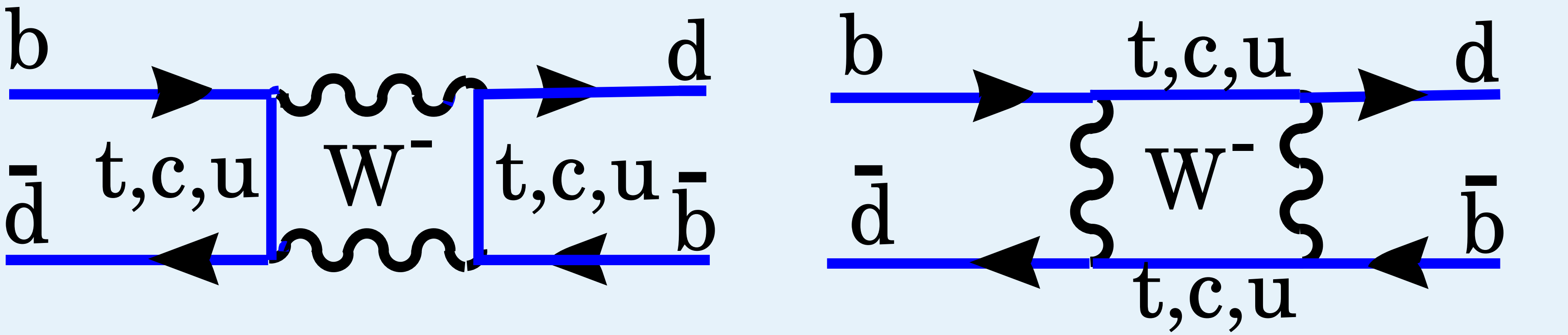
Impact of Flavour Measurements



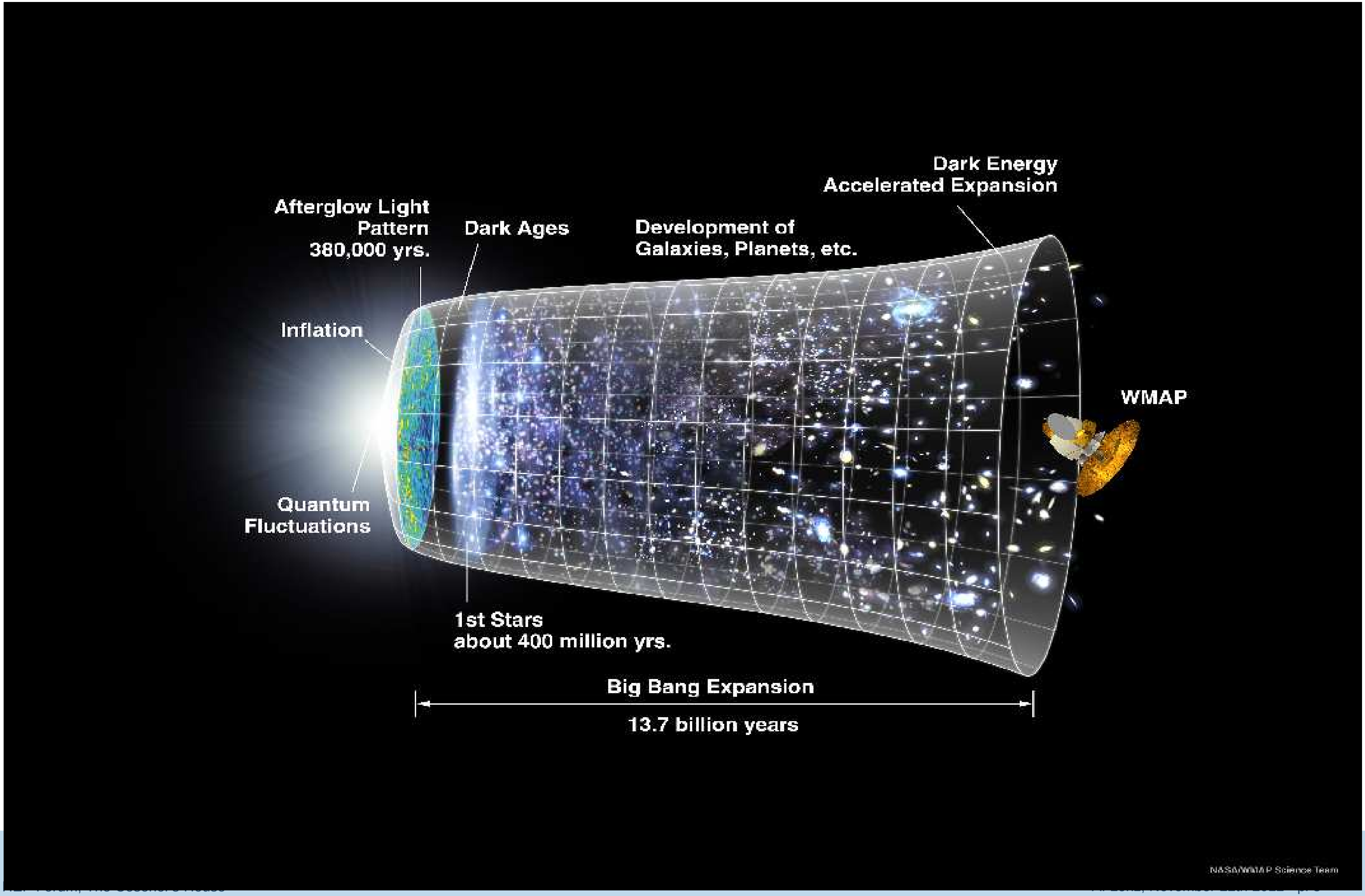
Alexander Lenz

IPPP

Content

- Motivation for Flavour Physics
- Status before LHC
  - CKM paradigm works very well
  - Several intriguing hints for New Physics!
- Status in November 2012 No $\tan\beta - M_A$-plots
  - No convincing hints for New Physics!
  - CKM paradigm and QCD work even better
  - Unexpected results from the Charm sector
- Outlook/Wishlist
  - Higher Precision in Experiment needed
  - Higher Precision in Theory needed

Motivation I



Motivation II - Baryon Asymmetry

symmetric initial conditions
(Inflation: initial asymmetry is wiped out)

$$\Rightarrow N_{\text{matter}} = N_{\text{antimatter}}$$

But we exist and stars and...

Search for annihilation lines, nucleosynthesis, CMB,...

Motivation II - Baryon Asymmetry

Search for annihilation lines, nucleosynthesis, CMB,...

Motivation II - Baryon Asymmetry

Search for annihilation lines, nucleosynthesis, CMB,...

$$\eta_B = \frac{n_B - n_{\bar{B}}}{n_\gamma} \approx 6 \cdot 10^{-10}$$

How can this be created from symmetric initial conditions?

Motivation II - Baryon Asymmetry

Search for annihilation lines, nucleosynthesis, CMB,...

$$\eta_B = \frac{n_B - n_{\bar{B}}}{n_\gamma} \approx 6 \cdot 10^{-10}$$

How can this be created from symmetric initial conditions?

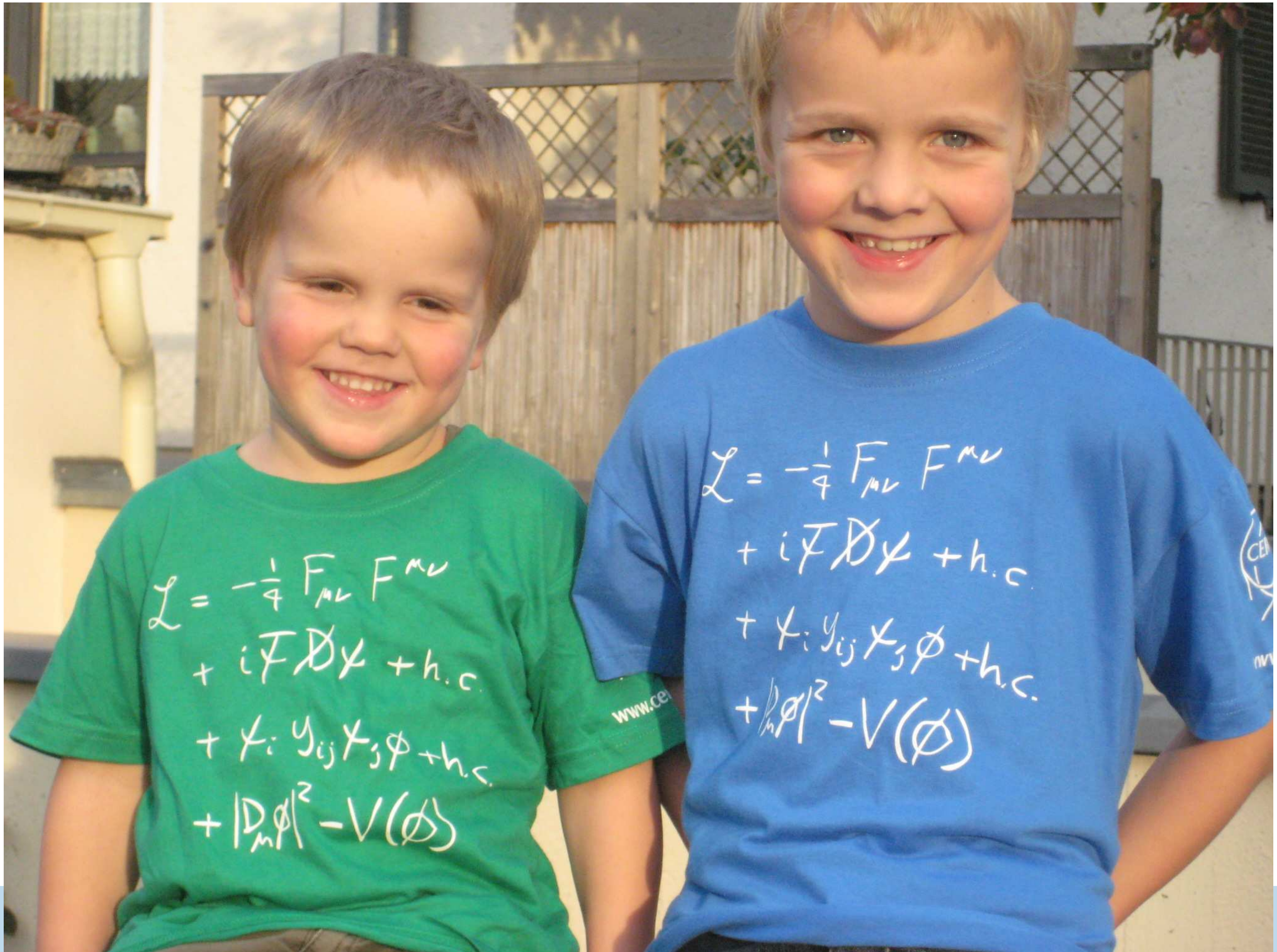
1967 Sakharov: The fundamental laws of nature must have several properties, in particular

CP-violation: 1964 Kaons (NP '80); 2000 B-Mesons; 2011 Charm

Can our fundamental theory cope with these requirements?

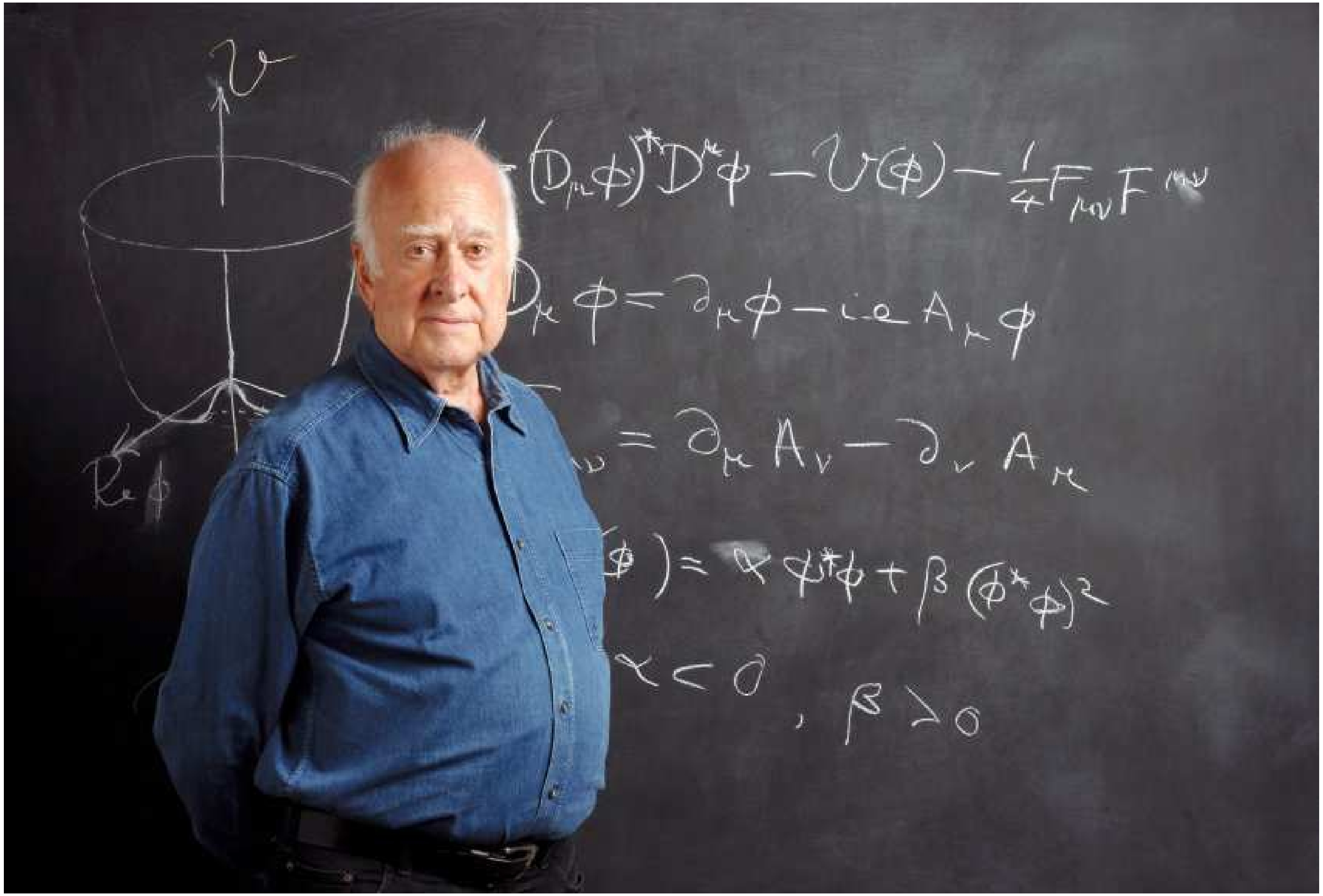
Motivation III - Our fundamental theory

The Standard Model = Elegant description of nature at per mille precision



Motivation IV - Our fundamental theory

Finally Higgs seems to be found



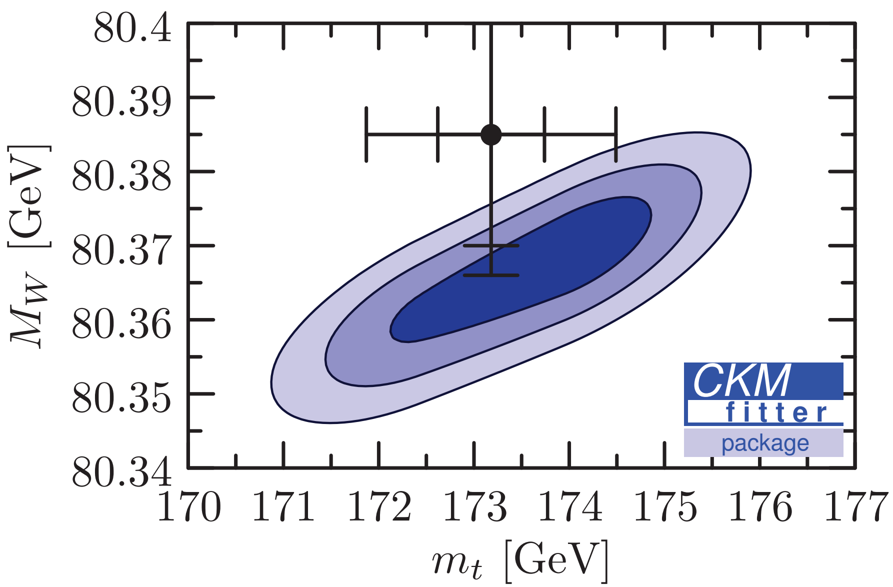
also Englert, Brout; Guralnik, Hagen and Kibble

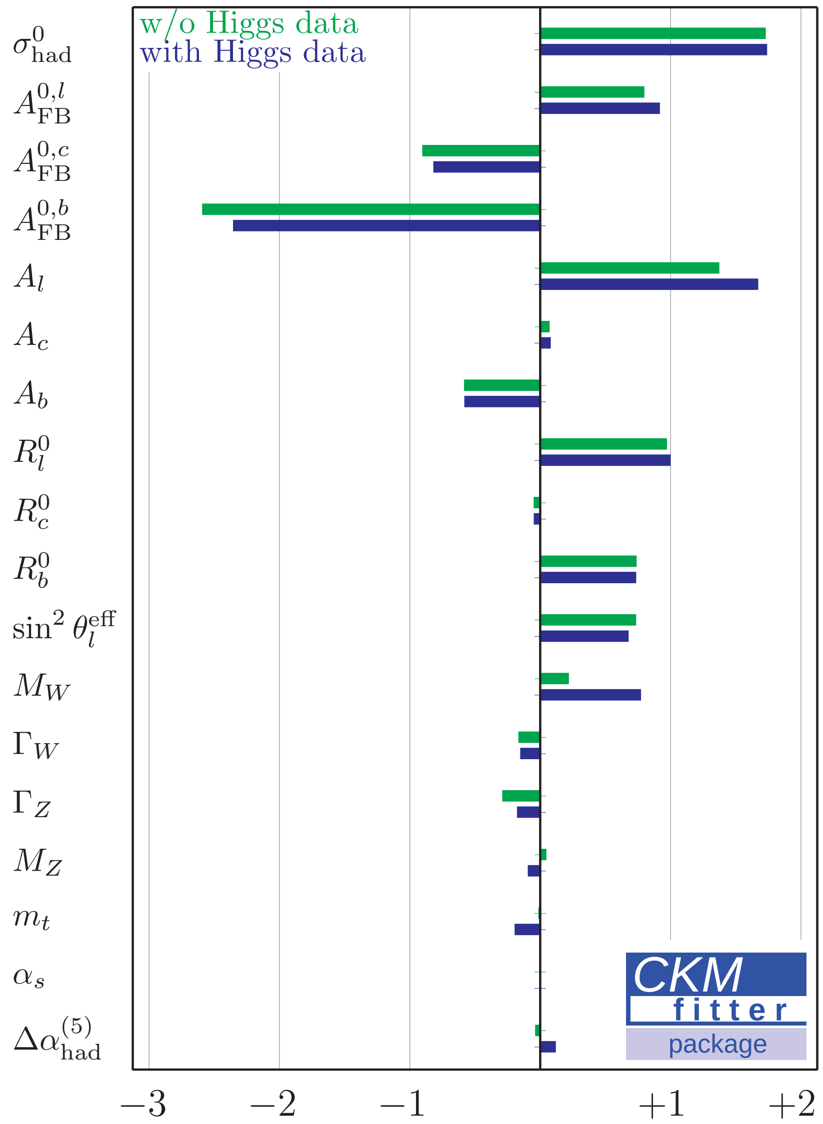
Motivation V - Our fundamental theory

Elegant description of nature at per mille level

SM Fit: Eberhardt et al 1209.1101;
see also GFitter 1209.2716

- **Electroweak precision tests**





Motivation VI - Our fundamental theory

Elegant description of nature at per mille level

- **CKM-mechanism NP 2008**

How can CP-violation be incorporated in the SM?

1972 only u,d and s-quarks were known, Kobayashi and Maskawa postulated six quarks!

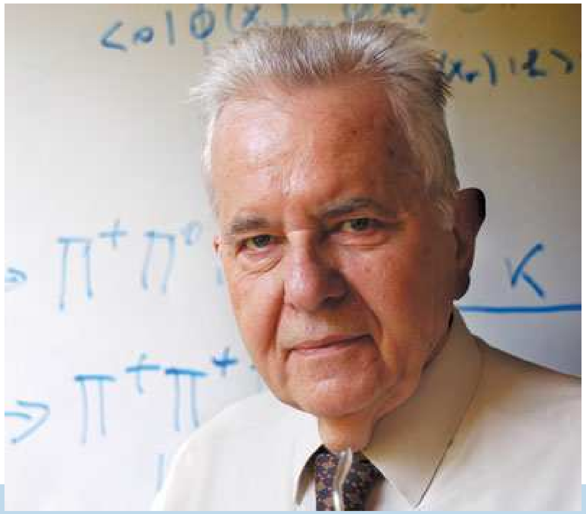
Status before LHC - CKM matrix I

Good overall consistency

$$V_{CKM} = \begin{pmatrix} 0.97425^{+0.00022}_{-0.00014} & 0.22543^{+0.00059}_{-0.00095} & 0.00355^{+0.00015}_{-0.00012} \\ 0.22529^{+0.00060}_{-0.00094} & 0.97342^{+0.00022}_{-0.00015} & 0.04126^{+0.00060}_{-0.00104} \\ 0.00857^{+0.00033}_{-0.00030} & 0.04051^{+0.00060}_{-0.00104} & 0.999142^{+0.000043}_{-0.000025} \end{pmatrix}$$

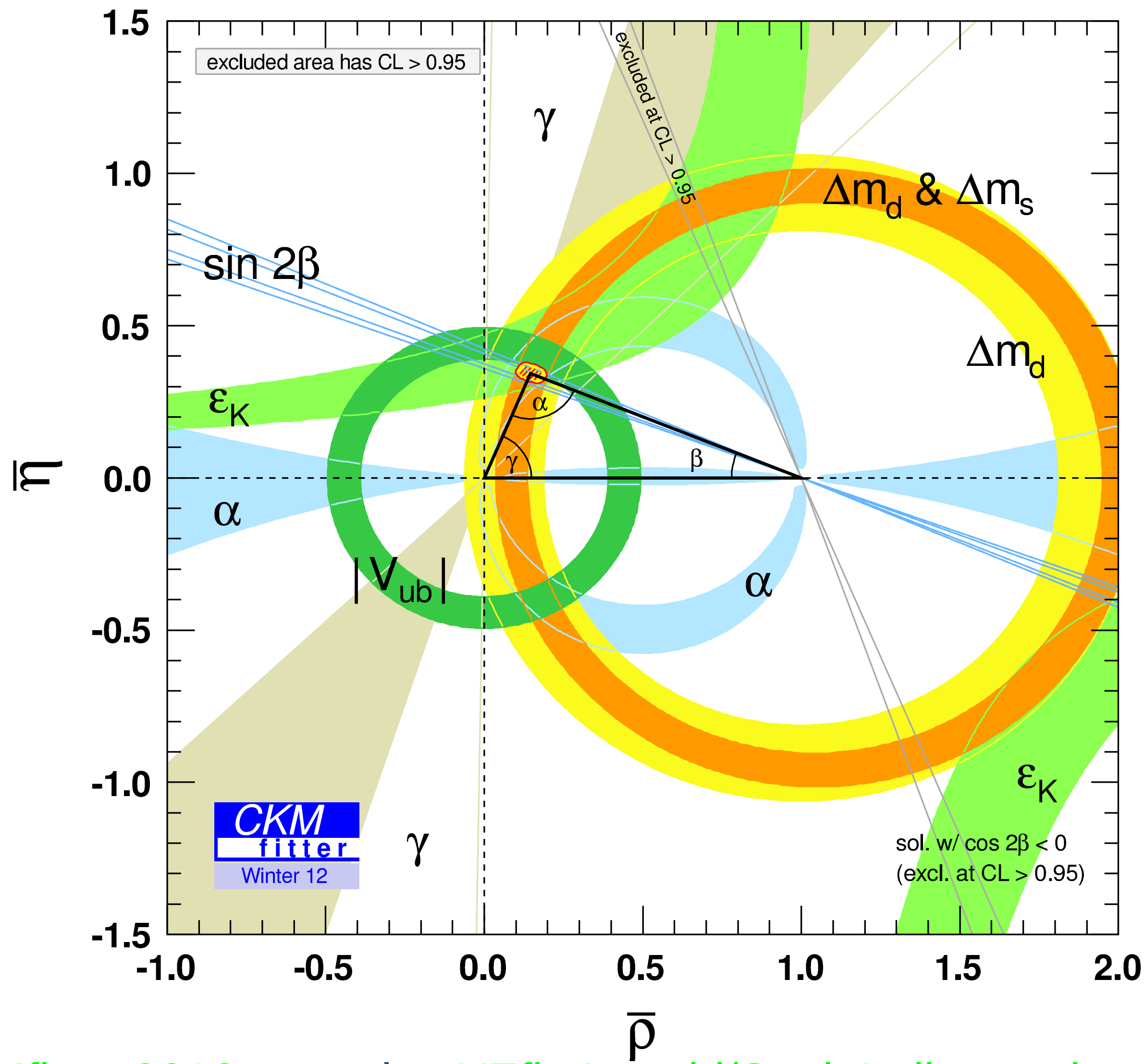
Fit from CKMfitter 2012

see also UTfit 1010.5089, Lunghi/Soni 1010.6069, Laiho/Lunghi/Van de Water 1102.3917, PDG, HFAG ...



NP 2008

Status before LHC: CKM matrix II



$$A = 0.812^{+0.015}_{-0.022}$$
$$\lambda = 0.22543^{+(59)}_{-(95)}$$
$$\bar\rho = 0.145(27)$$
$$\bar\eta = 0.343(15)$$

Picture from CKMfitter 2012, see also UTfit, Lunghi/Soni, Laiho et al...

Status before LHC: V_{ub}-problem

Exclusive	$\lvert V_{ub}\rvert = 0.00351 \pm 0.00047$
Inclusive	$\lvert V_{ub}\rvert = 0.00432 \pm 0.00027$
$B \to \tau\nu$	$\lvert V_{ub}\rvert = 0.00504 \pm 0.00064$
Fit	$\lvert V_{ub}\rvert = 0.00356 \pm 0.00020$

HFAG; HPQCD 2007; MILC Fermilab 2008;Ball/Zwicky 2005; Lange/Neubert/Paz 2005; Andersen/Gardi 2006,2008; Gambino/Giordano/Ossola/Uraltsev 2007; Aglietti/Di Lodovico/Ferrera/Ricciardi 2009; Aglietti/Ferrera/Ricciardi 2007; Bauer/Ligeti/Luke 2001,...

- V_{ub} is actually of order λ^4 and not λ^3: $0.00356 = (0.2254)^{3.79}$
- Hadronic uncertainties (lattice, LCSR) underestimated?
- Soni and Lunghi: do not to use V_{ub} in the global fit
- Crivellin0907.2461; Buras/Gemmler/Isidori 1007.1993: RH currents $\Rightarrow$ *incl.* $\neq$ *excl.*
- New Physics in $B \to \tau\nu$ vs. B_d-mixing

Status before LHC: A new clue to explain existence I

- 17.5.2010 **New York Times**
  A new Clue to explain existence
- 19.5.2010 **BBC News**
  New Clue to anti-matter mystery
- 20.5.2010 **Scientific American**
  Fermilab finds new mechanism for matter’s dominance over antimatter
- 20.5.2010 **The Times**
  Atom-smasher takes man closer to heart of matter
- 25.5.2010 **Spiegel**
  Neue Asymmetrie zwischen Materie und Antimaterie entdeckt
- 28.5.2010 **Science**
  Hints of greater matter-antimatter asymmetry challenge theorists
- 28.5.2010 **Die Zeit**
  Rätselhafte Asymmetrie
- 29.5.2010 **Chicago Tribune**
  Fermilab test throws off more matter than antimatter - and this matters
- ...

Status before LHC: A new clue to explain existence II

- 1005.2757 Dzero (submitted sunday, 16.5.2010) 222 citations

PHYSICAL REVIEW D **82,** 032001 (2010)

Evidence for an anomalous like-sign dimuon charge asymmetry

V. M. Abazov,[36] B. Abbott,[74] M. Abolins,[63] B. S. Acharya,[29] M. Adams,[49] T. Adams,[47] E. Aguilo,[6] G. D. Alexeev,[36]

We measure the charge asymmetry A of like-sign dimuon events in 6.1 fb^{-1} of $p\bar{p}$ collisions recorded with the D0 detector at a center-of-mass energy $\sqrt{s} = 1.96$ TeV at the Fermilab Tevatron collider. From A, we extract the like-sign dimuon charge asymmetry in semileptonic b-hadron decays: $A^b_{\rm sl} = -0.00957 \pm 0.00251\,(\text{stat}) \pm 0.00146\,(\text{syst})$. This result differs by 3.2 standard deviations from the standard model prediction $A^b_{\rm sl}(\text{SM}) = (-2.3^{+0.5}_{-0.6}) \times 10^{-4}$ and provides first evidence of anomalous CP violation in the mixing of neutral B mesons.

DOI: 10.1103/PhysRevD.82.032001 PACS numbers: 13.25.Hw, 11.30.Er, 14.40.Nd

[1] A. Lenz and U. Nierste, J. High Energy Phys. 06 (2007) 072.
[2] C. Amsler *et al.*, Phys. Lett. B **667**, 1 (2008), and 2009 partial update for the 2010 edition.
[15] V. M. Abazov *et al.* (D0 Collaboration), Nucl. Instrum. Methods Phys. Res., Sect. A **565**, 463 (2006).
[16] S. N. Ahmed *et al.*, arXiv:1005.0801 [Nucl. Instrum. Methods Phys. Res. Sect. A (to be published)]; R.

17.5.'10 NYT: "A new clue to explain existence" ($111 \cdot 10^6$ google entries)

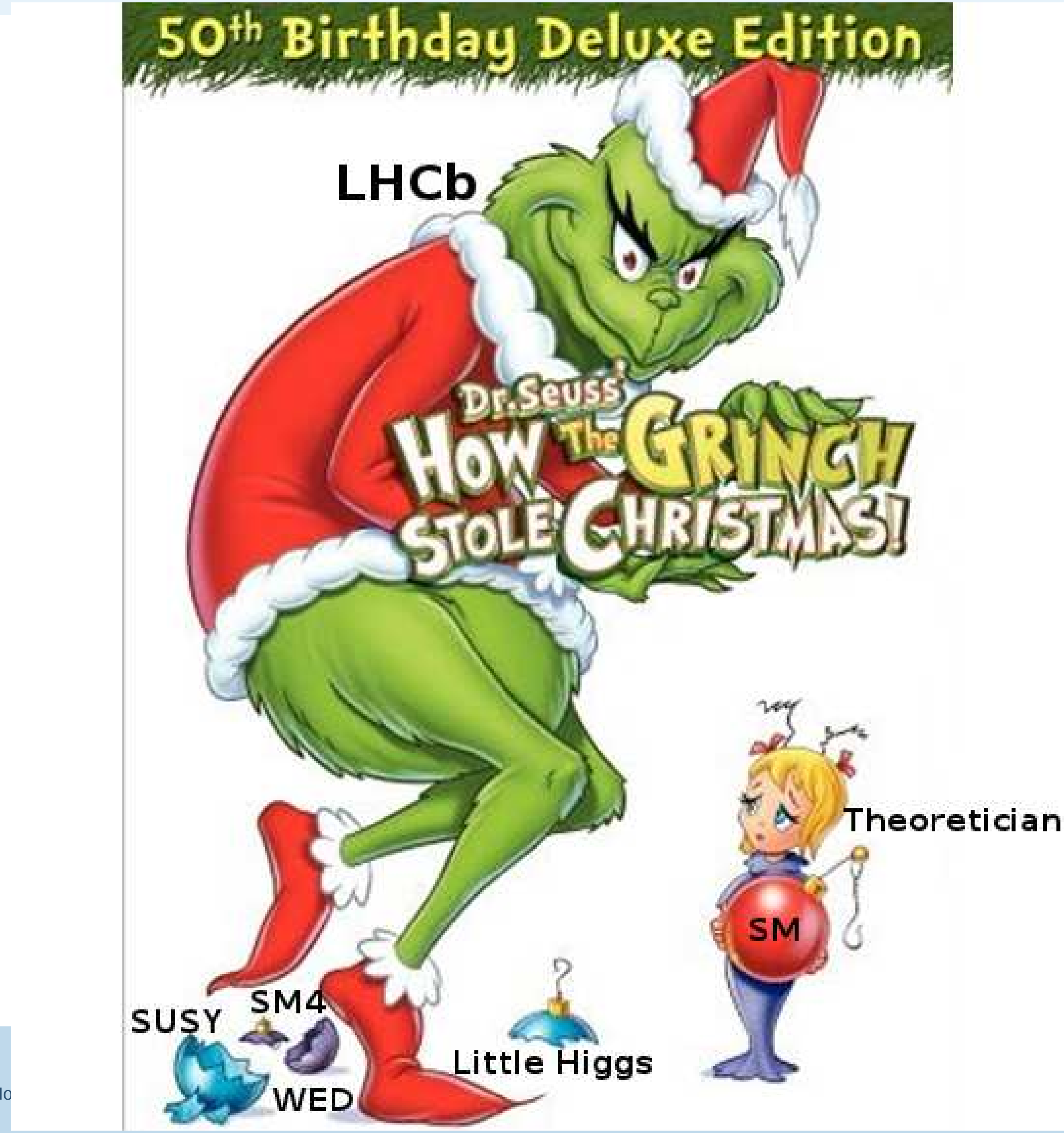
- 1106.6308: 9 fb^{-1}, $A^b_{sl} = (-0.787 \pm 0.172(stat) \pm 0.093(syst))\% \Rightarrow 3.9\sigma$

Status before LHC: Overview

- Overall consistency of the CKM picture is very good
  - Mechanism awarded with the Nobel prize
  - Also agreement on loop-level e.g. $b \to s\gamma$
  - Still higher precision necessary
    Current constraints still allow $V_{u'b} > V_{ub}$ and $V_{c'b} > V_{cb}$
    V_{td} and V_{ts} more or less unconstrained

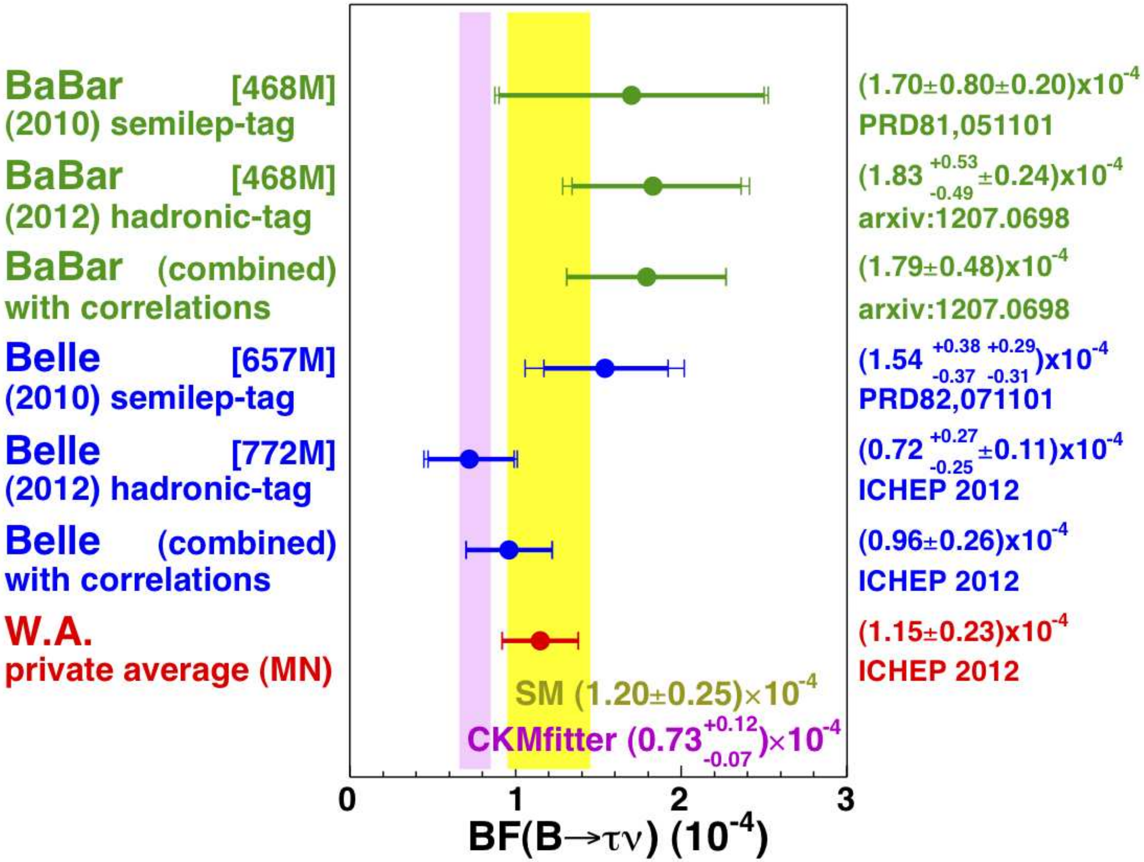
- Several interesting deviations from the CKM picture have arisen
  - Evidence for new physics in B-mixing: Dimuon asymmetry; $B_s \to J/\psi\phi$...
  - Problems with $\sin 2\beta$ - V_{ub} - $B \to \tau\nu$
  - CDF has hints for a large $B_s \to \mu\mu$ branching ratio
  - ...

Status in 11/12: We expected a lot, and then...



Status in Nov. 2012: $B \to \tau\nu$

Also new results from Belle 1208.4678 confirm the SM



Is there a similar problem in $B \to D^{(*)}\tau\nu$? BaBar 1205.5442 or also hadronic uncertainties Becirevic et al 1206.4977

Status in Nov. 2012: $B_s \to \mu\mu$

CDF was not confirmed by ATLAS, CMS and **LHCb** 1211.2674

$$Br(B_s \to \mu\mu) = 3.2^{+1.5}_{-1.2} \cdot 10^{-9} \qquad (3.5\sigma)$$

This agrees perfectly with the SM expectation

$$\begin{aligned} Br(B_s \to \mu\mu) &= 3.64^{+0.21}_{-0.32} \cdot 10^{-9} && \text{CKMfitter} \\ Br(B_s \to \mu\mu) &= 3.23 \pm 0.27 \cdot 10^{-9} && \text{Buras et al 1208.0934} \end{aligned}$$

This numbers have to be corrected due to

- Finite $\Delta\Gamma_s$: about $+10\%$ Fleischer et al. 1204.1735; 1204.1737
- Soft Photons: about: -10% Petrov in April at CERN; Buras et al 1208.0934

Also investigations of the rare decay $B \to Kll$ confirm the SM, see e.g. *Workshop on the physics reach of rare and exclusive B decays* (Nov. 2012; University of Sussex) - except Isopsin asymmetry!

Status in Nov. 2012: $B_s \to \mu\mu$

Is SUSY killed by LHCb?

Quotes I learnt recently

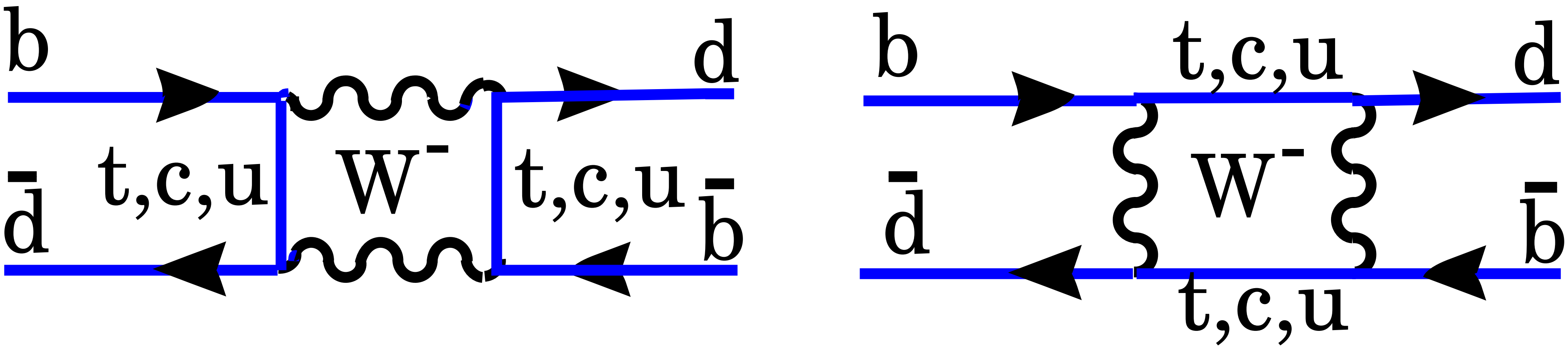
- *Absence of evidence is not evidence of absence*
  This was not true for the SM4 (see Djouadi, AL 2012; Eberhardt et al. 2012), but it is true for decoupling theories, like SUSY
- *SUSY is not dead yet, but it is not showing any sign of life*
  A lot of the parameter space which was considered some years ago, is ruled out by the $B_s \to \mu\mu$ measurement!

Status in Nov. 2012: B-mixing I

Time evolution of a decaying particle: $B(t) = \exp\left[-i m_B t - \Gamma_B/2 t\right]$
can be written as

$$i \frac{d}{dt} \left(\begin{array}{c} |B(t)\rangle \\ |\bar{B}(t)\rangle \end{array} \right) = \left(\hat{M} - \frac{i}{2} \hat{\Gamma} \right) \left(\begin{array}{c} |B(t)\rangle \\ |\bar{B}(t)\rangle \end{array} \right)$$

BUT: In the neutral B-system transitions like $B_{d,s} \to \bar{B}_{d,s}$ are possible due to weak interaction: **Box diagrams**



Status in Nov. 2012: Mixing II

Mixing is a macroscopic quantum effect!

It was observed in

- K^0-system: 1950s (see text books, regeneration...)
- B_d-system: 1986 ΔM_d
- B_s-system: 2006 ΔM_s; 2012 $\Delta \Gamma_s$
- D^0-system: 2007 $\Delta M_D, \ \Delta \Gamma_D$

Strongly suppressed in the SM (higher order in weak interaction)
New physics effects might be of comparable size

?Is QCD under control?

Status in Nov. 2012: Mixing III

Time evolution of a decaying particle: $B(t) = \exp\left[-i m_B t - \Gamma_B/2 t\right]$
can be written as

$$i \frac{d}{dt} \left(\begin{array}{c} |B(t)\rangle \\ |\bar{B}(t)\rangle \end{array} \right) = \left(\hat{M} - \frac{i}{2} \hat{\Gamma} \right) \left(\begin{array}{c} |B(t)\rangle \\ |\bar{B}(t)\rangle \end{array} \right)$$

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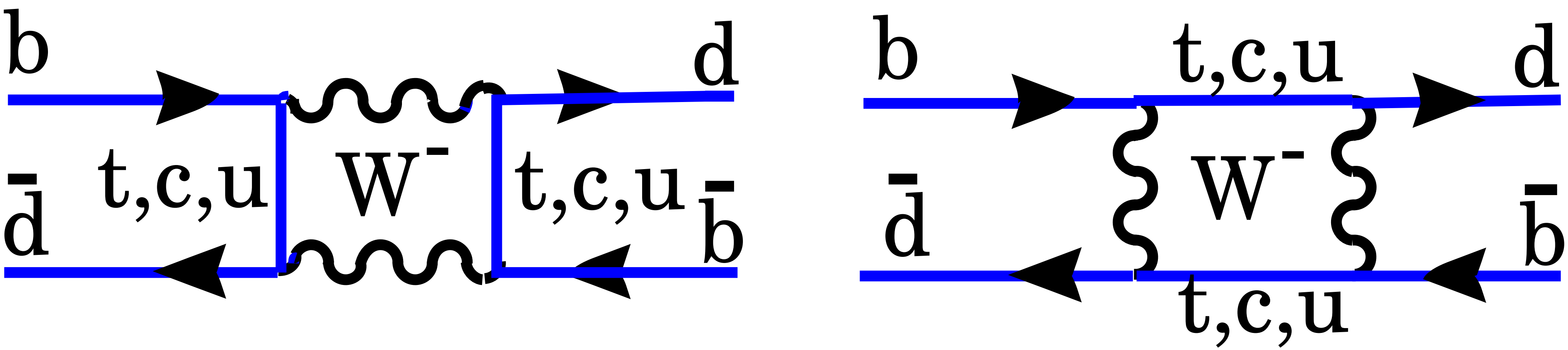

$\Rightarrow$ **off-diagonal elements** in $\hat{M}$, $\hat{\Gamma}$: M_{12}, Γ_{12} (complex)

Diagonalization of $\hat{M}$, $\hat{\Gamma}$ gives the physical eigenstates B_H and B_L with the masses M_H, M_L and the decay rates Γ_H, Γ_L

CP-odd: $B_H := p\, B + q\, \bar{B}$, CP-even: $B_L := p\, B - q\, \bar{B}$ with $|p|^2 + |q|^2 = 1$

Status in Nov. 2012: Mixing IV

$|M_{12}|$, $|\Gamma_{12}|$ and $\phi = \text{arg}(-M_{12}/\Gamma_{12})$ can be related to three observables:

- **Mass difference:** $\Delta M := M_H - M_L = 2|M_{12}| \left(1 - \frac{1}{8}\frac{|\Gamma_{12}|^2}{|M_{12}|^2}\sin^2\phi + ...\right)$
  $|M_{12}|$: heavy internal particles: t, SUSY, ...

- **Decay rate difference:** $\Delta\Gamma := \Gamma_L - \Gamma_H = 2|\Gamma_{12}|\cos\phi \left(1 + \frac{1}{8}\frac{|\Gamma_{12}|^2}{|M_{12}|^2}\sin^2\phi + ...\right)$
  $|\Gamma_{12}|$: light internal particles: u, c, ... (almost) no NP!!!

- **Flavor specific/semileptonic CP asymmetries:**
  $\bar{B}_q \to f$ and $B_q \to \bar{f}$ forbidden
  No direct CP violation: $|\langle f|B_q\rangle| = |\langle \bar{f}|\bar{B}_q\rangle|$
  e.g. $B_s \to D_s^- \pi^+$ or $B_q \to Xl\nu$ (*semileptonic*)

$$a_{sl} \equiv a_{fs} = \frac{\Gamma(\overline{B}_q(t) \to f) - \Gamma(B_q(t) \to \overline{f})}{\Gamma(\overline{B}_q(t) \to f) + \Gamma(B_q(t) \to \overline{f})} = -2\left(\left|\frac{q}{p}\right| - 1\right) = \text{Im}\frac{\Gamma_{12}}{M_{12}} = \frac{\Delta\Gamma}{\Delta M}\tan\phi$$

Status 11/12: The Mass Difference ΔM

Calculating the box diagram with an internal top-quark yields

$$M_{12,q} = \frac{G_F^2}{12\pi^2}(V_{tq}^* V_{tb})^2 M_W^2 S_o(x_t) B_{B_q} f_{B_q}^2 M_{B_q} \hat{\eta}_B$$

(Inami, Lim '81)

- Hadronic matrix element: $\frac{8}{3} B_{B_q} f_{B_q}^2 M_{B_q} = \langle \bar{B}_q | (\bar{b}q)_{V-A} (\bar{b}q)_{V-A} | B_q \rangle$
- Perturbative QCD corrections $\hat{\eta}_B$ (Buras, Jamin, Weisz, '90)

Theory 1102.4274 vs. Experiment : HFAG 12

$\Delta M_d = 0.543 \pm 0.091\ ps^{-1}$	$\Delta M_d = 0.507 \pm 0.004\ ps^{-1}$ ALEPH, CDF, D0, DELPHI, L3, OPAL, BABAR, BELLE, ARGUS, CLEO
$\Delta M_s = 17.30 \pm 2.6\ ps^{-1}$	$\Delta M_s = 17.719 \pm 0.043\ ps^{-1}$ CDF, D0, LHCb

Important bounds on the unitarity triangle and new physics

Status 11/12: Determination of Γ_{12}

Sensitive to real intermediate states $\Rightarrow$ much more complicated than M_{12}

1. OPE I: Integrate out W: like $M_{12} \propto f_B^2 B$
2. OPE II: Heavy quark expansion $\Rightarrow \Gamma_i^{(j)} \propto f_B^2 \sum C_k B_K$

$$\boxed{\Gamma_{12} = \left(\frac{\Lambda}{m_b}\right)^3 \left(\Gamma_3^{(0)} + \frac{\alpha_s}{4\pi}\Gamma_3^{(1)} + ...\right) + \left(\frac{\Lambda}{m_b}\right)^4 \left(\Gamma_4^{(0)} + ...\right) + \left(\frac{\Lambda}{m_b}\right)^5 \left(\Gamma_5^{(0)} + ...\right) + ...}$$

1996: Beneke, Buchalla, Dunietz; 1998: Beneke, Buchalla, Greub, A.L., Nierste
2003: Ciuchini, Franco, Lubicz, Mescia, Tarantino; Beneke, Buchalla, A.L., Nierste
2006: A.L., Nierste; 2007: Badin, Gabbiani, Petrov

Energy release is small $\Rightarrow$ naive dim. estimate: series might not converge
Do a real calculation:

$$\boxed{\begin{aligned} \Delta\Gamma_s &= \Delta\Gamma_s^0 \left(1 + \delta^{\text{Lattice}} + \delta^{\text{QCD}} + \delta^{\text{HQE}}\right) \\ &= 0.142\ \text{ps}^{-1} \left(1 - 0.14 - 0.06 - 0.19\right) \end{aligned}}$$

Status 11/12: HQE under attack!

OPE II might be questionable - relies on quark hadron duality

- Mid 90's: Missing Charm puzzle $n_c^{\mathrm{Exp.}} < n_c^{\mathrm{SM}}$, semi leptonic branching ratio
- Mid 90's: Λ_b lifetime is too short
- before 2003: $\tau_{B_s}/\tau_{B_d} \approx 0.94 \neq 1$
- 2010/2011: Di-muon asymmetry too large

Theory arguments for HQE

$\Rightarrow$ calculate corrections in all possible "directions", to test convergence
$\Rightarrow \Gamma_{12}$ seems to be ok!

$\Rightarrow$ test reliability of OPE II via lifetimes (no NP effects expected), to test convergence
$\Rightarrow \tau(B^+)/\tau(B_d)$ Experiment and theory agree within hadronic uncertainties

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- 2012: $n_c^{2011\text{PDG}} = 1.20 \pm 0.06$ vs. $n_c^{\text{SM}} = 1.23 \pm 0.08$
  Eberhardt, Krinner, A.L., Rauh in prep.
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  Shift by 2.5σ!; ATLAS: 1.45 ± 0.04 ps/CMS: 1.50 ± 0.06 ps Waiting for LHCb!
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- **Moriond 2012 LHCb:** $\tau_{B_s}/\tau_{B_d} = 1.001 \pm 0.014$ LHCb-CONF-2012-002
- 2010/2011: Di-muon asymmetry too large

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- **Moriond 2012 LHCb:** $\tau_{B_s}/\tau_{B_d} = 1.001 \pm 0.014$ LHCb-CONF-2012-002
- 2010/2011: Di-muon asymmetry too large — Test Γ_{12} with $\Delta\Gamma_s$!

Theory arguments for HQE

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Status 11/12: Finally $\Delta\Gamma_s$ is measured!

$$\Delta\Gamma_s^{\rm SM} = (0.087 \pm 0.021)\,\text{ps}^{-1}$$

A.L., Nierste 1102.4274

LHCb from $B_s \to J/\psi\phi$ Dunietz, Fleischer, Nierste

$\Delta\Gamma_s = (0.116 \pm 0.019)\,\text{ps}^{-1}$	:	LHCb-Conf-2012-002 $> 5\sigma!$
$\Delta\Gamma_s = (0.163 \pm 0.065)\,\text{ps}^{-1}$	:	D0 8fb^{-1} 1109.3166
$\Delta\Gamma_s = (0.068 \pm 0.027)\,\text{ps}^{-1}$	:	CDF 9.6fb^{-1} 1208.2967
$\Delta\Gamma_s = (0.053 \pm 0.022)\,\text{ps}^{-1}$	:	ATLAS 4.9 fb^{-1} 1208.0572

$$\Delta\Gamma_s^{\rm Exp} = (0.089 \pm 0.012)\,\text{ps}^{-1}$$

CKM 2012
F. Dordei LHCb

Status 11/12: Finally $\Delta\Gamma_s$ is measured!

Get rid off the dependence on f_{B_s} (No NP in ΔM)

$$\boxed{\begin{aligned} \frac{\Delta\Gamma_s}{\Delta M_s} &= 10^{-4} \cdot \left[46.2 + 10.6 \frac{\tilde{B}'_S}{B} - \left(13.2 \frac{B_{\tilde{R}_2}}{B} - 2.5 \frac{B_{R_0}}{B} + 1.2 \frac{B_R}{B} \right) \right] \\ &= 0.0050 \pm 0.0010 \end{aligned}}$$

HQE vs. Experiment

$$\boxed{\left(\frac{\Delta\Gamma_s}{\Delta M_s} \right)^{\mathrm{Exp}} / \left(\frac{\Delta\Gamma_s}{\Delta M_s} \right)^{\mathrm{SM}} = 1.00 \pm 0.13 \pm 0.20}$$

Status 11/12: Most important lesson from LHCb?

HQE works also for Γ_{12}!

- despite small energy release $M_{B_s} - 2M_{D_s} \approx 1.4$ GeV
- Theoreticians were fighting for 35 years whether there is a violation of quark hadron duality

How precise does it work? 30%? 10%?

Still more accurate data needed!

LHCb, ATLAS, CMS?, TeVatron, Super-B(elle)

1. Apply HQE to quantities that are sensitive to NP
2. Apply HQE to quantities in the charm system?

Status 11/12: Semi leptonic CP-asymmetries

SM predictions: A.L., U. Nierste, 1102.4274; A.L. 1108.1218

$$a_{fs}^s = (1.9 \pm 0.3) \cdot 10^{-5} \qquad \phi_s = 0.22^\circ \pm 0.06^\circ$$

$$a_{fs}^d = -(4.1 \pm 0.6) \cdot 10^{-4} \qquad \phi_d = -4.3^\circ \pm 1.4^\circ$$

$$A_{sl}^b = 0.406 a_{sl}^s + 0.594 a_{sl}^d = (-2.3 \pm 0.4) \cdot 10^{-4}$$

Experimental bounds

$$\phi_s = -51.6^\circ \pm 12^\circ$$ (A.L., Nierste, CKMfitter, 1008.1593)

$$= -0.1^\circ \pm 5.0^\circ$$ LHCb Moriond 2012

$$a_{fs}^d = -(5 \pm 56) \cdot 10^{-4}$$ (HFAG 12)$\Upsilon(4s)$

$$\left| \frac{\Delta\Gamma_d}{\Gamma_d} \right| = (15 \pm 1) \cdot 10^{-3}$$ (HFAG 12)

$$A_{sl}^b = -(7.87 \pm 1.72 \pm 0.93) \cdot 10^{-3}$$ (D0,1106.6308)

$A_{sl}^b(Exp.)/A_{sl}^b(Theory) = \mathbf{34}$ $\qquad 3.9 - \sigma$**-effect**

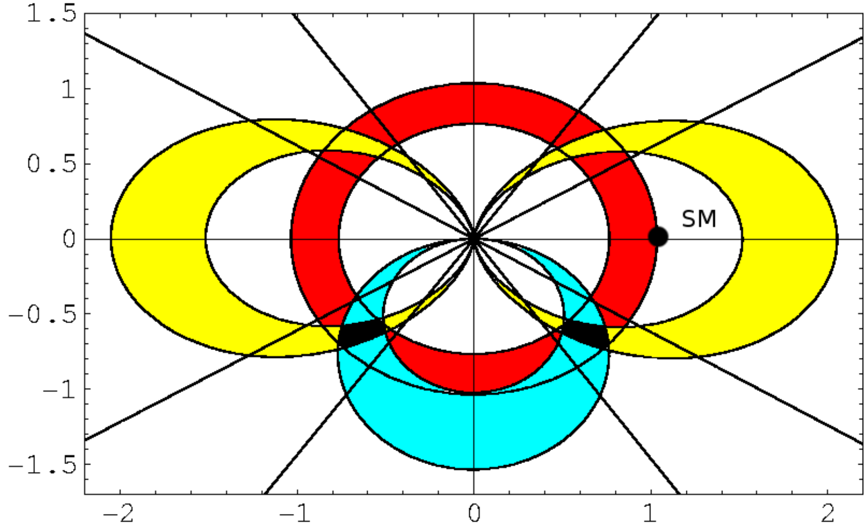
Status 11/12: New Physics in B-Mixing I

$$\Gamma_{12,s} = \Gamma_{12,s}^{\rm SM}\,, \qquad M_{12,s} = M_{12,s}^{\rm SM} \cdot \Delta_s\,; \qquad \Delta_s = |\Delta_s| e^{i\phi_s^\Delta}$$

$$\begin{aligned}
\Delta M_s &= 2|M_{12,s}^{\rm SM}| \cdot |\Delta_s| \\
\Delta \Gamma_s &= 2|\Gamma_{12,s}| \cdot \cos\left(\phi_s^{\rm SM} + \phi_s^\Delta\right) \\
\frac{\Delta\Gamma_s}{\Delta M_s} &= \frac{|\Gamma_{12,s}|}{|M_{12,s}^{\rm SM}|} \cdot \frac{\cos\left(\phi_s^{\rm SM} + \phi_s^\Delta\right)}{|\Delta_s|} \\
a_{fs}^s &= \frac{|\Gamma_{12,s}|}{|M_{12,s}^{\rm SM}|} \cdot \frac{\sin\left(\phi_s^{\rm SM} + \phi_s^\Delta\right)}{|\Delta_s|}
\end{aligned}$$

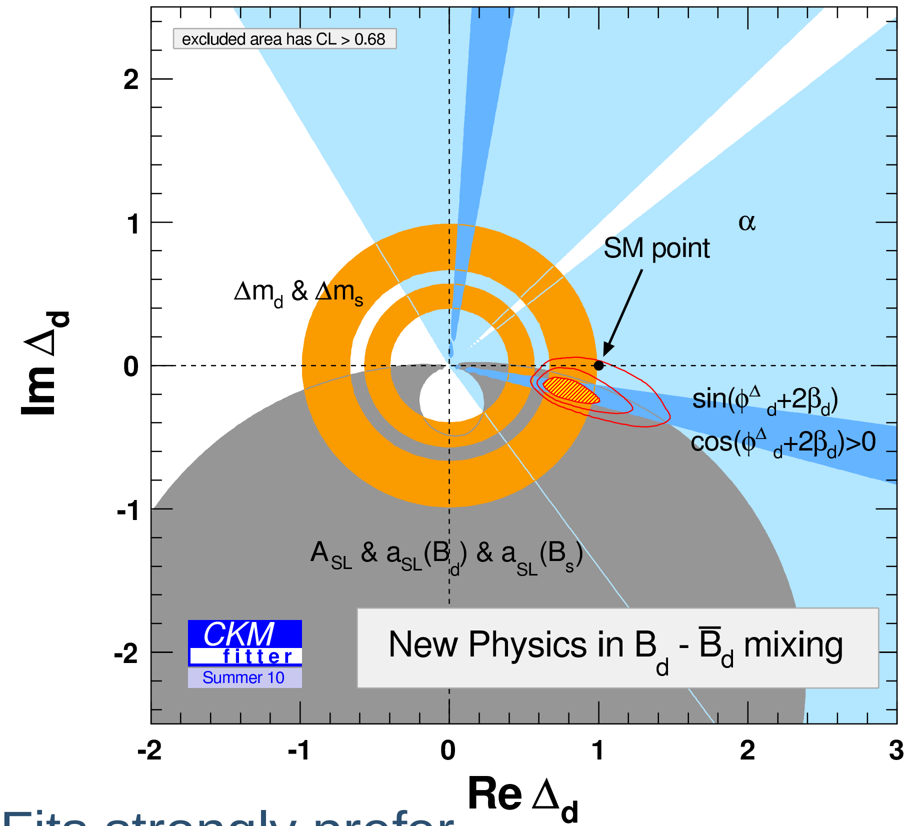
$$\sin(\phi_s^{\rm SM}) \approx 1/240$$

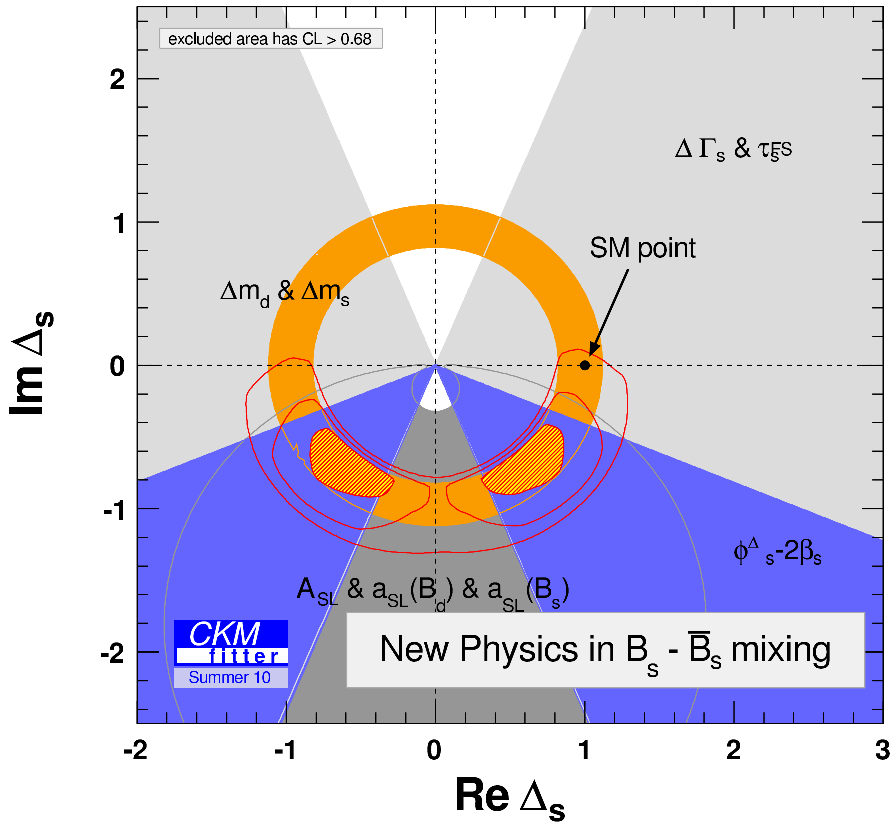
For $|\Delta_s| = 0.9$ and $\phi_s^\Delta = -\pi/4$ one gets the following bounds in the **complex Δ-plane**:



Status 11/12: New Physics in B-Mixing II

Combine all data before summer 2010 and neglect penguins
fit of Δ_d and Δ_s 1008.1593



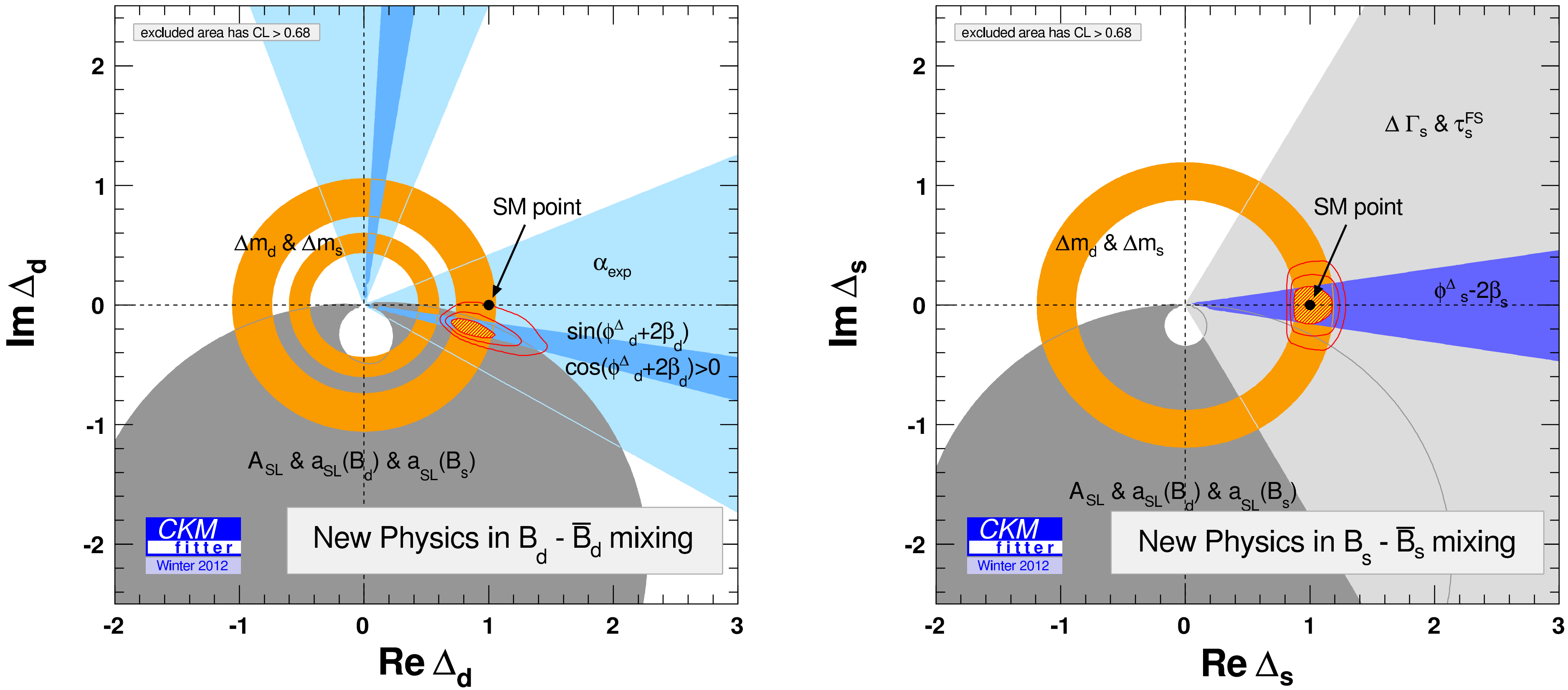


Fits strongly prefer

- large new physics effects in the B_s-system
- some new physics effects in the B_d-system

Status 11/12: New Physics in B-Mixing III

Combine all data till Moriond and neglect penguins
fit of Δ_d and Δ_s 1203.0238v2

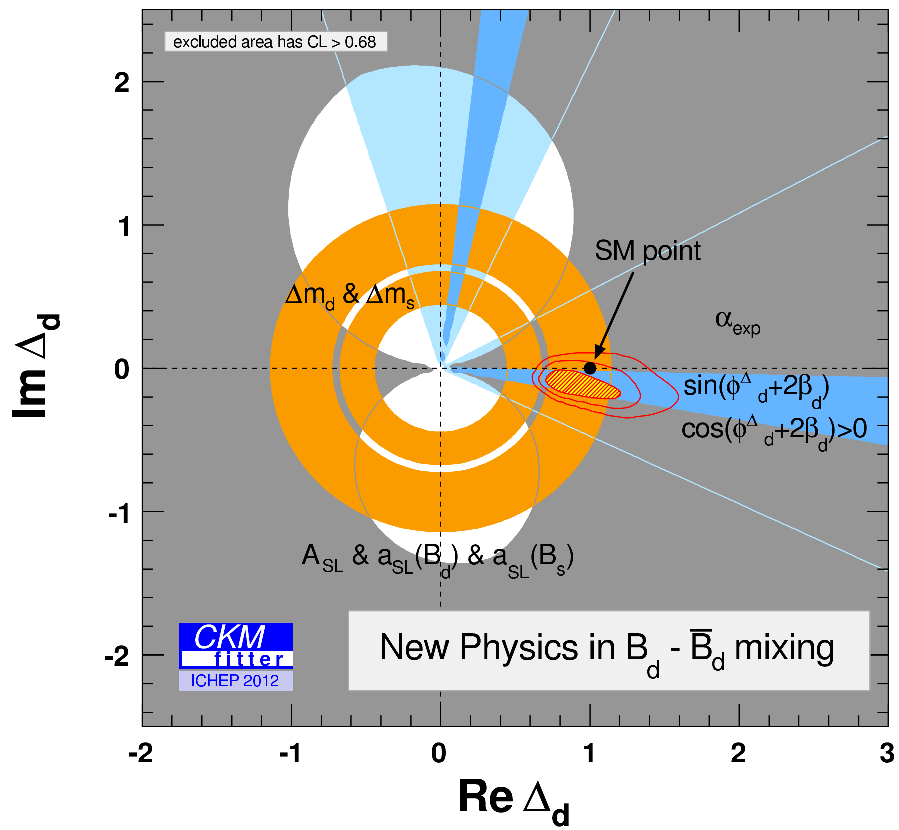


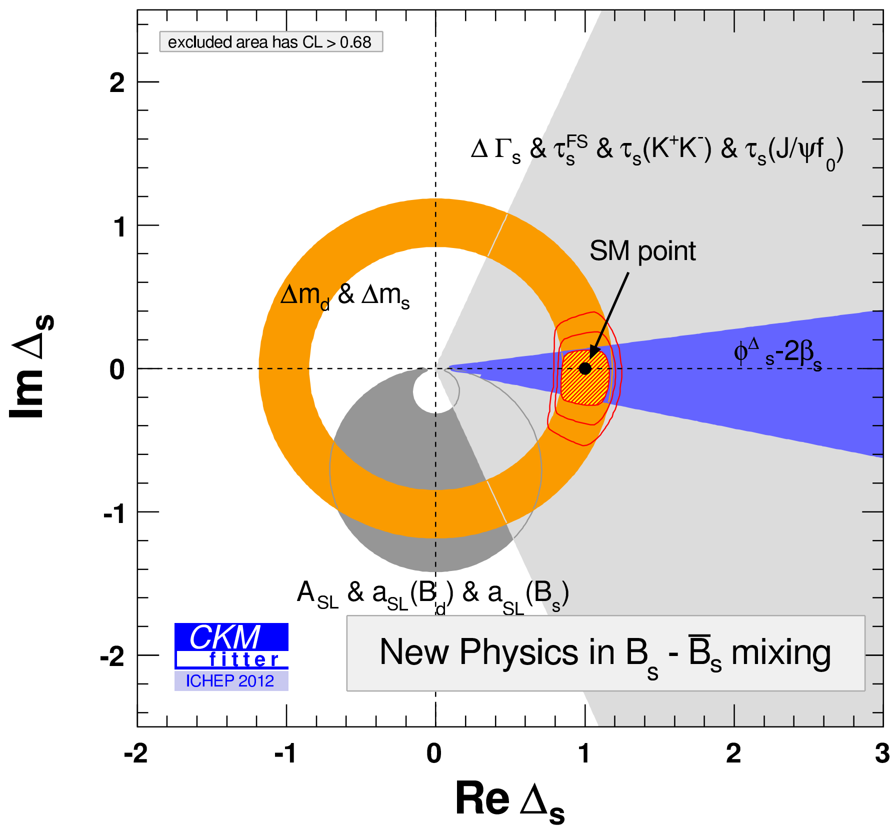
- Fits not so good anymore (LHCb vs. Dzero) - still sizeable room
- $B \to \tau\nu$ vs. $\sin 2\beta$ solved with ϕ_d^Δ — No tension for ϵ_K

Status 11/12: New Physics in B-Mixing IV

BRAND NEW: Combine all data till now and neglect penguins

fit of Δ_d and Δ_s Thanks to CKMfitter!!





- SM seems to be perfect
- Still quite some room for NP

Status 11/12: The dimuon asymmetry

The central value of the diμasymmetry is larger than *theoretically* possible!

$$\begin{aligned} A_{sl} &\approx (0.594 \pm 0.022)(5.4 \pm 1.0) \cdot 10^{-3} \frac{\sin(\phi_d^{SM} + \phi_d^{\Delta})}{|\Delta_d|} \\ &\quad + (0.406 \pm 0.022)(5.0 \pm 1.1) \cdot 10^{-3} \frac{\sin(\phi_s^{SM} + \phi_s^{\Delta})}{|\Delta_s|} \\ &\leq (-1.7[1\sigma]; -2.8[3\sigma]) \cdot 10^{-3} \\ A_{sl}^{D0} &= (-7.8 \pm 2.0) \cdot 10^{-3} \end{aligned}$$

A.L. 1205.1444

Possible solutions:

1. HQE violated by $\mathcal{O}(200\% - 3300\%)$ now excluded!
2. Huge new physics in Γ_{12}? - No! Bobeth, Haisch 1109.1826
3. Contradiction to $B_s \to J/\psi\phi$ from LHCb? - Be aware of Penguins!
4. Stat. fluctuation (2.5 σ) of the D0 result? (Actual value is below -2.8 per mille?)
   Independent measurements of semi leptonic asymmetries needed!

Status 11/12: Experimental cross-checks of A_{sl}^b

Recently new measurements for the individual semi leptonic CP asymmetries were made public

$a_{sl}^s = -0.24 \pm 0.54 \pm 0.33\%$	LHCB-CONF-2012-022
$a_{sl}^s = -1.08 \pm 0.72 \pm 0.17\%$	D0 1207.1769
$a_{sl}^d = 0.68 \pm 0.45 \pm 0.14\%$	D0 1208.5813
$a_{sl}^d = 0.06 + 0.39 - 0.36\%$	BaBar CKM2012

All numbers are consistent with the SM
(no confirmation of large new physics effects)
but also consistent with the value of the dimuon asymmetry
more data urgently needed.

Status in Nov. 2012: CHARM Revolution I

- D-mixing rate is large (HFAG 2012)

$$\frac{\Delta M}{\Gamma} = 0.63^{+0.19}_{-0.20}\% \qquad \frac{\Delta \Gamma}{2\Gamma} = 0.75 \pm 0.12\%$$

First single $> 5 = 9.3\sigma$ measurement by LHCb 1211.1230!

- Direct CP violation in hadronic Charm decays seen!

$$\Delta A_{CP}^{dir} = -0.656 \pm 0.154\%$$

LHCb 1112.0938; CDF 1207.2158; Belle B.R. Ko talk at ICHEP

The crucial question: Can this be described within the SM or is it NP?

HQE seems to work well in the B-sector $\Rightarrow$ Try to apply it for Charm
Standard argument: the energy release is much too small, but

$$\begin{aligned} m_{B_s} - 2m_{D_s} &\approx 1.43 \text{ GeV} \\ m_D - 2m_K &\approx 0.9 \text{ GeV} \\ m_D - 2m_\pi &\approx 1.6 \text{ GeV} \end{aligned}$$

Let's try!

Status in Nov. 2012: CHARM Revolution II

From a theory point the most "simple" quantities are the lifetimes

In the Charm-system huge lifetimes ratios appear, e.g.

$$\frac{\tau(D+)}{\tau(D^0)} = 2.536 \pm 0.019 \qquad \text{PDG 12}$$

Can theory cope with this?

Be aware:

- Λ/m_c might be too large ($\Lambda \neq \Lambda_{QCD}$!)
- $\alpha_s(m_c)$ might be too large

Status in Nov. 2012: CHARM Revolution III

- Naive expectations (**before first data**): $\tau(D+)/\tau(D^0) \approx 1$
  Gaillard, Lee, Rosner; Ellis, Gaillard, Nanopulos (1975); Cabibbo, Maiani (1978)
- Naive expectations (**after first data hinting for a large difference**)
  - only Pauli interference is relevant: $\tau(D+)/\tau(D^0) \approx 10$
    Guberina, Nussinov, Peccei, Rückl (1979); Altarelli, Maiani (1982)
    This is in principle correct, unknown parameters were overestimated
  - only Weak Annihilation is relevant: $\tau(D+)/\tau(D^0) \approx 6-7$
    Bander, Silverman, Soni (1980); Fritzsch, Minkowski (1980); Bernreuther, Nachtmann, Stech (1980)
    This is wrong - weak annihilation is a small effect Bigi, Uraltsev (1992)
- Systematic HQE estimates
  - LO-QCD, 1/N_c: $\tau(D+)/\tau(D^0) \approx 1.5$ Voloshin, Shifman (1981,85)
  - LO-QCD, 1/N_c: $\tau(D+)/\tau(D^0) \approx 2$ Bigi, Uraltsev (1992-...)
  - up-to-date estimate; NLO QCD Bobrowski, A.L., Rauh; 1208.6438

$$\tau(D+)/\tau(D^0) = 2.8 \pm 1.5(\text{hadronic ME})^{+0.3}_{-0.7}(\text{scale}) \pm 0.2(\text{parametric})$$

- Looks promising: huge lifetime difference might be explainable by the HQE
- Hadronic matrix elements of the 4-quark operators urgently needed

Conclusions

1. Experimental proof of our theoretical tools - there were many fights
   - $\Delta\Gamma_s^{\mathrm{SM}} = \Delta\Gamma_s^{\mathrm{Exp}} \Rightarrow$ Heavy Quark Expansion works very well for b-quarks
   - $\Delta\Gamma_s^{\mathrm{SM}} = \Delta\Gamma_s^{\mathrm{Exp}} \Rightarrow$ Violations of Quark Hadron duality cannot be sizeable
2. No huge NP effects in B-mixing and rare decays - what does this tell us?
   - Still some room for NP effects in B-mixing and B-decays
   - Some remaining discrepancies
     - V_{ub} softened but not settled
     - Isopsin asymmetry in $B \to Kll$
     - $B \to D^{(*)}\tau\nu$ - wait for Belle
3. There are many new, exciting results for the charm-system

   Try to understand the SM contribution!

4. Life becomes harder: higher precision in experiment and theory needed
   - higher order perturbative corrections
   - non-perturbative effects, e.g. penguin pollution, hadronic matrix elements
   - Investigate baryons and the charm sector