Theoretical issues and techniques in bottom and charm physics

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Outline

- Interplay between High-Energy and High-Intensity Physics
- Theoretical Methods:
  - Effective Theories (various B decays)
  - Lattice-QCD (Form Factors, Unitarity Triangle)
  - Light-Cone QCD Sum Rules (won't discuss)
  - Isospin, U-spin Symmetries (α, γ, A_{CP} in $D \to K^+K^-$, $\pi^+\pi^-$)

The Standard Model

$SU(3) \times SU(2) \times U(1)$ has been throughly established:

$$\mathcal{L}_{\text{Gauge}} = \sum_{\psi,a,b} \bar{\psi}_a (i\not{\partial} - g\not{A}\,\delta^{ab})\psi_b$$

Spontaneous EW symmetry breaking via a single Higgs:

$$\mathcal{L}_{\text{Yukawa}} = \sum_{\psi,a,b} \bar{\psi}_{La}\, H\, Y^{ab}\psi_{Rb} = \bar{Q}_L H Y_U u_R + \bar{Q}_L H Y_D d_R + \bar{L}_L H Y_E E_R$$

- Flavor diagonal neutral currents:

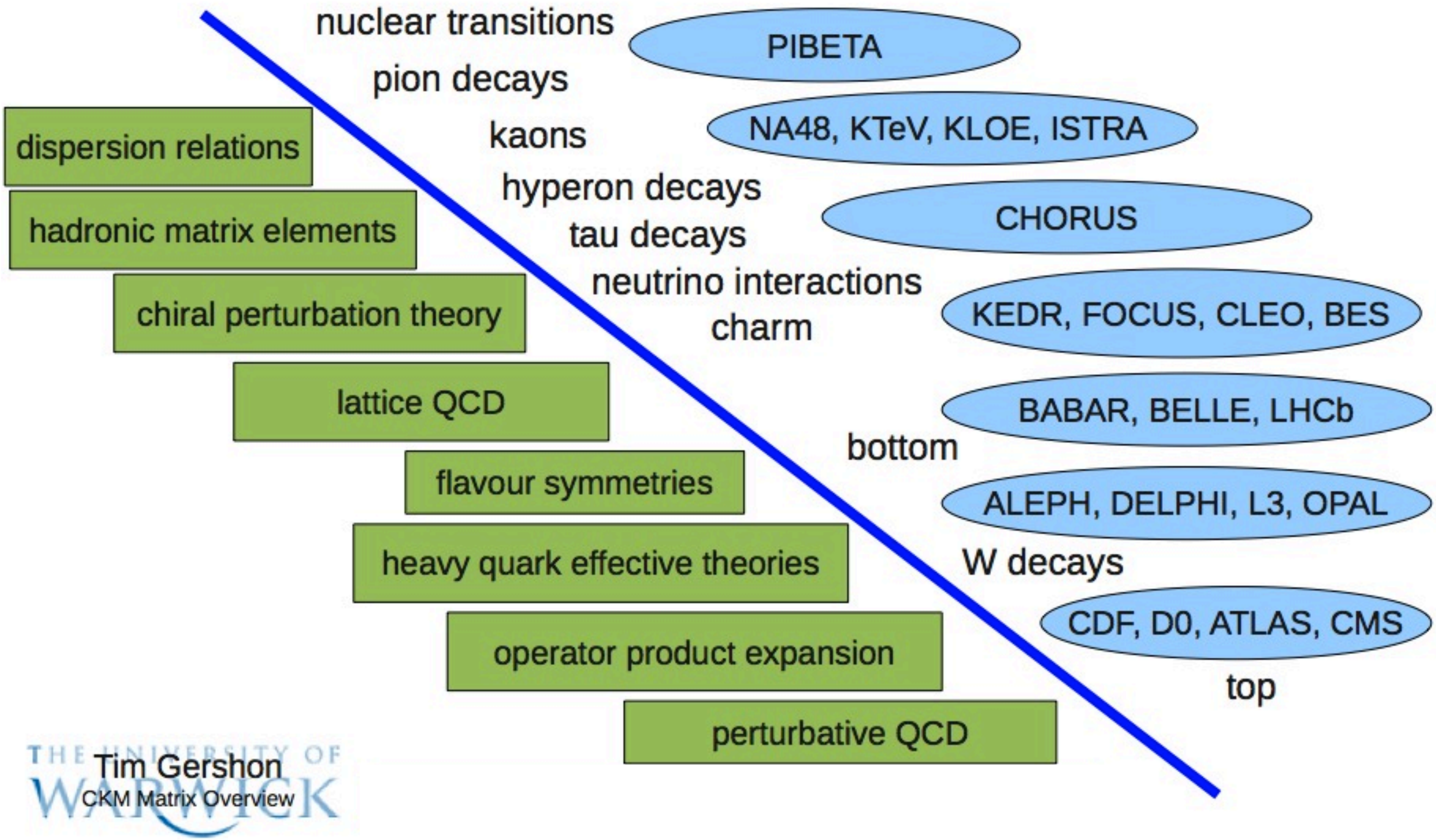
$$\bar{u}_L^0 \not{Z}\, u_L^0 \Longrightarrow \bar{u}_L \not{Z}\, U_L U_L^\dagger u_L = \bar{u}_L \not{Z}\, u_L$$

- Flavor changing charged currents:

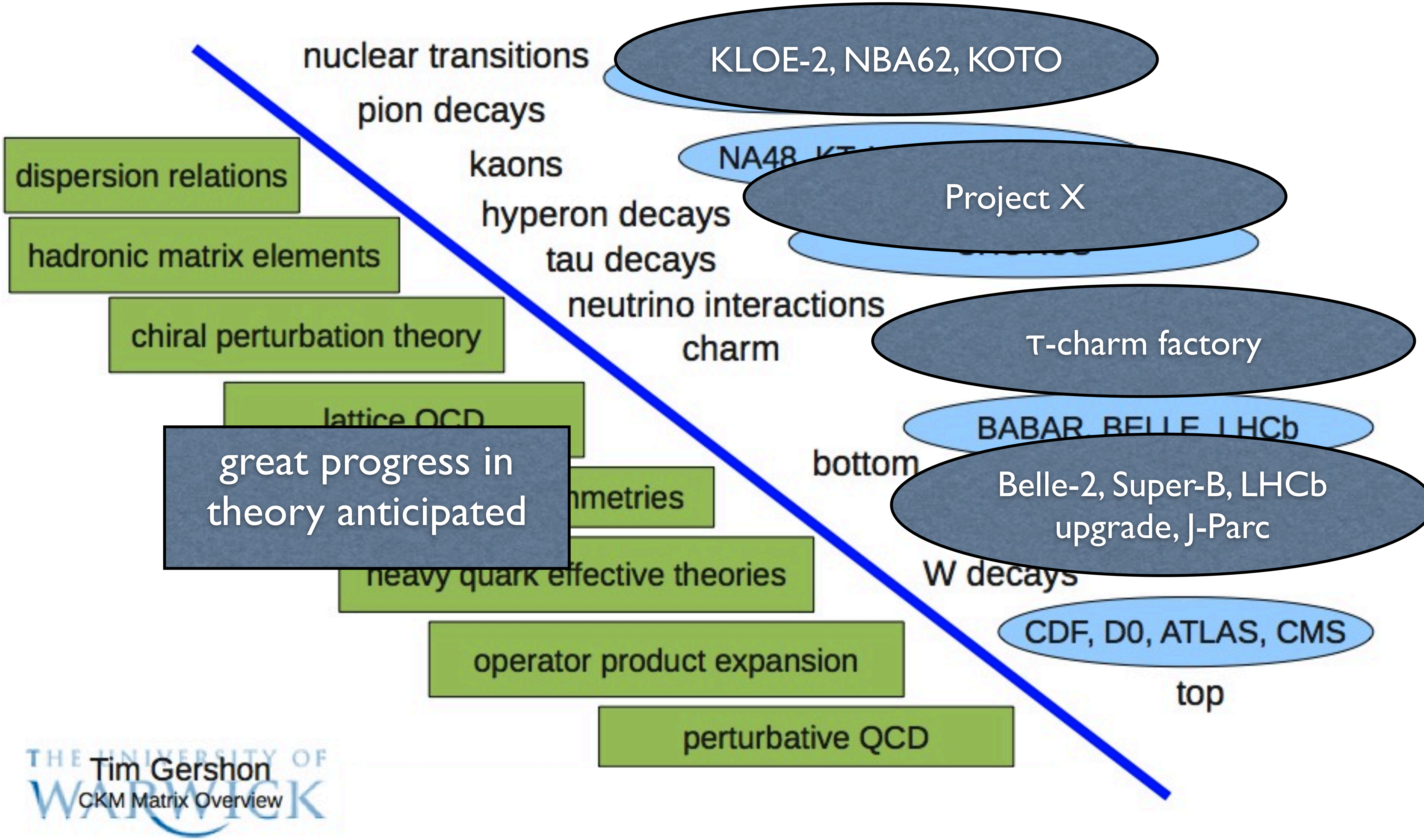
$$\bar{u}_L^0 \not{W} d_L^0 \Longrightarrow \bar{u}_L \not{W} U_L D_L^\dagger d_L = \bar{u}_L \not{W} V_{\text{CKM}} d_L$$

Predictions are very strong and easily affected by NP

The CKM awesome predictive power



The CKM awesome predictive power



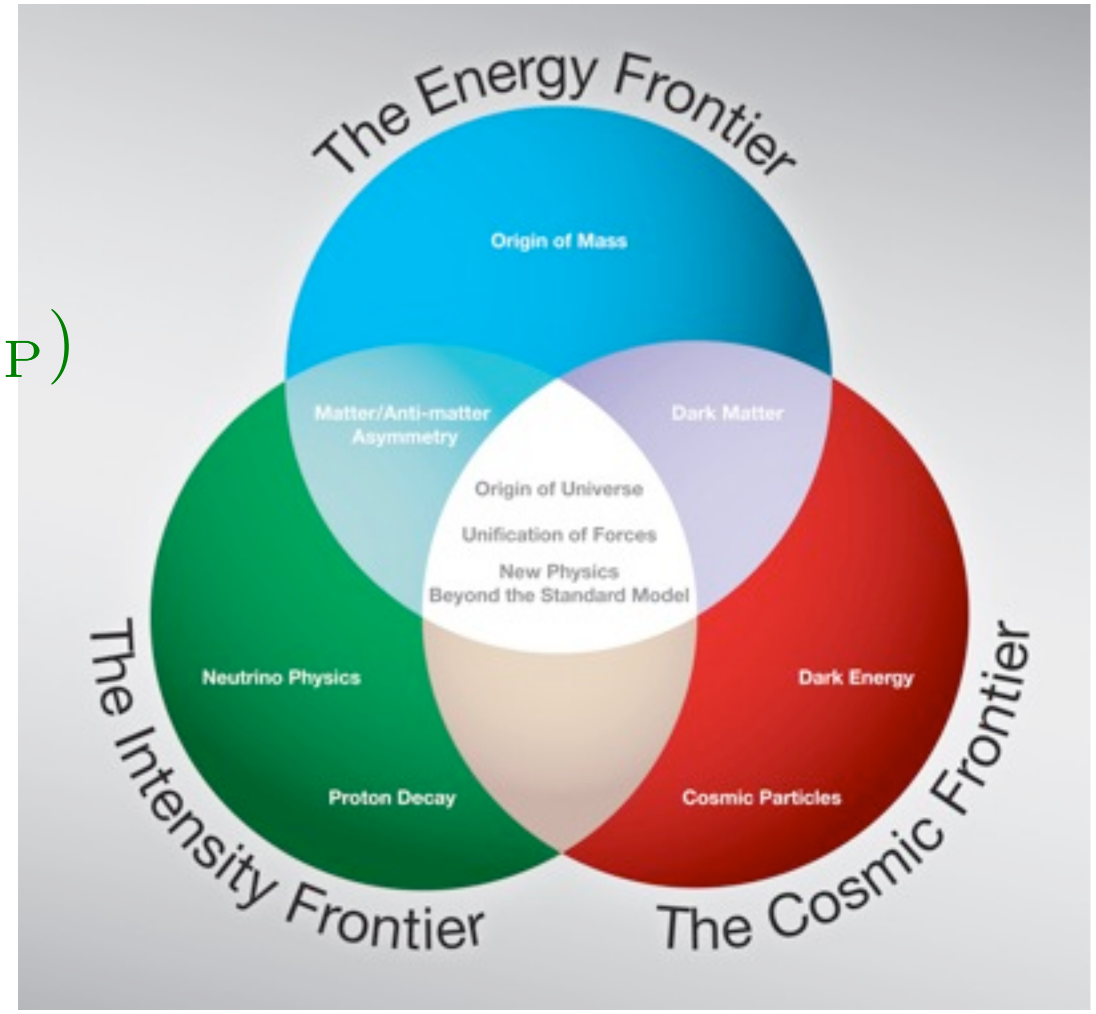
The HIP-HEP tune

1

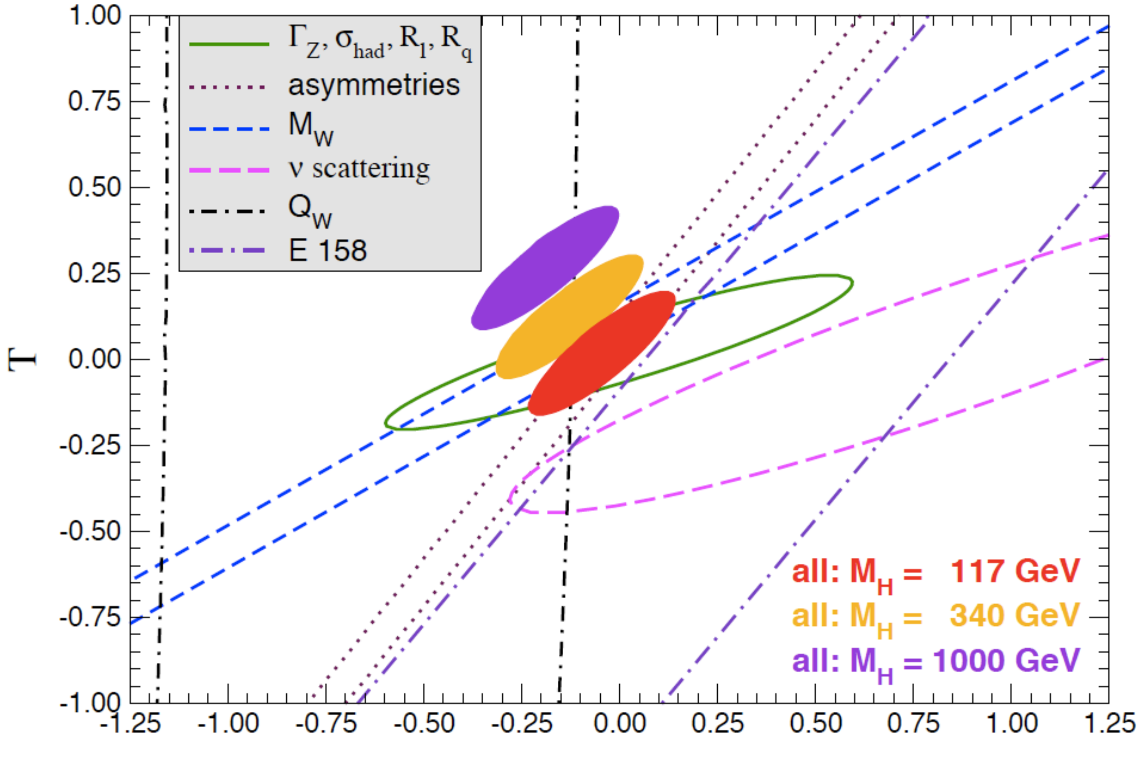
- **H**igh **E**nergy **P**hysics finds new physics around 1 TeV: $g_{ii} \times f_T(M_{\rm NP})$
- **H**igh **I**ntensity **P**hysics will tell us couplings and loop structure: $g_{ij} \times f_L(M_{\rm NP})$

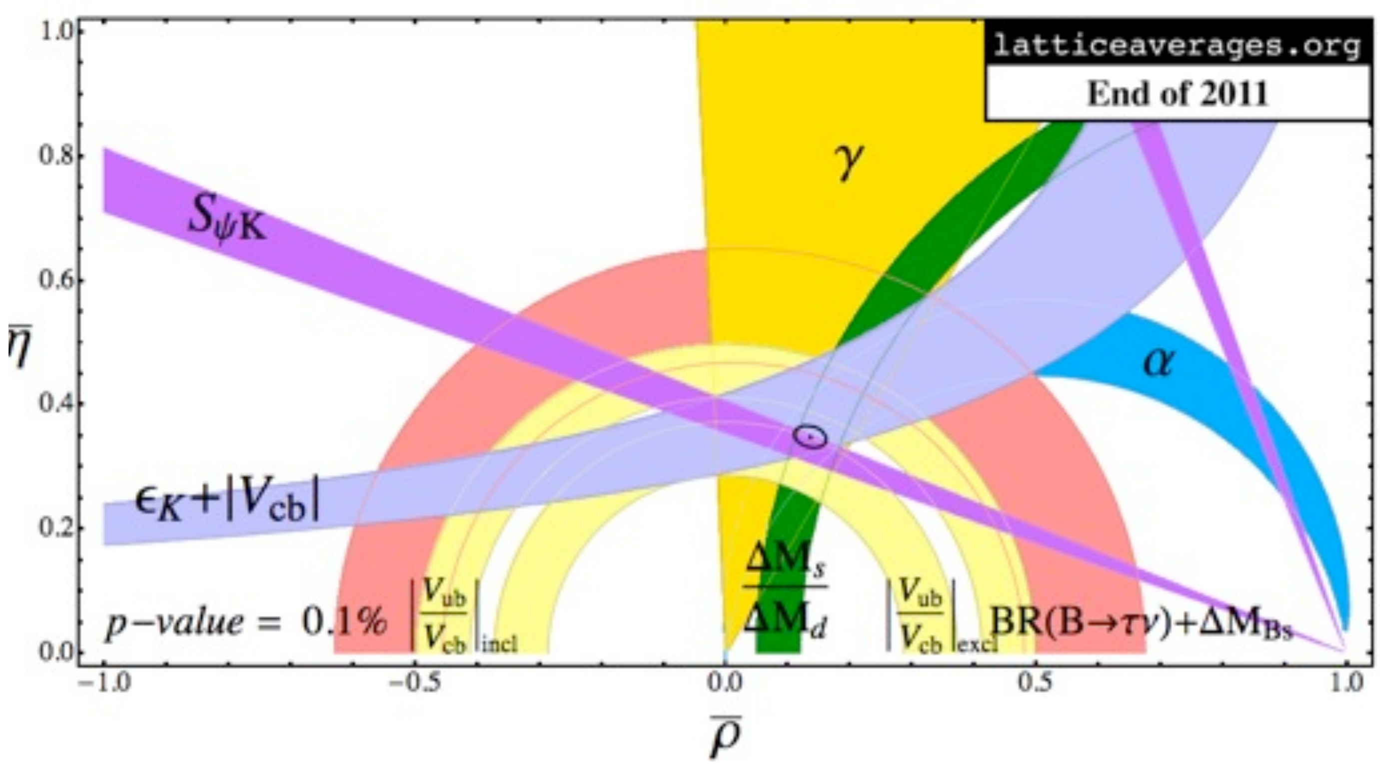
2

- If **HEP** doesn't find new physics (besides a standard Higgs), **HIP** can push the search to much higher scales under the assumptions of not too small flavor changing new couplings



Present Status





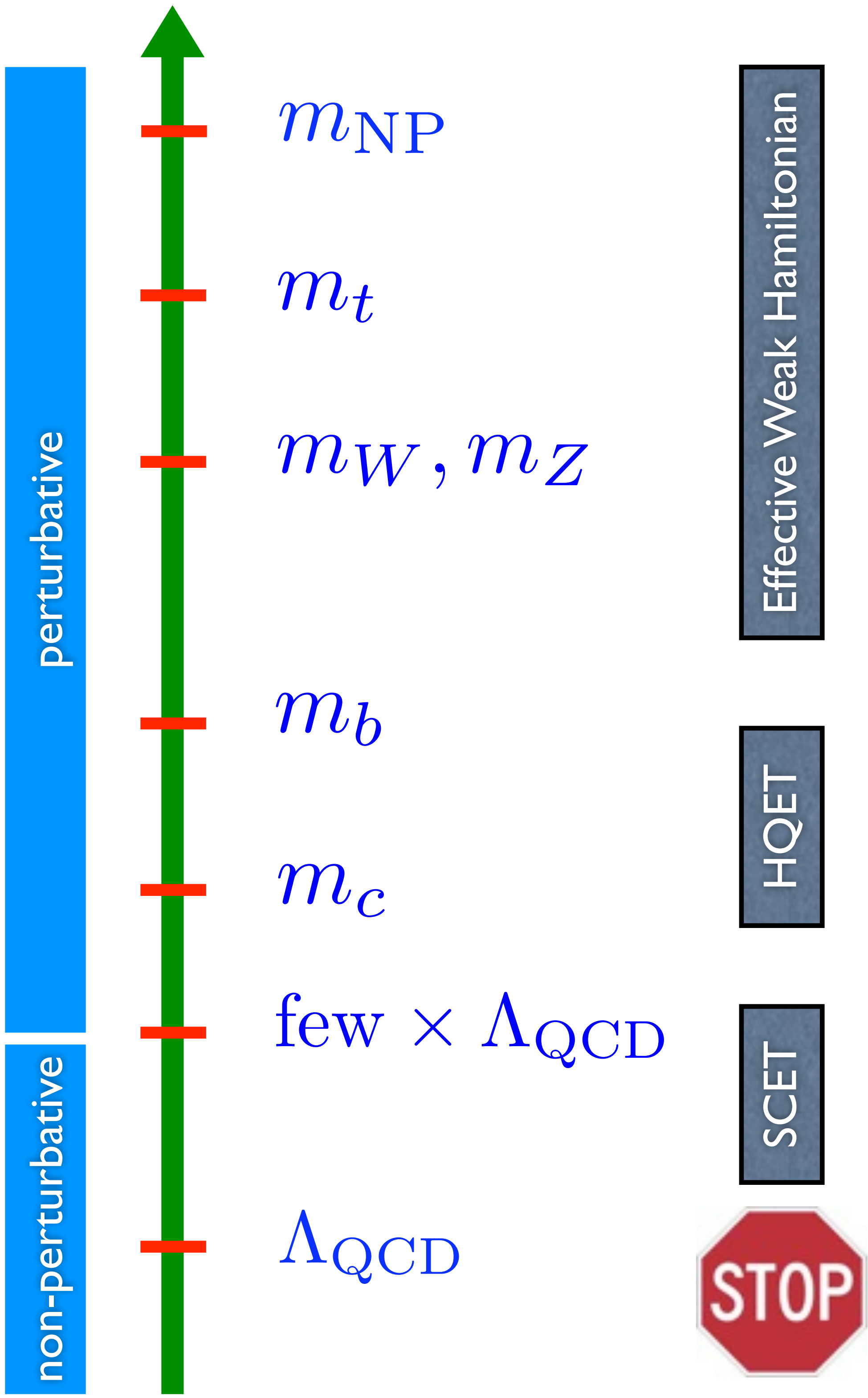
- Test of the Gauge Structure (LEP, Tevatron)

- Test of the Flavor Sector (BaBar, Belle, LHCb):
  - inclusive/exclusive V_{ub}
  - $\sin(2\beta)$ vs $B\to\tau\nu$

- Close to a Higgs discovery?
- Muon g-2?
- Is something going on with the charm?

Need for precision calculations and control over theoretical uncertainties

Effective Theories



- The basic idea is to isolate and integrate out heavy degree of freedom:

$$Z = \int [d\phi][d\phi_H] \exp\left(-i \int [\mathcal{L}(\phi, \phi_H) + j\phi]\right)$$
$$= \int [d\phi] \exp\left(-i \int [\mathcal{L}_{\mathrm{eff}}(\phi) + j\phi]\right)$$

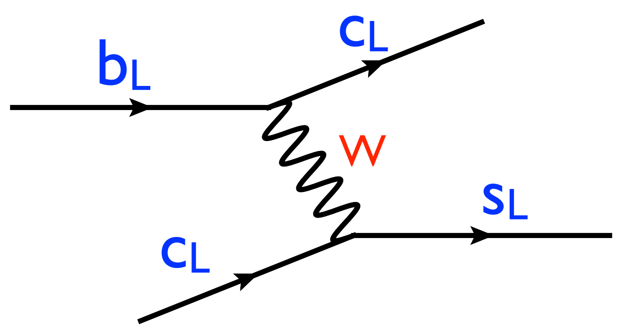
- $\mathcal{L}_{\mathrm{eff}} = \sum C_i O_i$ admits an expansion in Λ^{-1}, where Λ is the scale associated with ϕ_H
  - if ϕ_H is not an external state, $\Lambda = m_\phi$ appears explicitly in the Wilson coefficients C_i
  - if ϕ_H is an external state, the Λ^{-1} suppression appears dynamically in the calculation of the matrix elements $\langle O_i \rangle$

$b \to s\ell^+\ell^-$: a case study

- The effective Hamiltonian is: $\mathcal{H}_{eff} = -\frac{4G_F}{\sqrt{2}} V_{ts}^* V_{tb} \sum_{i=1}^{10} C_i(\mu) O_i(\mu)$

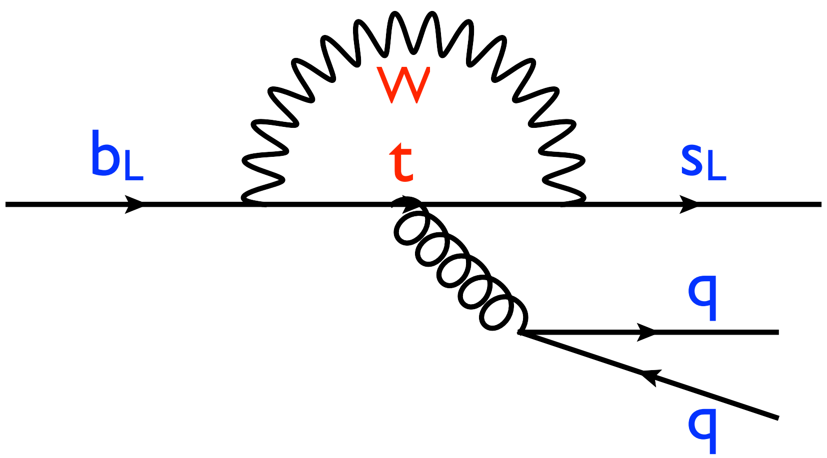
$$O_2 = (\bar{s}_L \gamma_\mu c_L)(\bar{c}_L \gamma^\mu b_L)$$

Tree



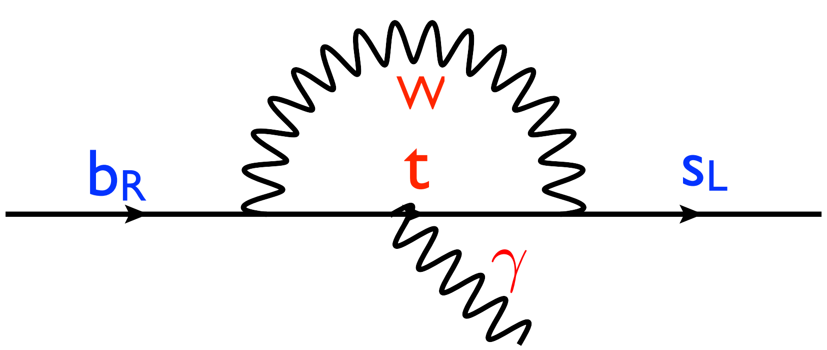
$$O_3 = (\bar{s}_L \gamma_\mu b_L) \sum (\bar{q} \gamma^\mu q)$$

QCD penguin



$$O_7 = \frac{e}{16\pi^2} m_b (\bar{s}_L \sigma^{\mu\nu} b_R) F_{\mu\nu}$$

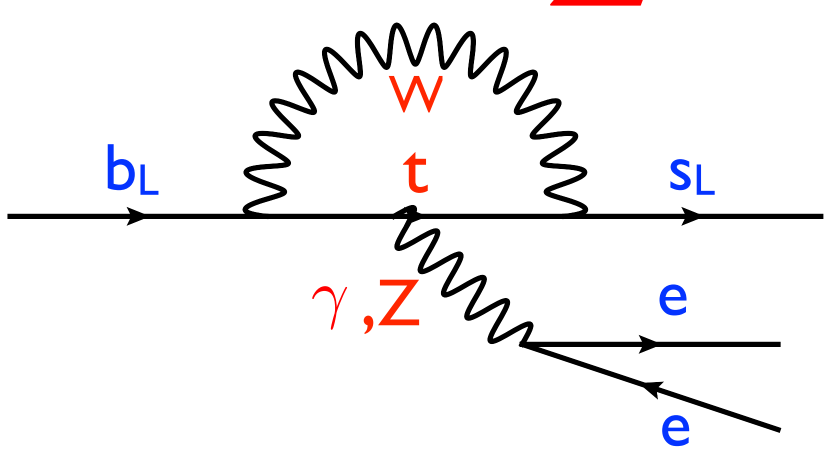
magnetic moment



$$O_9 = (\bar{s}_L \gamma_\mu b_L) \sum (\bar{l} \gamma^\mu l)$$

$$O_{10} = (\bar{s}_L \gamma_\mu b_L) \sum (\bar{l} \gamma^\mu \gamma_5 l)$$

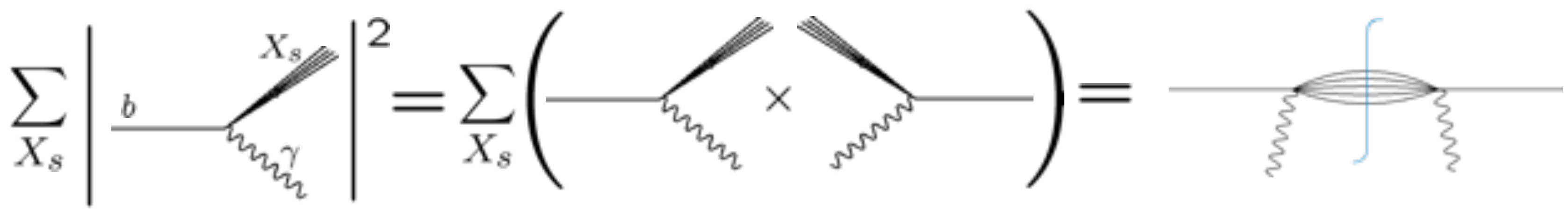
Semileptonic



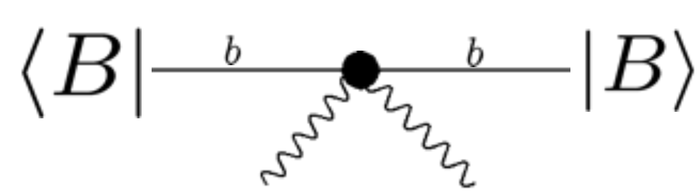
$b \to s\ell^+\ell^-$: a case study

- Inclusive channel:

$$\Gamma\left[\bar{B} \to X_s \ell^+\ell^-\right] = \Gamma\left[\bar{b} \to X_s \ell^+\ell^-)\right] + O\left(\frac{\Lambda^2_{QCD}}{m_b^2}, \frac{\Lambda^2_{QCD}}{m_c^2}, \ldots\right)$$



[local OPE, optical theorem, quark-hadron duality]

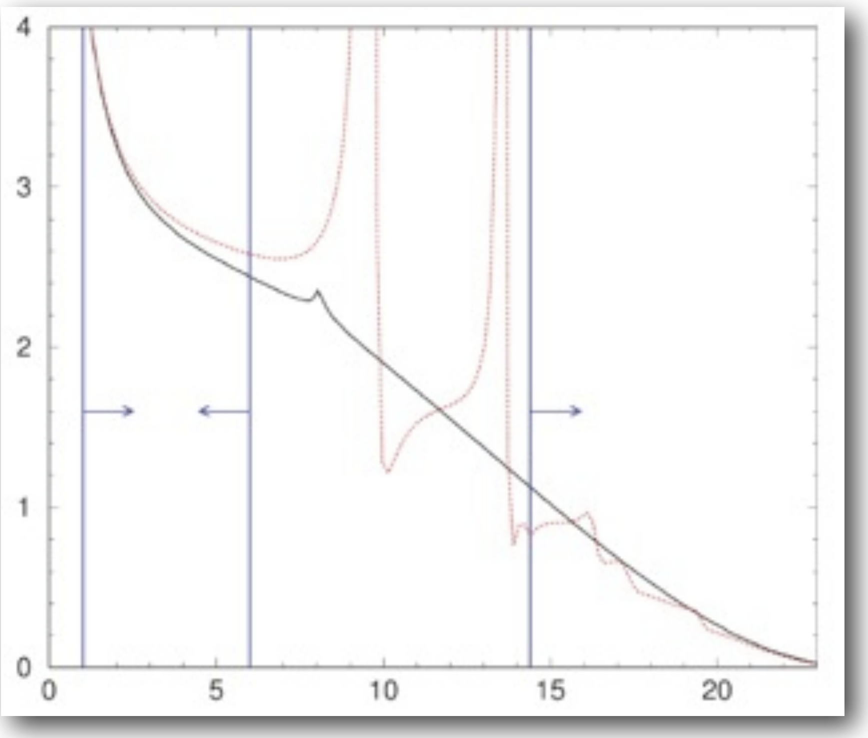


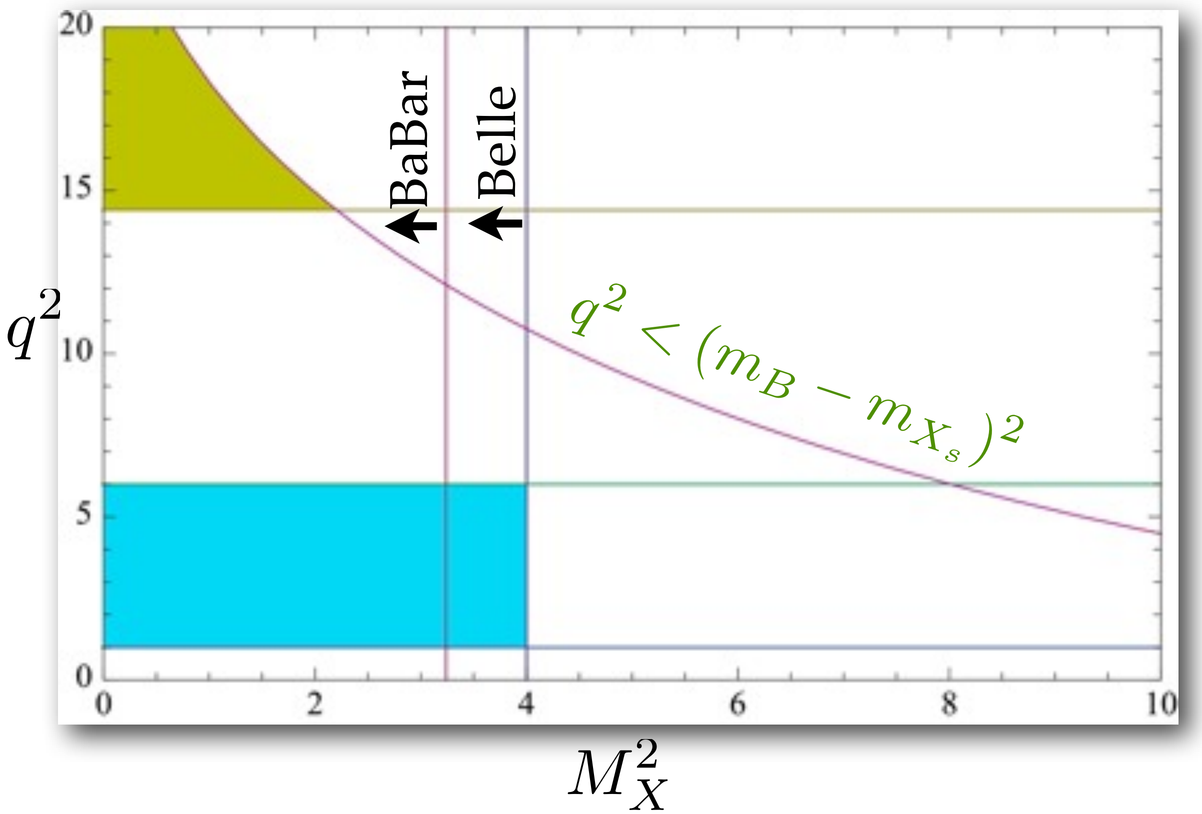
HQET

- Non-perturbative QCD enters only through few HQET local matrix elements
- The same technique is applied to $B \to X_s\gamma$, $B \to X_c\ell\nu$, $B \to X_u\ell\nu$
- Purely leptonic channels are easier to treat ($B \to \mu\mu$, $B \to \tau\nu$ are proportional to the B decay constant)
- Other channels present slightly harder challenges ($B \to \gamma\ell\nu$ requires the light-cone wave function of the B meson)

$b \to s\ell^+\ell^-$: a case study

- Inclusive channel: di-lepton and hadronic invariant mass cuts introduce **sensitivity to scales lower than m_b**





- eliminate charmonium resonances
- At high-q^2 the OPE breaks down. Problem is eased by considering:

$$\frac{\int_{q_0^2}^{m_b^2} \mathrm{d}q^2 \, \frac{\mathrm{d}\Gamma(B \to X_s \ell^+ \ell^-)}{\mathrm{d}q^2}}{\int_{q_0^2}^{m_b^2} \mathrm{d}q^2 \, \frac{\mathrm{d}\Gamma(B^0 \to X_u \ell \nu)}{\mathrm{d}q^2}}$$

- remove double semileptonic background
- At low-q^2 the effects of the M_X cut is reduced by considering the ratio:

$$\frac{\int_0^{M_X^{\mathrm{cut}}} \mathrm{d}M_X \, \frac{\mathrm{d}\Gamma(B \to X_s \ell^+ \ell^-)}{\mathrm{d}M_X}}{\int_0^{M_X^{\mathrm{cut}}} \mathrm{d}M_X \, \frac{\mathrm{d}\Gamma(B \to X_u \ell \nu)}{\mathrm{d}M_X}}$$

$b \to s\ell^+\ell^-$: a case study

- Exclusive channels (K, K*):

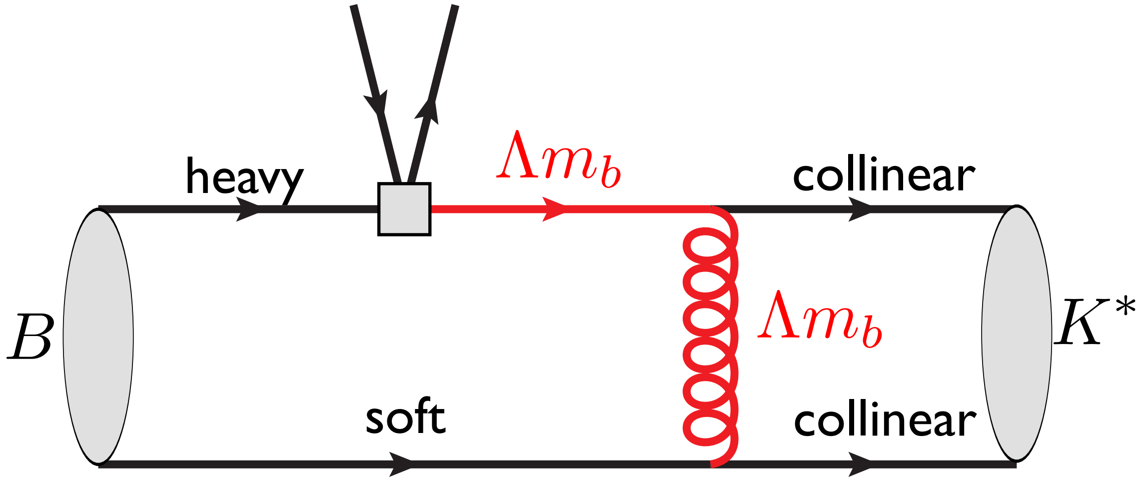
$$\mathcal{A}(B \to K^*\ell^+\ell^-) = C_i(\mu)\ \langle K^*\ell^+\ell^-|O_i(\mu)|B\rangle$$

  - For operators that contain an explicit photon or di-lepton pair this is trivial

$$C_i(\mu)\ \langle K^*\ell^+\ell^-|O_i(\mu)|B\rangle = C_i(\mu)\ \bar{\ell}\Gamma_1^i\ell\ \underbrace{\langle K^*|\bar{s}\Gamma_2^i b|B(p_B)\rangle}_{B\to K^*\ \text{FormFactor}} \longrightarrow \text{Lattice QCD, LC-QCDSR}$$

  - For all the other operators we must understand the dynamics at scales smaller than m_b

- At low q^2 there are three scales m_b , $\sqrt{\Lambda_{QCD}\, m_b}$ and Λ_{QCD} : SCET



$$(p_{\text{soft}} + p_{\text{collinear}})^2 \sim \Lambda_{\text{QCD}} m_b$$

$b \to s\ell^+\ell^-$: a case study

- Matrix elements read:

$$\langle K_a^*|T\{J_{\rm em}^\mu H_{eff}\}|B\rangle = T_a^I(q^2)\zeta_a(q^2) + \sum_\pm \int_0^\infty \frac{d\omega}{\omega}\phi_\pm^B(\omega)\int_0^1 du\ \phi_{K^*}^a(u)T_{a,\pm}^{II}(\omega,u,q^2)$$

hard scattering (m_b^2)

soft form factors (Λ^2)

light-cone wave functions (Λ^2)

hard scattering (m_b^2)

jet function (Λm_b)

- Need two soft form factors: $\xi_\perp(q^2)$, $\xi_\parallel(q^2)$
- Need light-cone wave functions of B and light mesons

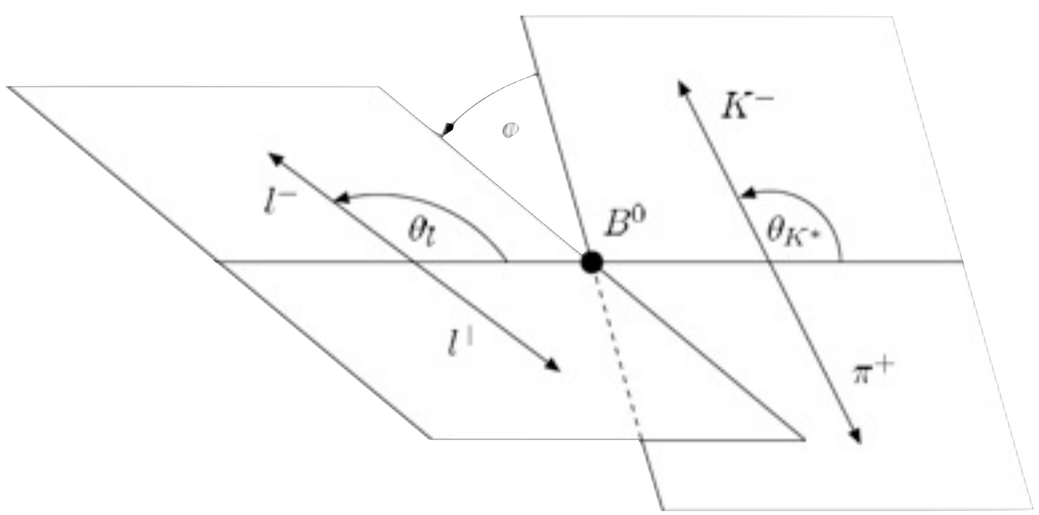
- At high q^2 the only scales are three scales m_b and Λ_{QCD}
  - Everything is expressed in terms of form factors at low recoil
- Both approaches are expansions in $\frac{\Lambda_{\rm QCD}}{m_b}$
  - At large recoil this is a big problem (higher-twist wave functions, ...)
  - At low recoil in principle we can get help from lattice-QCD

$b \to s\ell^+\ell^-$: a case study

- Inclusive phenomenology is limited to three quantities ($z = \cos\theta_l$):

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

- The exclusive K* mode has a very rich structure:



$$\frac{d^4\Gamma}{dq^2\, d\cos\theta_l\, d\cos\theta_{K^*}\, d\phi} \propto$$

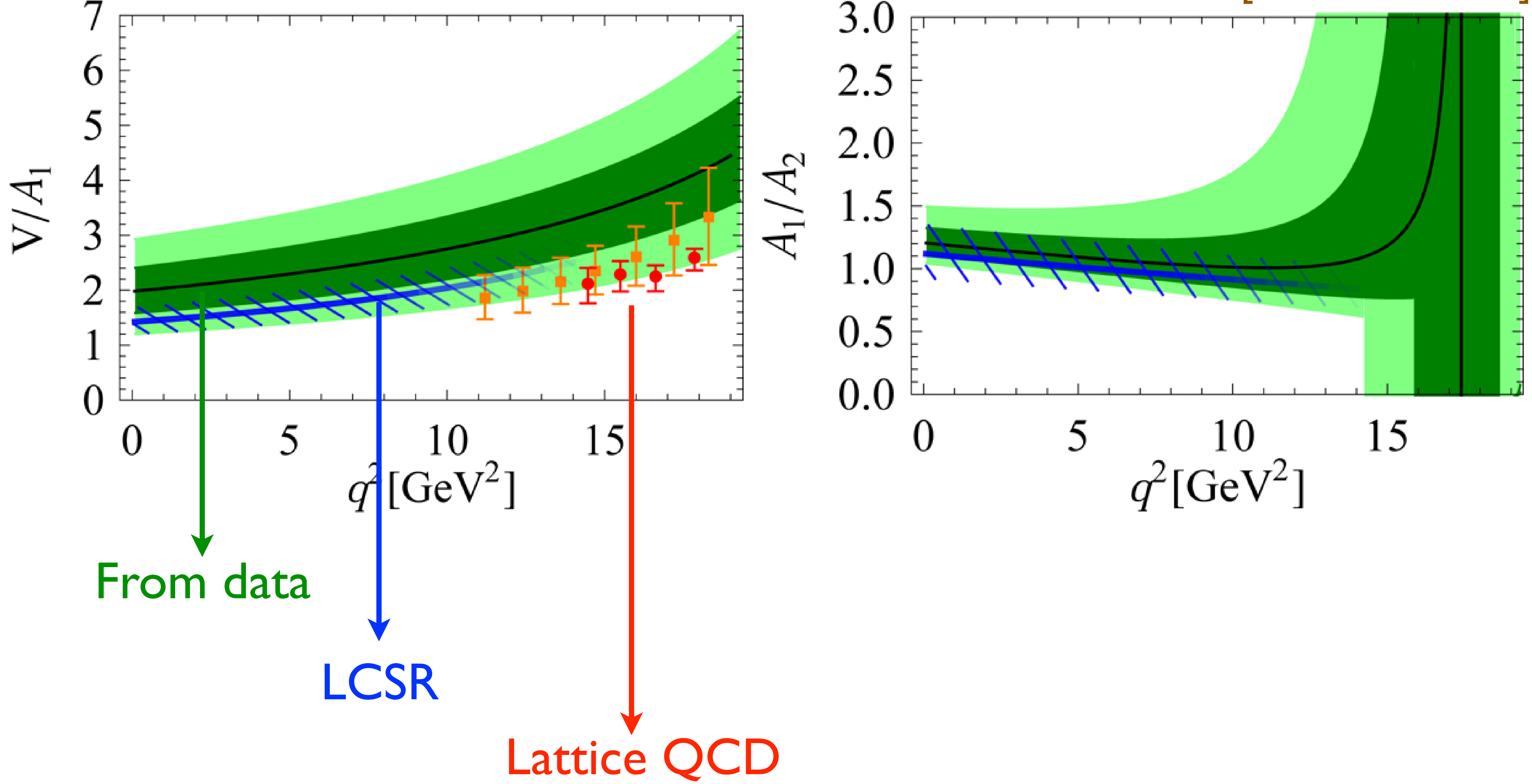
$$I_1^s \sin^2\theta_{K^*} + I_1^c \cos^2\theta_{K^*} + (I_2^s \sin^2\theta_{K^*} + I_2^c \cos^2\theta_{K^*})\cos 2\theta_\ell$$
$$+ I_3 \sin^2\theta_{K^*} \sin^2\theta_\ell \cos 2\phi + I_4 \sin 2\theta_{K^*} \sin 2\theta_\ell \cos\phi$$
$$+ I_5 \sin 2\theta_{K^*} \sin\theta_\ell \cos\phi$$
$$+ (I_6^s \sin^2\theta_{K^*} + I_6^c \cos^2\theta_{K^*})\cos\theta_\ell + I_7 \sin 2\theta_{K^*} \sin\theta_\ell \sin\phi$$
$$+ I_8 \sin 2\theta_{K^*} \sin 2\theta_\ell \sin\phi + I_9 \sin^2\theta_{K^*} \sin^2\theta_\ell \sin 2\phi$$

- At low and high recoil, the combinations of I's that have phenomenological relevance are different.
- At high recoil there are ratios that are independent of short distance physics (!!) and allow the extraction of the form factors.

$b \to s\ell^+\ell^-$: a case study

- At high recoil there are ratios that are independent of short distance physics (!!) and allow the extraction of the form factors.

[Hambrock, Hiller]

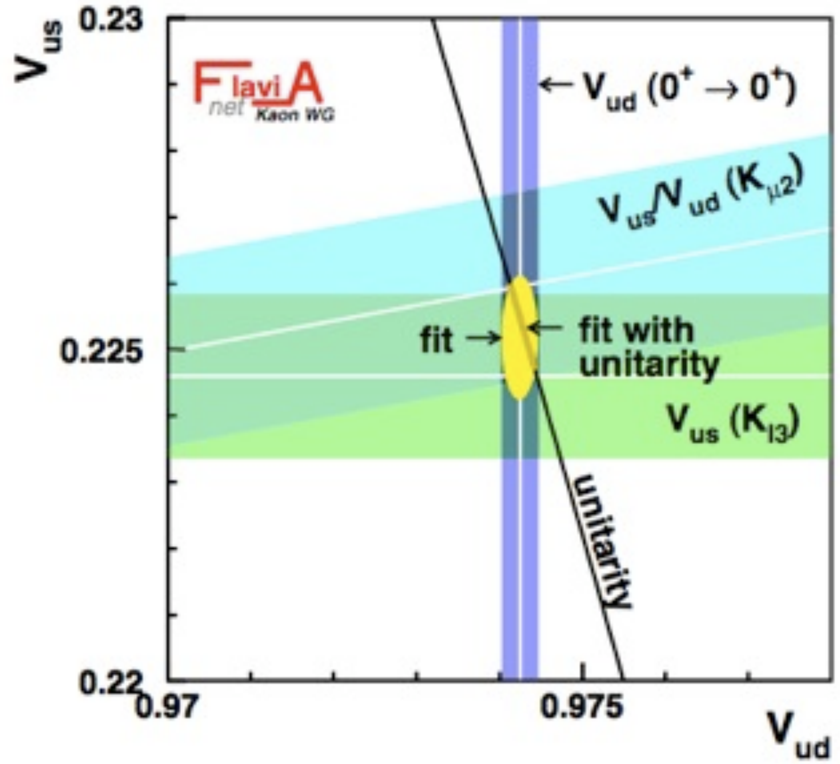


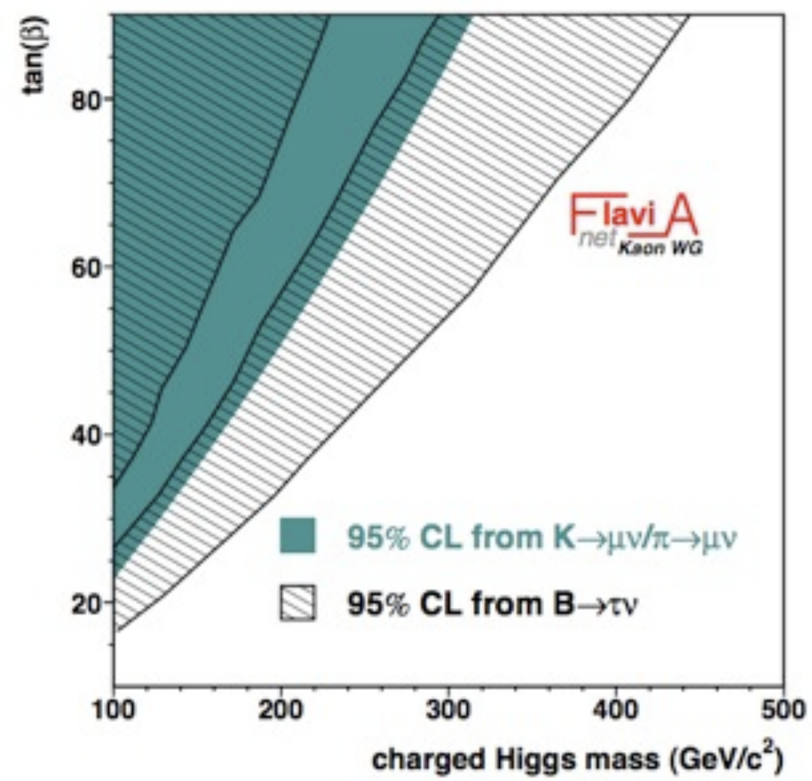
Lattice QCD

- *2+1 flavors* determinations *for most quantities of phenomenological interest*
- For the physics I discuss in this talk:
  - Ongoing efforts towards the $B \to K^{(*)}$ form factors
  - $B \to \pi$ and $B \to D^{(*)}$ form factors for the extraction of V_{ub} and V_{cb}
  - K, B and B_s decay constants and mixing matrix elements
- For the physics I don't discuss in this talk:
  - Progress towards the matrix elements relevant for $(\varepsilon'/\varepsilon)_K$
  - Progress towards the calculation of the hadronic contribution to $(g-2)_\mu$
  - ...
- Updated averages (2+1 flavors only, including correlations between the results of different collaborations) at: http://www.latticeaverages.org

Lattice QCD

- 1st-2nd family physics: $f_+(0) = 0.9599 \pm 0.0034^{+0.0034}_{-0.0045}$ $\quad \dfrac{f_K}{f_\pi} = 1.1925 \pm 0.0056$



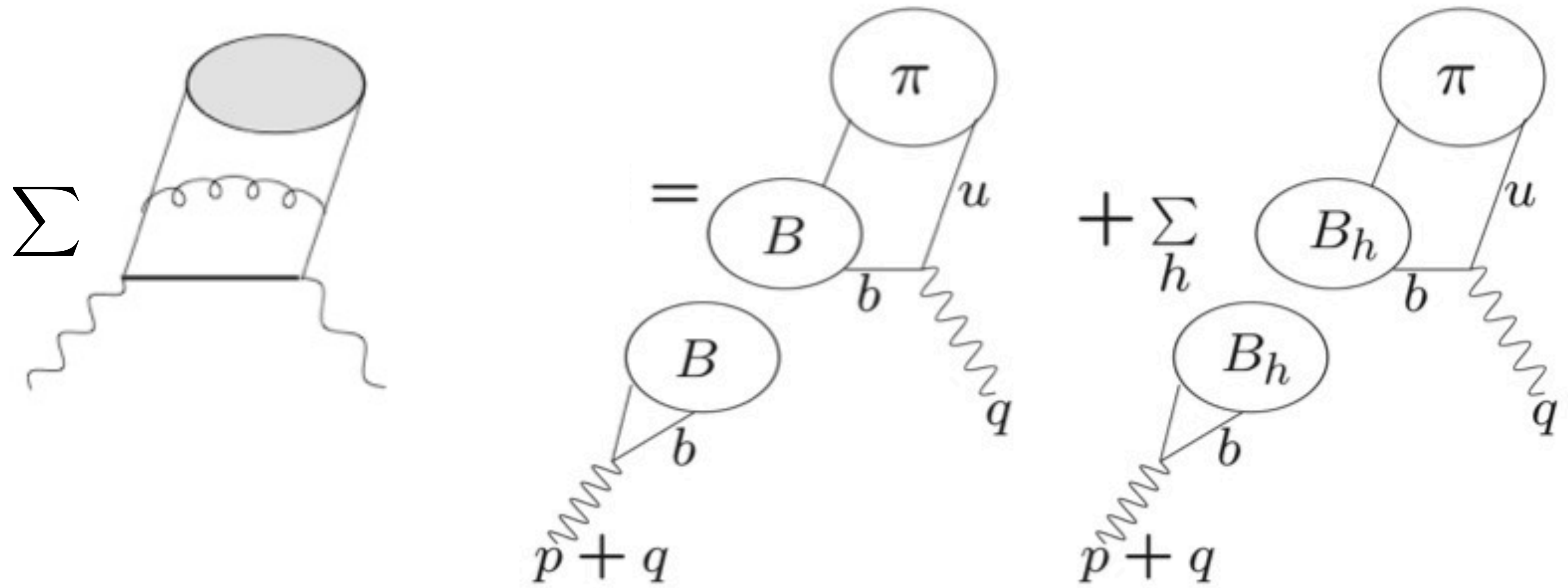


- Determination of $\Delta\Gamma_s$. Using an OPE + HQE, $\Delta\Gamma_s$ can be expressed in terms of f_{Bs} and the matrix elements of several 4-quarks operators

$$Q = \bar{s}\gamma_\mu(1-\gamma_5)b\;\bar{s}\gamma^\mu(1-\gamma_5)b \qquad \text{[leading power]}$$

$$R_2 = \frac{1}{m_b^2}\bar{s}\overleftarrow{D}_\rho\gamma^\mu(1-\gamma_5)D^\rho b\;\bar{s}\gamma_\mu(1-\gamma_5)b \qquad \text{[subleading power]}$$

Light Cone Sum Rules



$$\int T^{(n)}\phi^{(n)}$$

perturbative kernel

light-cone wave functions

$$f_B f^{+}_{B\pi}(q^2)$$

Form Factor

$$\sum_{B_h} \to duality$$

Related to $\int T^{(n)}\phi^{(n)}$

$b \to c\ell\nu$ (V_{cb})

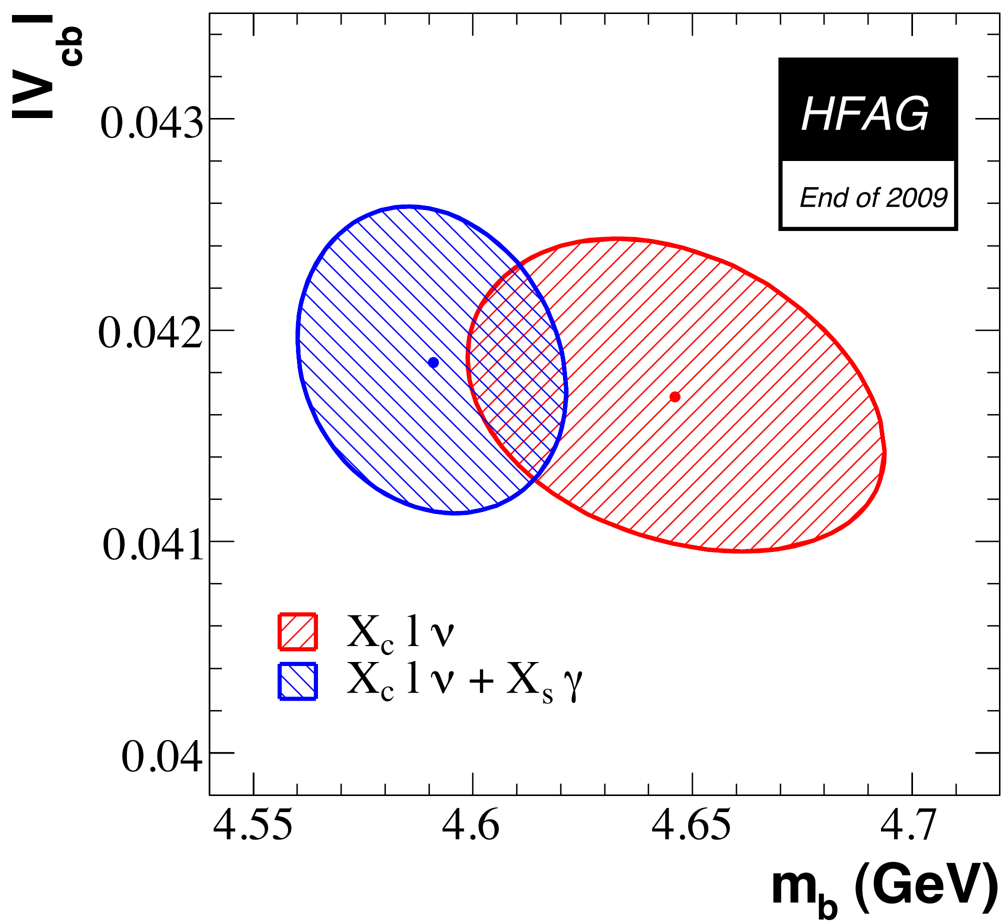
- Exclusive from $B \to D^{(*)} l\nu$. Using form factor from lattice QCD (2+1 dynamical staggered fermions) one finds:

$$|V_{cb}| = (39.5 \pm 1.0) \times 10^{-3}$$

[FNAL/MILC]
[average:Laiho,EL,Van de Water]

[exp. error on $B \to D^*$ rescaled to account for the large $\chi^2/\text{dof} = 39/21$]

- Inclusive from global fit of $B \to X_c l\nu$ moments. [Flächer]



- Inclusion of $b \to s\gamma$ has strong impact on quark masses but not on V_{cb}
- NNLO in α_s and $O(1/m_b^4)$ known
- $O(\alpha_s/m_b^2)$ corrections partially known
- Issue of m_b is relevant for V_{ub}

$$|V_{cb}| = (41.68 \pm 0.73) \times 10^{-3}$$

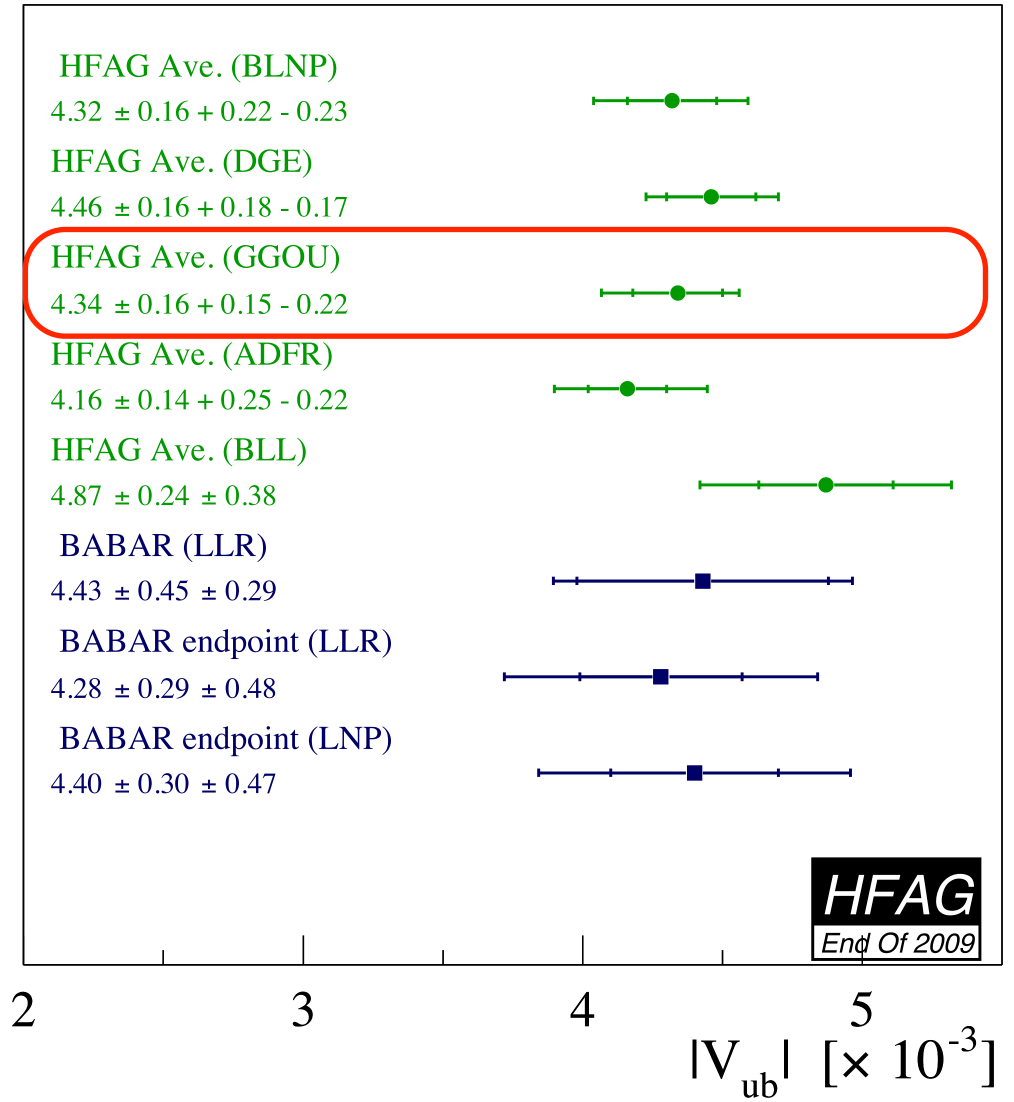
1.7σ discrepancy between inclusive and exclusive

$b \to u\ell\nu$ (V$_{ub}$)

- Exclusive from B→πlν: $|V_{ub}| = (3.12 \pm 0.26) \times 10^{-3}$ [HPQCD, FNAL/MILC]

  $|V_{ub}| = (3.50^{+0.38}_{-0.33} \pm 0.11) \times 10^{-3}$ [Khodjamirian, Mannel, Offen, Wang LCQCDSR]

- Inclusive from global fit of B→X_ulν moments



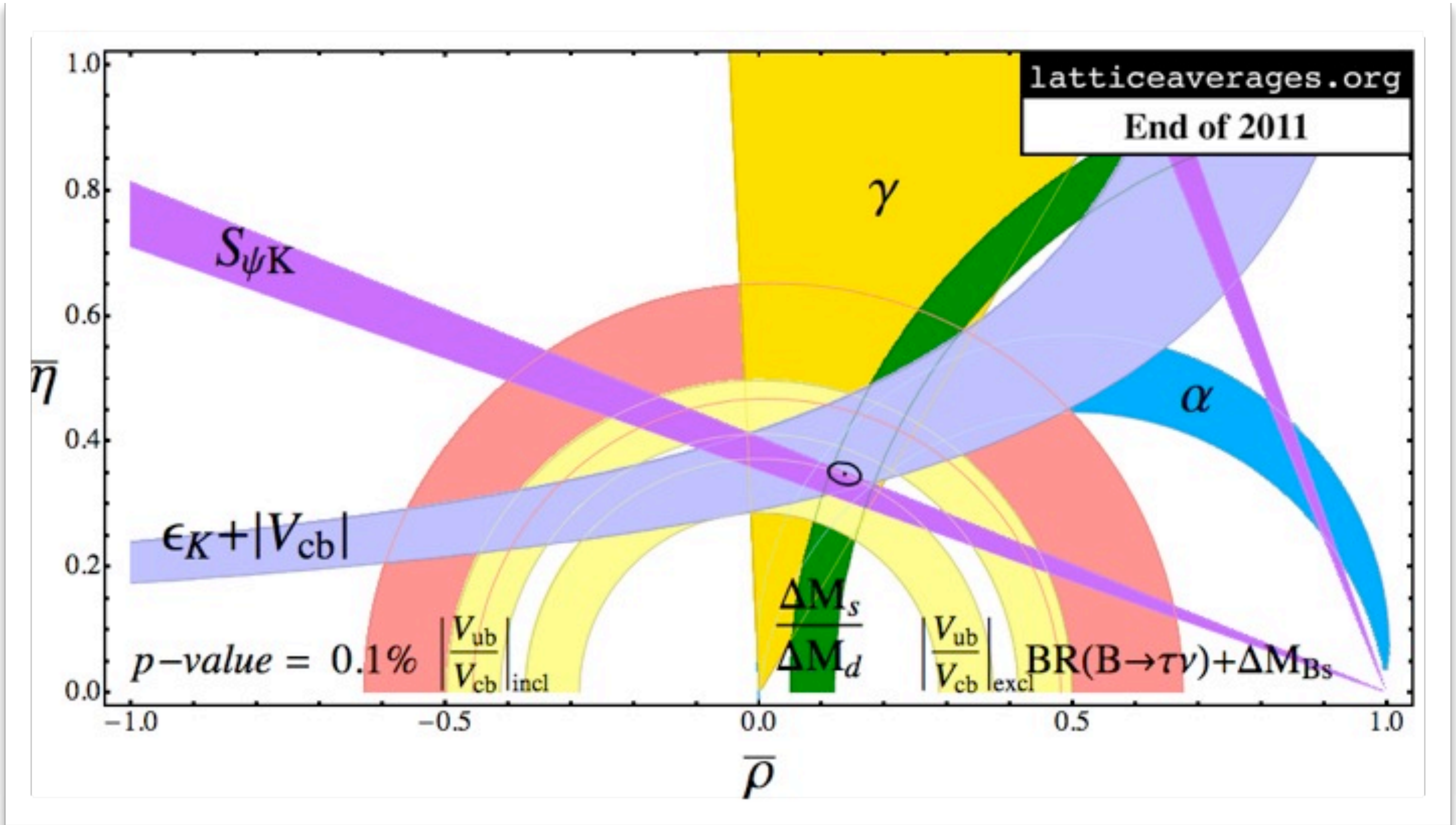
Legend:
BLNP = Bosch, Lange, Neubert, Paz
DGE = Andersen, Gardi
GGOU = Gambino,Giordano,Ossola,Uraltsev
ADFR = Aglietti, Di Lodovico, Ferrera, Ricciardi
BLL = Bauer, Ligeti, Luke
LLR = Leibovich, Low, Rothstein
LNP = Lange, Neubert, Paz

3.3σ discrepancy between inclusive and exclusive (*lattice*)

Flavor Symmetries

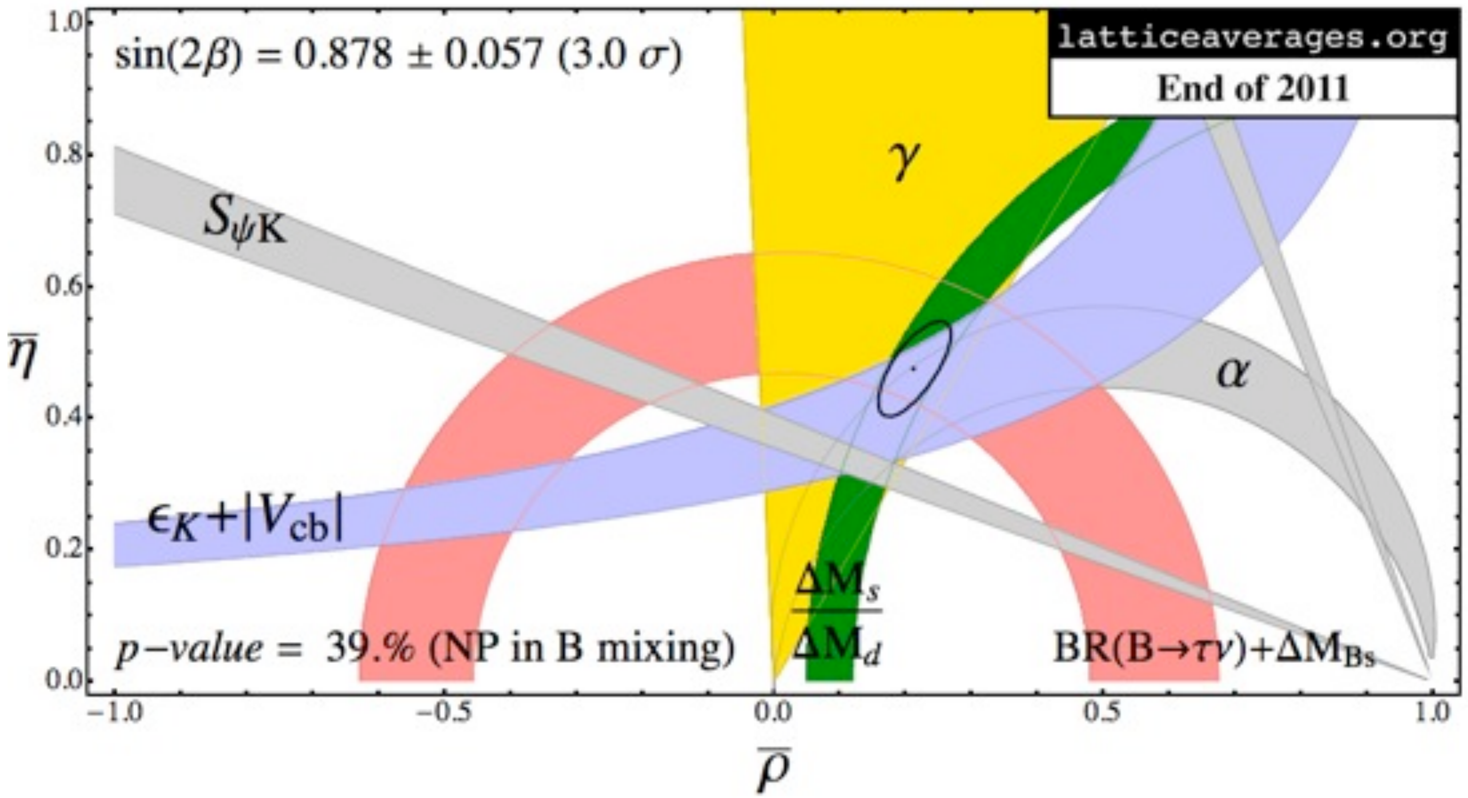
- Avoid QCD dynamics and use QCD symmetries instead:
  - Decompose full QCD amplitudes into topological (diagrammatic?) considerations (**T**, **C**, **E**, **P**, $\mathbf{P_{EW}}$, ...)
  - Factor weak phases
  - Use Isospin, U-spin, SU(3) to relate the QCD amplitudes that appear in different modes
  - Discuss the size (or include perturbatively the effect) of symmetry breaking corrections
- This method is especially powerful if
  - We don't have a solid enough handle of QCD dynamics
  - We have enough experimental data
- Famous examples are the extraction of α from $B\to(\pi\pi,\rho\rho,\rho\pi)$ decays and of γ from various $B\to D^{(*)}K^{(*)}$ modes.

Unitarity Triangle

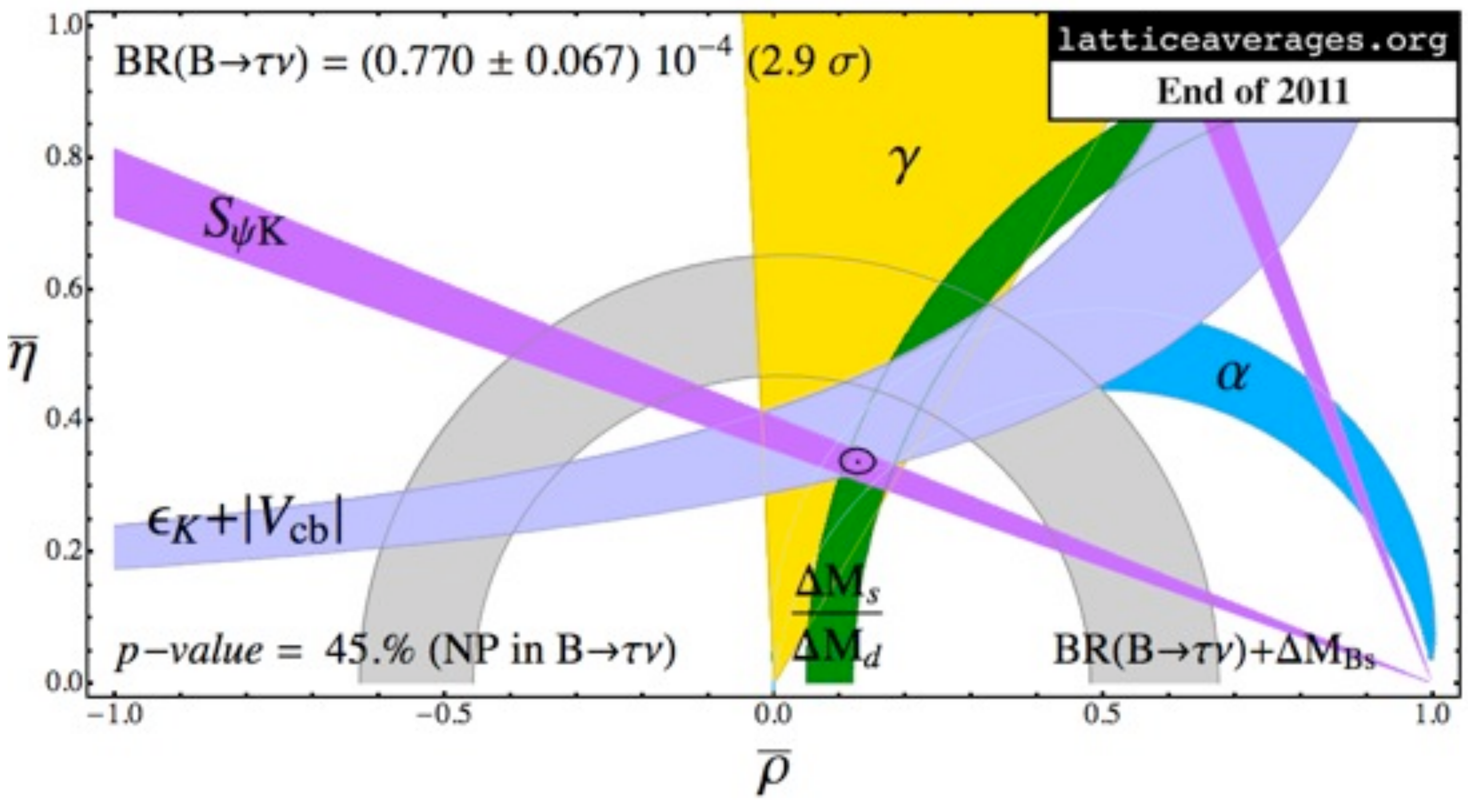


- The 3.3σ tension in inclusive and exclusive V_{ub} can be resolved only via the inclusion of new right-handed interactions
- The tension between sin2β and B→τν is easier to address

Unitarity Triangle



Scenario with NP in B mixing

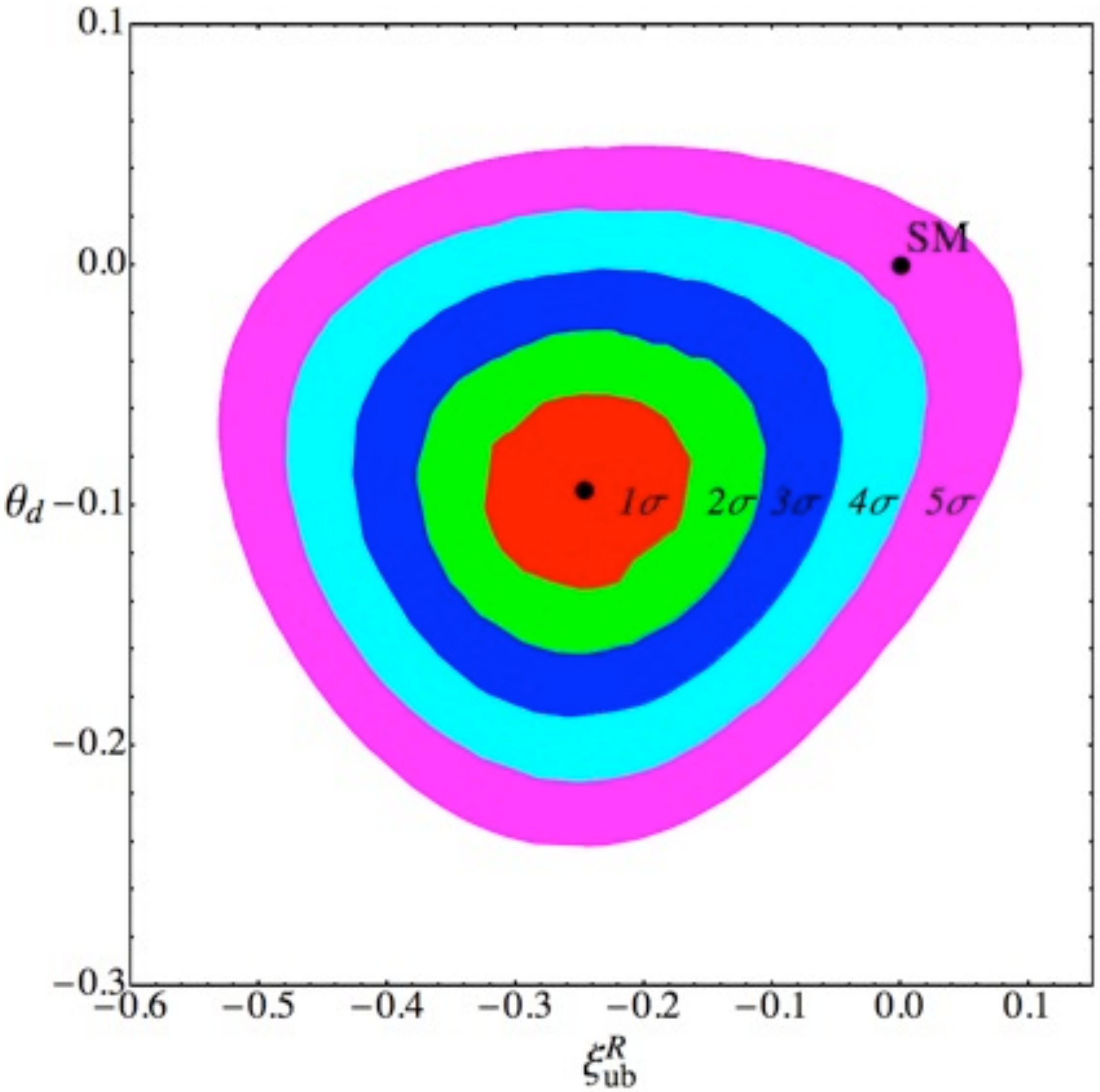


Scenario with NP in $B \to \tau\nu$

Unitarity Triangle

- Taking V_{ub} seriously:

$$M_{12} \Longrightarrow M_{12}\, e^{2i\phi_d}\, r_d^2$$
$$V_{ub} u_L \not{W} b_L \Longrightarrow V_{ub}(u_L \not{W} b_L + \xi_{ub}^R\, u_R \not{W} b_R)$$



$$\begin{aligned}
\sin 2\beta &\Longrightarrow \sin 2(\beta + \theta_d)\\
\sin 2\alpha &\Longrightarrow \sin 2(\alpha - \theta_d)\\
\Delta M_{B_d} &\Longrightarrow \Delta M_{B_d} r_d^2\\
|V_{ub}|_{\rm incl} &\Longrightarrow \sqrt{1 + |\xi_{ub}^R|^2}\,|V_{ub}|_{\rm incl}\\
|V_{ub}|_{\rm excl} &\Longrightarrow |1 + \xi_{ub}^R|\; |V_{ub}|_{\rm excl}\\
{\rm BR}(B \to \tau\nu) &\Longrightarrow |1 - \xi_{ub}^R|^2 {\rm BR}(B \to \tau\nu)
\end{aligned}$$

$$\begin{aligned}
\xi_{ub}^R &= -0.245 \pm 0.055 \quad (4.0\,\sigma)\\
\theta_d &= -(4.8 \pm 1.5)^{\rm o} \quad (3.2\,\sigma)\\
r_d &= 0.978 \pm 0.041
\end{aligned}$$

CP violation in the D sector?

- LHCb reported results for direct CP asymmetries in $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$

- When combined with previous measurements we have a 3.6σ effect:

  $$\Delta A_{\rm CP} = a^{\rm dir}_{KK} - a^{\rm dir}_{\pi\pi} = (-0.65 \pm 0.18)\%$$

- If taken seriously it is easy to find NP explanations. For instance new contributions to the chromomagnetic operator

  $$\frac{m_c}{4\pi} \bar{u}_L \sigma_{\mu\nu} T^a g_s G^{\mu\nu}_a c_R$$

  are achievable in the MSSM and can explain the effect
  [Grossman, Kagan, Nir, hep-ph/0609178]

CP violation in the D sector?

- In the SM the K^+K^- and $\pi^+\pi^-$ are related by U-spin symmetry
- Their direct CP asymmetries are due to interference between a real tree amplitude (T_f) and a complex penguin one ($P_f e^{i(\delta_f+\gamma)}$):

$$A_f^{\rm dir} = 2\frac{P_f}{T_f}\sin\delta_f \sin\gamma \simeq 2\frac{P_f}{T_f} = 2r_f$$

with f = K^+K^- , $\pi^+\pi^-$ and r_f factors in a $\lambda^4 \sim 10^{-3}$ CKM suppression.

- Using U-spin (there is a relative minus sign between the two modes) one gets:

$$\Delta A_{CP} = 4\, r$$

- Naive order of magnitude and QCD factorization estimates lead to r ~ 0.01%
- **Need an order of magnitude enhancement of *r* = *P/T***

CP violation in the D sector?

- A pre-existing anomaly in the branching ratios of these two modes [$BR(D^0 \to K^+K^-) = 2.8\, BR(D^0 \to \pi^+\pi^-)$] offers a hint that something is going on

- Fits to various D^0 branching ratio (e.g. $D^0 \to K^0 \bar{K}^0$ and $D^0 \to K^+ K^-$) show that the heavy quark $1/m_c$ expansion is broken: the W-exchange (***$E \sim O(1/m_c)$***) and tree (***$T \sim O(1)$***) amplitudes satisfy **$E \sim T$**.

- Using the **E/T** experimental ratio as benchmark for the size of power suppressed matrix elements one can show that some formally power suppressed penguin amplitudes are potentially large enough to explain the observed CP asymmetries *[Brod, Kagan, Zupan]*

- This is not a SM prediction but just a plausible argument that our theoretical tools (i.e. factorization) don't work well here.

- Using some apt sum-rules it is in principle possible to disentangle NP that contributes to $\Delta I=3/2$ operators

Outlook

- Enormous progresses in many channels
  - Inclusive $b \to sll$, $b \to cl\nu$, $b \to ul\nu$, $b \to s\gamma$
  - Exclusive $B \to (K, K^*, phi) ll$
  - Exclusive $B \to (D, D^*) l\nu$
  - $N_f = 2+1$ determinations of all matrix elements for UT studies
  - Use of symmetries allows sensitivity to weak physics in otherwise hopeless hadronic final states ($B \to \pi\pi, \rho\rho, \rho\pi, D^{(*)}K^{(*)}, \ldots$)
- Open problems
  - Inclusive (or exclusive!!) $b \to ul\nu$?
  - Is the tension in unitarity triangle fits due to some underestimate theoretical or experimental uncertainty?
  - Charm remains problematic if we cannot control even the order of magnitude of the SM prediction (note thought: use of isospin symmetry could help disentangle some types of NP)

Back-up slides

Hadronic uncertainties in $S_{\psi K}$

- The small penguin pollution can be extracted in the SU(3) limit from time-dependent studies of $B_s \to \psi K$ and $B \to \psi \pi^0$
  [Fleischer] [Faller, Jung, Fleischer, Mannel]
- Using a conservative approach about SU(3) effects one finds:

$$|\Delta S_{\psi K}| < 0.02$$

- Quantitative studies based on QCD factorization, pQCD and rescattering effects yield effects that are one order of magnitude smaller
- We conclude that presently one should not use $B \to \psi \pi^0$ decays as sole handle on hadronic uncertainties on $S_{\psi K}$
- Improved measurements of $B \to \psi \pi^0$ (at Belle II/super-B) and of $B_s \to \psi K$ (at LHC-b) will allow to keep this uncertainty under control

UT$_d$: inputs

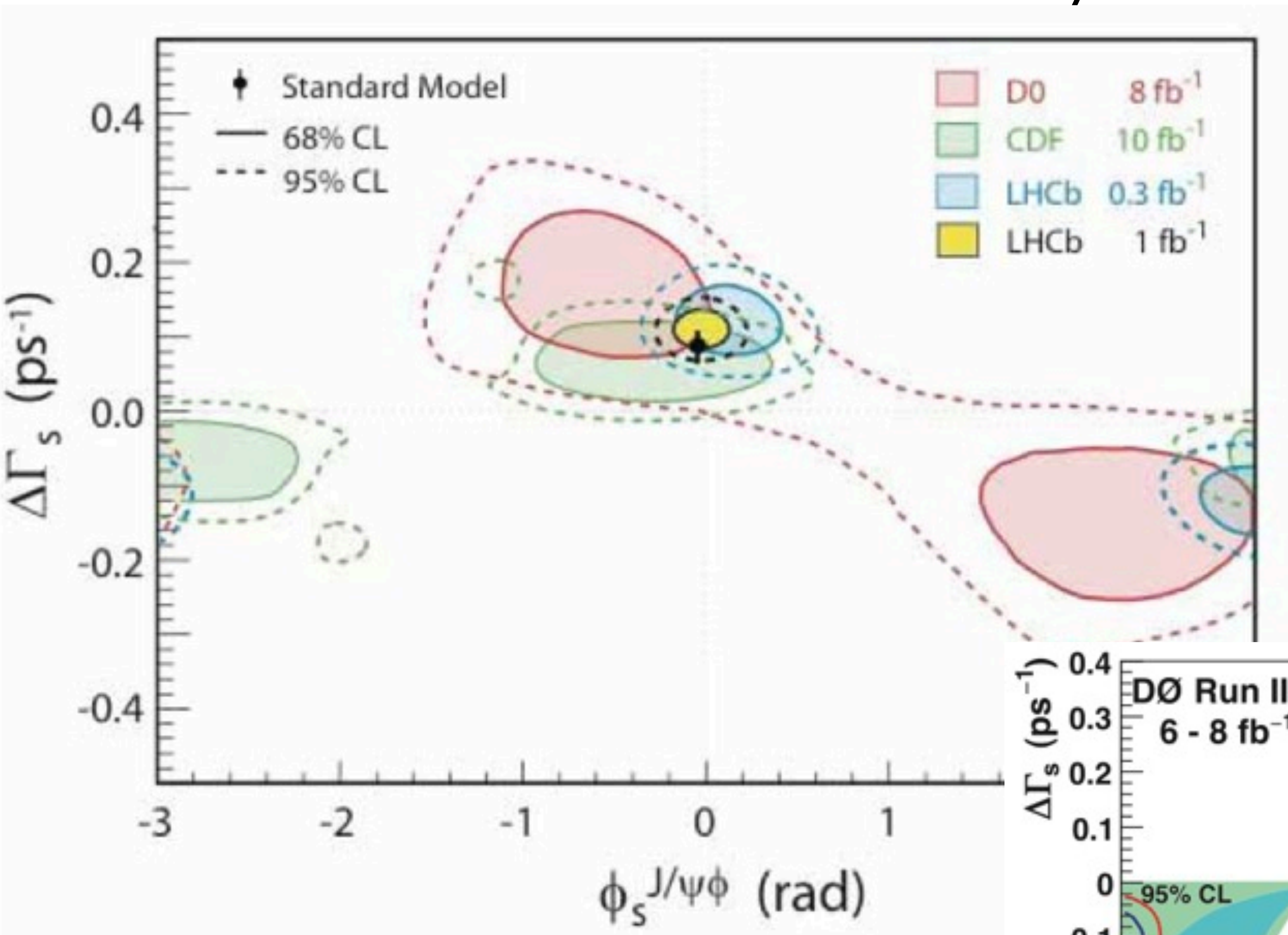
$\vert V_{cb}\vert_{\rm excl} = (39.5 \pm 1.0) \times 10^{-3}$	$\vert V_{ub}\vert_{\rm excl} = (3.12 \pm 0.26) \times 10^{-3}$
$\hat{B}_K = 0.7674 \pm 0.0099$	$f_B = (190.6 \pm 4.7)$ MeV
$\xi \equiv f_{B_s}\sqrt{\hat{B}_s}/(f_{B_d}\sqrt{\hat{B}_d}) = 1.237 \pm 0.032$	$f_{B_s}\sqrt{\hat{B}_{B_s}} = (248 \pm 15)$ MeV
$\kappa_\varepsilon = 0.94 \pm 0.01$	$\hat{B}_d = 1.26 \pm 0.11$
$\vert V_{cb}\vert_{\rm incl} = (41.68 \pm 0.44 \pm 0.09 \pm 0.58) \times 10^{-3}$	$\alpha = (89.5 \pm 4.3)^{\rm o}$
$\vert V_{ub}\vert_{\rm incl} = (4.34 \pm 0.16^{+0.15}_{-0.22} \pm 0.43) \times 10^{-3}$	$\gamma = (78 \pm 12)^{\rm o}$
$\mathrm{BR}(B \to \tau\nu) = (1.68 \pm 0.31) \times 10^{-4}$	$S_{\psi K_S} = 0.668 \pm 0.023$
$\Delta m_{B_d} = (0.507 \pm 0.005)\ \mathrm{ps}^{-1}$	$\eta_1 = 1.87 \pm 0.76$
$\Delta m_{B_s} = (17.77 \pm 0.10 \pm 0.07)\ \mathrm{ps}^{-1}$	$\eta_2 = 0.5765 \pm 0.0065$
$m_{t,pole} = (172.4 \pm 1.2)$ GeV	$\eta_3 = 0.494 \pm 0.046$
$m_c(m_c) = (1.268 \pm 0.009)$ GeV	$\eta_B = 0.551 \pm 0.007$
$\varepsilon_K = (2.229 \pm 0.012) \times 10^{-3}$	$\lambda = 0.2255 \pm 0.0007$
$\vert V_{cb}\vert_{\rm avg} = (40.77 \pm 0.81) \times 10^{-3}$	$\vert V_{ub}\vert_{\rm avg} = (3.37 \pm 0.49) \times 10^{-3}$

- Updated averages on: *www.latticeaverages.org*

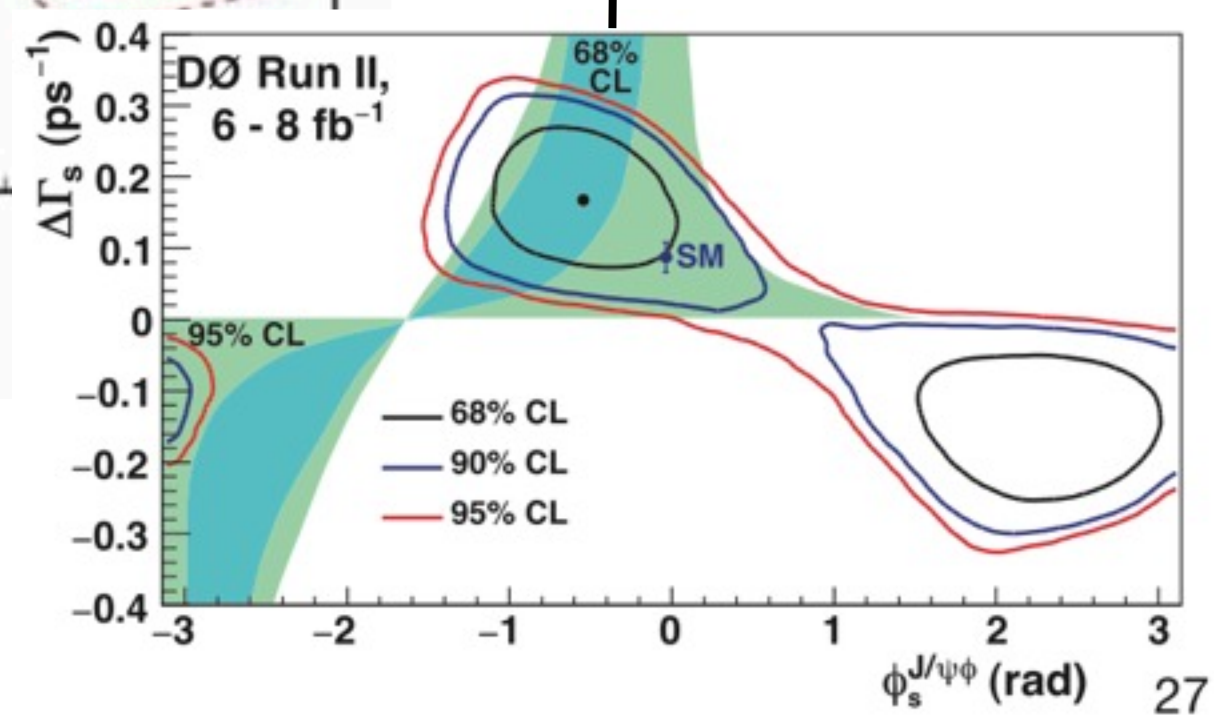
[Laiho, EL, Van de Water]

The B_s anomaly

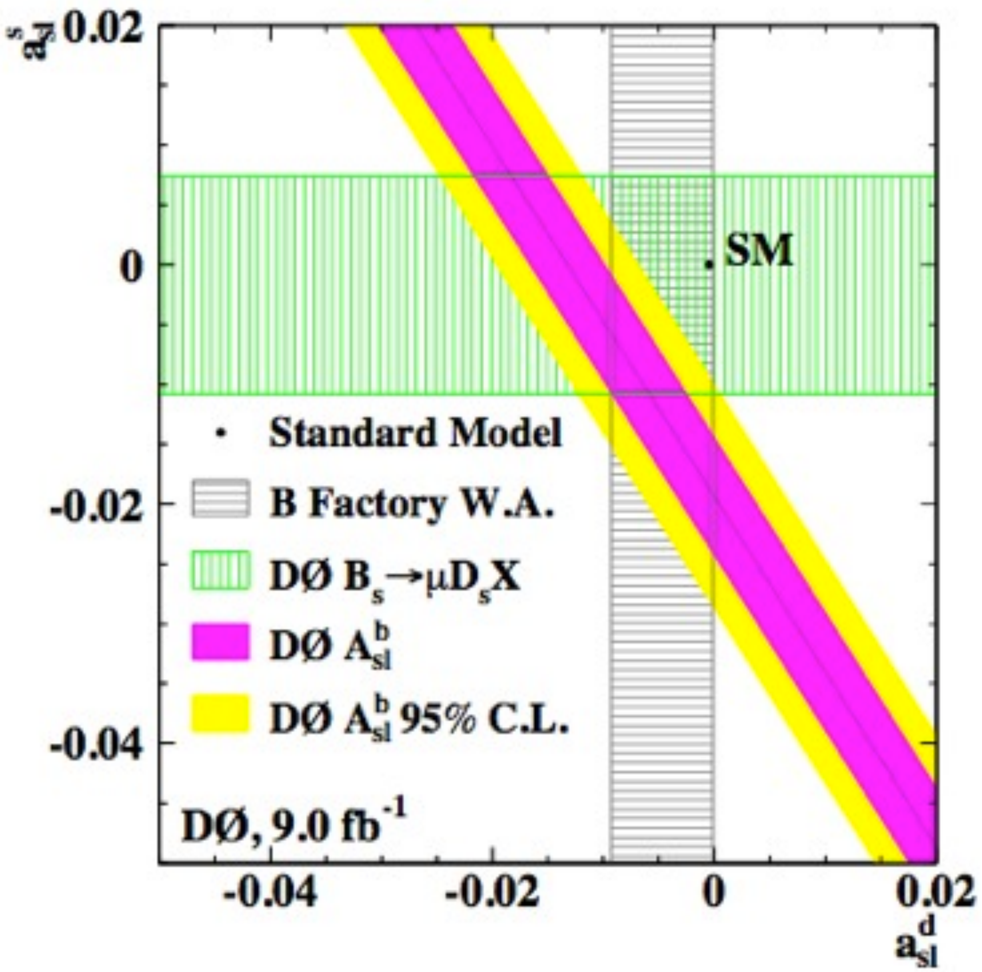
- We don’t have an official combination - only visual overlay

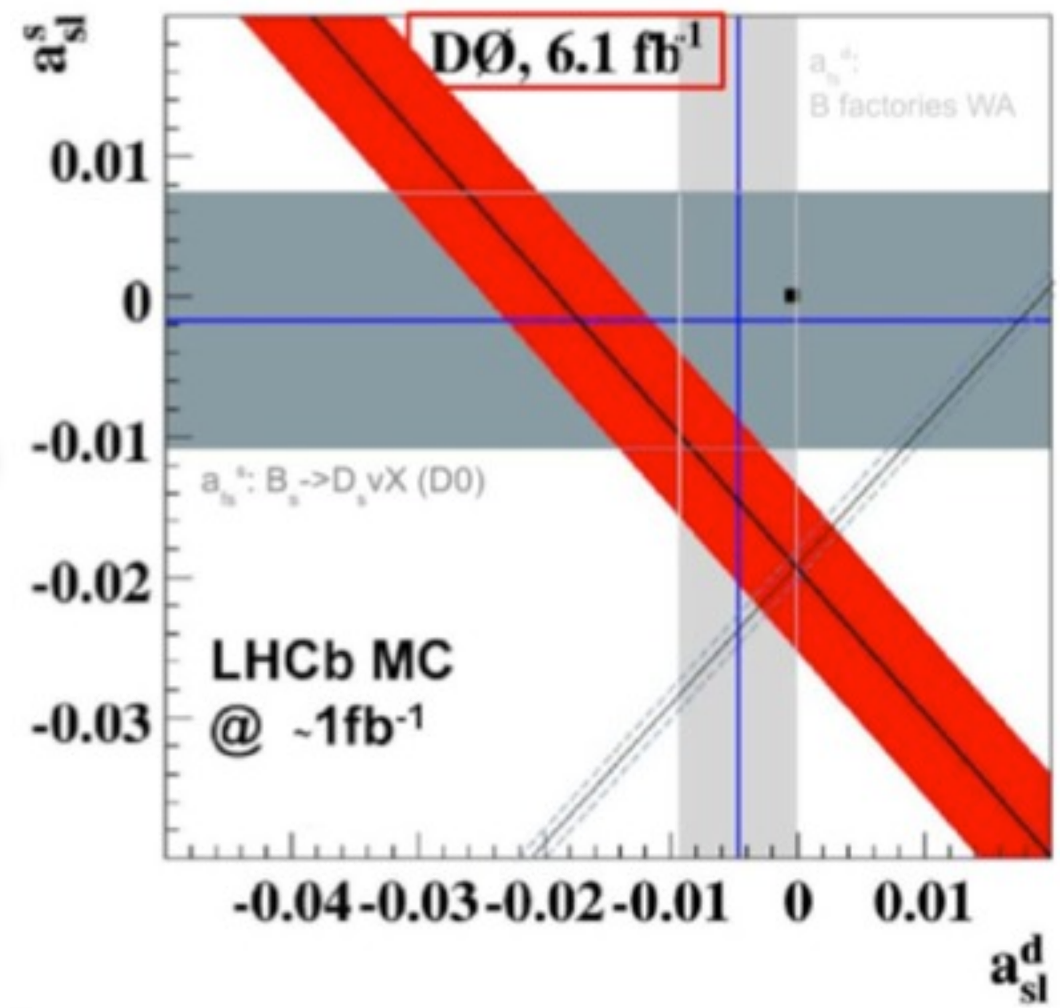


shaded area is from
the semileptonic di-muon
asymmetry



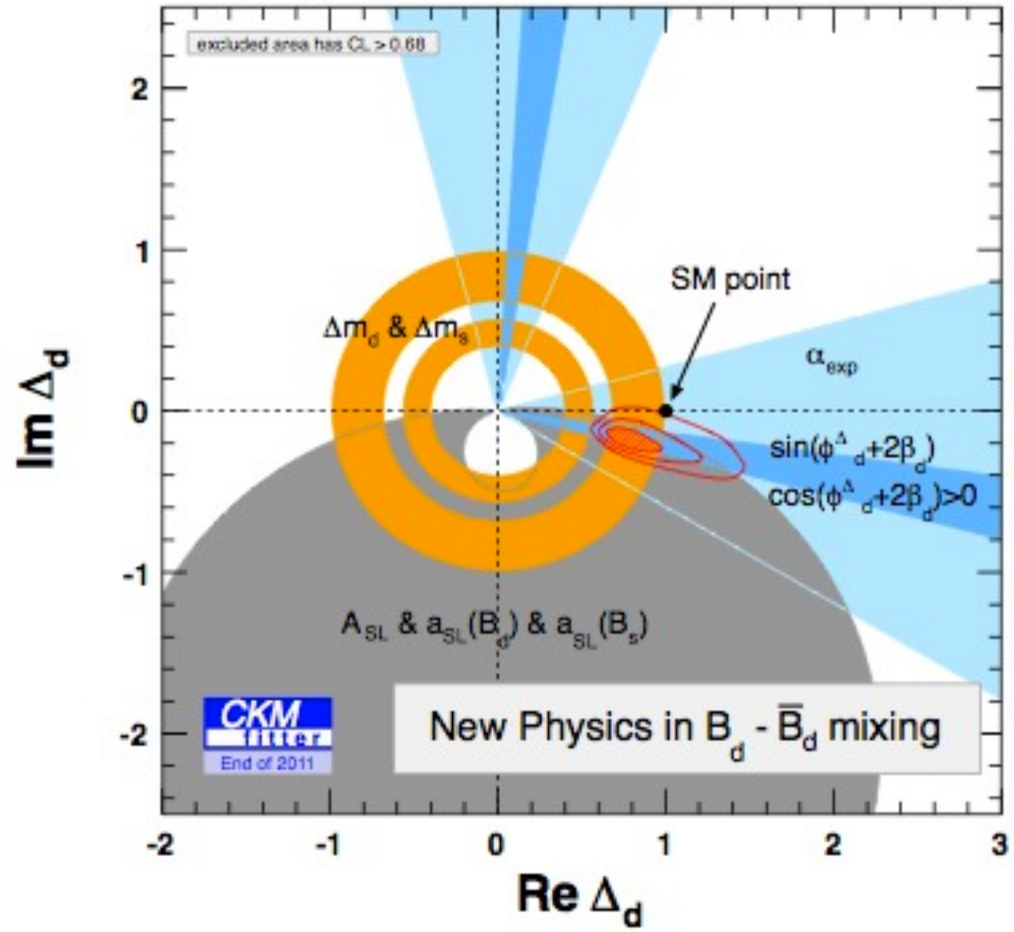
- Eagerly waiting to see what LHCb has to say on the semileptonic asymmetries

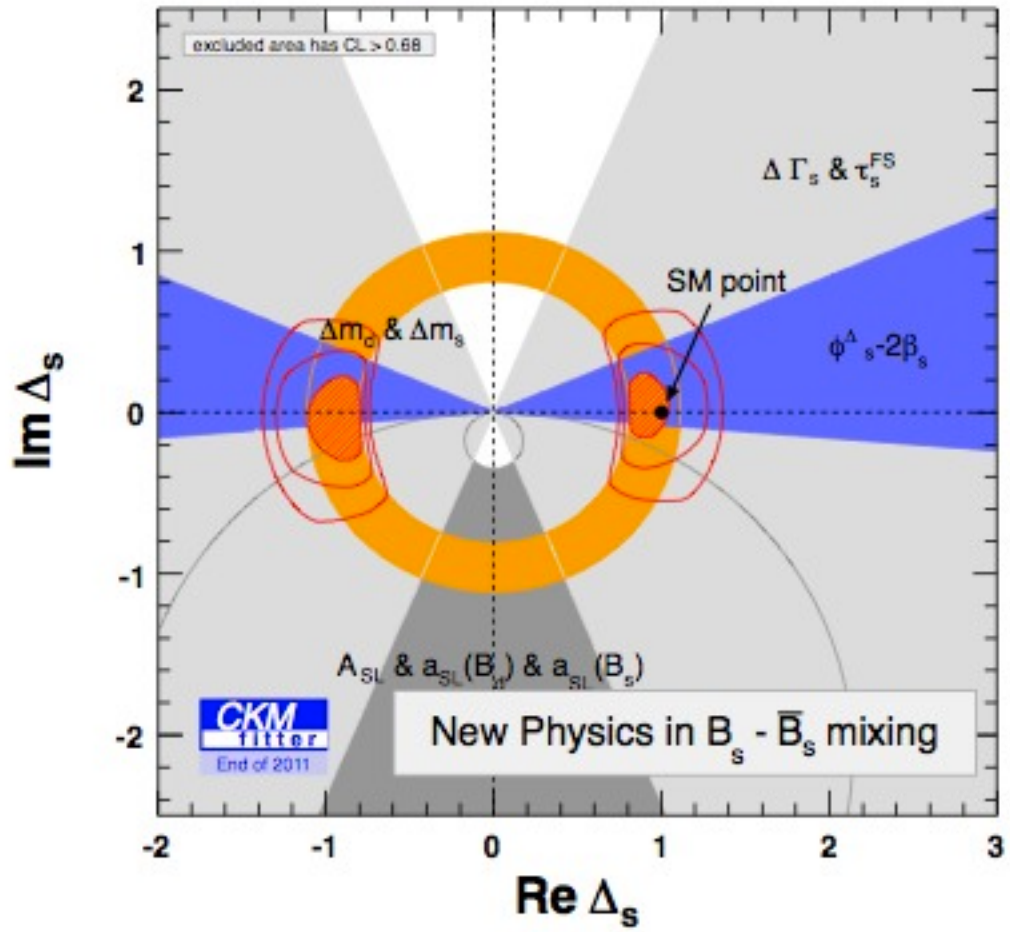




The B_s anomaly

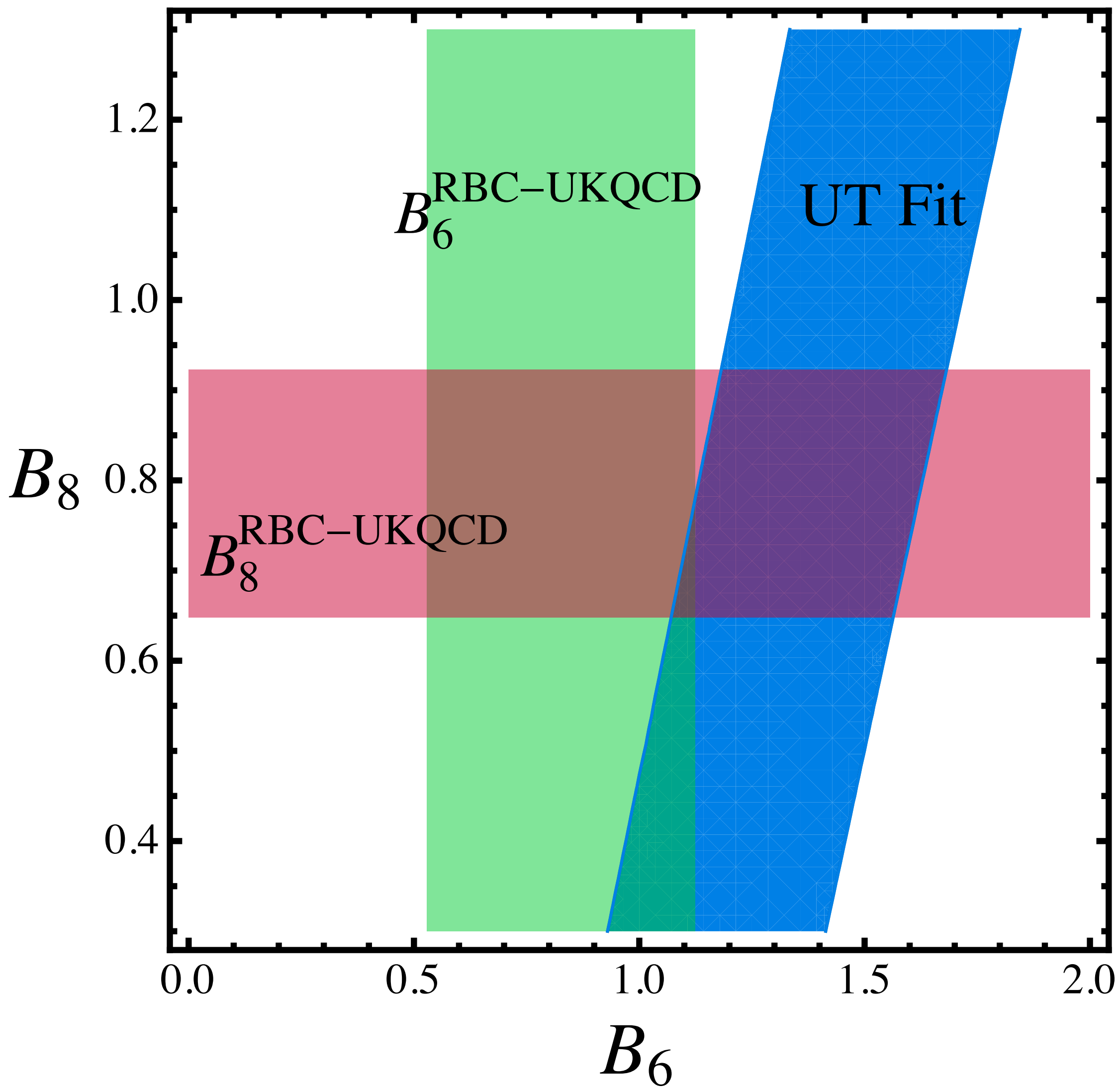
- The updated LHCb result doesn't allow for a clean interpretation of the tension in the Unitarity Triangle and of the B_s anomaly in terms of NP contributions to B and Bs mixing alone *[Lenz, Nierste 1203.0238]*
- Using the parametrization $M_{12}^q \equiv M_{12}^{\mathrm{SM},q} \cdot \Delta_q$, the fit with arbitrary complex Δd and Δs still has pulls at the 2.7σ and 2.9σ level for ϕ_s and A_{SL}





$(\varepsilon'/\varepsilon)_K$

- At last lattice-QCD started to tackle the complex task of calculating Im[A_2] and Im[A_0] [RBC and UKQCD]
- Taking the error on Im[A_2] at face value we can use the UT fit and the experimental determination of $(\varepsilon'/\varepsilon)_K$ to extract a prediction for B_6



- Present uncertainties (preliminary and for somewhat heavy mesons) already constrain the SM
- Given the extreme sensitivity to new physics, improvements on these B parameters is extremely important