

Flavor Physics & CP Violation

FPCP

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Marseille
France

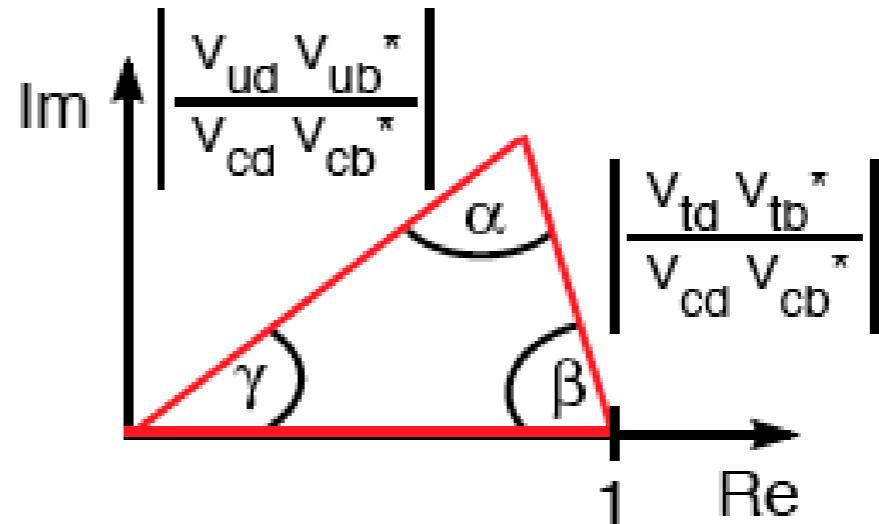
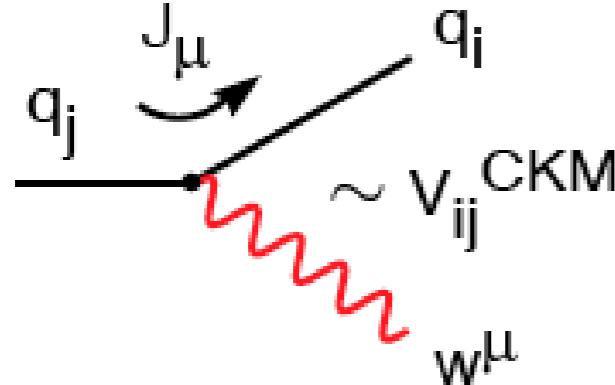
Y 2014

Recent phenomenological results in rare B decays



Tobias Hurth

CKM mechanism of flavour mixing and CP violation: V_{CKM} , J_{CKM}



$$Im[V_{ij} V_{kl} V_{il}^* V_{kj}^*] = J_{CKM} \sum_{m,n=1}^3 \epsilon_{ikm} \epsilon_{jln} \quad J_{CKM} \sim \mathcal{O}(10^{-5})$$

Status of flavour physics in the pre-LHC(b) era:

All measurements (Babar, Belle, Cleo, CDF, DO, ...)

of rare decays ($\Delta F = 1$),

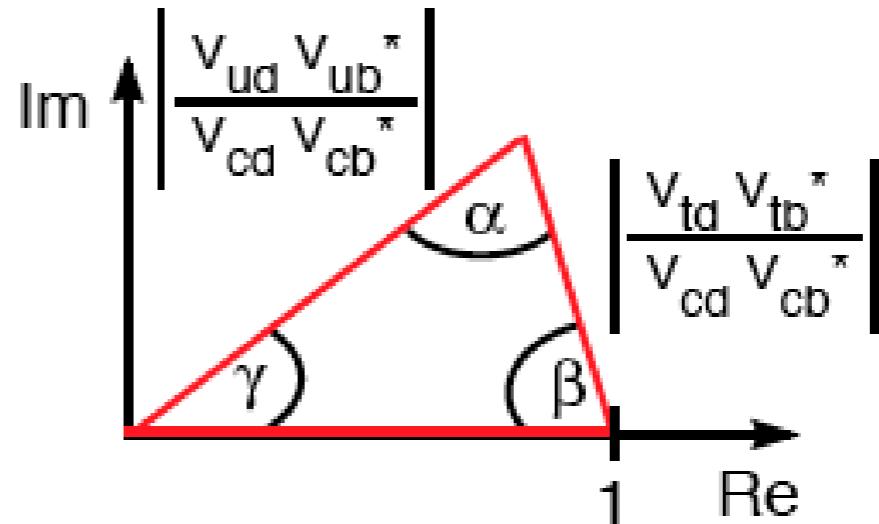
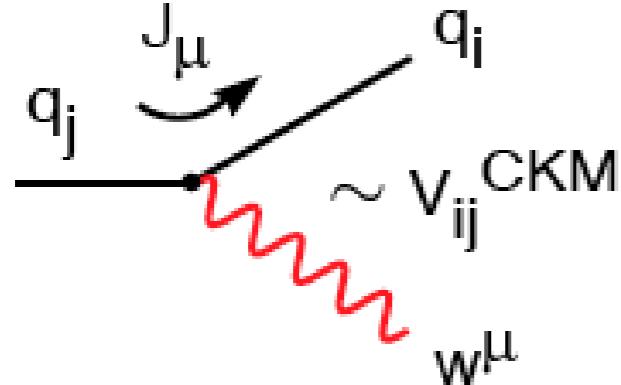
of mixing phenomena ($\Delta F = 2$) and

of all CP violating observables at tree and loop level

have been consistent with the CKM theory.

Impressing success of SM and CKM theory !!

CKM mechanism of flavour mixing and CP violation: V_{CKM} , J_{CKM}



$$\text{Im}[V_{ij} V_{kl} V_{il}^* V_{kj}^*] = J_{CKM} \sum_{m,n=1}^3 \epsilon_{ikm} \epsilon_{jln} \quad J_{CKM} \sim \mathcal{O}(10^{-5})$$

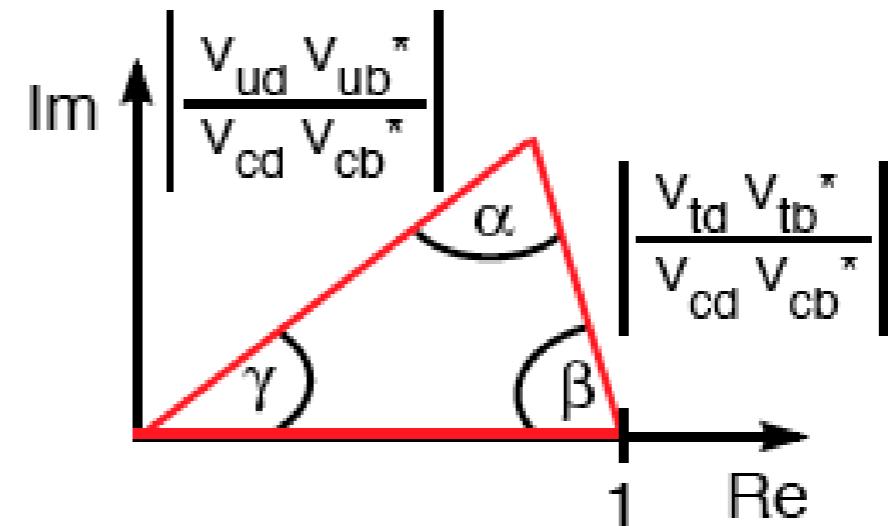
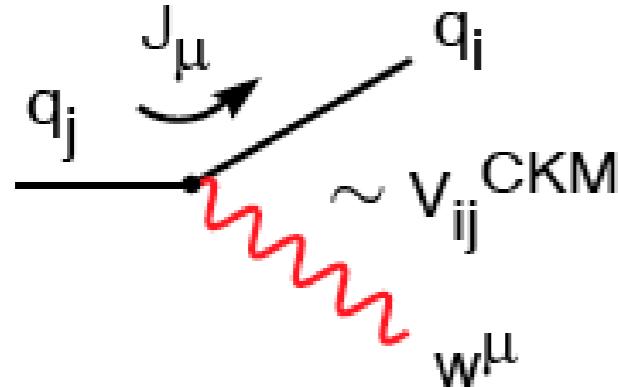
Status of flavour physics in the pre-LHC(b) era:

Of course there have been so-called puzzles, tensions, anomalies in the flavour data at the $1, 2, \text{ or } 3\sigma$ level.

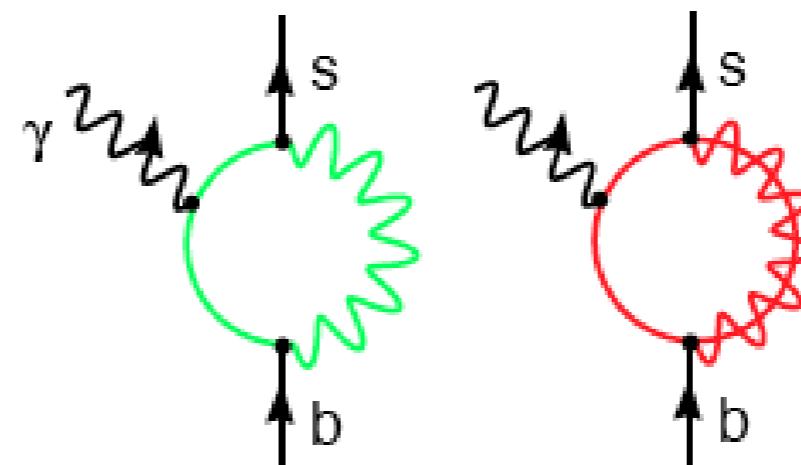
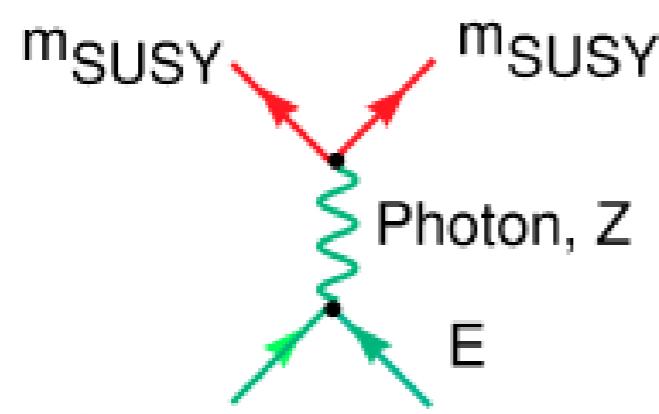
For example: Tension between $\mathcal{B}(B \rightarrow \tau\nu)$ and $\sin \beta$.
Mixing phase in $B_s - \bar{B}_s$ mixing

Impressing success of SM and CKM theory !!

CKM mechanism of flavour mixing and CP violation: V_{CKM} , J_{CKM}



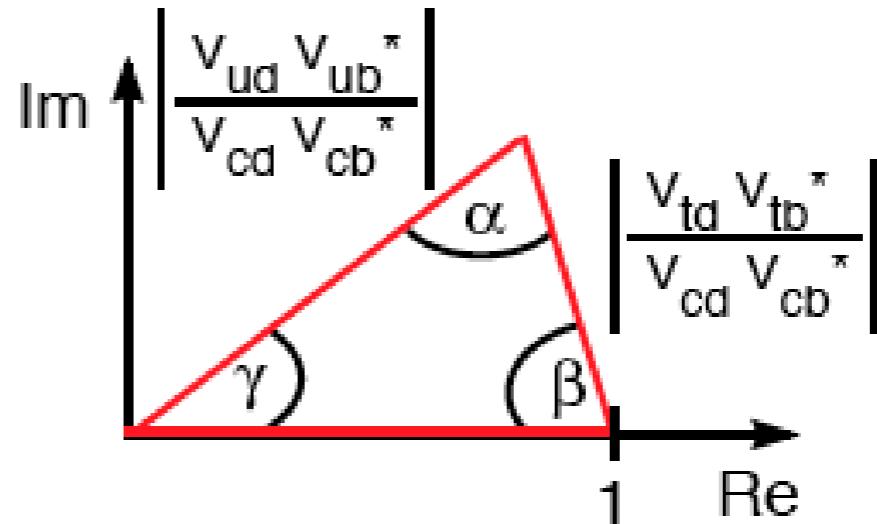
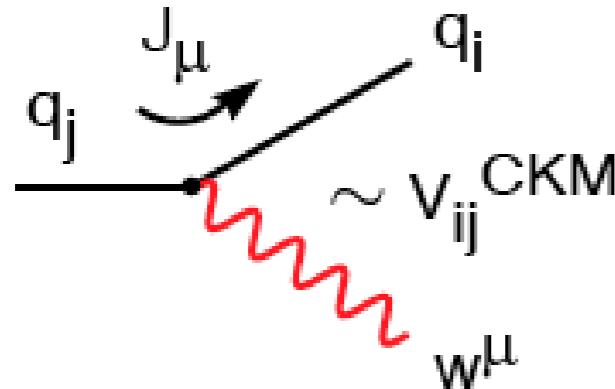
This success is somehow unexpected !!



Flavour-changing-neutral-currents as loop-induced processes are highly-sensitive probes for possible new degrees of freedom

Impressing success of SM and CKM theory !!

CKM mechanism of flavour mixing and CP violation: V_{CKM} , J_{CKM}

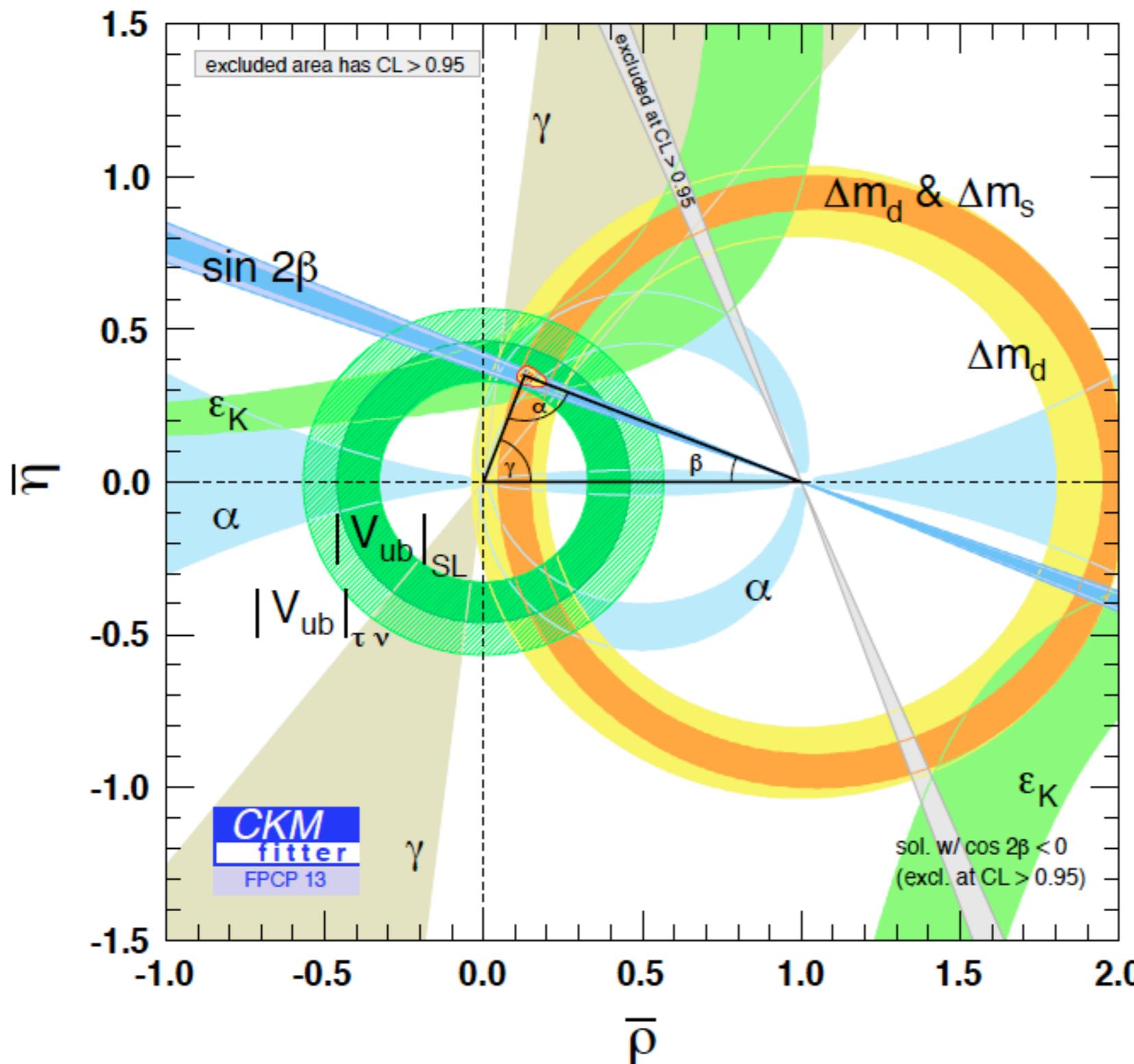


$$Im[V_{ij} V_{kl} V_{il}^* V_{kj}^*] = J_{CKM} \sum_{m,n=1}^3 \epsilon_{ikm} \epsilon_{jln} \quad J_{CKM} \sim \mathcal{O}(10^{-5})$$

LHC(b) has not changed this, in contrary !!

All measurements (Babar, Belle, Cleo, CDF, DO, **LHC(b)**,...) of rare decays ($\Delta F = 1$), of mixing phenomena ($\Delta F = 2$) and of all CP violating observables at tree and loop level **are consistent with the CKM theory.**

Impressing success of SM and CKM theory !!



Global fit,
consistency check
of
the CKM theory.

There is much more data not shown in the unitarity fits which confirms the SM predictions of flavour mixing like rare decays ($\Delta F = 1$)

- No guiding principle in the flavour sector

$$\mathcal{L}_{SM} = \mathcal{L}_{Gauge}(A_i, \psi_i) + \mathcal{L}_{Higgs}(\Phi, \psi_i, v)$$

$$|V_{us}| \approx 0.2, |V_{cb}| \approx 0.04, |V_{ub}| \approx 0.004 \quad \text{versus} \quad g_s \approx 1, g \approx 0.6, g' \approx 0.3$$

- Approximate symmetries (Froggatt -Nielsen)
- Geometry in extra dimensions (Randall-Sundrum)

- Ambiguity of new physics scale from flavour data

$$\mathcal{L} = \mathcal{L}_{Gauge} + \mathcal{L}_{Higgs} + \sum_i \frac{c_i^{New}}{\Lambda_{NP}} \mathcal{O}_i^{(5)} + \dots$$

$$\Lambda_{\text{Flavour}} > \Lambda_{NP} ?$$

Implications of the latest measurements of $B_s \rightarrow \mu\mu$

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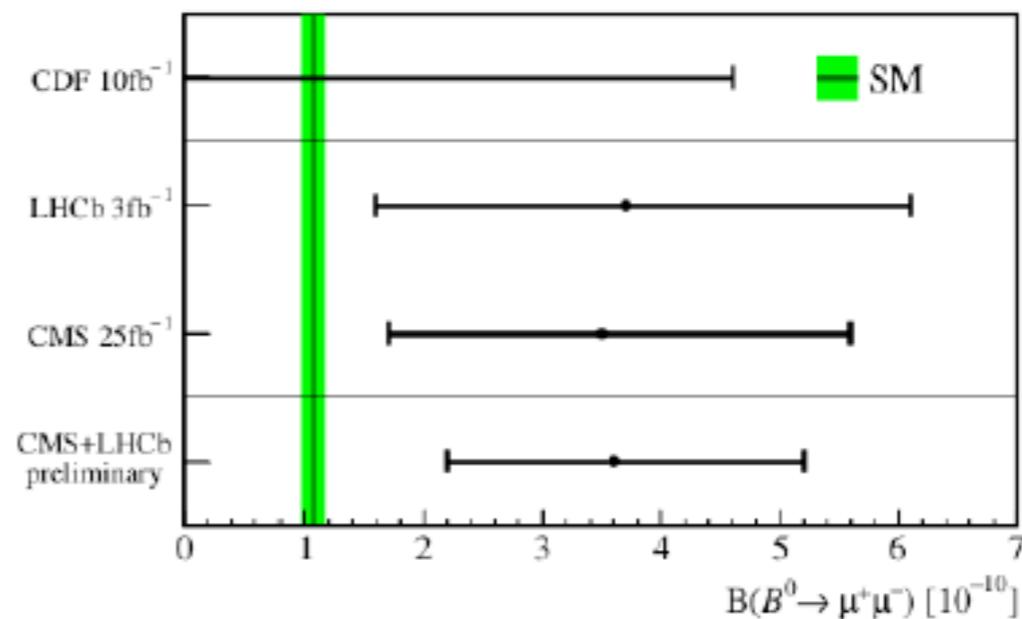
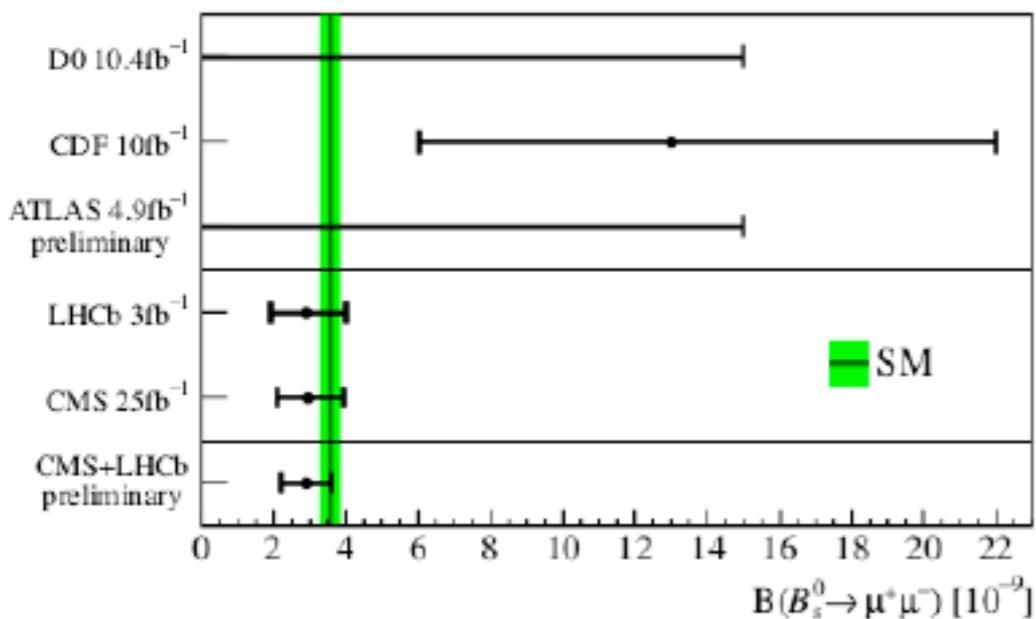
new @ EPS2013

Observation:

$$\text{BR}(B_s \rightarrow \mu^+ \mu^-) = (2.9 \pm 0.7) \times 10^{-9}$$



$$\text{BR}(B^0 \rightarrow \mu^+ \mu^-) = 3.6^{+1.6}_{-1.4} \times 10^{-10}$$



LHCb-CONF-2013-012, CMS-PAS-BPH-13-007

Stephanie Hansmann-Menzemer

Recent theory effort to eliminate perturbative uncertainties of 7%

NLO QCD corrections

→ NNLO QCD corrections

Buchalla,Buras 1999, Misiak, Urban1999

Hermann,Misiak,Steinhauser arXiv:1311.1347

Leading- m_t NLO electroweak corrections

→ NLO electroweak corrections

Buchalla,Buras 1998

Bobeth,Gorbahn.Stamou arXiv:1311.1348

Experiment versus Theory

$$\overline{\mathcal{B}}_{s\mu}^{\text{exp}} = (2.9 \pm 0.7) \times 10^{-9}$$

$$\overline{\mathcal{B}}_{s\mu}^{\text{th}} = (3.65 \pm 0.23) \times 10^{-9}$$

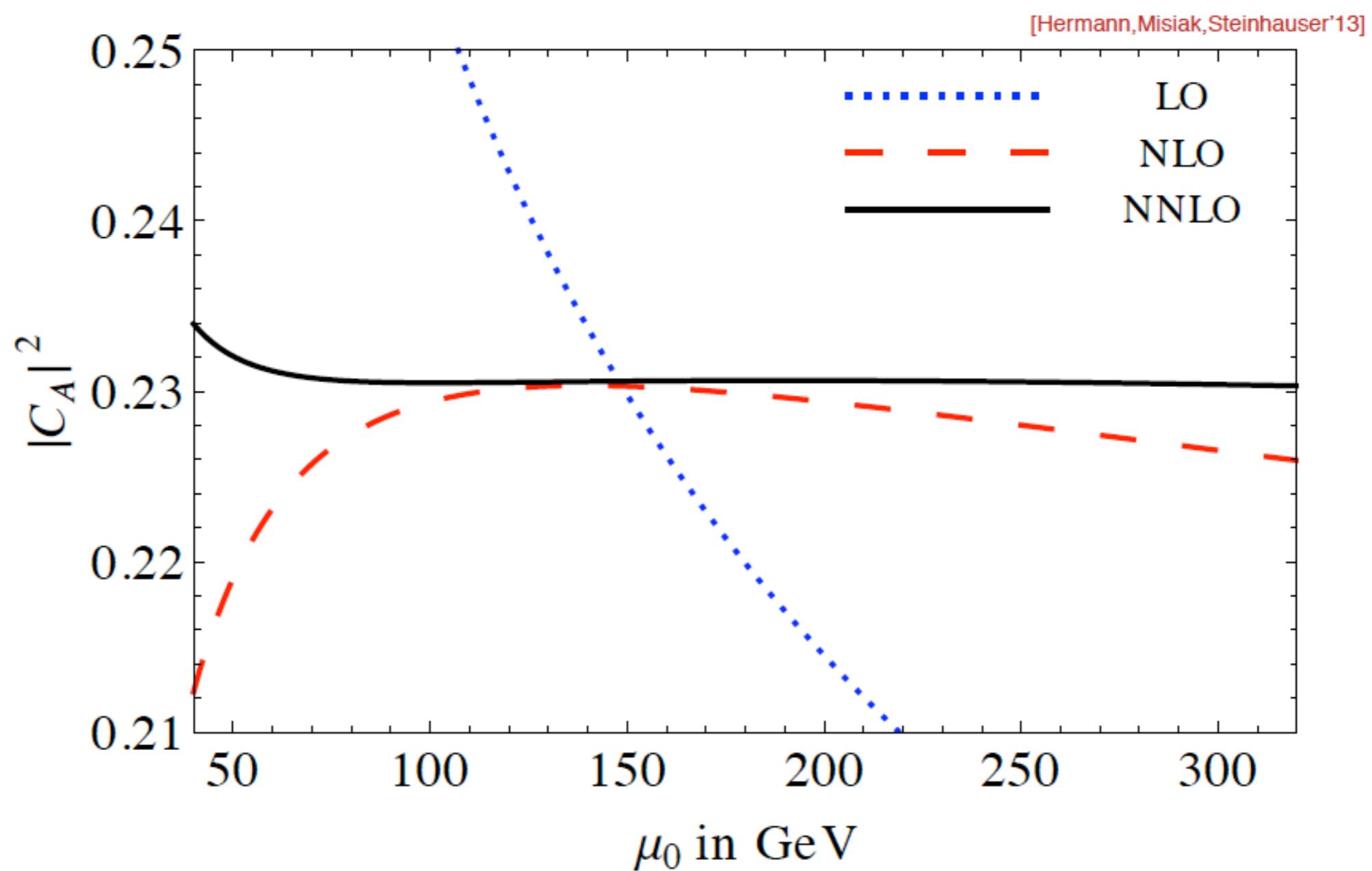
$$\overline{\mathcal{B}}_{d\mu}^{\text{exp}} = (3.6^{+1.6}_{-1.4}) \times 10^{-10}$$

$$\overline{\mathcal{B}}_{d\mu}^{\text{th}} = (1.06 \pm 0.09) \times 10^{-10}$$

Error budget:

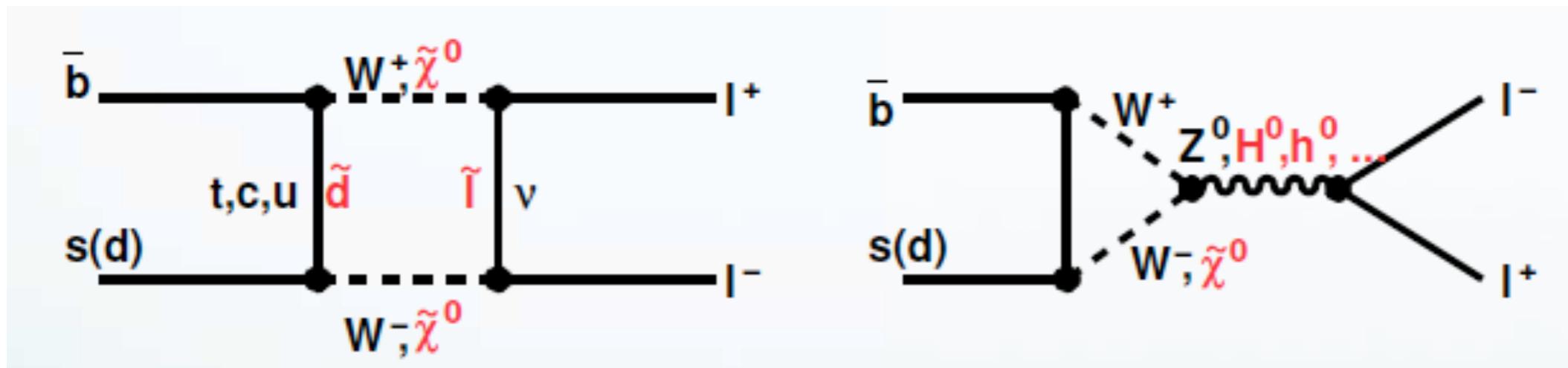
	f_{B_s}	CKM	τ_H^s	M_t	α_s	other param.	non-param.	Σ
$\bar{\mathcal{B}}_{s\ell}$	4.0%	4.3%	1.3%	1.6%	0.1%	< 0.1%	1.5%	6.4%

Scale dependence:



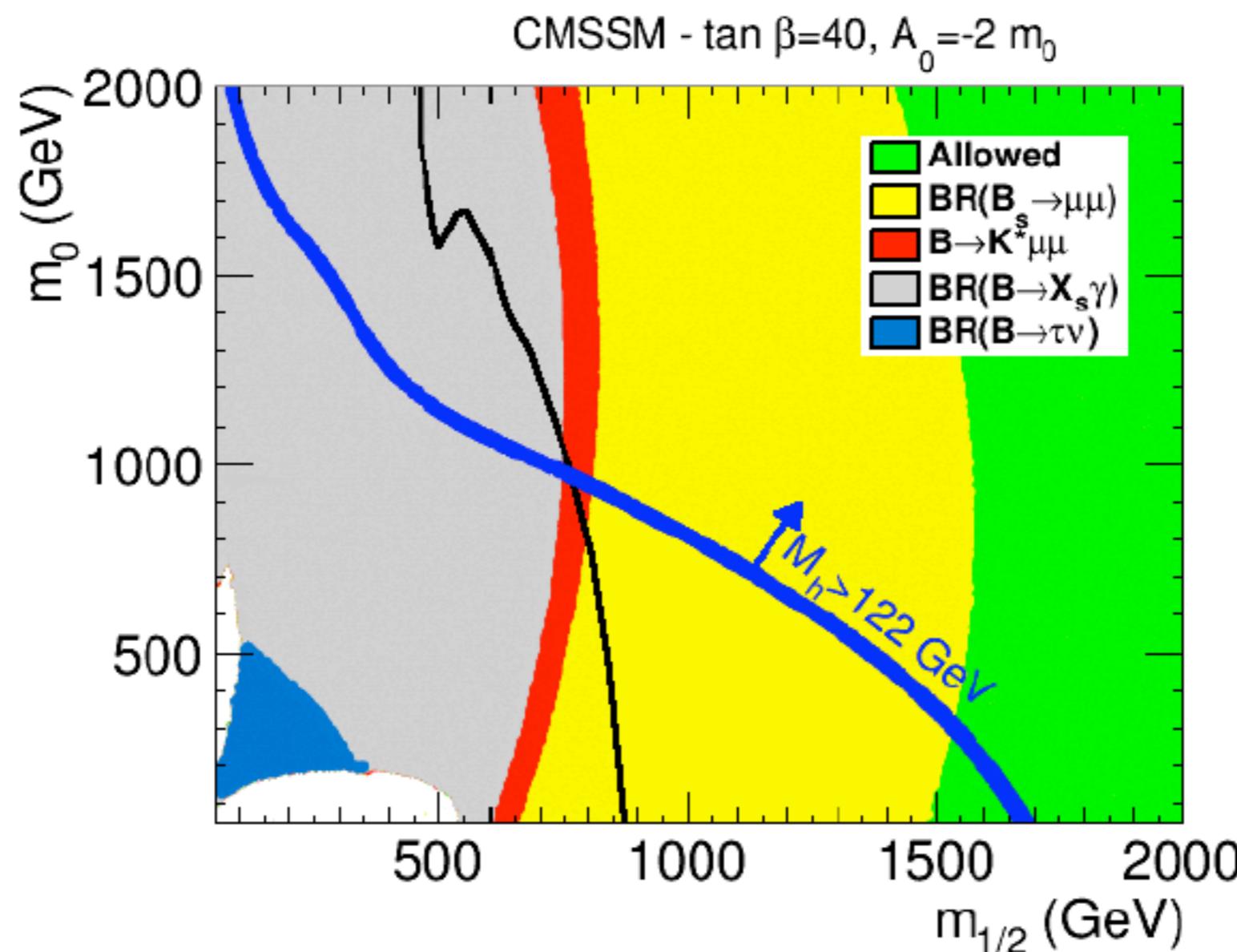
Implications of the latest measurements of $B_s \rightarrow \mu\mu$

$$A_{\text{SM}} \sim m_\mu/m_b \Leftrightarrow A_{H^0, A^0} \sim \tan^3 \beta$$



Constraints on CMSSM

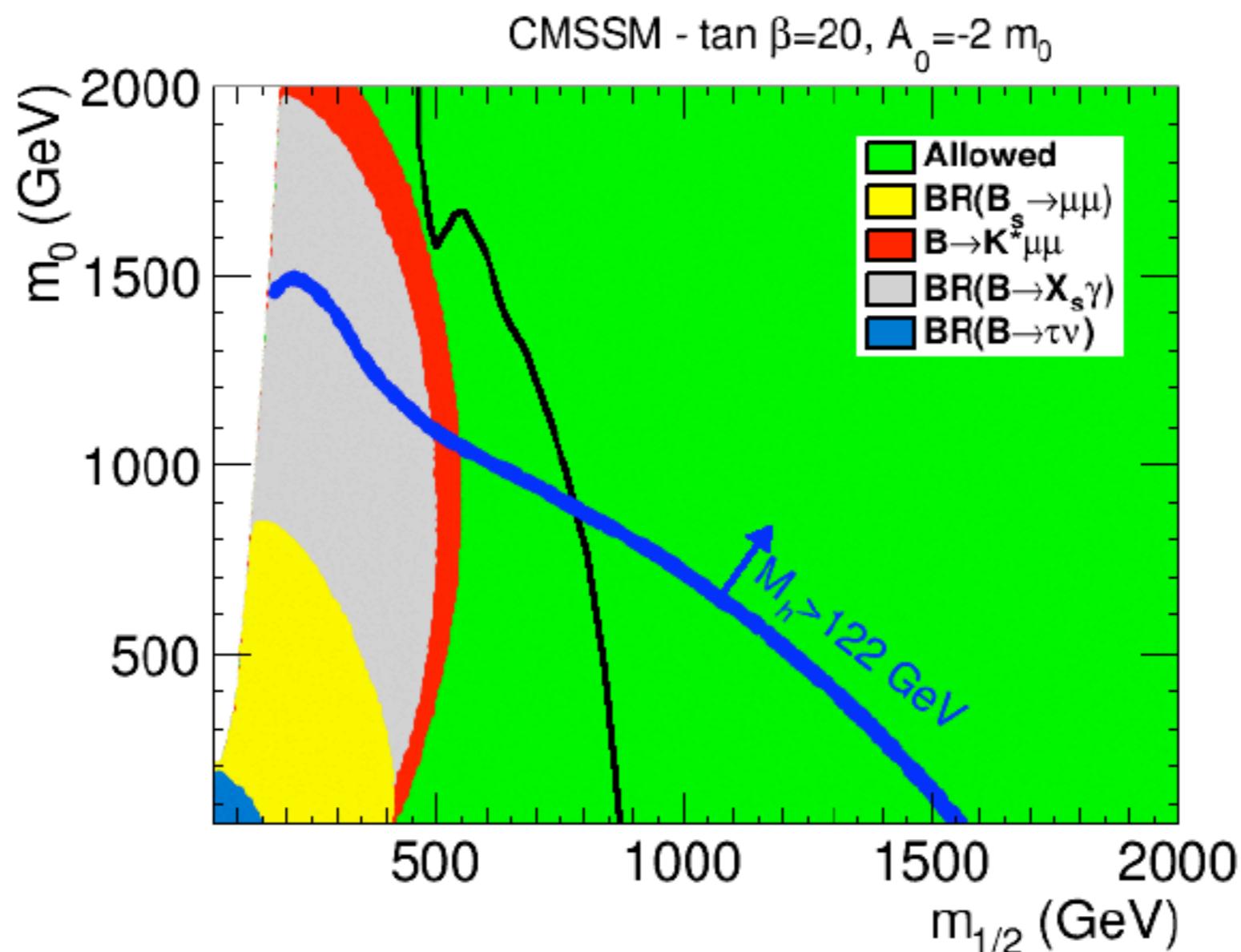
Mahmoudi,Neshatpour,Virto arXiv:1401.2145



Black line corresponds to direct search: ATLAS with 20.3 fb^{-1}

Constraints on CMSSM

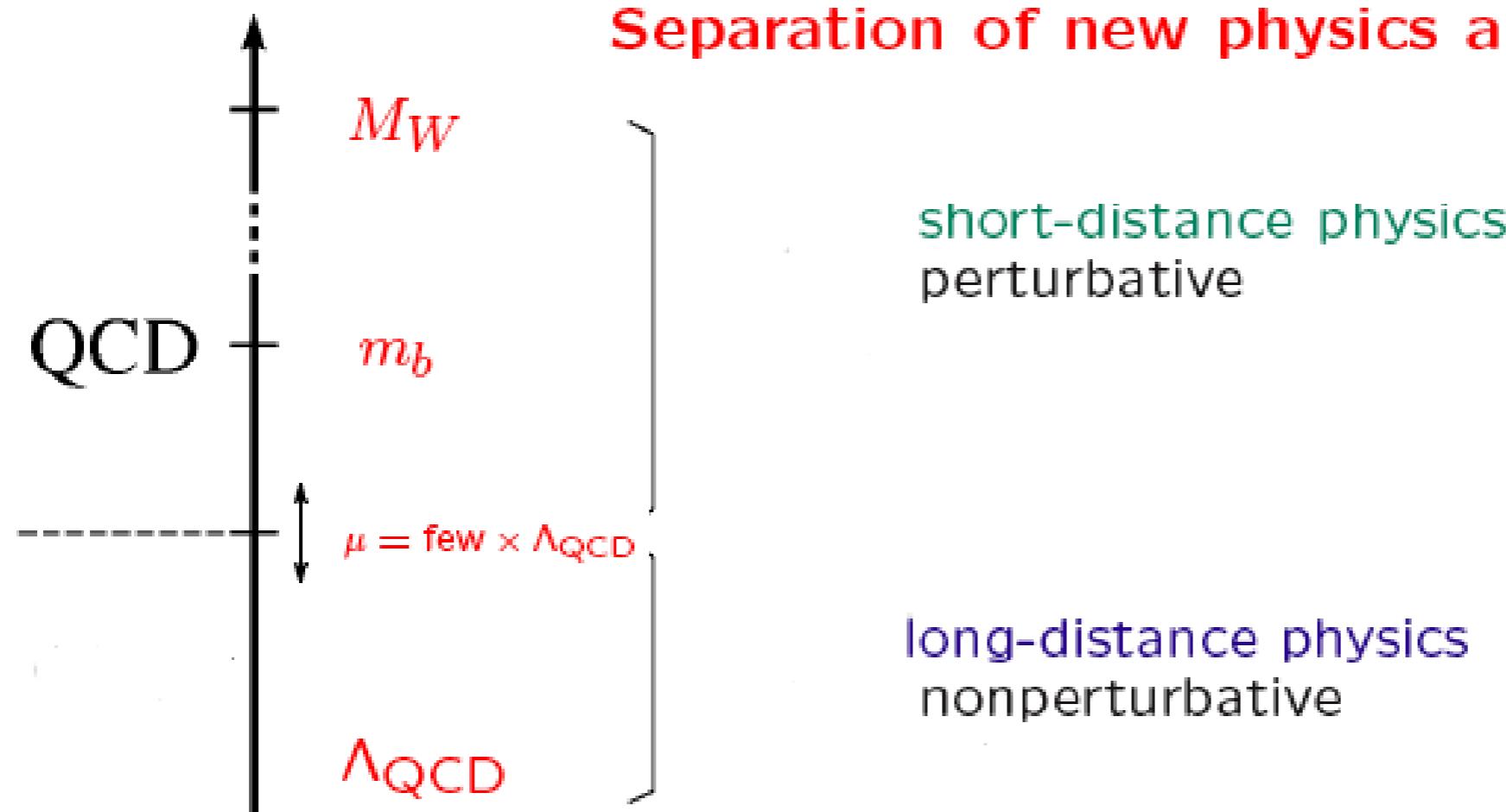
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Black line corresponds to direct search: ATLAS with 20.3 fb^{-1}

Radiative and semileptonic penguin decays

Separation of new physics and hadronic effects



Operator product expansion: Factorization of short- and long-distance physics

- Electroweak effective Hamiltonian: $H_{eff} = -\frac{4G_F}{\sqrt{2}} \sum C_i(\mu, M_{heavy}) \mathcal{O}_i(\mu)$
- $\mu^2 \approx M_{New}^2 \gg M_W^2$: 'new physics' effects: $C_i^{SM}(M_W) + C_i^{New}(M_W)$

How to compute the hadronic matrix elements $\mathcal{O}_i(\mu = m_b)$?

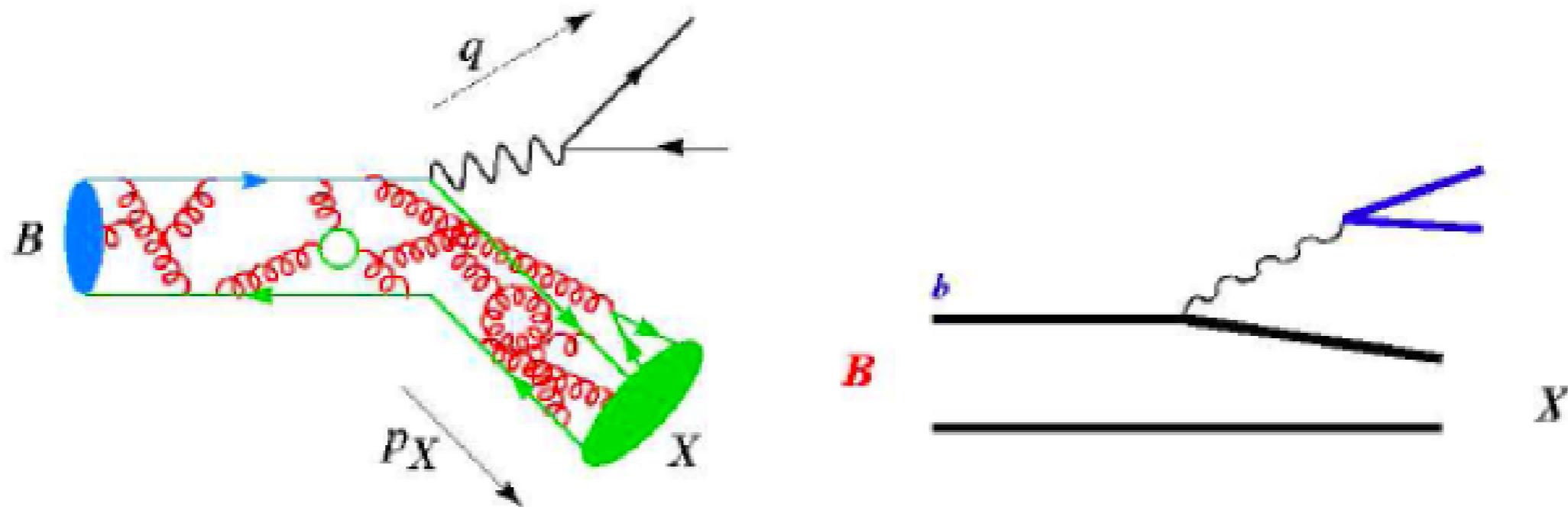
How to compute the hadronic matrix elements $\mathcal{O}_i(\mu = m_b)$?

Inclusive modes $B \rightarrow X_s \gamma$ or $B \rightarrow X_s \ell^+ \ell^-$

- Heavy mass expansion for inclusive modes:

$$\Gamma(\bar{B} \rightarrow X_s \gamma) \xrightarrow{m_b \rightarrow \infty} \Gamma(b \rightarrow X_s^{\text{parton}} \gamma), \quad \Delta^{\text{nonpert.}} \sim \Lambda_{QCD}^2 / m_b^2$$

No linear term Λ_{QCD}/m_b (perturbative contributions dominant)



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No linear term Λ_{QCD}/m_b (perturbative contributions dominant)

An old story:

- If one goes beyond the leading operator ($\mathcal{O}_7, \mathcal{O}_9$):
breakdown of local expansion

A new dedicated analysis:

naive estimate of non-local matrix elements leads to 5% uncertainty.

Benzke, Lee, Neubert, Paz, arXiv:1003.5012



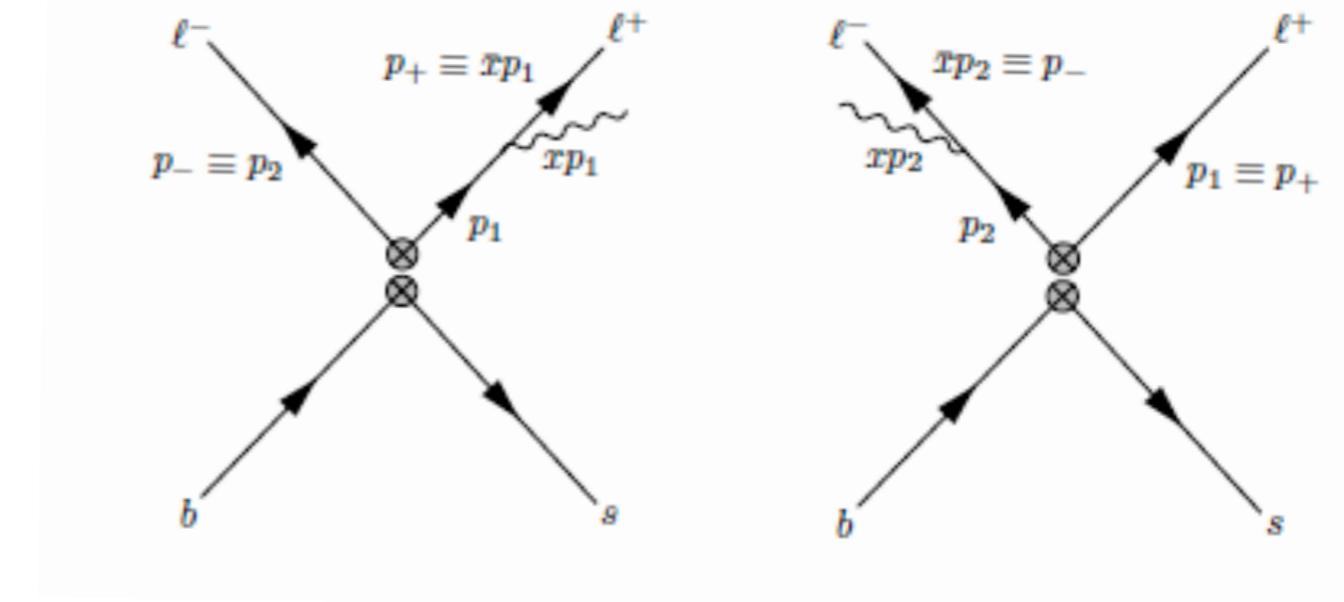
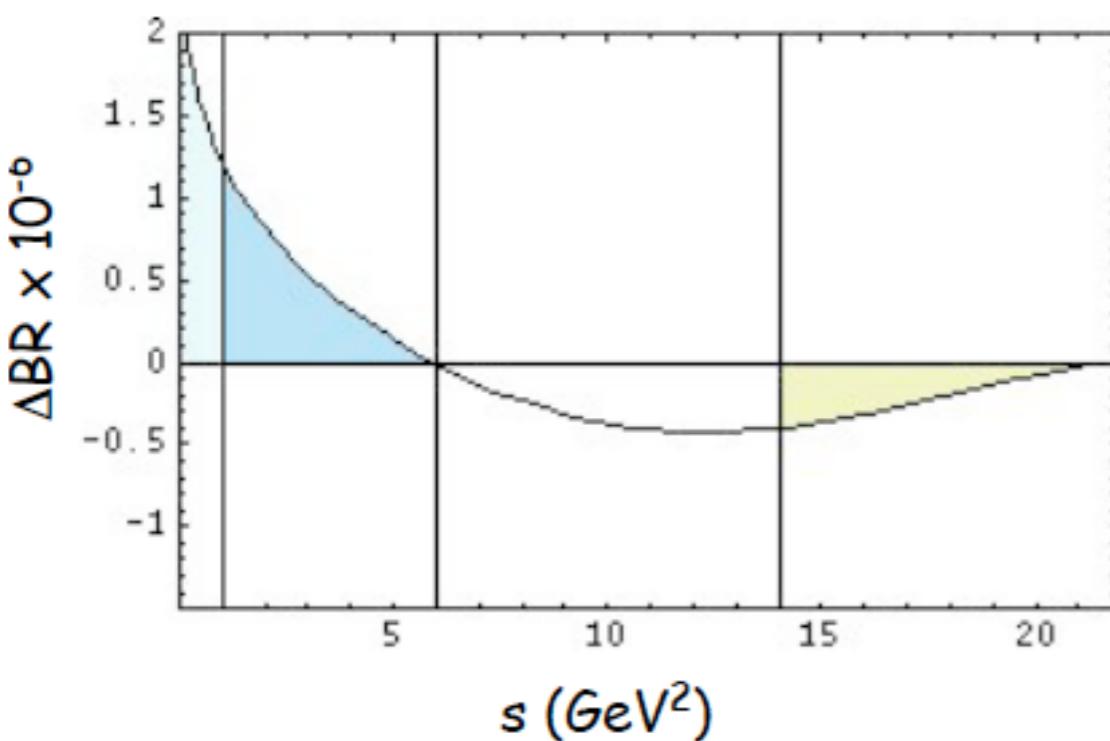
Latest improvements of inclusive $\bar{B} \rightarrow X_s \ell^+ \ell^-$

Beyond existing NNLL QCD precision electromagnetic corrections

were calculated: Huber,Hurth,Lunghi,Nucl.Phys.B802(2008)40 and work in progress

Corrections to matrix elements lead to large collinear $\text{Log}(m_b/m_\ell)$

$$\delta\text{BR}(B \rightarrow X_s \mu^+ \mu^-) = \begin{cases} (+2.0\%) & \text{low } q^2 \\ (-6.8\%) & \text{high } q^2 \end{cases} \quad \delta\text{BR}(B \rightarrow X_s e^+ e^-) = \begin{cases} (+5.2\%) & \text{low } q^2 \\ (-17.6\%) & \text{high } q^2 \end{cases}$$



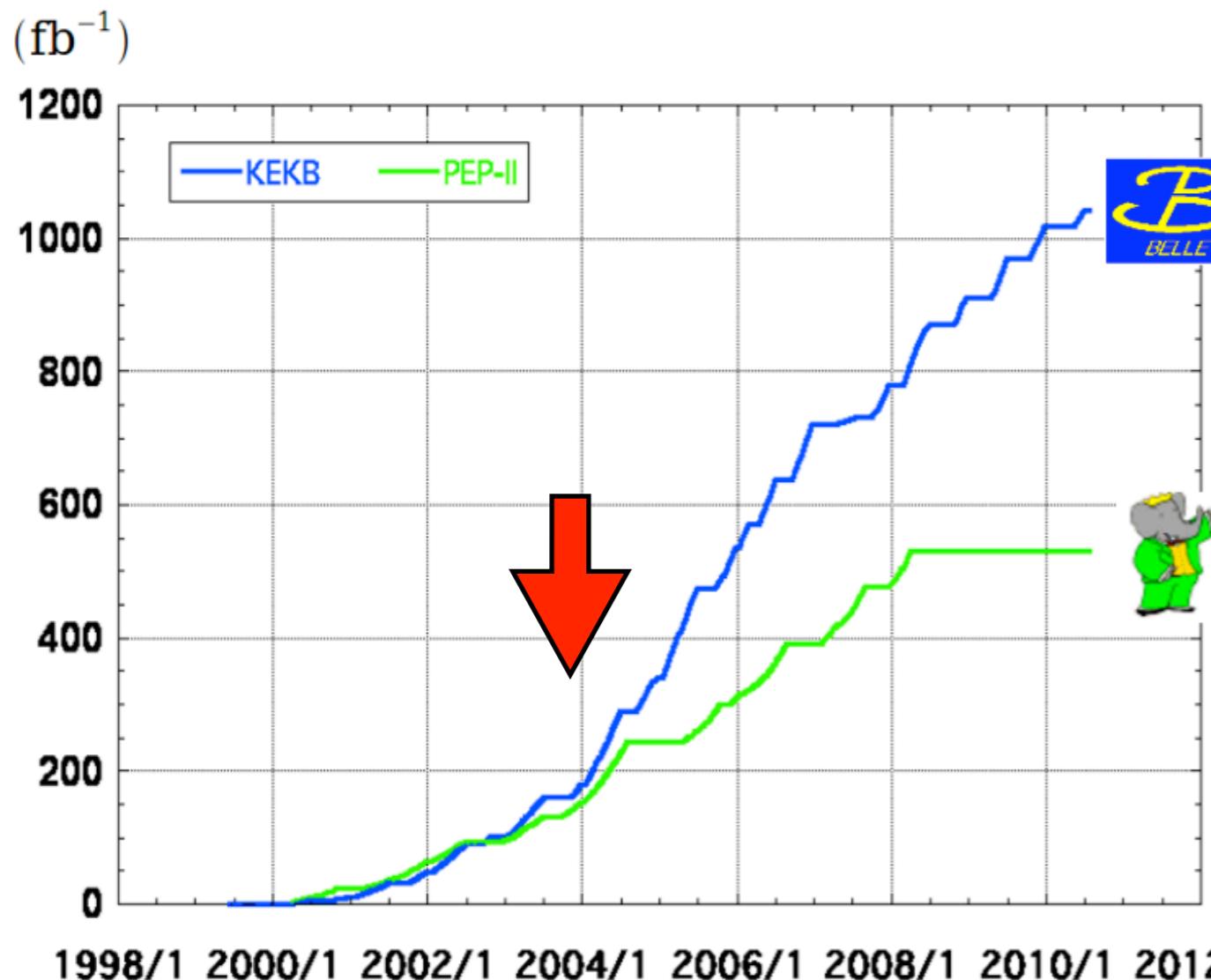
Until very recently:

'Latest' Babar and Belle measurements of inclusive $\mathcal{B}(b \rightarrow s\ell\ell)$

Belle hep-ex/0503044 (!!!) (based $152 \times 10^6 B\bar{B}$ events)

Babar hep-ex/0404006 (!!!) (based $89 \times 10^6 B\bar{B}$ events)

Integrated luminosity of B factories



$> 1 \text{ ab}^{-1}$

On resonance:

$\Upsilon(5S): 121 \text{ fb}^{-1}$
 $\Upsilon(4S): 711 \text{ fb}^{-1}$
 $\Upsilon(3S): 3 \text{ fb}^{-1}$
 $\Upsilon(2S): 25 \text{ fb}^{-1}$
 $\Upsilon(1S): 6 \text{ fb}^{-1}$

Off reson./scan:

$\sim 100 \text{ fb}^{-1}$

$\sim 550 \text{ fb}^{-1}$

On resonance:

$\Upsilon(4S): 433 \text{ fb}^{-1}$
 $\Upsilon(3S): 30 \text{ fb}^{-1}$
 $\Upsilon(2S): 14 \text{ fb}^{-1}$

Off resonance:

$\sim 54 \text{ fb}^{-1}$

Two new analyses from the B factories:

New Babar analysis on dilepton spectrum arXiv:1312.3664

New Belle analysis on AFB arXiv:1402.7134

Forthcoming theory analysis including all three
independent angular observables ($z = \cos\theta$)

Huber, Hurth, Lunghi

$$\frac{d^2\Gamma}{dq^2 dz} = 3/8 \left[(1 + z^2) H_T(q^2) + 2z H_A(q^2) + 2(1 - z^2) H_L(q^2) \right]$$

$$\frac{d\Gamma}{dq^2} = H_T(q^2) + H_L(q^2), \quad \frac{dA_{\text{FB}}}{dq^2} = 3/4 H_A(q^2)$$

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Huber, Hurth, Lunghi

Low- q^2 ($1\text{GeV}^2 < q^2 < 6\text{GeV}^2$)

$$BR(B \rightarrow X_s ee) = (1.67 \pm 0.12) 10^{-6} \text{ (preliminary)}$$

$$BR(B \rightarrow X_s \mu\mu) = (1.62 \pm 0.11) 10^{-6} \text{ (preliminary)}$$

Babar: $BR(B \rightarrow X_s \ell\ell) =$

$$= (1.60 (+0.41 - 0.39)_{stat} (+0.17 - 0.13)_{syst} (\pm 0.18)_{mod}) 10^{-6}$$

good agreement with SM

Two new analyses from the B factories:

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Forthcoming theory analysis including all three
independent angular observables ($z = \cos\theta$)

Huber, Hurth, Lunghi

High- q^2 , Theory: $q^2 > 14.4 \text{ GeV}^2$, Babar: $q^2 > 14.2 \text{ GeV}^2$

$BR(B \rightarrow X_s ee) = (0.221 \pm 0.069) 10^{-6}$ (preliminary)

$BR(B \rightarrow X_s \mu\mu) = (0.162 \pm 0.069) 10^{-6}$ (preliminary)

Babar: $BR(B \rightarrow X_s \ell\ell) =$

$(0.57 (+0.16 - 0.15)_{stat} (+0.03 - 0.02)_{syst}) 10^{-6}$

2σ higher than SM

Comparison with $B \rightarrow K^* \ell\ell$ data >>>

Further refinements:

- Normalization to semileptonic $B \rightarrow X_u \ell \nu$ decay rate **with the same cut** reduces the impact of $1/m_b$ corrections in the high- q^2 region significantly.

Ligeti, Tackmann arXiv:0707.1694

Theory prediction for ratio (preliminary)

$$R(s_0)_{ee} = (2.26 \pm 0.30) 10^{-3}$$

$$R(s_0)_{\mu\mu} = (2.63 \pm 0.29) 10^{-3}$$

- Additional $O(5\%)$ uncertainty due to nonlocal power corrections $O(\alpha_s \Lambda / m_b)$

How to compute the hadronic matrix elements $\mathcal{O}(m_b)$?

Exclusive modes $B \rightarrow K^*\gamma$ or $B \rightarrow K^*\ell^+\ell^-$

Naive approach:

Parametrize the hadronic matrix elements in terms of form factors

Exclusive modes $B \rightarrow K^*\gamma$ or $B \rightarrow K^*\ell^+\ell^-$

QCD-improved factorization: BBNS 1999

$$T_a^{(i)} = C_a^{(i)} \xi_a + \phi_B \otimes T_a^{(i)} \otimes \phi_{a,K^*} + O(\Lambda/m_b)$$

Existence of 'non-factorizable' strong interaction effects
which do *not* correspond to form factors

Exclusive modes $B \rightarrow K^*\gamma$ or $B \rightarrow K^*\ell^+\ell^-$

QCD-improved factorization: BBNS 1999

$$T_a^{(i)} = C_a^{(i)} \xi_a + \phi_B \otimes T_a^{(i)} \otimes \phi_{a,K^*} + O(\Lambda/m_b)$$

- Separation of perturbative hard kernels from process-independent nonperturbative functions like form factors
- Relations between formfactors in large-energy limit
- Limitation: insufficient information on power-suppressed Λ/m_b terms
(breakdown of factorization: 'endpoint divergences')

Phenomenologically highly relevant issue

general strategy of LHCb to look at ratios of exclusive modes

Egede,Hurth,Matias,Ramon,Reece,arXiv:0807.2589,arXiv:1005.0571

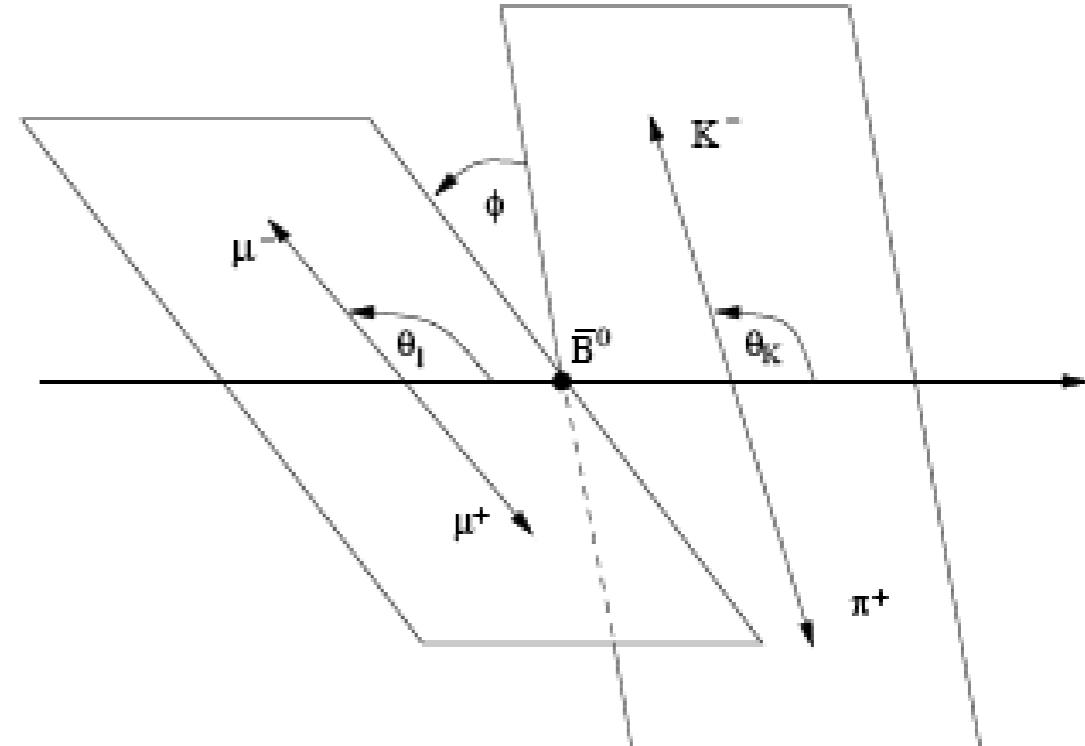
see also Altmannshofer et al.,arXiv:0811.1214; Bobeth et al.,arXiv:0805.2525

Kinematics

- Assuming the \bar{K}^* to be on the mass shell, the decay $\bar{B}^0 \rightarrow \bar{K}^{*0}(\rightarrow K^-\pi^+) \ell^+ \ell^-$ described by the lepton-pair invariant mass, s , and the three angles θ_l , θ_{K^*} , ϕ .

After summing over the spins of the final particles:

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



$$J(q^2, \theta_l, \theta_K, \phi) =$$

$$\begin{aligned}
 &= J_{1s} \sin^2 \theta_K + J_{1c} \cos^2 \theta_K + (J_{2s} \sin^2 \theta_K + J_{2c} \cos^2 \theta_K) \cos 2\theta_l + J_3 \sin^2 \theta_K \sin^2 \theta_l \cos 2\phi \\
 &\quad + J_4 \sin 2\theta_K \sin 2\theta_l \cos \phi + J_5 \sin 2\theta_K \sin \theta_l \cos \phi + (J_{6s} \sin^2 \theta_K + J_{6c} \cos^2 \theta_K) \cos \theta_l \\
 &\quad + J_7 \sin 2\theta_K \sin \theta_l \sin \phi + J_8 \sin 2\theta_K \sin 2\theta_l \sin \phi + J_9 \sin^2 \theta_K \sin^2 \theta_l \sin 2\phi
 \end{aligned}$$

However: Subtleties in measuring the 12 coefficients J_i

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- Angular distribution functions: depend on the 6 complex K^* spin amplitudes

$$J_i = J_i(A_{\perp L/R}, A_{\parallel L/R}, A_{0L/R}) \quad A_{\perp,\parallel} = (H_{+1} \mp H_{-1})/\sqrt{2}, \quad A_0 = H_0$$

- By inspection one finds: $J_{1s} = 3J_{2s}$, $J_{1c} = -J_{2c}$

Moreover, $J_{6c} = 0$ for $m_{lepton} = 0$

12 theoretical independent amplitudes A_j

?

\Leftrightarrow 9 independent coefficient functions J_i

Symmetries of $J_i = J_i(A_{\perp L/R}, A_{\parallel L/R}, A_{0L/R})$

Angular distribution spin averaged !

- Global phase transformation of the L amplitudes

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

- Global phase transformations of the R amplitudes

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

- Continuous $L-R$ rotation

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

Only 9 amplitudes A_j are independent in respect to the angular distribution

Observables as $F(I_i)$ are also invariant under the 3 symmetries !

Additional symmetry

Observation -correlations in the Monte-Carlo fit between different A_i -guided us to fourth symmetry:

$$n'_i = \begin{bmatrix} e^{i\phi_L} & 0 \\ 0 & e^{-i\phi_R} \end{bmatrix} \begin{bmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{bmatrix} \begin{bmatrix} \cosh i\tilde{\theta} & -\sinh i\tilde{\theta} \\ -\sinh i\tilde{\theta} & \cosh i\tilde{\theta} \end{bmatrix} n_i$$

$$n_1 = (A_{\parallel}^L, A_{\parallel}^{R*}), \quad n_2 = (A_{\perp}^L, -A_{\perp}^{R*}), \quad n_3 = (A_0^L, A_0^{R*}),$$

where ϕ_L , ϕ_R , θ and $\tilde{\theta}$ can be varied independently

There is an additional non-trivial relationship between the angular distributions J_i

$$\begin{aligned} J_{1s} &= 3J_{2s} & J_{1c} &= -J_{2c} & J_{1c} &= 6 \frac{(2J_{1s} + 3J_3)(4J_4^2 + J_7^2) + (2J_{1s} - 3J_3)(J_5^2 + 4J_8^2)}{16J_1^{s2} - 9(4J_3^2 + J_6^{s2} + 4J_9^2)} \\ & & & & & - 36 \frac{J_{6s}(J_4J_5 + J_7J_8) + J_9(J_5J_7 - 4J_4J_8)}{16J_{1s}^2 - 9(4J_3^2 + J_{6s}^2 + 4J_9^2)}. \end{aligned}$$

Careful design of theoretical clean angular observables

Egede,Hurth,Matias,Ramon,Reece,arXiv:0807.2589,arXiv:1005.0571

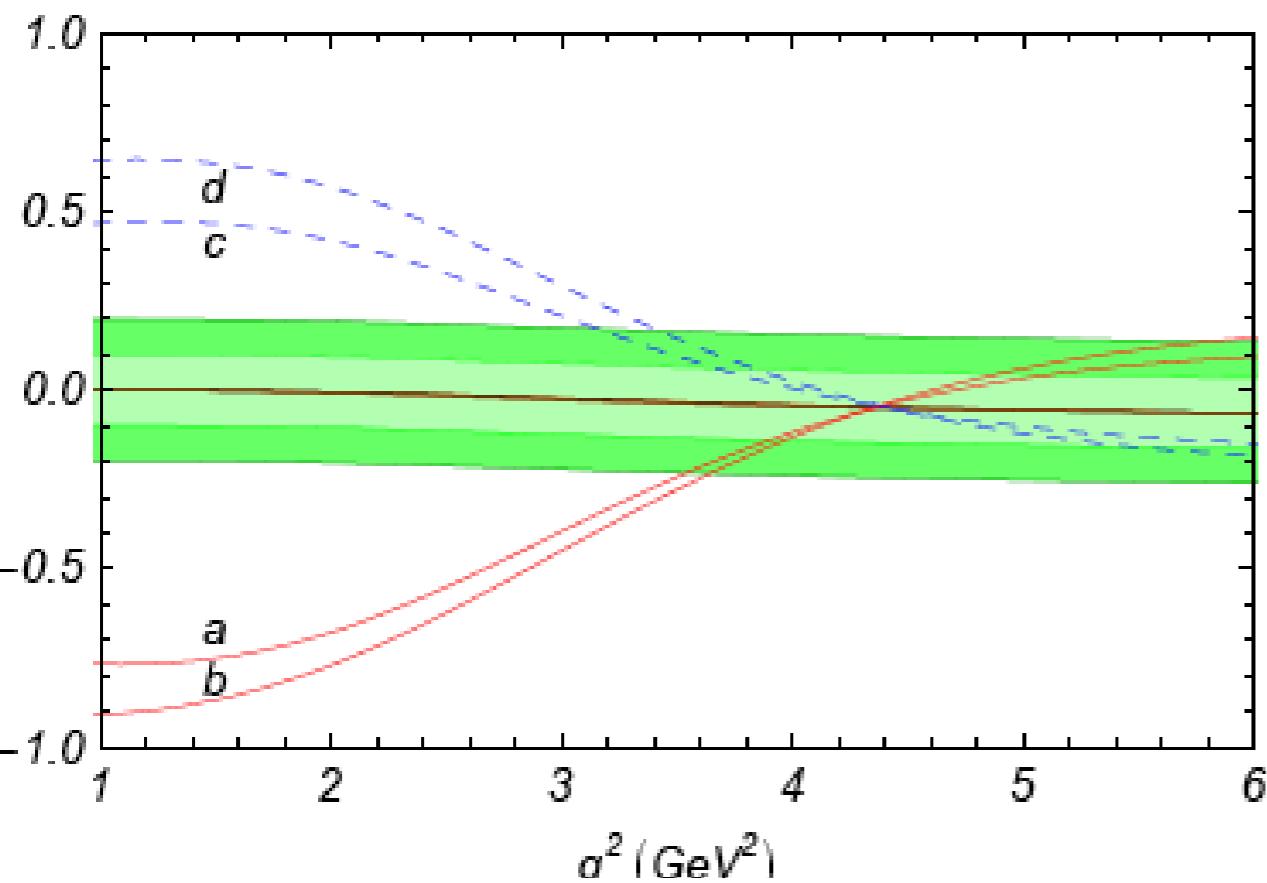
- Observables have to respect all symmetries of the angular distribution
- Good sensitivity to NP contributions, i.e. to $C_7^{eff'}$
- Small theoretical uncertainties
 - Dependence of soft form factors, ξ_{\perp} and ξ_{\parallel} , to be minimized !
form factors should cancel out exactly at LO, best for all s
 - unknown Λ/m_b power corrections
$$A_{\perp,\parallel,0} = A_{\perp,\parallel,0}^0 (1 + c_{\perp,\parallel,0})$$
 vary c_i in a range of $\pm 10\%$ and also of $\pm 5\%$
 - Scale dependence of NLO result
 - Input parameters
- Good experimental resolution

Optimised basis of clean (formfactor-independent) observables: P_i

Descotes-Genon, Hurth, Matias, Virto arXiv:1303.5794

Careful design of theoretical clean angular observables

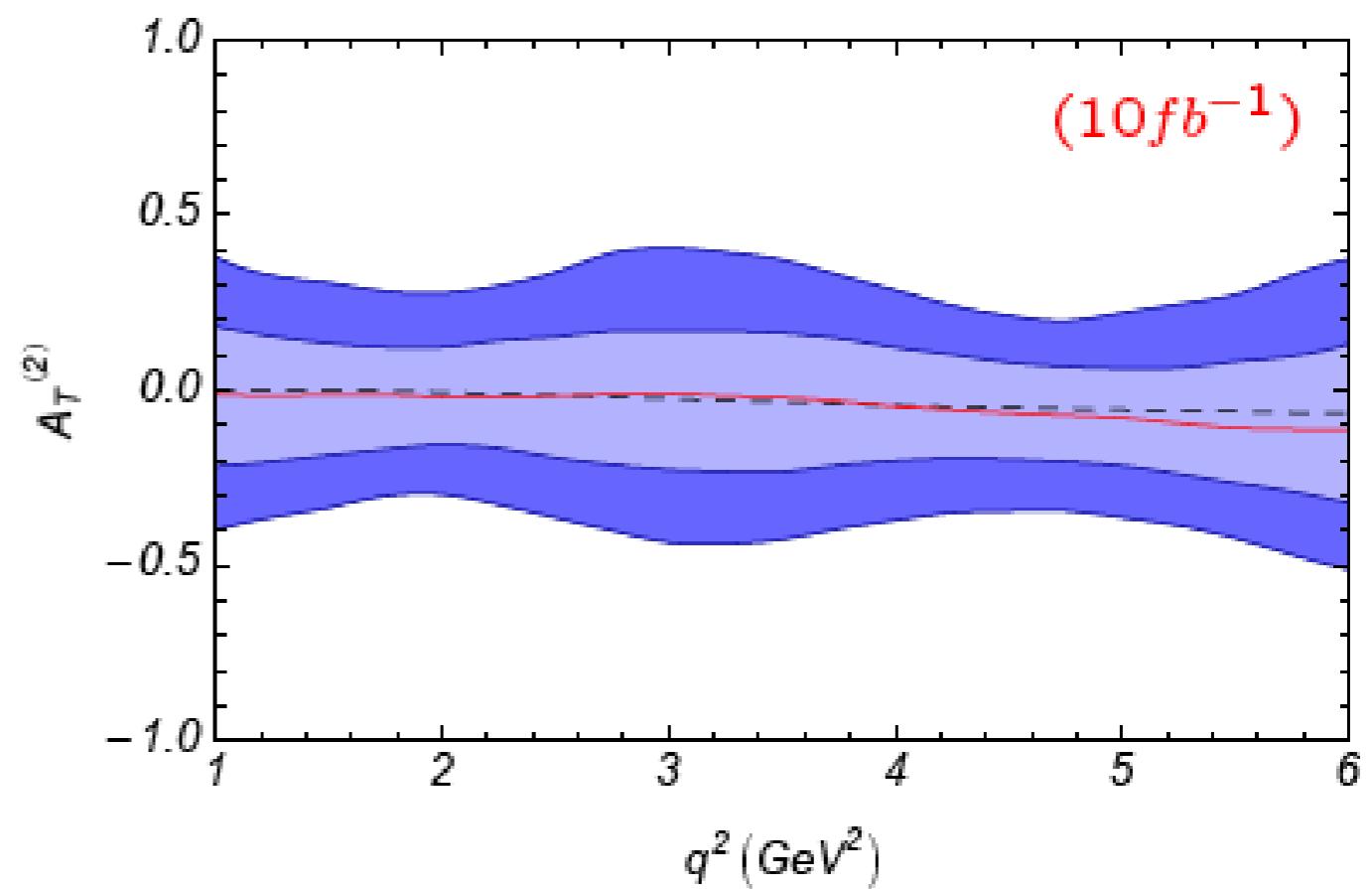
$$A_T^{(2)} = \frac{|A_{\perp}|^2 - |A_{\parallel}|^2}{|A_{\perp}|^2 + |A_{\parallel}|^2}$$



Theoretical sensitivity

light green $\pm 5\% \Lambda/m_b$

dark green $\pm 10\% \Lambda/m_b$



Experimental sensitivity

light green 1 σ

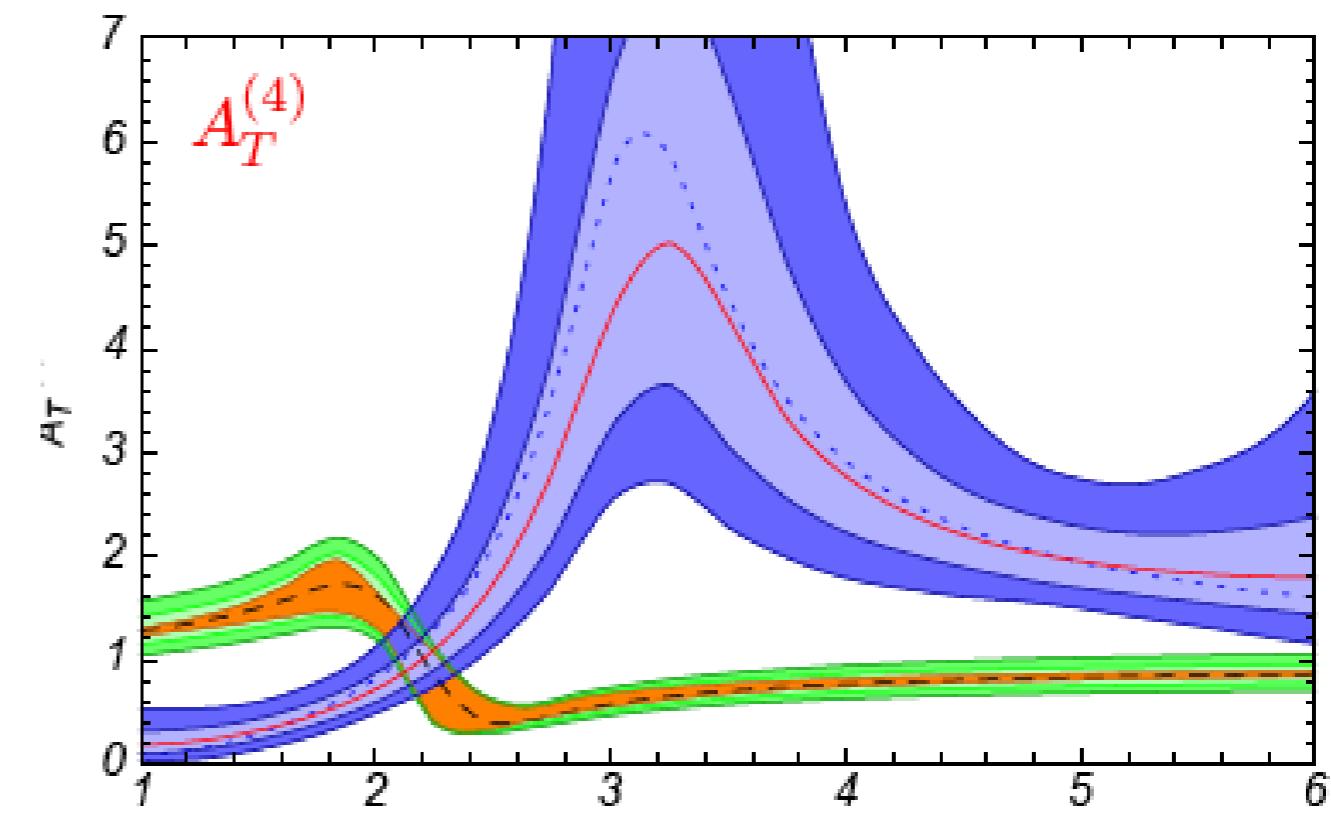
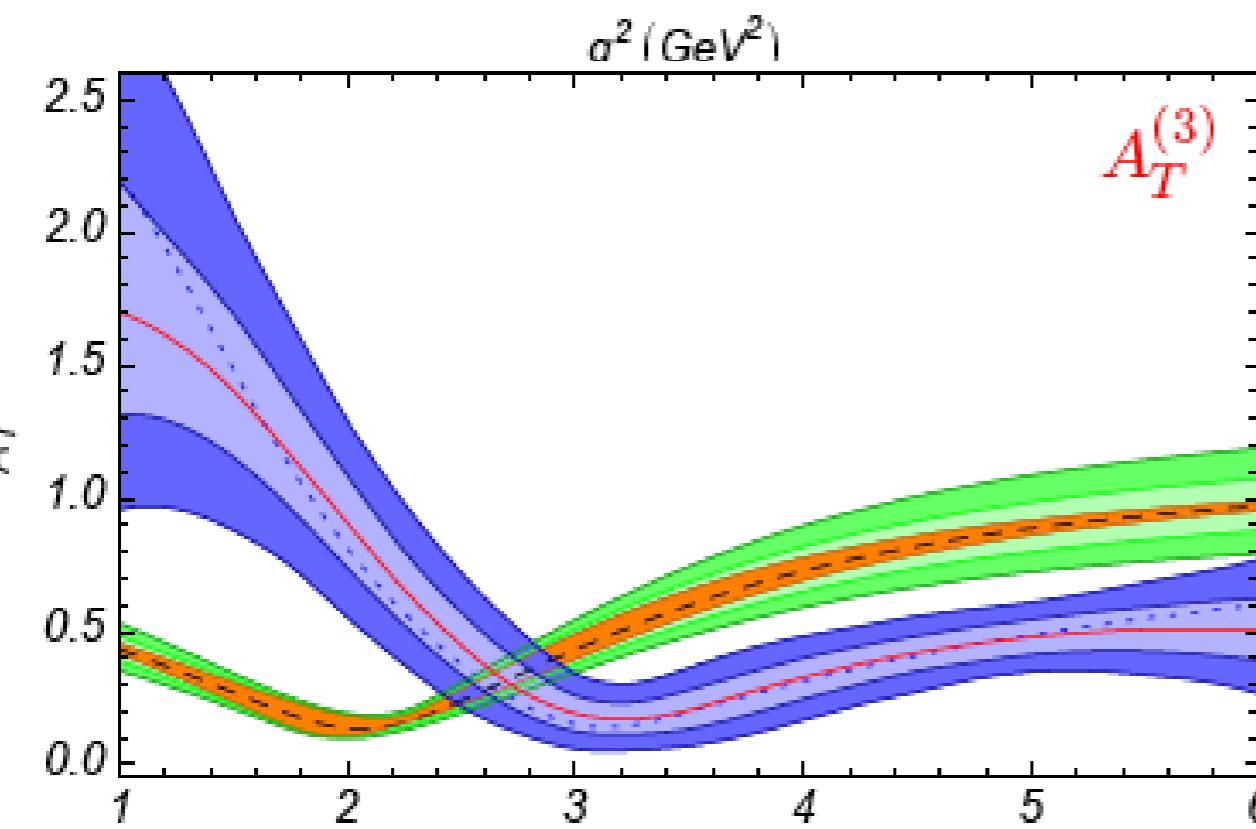
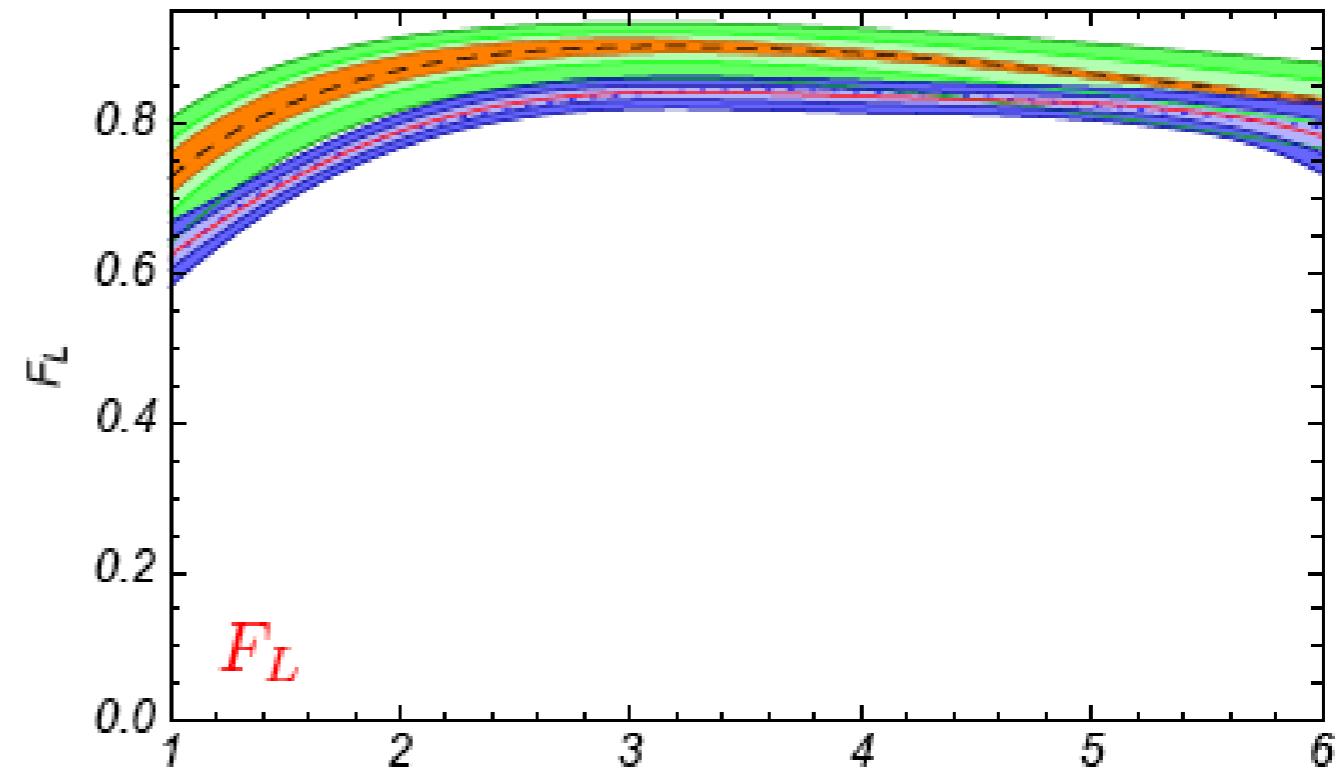
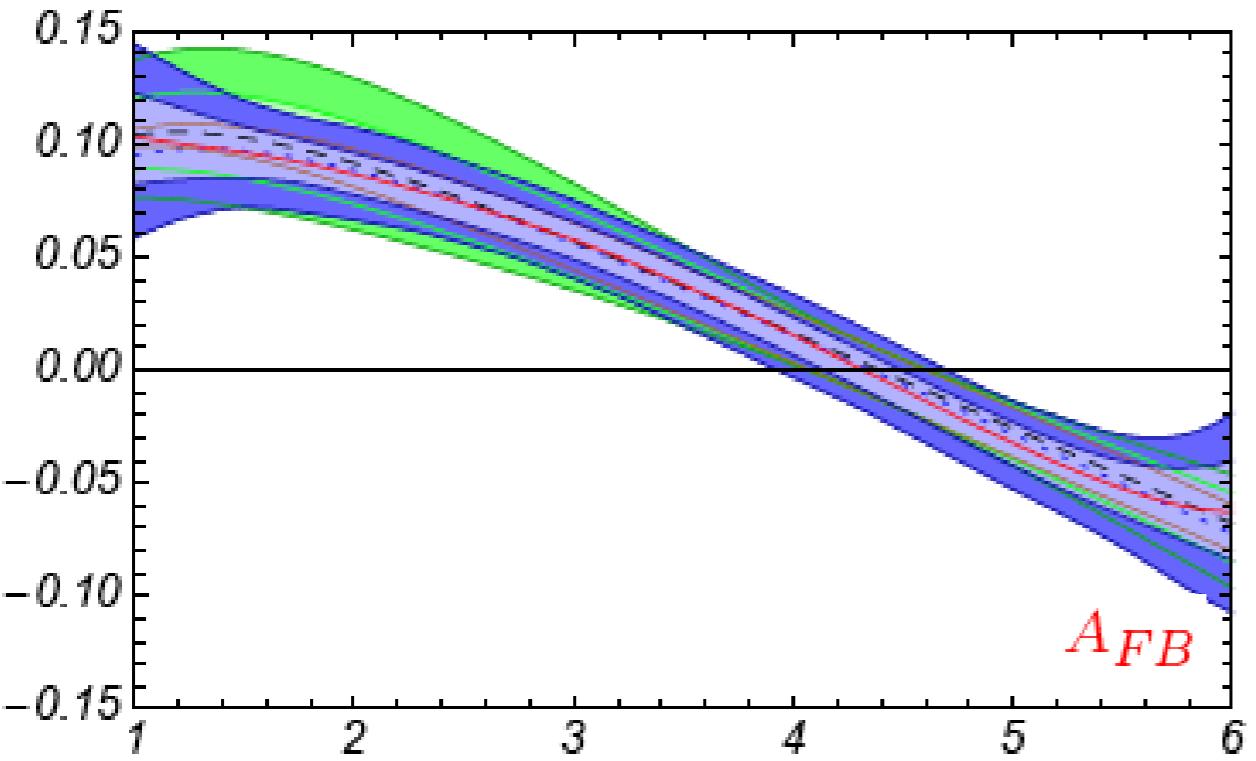
dark green 2 σ

SuperLHC/SuperB can offer more precision

Crucial: theoretical status of Λ/m_b corrections has to be improved

Comparison of NP reach of old and new observables

Egede,Hurth,Matias,Ramon,Reece,arXiv:0807.2589,arXiv:1005.0571



The experimental errors assuming SUSY scenario (b) with large-gluino mass and positive mass insertion , is compared to the theoretical errors assuming the SM .

Definition of P'_5

$$n_{\parallel} = \begin{pmatrix} A_{\parallel}^L \\ A_{\parallel}^{R*} \end{pmatrix}, \quad n_{\perp} = \begin{pmatrix} A_{\perp}^L \\ -A_{\perp}^{R*} \end{pmatrix}, \quad n_0 = \begin{pmatrix} A_0^L \\ A_0^{R*} \end{pmatrix}$$

$$P_1 = \frac{|n_{\perp}|^2 - |n_{\parallel}|^2}{|n_{\perp}|^2 + |n_{\parallel}|^2} = \frac{J_3}{2J_{2s}},$$

$$P_2 = \frac{\text{Re}(n_{\perp}^\dagger n_{\parallel})}{|n_{\parallel}|^2 + |n_{\perp}|^2} = \beta_\ell \frac{J_{6s}}{8J_{2s}},$$

$$P_3 = \frac{\text{Im}(n_{\perp}^\dagger n_{\parallel})}{|n_{\parallel}|^2 + |n_{\perp}|^2} = -\frac{J_9}{4J_{2s}},$$

$$P_4 = \frac{\text{Re}(n_0^\dagger n_{\parallel})}{\sqrt{|n_{\parallel}|^2 |n_0|^2}} = \frac{\sqrt{2} J_4}{\sqrt{-J_{2c}(2J_{2s} - J_3)}},$$

$$P_5 = \frac{\text{Re}(n_0^\dagger n_{\perp})}{\sqrt{|n_{\perp}|^2 |n_0|^2}} = \frac{\beta_\ell J_5}{\sqrt{-2J_{2c}(2J_{2s} + J_3)}},$$

$$P_6 = \frac{\text{Im}(n_0^\dagger n_{\parallel})}{\sqrt{|n_{\parallel}|^2 |n_0|^2}} = -\frac{\beta_\ell J_7}{\sqrt{-2J_{2c}(2J_{2s} - J_3)}},$$

Redefinition:

$$P'_4 \equiv P_4 \sqrt{1 - P_1} = \frac{J_4}{\sqrt{-J_{2c}J_{2s}}}$$

$$P'_5 \equiv P_5 \sqrt{1 + P_1} = \frac{J_5}{2\sqrt{-J_{2c}J_{2s}}}$$

$$P'_6 \equiv P_6 \sqrt{1 - P_1} = -\frac{J_7}{2\sqrt{-J_{2c}J_{2s}}}$$

$B \rightarrow K^* \ell^+ \ell^-$ observables in the high- q^2 region

Grinstein,Pirjol hep-ph/0404250, Beylich,Buchalla,Feldmann arXiv:1101.5118
Bobeth,Hiller,van Dyk arXiv:1006.5013,1105.0376

local operator product expansion is applicable ($q^2 \sim m_b^2$)

the leading power corrections are shown to be suppressed by $(\Lambda/m_b)^2$ or $\alpha_s \Lambda/m_b$

Magnitude of Λ/m_b can be estimated due to existence of an OPE/HQET

Formfactors at high- q^2 : extrapolation, future unquenched lattice results

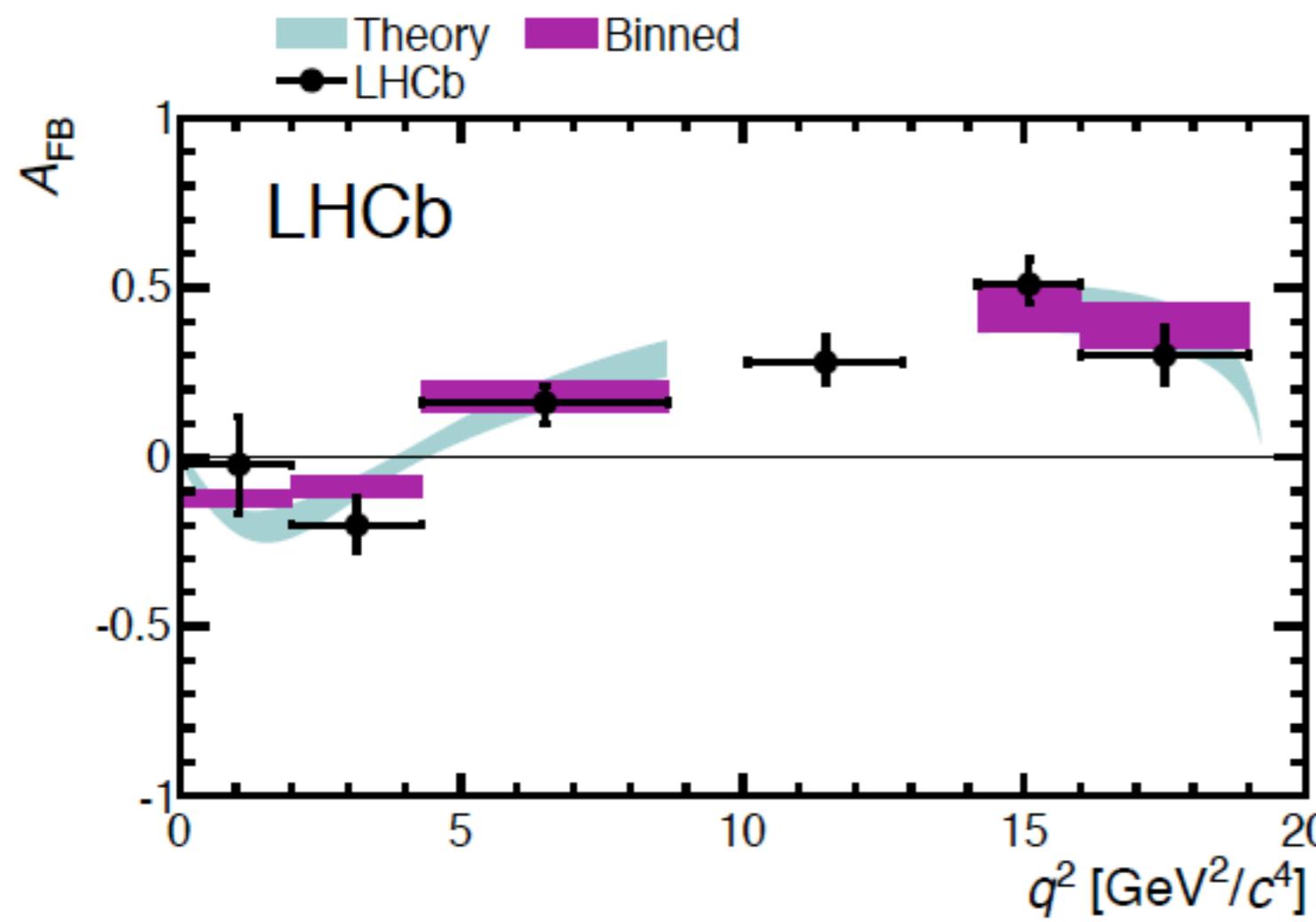
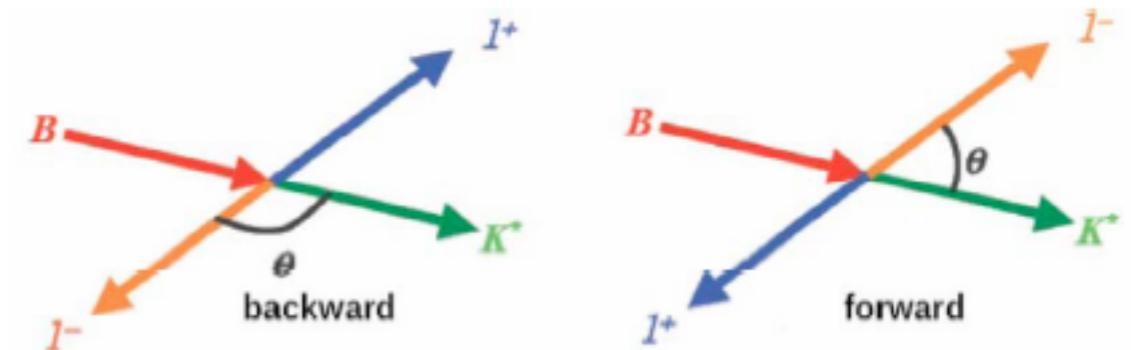
thus, small theoretical uncertainties,
but less sensitivity to short-distance
Wilson coefficients than in the low- q^2 region

The theoretical treatment in the low- and high- q^2 based
on different theoretical concepts.

⇒ the consistency of the consequences out of the two sets
of measurements will allow for an important crosscheck.

Measurements of forward-backward asymmetry in $B \rightarrow K^* \mu^+ \mu^-$

$$A_{FB} \left(s = m_{\mu^+ \mu^-}^2 \right) = \frac{N_F - N_B}{N_F + N_B}$$



Excellent agreement with SM at current level of precision.

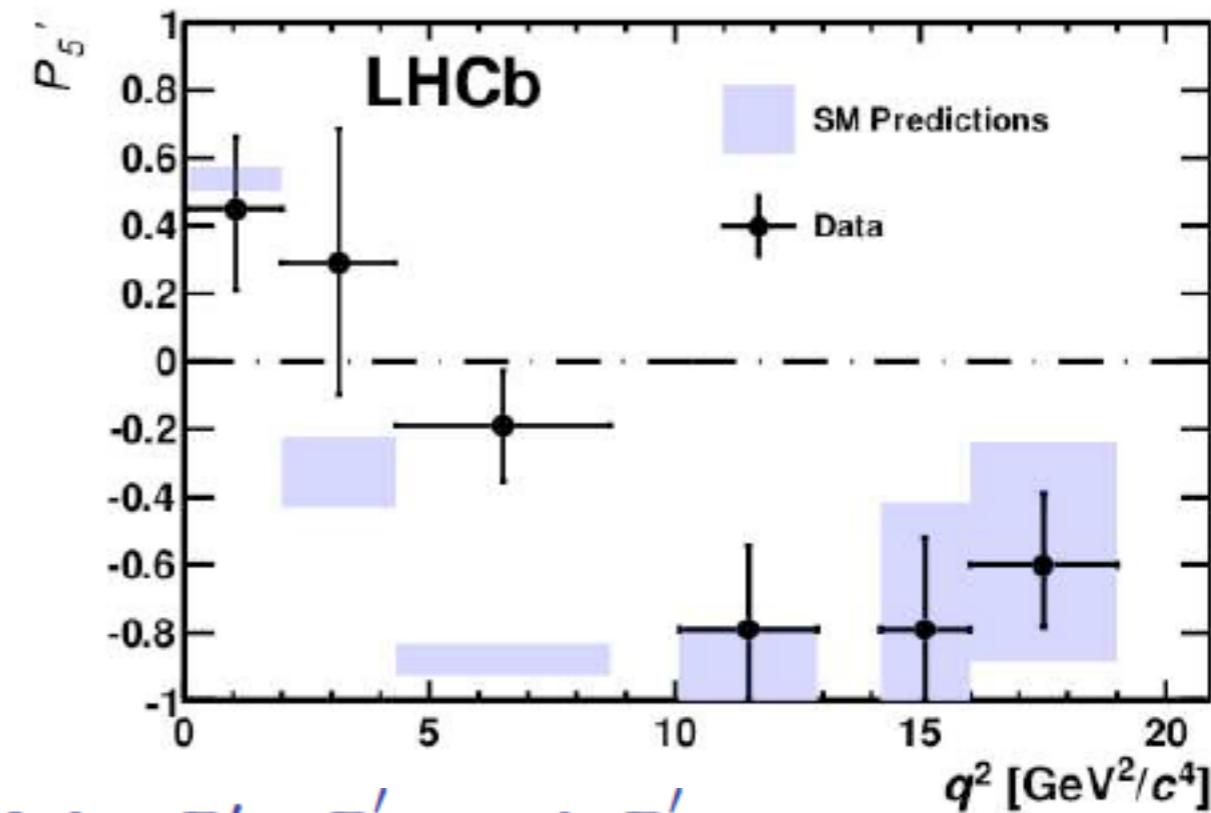
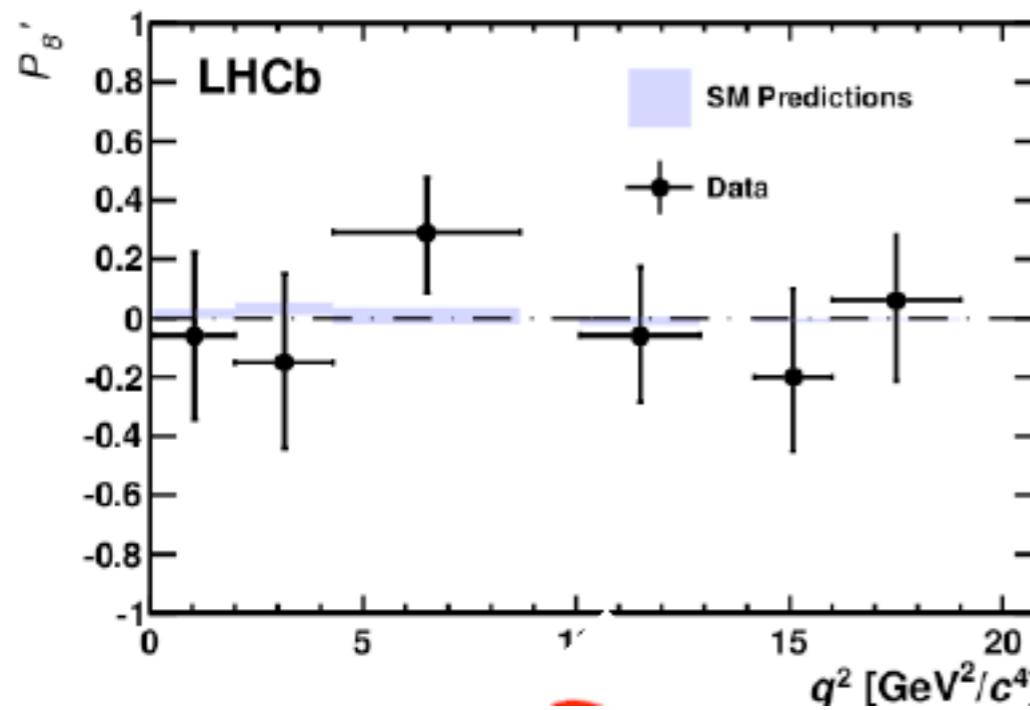
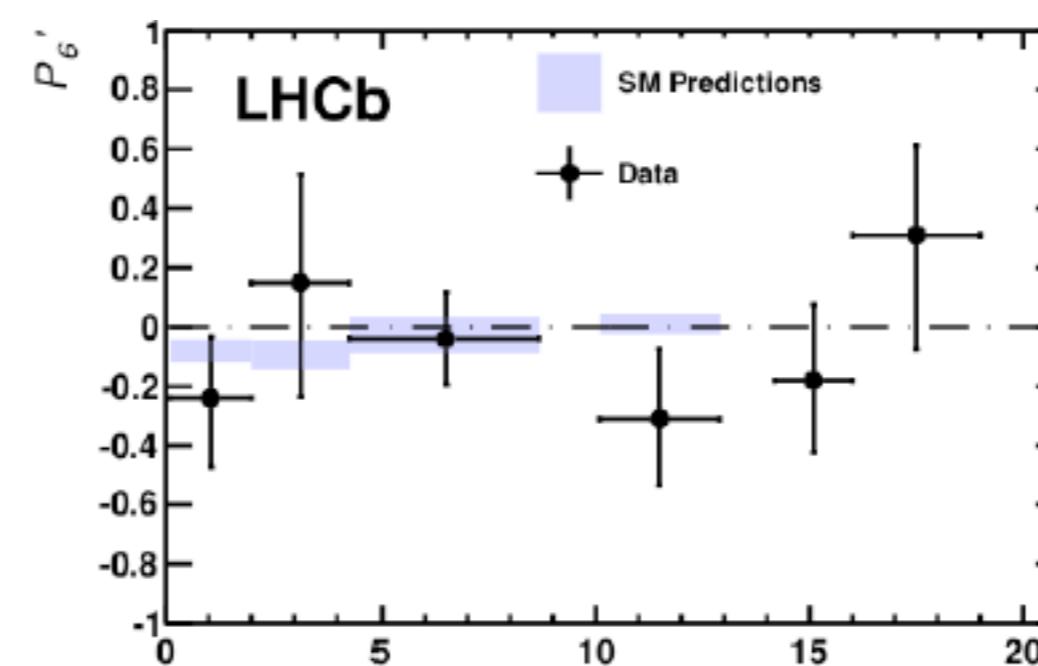
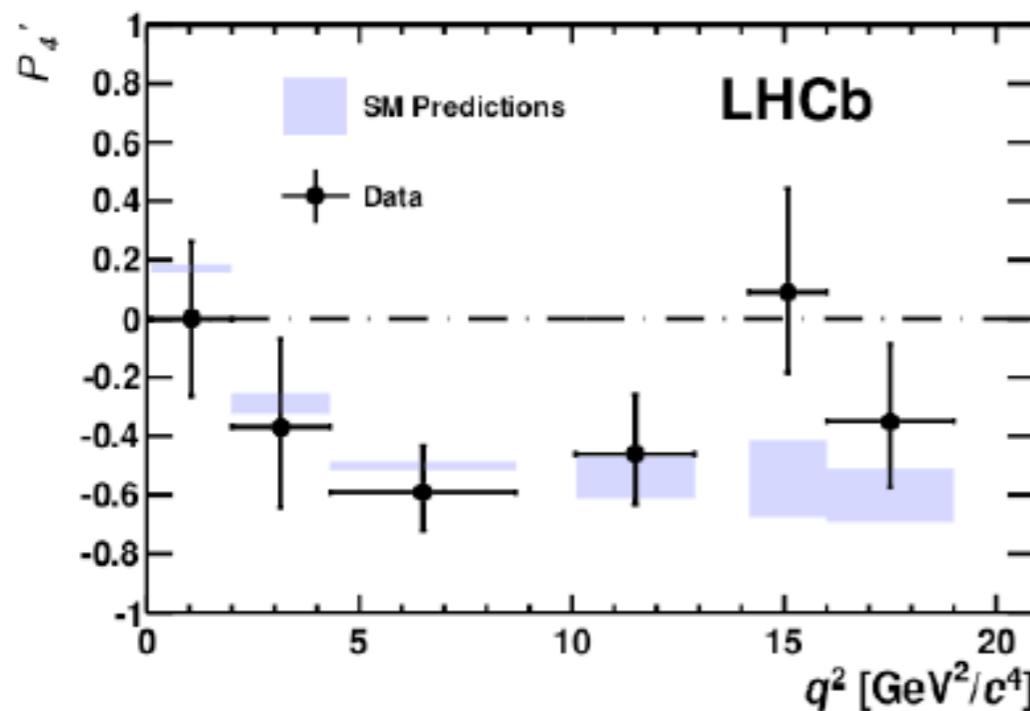
However:

Many more angular observables in $B \rightarrow K^* \mu \mu$ to be measured, more sensitive to NP than AFB.
New flavour structures needed !

LHCb arXiv:1304.6325

First measurements of new angular observables

LHCb arXiv:1308.1707



Good agreement with SM in P'_4 , P'_6 and P'_8 ,

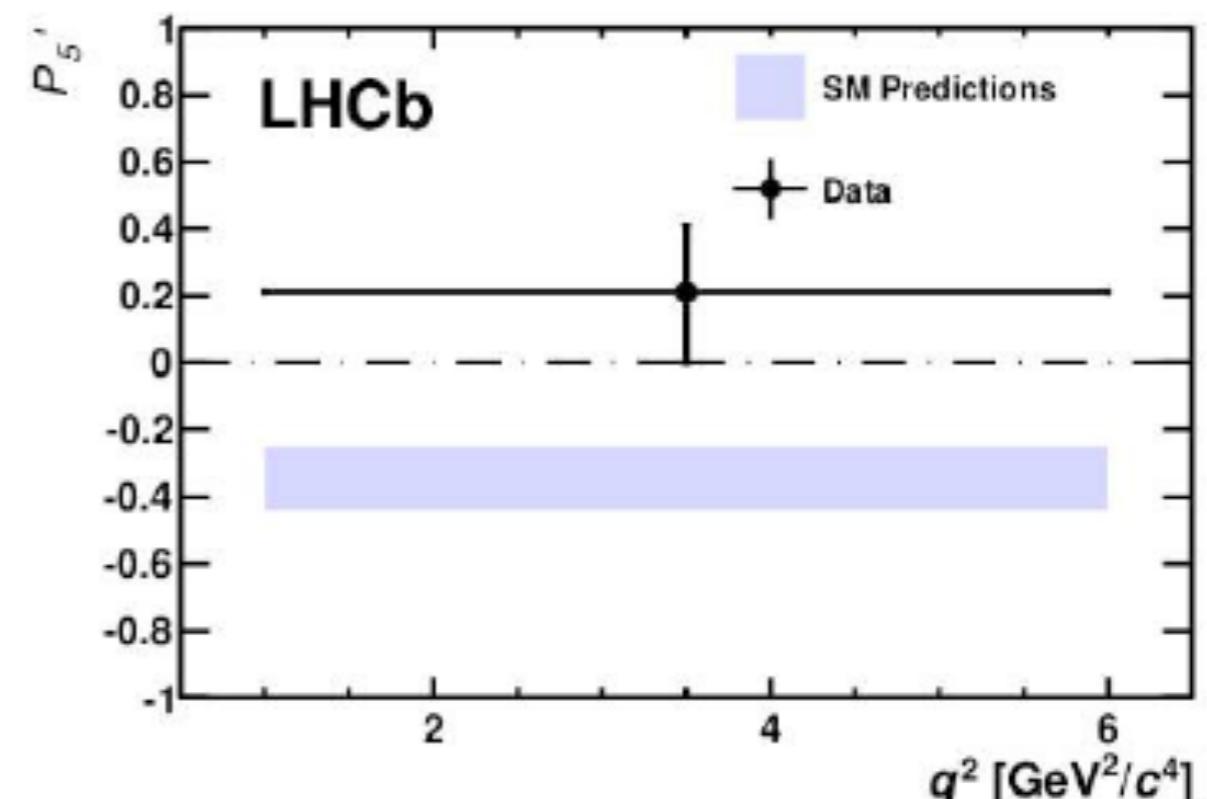
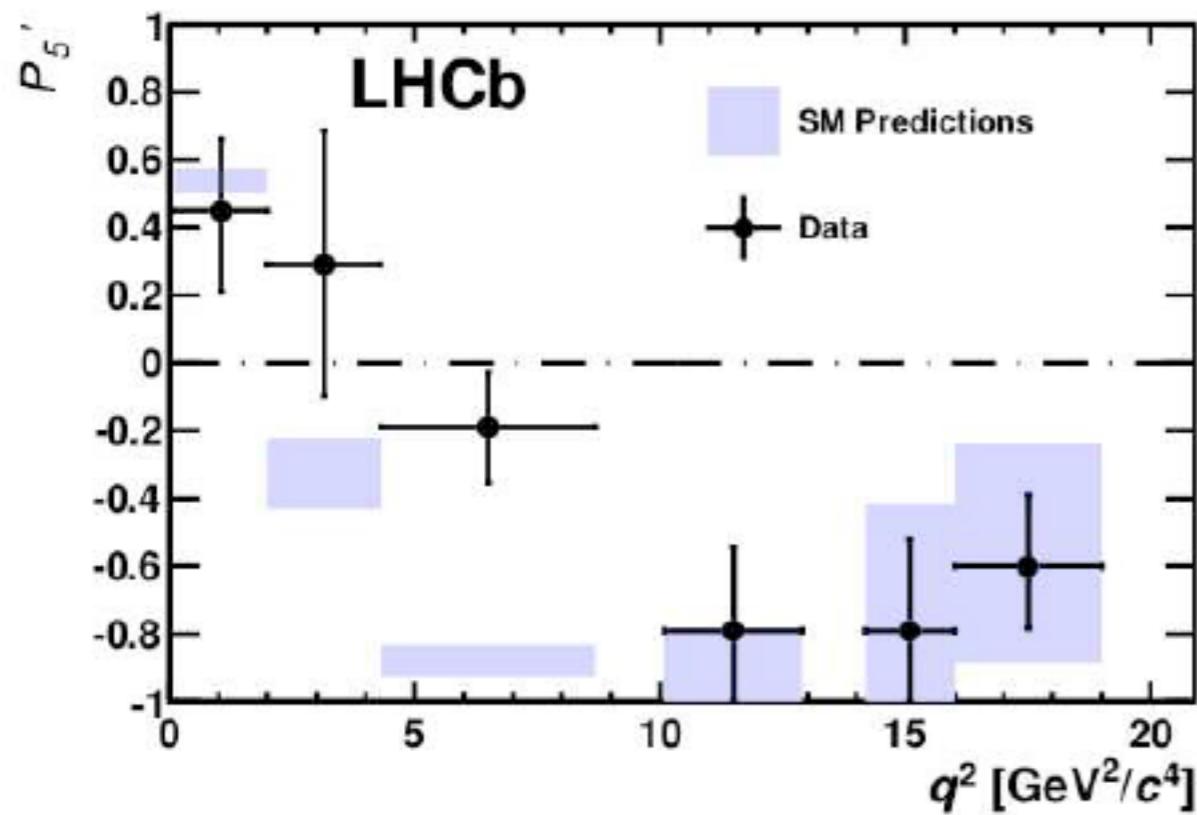
but a 4.0σ deviation in the third bin in P'_5

SM predictions

Descotes-Genon, Hurth, Matias, Virto arXiv:1303.5794

First measurements of new angular observables

LHCb arXiv:1308.1707



LHCb Anomaly

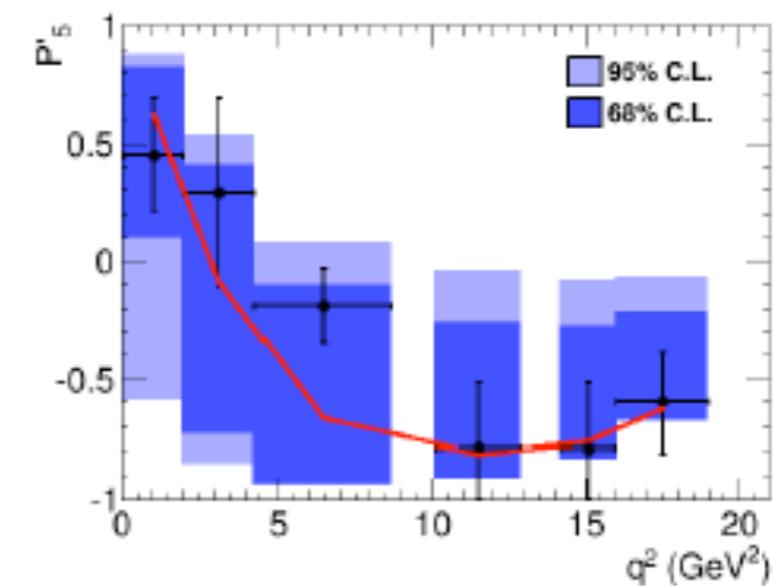
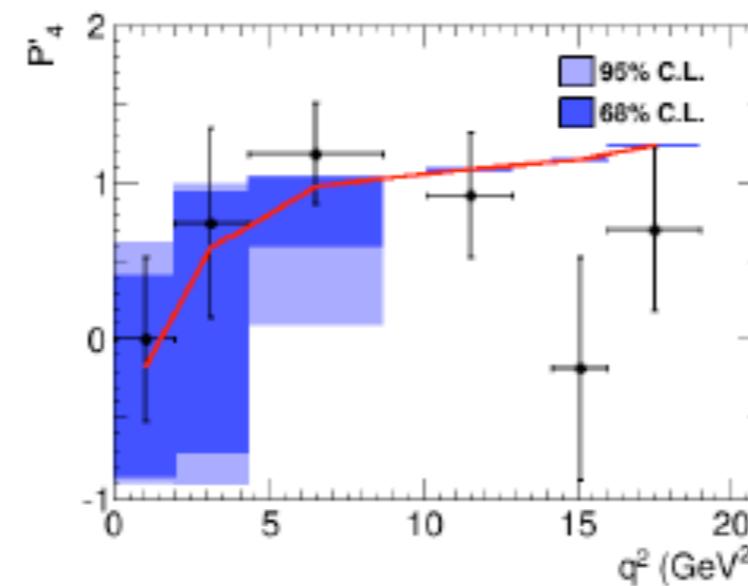
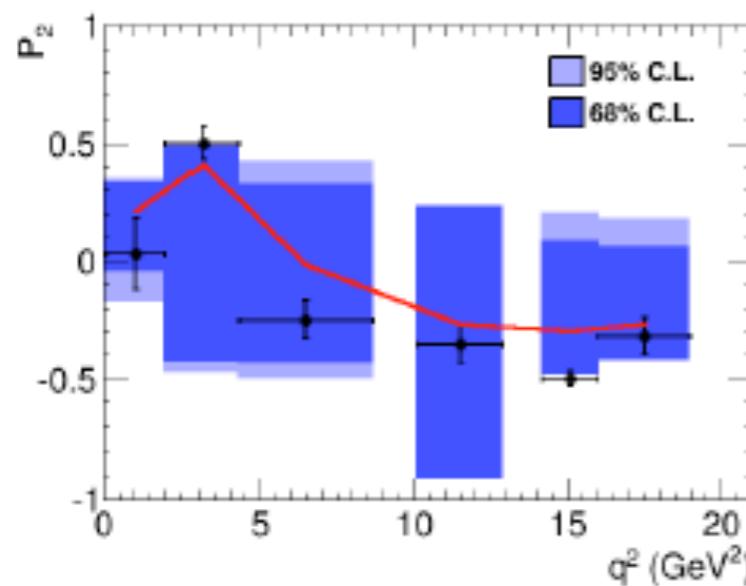
a statistical fluctuation, an underestimation
of Λ/m_b corrections or new physics in C_9 ?

C_7 ($B \rightarrow X_s \gamma$) C_{10} ($B \rightarrow \mu^+ \mu^-$)

- **Power corrections:** No strict theory: $A'_i = A_i(1 + C_i)$, $|C_i| \lesssim 10\%$
3% on the observable level: 4.0σ
More realistic: 10% on the observable level: 3.6σ
Dimensional estimate, some soft arguments
Assume 30% : 2.2σ
- **Validity of QCDF and of perturbative description of charm loops:** $[1\text{GeV}^2, 6\text{GeV}^2]$,
but local bin is $q^2 \in [4.3, 8.63]\text{GeV}^2$
- **Issue of charm loops** Khodjamirian et al. arXiv:1006.4945
Only soft gluon (but no spectator) contributions included yet

- If new physics (negative C_9 and less significant nontrivial C'_9) then it is compatible with the hypothesis of Minimal Flavour Violation

no new flavour structures beyond the SM Yukawa needed



MFV predictions for P_2 , P'_4 , and P'_5

- **Crosscheck with the high- q^2 region:**
 - hadronic uncertainties better under control (OPE)

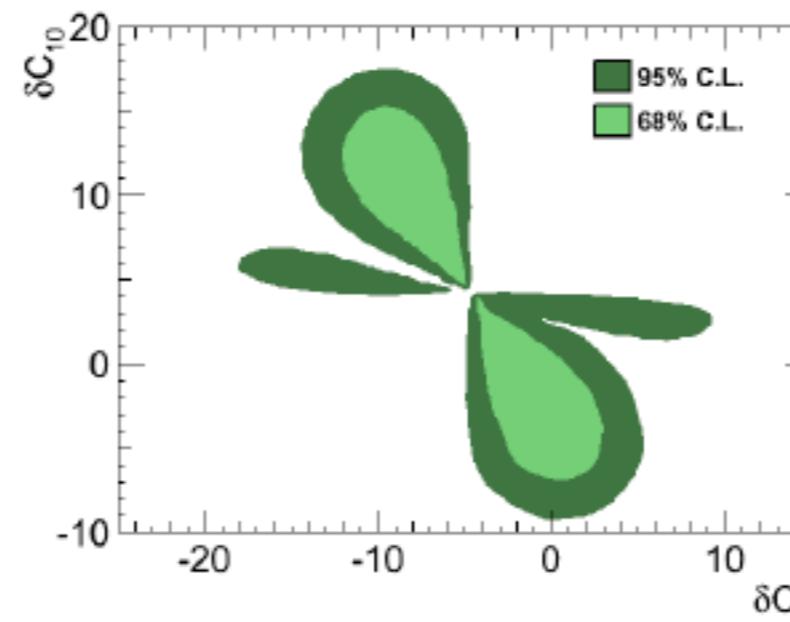
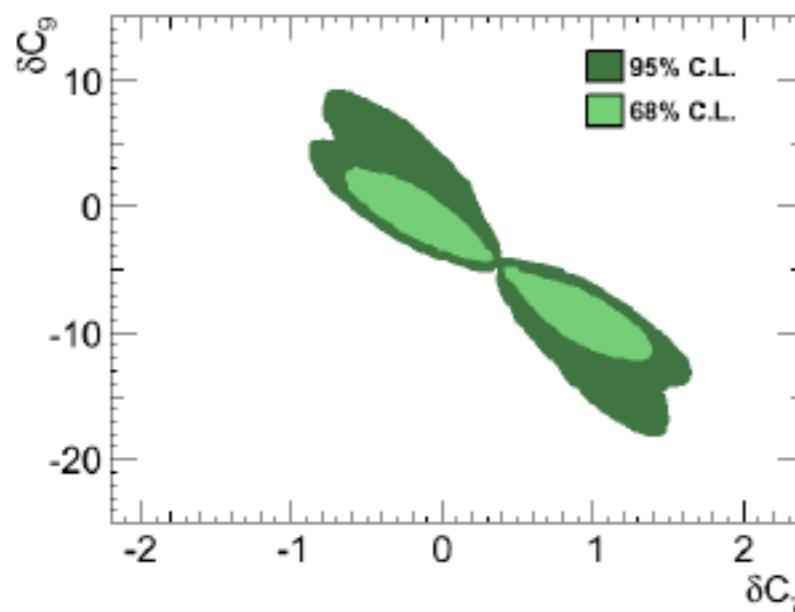
New lattice calculations are nicely compatible
with the best fit solution in low- q^2 region

$$C_9^{NP} = -1.0 \pm 0.6; C'_9 = 1.2 \pm 1.0$$

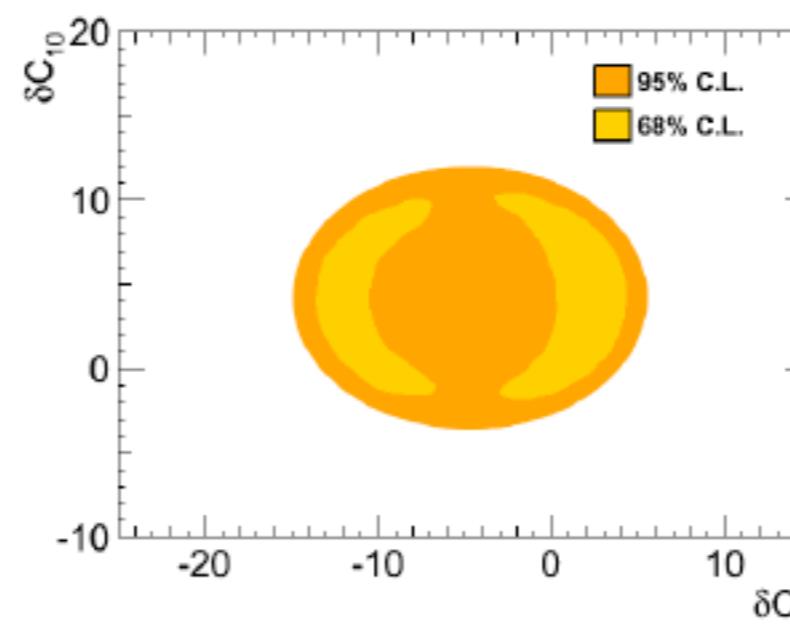
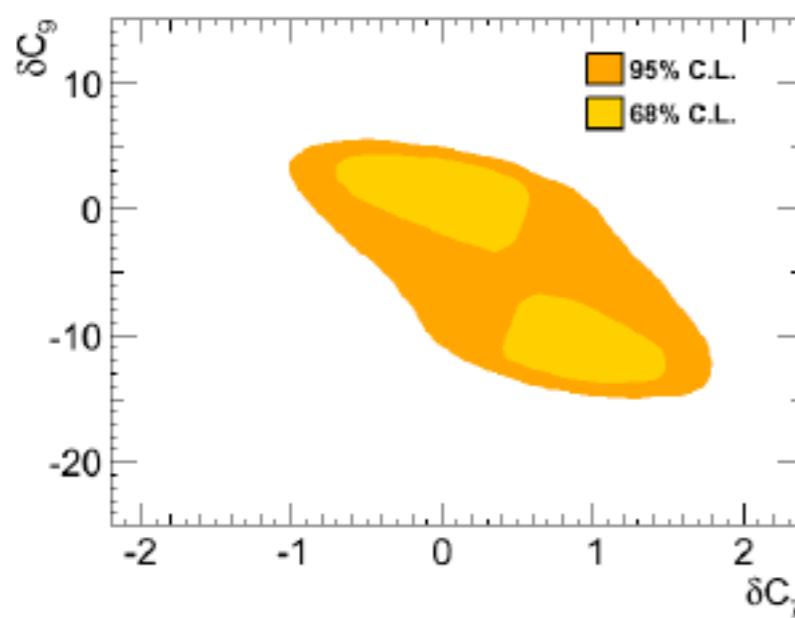
(low- q^2 : $C_9^{NP} \in [-1.6, -0.9]$; $C'_9 \in [-0.2, 0.8]$ (1σ))

Horgan,Liu,Meinel,Wingate arXiv:1310.3887

- Crosscheck with Inclusive mode



Exclusive observables

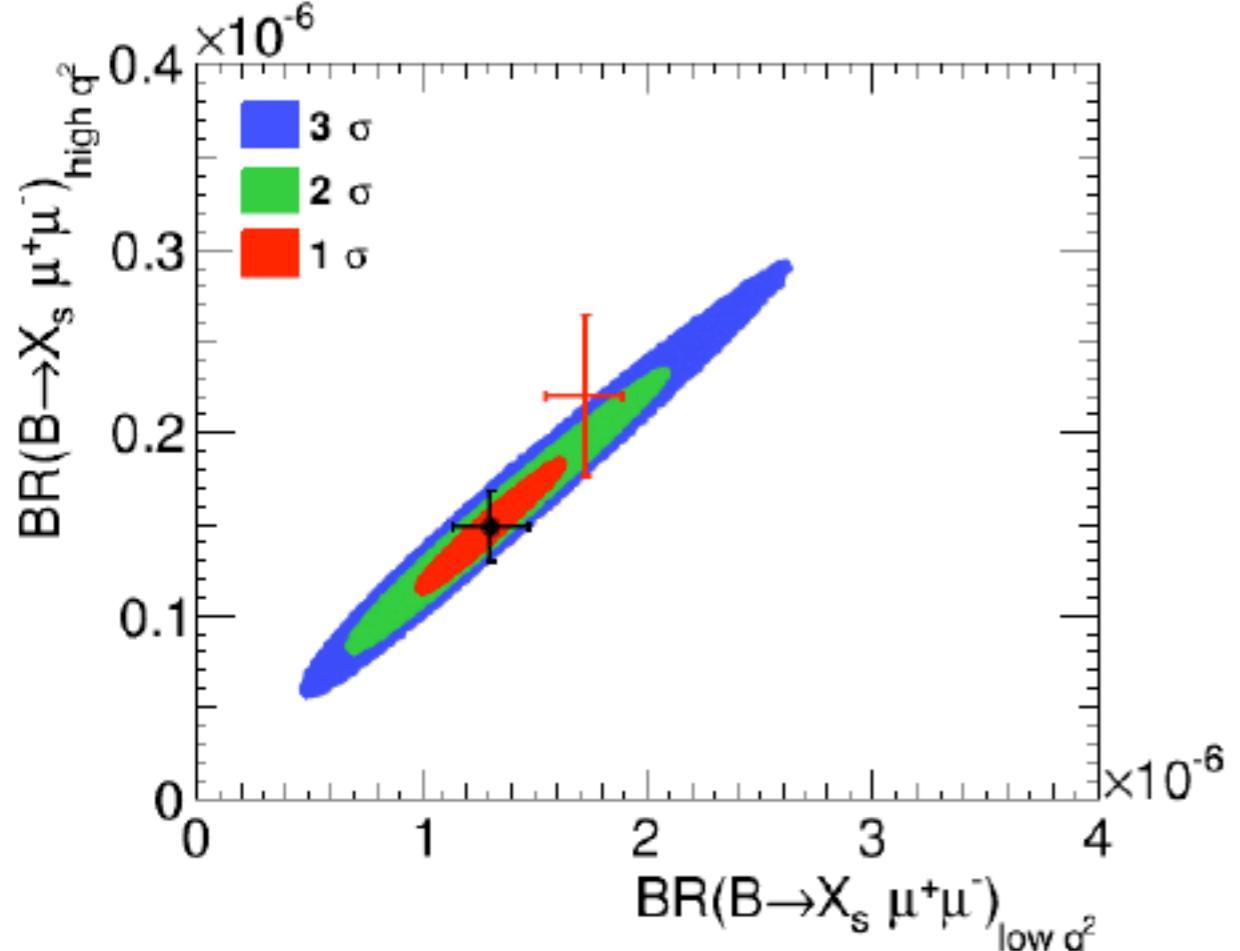


Inclusive observables

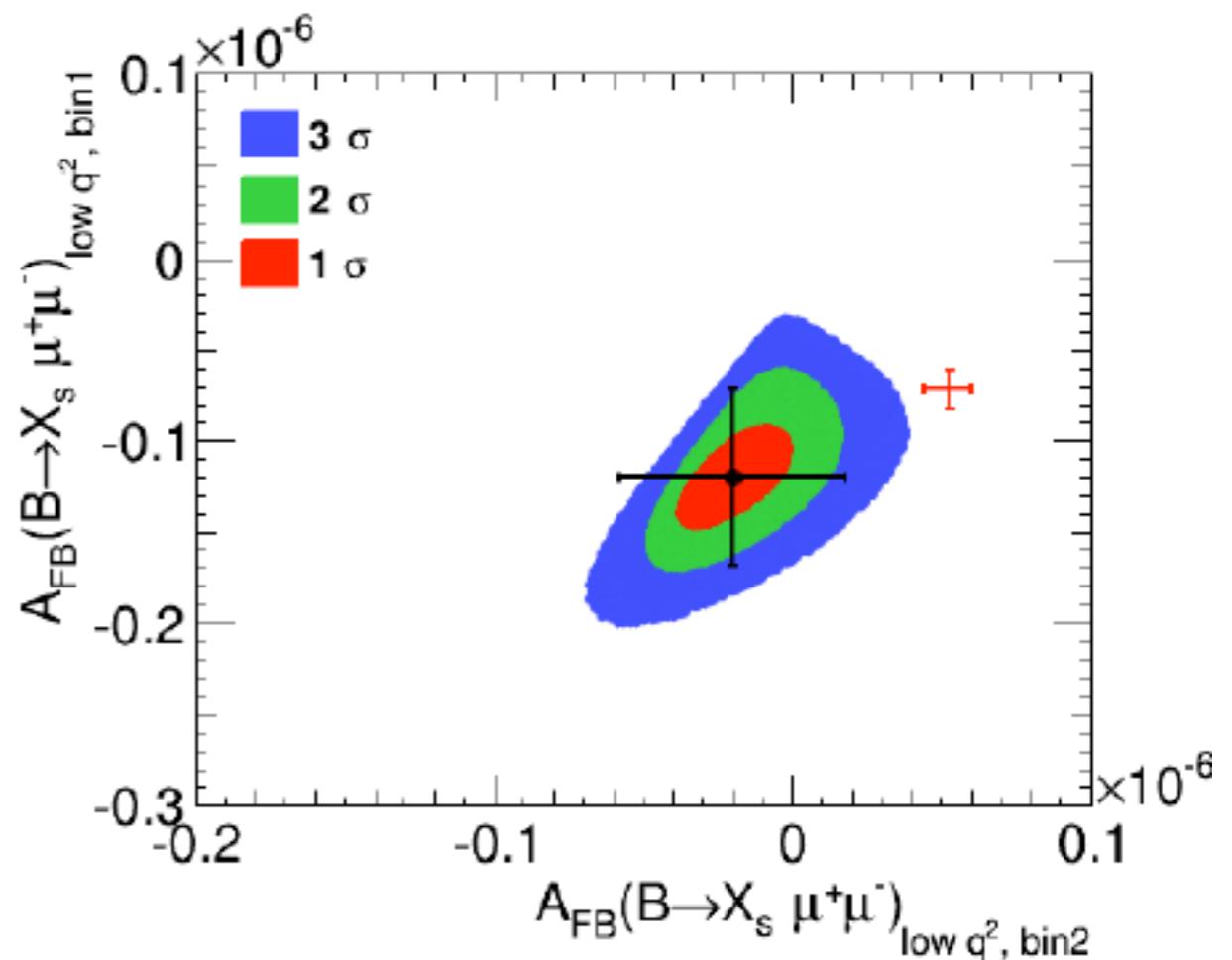
inclusive data of 2004 only

New Babar analysis on dilepton spectrum arXiv:1312.3664

New Belle analysis on AFB arXiv:1402.7134



Assuming 13% uncertainty for the final combined result of B-factories



Future measurement of AFB at the Belle-II Super-B-factory

- **Future opportunities:**

LHCb upgrade: $5 fb^{-1}$ to $50 fb^{-1}$

Super-B Factory Belle-II: $50 ab^{-1}$

• New physics explanations

- "The usual suspects, such as the MSSM, warped extra dimension scenarios, or models with partial compositeness, cannot accommodate the observed deviations"
- Gauld, Goertz, Haisch arXiv:1308.1959;1310.1082
Altmannshofer, Straub arXiv:1308.1501

Coefficient	1σ	2σ	3σ
$\mathcal{C}_7^{\text{NP}}$	[-0.05, -0.01]	[-0.06, 0.01]	[-0.08, 0.03]
$\mathcal{C}_9^{\text{NP}}$	[-1.6, -0.9]	[-1.8, -0.6]	[-2.1, -0.2]
$\mathcal{C}_{10}^{\text{NP}}$	[-0.4, 1.0]	[-1.2, 2.0]	[-2.0, 3.0]
$\mathcal{C}_{7'}^{\text{NP}}$	[-0.04, 0.02]	[-0.09, 0.06]	[-0.14, 0.10]
$\mathcal{C}_{9'}^{\text{NP}}$	[-0.2, 0.8]	[-0.8, 1.4]	[-1.2, 1.8]
$\mathcal{C}_{10'}^{\text{NP}}$	[-0.4, 0.4]	[-1.0, 0.8]	[-1.4, 1.2]

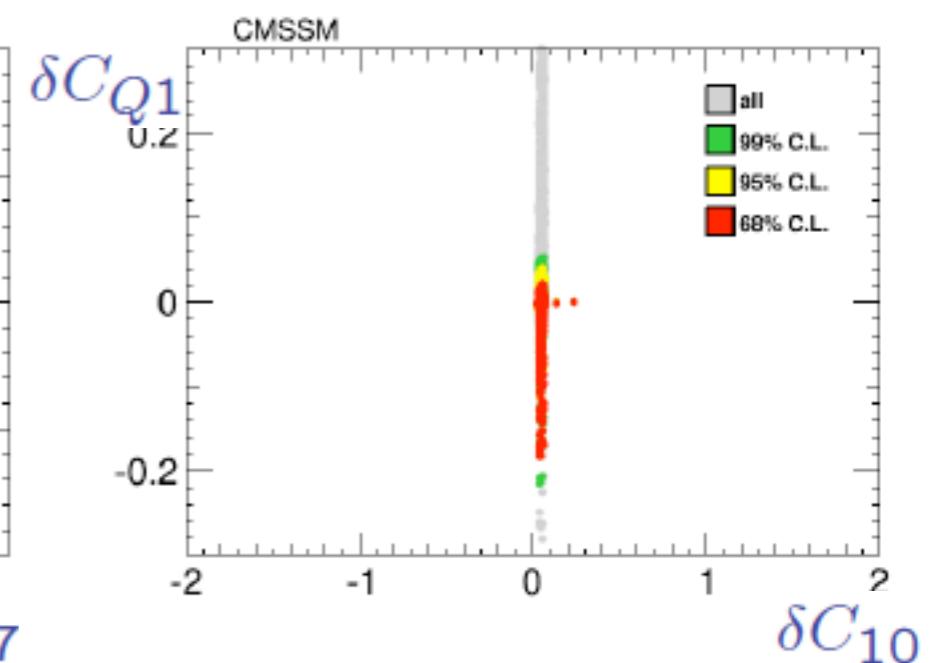
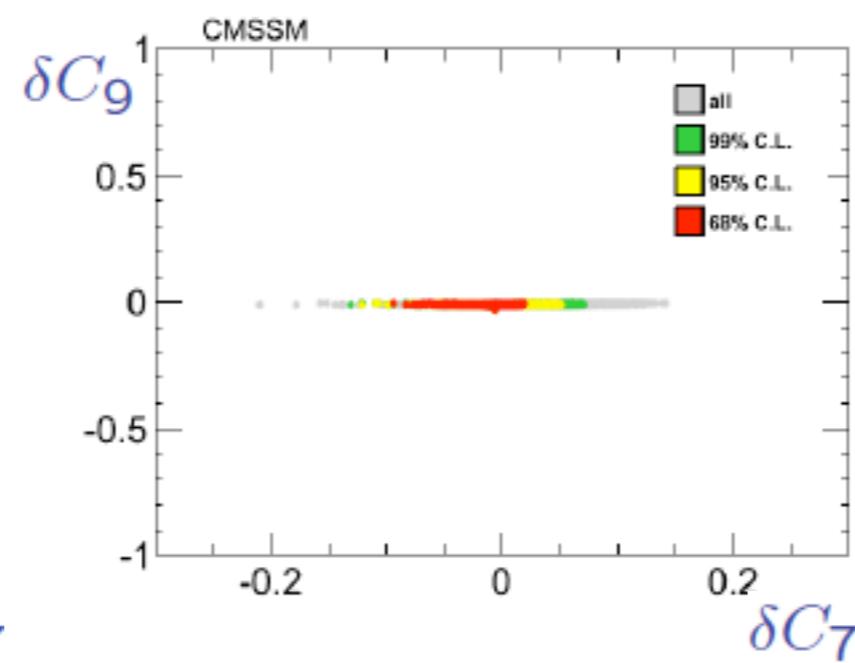
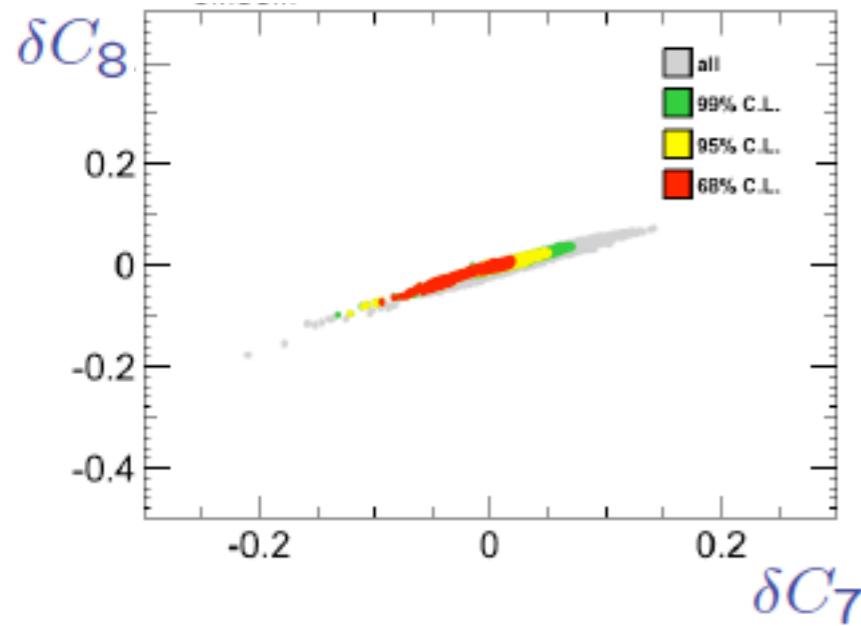
Model-independent analysis Descotes,Matias,Virto arXiv:1307.5683

- 1σ solutions: Z' -models (331-models...): only change C_9
Descotes,Matias,Virto arXiv:1307.5683
Altmannshofer, Straub arXiv:1308.1501
Gauld, Goertz, Haisch arXiv:1308.1959;1310.1082
Buras,De Fazio,Girrbach arXiv:1311.6729
Altmannshofer,Gori,Pospelov,Yavin arXiv:1403.1269

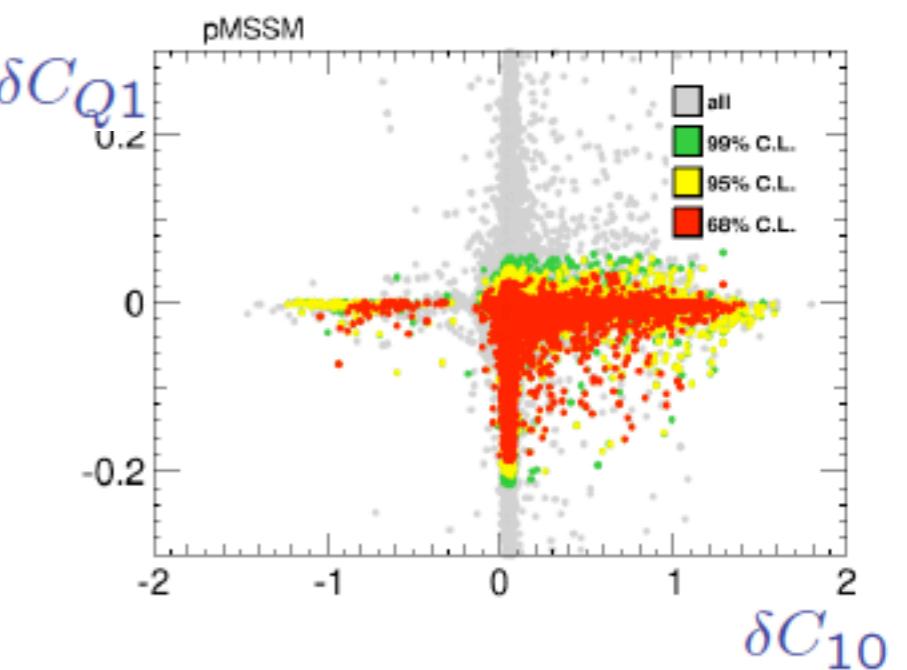
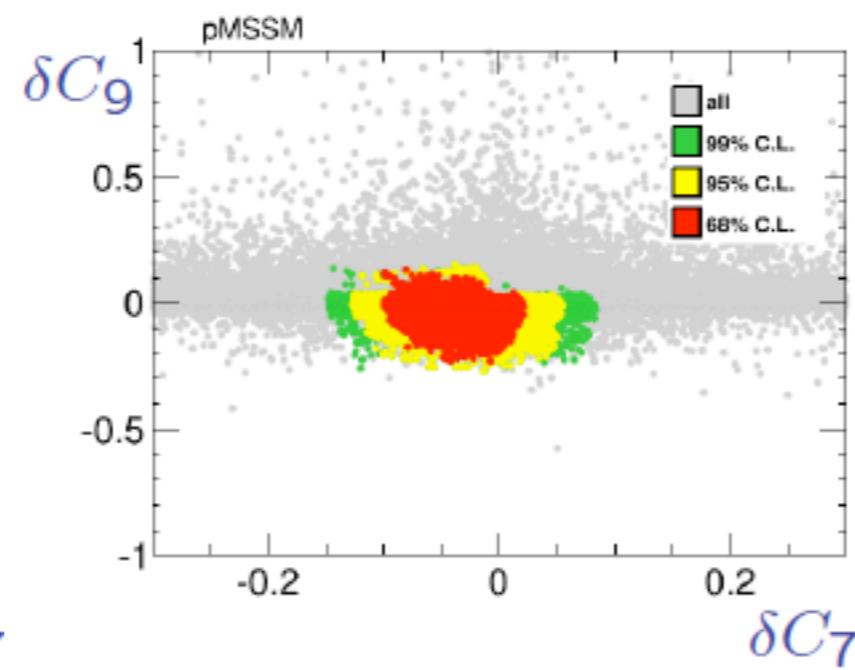
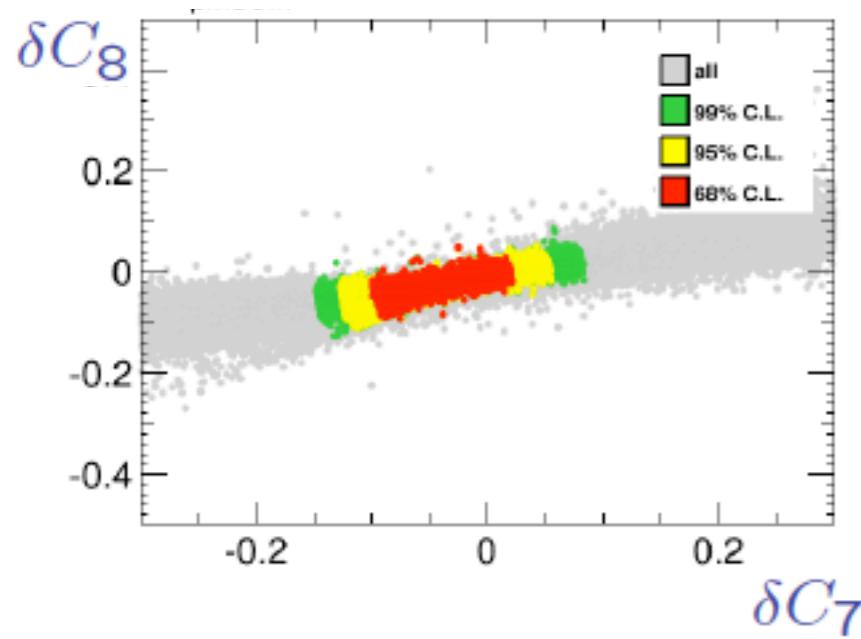
- SUSY are compatible with the anomaly at the 2σ level

Mahmoudi,Neshatpour,Virto arXiv:1401.2145

CMSSM



pMSSM



**Let us wait for the new LHCb analysis based on the
 $3fb^{-1}$ data set !**