Rare K- (vs.) B-decays

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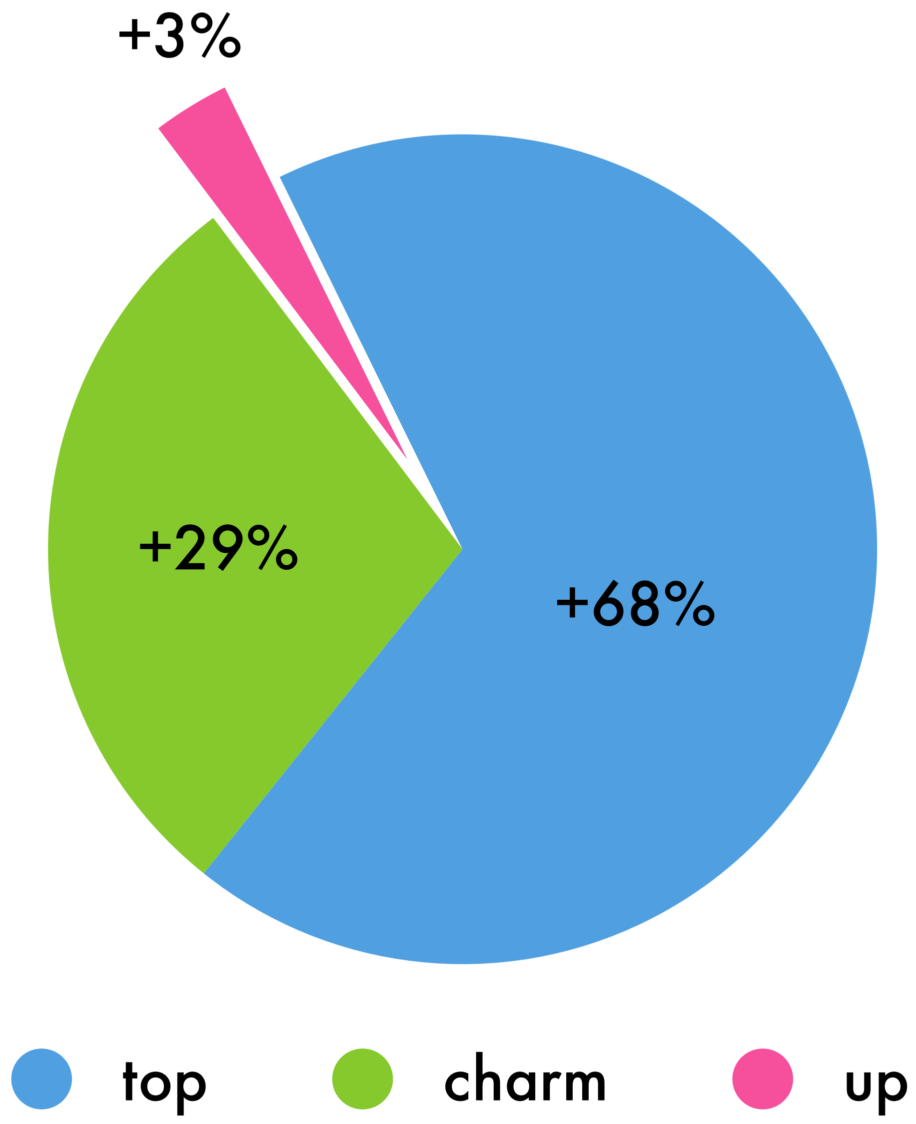
Kaon International Conference 2007,
May 21–25, 2007, Frascati, Italy

Warm-up: basic facts about s→dνν̄

$$\mathcal{A}_{\rm SM}(s \to d\nu\bar{\nu}) = \sum_{q=u,c,t} V_{qs}^* V_{qd}\, X_{\rm SM}^q \propto \boxed{\frac{m_t^2}{M_W^2}(\lambda^5 + i\lambda^5)} + \boxed{\frac{m_c^2}{M_W^2} \ln \frac{m_c}{M_W}\lambda} + \boxed{\frac{\Lambda^2}{M_W^2}\lambda}$$

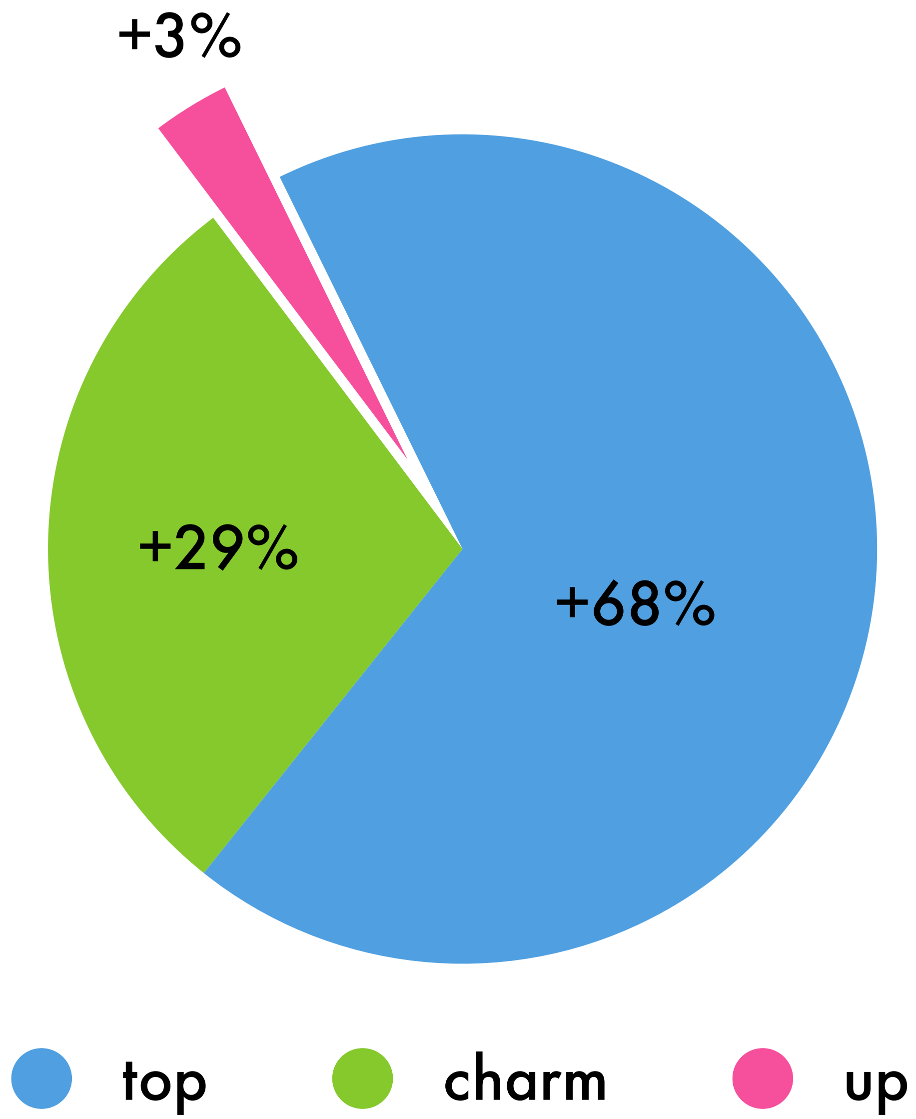


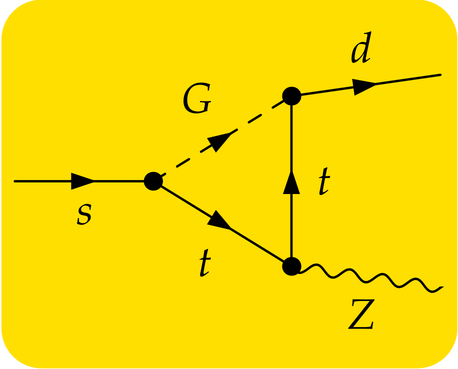
$$\boxed{Q_\nu = (\bar{s}_L \gamma_\mu d_L)(\bar{\nu}_L \gamma^\mu \bar{\nu}_L)}$$

- V–A current is conserved: large logarithms appear only in charm sector

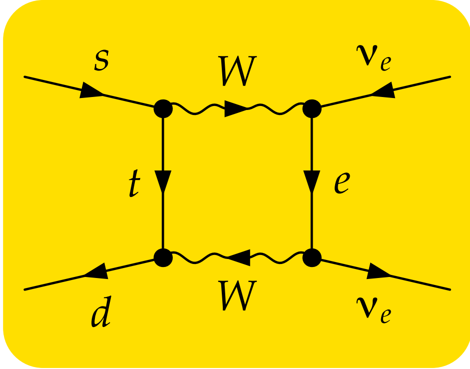
Warm-up: basic facts about $s \to d\nu\bar{\nu}$

$$\mathcal{A}_{\rm SM}(s \to d\nu\bar{\nu}) = \sum_{q=u,c,t} V_{qs}^* V_{qd}\, X_{\rm SM}^q \propto \boxed{\frac{m_t^2}{M_W^2}(\lambda^5 + i\lambda^5)} + \boxed{\frac{m_c^2}{M_W^2} \ln \frac{m_c}{M_W}\lambda} + \boxed{\frac{\Lambda^2}{M_W^2}\lambda}$$





$\propto \dfrac{m_t^2}{M_W^2}$

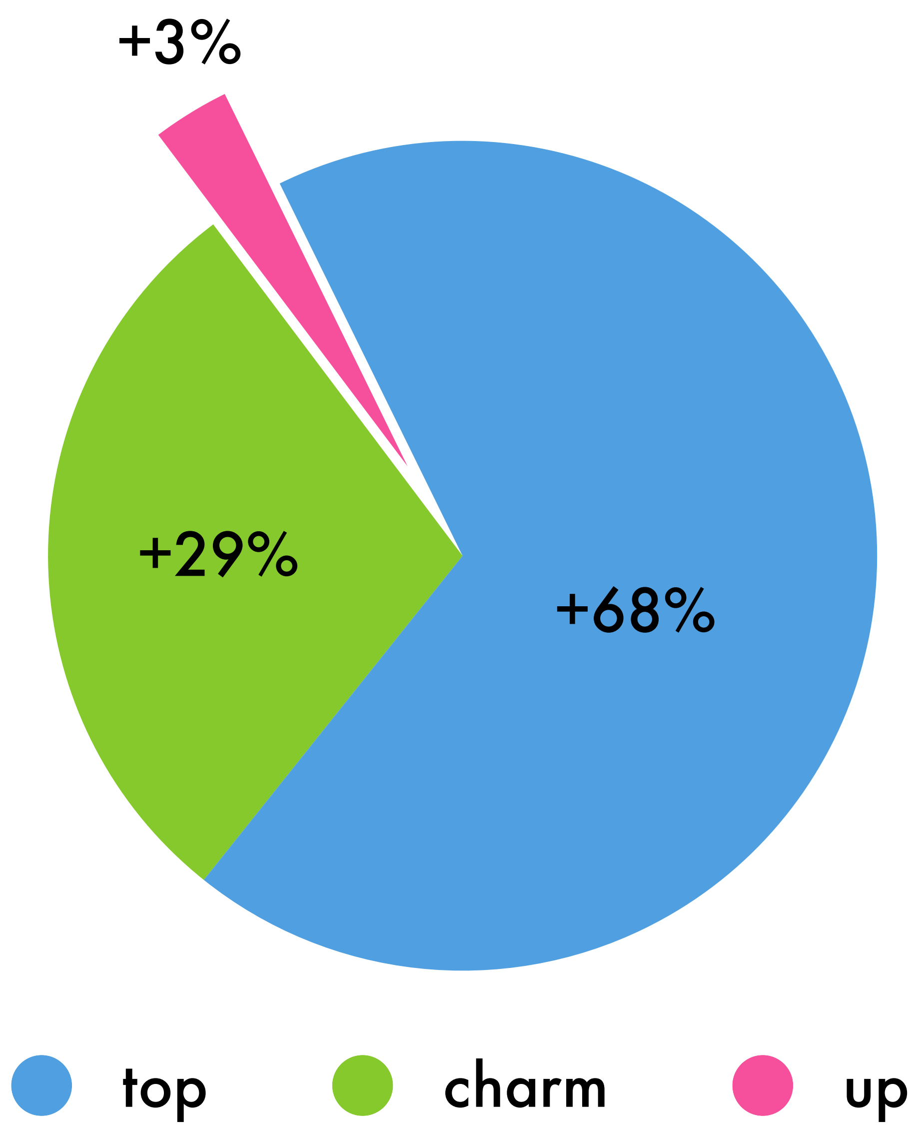


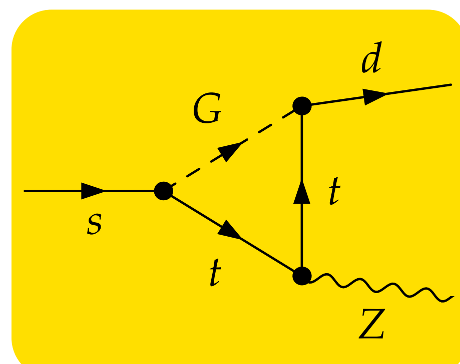
$\propto$ const.

- *SU*(2)$_{\rm L}$ breaking in *Z*-penguin amplitude leads to power-like GIM mechanism

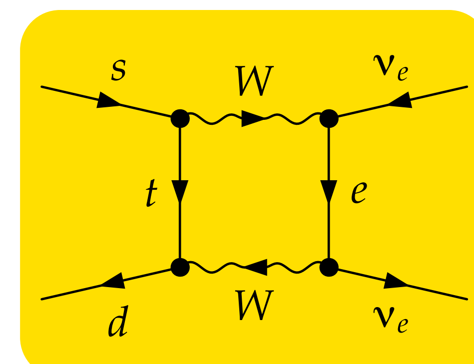
Warm-up: basic facts about $s \to d\nu\bar{\nu}$

$$\mathcal{A}_{\rm SM}(s \to d\nu\bar{\nu}) = \sum_{q=u,c,t} V_{qs}^* V_{qd}\, X_{\rm SM}^q \propto \boxed{\frac{m_t^2}{M_W^2}(\lambda^5 + i\lambda^5)} + \boxed{\frac{m_c^2}{M_W^2} \ln \frac{m_c}{M_W}\lambda} + \boxed{\frac{\Lambda^2}{M_W^2}\lambda}$$





$\propto \dfrac{m_t^2}{M_W^2}$

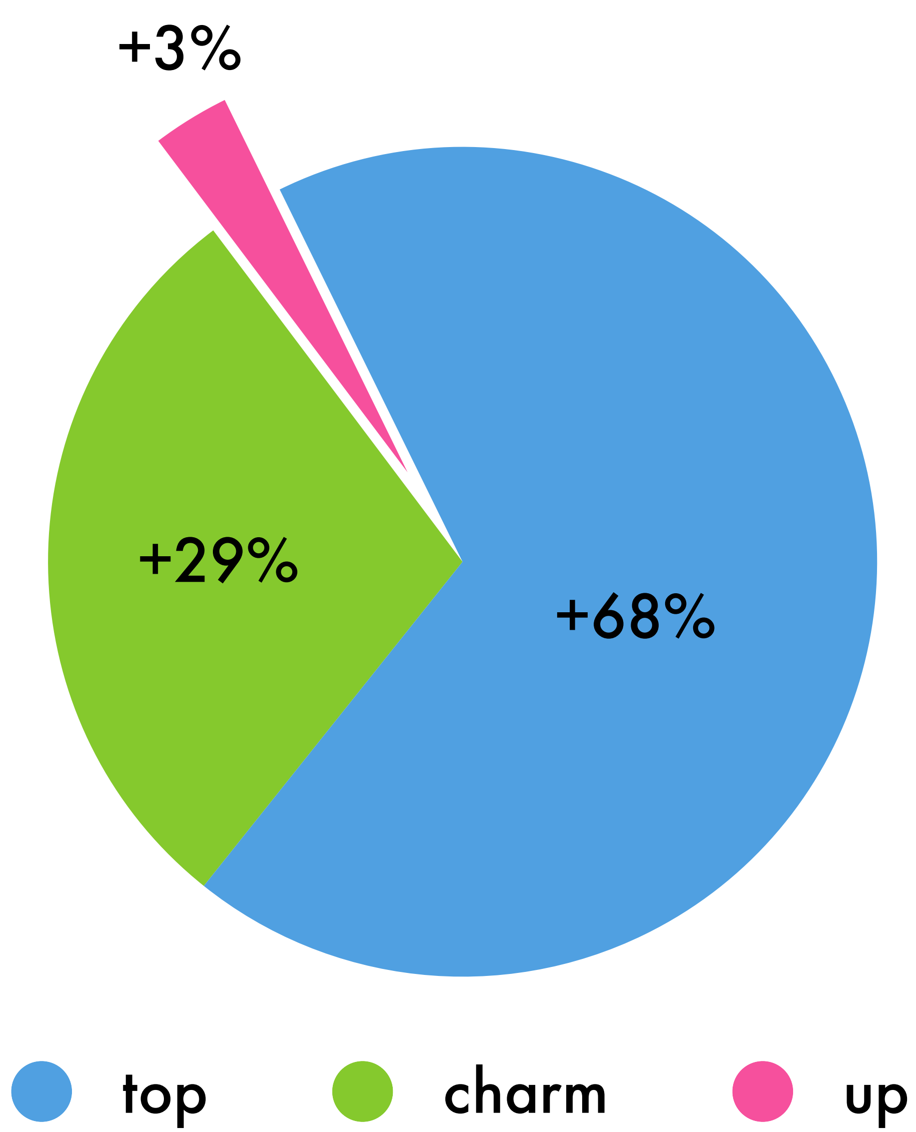


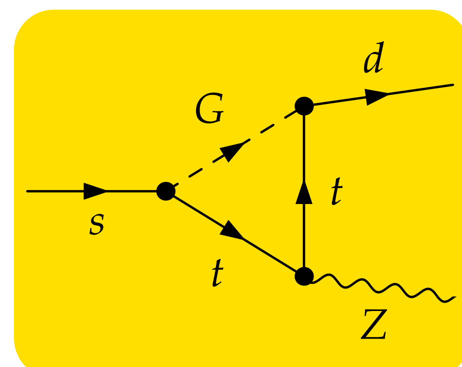
$\propto$ const.

- large *CP* violating phase in dominant short-distance contribution due to top

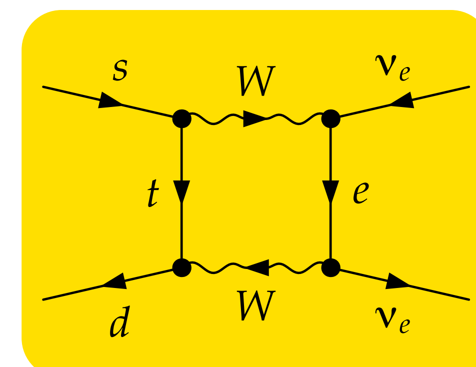
Warm-up: basic facts about $s \to d\nu\bar{\nu}$

$$\mathcal{A}_{\rm SM}(s \to d\nu\bar{\nu}) = \sum_{q=u,c,t} V_{qs}^* V_{qd}\, X_{\rm SM}^q \propto \frac{m_t^2}{M_W^2}(\lambda^5 + i\lambda^5) + \frac{m_c^2}{M_W^2} \ln \frac{m_c}{M_W}\lambda + \frac{\Lambda^2}{M_W^2}\lambda$$





$$\propto \frac{m_t^2}{M_W^2}$$

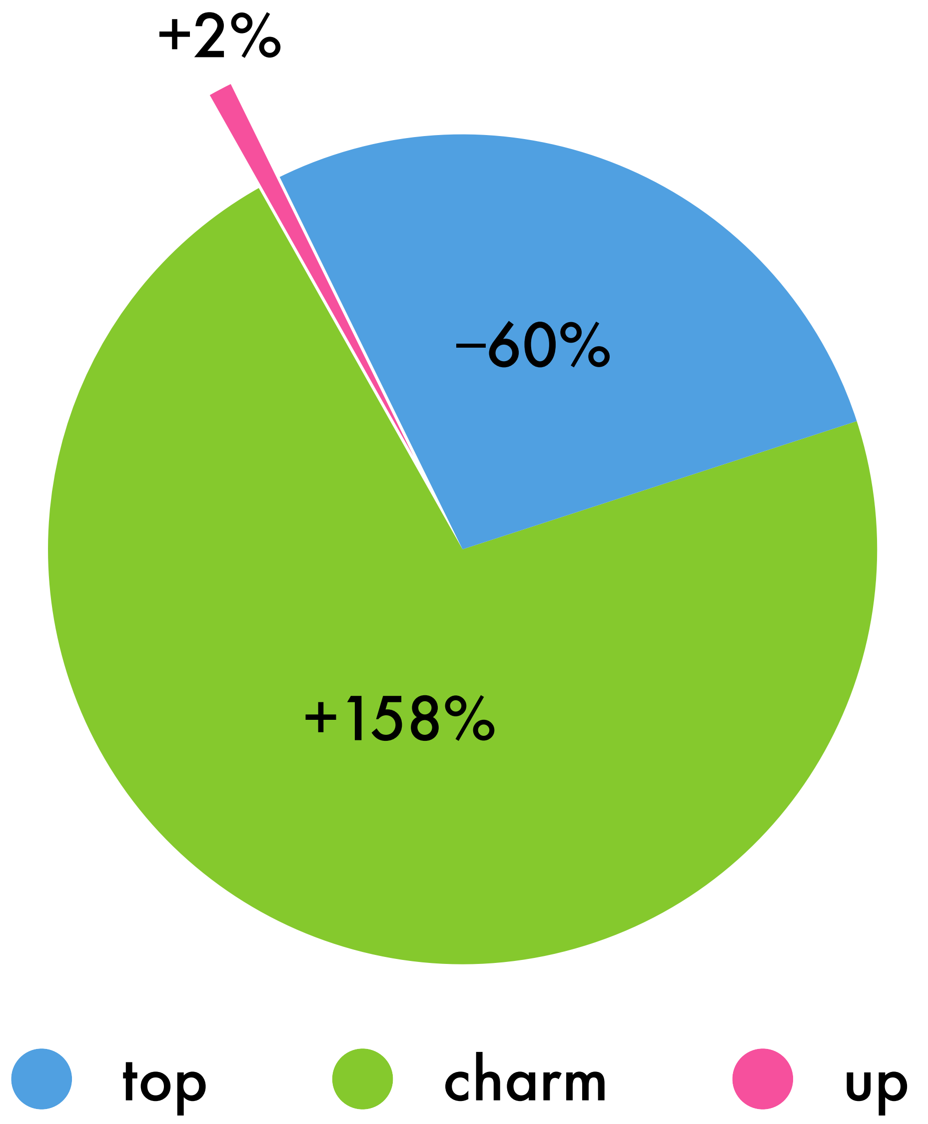


$$\propto \text{const.}$$

- thus: $s \to d\nu\bar{\nu}$ exceptional tool to discover non-MFV physics where hard GIM is not active

Warm-up: basic facts about $b\to s\gamma$

$$\mathcal{A}_{\rm SM}(b\to s\gamma) = \sum_{q=u,c,t} V_{qb}^* V_{qs}\, K_{\rm SM}^q \propto \ln\frac{m_b}{M_W}\lambda^2 + \ln\frac{m_b}{M_W}\lambda^2 + \ln\frac{m_b}{M_W}\lambda^4$$

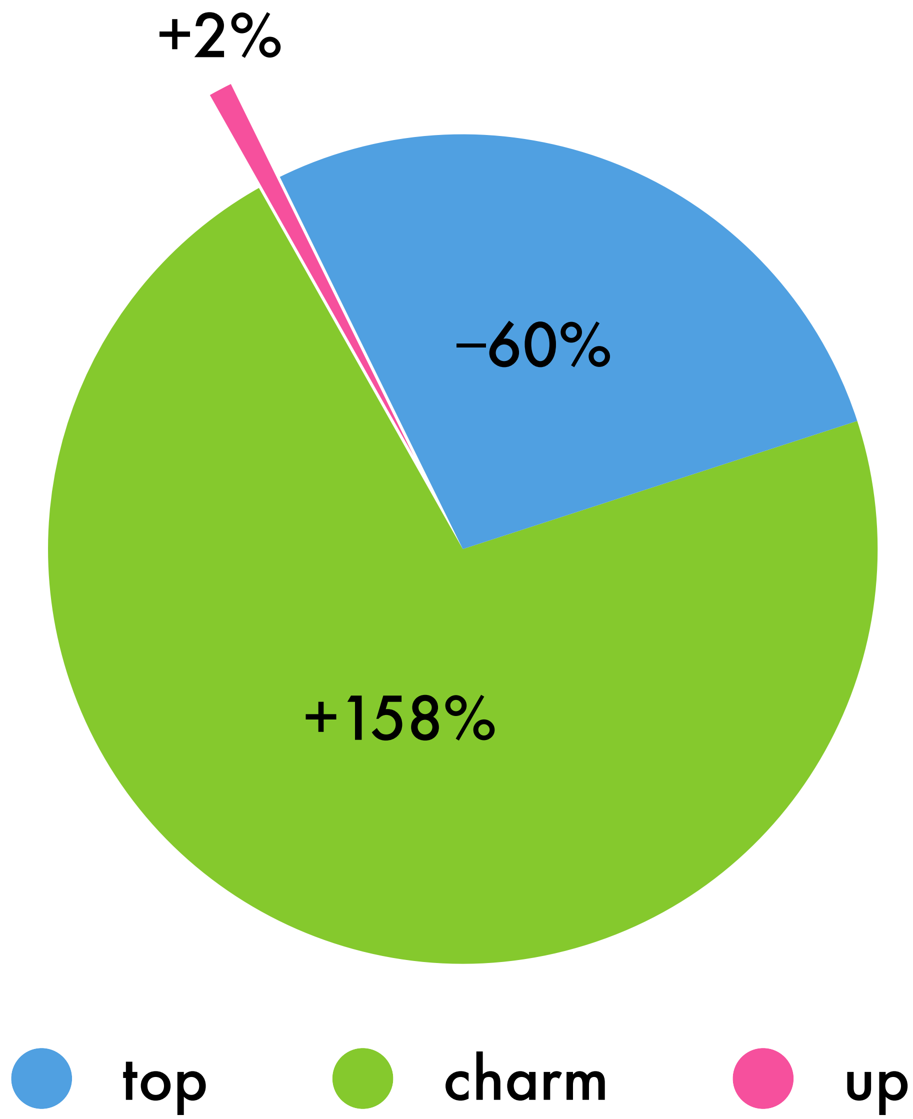


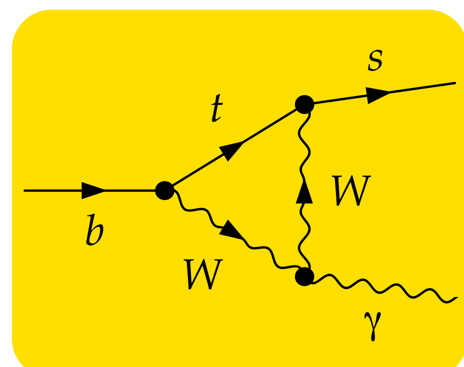
$$Q_7 = \frac{e}{16\pi^2} m_b (\bar{s}_L \sigma_{\mu\nu} b_R) F^{\mu\nu}$$

- tensor current not conserved: $b\to s\gamma$ depends logarithmically on scale where Q_7 is generated

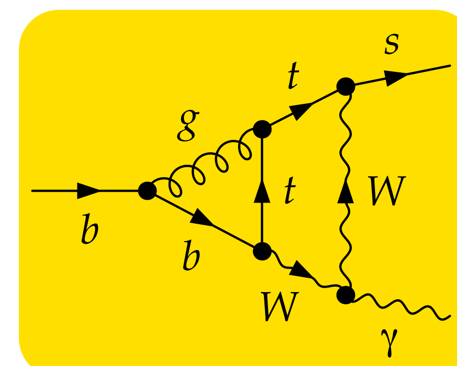
Warm-up: basic facts about $b \to s\gamma$

$$\mathcal{A}_{\rm SM}(b \to s\gamma) = \sum_{q=u,c,t} V_{qb}^* V_{qs}\, K_{\rm SM}^q \propto \ln \frac{m_b}{M_W}\lambda^2 + \ln \frac{m_b}{M_W}\lambda^2 + \ln \frac{m_b}{M_W}\lambda^4$$





$\propto$ const.

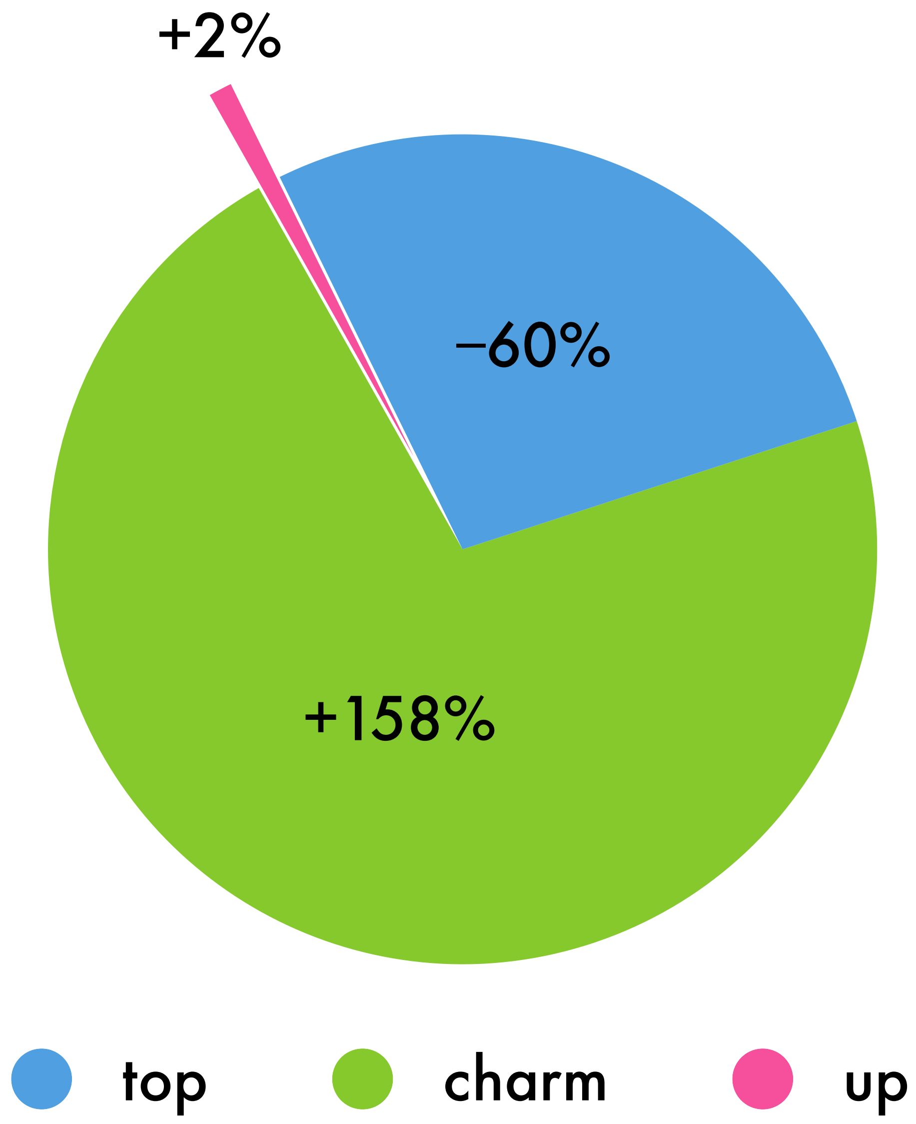


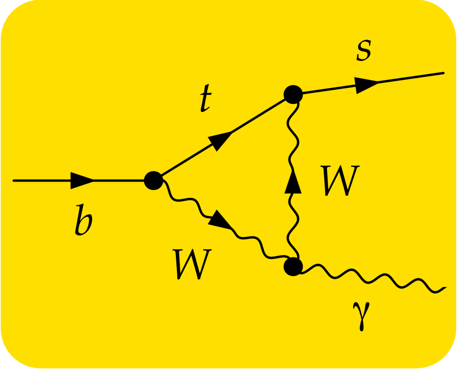
$\propto \alpha_s \ln \dfrac{m_b}{M_W}$

- gluonic corrections lead to mild logarithmic GIM suppression of $b \to s\gamma$ amplitude

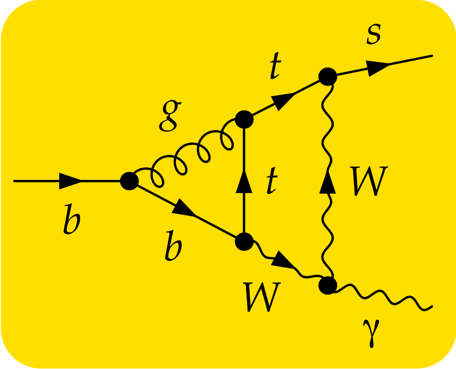
Warm-up: basic facts about $b \to s\gamma$

$$\mathcal{A}_{\rm SM}(b \to s\gamma) = \sum_{q=u,c,t} V_{qb}^* V_{qs}\, K_{\rm SM}^q \propto \boxed{\ln \frac{m_b}{M_W} \lambda^2} + \boxed{\ln \frac{m_b}{M_W} \lambda^2} + \boxed{\ln \frac{m_b}{M_W} \lambda^4}$$





$\propto$ const.

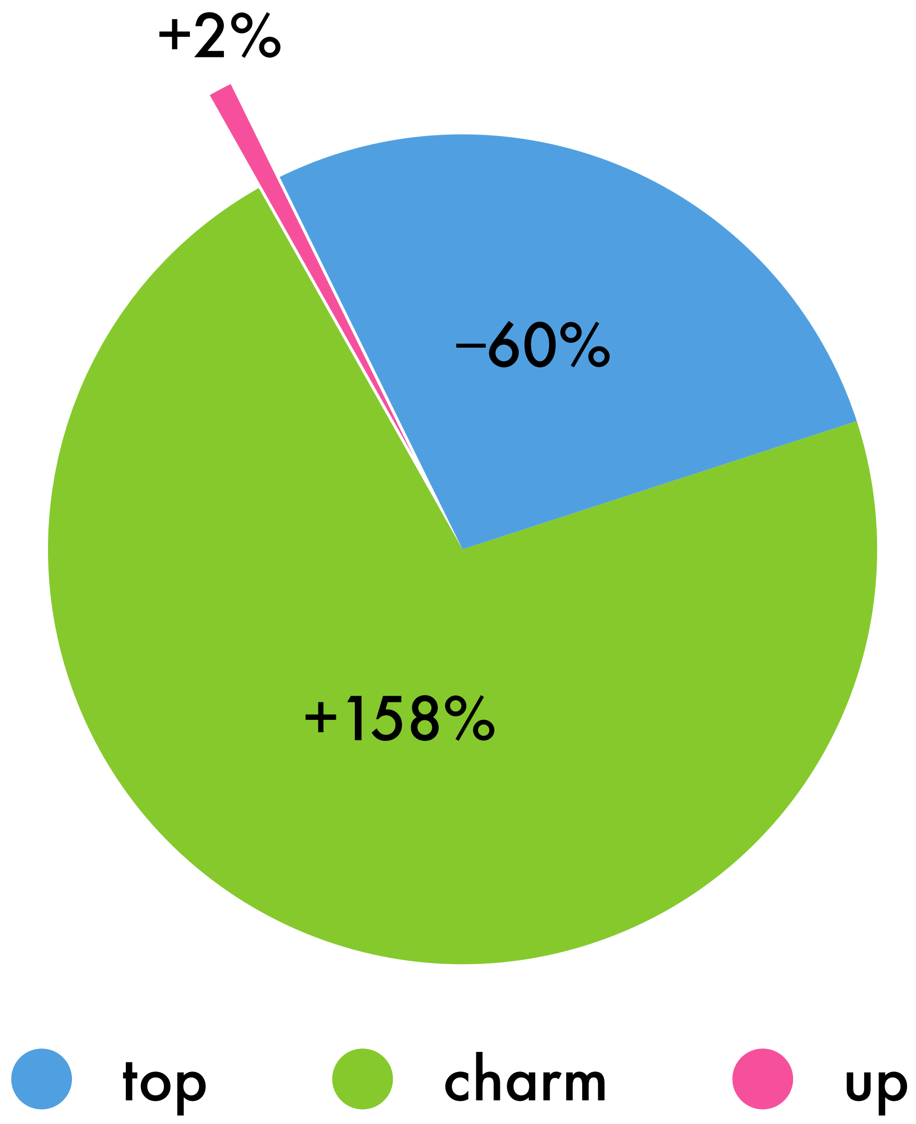


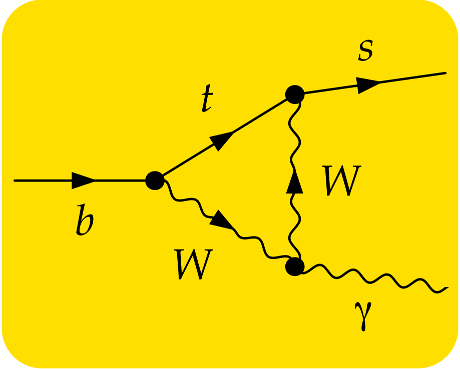
$\propto \alpha_s \ln \frac{m_b}{M_W}$

- sensitivity on high scale physics "swamped" by renormalization group effects

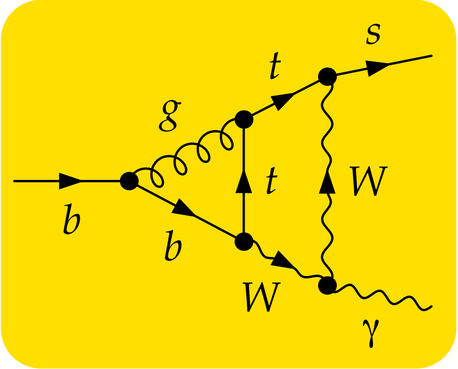
Warm-up: basic facts about $b \to s\gamma$

$$\mathcal{A}_{\rm SM}(b \to s\gamma) = \sum_{q=u,c,t} V_{qb}^* V_{qs} \, K_{\rm SM}^q \propto \ln\frac{m_b}{M_W}\lambda^2 + \ln\frac{m_b}{M_W}\lambda^2 + \ln\frac{m_b}{M_W}\lambda^4$$





$\propto$ const.

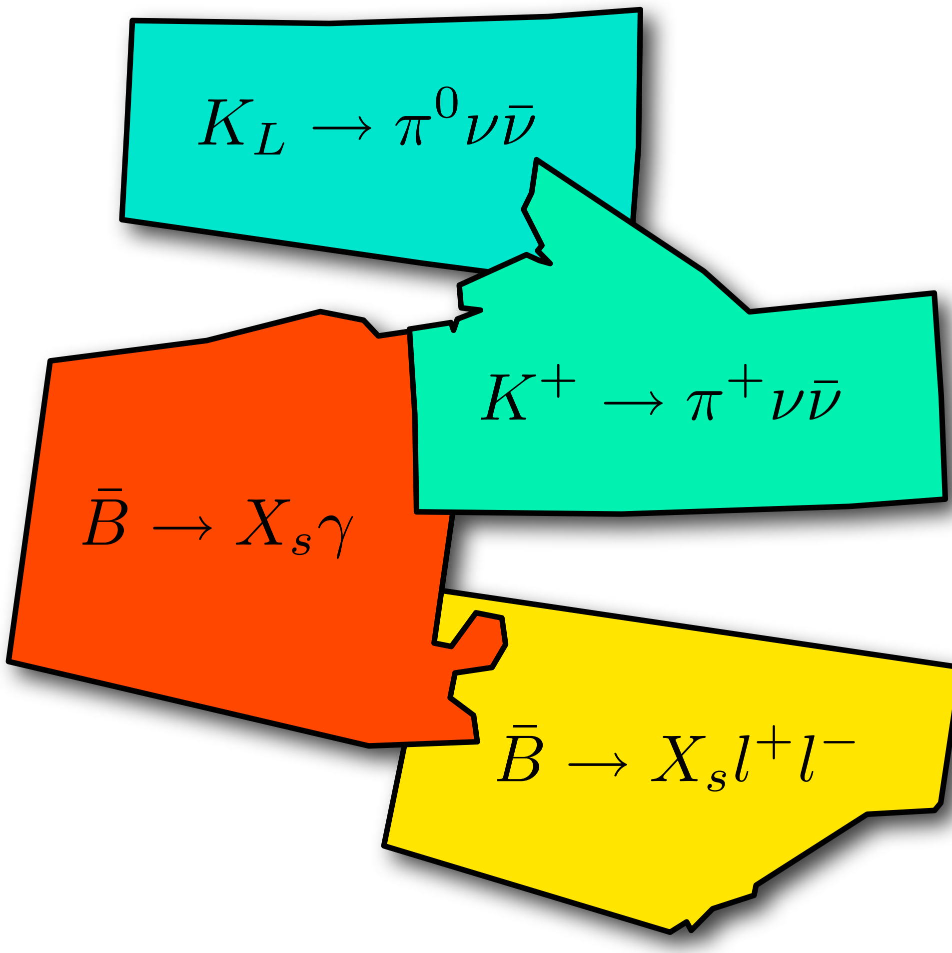


$\propto \alpha_s \ln\frac{m_b}{M_W}$

- thus: $b \to s\gamma$ wonderful QCD laboratory, providing stringent constraints on new physics

Next $23^{(+)}$ minutes ...

- recent progress in SM
- next theoretical obstacles
- joining forces: *K*- & *B*-decays
- no conclusions



$K \to \pi\nu\bar{\nu}$ matrix elements from K_{l3} in ChPT

$$\kappa_L = \frac{G_F^2 m_K^5 \alpha^2(M_Z)}{256\,\pi^5 s_W^4}\,\lambda^8\,(\tau_L|\lambda \times f_+^{K^0\pi^+}(0)|^2)_{\exp}\left(\frac{r\,r_K}{r_{0+}}\right)^2 \mathcal{I}_\nu^0\,,$$

$$\kappa_+ = \frac{G_F^2 m_K^5 \alpha^2(M_Z)}{256\,\pi^5 s_W^4}\,\lambda^8\,\tau_+\,(r_K|\lambda \times f_+^{K^0\pi^+}(0)|^2)_{\exp}\,\mathcal{I}_\nu^+$$

$$r_K = \frac{f_+^{K^+\pi^+}(0)}{f_+^{K^0\pi^+}(0)} = 1.0015 \pm 0.0007 \quad \dagger$$

$$r_{0+} = \frac{f_+^{K^+\pi^{0(+)}}(q^2)}{f_+^{K^0\pi^{+(0)}}(q^2)} = 1.0238 \pm 0.0035 \quad \dagger$$

$$r = \frac{f_+^{K^+\pi^0}(q^2)\, f_+^{K^0\pi^0}(q^2)}{f_+^{K^0\pi^+}(q^2)\, f_+^{K^+\pi^+}(q^2)} = 1.0000 \pm 0.0002 \quad \dagger$$

$$\epsilon^{(2)} \propto \frac{m_u - m_d}{m_s}$$

- classic ChPT analysis of $O(p^2\epsilon^{(2)})$* isospin-breaking effects very recently extended to $O(p^4\epsilon^{(2)})$ & partially $O(p^6\epsilon^{(2)})^\dagger$

*Marciano & Parsa '96 †Mescia & Smith '07

K_L & K_+: main messages*

- overall uncertainties on $K_L \to \pi^0 \nu\bar{\nu}$ & $K^+ \to \pi^+ \nu\bar{\nu}$ matrix elements are reduced by factor 4 & 7

- further reduction of errors possible with better data on K_{l3} slopes & K^+_{l3} branching ratios

	$(r_{0+})_{\text{theo}}$	$(r_{0+})^{\text{KLOE}}_{\text{exp}}$	$(r_{0+})_{\text{exp}}$	τ_+	$f(0)_{K_{l3}}$	$\mathcal{I}$	r_K	r	future (?)
K_L	2.229 ± 0.017	2.229 ± 0.036	2.190 ± 0.018	–	77%	12%	9%	2%	± 0.013
K_+	5.168 ± 0.025	5.168 ± 0.025	5.168 ± 0.025	19%	43%	21%	17%	–	± 0.023

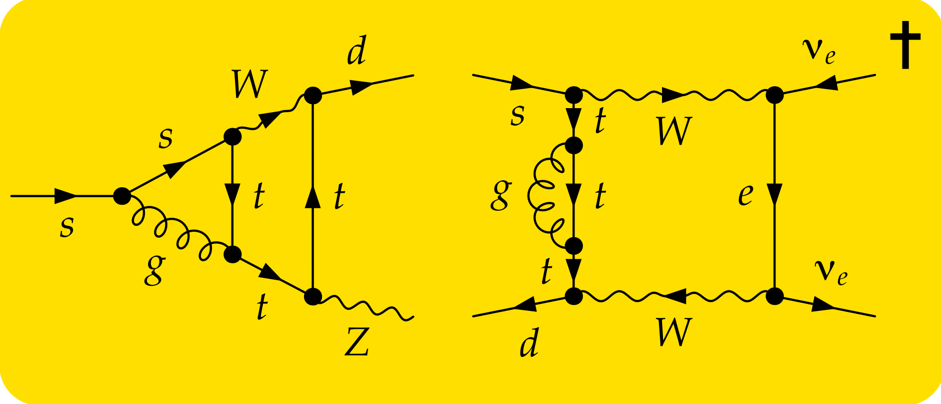
*Mescia & Smith '07

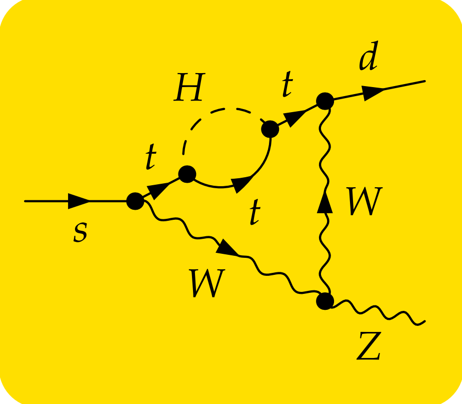
SM prediction of $K_L \to \pi^0 \nu\bar{\nu}$

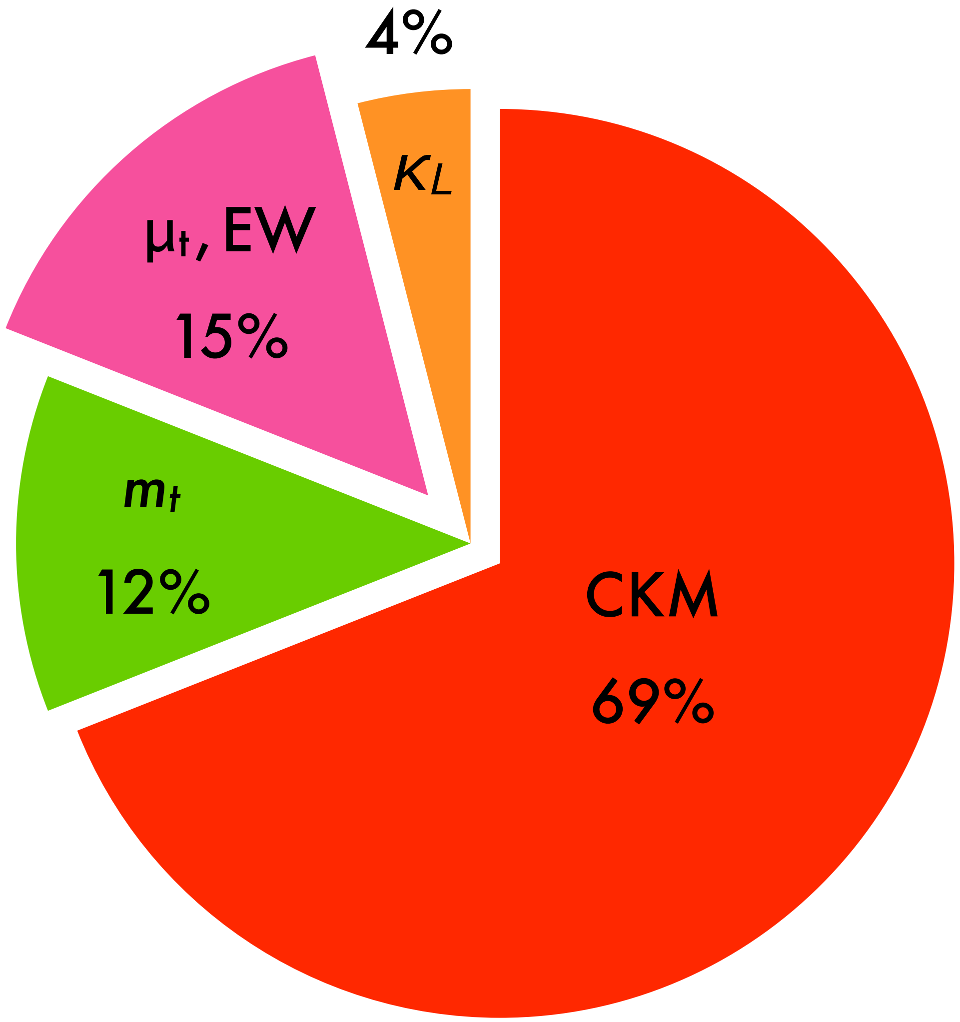
$$\mathcal{B}(K_L \to \pi^0 \nu\bar{\nu}) = \kappa_L \left[\frac{\mathrm{Im}(V_{ts}^* V_{td})}{\lambda^5} X \right]^2 = (2.54 \pm 0.35) \times 10^{-11}$$

$$\kappa_L = (2.229 \pm 0.017) \times 10^{-10} \left(\frac{\lambda}{0.225} \right)^8 \quad *$$

$$X = 1.456 \pm 0.017_{m_t} \pm 0.013_{\mu_t} \overset{?}{\pm} 0.015_{\mathrm{EW}}^{\ddagger}$$







*Mescia & Smith '07 †Misiak & Urban '99, Buchalla & Buras '99 ‡Buchalla & Buras '97

SM prediction of $K_L \to \pi^0 \nu\bar{\nu}$: upshot

$$\mathcal{B}(K_L \to \pi^0 \nu\bar{\nu}) = \kappa_L \left[\frac{\mathrm{Im}(V_{ts}^* V_{td})}{\lambda^5} X \right]^2 = (2.54 \pm 0.35) \times 10^{-11}$$

$$\kappa_L = (2.229 \pm 0.017) \times 10^{-10} \left(\frac{\lambda}{0.225} \right)^8 \; {}^{*}$$

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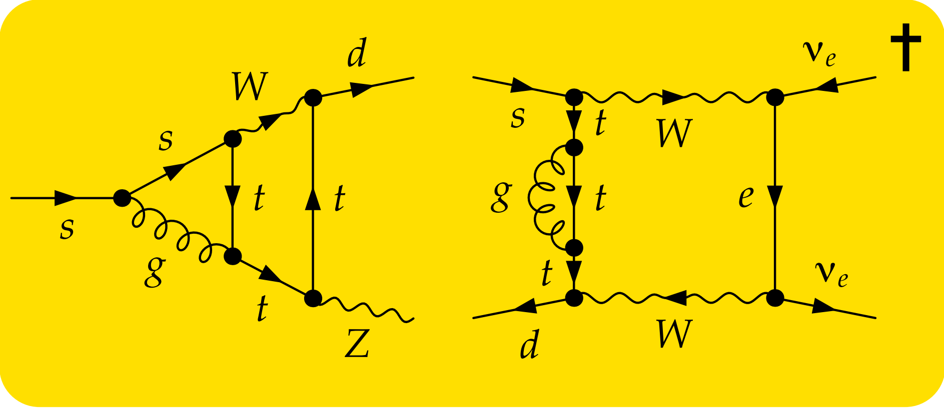
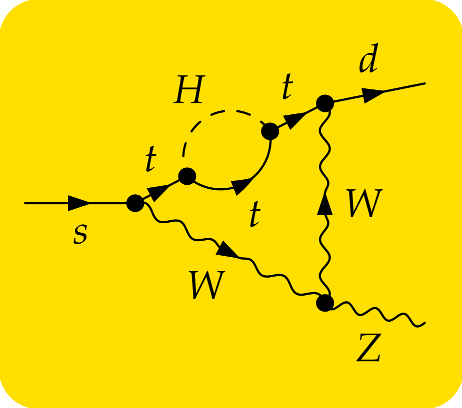




- unkown NNLO & EW corrections dominate theory error of 3%
- within SM amount of CP violation could be determined with unmatched precision

*Mescia & Smith '07 †Misiak & Urban '99, Buchalla & Buras '99 ‡Buchalla & Buras '97

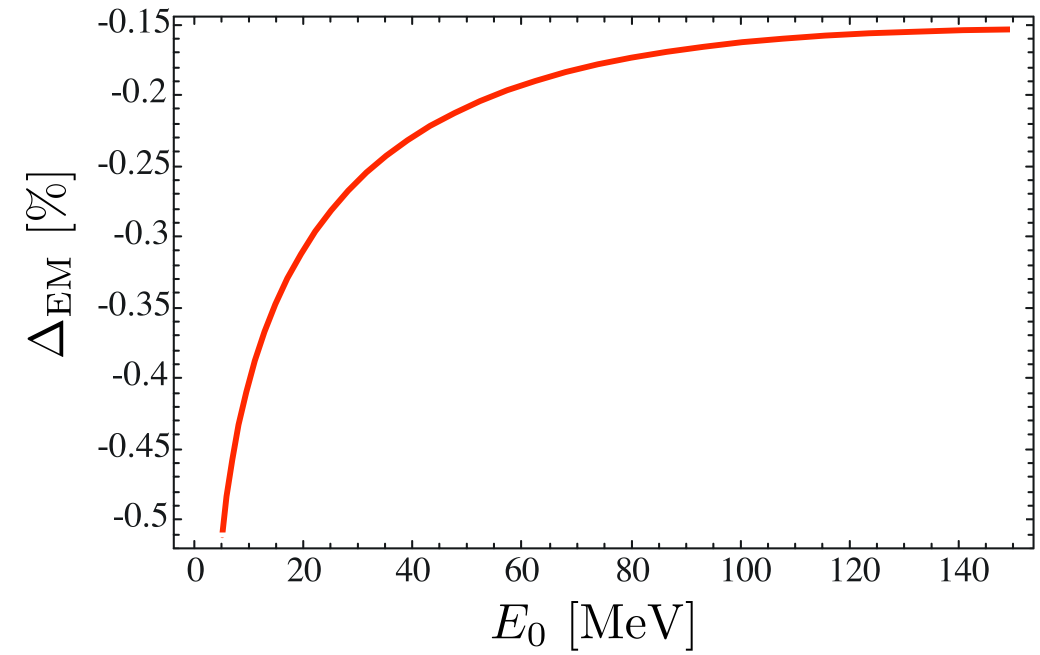
SM prediction of $K^+ \to \pi^+ \nu\bar{\nu}$: κ_+ & Δ_{EM}

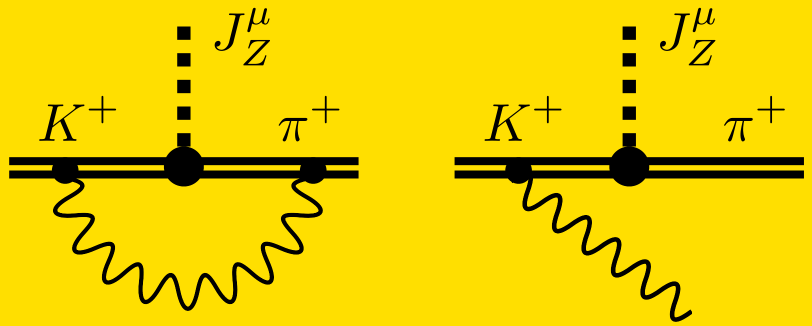
$$\mathcal{B}(K^+ \to \pi^+ \nu\bar{\nu}(\gamma)) = \kappa_+ (1 + \Delta_{\rm EM}) \left| \frac{x}{\lambda^5} \right|^2$$

$$\Delta_{\rm EM}(E_\gamma < 20\,\text{MeV}) = -0.003 \; ^*$$

$$x = V_{ts}^* V_{td} X + \lambda^4 \,\text{Re}(V_{cs}^* V_{cd})(P_c + \delta P_{c,u})$$

$$\kappa_+ = (5.168 \pm 0.025) \times 10^{-10} \left(\frac{\lambda}{0.225} \right)^8 \; ^*$$





- long-distance QED corrections at $O(p^2\alpha)$ in ChPT are known now

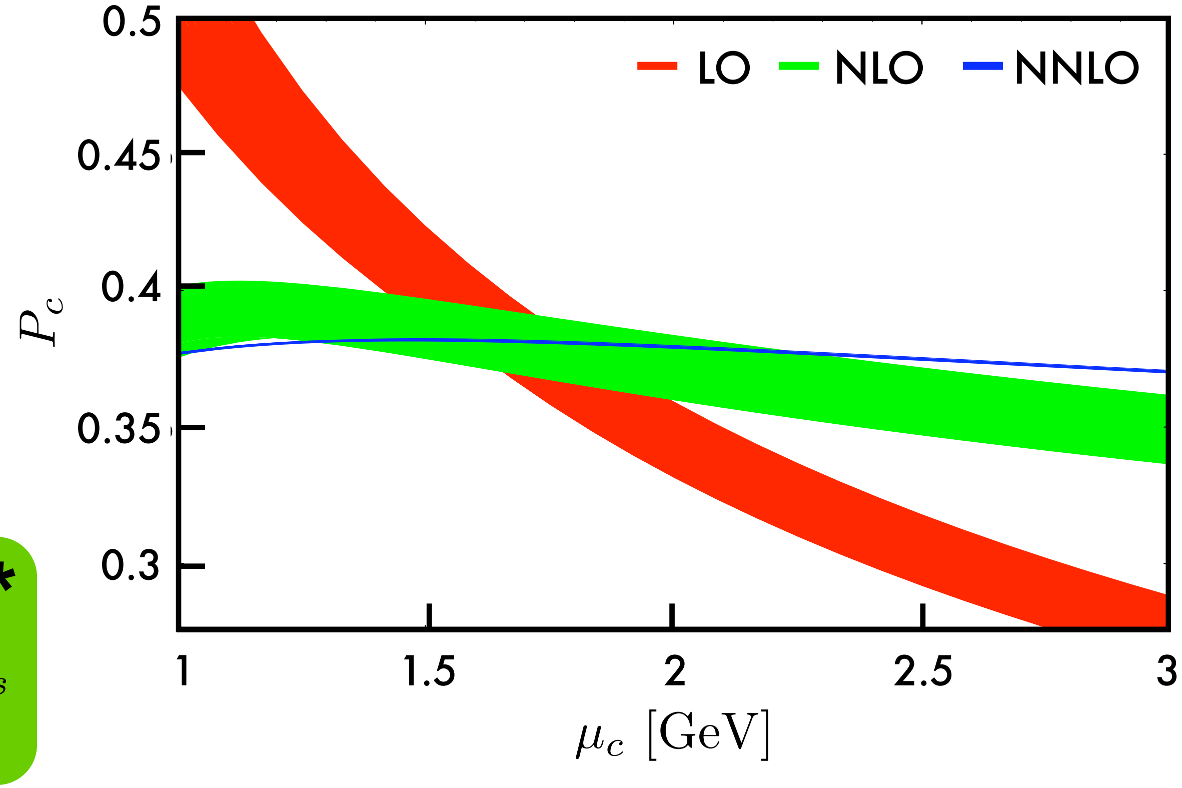
*Mescia & Smith '07

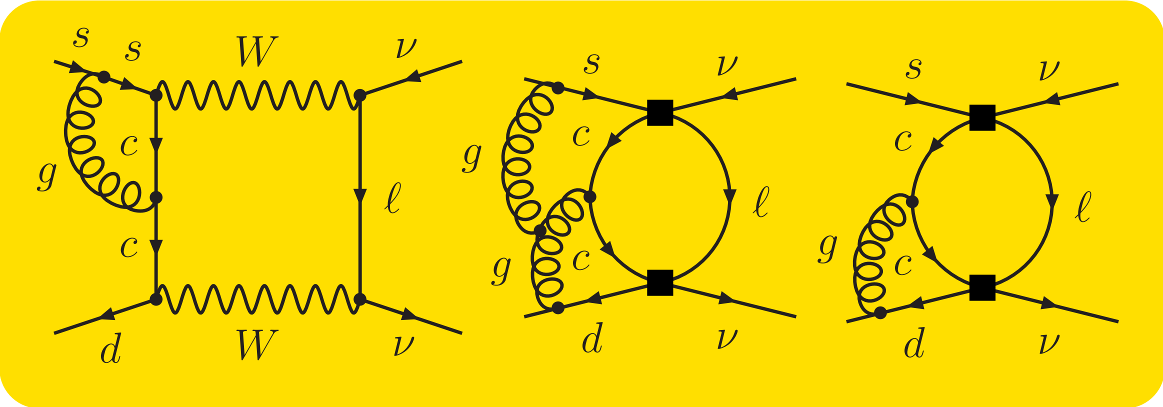
SM prediction of $K^+ \to \pi^+ \nu\bar{\nu}$: P_c

$$\mathcal{B}(K^+ \to \pi^+ \nu\bar{\nu}(\gamma)) = \kappa_+ (1 + \Delta_{\rm EM}) \left| \frac{x}{\lambda^5} \right|^2$$

$$x = V_{ts}^* V_{td} X + \lambda^4 \, \mathrm{Re}(V_{cs}^* V_{cd}) (P_c + \delta P_{c,u})$$

$$P_c = 0.374 \pm 0.009_{\rm pert} \pm 0.031_{m_c} \pm 0.009_{\alpha_s}$$ *





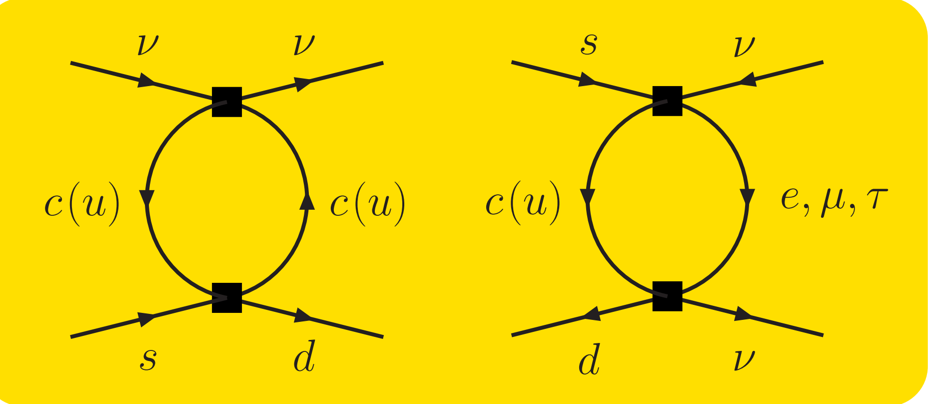
- NNLO calculation of P_c leads to reduction of theoretical error from 10% down to 2.5%

*Buras et al. '05, '06

SM prediction of $K^+ \to \pi^+ \nu\bar{\nu}$: $\delta P_{c,u}$

$$\mathcal{B}(K^+ \to \pi^+ \nu\bar{\nu}(\gamma)) = \kappa_+ (1 + \Delta_{\rm EM}) \left| \frac{x}{\lambda^5} \right|^2$$

$$x = V_{ts}^* V_{td} X + \lambda^4 \, {\rm Re}(V_{cs}^* V_{cd}) (P_c + \delta P_{c,u})$$



*

$$Q_1^{(8)} = (\bar{s}_L \gamma_\mu d_L) \partial^2 (\bar{\nu}_L \gamma^\mu \nu_L) \,,$$

$$Q_2^{(8)} = (\bar{s}_L \overleftarrow{D}_\nu \gamma_\mu \overrightarrow{D}^\nu d_L)(\bar{\nu}_L \gamma^\mu \nu_L) \,,$$

$$Q_3^{(8)} = (\bar{s}_L \overleftarrow{D}_\nu \gamma_\mu d_L)(\bar{\nu}_L (\overleftarrow{\partial}^\nu - \overrightarrow{\partial}^\nu) \gamma^\mu \nu_L)$$

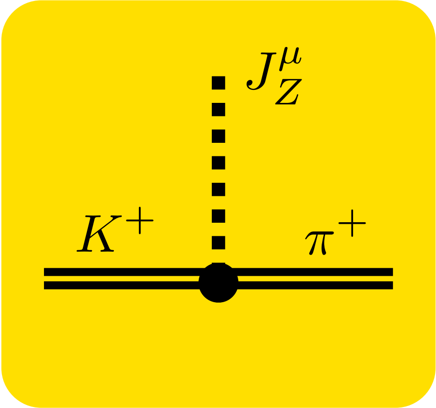
- local charm effects due to dimension-eight operators naively of $O(m_K^2/m_c^2) \approx 15\%$
- genuine long-distance up effects of $O(\Lambda^2/m_c^2) \approx 10\%$

*Falk et al. '00

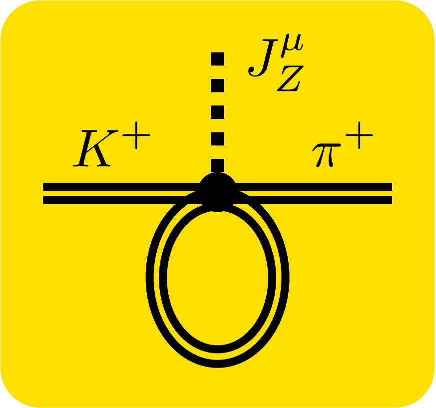
SM prediction of $K^+\to\pi^+\nu\bar{\nu}$: $\delta P_{c,u}$

$$\mathcal{B}(K^+ \to \pi^+\nu\bar{\nu}(\gamma)) = \kappa_+(1+\Delta_{\rm EM})\left|\frac{x}{\lambda^5}\right|^2$$

$$x = V_{ts}^* V_{td}\, X + \lambda^4\, \mathrm{Re}(V_{cs}^* V_{cd})(P_c + \delta P_{c,u})$$



$O(G_F^2 p^2)$



$O(G_F^2 p^4)$

$$\delta P_{c,u} = 0.04 \pm 0.02$$ *

- effects scale as $O(\pi^2 F_\pi^2/m_c^2) \approx 5\%$ & enhance SM branching ratio by 6%

- theoretical uncertainty related to non-perturbative effects due to charm & up may be reduced further by dedicated lattice analysis†

*Isidori et al. '05 †Isidori et al. '05

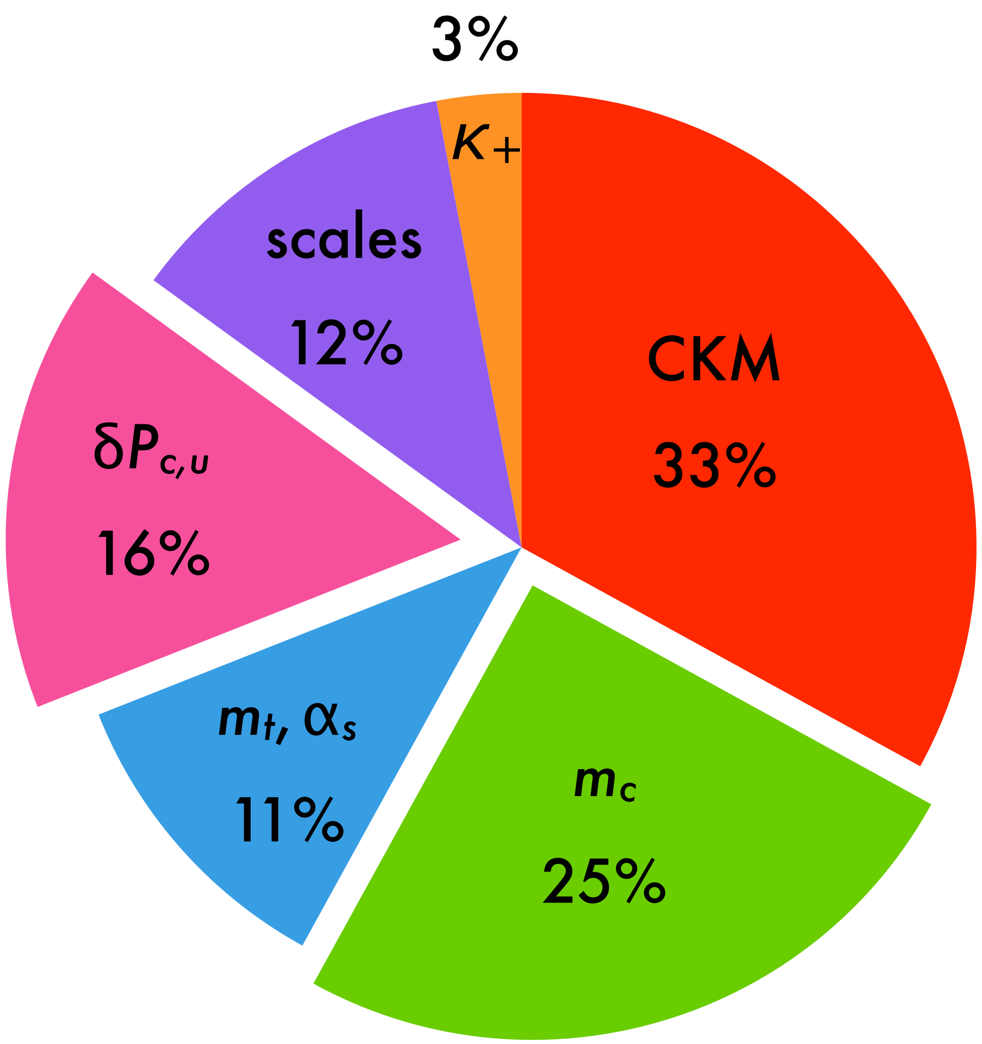
SM prediction(s) of $K^+ \to \pi^+ \nu\bar{\nu}$

$$\mathcal{B}(K^+ \to \pi^+ \nu\bar{\nu}(\gamma)) = \{7.96 \pm 0.86, 7.90 \pm 0.67, 7.46 \pm 0.91\} \times 10^{-11}$$

$$m_c(m_c) = (1.30 \pm 0.05)\ \mathrm{GeV}$$

$$m_c(m_c) = (1.286 \pm 0.013)\ \mathrm{GeV}^{*}$$

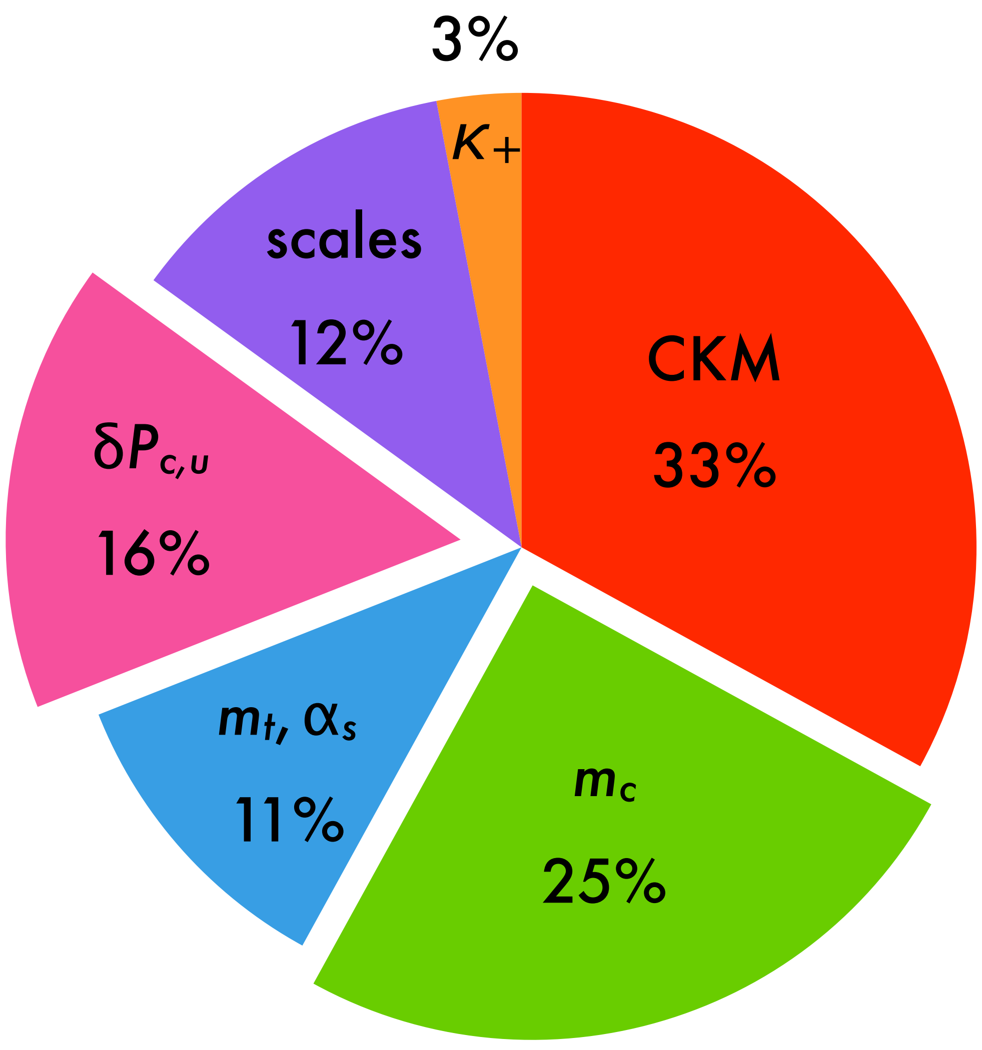
$$m_c(m_c) = (1.224 \pm 0.017 \pm 0.054)\ \mathrm{GeV}^{\dagger}$$



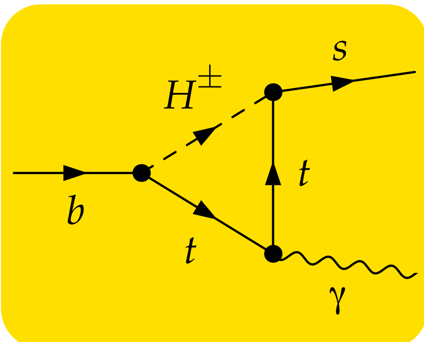
*Kühn et al. '07 †Hoang & Manohar '05

SM prediction of $K^+ \to \pi^+ \nu\bar{\nu}$: upshot

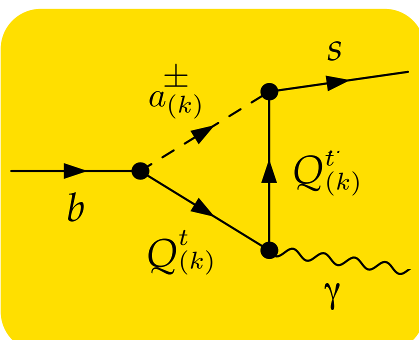
- theoretical progress in $K^+ \to \pi^+ \nu\bar{\nu}$ closely related to precision determination of charm mass
- better knowledge of long-distance effects desirable
- $K^+ \to \pi^+ \nu\bar{\nu}$ new field of interesting physical applications for lattice community



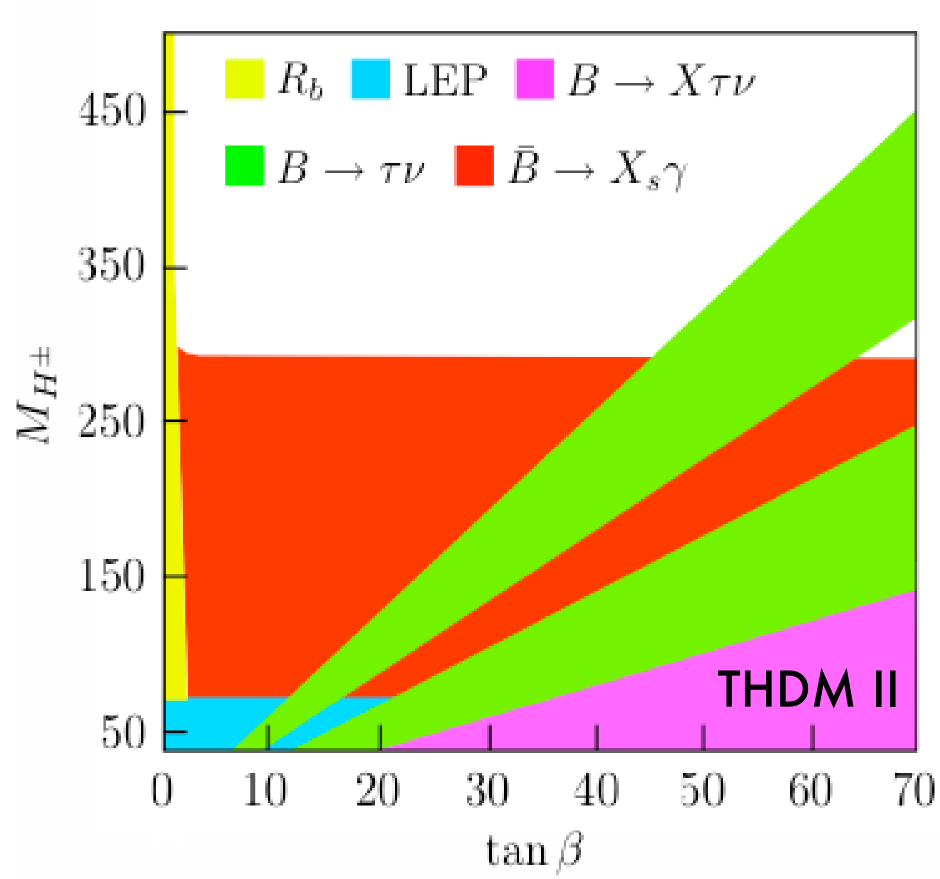
Constraints on new physics from $\bar{B} \to X_s \gamma$

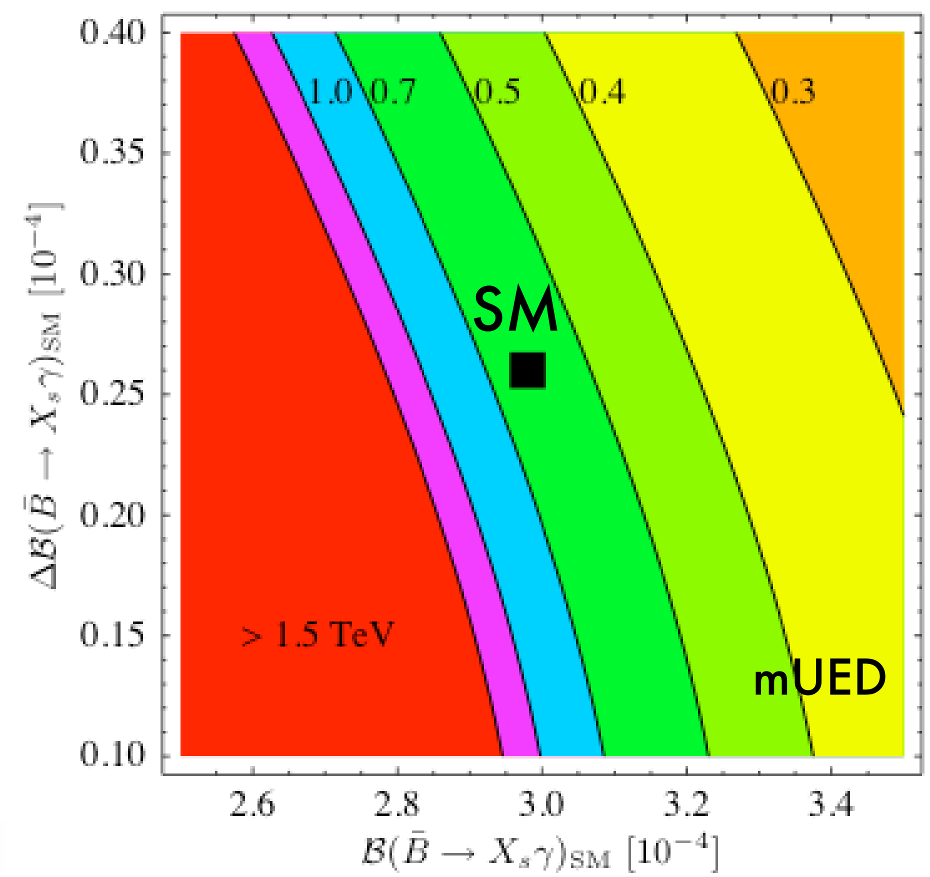


THDM II



mUED

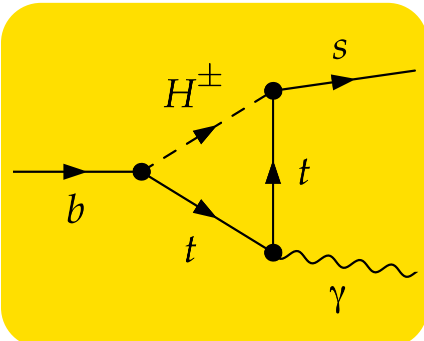




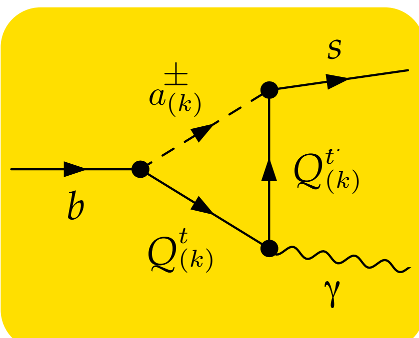
model	accuracy	effect	bound
THDM II	NLO	⇑	$M_{H^\pm} > 295$ GeV (95% CL)*
general MSSM	LO	⇕	$\lvert(\delta^d_{23})_{LL}\rvert \lesssim 4 \times 10^{-1}$, $\lvert(\delta^d_{23})_{RR}\rvert \lesssim 8 \times 10^{-1}$, $\lvert(\delta^d_{23})_{LR}\rvert \lesssim 6 \times 10^{-2}$, $\lvert(\delta^d_{23})_{RL}\rvert \lesssim 2 \times 10^{-2}$
mUED	LO	⇓	$1/R > 600$ GeV (95% CL)†
RS	LO	⇑	$M_{KK} \gtrsim 2.4$ TeV

*Misiak et al. '06 †UH & Weiler '07

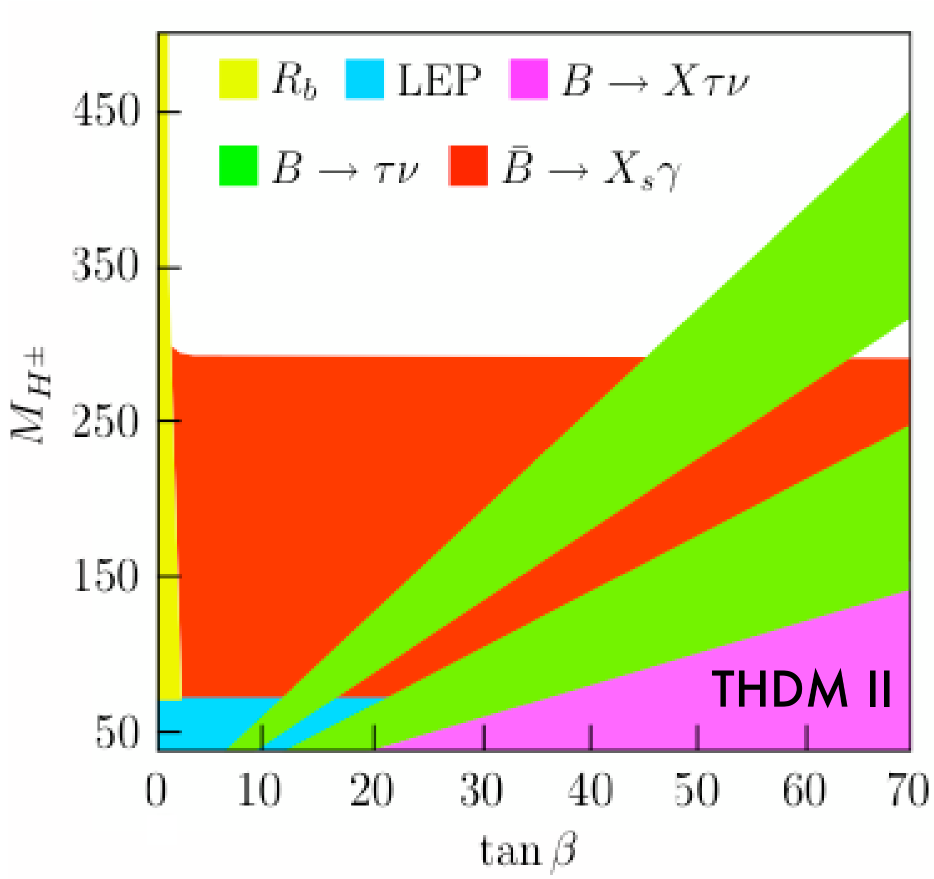
Constraints on new physics from $\bar{B}\to X_s\gamma$

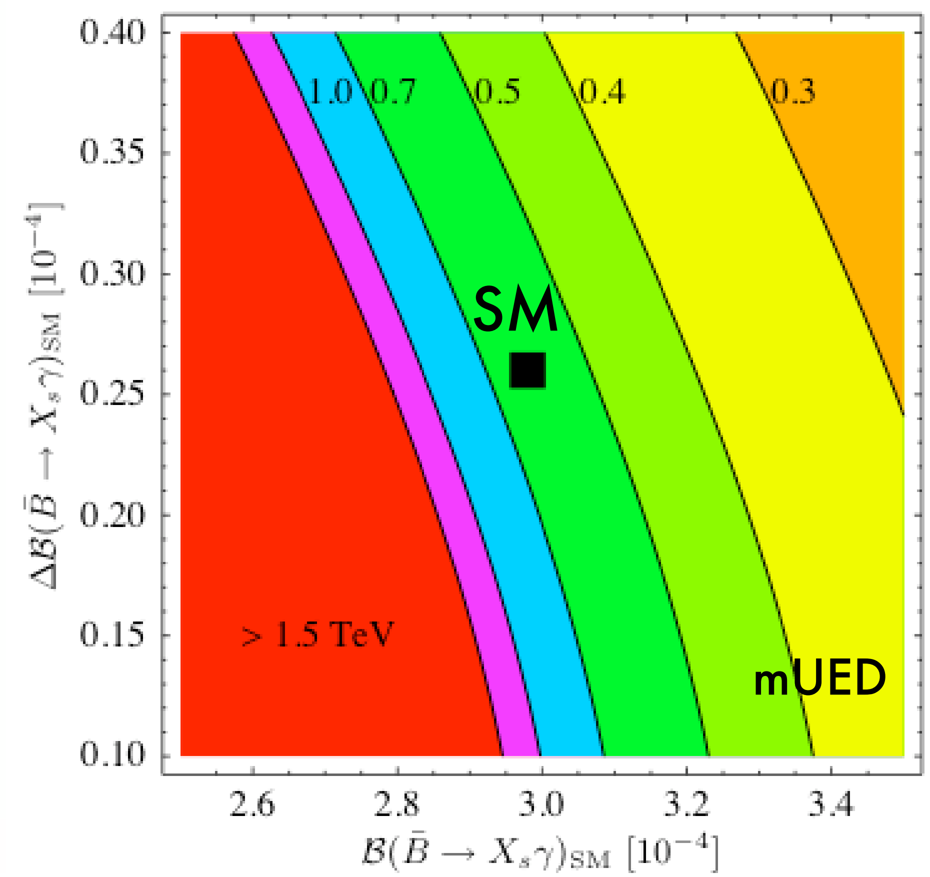


THDM II



mUED





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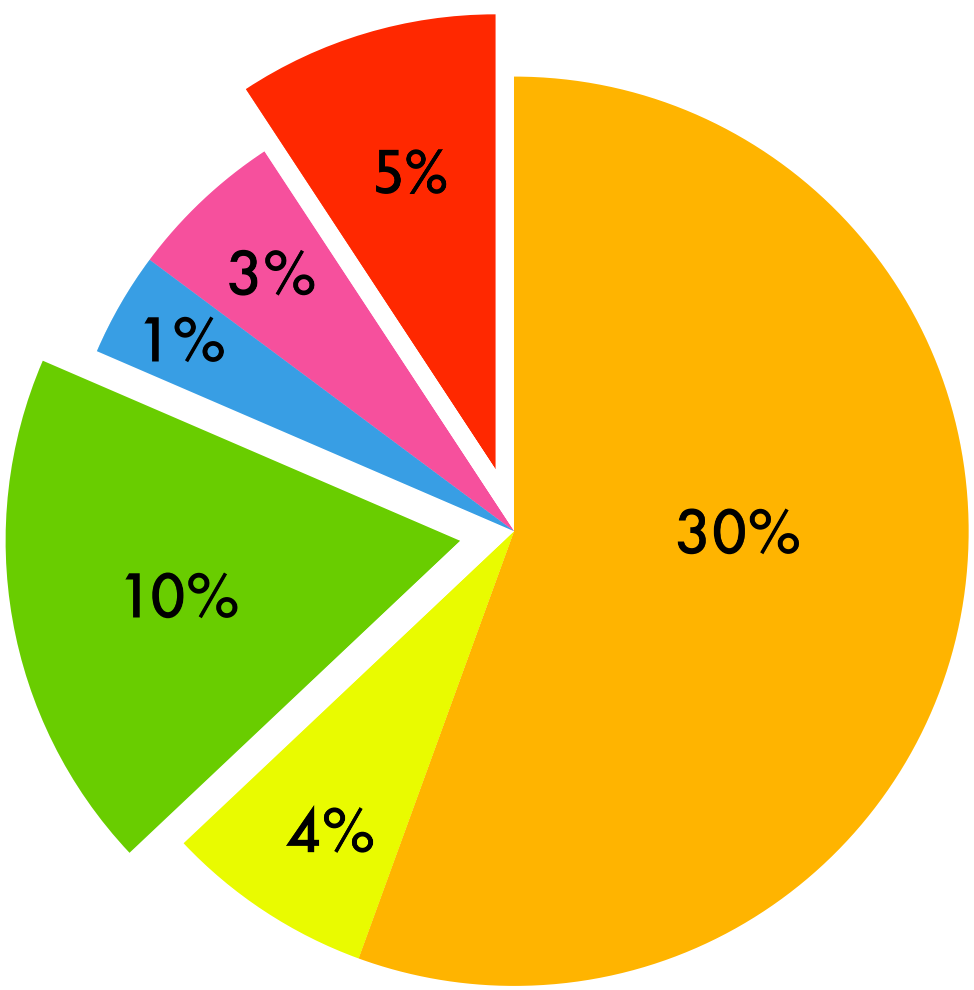
- constraints depend in non-negligible way on theory error in SM

*Misiak et al. '06 †UH & Weiler '07

Corrections to $\bar{B} \to X_s\gamma$ beyond LO in SM

$$\mathcal{B}(\bar{B} \to X_s\gamma)^{E_\gamma > 1.6\ \mathrm{GeV}}_{\mathrm{SM}} = \mathcal{B}(\bar{B} \to X_c e\bar{\nu}) \left[\frac{\Gamma(b \to s\gamma)}{\Gamma(b \to c e\bar{\nu})}\right]_{\mathrm{LO}} f\left(\frac{\alpha_s(M_W)}{\alpha_s(m_b)}\right)$$

$$\times \left\{1 + \mathcal{O}(\alpha_s) + \mathcal{O}(\alpha) + \mathcal{O}(\alpha_s^2) + \mathcal{O}\left(\frac{\Lambda^2}{m_b^2}\right) + \mathcal{O}\left(\frac{\Lambda^2}{m_c^2}\right) + \mathcal{O}\left(\alpha_s \frac{\Lambda}{m_b}\right)\right\}$$



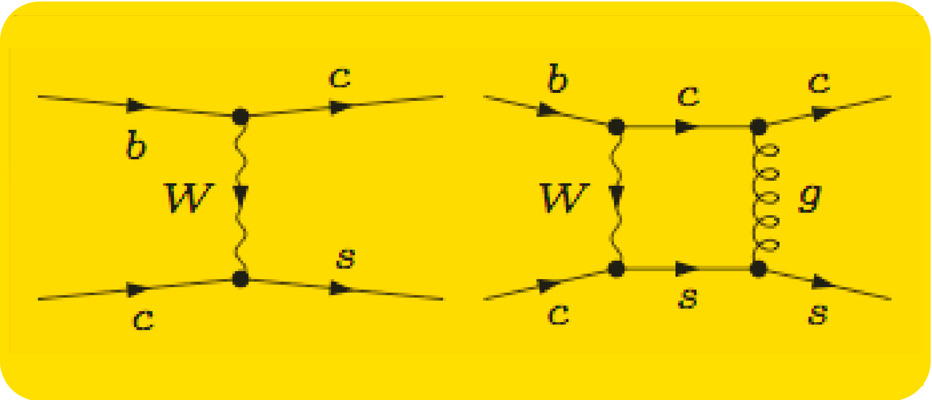
- NLO QCD
- NLO EW
- NNLO QCD

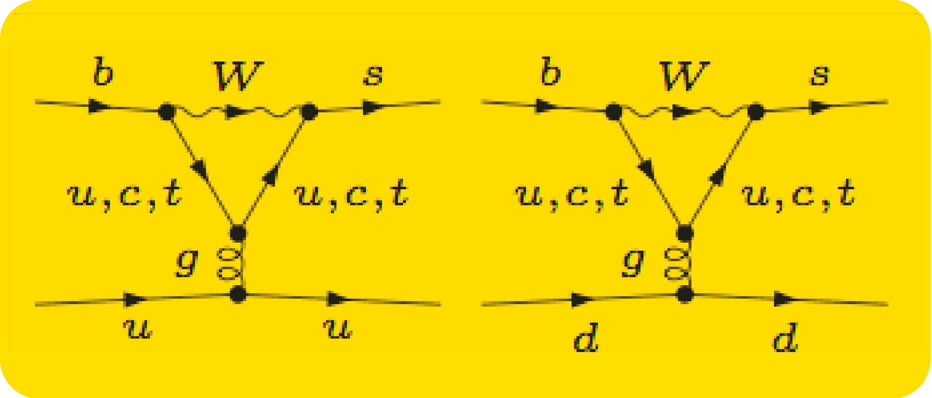
perturbative

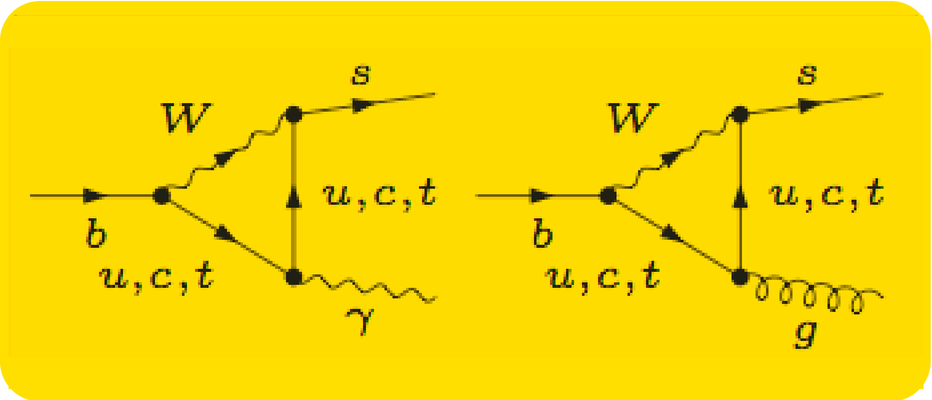
- LO QCD + NLO m_b
- LO QCD + NLO m_c
- NLO QCD + LO m_b

non-perturbative

Usual suspects in $\bar{B} \to X_s \gamma$







$$\mathcal{L}_{\rm eff} = \mathcal{L}_{\rm QCD\times QED} + \frac{4G_F}{\sqrt{2}} V_{ts}^* V_{tb} \sum_{i=1}^{8} C_i(\mu) Q_i + \ldots$$

$$Q_{1,2} = (\bar{s}\Gamma_i c)(\bar{c}\Gamma_i' b)$$

$$|C_{1,2}(m_b)| \approx 1$$

$$Q_{3-6} = (\bar{s}\Gamma_i b) \sum\nolimits_q (\bar{q}\Gamma_i' q)$$

$$|C_{3-6}(m_b)| < 0.07$$

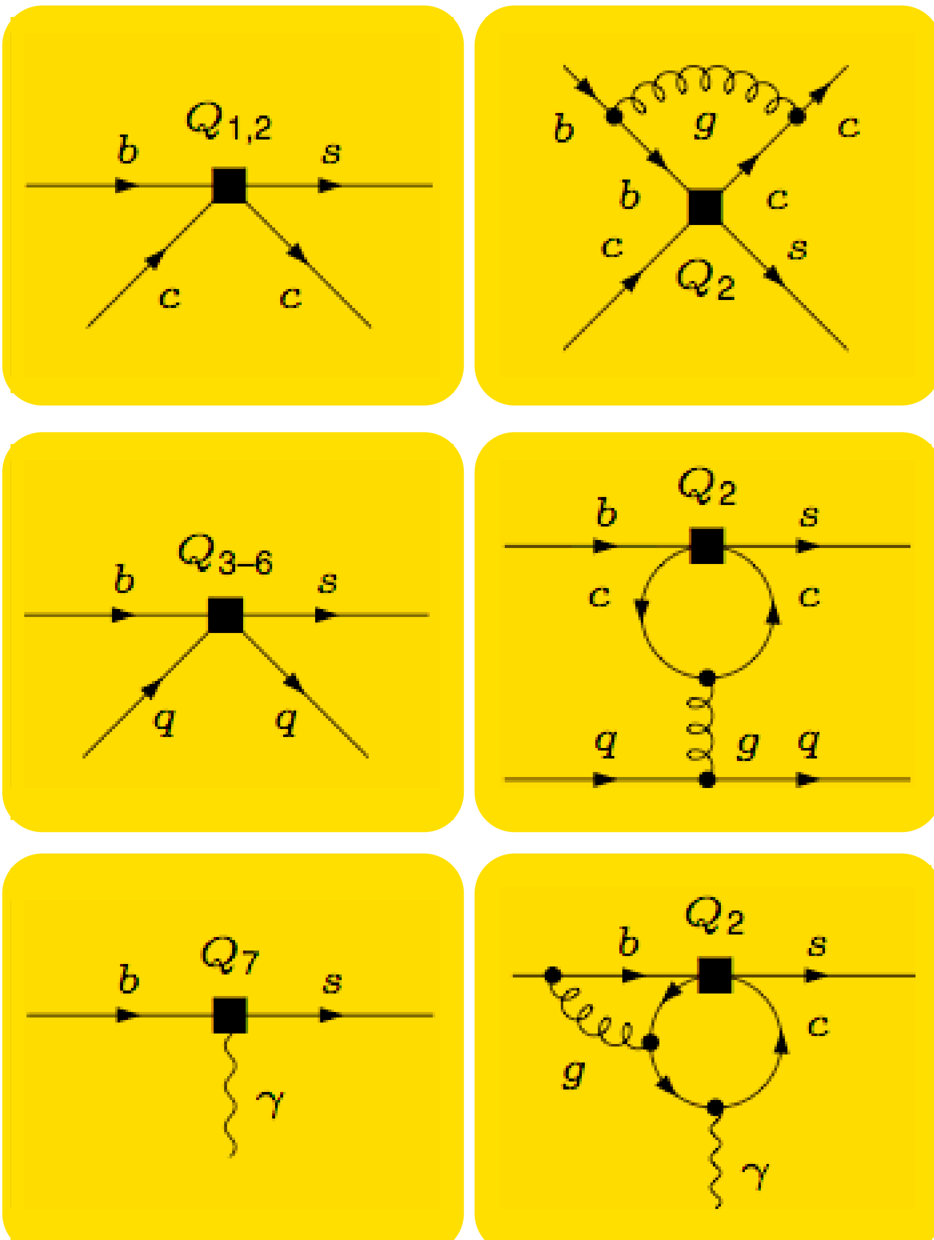
$$Q_7 = \frac{e m_b}{16\pi^2} (\bar{s}_L \sigma^{\mu\nu} b_R) F_{\mu\nu}$$

$$Q_8 = \frac{g m_b}{16\pi^2} (\bar{s}_L \sigma^{\mu\nu} T^a b_R) G^a_{\mu\nu}$$

$$C_7(m_b) \approx -0.3$$

$$C_8(m_b) \approx -0.15$$

Usual suspects in $\bar{B} \to X_s \gamma$



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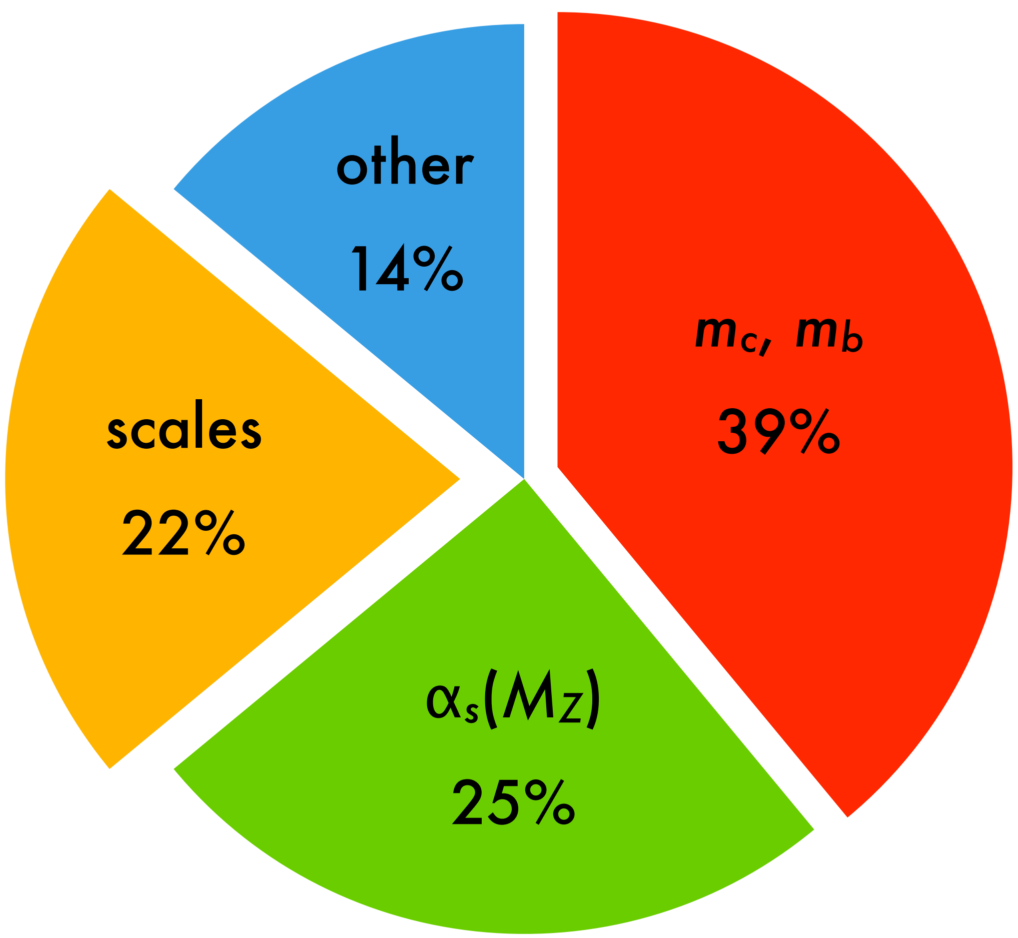
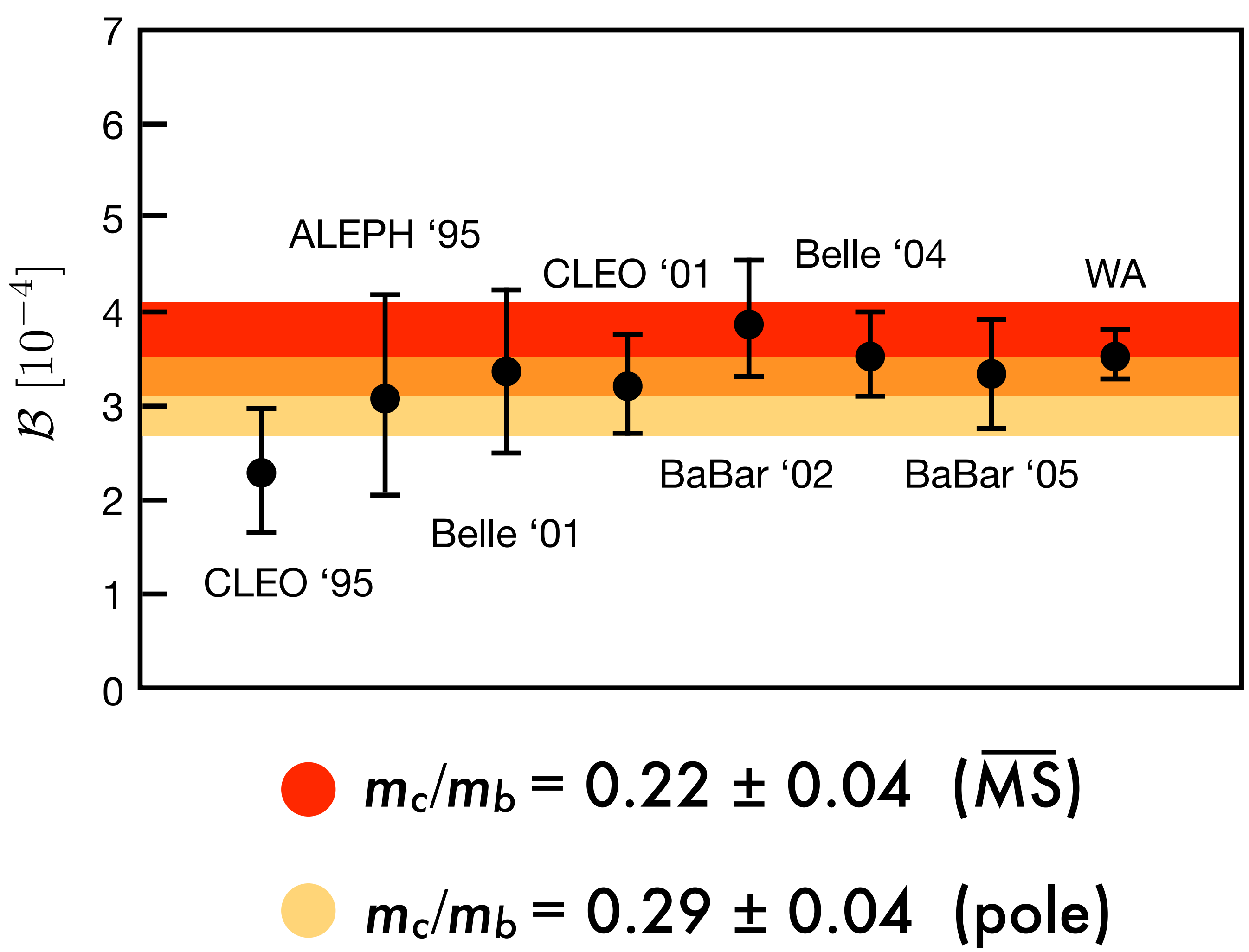
Error budget of $\bar{B} \to X_s \gamma$ at NLO in SM

$$\mathcal{B}_{\rm exp}^{E_\gamma > 1.6 \ {\rm GeV}} = \left(3.55 \pm 0.24 \, {}^{+0.09}_{-0.10} \pm 0.03\right) \times 10^{-4}$$ *

$$\mathcal{B}_{\rm NLO}^{E_\gamma > 1.6 \ {\rm GeV}} = (3.33 \pm 0.29) \times 10^{-4}, \ m_c/m_b = 0.26$$





*HFAG '06

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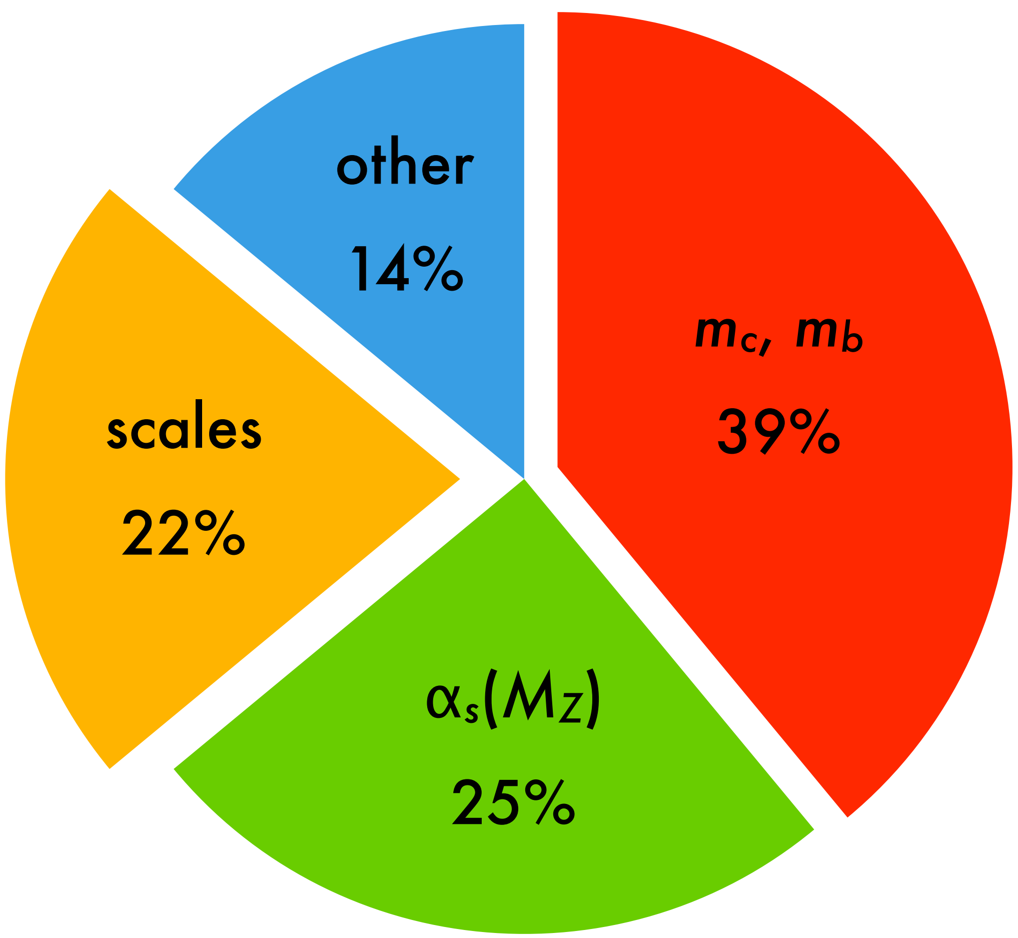

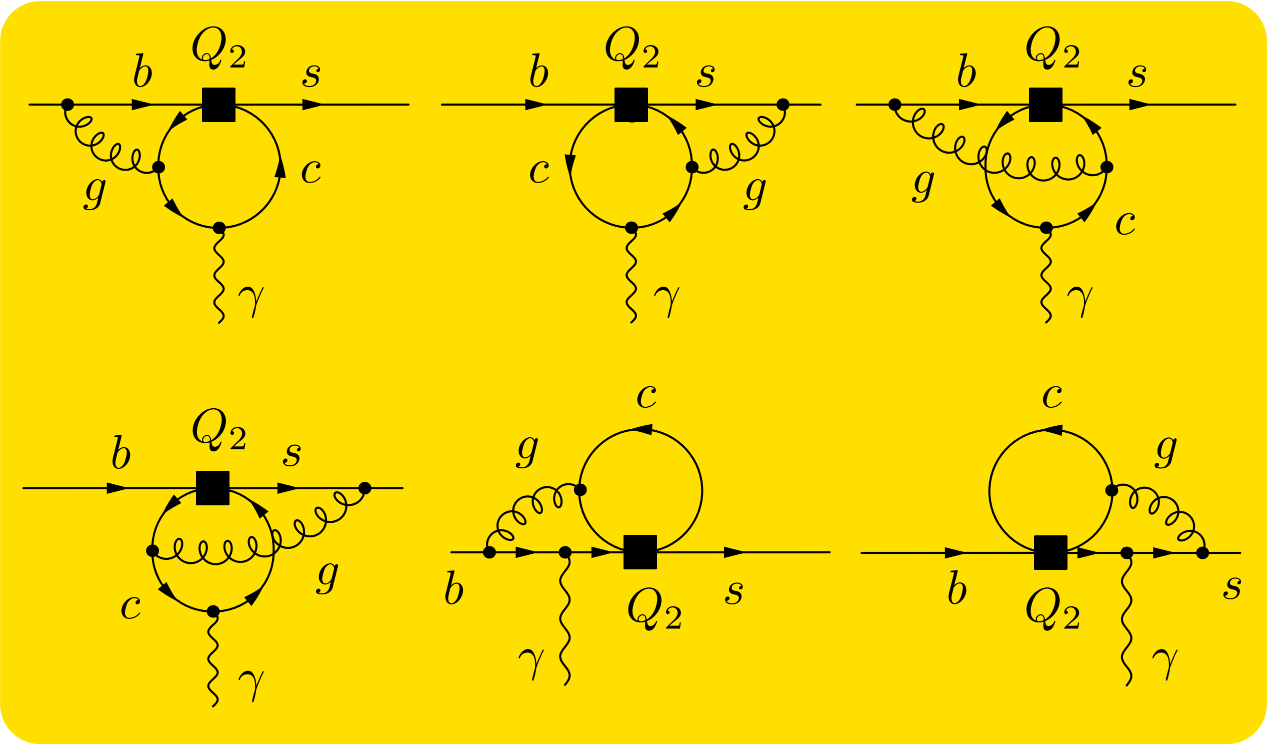

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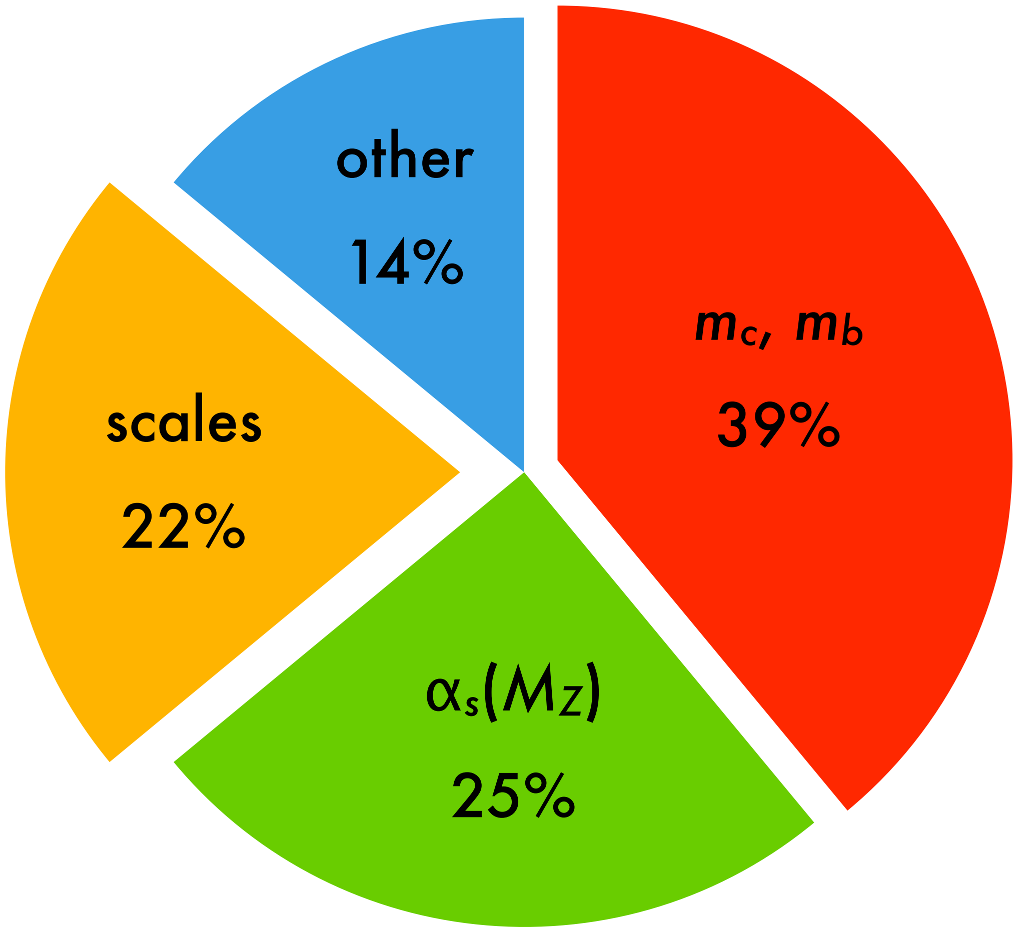
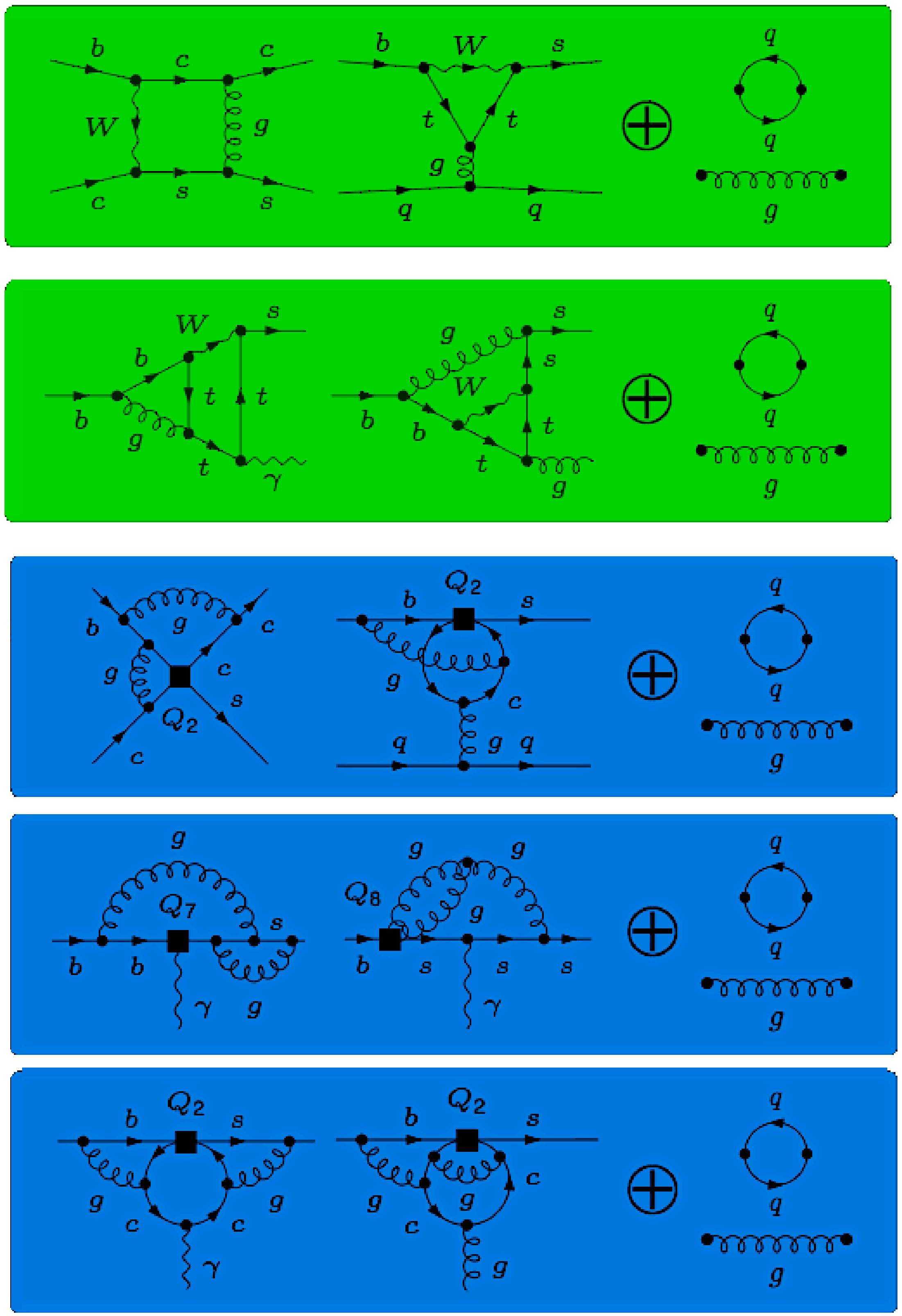
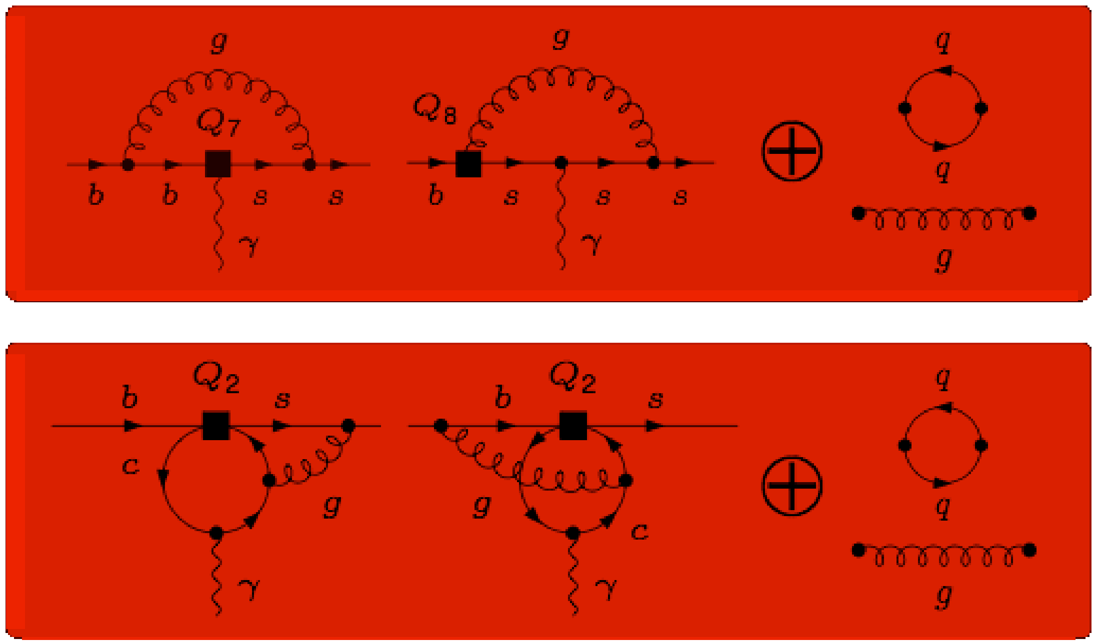


- scheme ambiguity associated with charm mass, first appearing at NLO, can only be resolved by dedicated NNLO calculation

*HFAG '06

Flavor of NNLO $\bar{B} \to X_s \gamma$ SM calculation

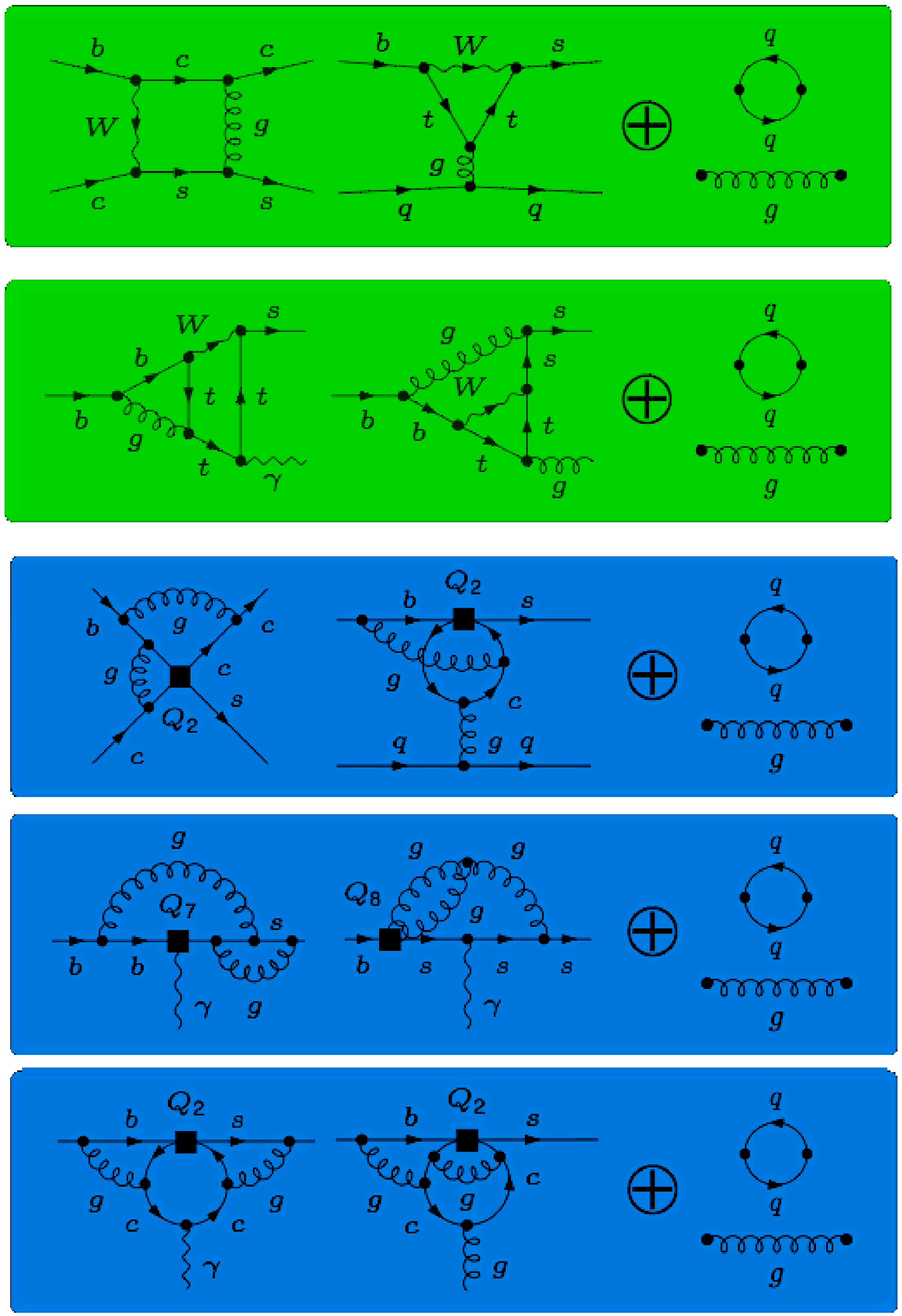


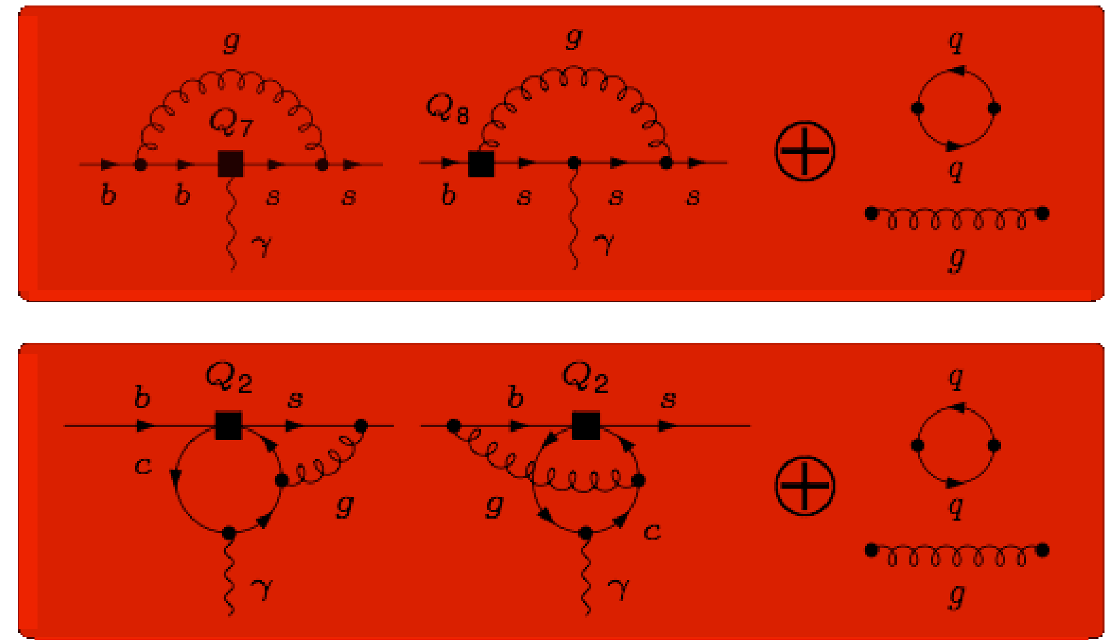


- matching
- running
- matrix elements

- very involved task as $> 10^2$ 3-loop on-shell & $> 10^4$ 4-loop tadpole diagrams need to be computed

Flavor of NNLO $\bar{B}\to X_s\gamma$ SM calculation





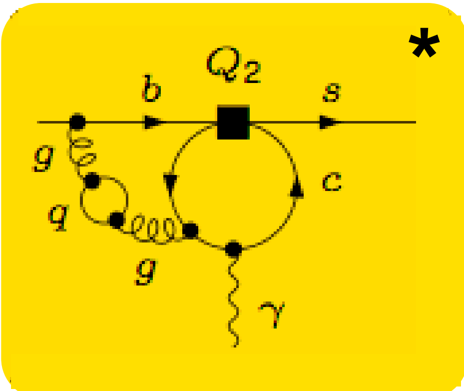
- matching*
- running†
- matrix elements‡

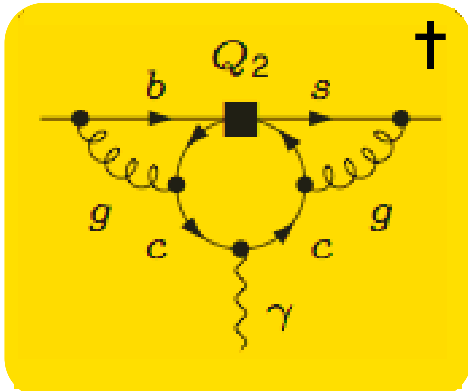
*Bobeth et al. '00; Misiak & Steinhauser '04

†Gorbahn & UH '04; Gorbahn et al. '05; Czakon et al. '06

‡Bieri et al. '03; Blokland et al. '05; Melnikov & Mitov '05; Asatrian et al. '05, '06; Misiak & Steinhauser '06

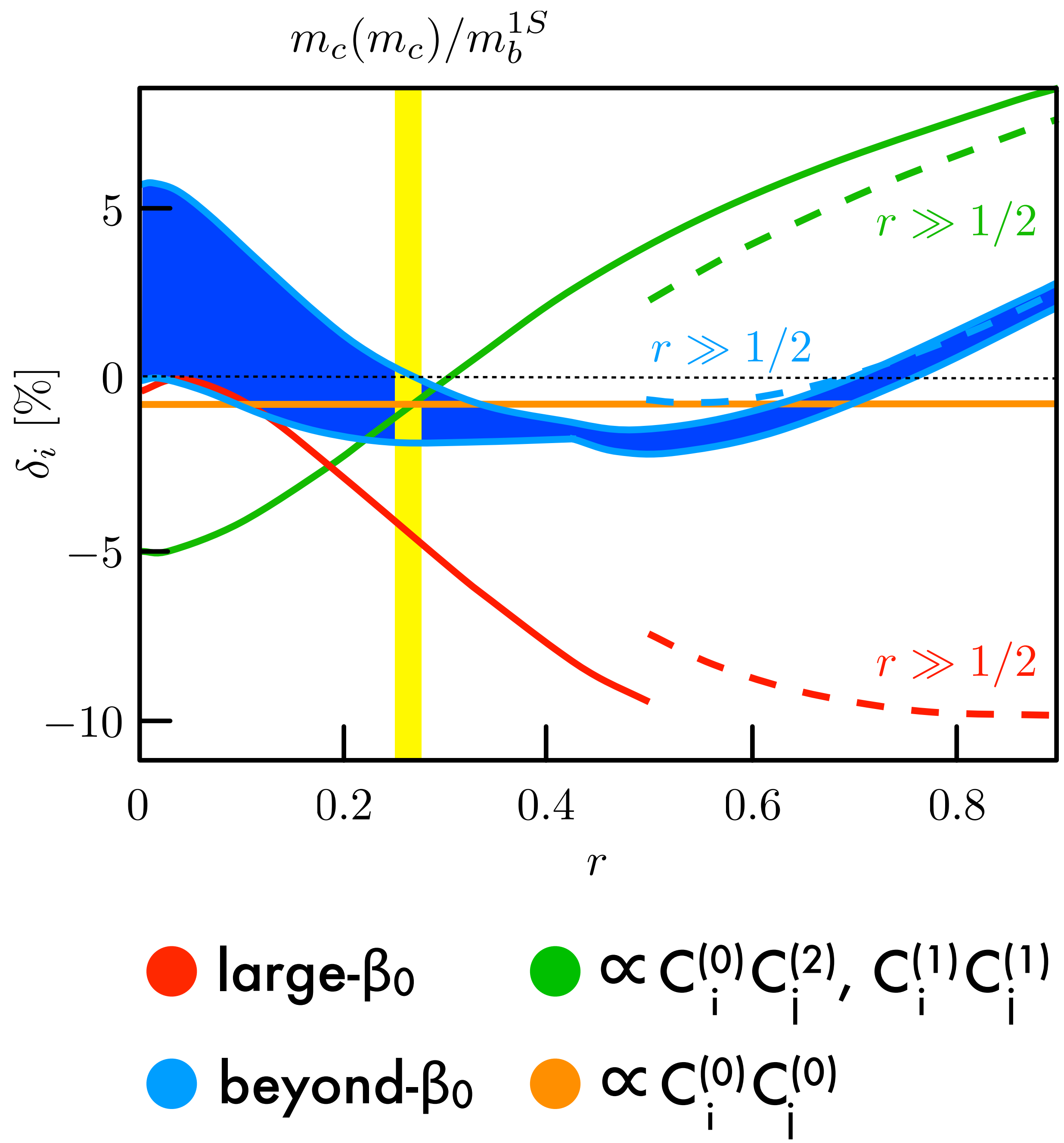
Interpolation in charm mass for $\bar{B} \to X_s \gamma$





- (Q_2, Q_7) interference at NNLO known for arbitrary $r = m_c/m_b$ in large β_0 limit, while beyond-β_0 part only calculated for $r >> 1/2$

- assume that β_0 piece describes full result accurately for $m_c = 0$ & perform interpolation in r



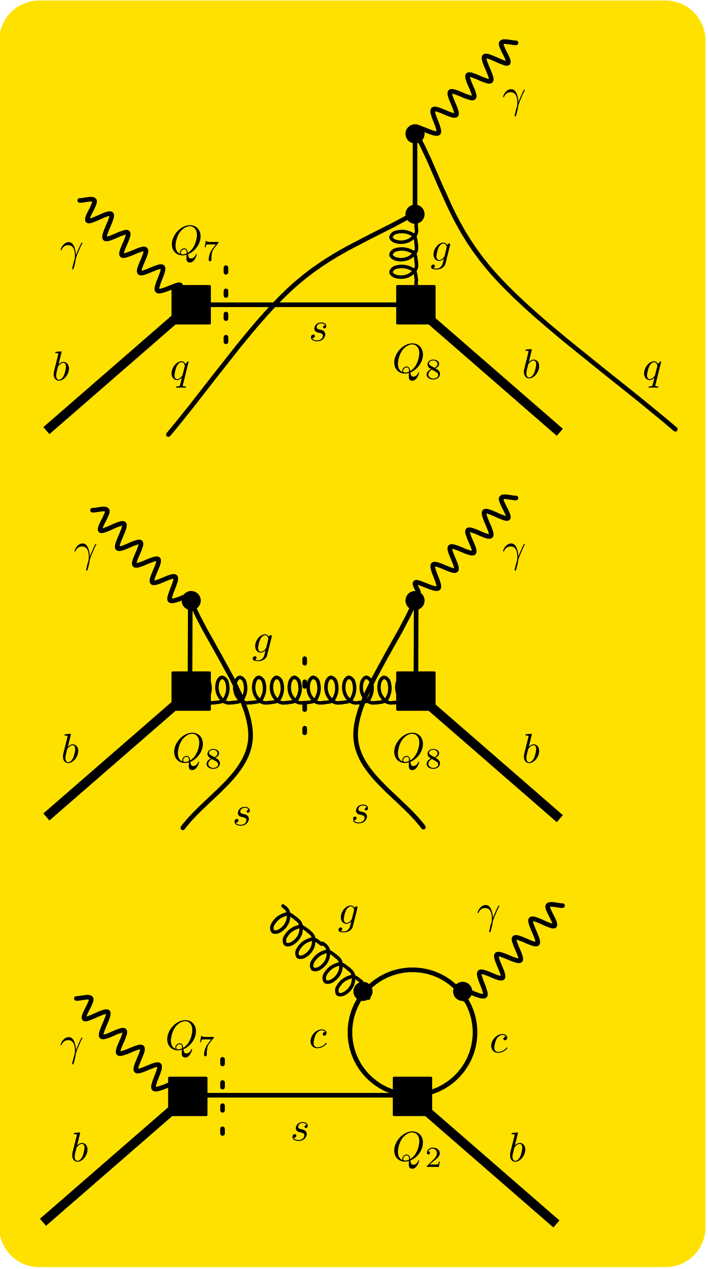
*Bieri et al. '03 †Misiak & Steinhauser '06

Non-local power corrections in $\bar{B} \to X_s \gamma$

- matrix elements of non-local operators promote corrections that scale like $\alpha_s \Lambda^3/m_b^3$ & $\alpha_s \Lambda^2/m_c^2$ in heavy quark to $\alpha_s \Lambda/m_b$
- part involving Q_7 & Q_8 calculated in vacuum insertion approximation:

$$\frac{\Delta\Gamma_{\rm VIA}^{78}}{\Gamma_{77}} = -\frac{2\pi\alpha_s}{9} \sum_{q=u,d} Q_q \frac{C_8}{C_7} \frac{f_B^2 m_B}{\lambda_B^2 m_b} \approx (-1.6 \pm 1.4)\%$$ *

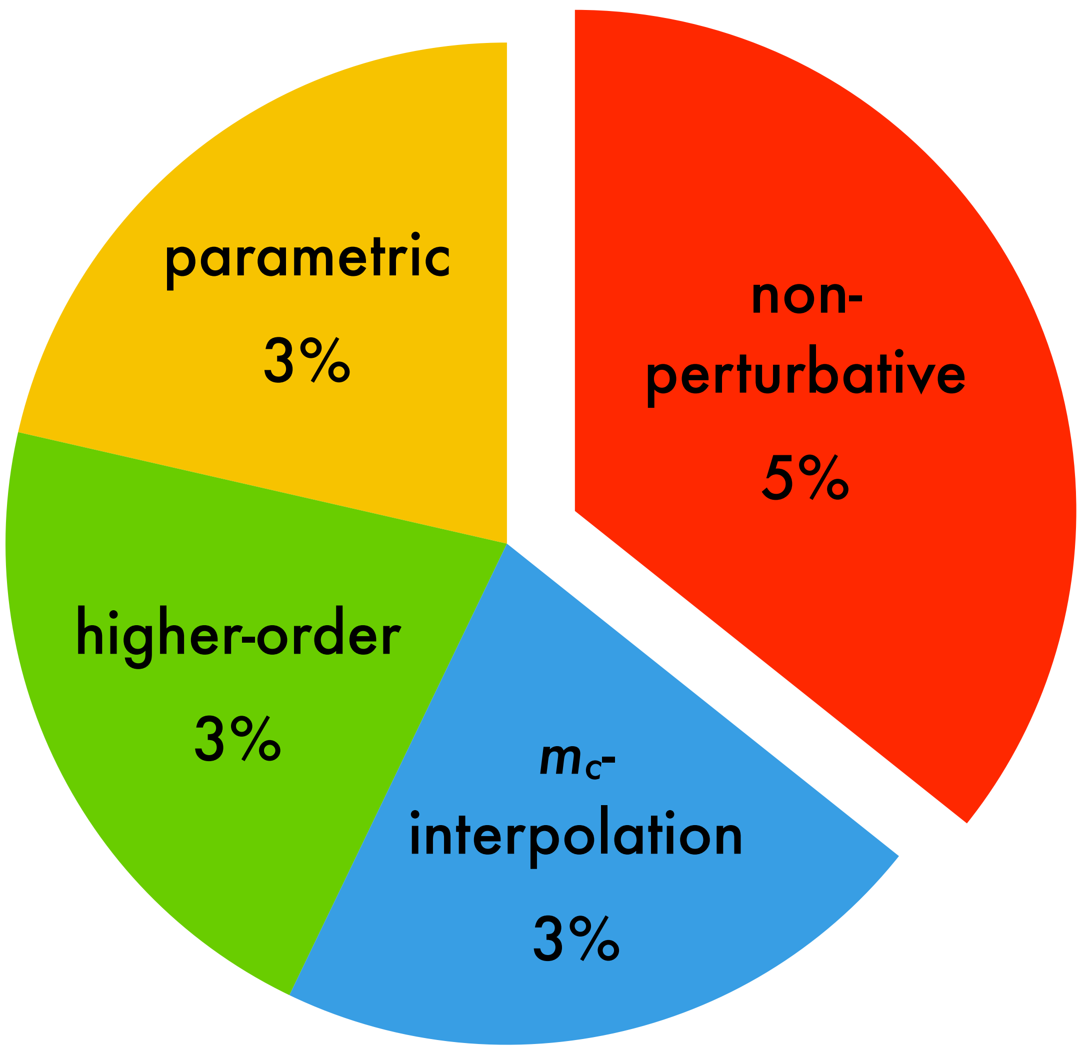
- size of power corrections difficult to estimate given present command of non-perturbative QCD on light cone

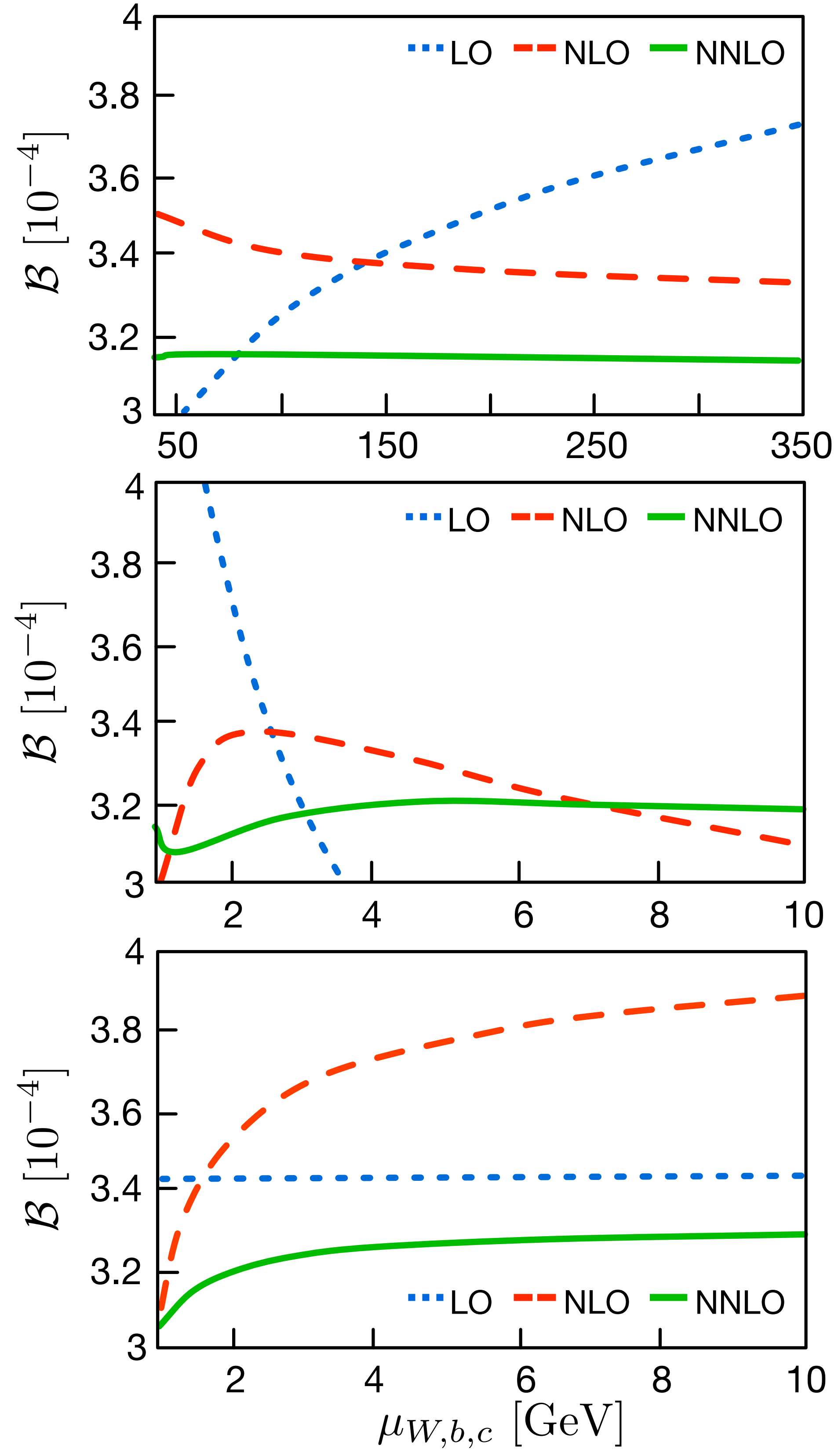


*Lee et al. '06

First NNLO estimate of $\bar{B} \to X_s \gamma$ in SM*

$$\mathcal{B}^{E_\gamma > 1.6\ \mathrm{GeV}}_{\mathrm{NNLO}} = (3.15 \pm 0.23) \times 10^{-4}$$

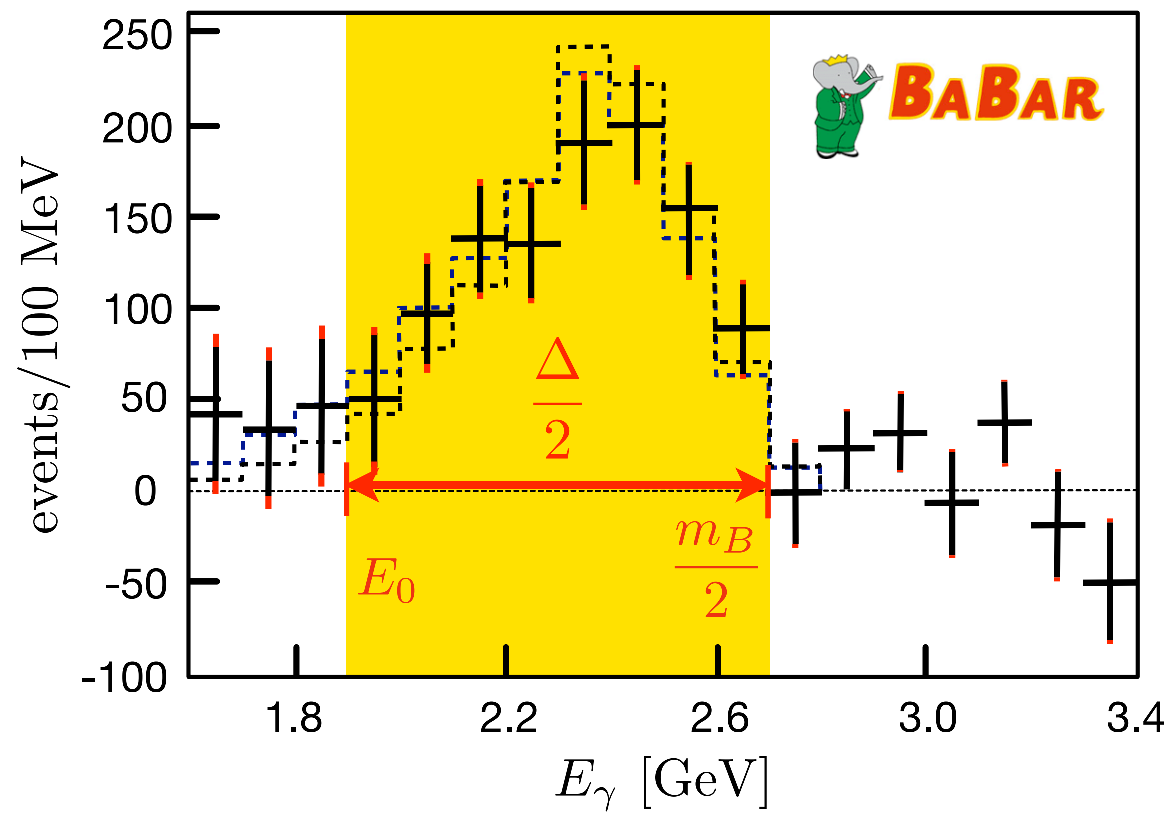




*Misiak et al. '06

Photon energy cut effects in $\bar{B} \to X_s \gamma$

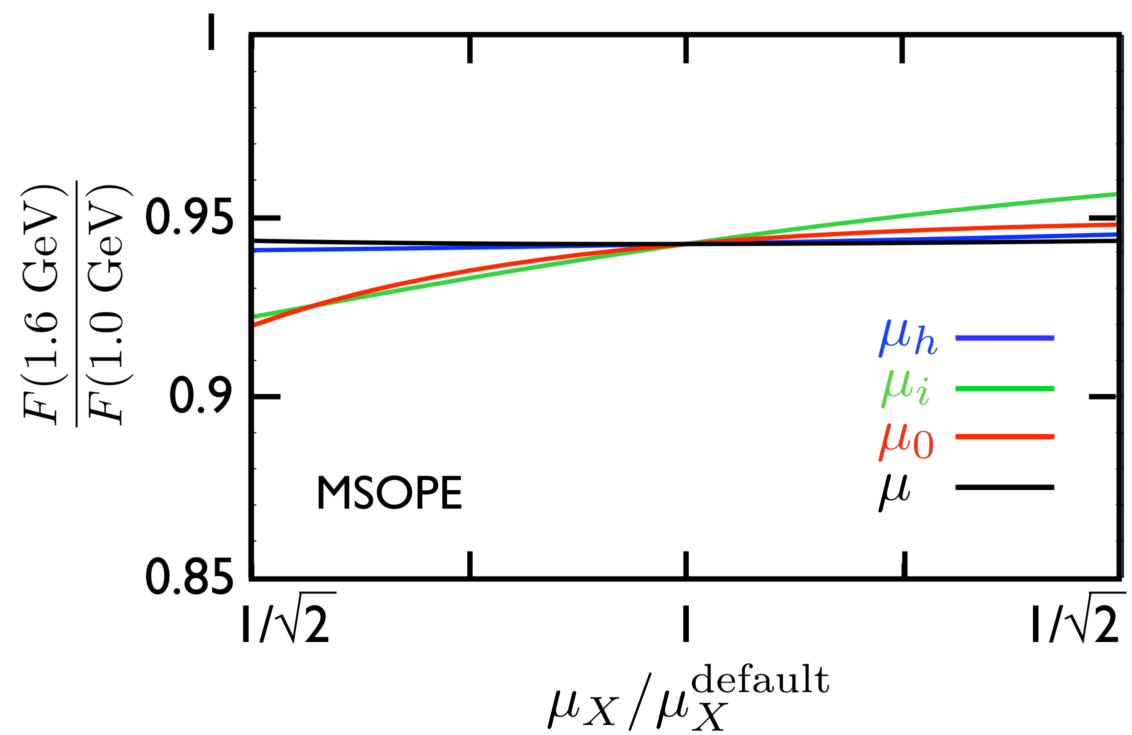
- total rate cannot be measured
- at present experimental cut of $E_0 > 1.8\,\text{GeV}$ on photon energy E_γ
- how big is rate in tail?



$$\frac{F(1.6\,\text{GeV})}{F(1.0\,\text{GeV})} \overset{*}{=}_{\text{DGE}} 0.98^{+0.02}_{-0.03}$$

$$\frac{F(1.6\,\text{GeV})}{F(1.0\,\text{GeV})} \overset{\dagger}{=}_{\text{OPE}} 0.96$$

$$\frac{F(1.6\,\text{GeV})}{F(1.0\,\text{GeV})} \overset{\ddagger}{=}_{\text{MSOPE}} 0.93^{+0.03}_{-0.05}{}_{\text{pert}}{}^{+0.02}_{-0.02}{}_{\text{hadr}}{}^{+0.02}_{-0.02}{}_{\text{para}}$$



*Gardi & Andersen '06 †Misiak et al. '06 ‡Becher & Neubert '06

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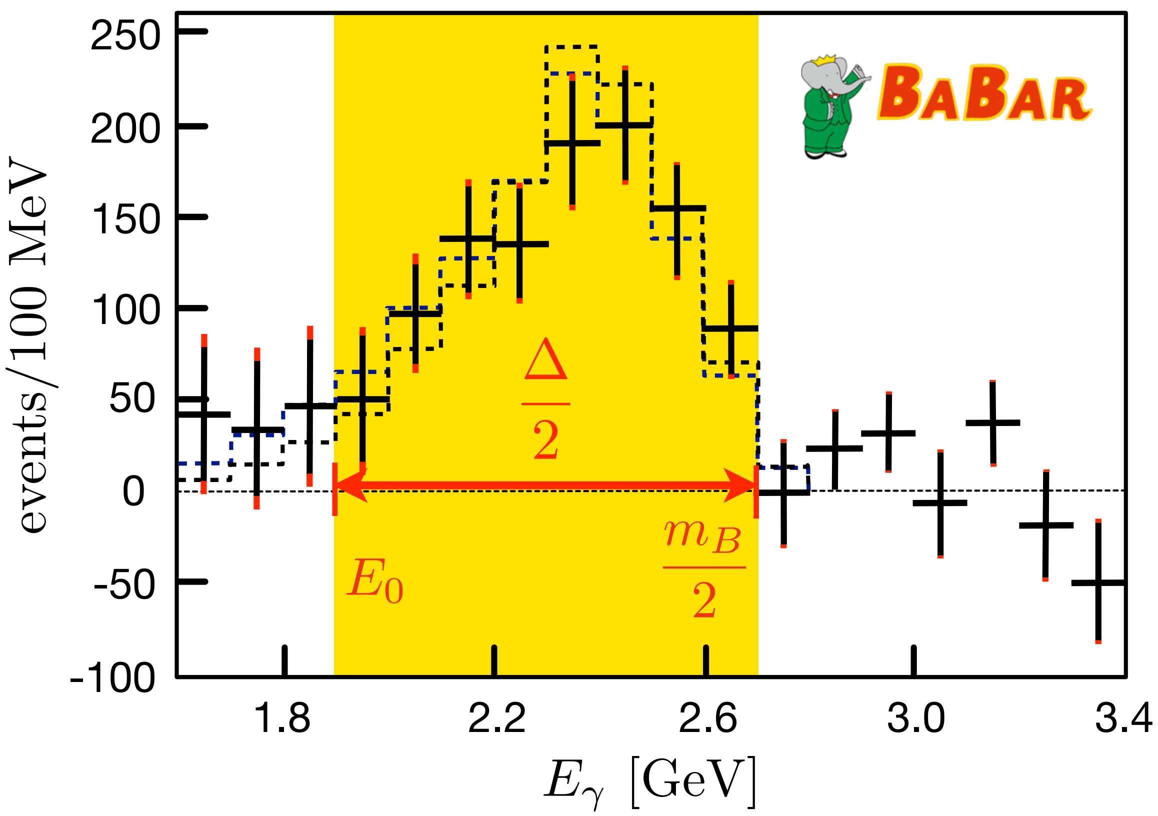

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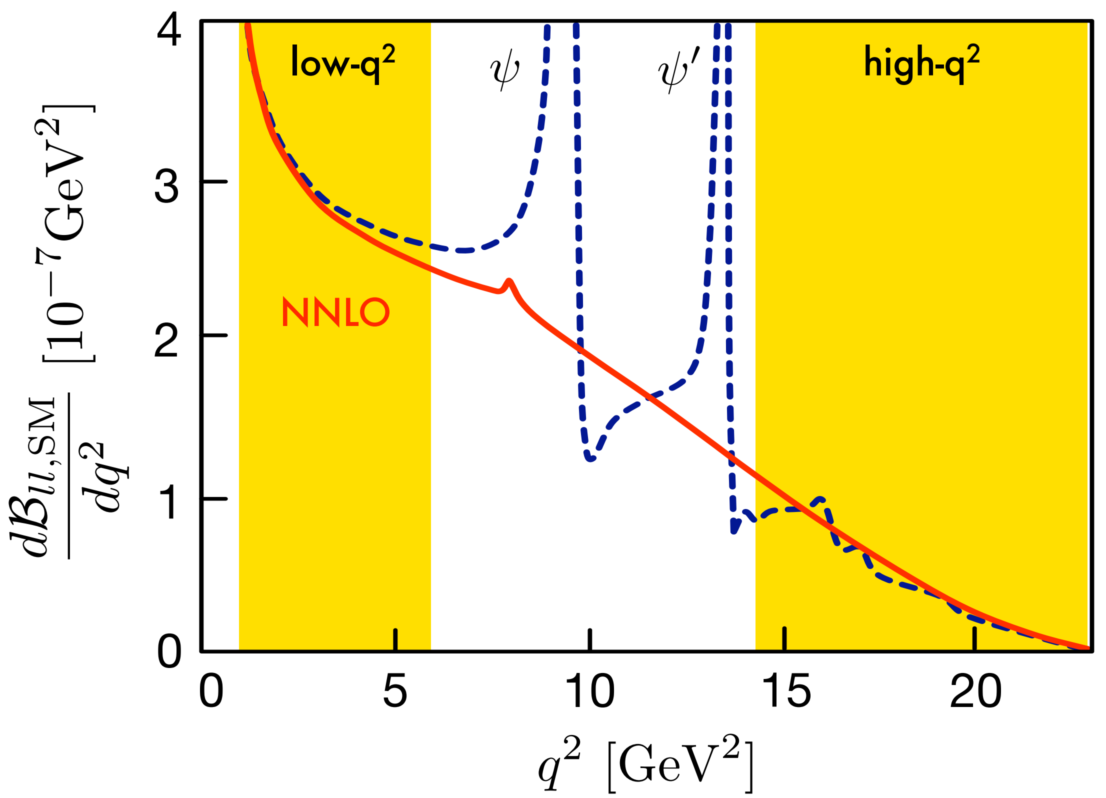
- to understand better if & how to precisely calculate tail of spectrum crucial

*Gardi & Andersen '06 †Misiak et al. '06 ‡Becher & Neubert '06

$\bar{B} \to X_s l^+ l^-$ in SM: solved problems*

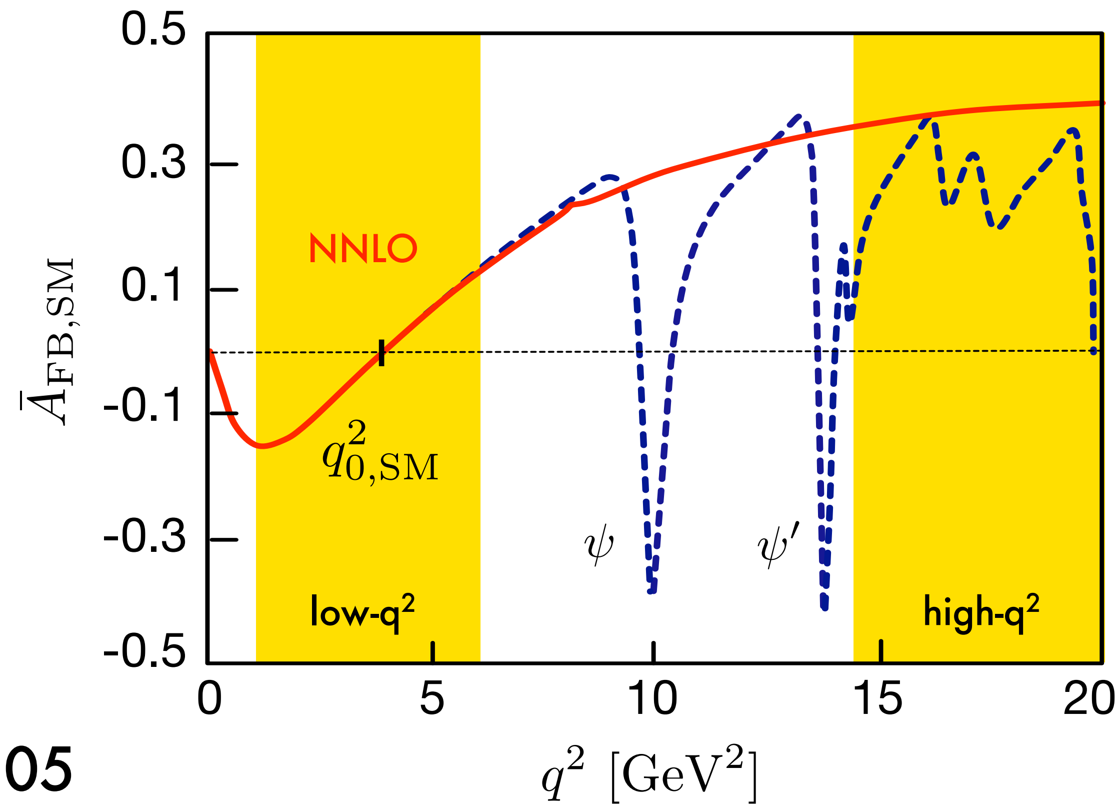
- differential rate in low-q² region allows high precision test of SM & constraints new physics:

$$\mathcal{B}_{ll,\mathrm{SM}}^{\text{low-}q^2} = (1.60 \pm 0.16) \times 10^{-6}$$



- zero of FB asymmetry very interesting to determine sign & magnitude of $C_7/C_9 \propto -q_0^2$:

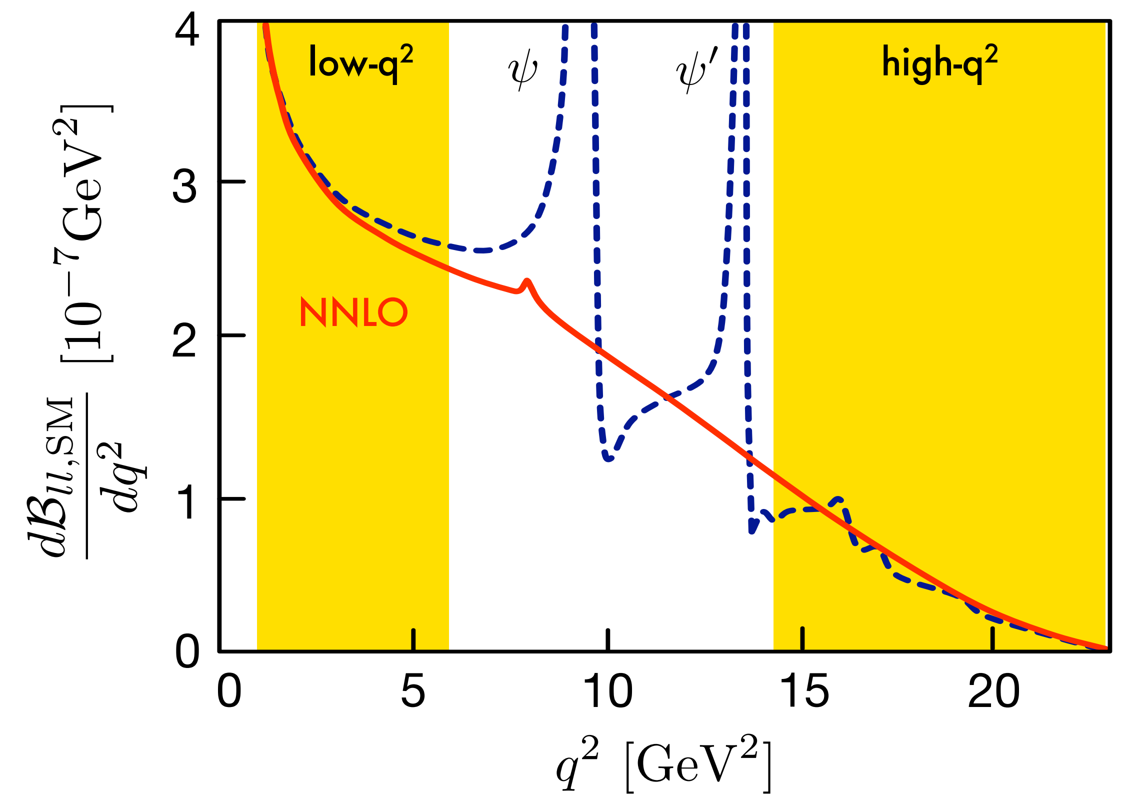
$$q_{0,\mathrm{SM}}^2 = (3.76 \pm 0.33)\ \mathrm{GeV}^2$$

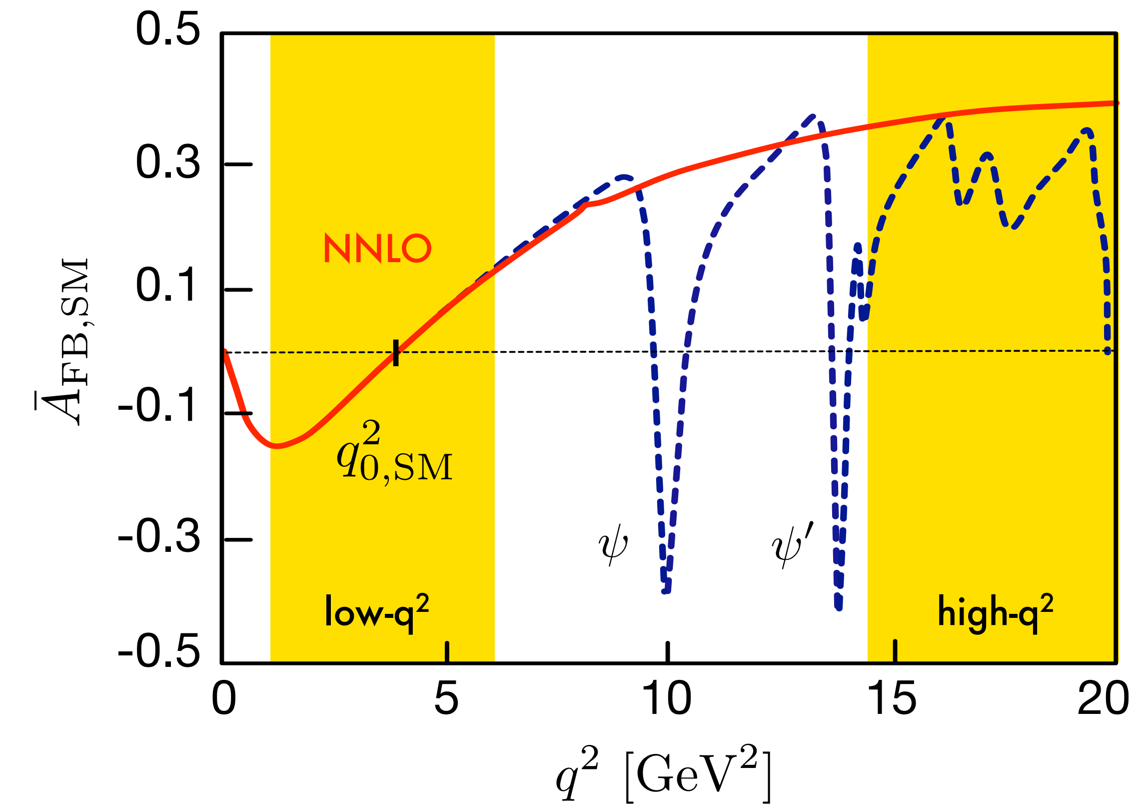


*Ghinculov et al. '03; Bobeth et al. '03; Huber et al. '05

$\bar{B}\to X_s l^+ l^-$ in SM: open issues

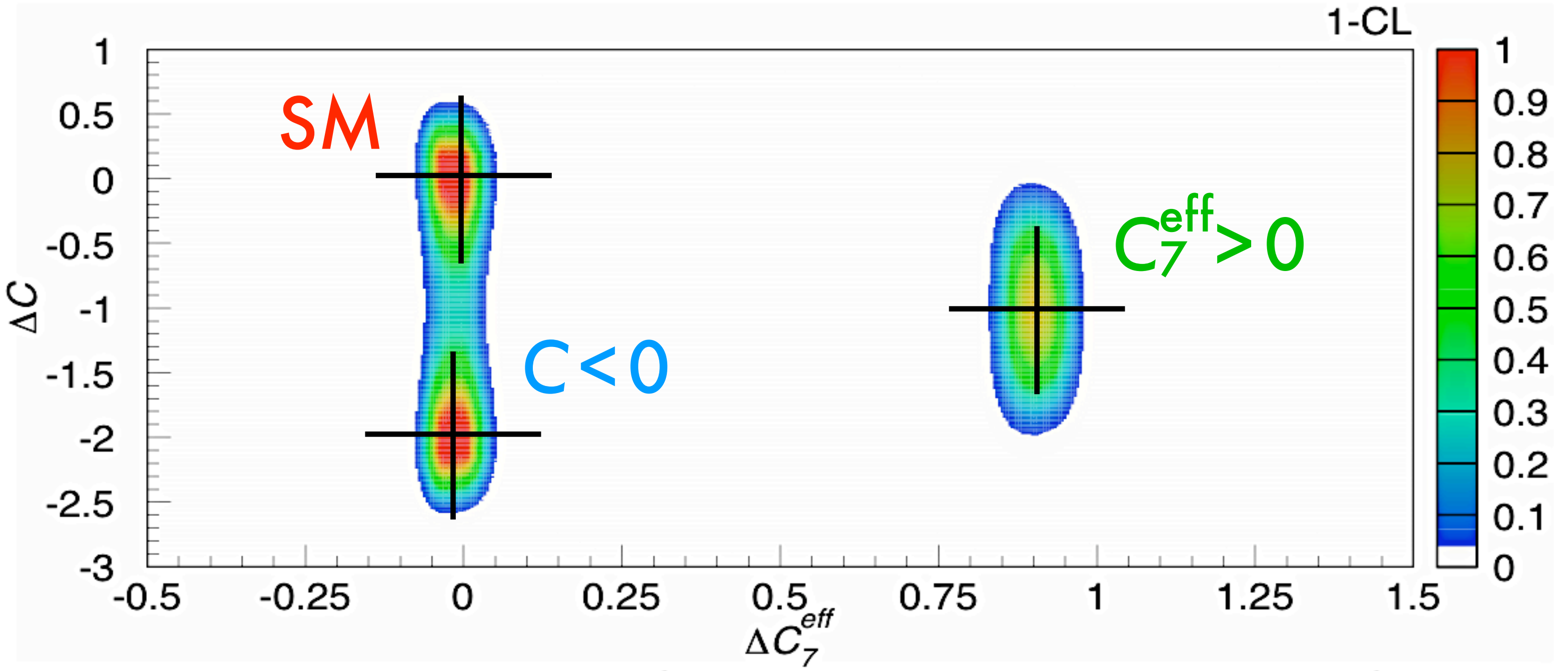
- model-independent study of M_X-cut dependence of low-q^2 spectrum only known at NLO*
- consistent to cut out ψ, ψ', ... & compare data with short-distance calculation?
- like in $\bar{B}\to X_s\gamma$ difficult to quantify size of effects of non-local power corrections $\alpha_s\Lambda/m_b$

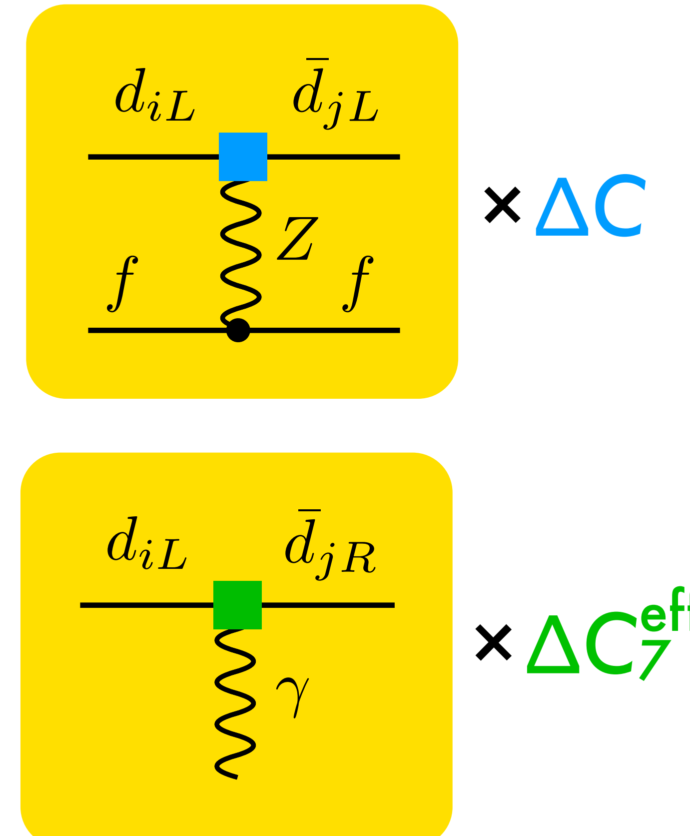


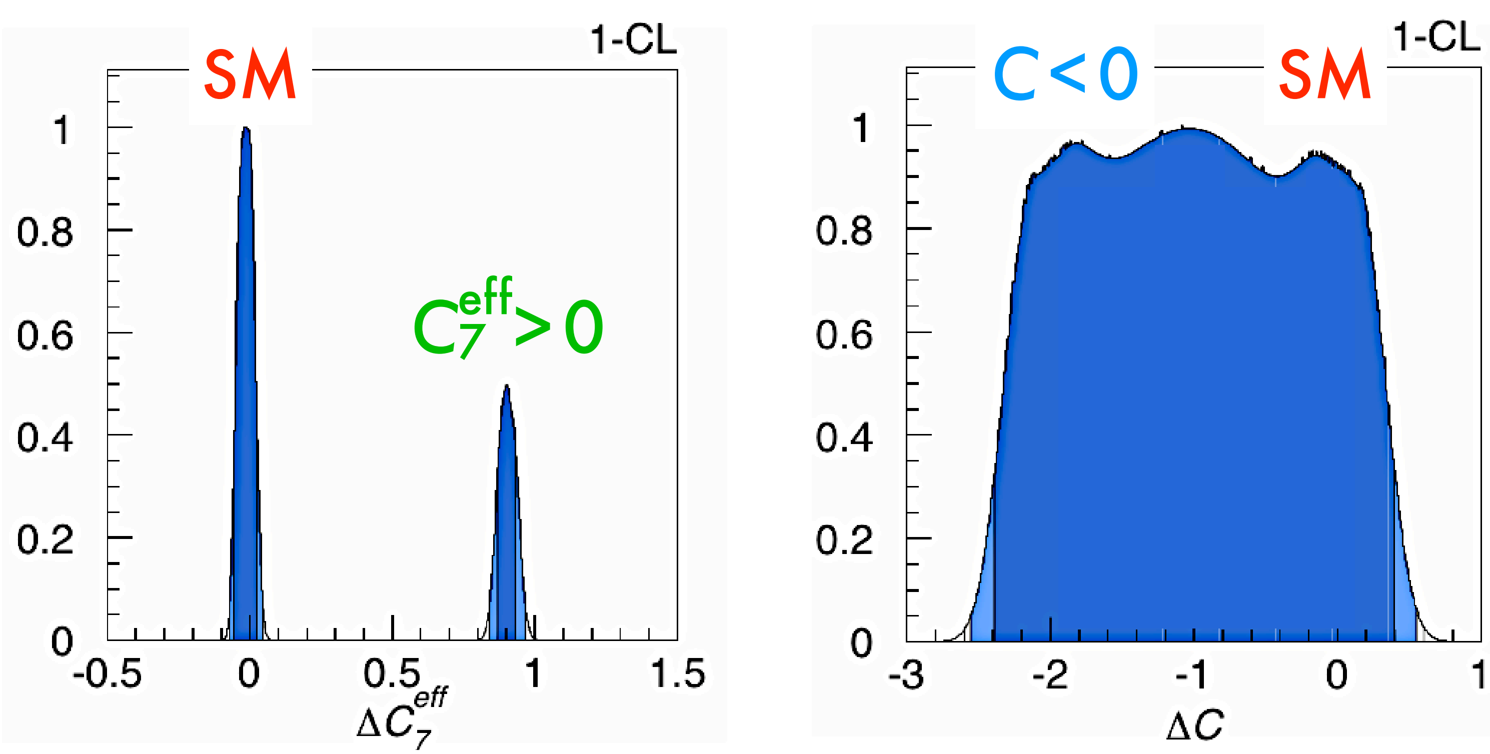


*Lee et al. '06

CMFV: combining $\bar{B} \to X_s \gamma$ & $\bar{B} \to X_s l^+ l^-$



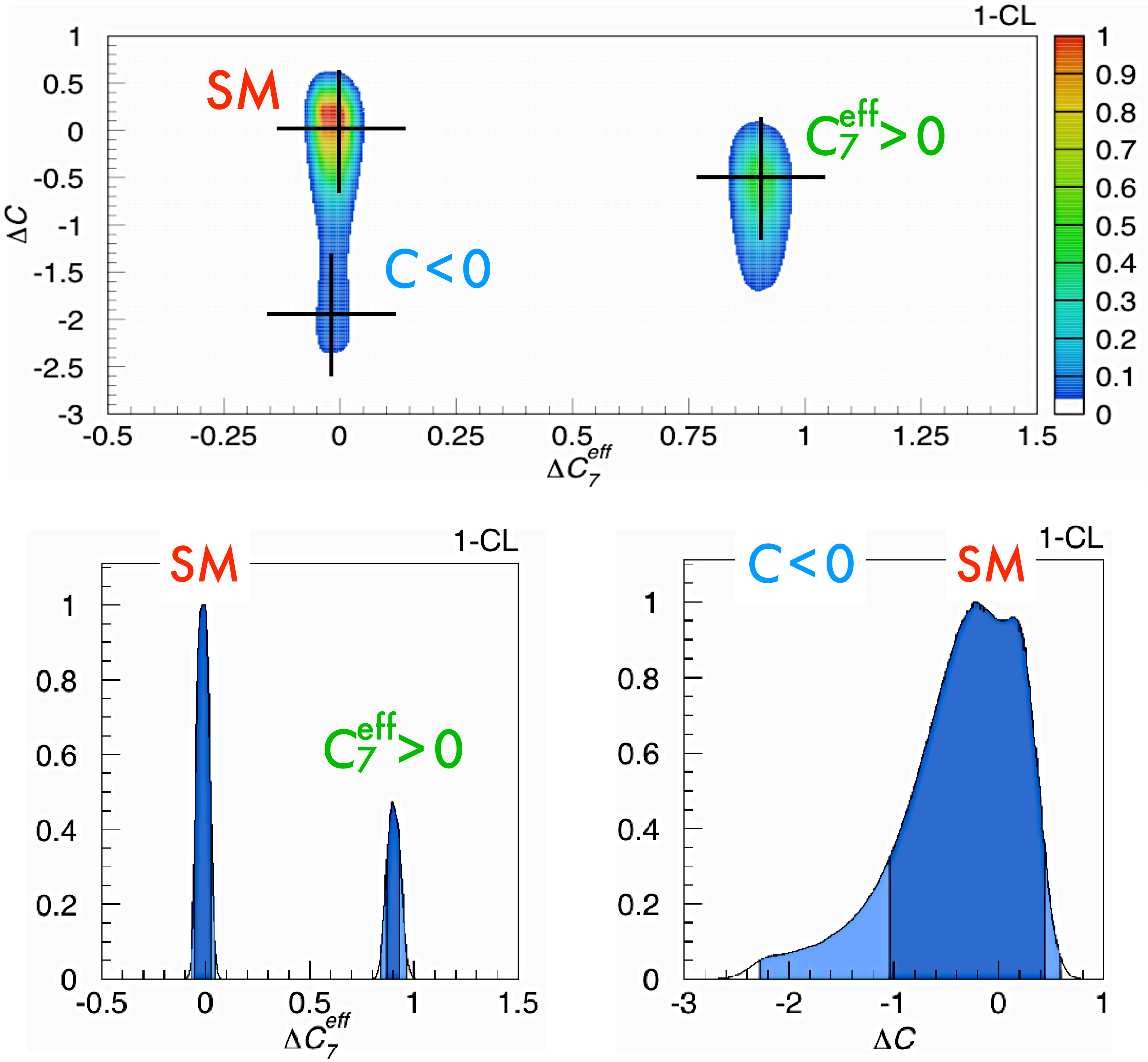


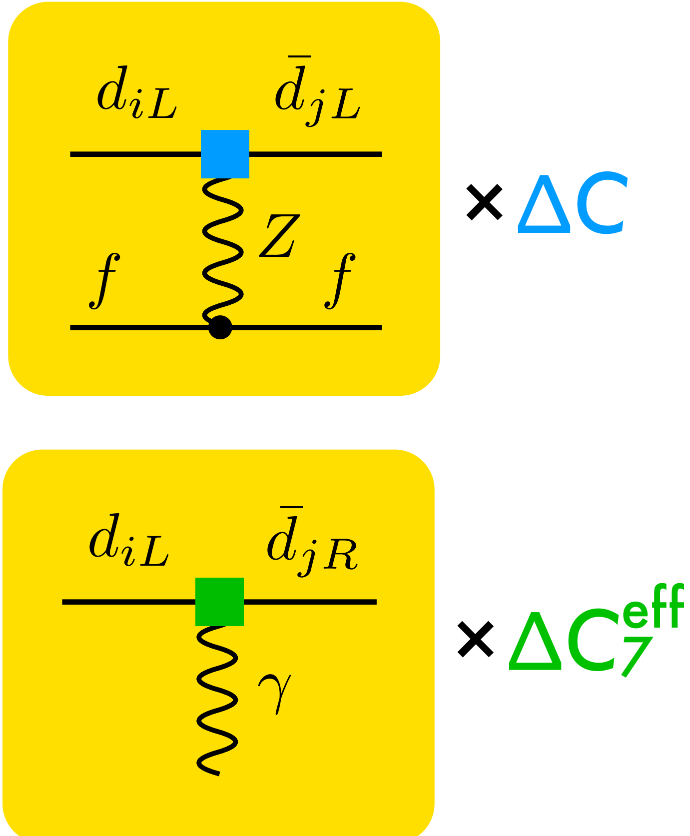


- opposite sign of C_7^{eff} disfavored by $\bar{B} \to X_s l^+ l^-$ measurements*

*Gambino et al. '04

CMFV: combining $\bar{B} \to X_s\gamma, l^+l^-$ & $K^+ \to \pi^+\nu\bar{\nu}$

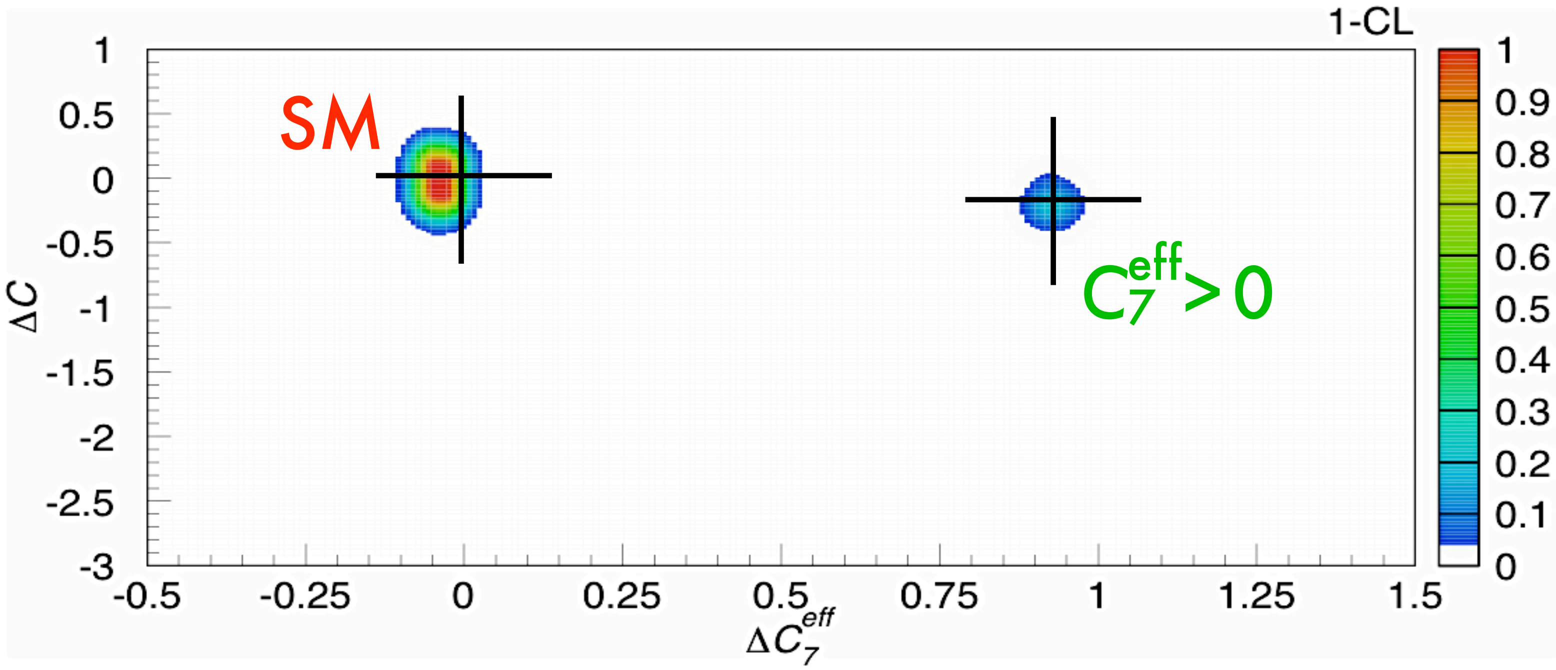


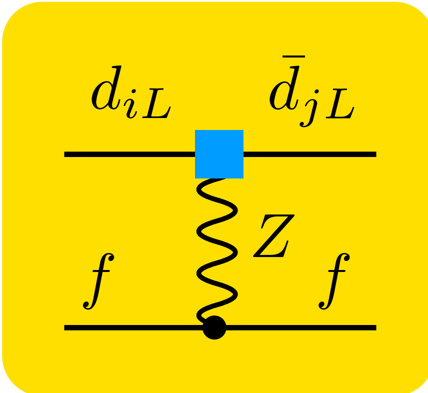


- large destructive *Z*-penguin allowed by flavor constraints*

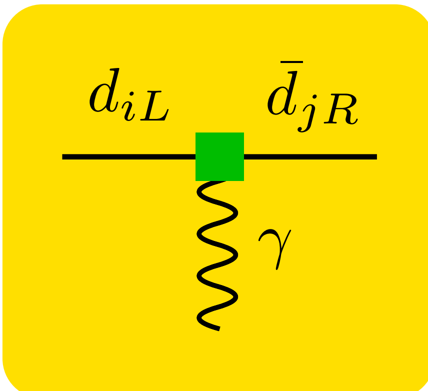
*Bobeth et al. '05

CMFV: combining $\bar{B}\to X_s\gamma, l^+l^-$ & $K^+\to\pi^+\nu\bar{\nu}$

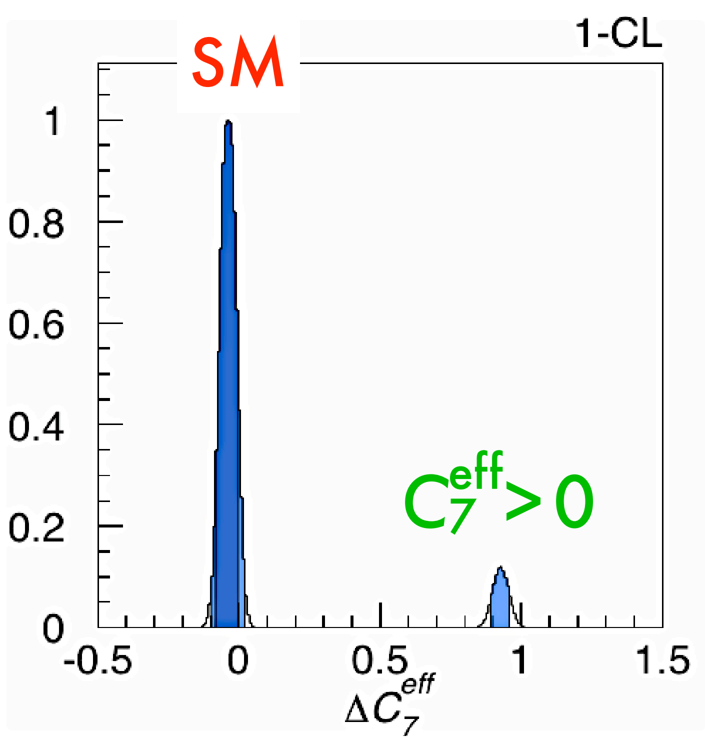


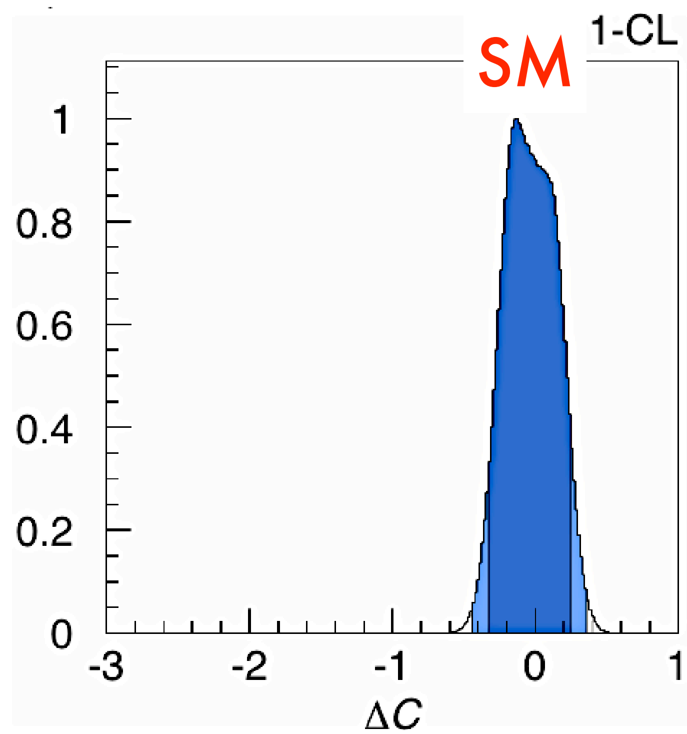


$\times\,\Delta C$



$\times\,\Delta C_7^{eff}$

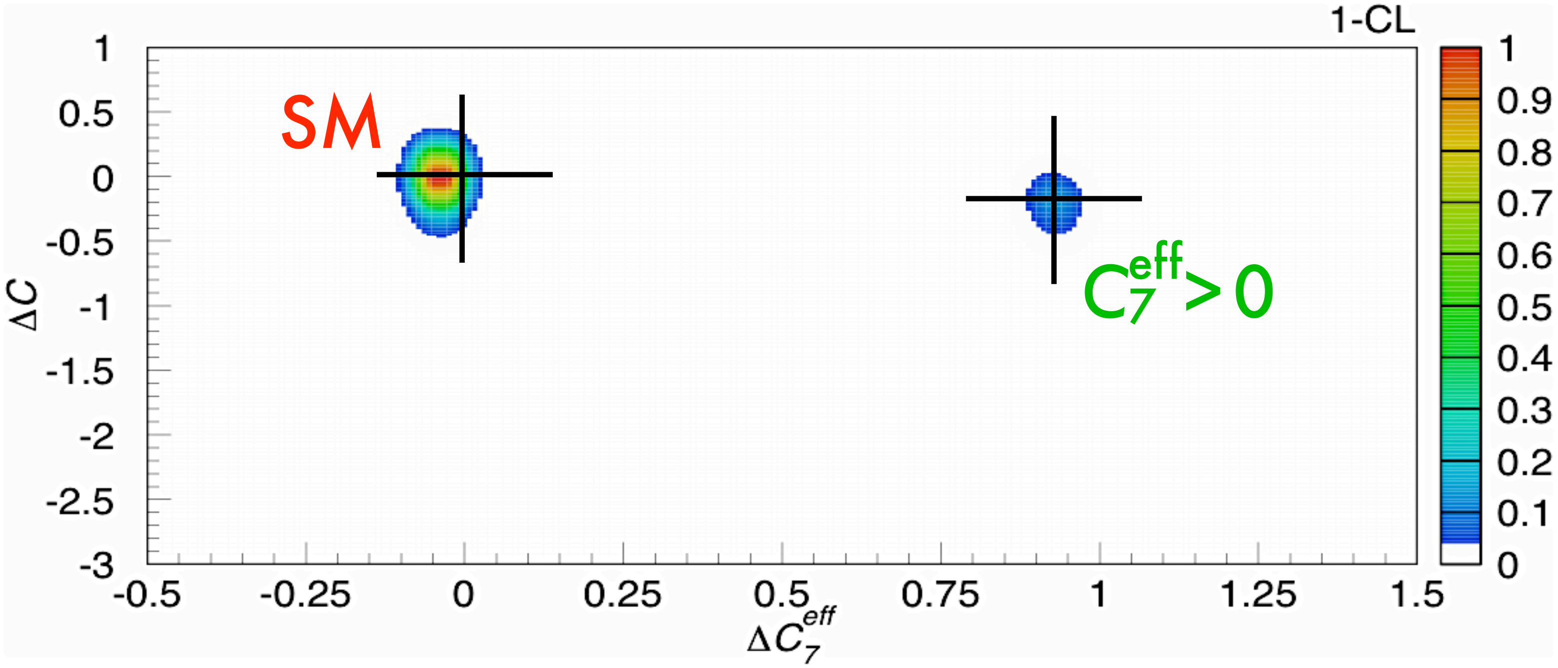


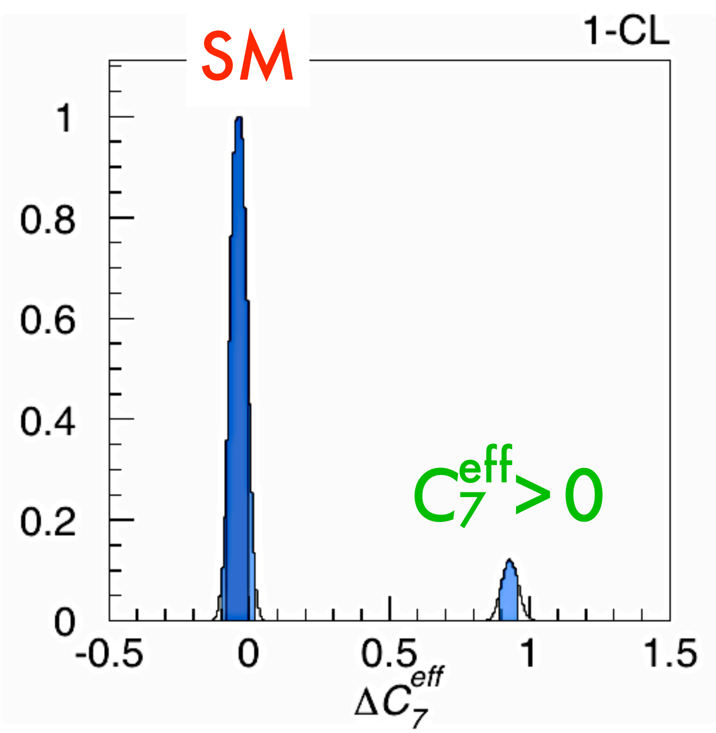


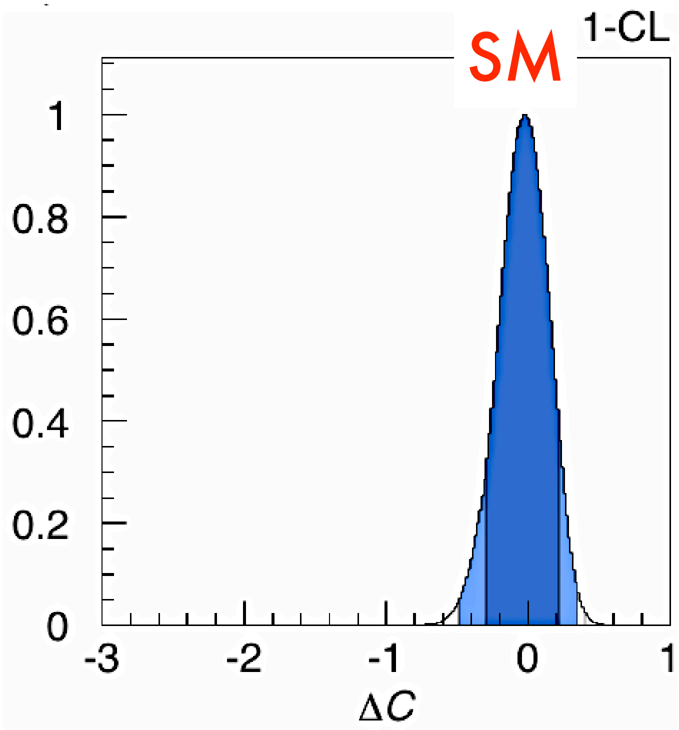
- 2015 (?): measurement of $K^+\to\pi^+\nu\bar{\nu}$ close to SM excludes $\Delta C \approx -2$*

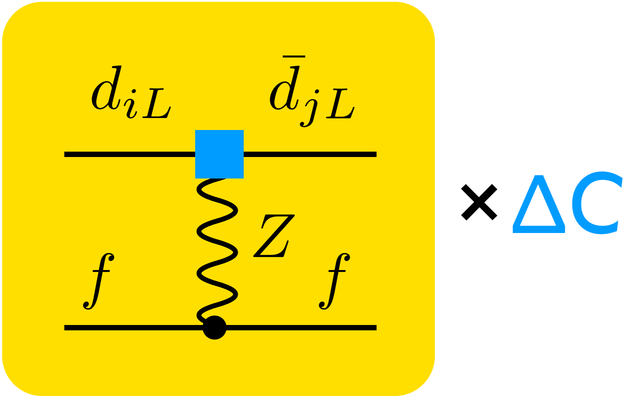
*Bobeth et al. '05

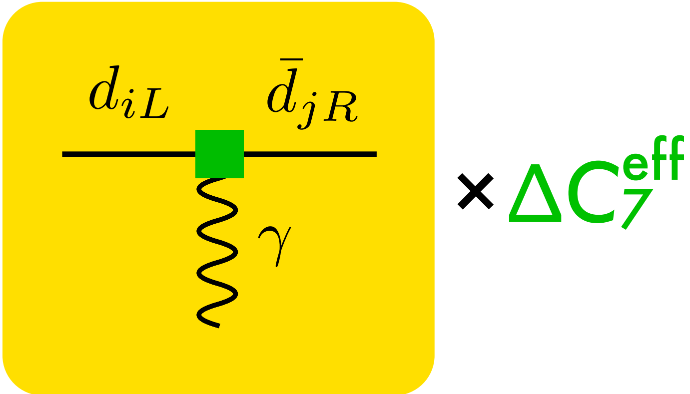
CMFV: combining $\bar{B}\to X_s\gamma, l^+l^-$ & $Z\to b\bar{b}$







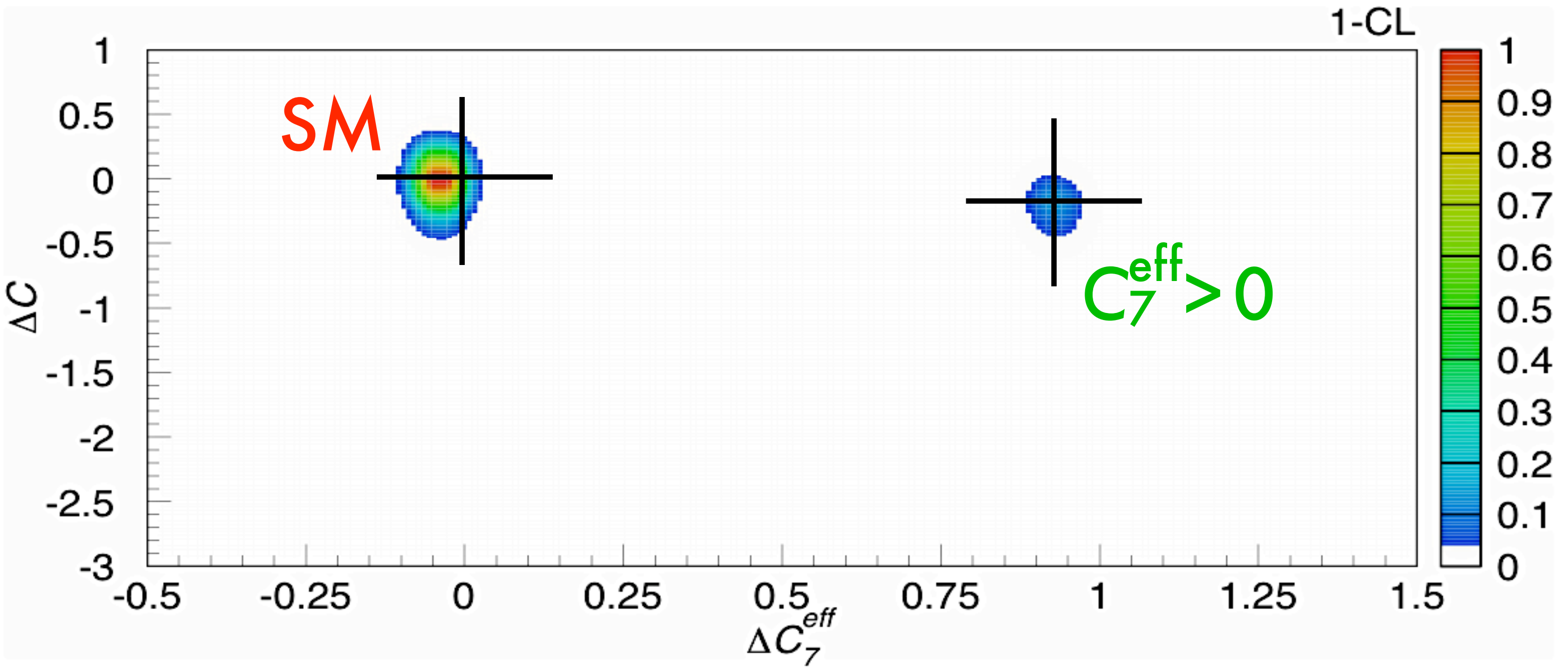


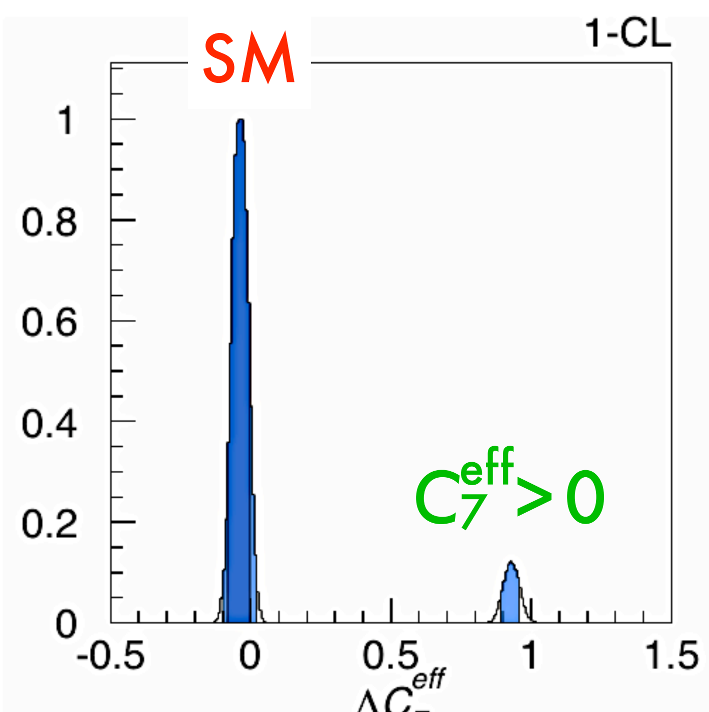


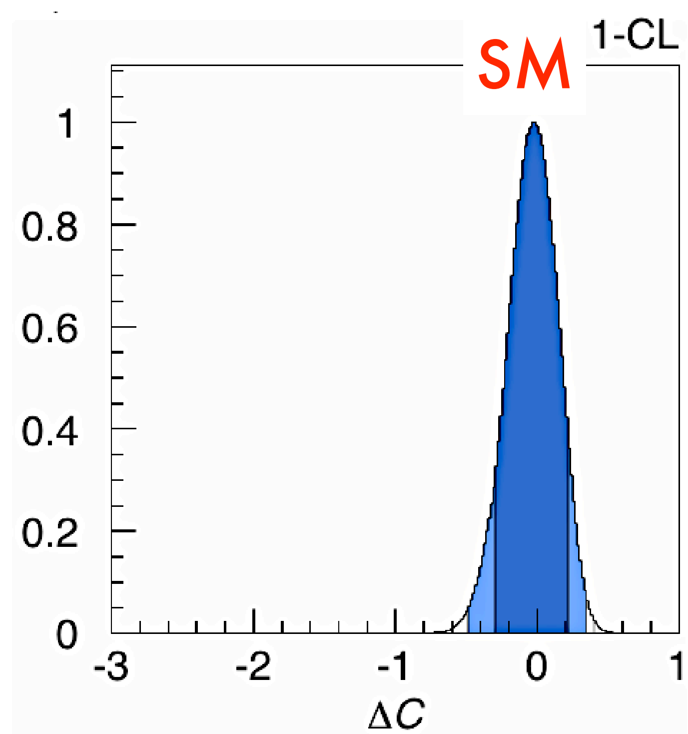
- existing $Z\to b\bar{b}$ data rule out large CMFV Z-penguin*

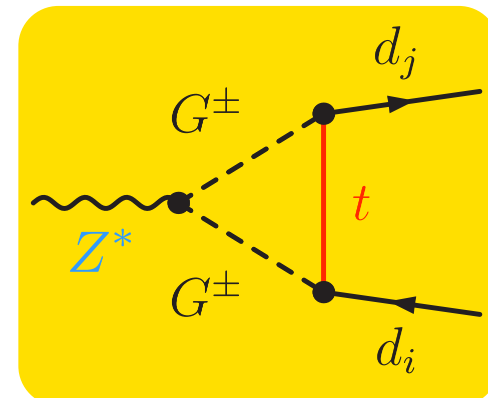
*UH & Weiler '07 (?)

CMFV: combining $\bar{B}\to X_s\gamma, l^+l^-$ & $Z\to b\bar{b}$

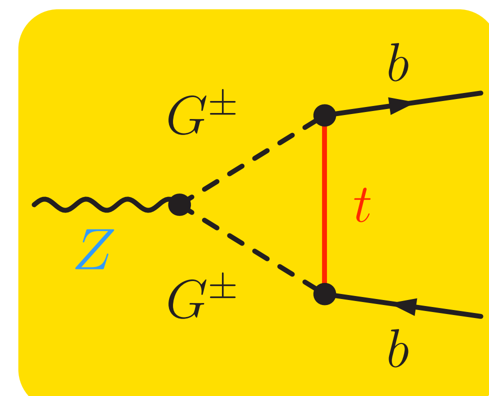








$$\propto V_{tj}^* V_{ti} \frac{m_t^2}{M_W^2}$$

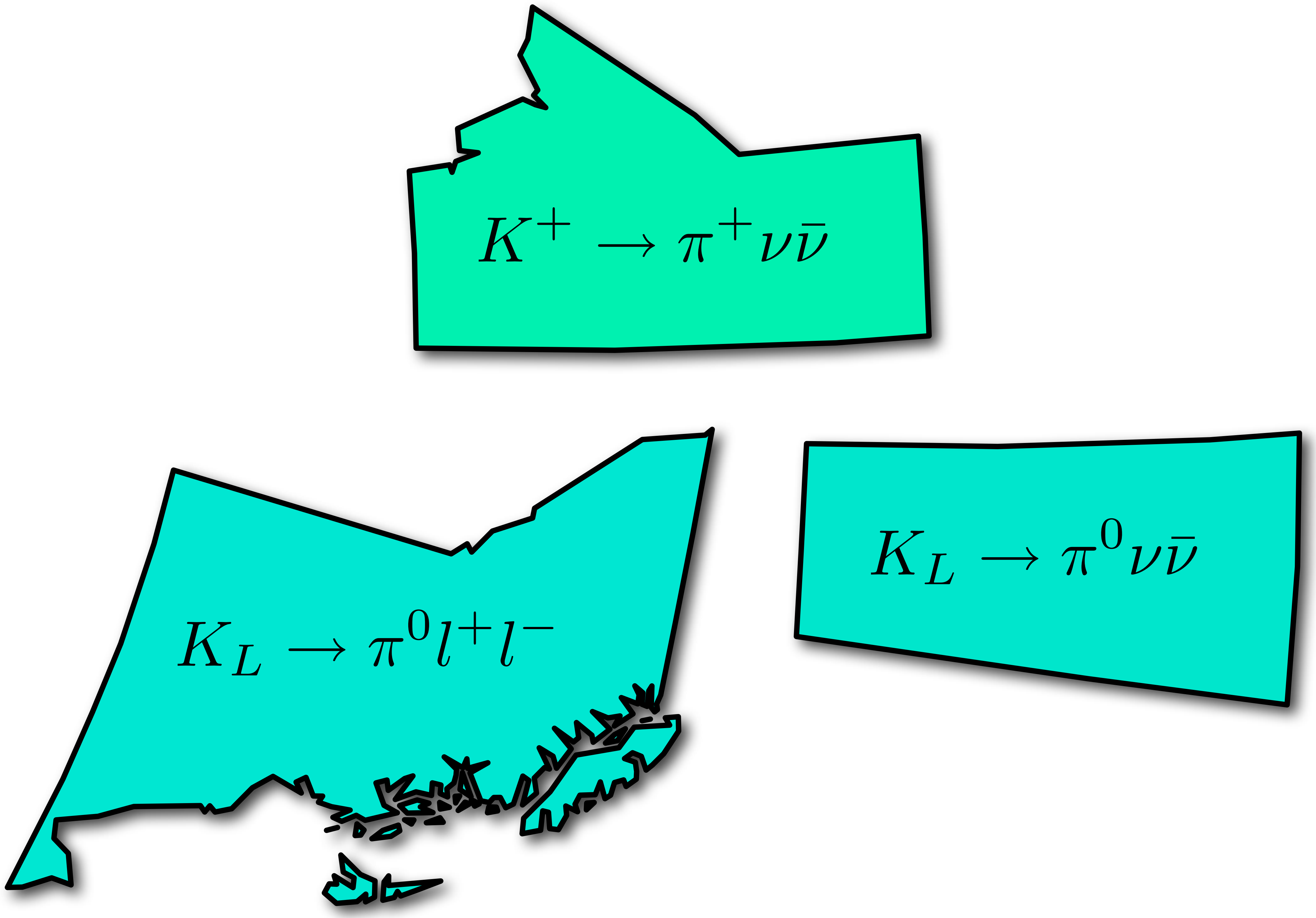


$$\propto |V_{tb}|^2 \frac{m_t^2}{M_W^2}$$

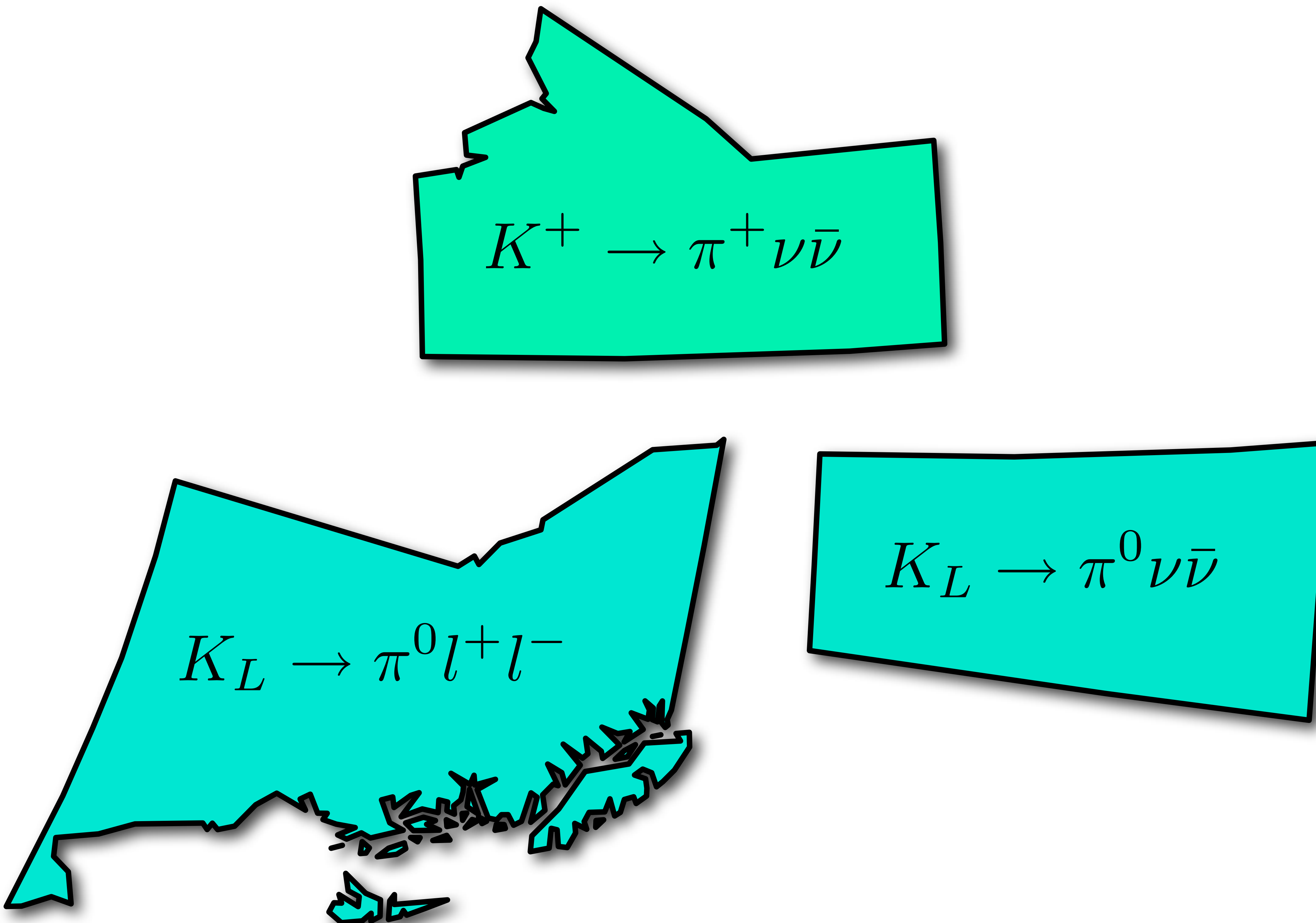
- based on observation that in CMFV $Z\to b\bar{b}$, $d_i\bar{d}_i$ are "identical"*

*UH & Weiler '07 (?)

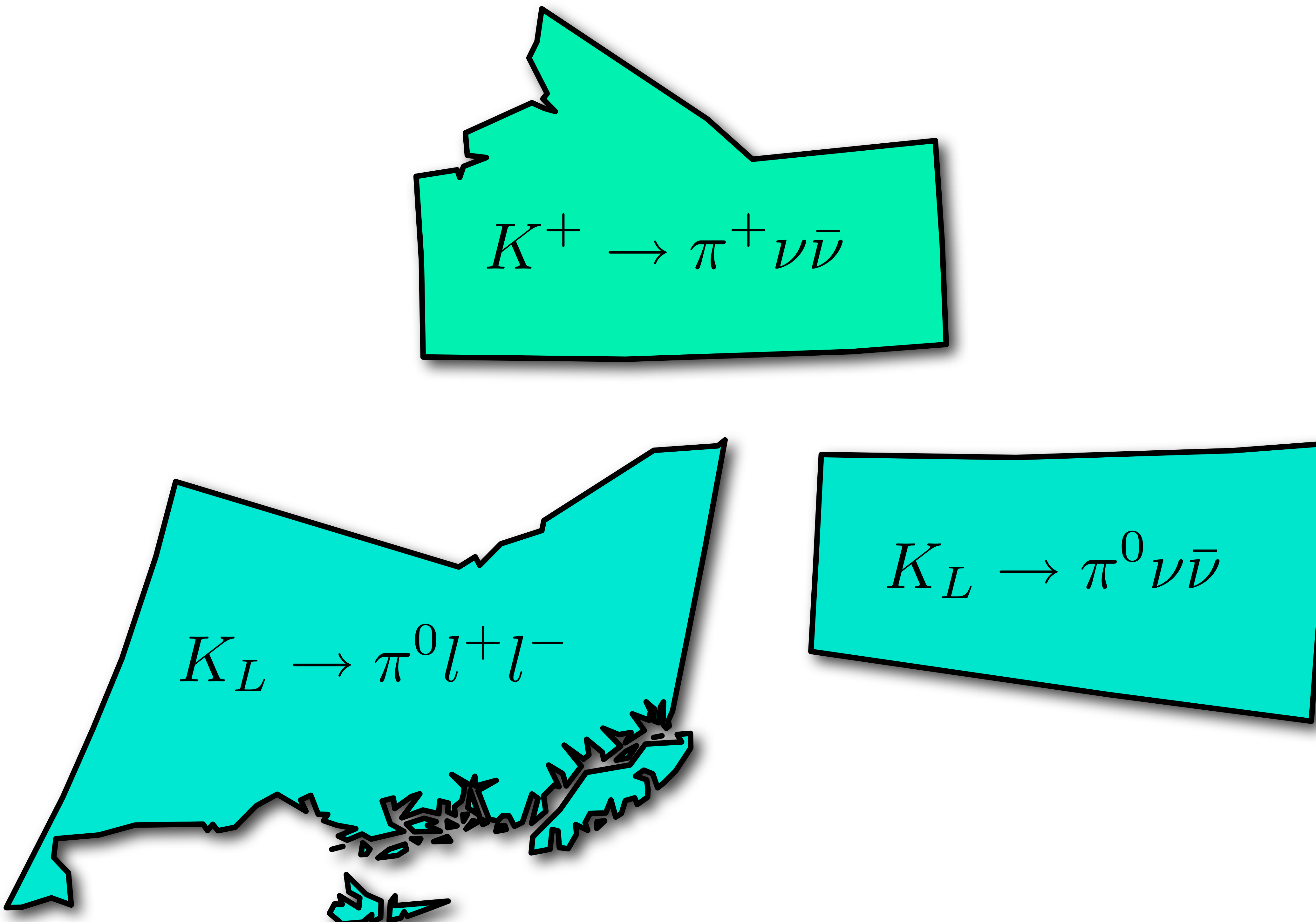
After this "upset" of rare K-decays ...



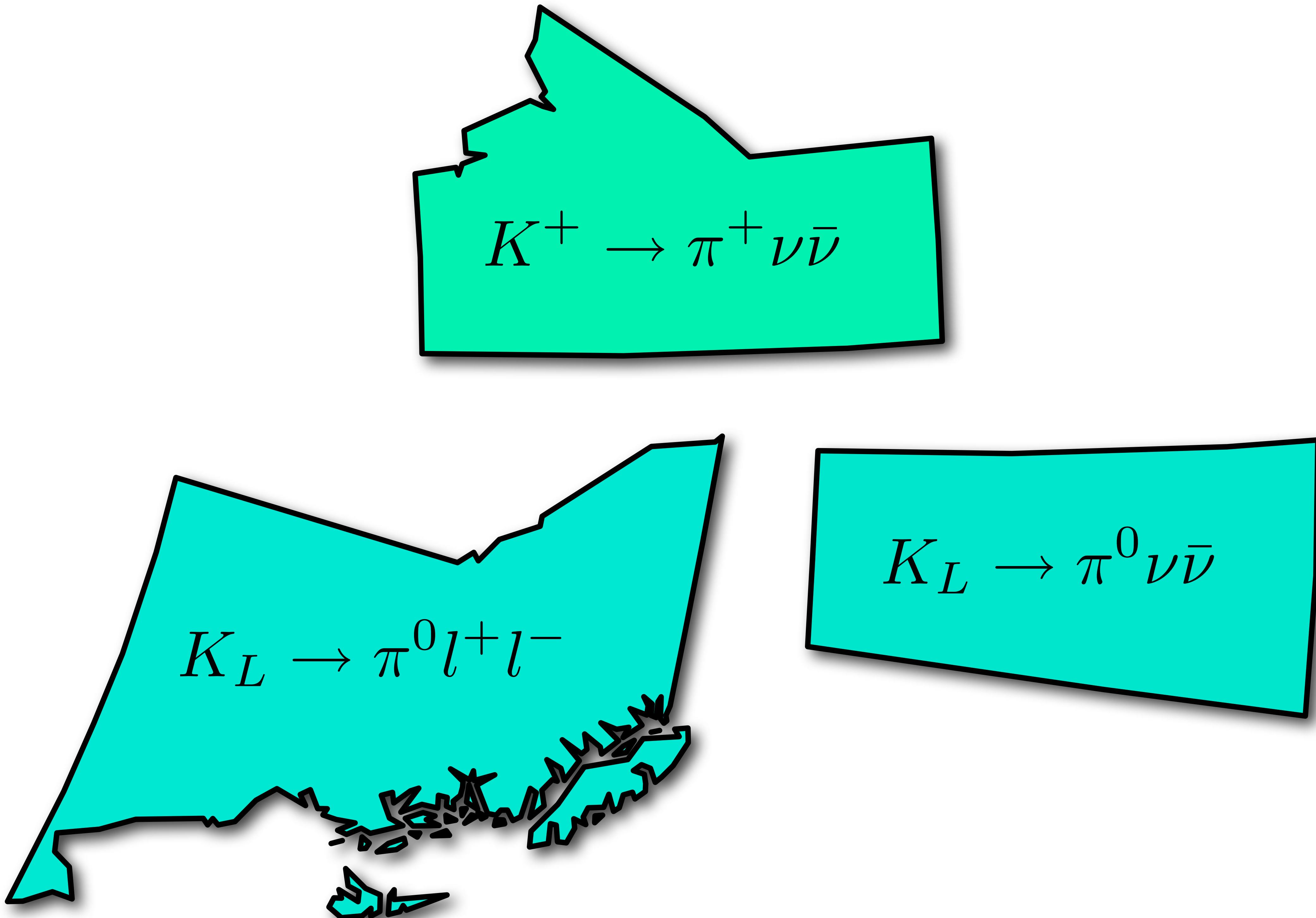
Cecilia & Chris will tell you now why …



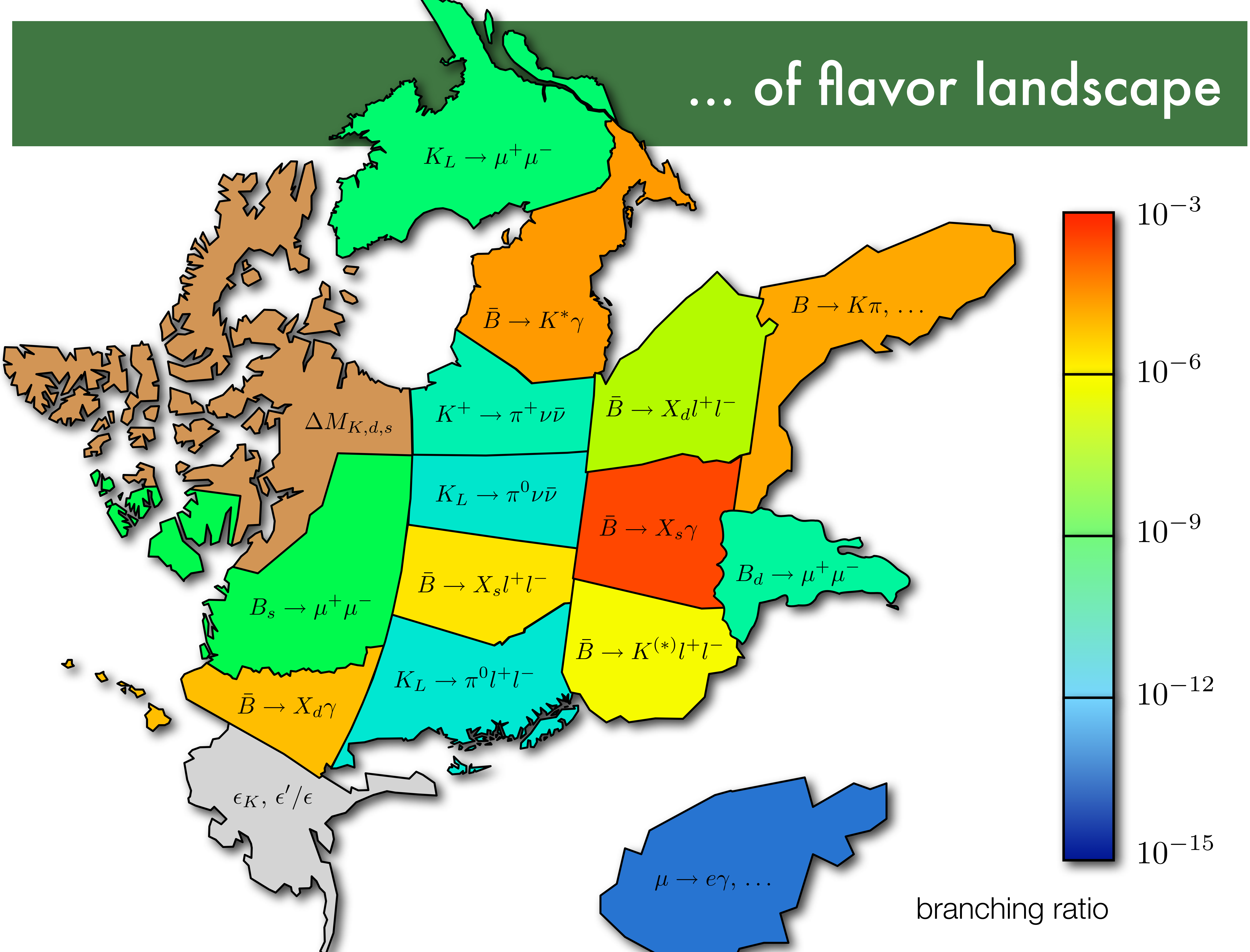
concerning physics beyond MFV ...



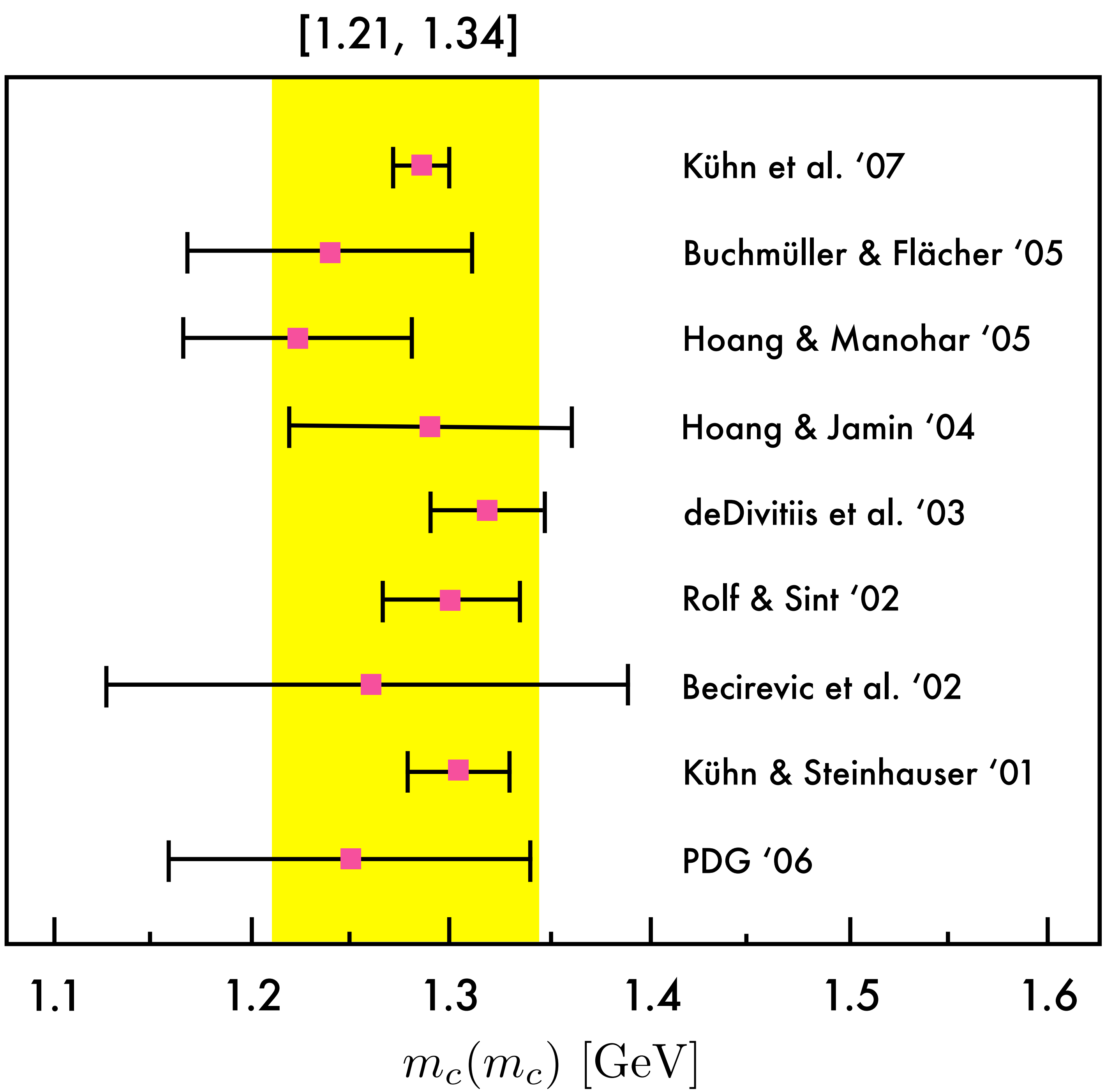
these modes are superpowers …



... of flavor landscape

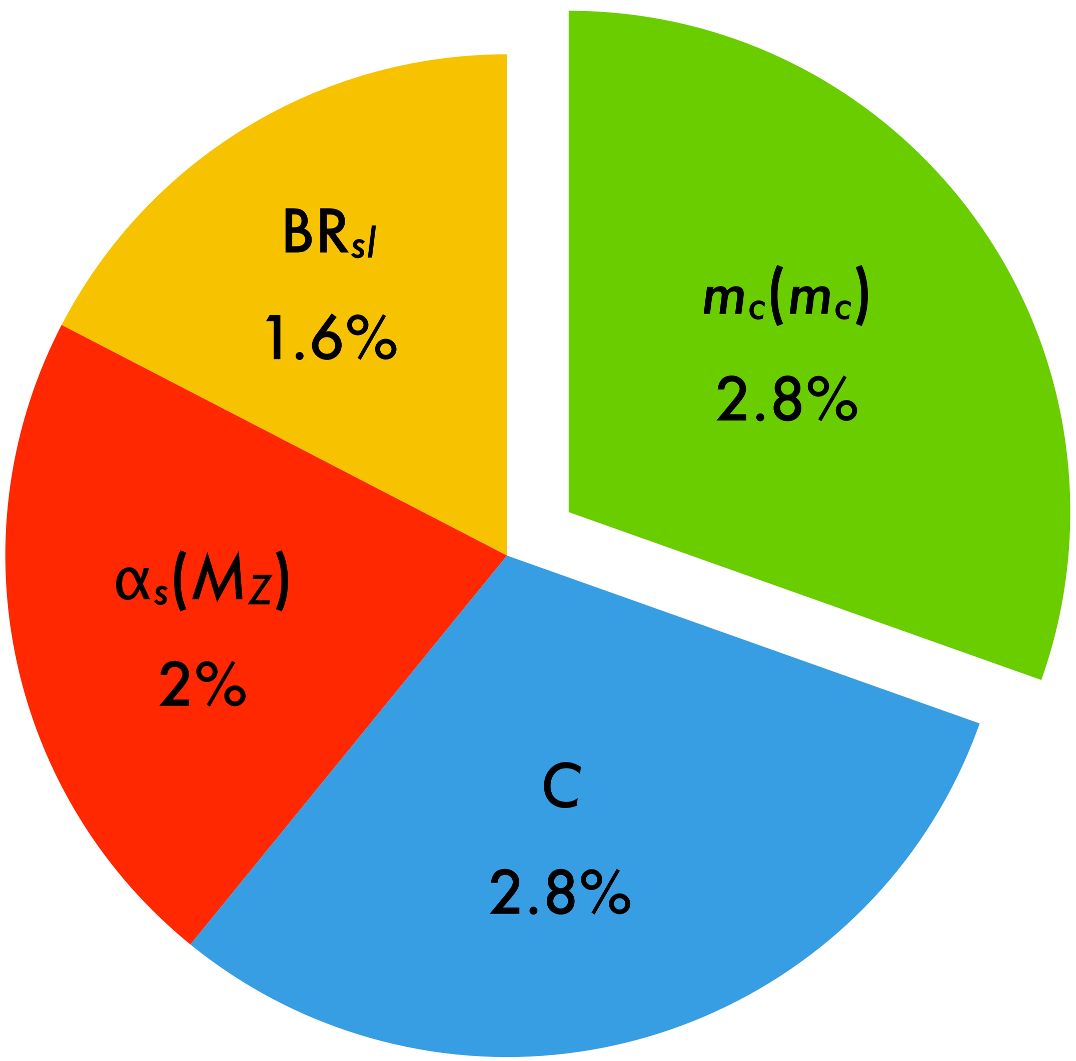


Recent determinations of charm mass



$m_c(m_c)$ [GeV]	method
1.286 ± 0.013	low-momentum sum rules, N^3LO
1.24 ± 0.07	fit to *B*-decay distribution, $\alpha_s^2\beta_0$
1.224 ± 0.017 ± 0.054	fit to *B*-decay data, $\alpha_s^2\beta_0$
1.29 ± 0.07	NNLO moments
1.319 ± 0.028	lattice, quenched
1.301 ± 0.034	lattice, quenched
1.26 ± 0.04 ± 0.12	lattice, quenched
1.304 ± 0.027	low-momentum sum rules, NNLO
1.25 ± 0.09	PDG 2006

Parametric errors in $\bar{B} \to X_s \gamma$ at NNLO*



$$m_c(m_c) = (1.224 \pm 0.017 \pm 0.054)\,\mathrm{GeV}^{\dagger}$$

- parametric uncertainty related to charm mass already slightly smaller than estimated left over scheme ambiguity

*Misiak & Steinhauser '06 †Hoang & Manohar '05

Future (?) CKM fit from $K\to\pi\nu\bar{\nu}$*

$$\mathcal{B}(K^+ \to \pi^+\nu\bar{\nu}) = (8.0 \pm 0.8) \times 10^{-11}$$

$$\mathcal{B}(K_L \to \pi^0\nu\bar{\nu}) = (3.0 \pm 0.3) \times 10^{-11}$$

Future (?)

$$\frac{\sigma(|V_{td}|)}{|V_{td}|} = \pm 4.0\%$$

$$\sigma(\sin 2\beta) = \pm 0.024$$

$$\sigma(\gamma) = \pm 4.7^\circ$$

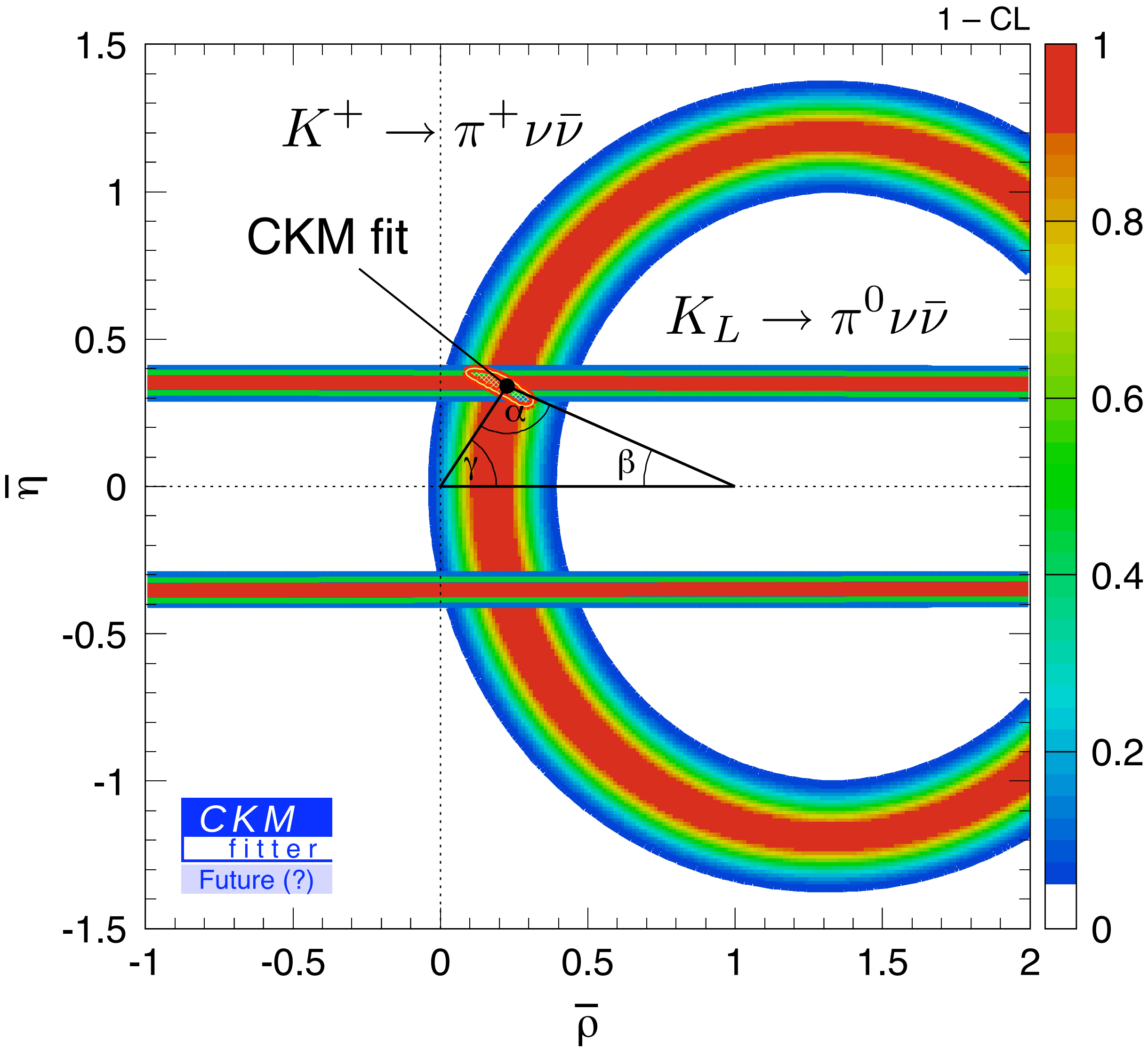
NLO
(theory error only)

$$\frac{\sigma(|V_{td}|)}{|V_{td}|} = \pm 1.0\%$$

$$\sigma(\sin 2\beta) = \pm 0.006$$

$$\sigma(\gamma) = \pm 1.2^\circ$$

NNLO
(theory error only)



- nice CKM fit from $K\to\pi\nu\bar{\nu}$, almost comparable to present global analysis, but not ultimate goal

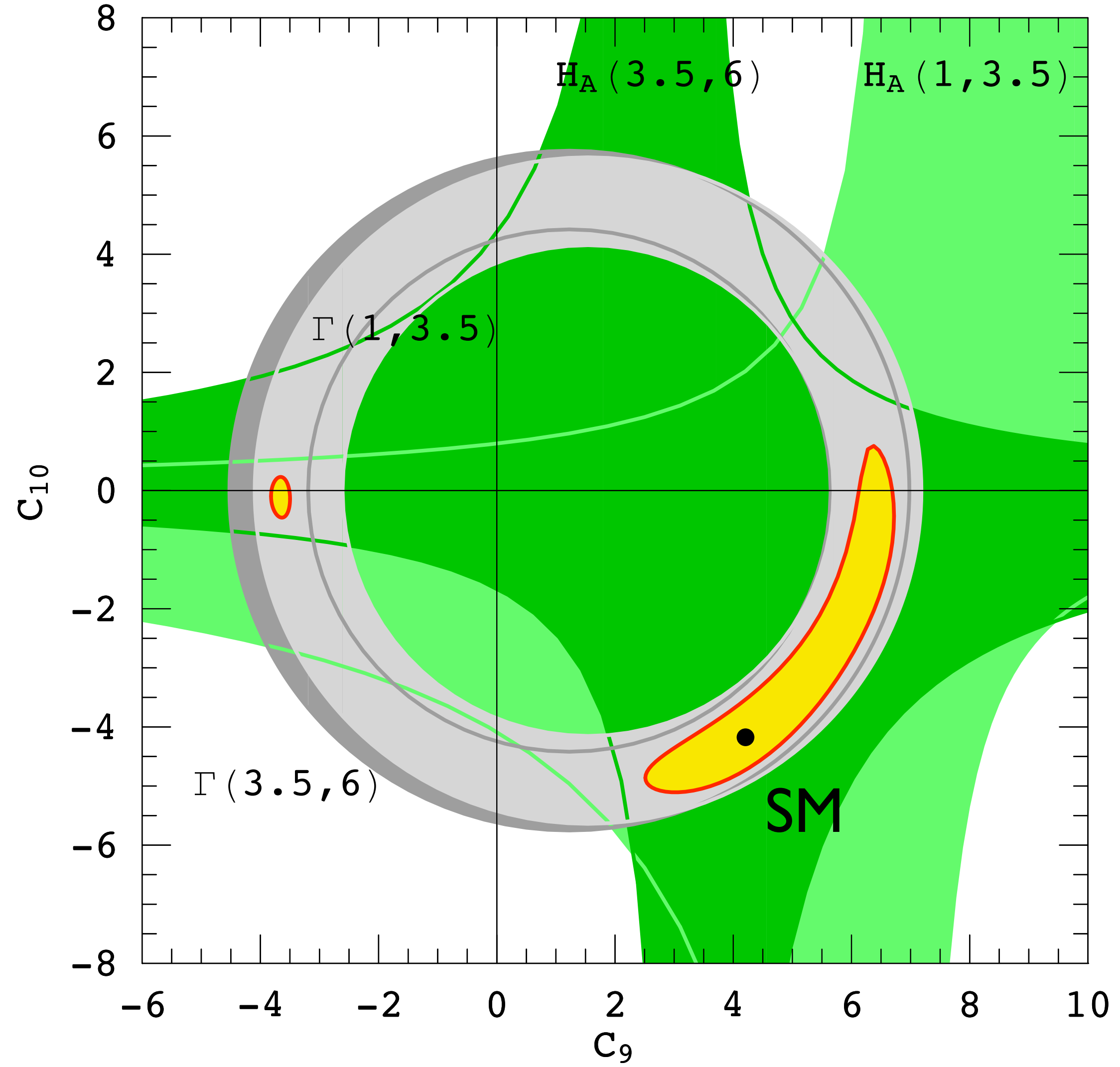
*Buras et al. ’05, ’06

$\bar{B}\to X_s l^+ l^-$: learning effectively from 1ab^{-1} data*

- **angular decomposition:**

$$\frac{d^2\Gamma}{dsdz} \sim \left\{(1+z^2)\left[\left(C_9+\frac{2}{s}C_7\right)^2+C_{10}^2\right]\right.$$
$$+(1-z^2)\left[(C_9+2C_7)^2+C_{10}^2\right]$$
$$\left.-4zsC_{10}\left(C_9+\frac{2}{s}C_7\right)\right\}$$
$$\equiv \underbrace{H_T+H_L}_{\sim\Gamma}+\underbrace{H_A}_{\sim A_{\rm FB}}$$

$$(s=q^2/m_b^2, z=\cos\theta, \theta:\sphericalangle\, b, l^+)$$



$$H_{T,L,A}(q_1^2,q_2^2)\equiv\int_{q_1^2}^{q_2^2}dq^2 H_{T,L,A}(q^2)$$

*Lee et al. '06

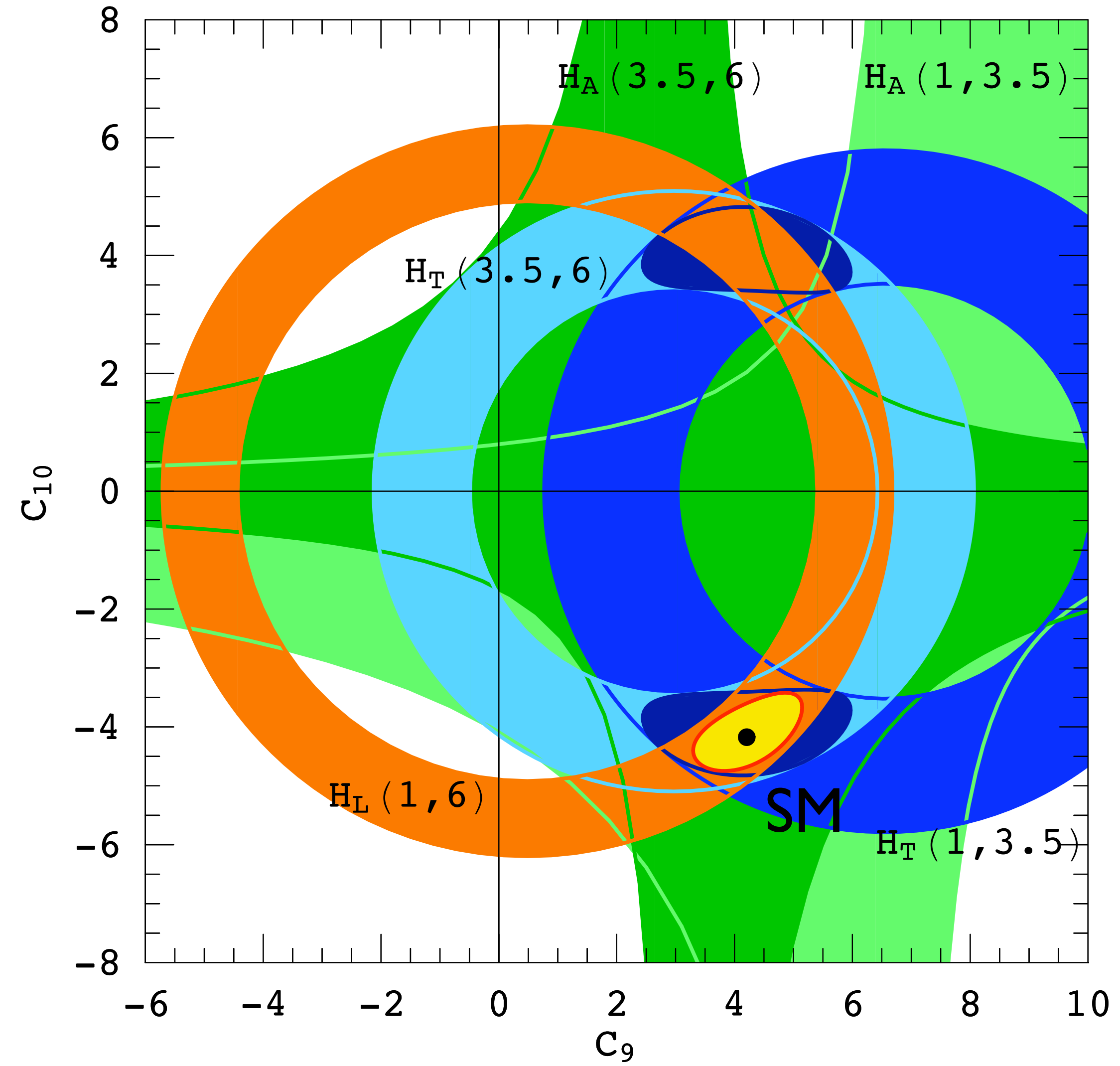
$\bar{B}\to X_s l^+ l^-$: learning effectively from 1ab^{-1} data*

- **angular decomposition:**

$$\frac{d^2\Gamma}{ds\,dz} \sim \Big\{ (1+z^2)\left[\left(C_9+\frac{2}{s}C_7\right)^2 + C_{10}^2\right] + (1-z^2)\left[(C_9+2C_7)^2+C_{10}^2\right] - 4zsC_{10}\left(C_9+\frac{2}{s}C_7\right)\Big\}$$

$$\equiv \underbrace{H_T + H_L}_{\sim\Gamma} + \underbrace{H_A}_{\sim A_{\rm FB}}$$

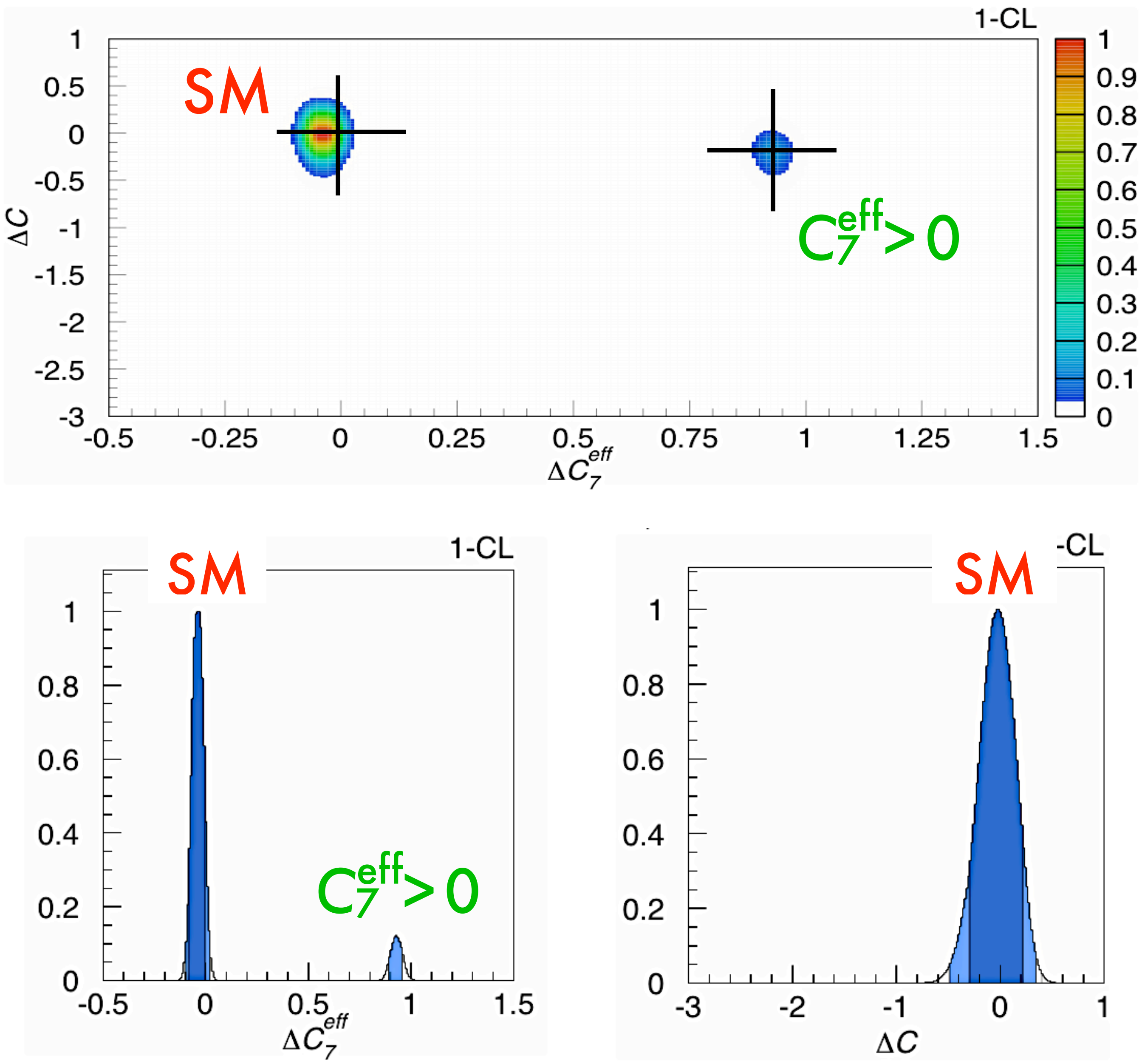
$$(s = q^2/m_b^2,\ z=\cos\theta,\ \theta : \sphericalangle\, b, l^+)$$



$$H_{T,L,A}(q_1^2,q_2^2) \equiv \int_{q_1^2}^{q_2^2} dq^2\, H_{T,L,A}(q^2)$$

*Lee et al. '06

Bounds on ΔC & ΔC_7^{eff} from $\bar{B}\to X_s\gamma, l^+l^-$ & $Z\to b\bar{b}$



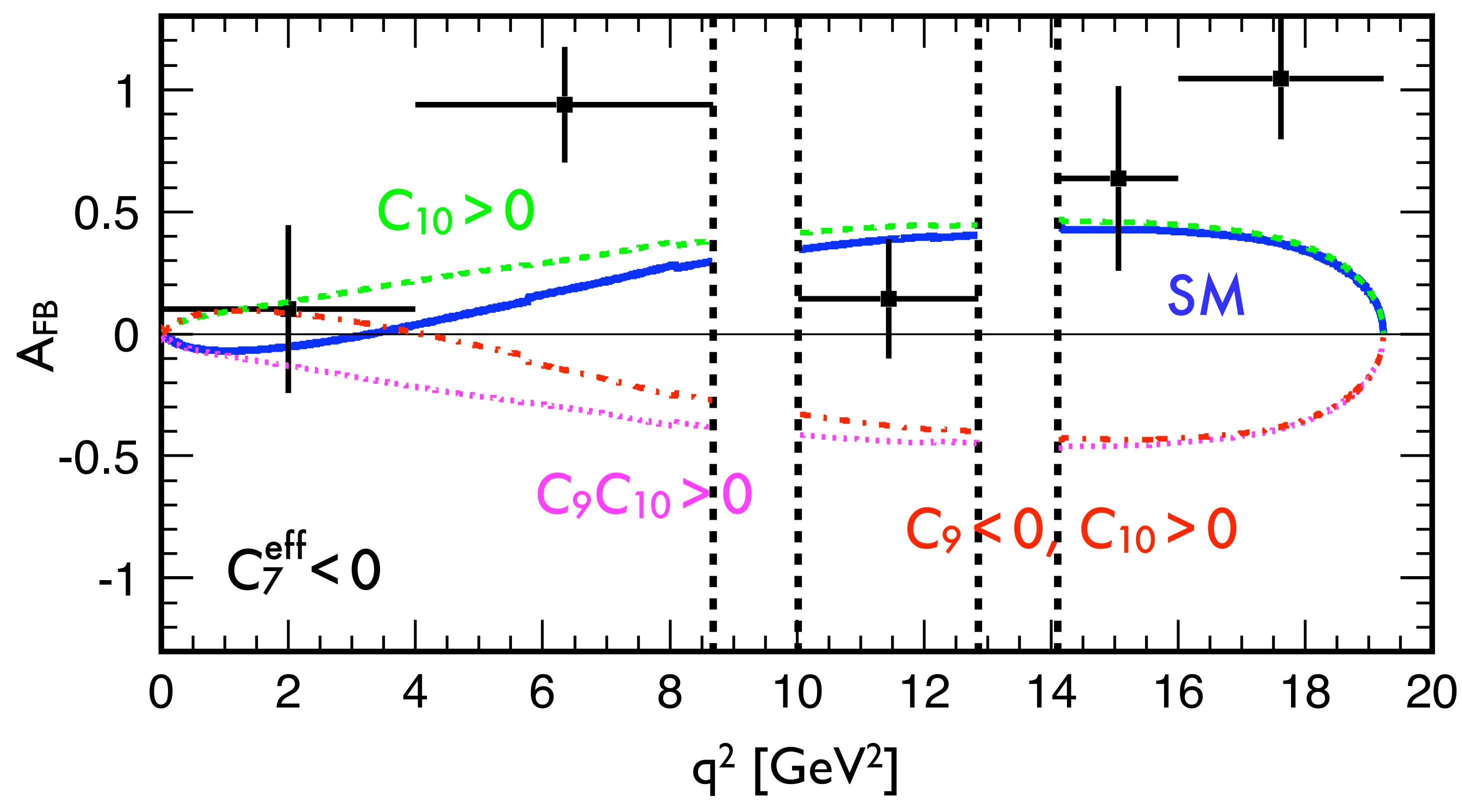
$$\Delta C = [-0.486, 0.366] \quad (95\%\ \text{CL})$$

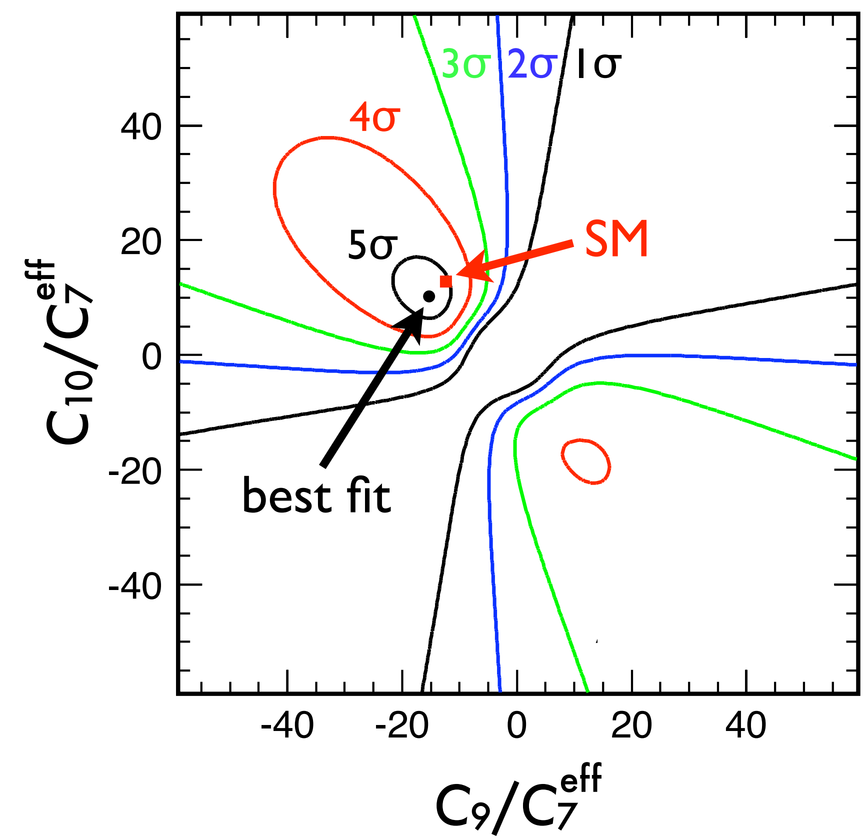
$$\Delta C_7^{\text{eff}} = [-0.104, 0.026] \cup [0.891, 0.968] \quad (95\%\ \text{CL})$$

- large corrections to off-shell photon penguin still allow for “wrong” sign of ΔC_7^{eff}

*UH & Weiler ’07 (?)

Hunting Z-penguin with $\bar{B} \to K^* l^+ l^-$





- forward-backward asymmetry in $\bar{B} \to K^* l^+ l^-$ excludes $C_9 C_{10} > 0$ at 95% CL*
- hints towards exclusion of large destructive Z-penguin: $|\Delta C| \lesssim 1.5$

*Belle '05; BaBar '06