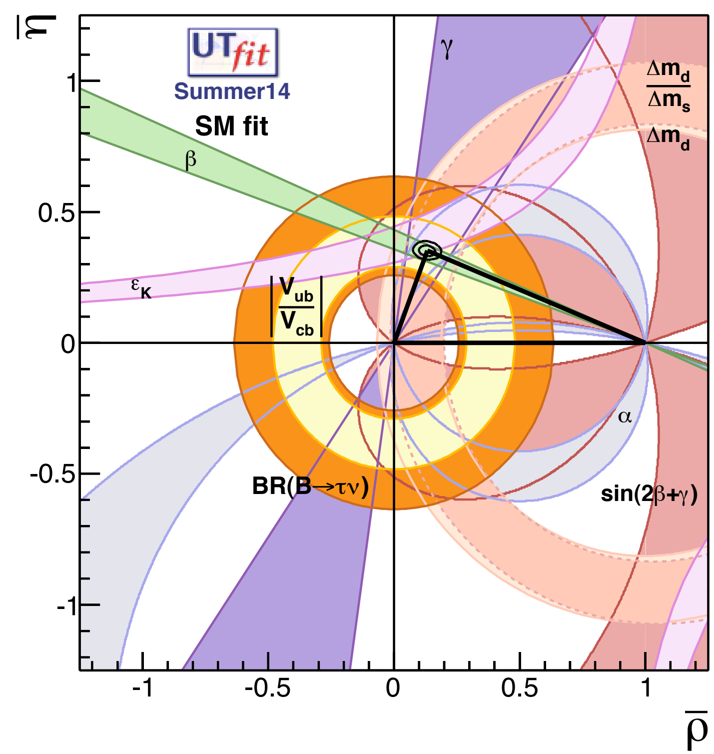
I: Unitarity triangle, legacy and prospect

Unitarity Triangle: Legacy

The B factories measured β (Φ_1) at a very high precision $(21.5\pm0.8)^o$.

HFAG





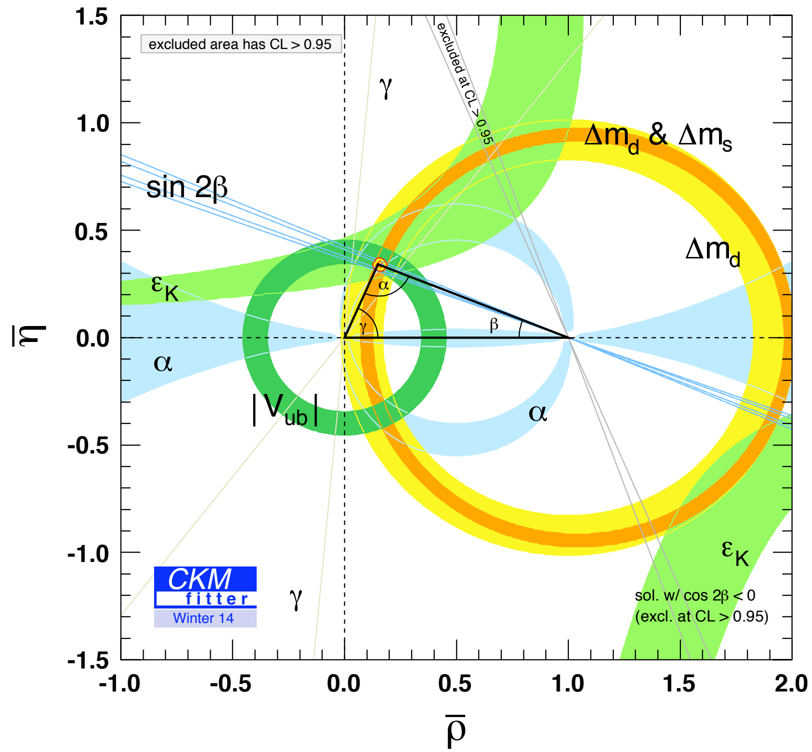
See more details, Book of Physics of B factories

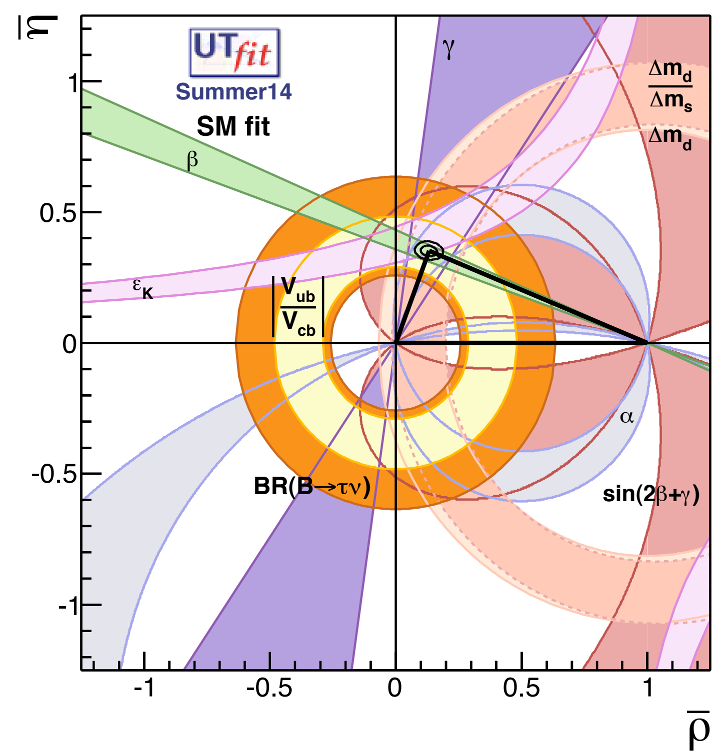
Implication

- The main source of CP violation comes from the KM phase.
- The so-called "approximate CP models" excluded!
- Direct CP violation observed in many B decays, super-weak model excluded!

Unitarity Triangle: Prospect

Further improvement in precision foreseen in coming years at LHCb and Belle II!





Prospect

- Improvement in γ (Φ_3) measurement foreseen: $\gamma(\Phi_3)=(67\pm11)^{\circ}$ -> a few degree in the future by LHCb/Belle II (BESIII).
- For the side determination, the hadronic input is crucial!

New physics search in b->s transition:

I: Measurement of the B_s mixing phase Φ_s

II: Measurement of β (Φ_1) in penguin channels

III: Measurement of the photon polarization of the b->sγ

B_s mixing phase measurement

$$\Delta M_q \equiv M_2 - M_1 = -2|M_{12}|$$

$$\Delta \Gamma_q \equiv \Gamma_1 - \Gamma_2 = 2|\Gamma_{12}| \cos\zeta_q$$

$$\frac{q}{p} \simeq e^{-i\phi_q}\left(1 + \frac{\Delta\Gamma_q}{2\Delta M_q}\tan\zeta_q\right)$$

$$\left|\frac{q}{p}\right| \simeq 1 + \frac{\Delta\Gamma_q}{2\Delta M_q}\tan\zeta_q$$

Golden-Channels to measure time-dependent CP asymmery

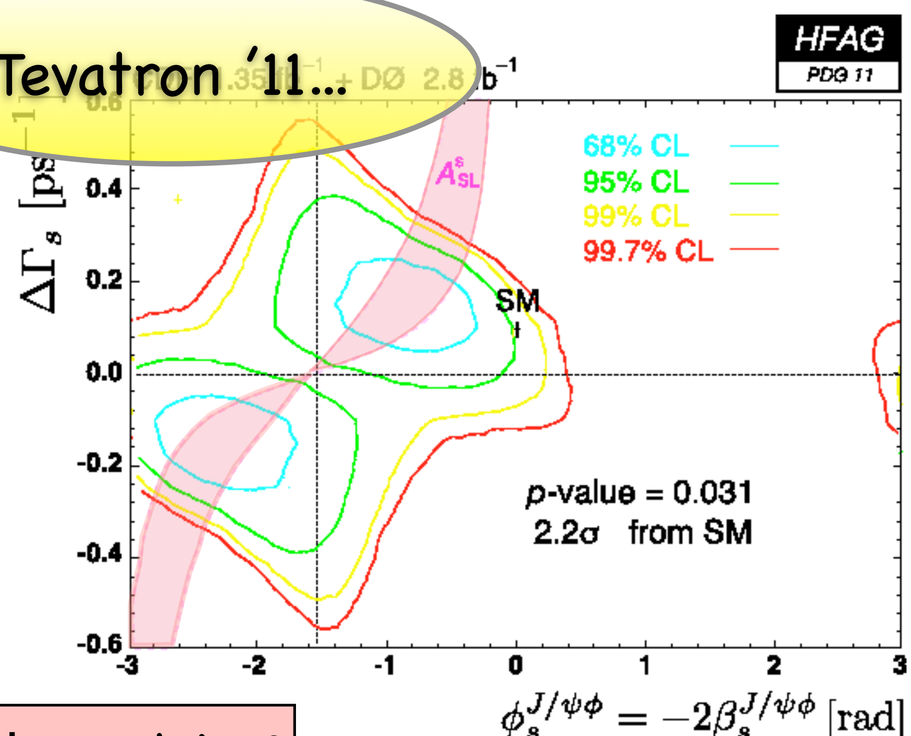
$B_s \to J/\psi\Phi$ ($\Phi_d = 2\beta_s$): Tevatron, LHCb

*$\Delta\Gamma/\Delta M$ is non-negligible for B_s

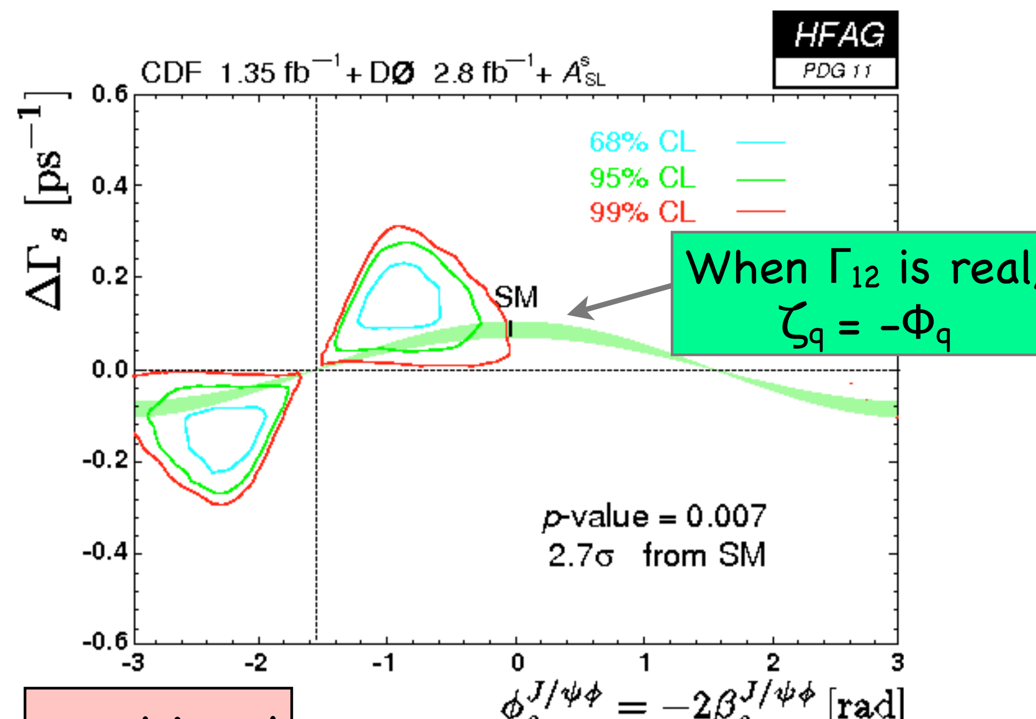
Di-lepton charge asymmetry

$A_{SL}{}^s = -0.0077 \pm 0.0042$

Tevatron '11...



Φ_s and $A_{SL}{}^s$



combined

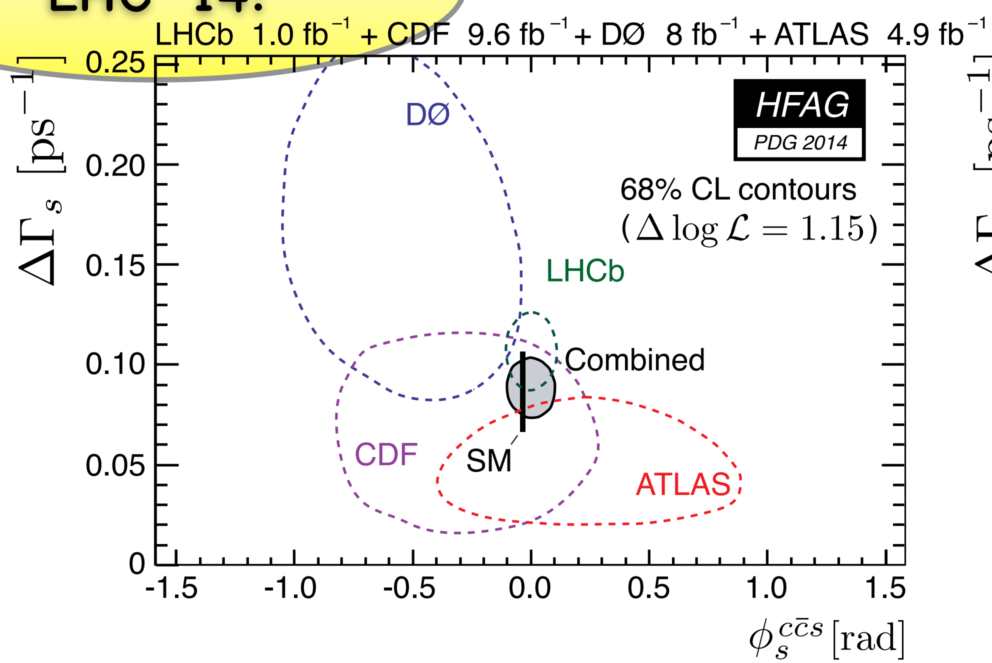
B_s mixing phase measurement

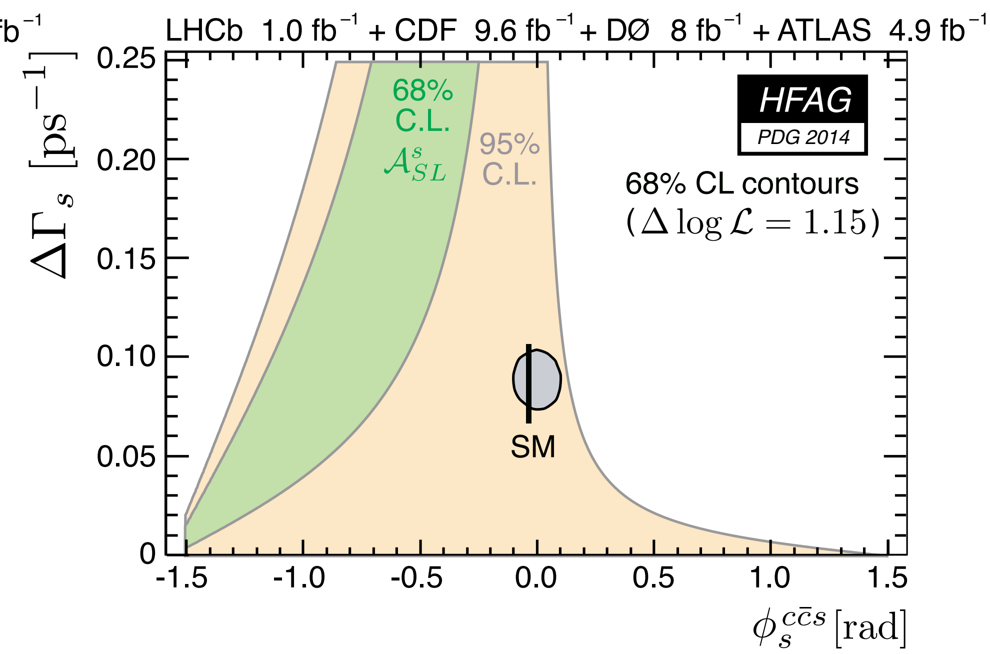
- The experimental errors are significantly reduced by the new LHCb measurement.
- The current measurement of Φs is consistent to SM (=-0.0363±0.0016):

Φs=0.070±0.055

- LHCb has an ability to reach to the error down to δΦs=±0.025 by 2018 and the upgrade can reach to the precision of δΦs=±0.009.
- So it is too early to conclude! New physics may appear here!

LHC '14!





β (Φ_1) measurements with $b \to s\bar{s}s$ modes

Time dependent CP asymmetry in the B_d system (c.f. similar measurement for Bs)

Gold-plated mode (tree)

$$
\begin{aligned}
S_{J/\psi K_s} &= Im\left[\underbrace{\frac{M_{12}}{M_{12}^*}}_{oscill.}\underbrace{\frac{A(\overline{B}\to J/\psi K_S)}{A(B\to J/\psi K_S)}}_{decay}\right] \\
&= Im\left[\underbrace{\frac{V_{tb}V_{td}^*}{V_{tb}^*V_{td}}}_{oscill.}\underbrace{\frac{V_{cb}V_{cs}^*}{V_{cb}^*V_{cs}}}_{decay}\right] \\
&= \sin 2\beta(2\phi_1)
\end{aligned}
$$

With penguin process

$$
\begin{aligned}
S_{\phi K_s} &= Im\left[\underbrace{\frac{M_{12}}{M_{12}^*}}_{oscill.}\underbrace{\frac{A(\overline{B}\to \phi K_S)}{A(B\to \phi K_S)}}_{decay}\right] \\
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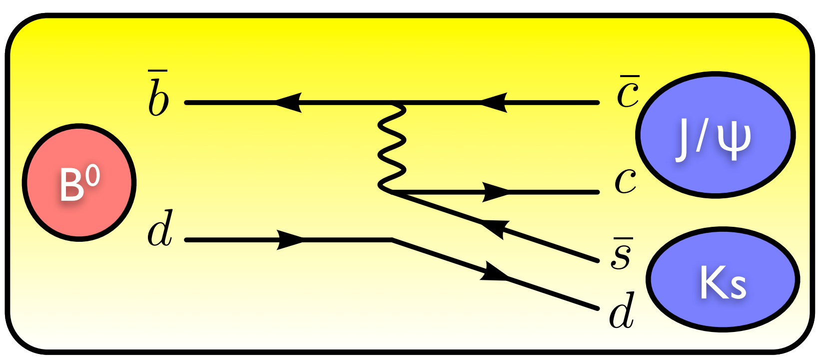

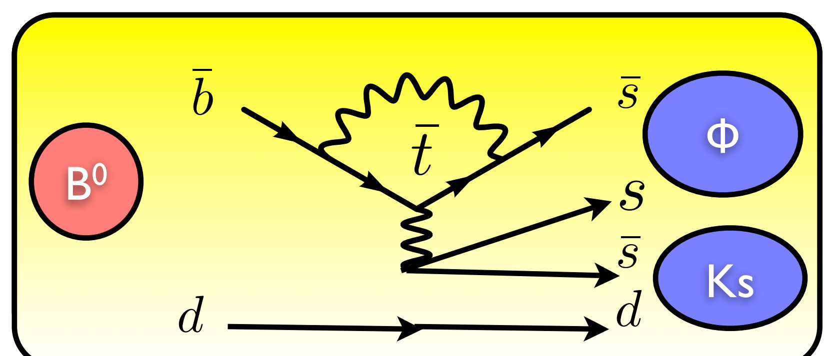

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$$= Im \left[\ldots \right]$$

$$= \sin 2 \ldots$$

With penguin process

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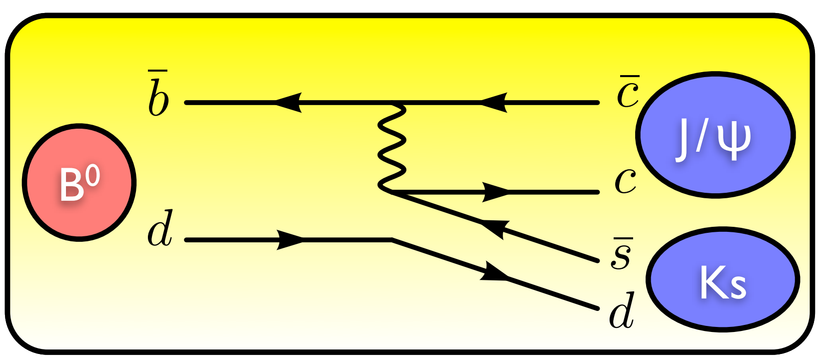
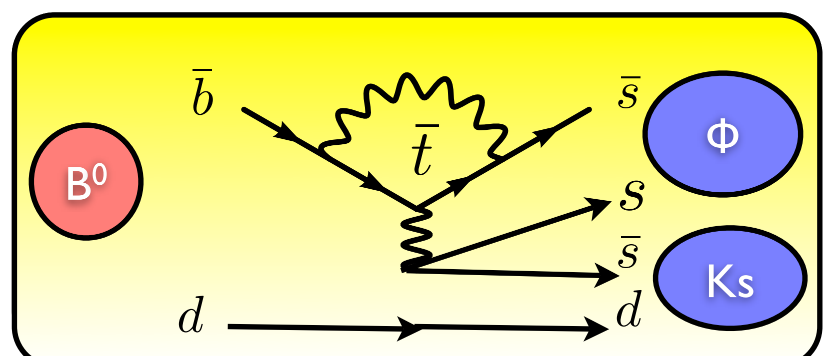
$$= \ldots \underbrace{\frac{V_{ts}^*}{V_{ts}}}_{\ldots cay}\Big]$$

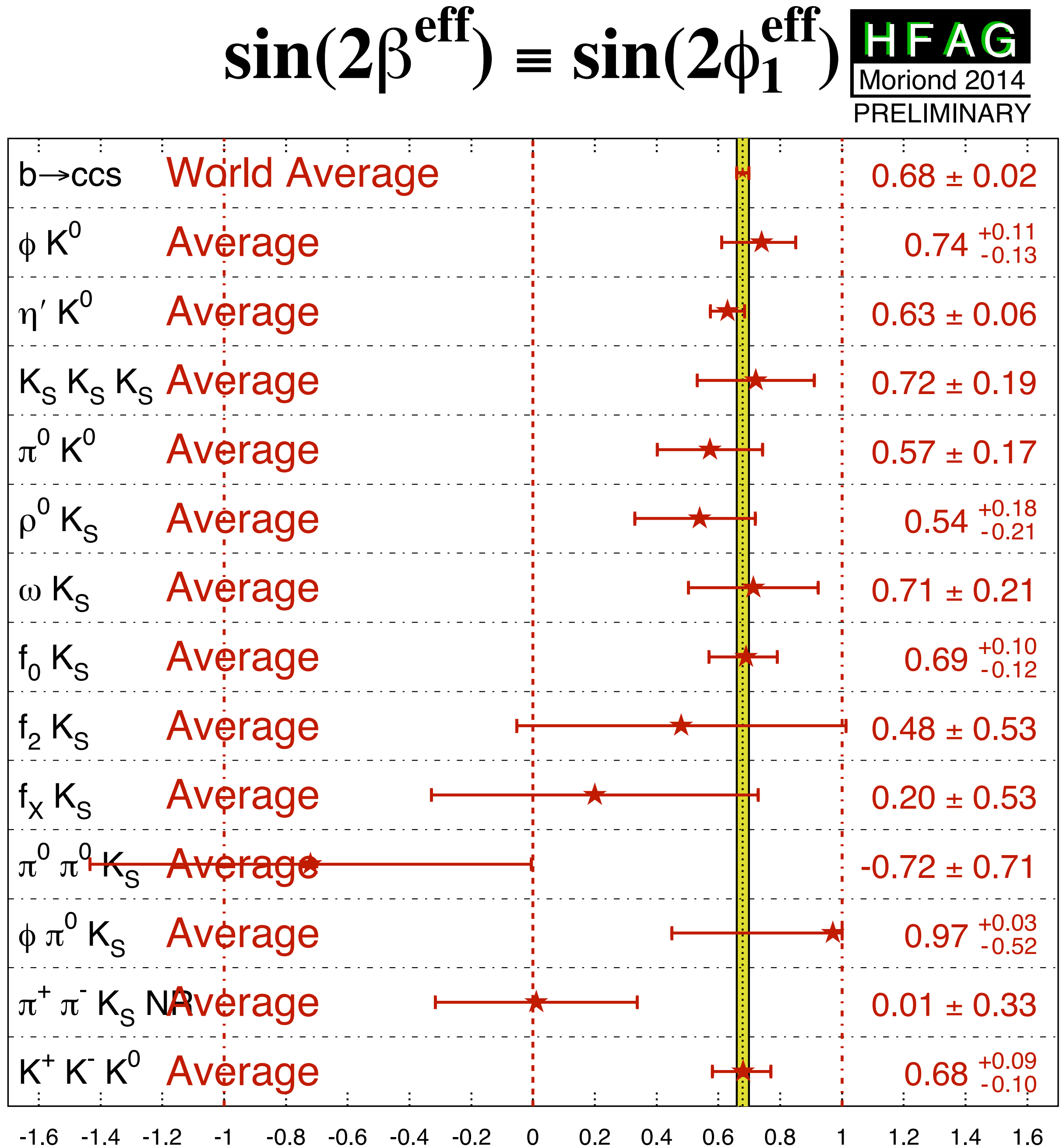
Difference in the measured β(Φ_1) value is the indication of the new physics in the penguin loop!





β (Φ_1) measurements with $b \to s\bar{s}s$ channels

- B factories measured various channels.
- The experimental errors are statistics dominant. Thus, Belle II and LHCb will improve the measurement (~2%).
- Theoretical errors are small especially for $B \to \Phi K_S$ and $\eta' K_S$ (table : theoretical CP errors).
- Similar study can be done for the B_s system with, e.g. $B_s \to \Phi\Phi$, $B_s \to \eta'\Phi$ etc.
- New physics contributions for difference channels can be significantly different.



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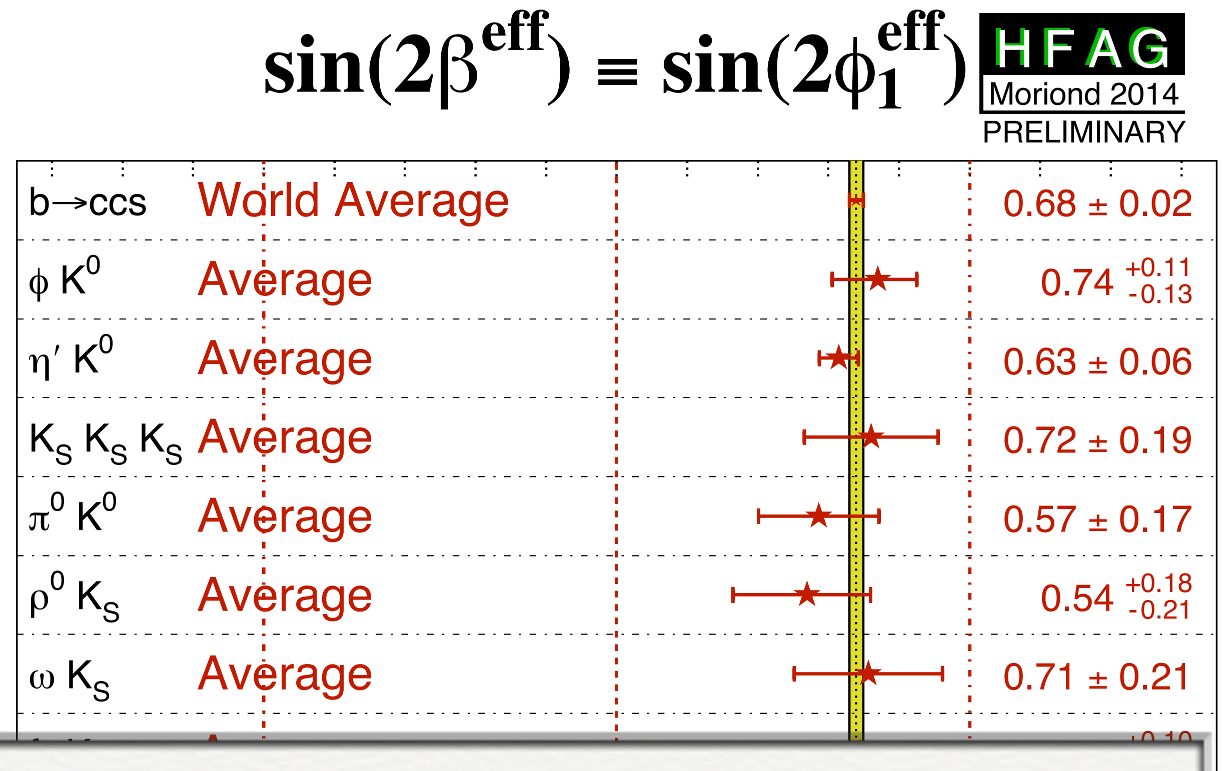

	pQCD	QCDF	SD	SD+LD
ϕK_S	$0.02^{+0.01}_{-0.01}$	$0.04^{+0.01}_{-0.01}$	$0.02^{+0.00}_{-0.04}$	$0.03^{+0.01+0.01}_{-0.04-0.01}$
$\eta' K_S$	$0.01^{+0.01}_{-0.01}$		$0.01^{+0.00}_{-0.04}$	$0.00^{+0.00+0.00}_{-0.04-0.00}$
πK_S	$0.07^{+0.05}_{-0.04}$	$0.07^{+0.02}_{-0.03}$	$0.06^{+0.02}_{-0.04}$	$0.04^{+0.02+0.01}_{-0.03-0.01}$
ωK_S	$0.13^{+0.08}_{-0.08}$	$0.17^{+0.03}_{-0.07}$	$0.12^{+0.05}_{-0.06}$	$0.01^{+0.02+0.02}_{-0.04-0.01}$
ρK_S	$-0.08^{+0.08}_{-0.12}$	$-0.17^{+0.01}_{-0.06}$	$-0.09^{+0.03}_{-0.07}$	$0.04^{+0.09+0.08}_{-0.10-0.11}$

E.K CKM'06

β (Φ_1) measurements with $b \rightarrow s\bar{s}s$ channels

- B factories measured various channels.
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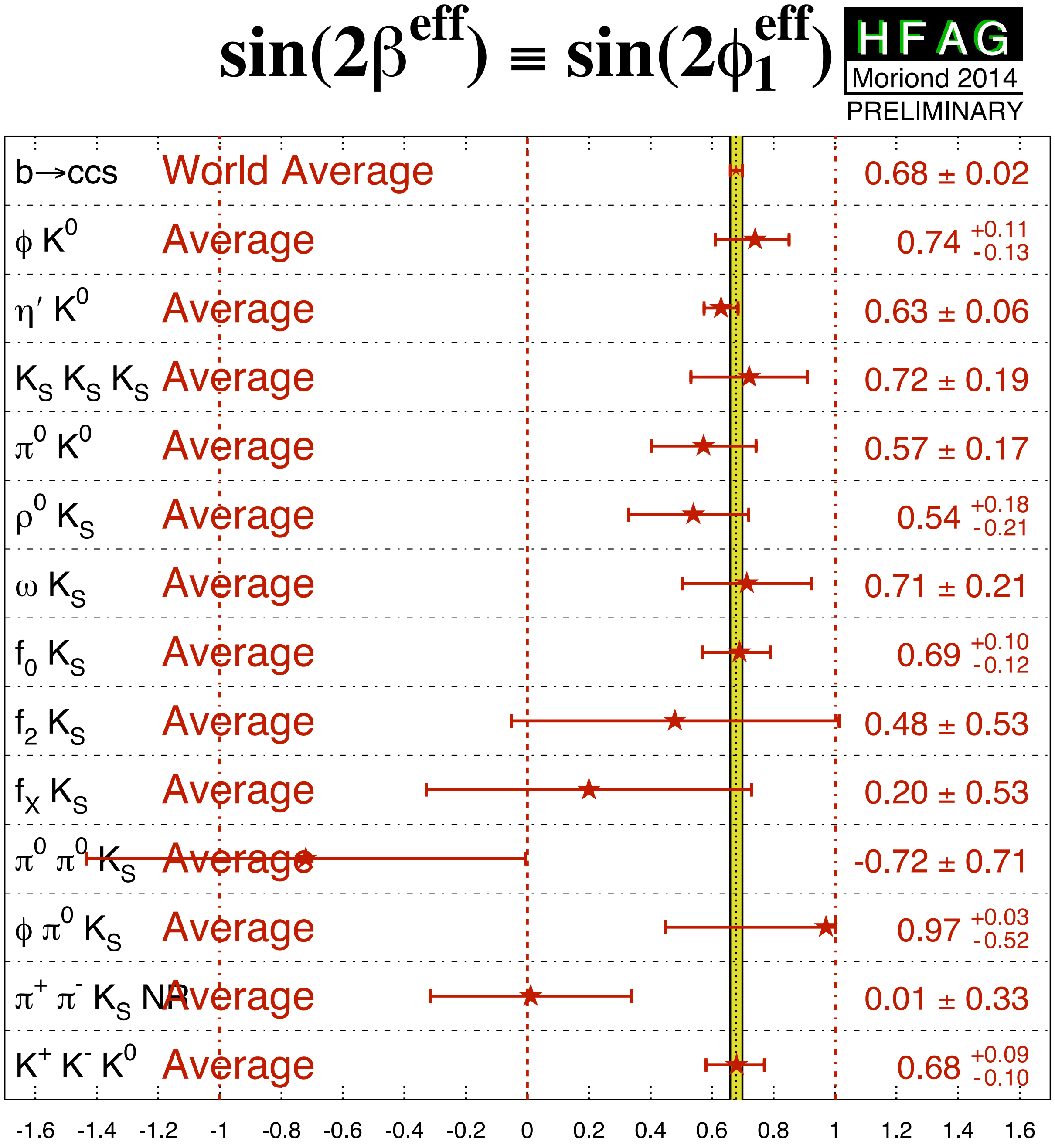

β (Φ_1) measurements with b→

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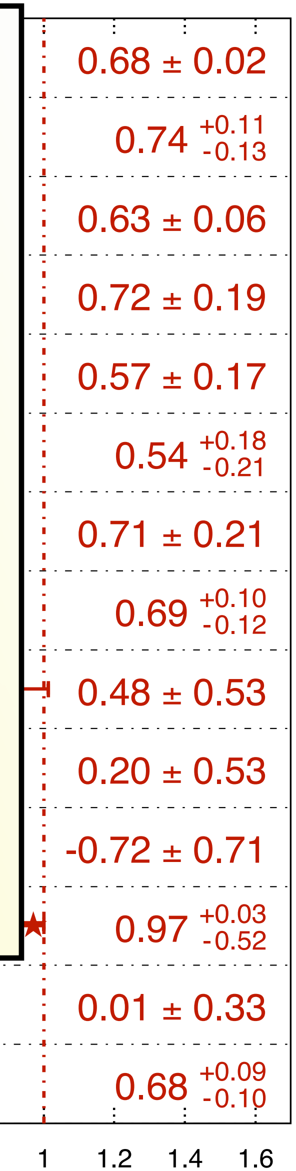
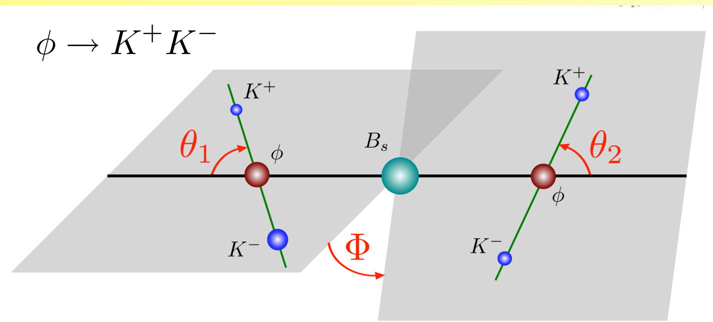
$\sin(2\beta^{eff}) \equiv \sin(2\phi_1^{eff})$



Φ_s measurements with $B_s \to \Phi\Phi$ channel

ICHEP '14



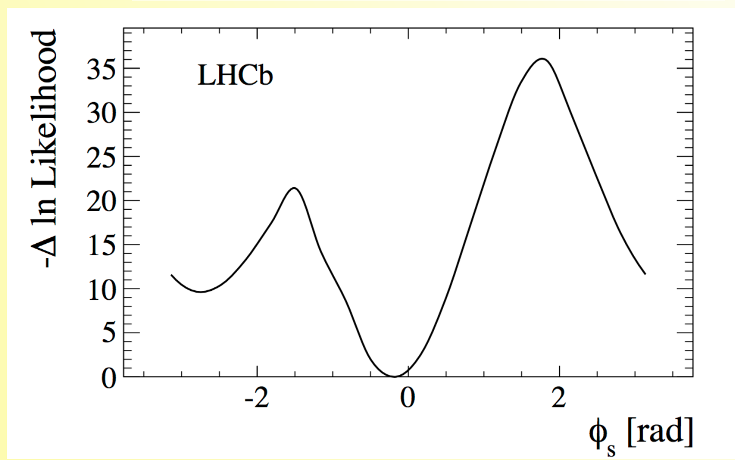
$$\frac{d\Gamma}{dt\,d\cos\theta_1\,d\cos\theta_2\,d\Phi} \propto 4|\mathcal{A}(t,\theta_1,\theta_2,\Phi)|^2 = \sum_{i=1}^{15} K_i(t) f_i(\theta_1,\theta_2,\Phi)$$

$$\phi_s = (-0.17 \pm 0.15 \pm 0.03)\ \text{rad}$$

$$|\lambda| = 1.04 \pm 0.07 \pm 0.03$$

$$|A_0|^2 = 0.364 \pm 0.012 \pm 0.009$$

$$|A_\perp|^2 = 0.305 \pm 0.013 \pm 0.005$$



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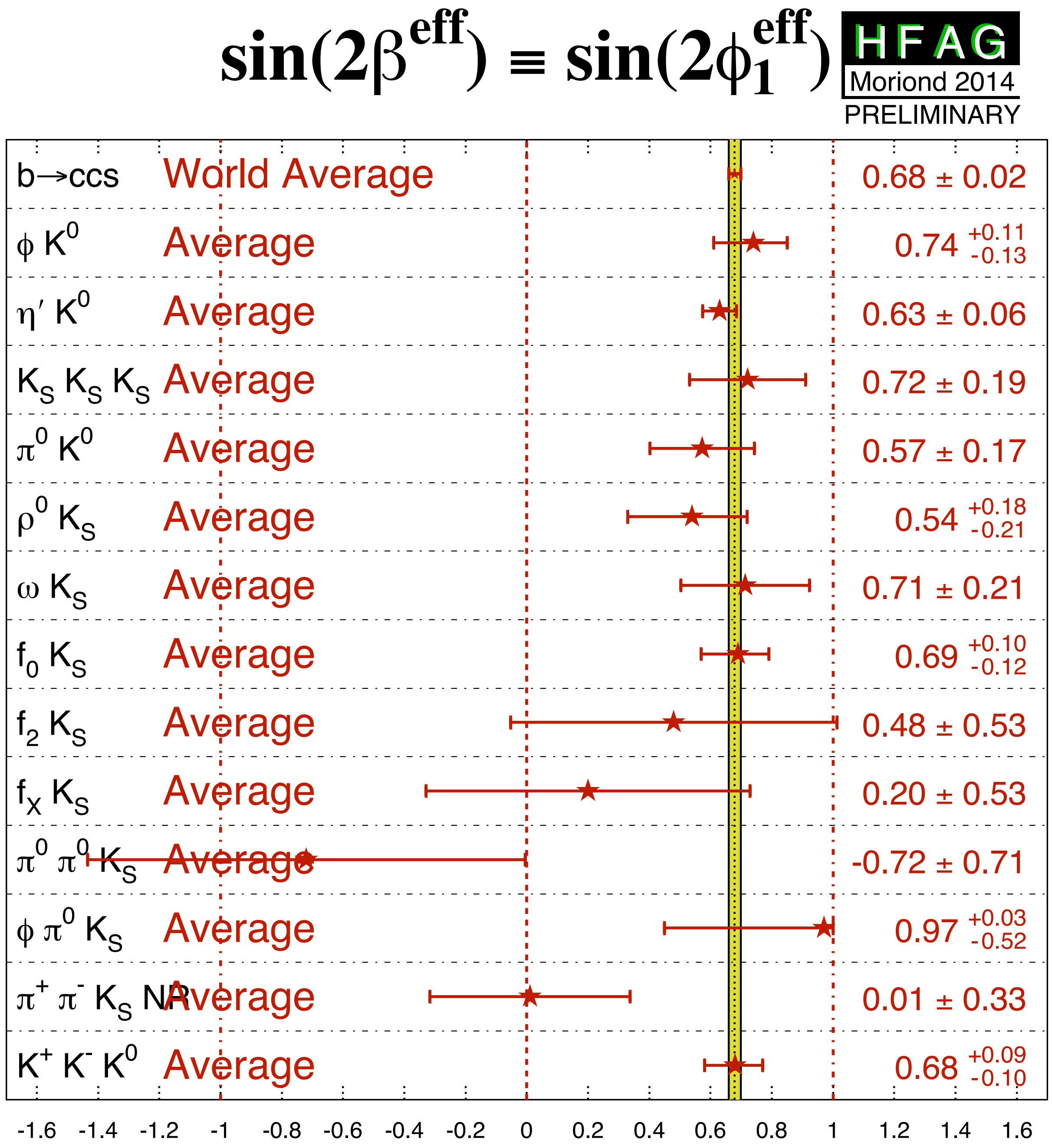


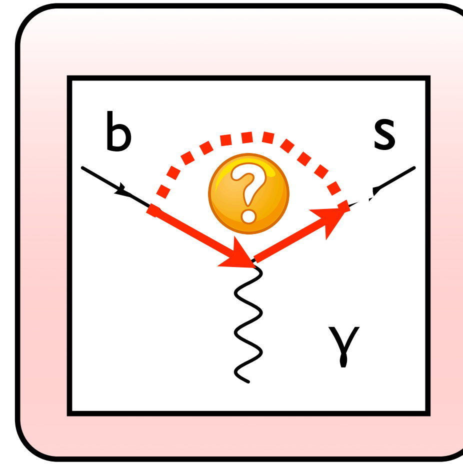
New physics search in $b \to s\gamma$ processes

I: Branching ratio measurement

II: Photon polarization measurement

Searching new physics with b→sγ modes

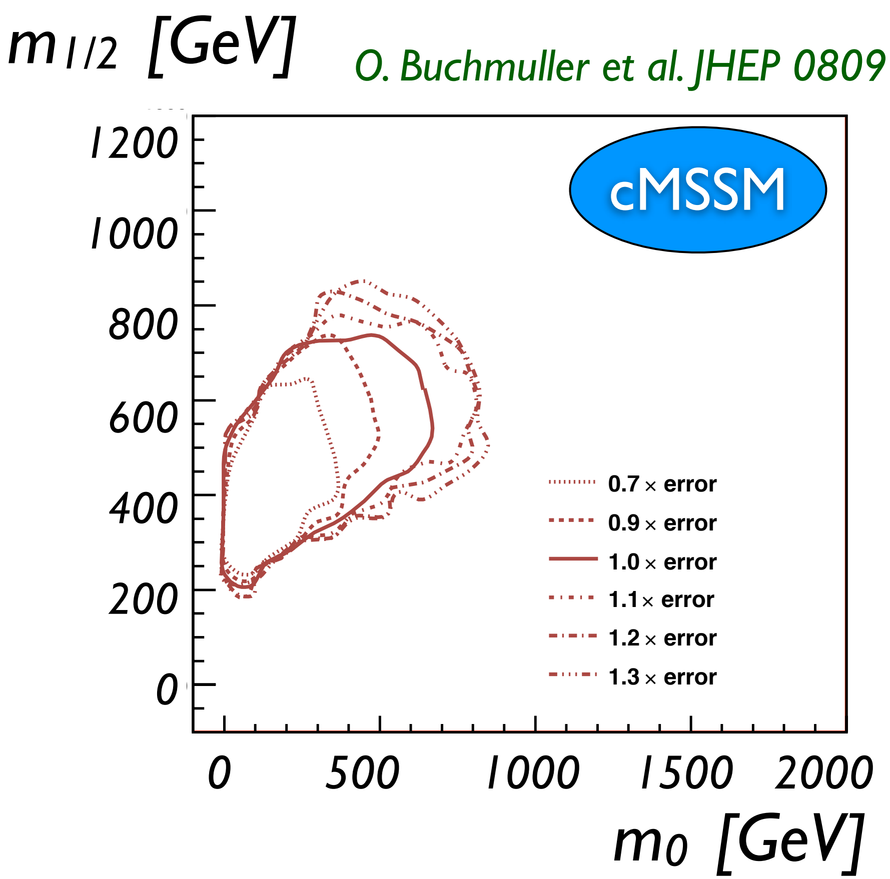
- The branching ratio measurement of b →sγ process has been offering important constraints on physics within and beyond the SM (CKM, top mass, new particle mass etc.).



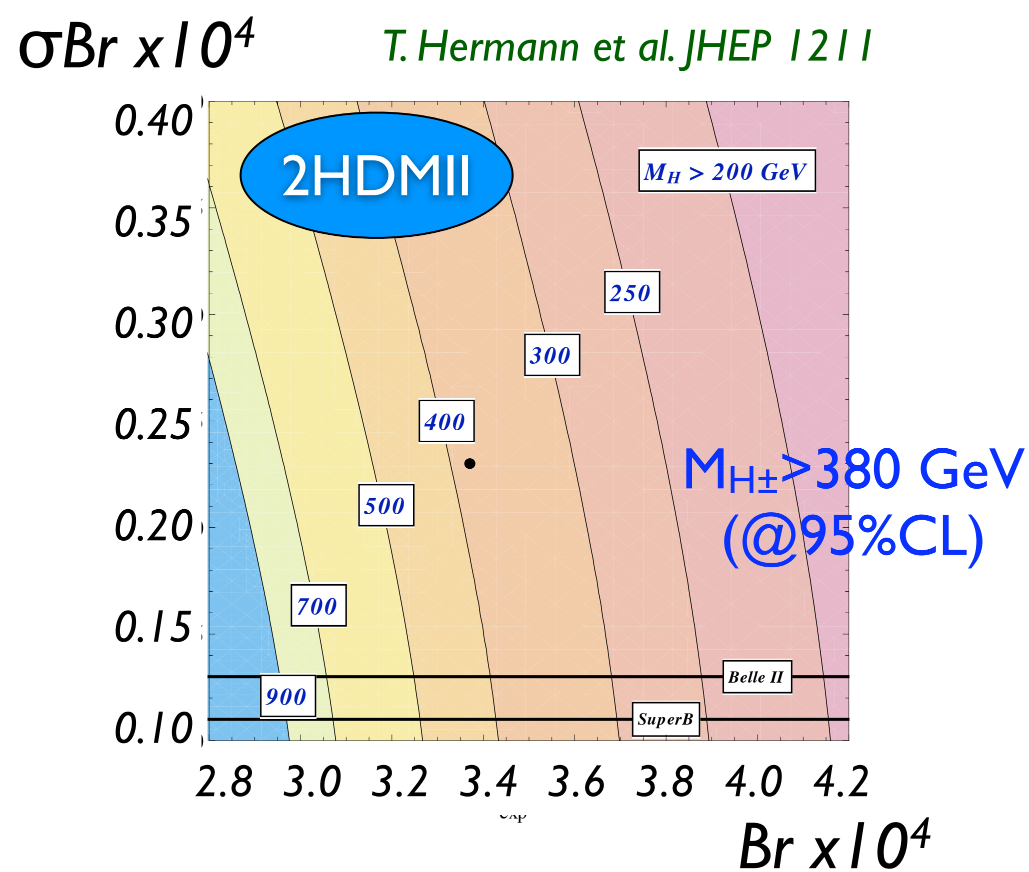
HFAG2013

Experiment: Br(B->Xsγ)=(3.43 ± 0.21 ± 0.07)x10^{-4}

O. Buchmuller et al. JHEP 0809

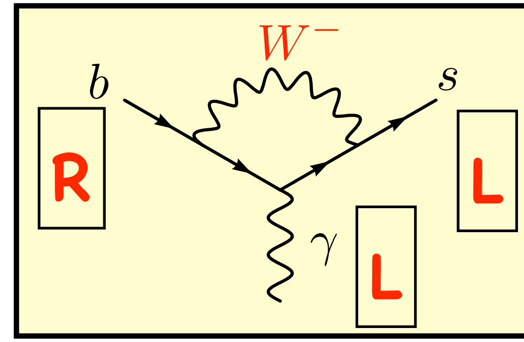


T. Hermann et al. JHEP 1211



Photon polarization of $b \to s\gamma$ modes

- The photon polarization of $b \to s\gamma$ process has an unique sensitivity to BSM with right-handed couplings.
- However, the photon polarization has never been measured at a hight precision so far: an important challenge for future experiments such as LHCb and Belle II.



In SM

W-boson couples only left-handed ⟺ γ of $b \to s\,\gamma$ should be circularly-polarized

- ✍ $b \to s\,\gamma_L$ (left-handed polarization)
- ✍ $b \to s\,\gamma_R$ (right-handed polarization)

Current status on the constraint on the right-handed contribution

We can write the amplitude including RH contribution as:

$$\mathcal{M}(b\to s\gamma)\simeq -\frac{4G_F}{\sqrt{2}}V_{ts}^{*}V_{tb}\left[\underbrace{(C_{7\gamma}^{\rm SM}+C_{7\gamma}^{\rm NP})\langle\mathcal{O}_{7\gamma}\rangle}_{\propto\mathcal{M}_L}+\underbrace{C_{7\gamma}^{\prime\rm NP}\langle\mathcal{O}_{7\gamma}^{\prime}\rangle}_{\propto\mathcal{M}_R}\right]$$

We have a constraint from inclusive branching ratio measurement:

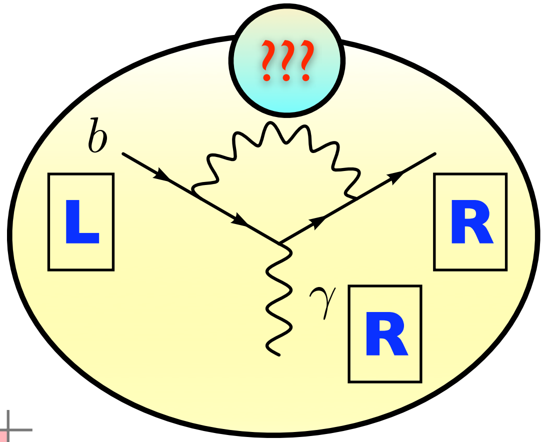
$$Br(B\to X_S\gamma)\propto|C_{7\gamma}^{\rm SM}+C_{7\gamma}^{\rm NP}|^2+|C_{7\gamma}^{\prime\rm NP}|^2$$

While the polarization measurement carries information on

$$\frac{\mathcal{M}_R}{\mathcal{M}_L}\simeq\frac{C_{7\gamma}^{\prime\rm NP}}{C_{7\gamma}^{\rm SM}+C_{7\gamma}^{\rm NP}}$$

Note: new physics contributions,
$C_{7\gamma}^{\rm NP}$ and/or $C'^{\rm NP}_{7\gamma}$ can be complex numbers!

Right-handed: which NP model?



- **What types of new physics models?**
  For example, models with right-handed neutrino, or custodial symmetry in general induces the right handed current.

Left-Right symmetric model (W_R)	SUSY GUT model δ_{RR} mass insertion	RS model with custodial symmetry
Blanke et al. JHEP1203	*Girrbach et al. JHEP1106*	*Blanke et al. JHEP1208*

- **Chiral-enhancement ?**
  The models that contain new particles which change the chirality inside of the b→sγ loop can induce **a large chiral enhancement!**

Left-Right symmetric model: mt/mb	SUSY with δ_{RL} mass insertions: m_{SUSY}/mb
Cho, Misiak, PRD49, '94 *Babu et al PLB333 '94*	*Gabbiani, et al. NPB477 '96* *Ball, EK, Khalil, PRD69 '04*

NP signal beyond the constraints from Bs oscillation parameters possible.

How do we measure the polarization?!

proposed methods

- Method I: Time dependent CP asymmetry in $B_d \rightarrow K_S \pi^0 \gamma$ $B_s \rightarrow K^+ K^- \gamma$ (called $S_{K_S\pi^0\gamma}$, $S_{K^+K^-\gamma}$)
- Method II: Transverse asymmetry in $B_d \rightarrow K^* l^+ l^-$ (called $A_T^{(2)}$, $A_T^{(im)}$)
- Method III: $B \rightarrow K_1 (\rightarrow K\pi\pi)\gamma$ (called λ_γ)
- Method IV: $\Lambda_b \rightarrow \Lambda^{(*)}\gamma$, $\Xi_b \rightarrow \Xi^* \gamma$ ...

Atwood et.al. PRL79

Kruger, Matias PRD71
Becirevic, Schneider, NPB854

Gronau et al PRL88
E.K. Le Yaouanc, Tayduganov PRD83

Gremm et al.'95, Mannel et al '97, Legger et al '07, Oliver et al '10

How to measure the polarization?

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- Method I: Time dependent CP asymmetry in $B_d \to K_S \pi^0 \gamma$ $B_s \to K^+ K^- \gamma$ (called $S_{K_S\pi^0\gamma}$, $S_{K^+K^-\gamma}$)

$$S_{K_S\pi^0\gamma} = \frac{2|C_{7\gamma}^{\rm SM} C_{7\gamma}^{\prime\rm NP}|}{|C_{7\gamma}^{\rm SM}|^2 + |C_{7\gamma}^{\prime\rm NP}|^2} \sin(2\phi_1 - \phi_R) \qquad \phi_R = \arg\left[\frac{C_{7\gamma}^{\prime\rm NP}}{C_{7\gamma}^{\rm SM}}\right]$$

- Method II: Transverse asymmetry in $B_d \to K^* l^+ l^-$ (called $A_T^{(2)}$, $A_T^{(im)}$)

$$\mathcal{A}_T^{(2)}(q^2=0) = \frac{2Re[C_{7\gamma}^{\rm SM} C_{7\gamma}^{\prime\rm NP*}]}{|C_{7\gamma}^{\rm SM}|^2 + |C_{7\gamma}^{\prime\rm NP}|^2} \qquad \mathcal{A}_T^{(im)}(q^2=0) = \frac{2Im[C_{7\gamma}^{\rm SM} C_{7\gamma}^{\prime\rm NP*}]}{|C_{7\gamma}^{\rm SM}|^2 + |C_{7\gamma}^{\prime\rm NP}|^2}$$

Assumption for γ^*/Z penguin (C_9, C_{10} contributions) necessary!

- Method III: $B \to K_1(\to K\pi\pi)\gamma$ (called λ_γ)

$$\lambda = \frac{|C_{7\gamma}^{\prime\rm NP}|^2 - |C_{7\gamma}^{\rm SM}|^2}{|C_{7\gamma}^{\prime\rm NP}|^2 + |C_{7\gamma}^{\rm SM}|^2}$$

How to measure the polarization?

proposed methods

- Method I: Time dependent CP asymmetry in $B_d \to K_S \pi^0 \gamma$ $B_s \to K^+ K^- \gamma$ (called $S_{K_S\pi0\gamma}$, $S_{K+K-\gamma}$)

$$S_{K_S\pi^0\gamma} = \frac{2|C_{7\gamma}^{\rm SM} C_{7\gamma}'^{\rm NP}|}{|C_{7\gamma}^{\rm SM}|^2 + |C_{7\gamma}'^{\rm NP}|^2} \qquad \phi_R = \arg\left[\frac{C_{7\gamma}'^{\rm NP}}{C_{7\gamma}^{\rm SM}}\right]$$

LHCb/Belle II
$\sigma_{S_{K_S\pi\gamma}}(0.02)$

- Method II: Transverse asymmetry in $B_d \to K^* l^+ l^-$ (called $A_T^{(2)}$, $A_T^{(im)}$)

$$\mathcal{A}_T^{(2)}(q^2=0) = \frac{2Re[C_{7\gamma}^{\rm SM} C_{7\gamma}'^{\rm NP}]}{|C_{7\gamma}^{\rm SM}|^2 + |C_{7\gamma}'^{\rm NP}|^2} \qquad (q^2 = 0) = \frac{2Im[C_{7\gamma}^{\rm SM} C_{7\gamma}'^{\rm NP*}]}{|C_{7\gamma}^{\rm SM}|^2 + |C_{7\gamma}'^{\rm NP}|^2}$$

LHCb
$\sigma_{A_T^{2(im)}}(0.2)$

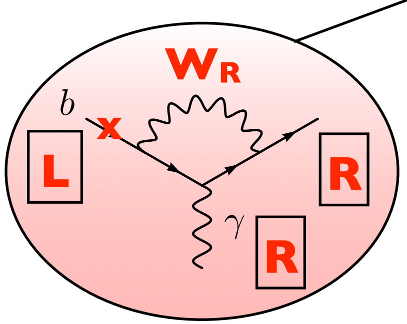
- Method III: $B \to K_1 (\to K\pi\pi)\gamma$ (called λ_γ)

LHCb/Belle II
$\sigma_\lambda(0.1\text{–}0.2)$

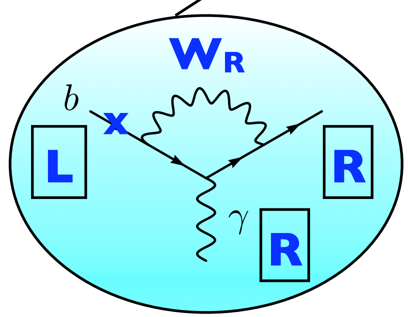
Example: Left-Right Symmetric Model

Right handed-photon contribution

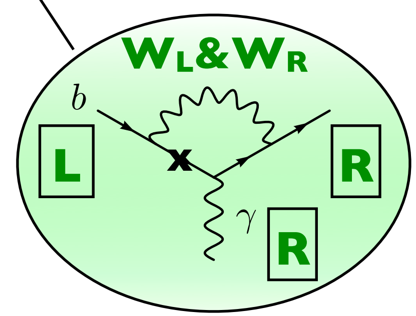
$$C'_{7\gamma}(\mu_R) = \frac{1}{2} \Bigg[\frac{g_R^2}{g_L^2} \frac{V_{ts}^{R*} V_{tb}^{R}}{V_{ts}^{L*} V_{tb}^{L}} \left(\sin^2\zeta A_{\rm SM}(x_t) + \cos^2\zeta \frac{M_1^2}{M_2^2} A_{\rm SM}(\tilde{x}_t) \right) + \frac{m_t}{m_b} \frac{g_R}{g_L} \frac{V_{ts}^{R*}}{V_{ts}^{L*}} \sin\zeta \cos\zeta e^{-iw} \left(A_{\rm LR}(x_t) - \frac{M_1^2}{M_2^2} A_{\rm LR}(\tilde{x}_t) \right) + ...$$



W_R contribution from W_1; Proportional to mb but suppressed by $1/M_2^2$



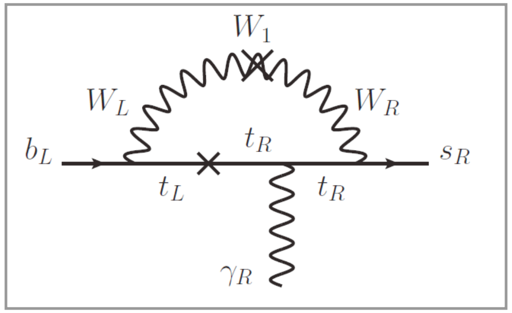
W_R contribution from W_1; Proportional to mb



W_L & W_R mixing contribution; proportional to mt !

Chiral enhancement term

β (Φ_1) measurements with b→sγ modes



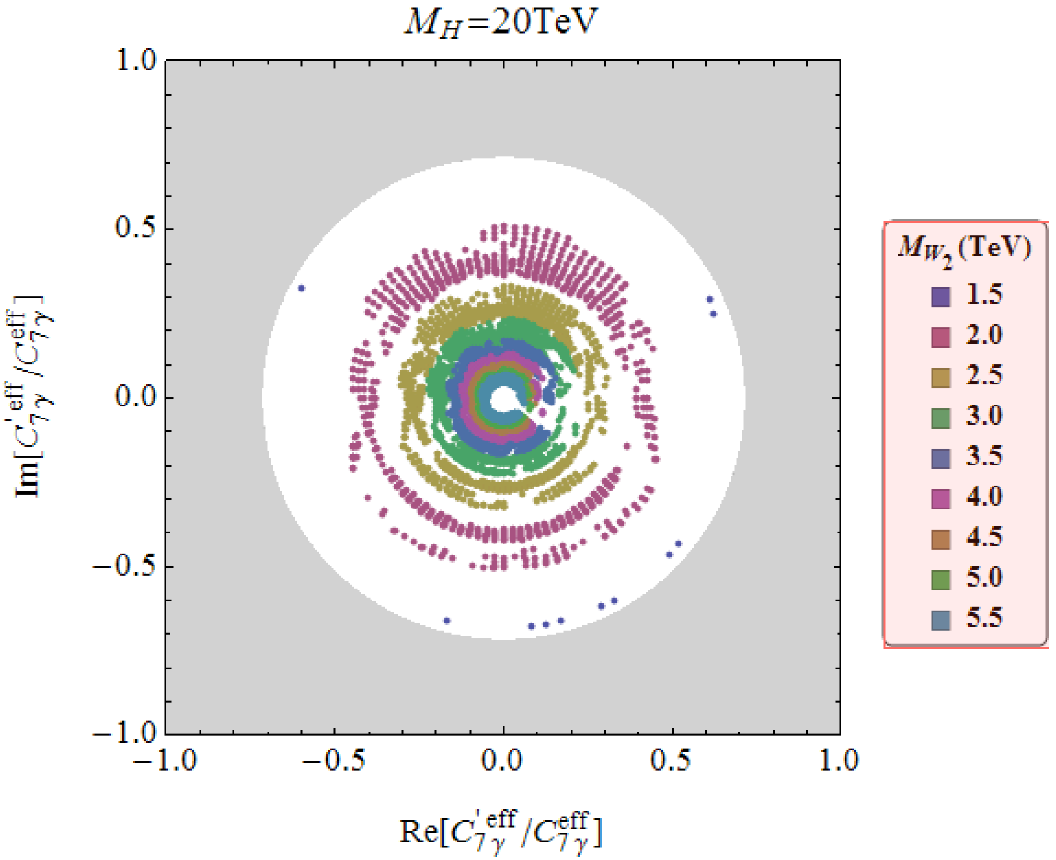
Left-Right symmetric model

- Left-right symmetric model with general V_{CKM}^R:

  $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$

- Constrained by various flavour phenomena and new LHC data.
- Chiral enhancement for $C_{7\gamma}'$ occurs with an enhancement factor:

  $(m_t/m_s) \times (V_{ts}^R/V_{ts}^L)$



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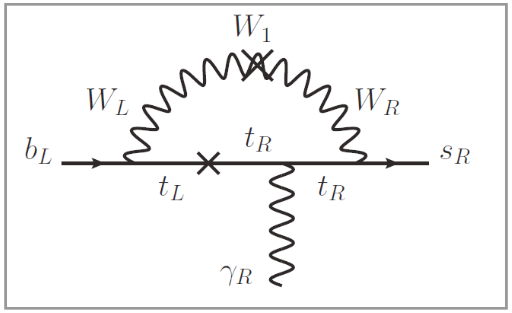
β (Φ_1) measurements with $b \to s\gamma$ modes



Left-Right symmetric model

- Left-right symmetric model with general V_{CKM}^R:

  $$SU(2)_L \times SU(2)_R \times U(1)_{B-L}$$

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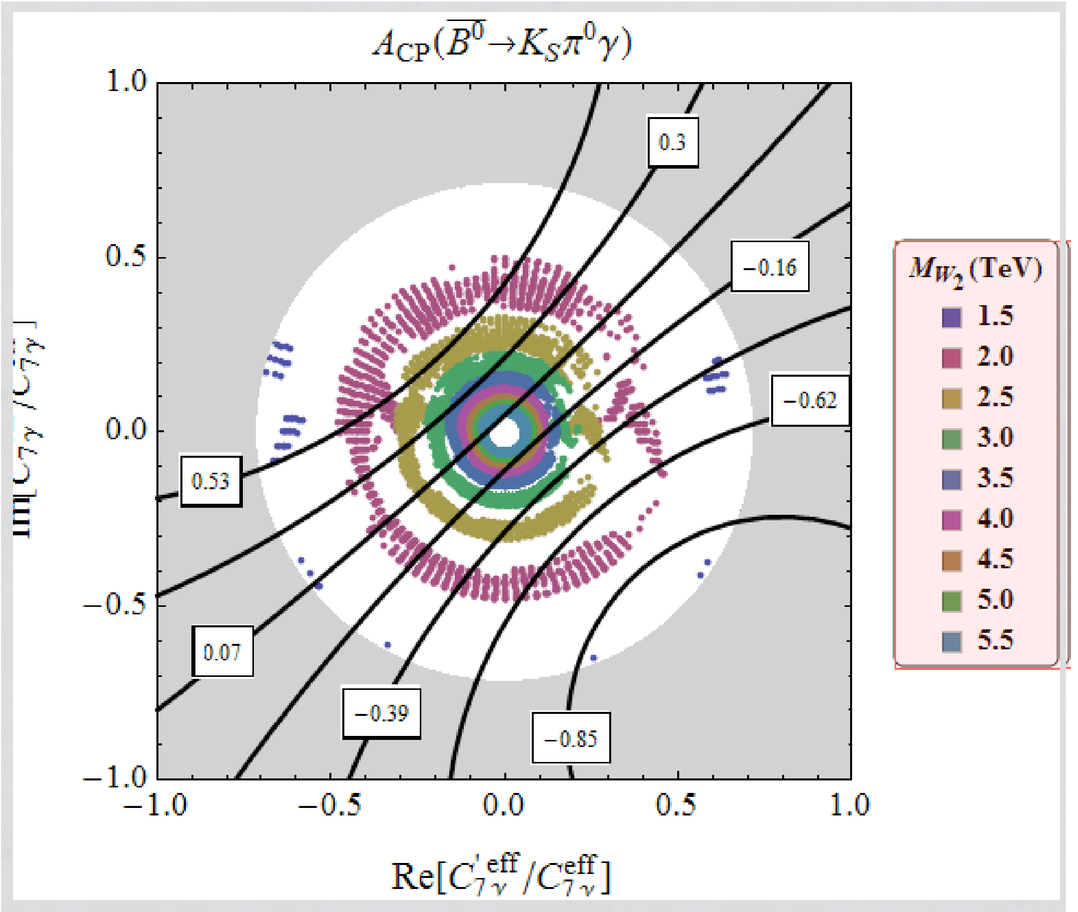
  $$(m_t/m_s) \times (V_{ts}^R/V_{ts}^L)$$



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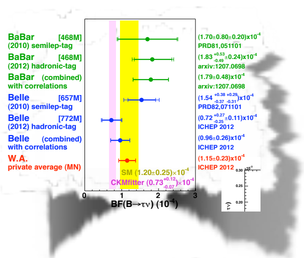
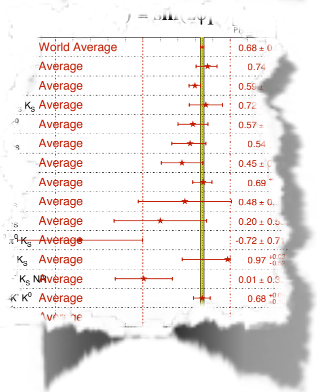
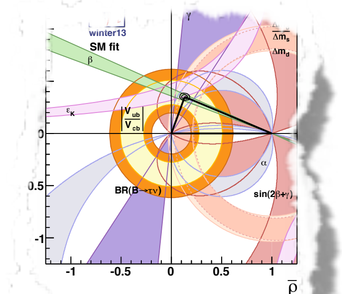
Conclusions

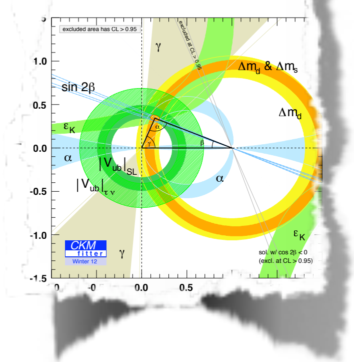
★ Era of B factories 2000-2010



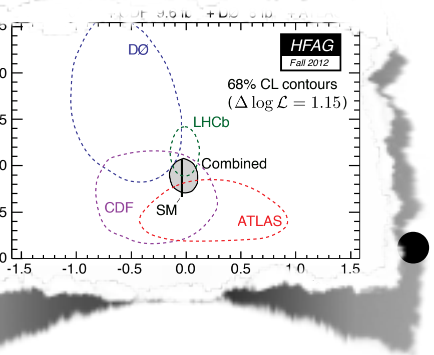


- The precise $\beta(\Phi_1)$ measurement is the most important success at the B factories.
- Some hints of new physics were announced but it had never exceeded more than 2-3 sigma deviations and most of them are now consistent to the SM.
- The exotic state is one of the surprises we ended up with. Starting with X(3872), a possible candidate of its charged partner is also Z_c^+ discovered at BESIII.
- Physics of B Factories Book, which summarizes all the achievements at B factories, is now COMPLETED!

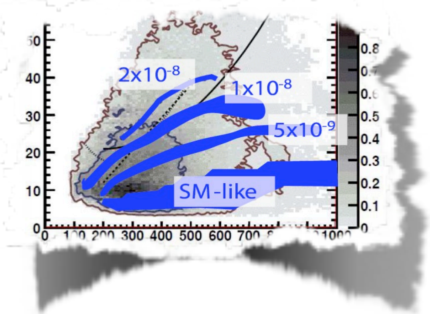




★ Era of LHCb (run @7-8 TeV) 2010-2012



- Bs oscillation has been explored at a higher precision at LHC. Unfortunately, what we see so far is consistent to the SM...



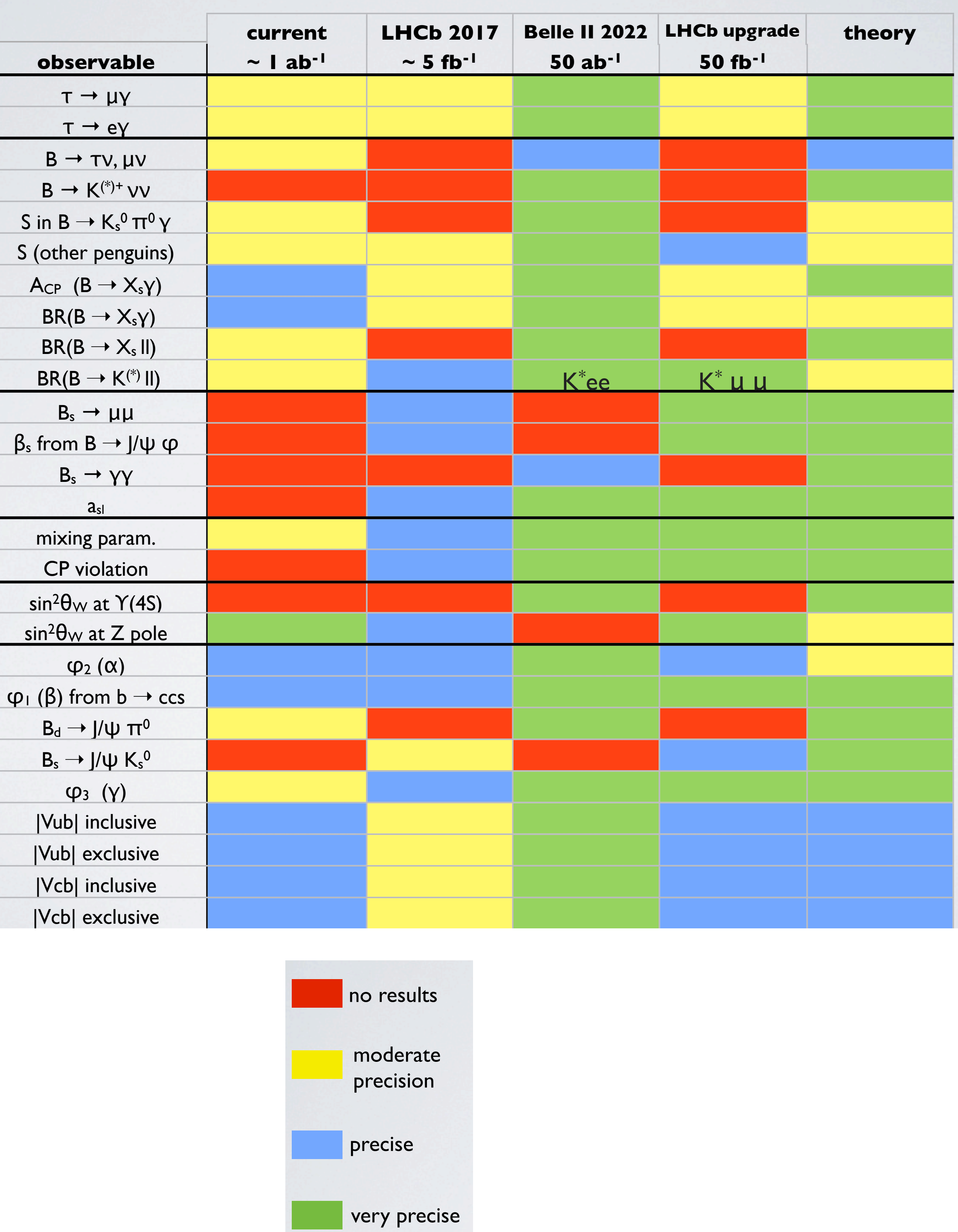
- At the LHC with its extremely high luminosity, many rare decays are also observed.

- Many new results on the charmonium are improving rapidly the pioneer works by Tevatron.

- Constructing new benchmark models and establishing the search strategies for them is the urgent tasks for theorists.

See more details, Book of Physics of B factories

Observable	4^{th} gen.	2HDM	MFV	eMFV	MFV-SUSY	genSUSY	aligSUSY	RS	Little H	SM
$\sin 2\phi_1$	★★★	★★★	★★★	★★	★★★	★	★★★	★★	★★	★★★
$B \to X_s \gamma$	★★★	★	★★	★★	★★	★	★★★	★★	★★★	★★★
$B \to \tau\nu$	★	★★	★	★	★	★	★	★	★	★
$D - \bar{D}$ mixing	★★	★★★	★★★	★★★	★★★	★	★	★★	★★	★★
$B \to \phi K_S$	★★★	★★	★★	★★★	★★★	★★	★★	★★★	★	★★
$g - 2$	★	★	–	–	★★	★★	–	★★	★★	★



★ **Future: LHCb (run @14 TeV), Belle II, LHCb upgrade**

- CP violation measurements (Bs oscillation, angle γ measurement, penguin $B_{(s)}$->ΦK_s, $\eta' K_s$, $\Phi\Phi$, radiative b->sγ) will be improved significantly.
- Many more new opportunities are open and discussed intensively!

Backup

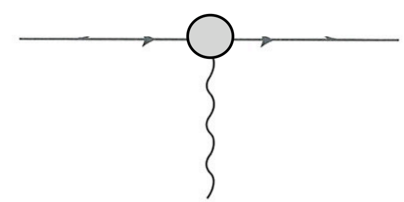
Constraint of magnetic operator

The $b \to s\gamma$ is induced by the electro-magnetic operator. The constraint on the coupling c_{ij} and new physics scale Λ depend on the chiral structure.

For $b \to s\gamma$: $i=2, j=3$

$$\frac{c_{ij}}{\Lambda}\, e\overline{\psi}_{iA}\sigma^{\mu\nu}\psi_{jB}F_{\mu\nu}$$

ij=generation, A, B: L or R



SM coupling $G_F m_b (V_{tb}V_{ts}^*) e$

	NP contribution		
The new physics has same Dirac/flavour structure as the SM	$m_b\, c_{23}(V_{tb}V_{ts}^*)e/\Lambda$	$Br_{SM} > Br_{NP}$, $\Lambda = 1$ TeV	$c_{23} < O(10^{-2})$
The new physics has same Dirac/flavour structure but "chirally-enhanced"	$m_t\, c_{23}(V_{tb}V_{ts}^*)e/\Lambda$	$Br_{SM} > Br_{NP}$, $\Lambda = 1$ TeV	$c_{23} < O(10^{-3})$
The new physics is "right-handed"	$m_t\, c_{23}(V_{tb}V_{ts}^*)e/\Lambda$	$Br_{SM} > Br_{NP}$, $\Lambda = 1$ TeV	$c_{23} < O(10^{-5})$

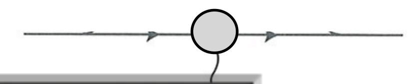
SM coupling $G_F m_s (V_{tb}V_{ts}^*) e$

Constraint of magnetic operator

The b->sγ is induced by the electro-magnetic operator. The constraint on the coupling c_{ij} and new physics scale Λ depend on the chiral structure.

For b->sγ: $i=2, j=3$

$$\frac{c_{ij}}{\Lambda} e\overline{\psi}_{iA}\sigma^{\mu\nu}\psi_{jB}F_{\mu\nu}$$



SM coupling

$G_F m_b($

The ne... same ... struct...

$<O(10^{-2})$

The new ... Dirac/flavour structure but "chirally-enhanced"

$m_t\, c_{23}(V_{tb}V_{ts}^*)e/\Lambda$

Λ= 1 TeV

$c_{23}<O(10^{-3})$

Even if the coupling is strongly constrained by other b->s transitions (e.g. Bs oscillation), New Physics contributions with new Dirac/flavour/chiral structures can lead to a large contribution, observable in the future!

NP contribution

The new physics is "right-handed"

$m_t\, c_{23}(V_{tb}V_{ts}^*)e/\Lambda$

$Br_{SM}>Br_{NP}$

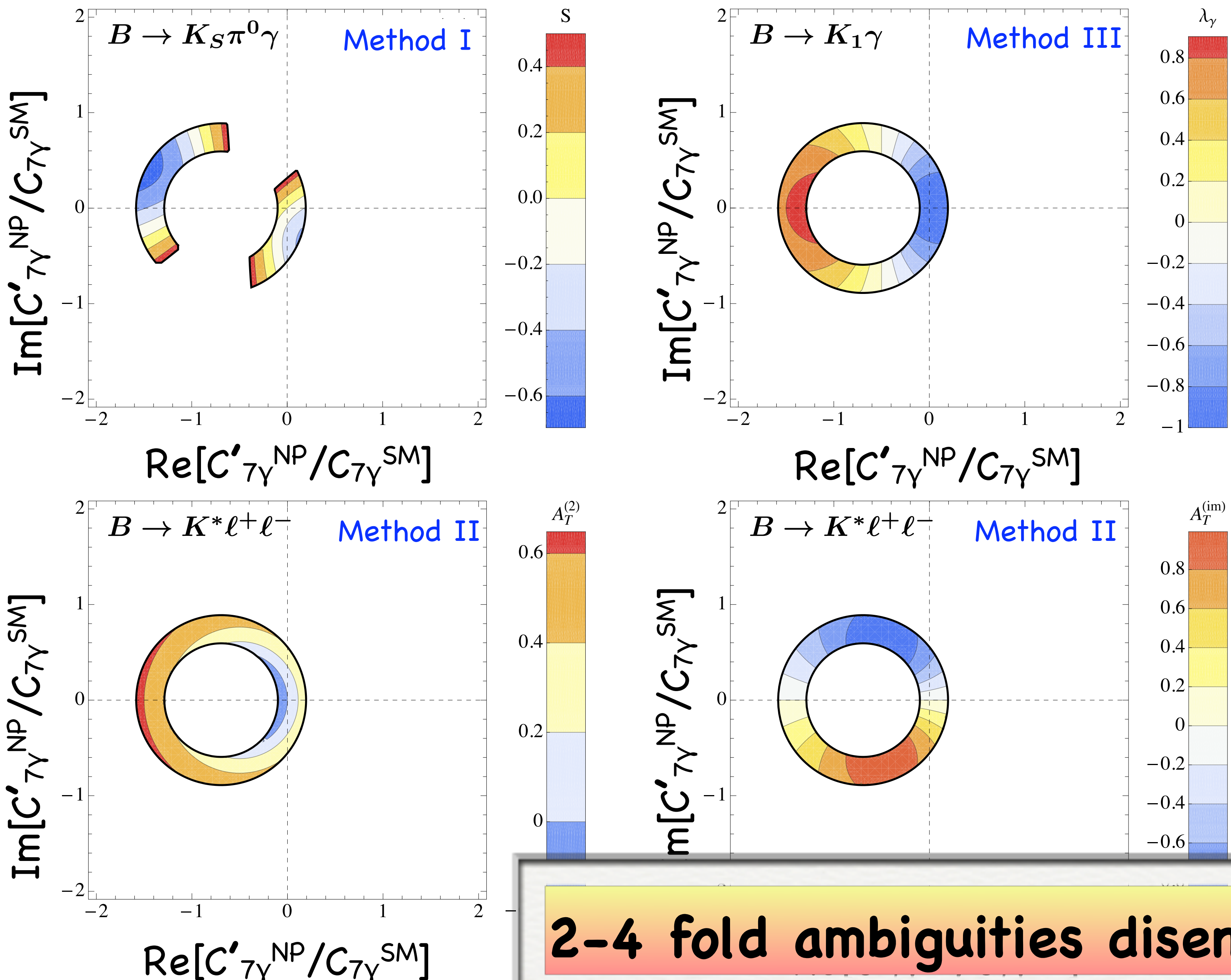
Λ= 1 TeV

$c_{23}<O(10^{-5})$

SM coupling $G_F m_s(V_{tb}V_{ts}^*)e$

Example of scenario (c): $C'^{NP}_{7\gamma} = C^{NP}_{7\gamma}$

A.Tayduganov et al.
JHEP 1208



2-4 fold ambiguities disentangled!

CKM matrix: test of unitarity

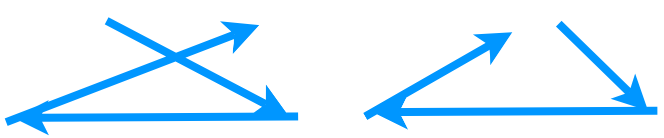
- The SM incorporates:
  - ✓ Natural suppression of FCNC (i.e. GIM mechanism)
  - ✓ A source of CP violation in the V_{CKM} matrix (i.e. KM mechanism)

$$V_{\rm CKM} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4)$$

$+A\lambda^4(1/2-\rho-i\eta)$

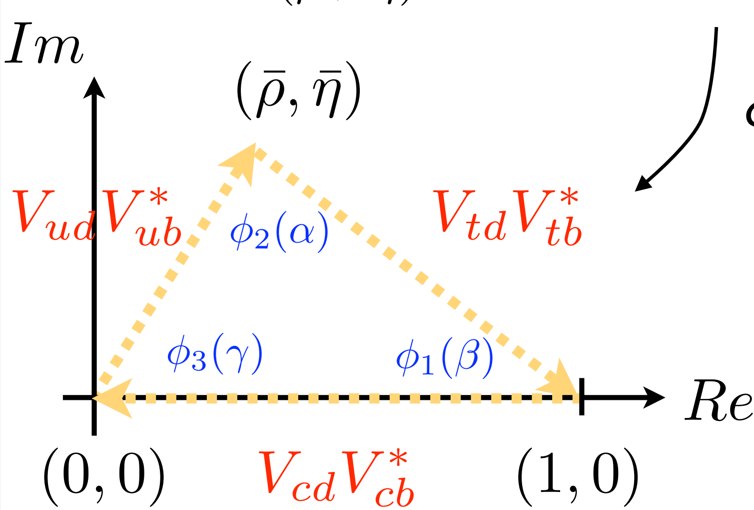
Unitarity Triangle

Test of Unitarity
Verify if the triangle closes at the apex by independently measuring the three sides and three angles.



$$\underbrace{V_{ud}V_{ub}^*}_{A\lambda^3(\rho+i\eta)} + \underbrace{V_{cd}V_{cb}^*}_{-A\lambda^3} + \underbrace{V_{td}V_{tb}^*}_{A\lambda^3(1-\rho-i\eta)} = 0$$

divide by $A\lambda^3$



$$arg\left(\frac{V_{tb}^*V_{td}}{V_{cb}^*V_{cs}}\right) \equiv -\phi_1$$
$$arg\left(\frac{V_{tb}^*V_{td}}{V_{ub}^*V_{ud}}\right) \equiv -\phi_2$$
$$arg\left(\frac{V_{cb}^*V_{cs}}{V_{ub}^*V_{ud}}\right) \equiv -\phi_3$$

Flavour Physics beyond SM

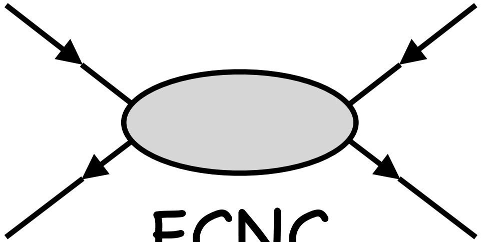
The indirect search of new physics through quantum loop effect: very powerful tool to search for new physics signal!

Example of K mixing

i=2, j=1

$$\frac{(\delta_{ij})^2}{M^2}\ \overline{\psi}_i\Gamma_\mu\psi_i\ \overline{\psi}_j\Gamma^\mu\psi_j$$

ij=generation, Γ: Dirac matrix



This interaction induces an extra contribution $(\delta_{21})^2/M^2$ → SM loop contribution agrees within 10-15% error → $M>10^4$ TeV

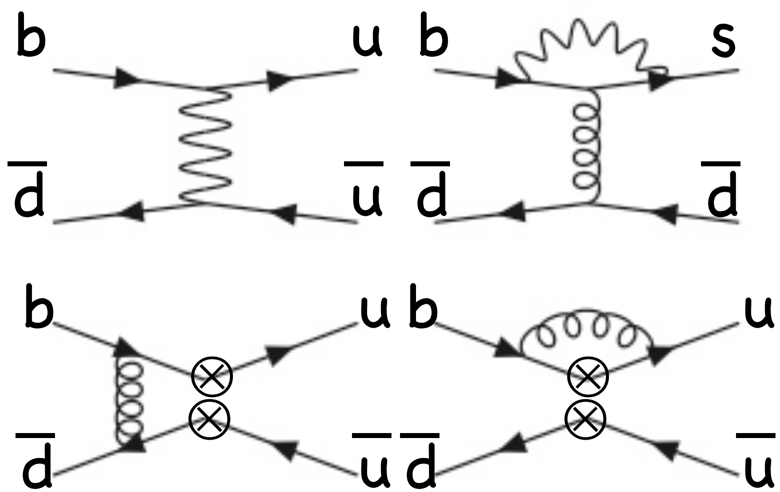
The higher the precision, the higher the NP scale we can probe!

Also if the coupling is CKM like **(e.g. Minimal Flavour Violation)**

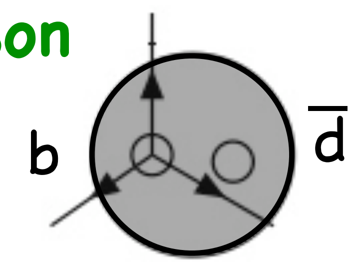
This interaction induces an extra contribution $(V_{td}V_{ts}^*)^2/M^2$ → SM loop contribution agrees within 10-15% error → M~ a few TeV

Hadronic issues in flavour physics

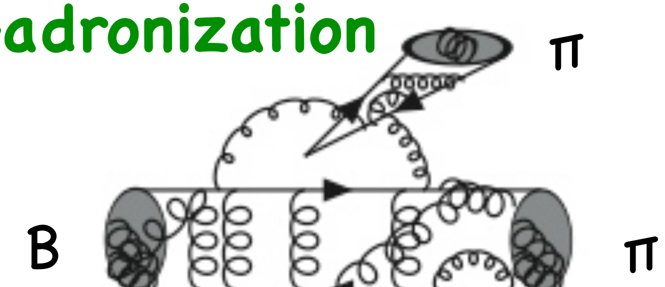
Quark level



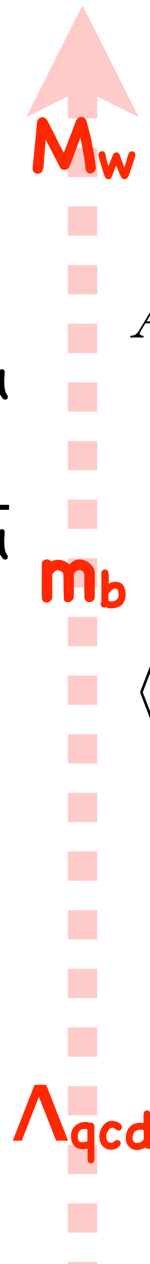
B meson



Hadronization



Factorization?!



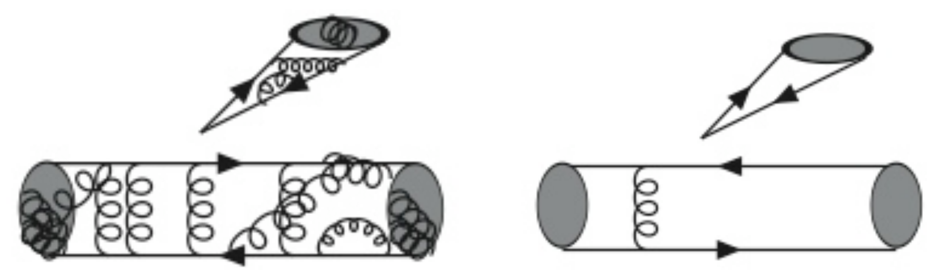
Wilson coefficient (perturbative)

$$A = \frac{G_F}{\sqrt{2}} V_{bu} V_{ud}^* C_1(\mu) (\bar{u}_\alpha b_\beta)_{V-A} (\bar{d}_\beta u_\alpha)_{V-A}$$

Matrix element (non-perturbative)

$$\langle A \rangle = \frac{G_F}{\sqrt{2}} V_{bu} V_{ud}^* C_1(\mu) \times$$

$$\langle \pi\pi | (\bar{u}_\alpha b_\beta)_{V-A} (\bar{d}_\beta u_\alpha)_{V-A} | B \rangle$$



Lattice QCD, QCD sum rules, Large Nc QCD, HQET, Perturbative QCD etc...

Many expectations, many 2–3 sigmas...