CKM2016, 9th International Workshop on the CKM Unitarity Triangle
TIFR, Mumbai, Nov 28 – Dec 3rd 2016

# Latest Results from CKMfitter

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**On behalf of the CKMfitter Group**

# Outline

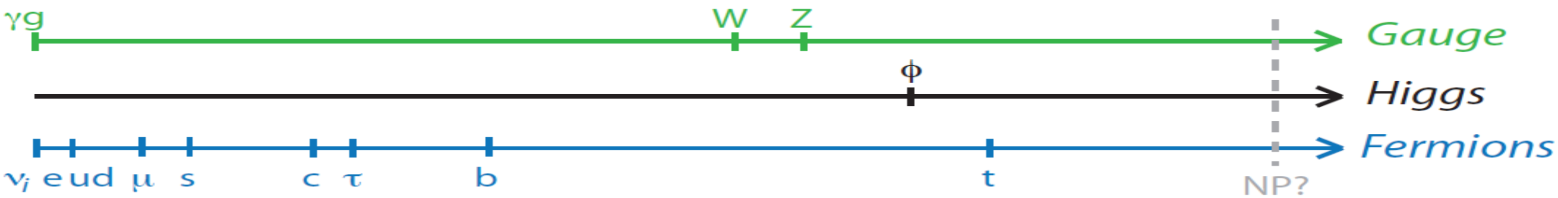
- **Introduction**
- **Latest update results**
  - The inputs
  - Standard Model CKM global fit
  - FCNC studies and New Physics (NP)
- **The CKM*live* project**
- **Summary and Outlook**

# Flavour and New Physics (NP)

$$\mathcal{L}_{SM} = \mathcal{L}_{gauge}(A_a, \Psi_j) + \mathcal{L}_{Higgs}(\phi, A_a, \Psi_j)$$

- Highly symmetric: gauge & flavour symmetries
- Stable w.r.t. quantum corrections
- Well-tested: electroweak precision tests

- Ad hoc potential
- Not stable w.r.t. quantum corrections
- Origin of SM favour structure: quark masses and CKM matrix
- Not fully tested: some room for NP




- **Unexplained hierarchy among 10 out of 19 SM parameters ($m_\nu$ = 0)**
  - Masses and CP violation (CPV)
- **Interesting phenomenology**
  - Strong hierarchy of CP asymmetries according to generations
  - GIM suppression of Flavour-Changing Neutral Currents (FCNC)
  - Quantum sensitivity (via loops) to large range of scales
  - Potential to unravel patterns of NP deviations at high energy scales

  ⇒ complementary to direct searches!

# The CKM matrix and the Unitarity Triangle

- **In SM, Mass states ≠ Weak states**
- **Flavour dynamics:** weak transitions which mix quarks of different generations

  ⇒ Encoded in unitary CKM matrix ($V_{CKM}$)

Weak states    CKM matrix    Mass states

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

- **3 generations ⇒ 4 parameters describing $V_{CKM}$**
  - 3 real and 1 phase ⇒ only source of CPV in SM
  - Wolfenstein parametrisation, defined to hold in all orders in λ and rephasing invariant

    ⇒ Explicitly shows $V_{CKM}$ generation hierarchy

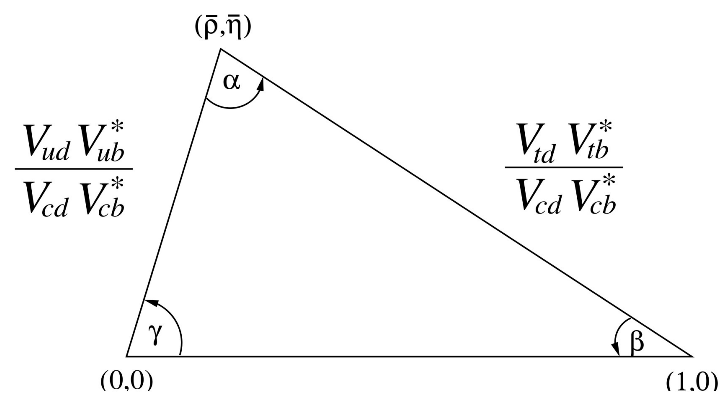
Wolfenstein parameterization:

$$\begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

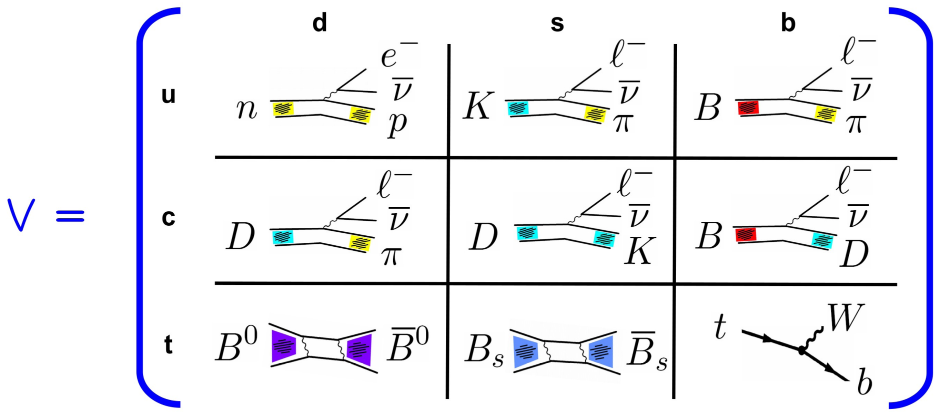
**$O(\lambda^4)$, $\lambda=\sin(\theta_c) \approx 0.22$**

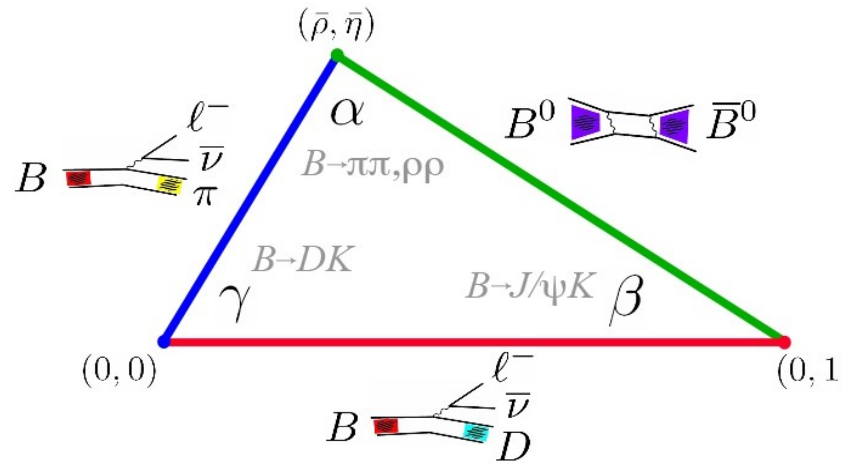
$$\lambda^2 = \frac{|V_{us}|^2}{|V_{ud}|^2 + |V_{us}|^2} \qquad A^2\lambda^4 = \frac{|V_{cb}|^2}{|V_{ud}|^2 + |V_{us}|^2} \qquad \bar{\rho} + i\bar{\eta} = -\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}$$

- **Unitarity triangles**
  - Graphical representation of $V_{CKM}$ unitarity
  - $B_d$ triangle: $V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$



# Extracting CKM parameters




- **Observables**
  - Use QCD CP invariance to build hadronic independent CPV asymmetries
  - Or determine hadronic inputs from data
  - Observables double requirement
    - Good experimental accuracy
    - Satisfying control of attached theoretical uncertainty

- **Statistical framework to combine data and assess theoretical uncertainties**

# CKMfitter Statistical Framework

Phys. J. C **41** (2005)

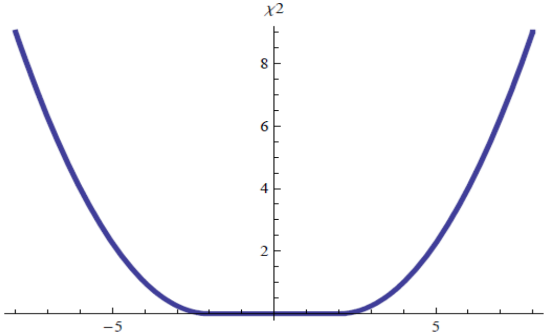
Alternative models for theo uncertainties discussed in 1611.04768 (2016)

- $q = (A, \lambda, \bar{\rho}, \bar{\eta} \ldots)$ **parameters to be determined**
  - $\mathcal{O}_{\rm meas} \pm \sigma_{\mathcal{O}}$ measured values of observables
  - $\mathcal{O}_{\rm th}(q)$ theoretical description of observables (in given model)
- **In case of statistical only uncertainties** $\chi^2(q) = \sum_{\mathcal{O}} \left( \frac{\mathcal{O}_{\rm th}(q) - \mathcal{O}_{\rm meas}}{\sigma_{\mathcal{O}}} \right)^2$
  - Central value: estimator $\hat{q}$ max likelihood: $\chi^2(\hat{q}) = \min_q \chi^2(q)$
  - Range: CL for each $q_0$ (p-value for $q = q_0$) by: $\Delta\chi^2(q_0) = \chi^2(q_0) - \min_q \chi^2(q)$

    assumed to obey $\chi^2$ law with ndf = dim(q) to yield CLs
  - Pull: comparison of $\chi^2_{\rm min}$ with and without one measurements

$$p_{\mathcal{O}} = \sqrt{\min_q \chi^2_{\rm with\ meas}(q) - \min_q \chi^2_{\rm without\ meas}(q)}$$

- **Theoretical uncertainties within Rfit scheme**
  - Modify likelihood $\mathcal{L} = \exp(-\chi^2/2)$ to get a $\chi^2$ with flat bottom (th. error) and parabolic wall (stat)
  - Values within range of th. error treated on the same footing



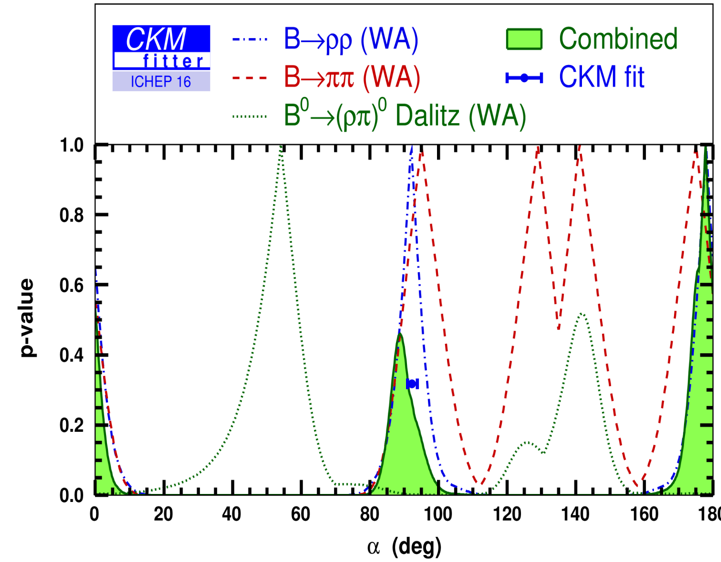
# The global CKM fit inputs: all at once

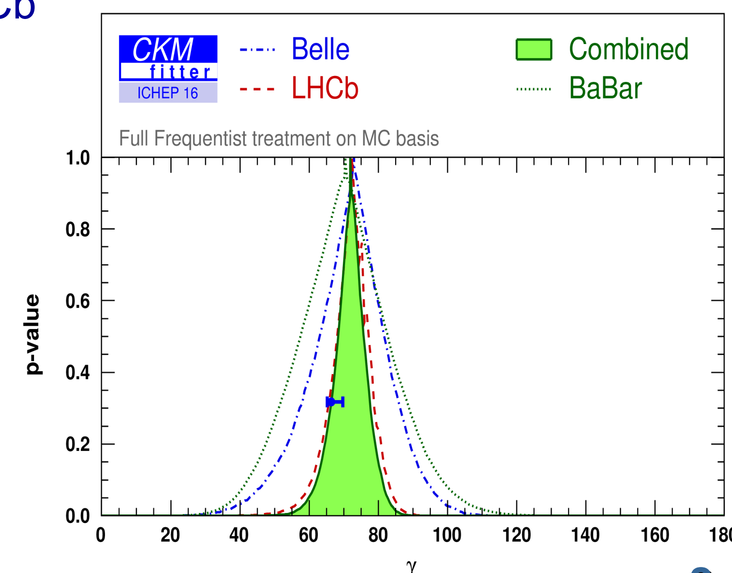
CKM fitter ICHEP 16

| Parameter | Value ± Error(s) | Reference | Errors GS | Errors TH |
|---|---|---|---|---|
| $\|V_{ud}\|$ (nuclei) | $0.97425 \pm 0 \pm 0.00022$ | [1] | - | ⋆ |
| $\|V_{us}\|f_+^{K\to\pi}(0)$ | $0.2163 \pm 0.0005$ | [3] | ⋆ | ⋆ |
| $\|V_{cd}\|$ ($\nu N$) | $0.230 \pm 0.011$ | [3] | ⋆ | - |
| $\|V_{cs}\|$ ($W \to c\bar{s}$) | $0.94^{+0.32}_{-0.26} \pm 0.13$ | [3] | ⋆ | ⋆ |
| $\|V_{ub}\|$ (semileptonic) | $(4.01 \pm 0.08 \pm 0.22) \times 10^{-3}$ | [4–6] | ⋆ | ⋆ |
| $\|V_{cb}\|$ (semileptonic) | $(41.00 \pm 0.33 \pm 0.74) \times 10^{-3}$ | [4, 6] | ⋆ | ⋆ |
| $\mathcal{B}(\Lambda_p \to p\mu^-\overline{\nu}_\mu)_{q^2>15}/\mathcal{B}(\Lambda_p \to \Lambda_c\mu^-\overline{\nu}_\mu)_{q^2>7}$ | $(1.00 \pm 0.09) \times 10^{-2}$ | [7] | ⋆ | - |
| $\mathcal{B}(B^- \to \tau^-\overline{\nu}_\tau)$ | $(1.08 \pm 0.21) \times 10^{-4}$ | [4, 8] | ⋆ | - |
| $\mathcal{B}(D_s^- \to \mu^-\overline{\nu}_\mu)$ | $(5.57 \pm 0.24) \times 10^{-3}$ | [4] | ⋆ | - |
| $\mathcal{B}(D_s^- \to \tau^-\overline{\nu}_\tau)$ | $(5.55 \pm 0.24) \times 10^{-2}$ | [4] | ⋆ | - |
| $\mathcal{B}(D^- \to \mu^-\overline{\nu}_\mu)$ | $(3.74 \pm 0.17) \times 10^{-4}$ | [4] | ⋆ | ⋆ |
| $\mathcal{B}(K^- \to e^-\overline{\nu}_e)$ | $(1.581 \pm 0.008) \times 10^{-5}$ | [3] | ⋆ | - |
| $\mathcal{B}(K^- \to \mu^-\overline{\nu}_\mu)$ | $0.6355 \pm 0.0011$ | [3] | ⋆ | - |
| $\mathcal{B}(\tau^- \to K^-\overline{\nu}_\tau)$ | $(0.6955 \pm 0.0096) \times 10^{-2}$ | [4] | ⋆ | - |
| $\mathcal{B}(K^- \to \mu^-\overline{\nu}_\mu)/\mathcal{B}(\pi^- \to \mu^-\overline{\nu}_\mu)$ | $1.3365 \pm 0.0032$ | [3] | ⋆ | - |
| $\mathcal{B}(\tau^- \to K^-\overline{\nu}_\tau)/\mathcal{B}(\tau^- \to \pi^-\overline{\nu}_\tau)$ | $(6.431 \pm 0.094) \times 10^{-2}$ | [4] | ⋆ | - |
| $\mathcal{B}(B_s \to \mu\mu)$ | $(2.8^{+0.7}_{-0.6}) \times 10^{-9}$ | [9] | ⋆ | - |
| $\|V_{cd}\|f_+^{D\to\pi}(0)$ | $0.148 \pm 0.004$ | [10] | ⋆ | - |
| $\|V_{cs}\|f_+^{D\to K}(0)$ | $0.712 \pm 0.007$ | [10, 11] | ⋆ | - |
| $\|\varepsilon_K\|$ | $(2.228 \pm 0.011) \times 10^{-3}$ | [3] | ⋆ | - |
| $\Delta m_d$ | $(0.510 \pm 0.003)$ ps$^{-1}$ | [4] | ⋆ | - |
| $\Delta m_s$ | $(17.757 \pm 0.021)$ ps$^{-1}$ | [4] | ⋆ | - |
| $\sin(2\beta)_{[c\bar{c}]}$ | $0.691 \pm 0.017$ | [4] | ⋆ | - |
| $(\phi_s)_{[b\to c\bar{s}s]}$ | $-0.015 \pm 0.035$ | [4] | ⋆ | - |
| $S_{\pi\pi}^{+-}$, $C_{\pi\pi}^{+-}$, $C_{\pi\pi}^{00}$, $\mathcal{B}_{\pi\pi}$ all charges | Inputs to isospin analysis | [12–20] | ⋆ | - |
| $S_{\rho\rho,L}^{+-}$, $C_{\rho\rho,L}^{+-}$, $S_{\rho\rho}^{00}$, $C_{\rho\rho}^{00}$, $\mathcal{B}_{\rho\rho,L}$ all charges | Inputs to isospin analysis | [21–27] | ⋆ | - |
| $B^0 \to (\rho\pi)^0 \to 3\pi$ | Time-dependent Dalitz analysis | [28, 29] | ⋆ | - |
| $B^- \to D^{(*)}K^{(*)-}$ | Inputs to GLW analysis | [30, 31] | ⋆ | - |
| $B^- \to D^{(*)}K^{(*)-}$ | Inputs to ADS analysis | [31, 32] | ⋆ | - |
| $B^- \to D^{(*)}K^{(*)-}$ | GGSZ Dalitz analysis | [33] | ⋆ | - |

# The global CKM fit inputs: Unitarity angles

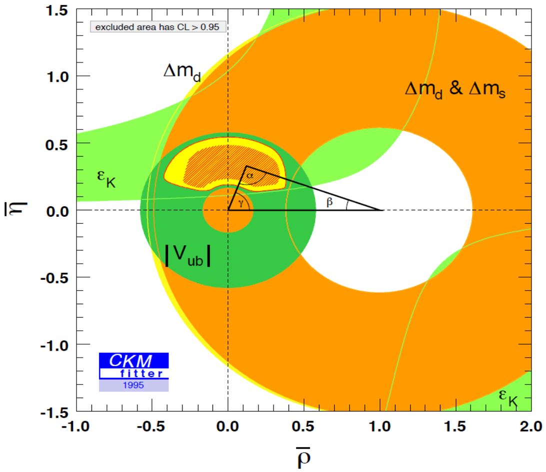
- **$\alpha$ and the legacy of B-factories**
  - Combined analysis $B\to\pi\pi,\rho\pi,\rho\rho$
  - Using isospin to separate penguin and tree
  - $\alpha_{WA} = (88.9^{+2.3}_{-2.4})^{o} \cup (177.6^{+2.9}_{-4.8})^{o}$
- **$\gamma$ and a some help from LHCb**
  - $B^{-}\to D^{(*)0}K^{(*)-}$ vs $\overline{D}^{(*)0}K^{(*)-}$ with 3 diff. $D^0$ decay modes
  - Charm inputs: CLEO, BES *BABAR*, Belle, CDF, LHCb
  - $\gamma_{WA} = (72.2^{+5.3}_{-5.8})^{o}$
- **$\beta$ in $B\to(c\bar{c})K$**
  - Interference between mixing and decay
  - $A_{CP}(t) = S\sin(\Delta m\, t) - C\cos(\Delta m\, t)$
  - $S = \eta_{CP}\sin(2\beta) = 0.691 \pm 0.017$ [HFAG]



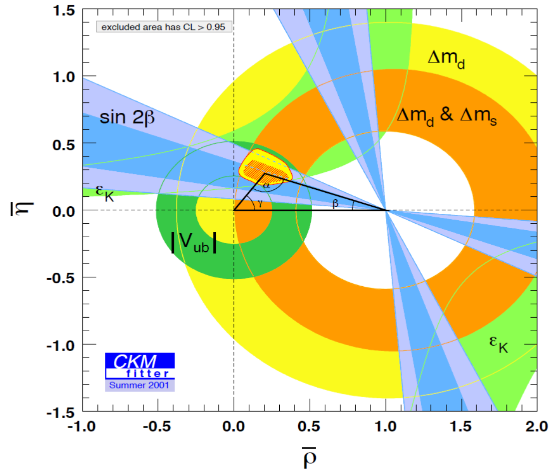



# Two decades of CKM

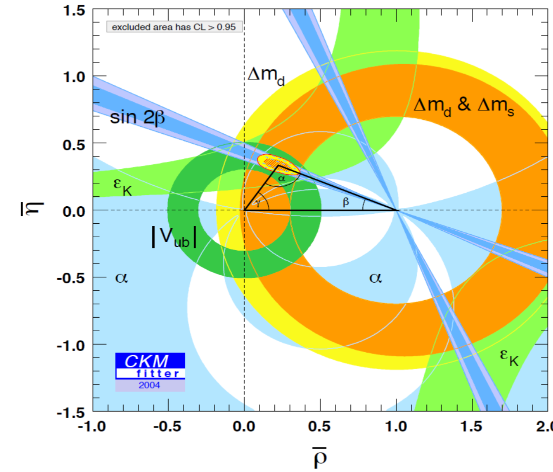
[LEP, KTeV, NA48, *BABAR*, Belle, CDF, DØ, LHCb, CMS. . . ]



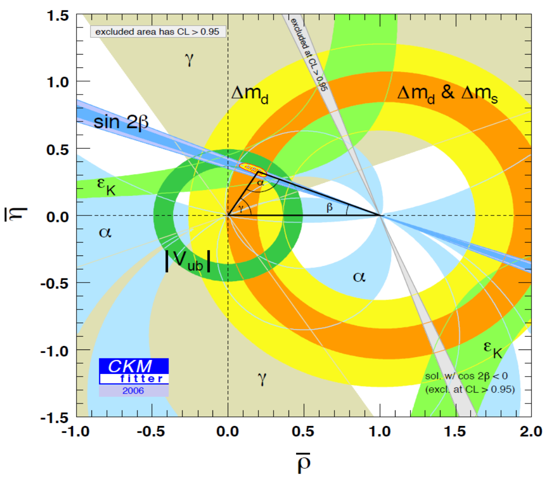

1995



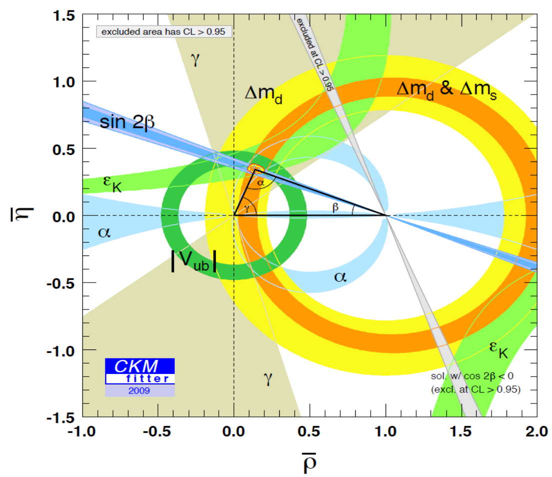

2001



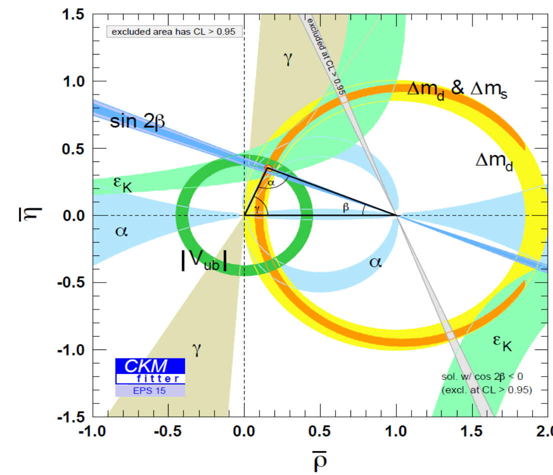

2004




2006




2009



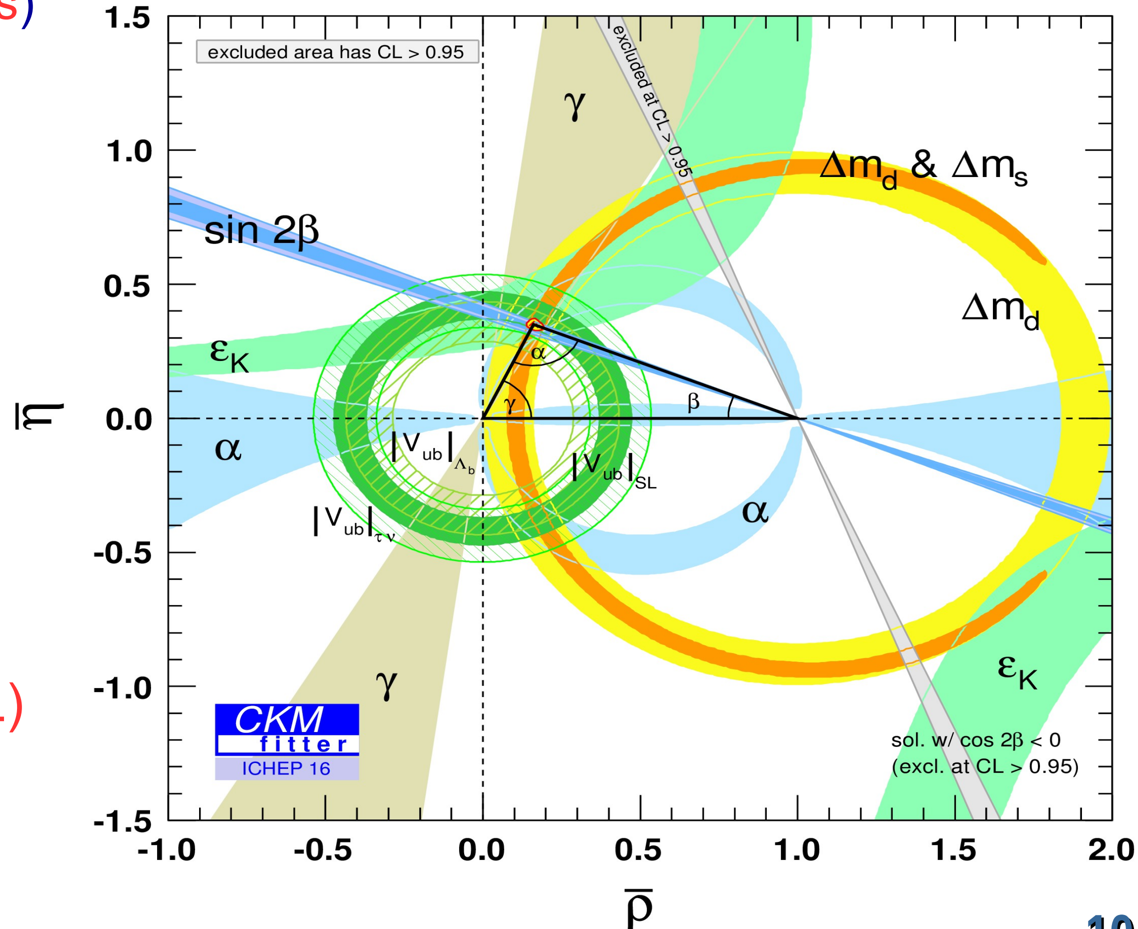

2015

# Latest global CKM fit

- **Global fit remains excellent:**
  - EPS-HEP 2015: $\chi^2_{min}$ = 28.0 ($N_{dof}$ = 21), p-value 14% (1.5 σ)
  - ICHEP 2016: $\chi^2_{min}$ = 33.5 ($N_{dof}$ = 21), p-value 4% (2.0 σ) ⇒ see next slides

($\chi^2_{min}$ assuming Gaussian errors)

$|V_{ud}|, |V_{us}|$
$|V_{cb}|, |V_{ub}|_{SL}$
$B \to \tau\nu$
$|V_{ub}/V_{cb}|_{\Lambda_b}$
$\Delta m_d, \Delta m_s$
$\epsilon_K$
$\sin 2\beta$
$\alpha$
$\gamma$




$$A = 0.8250^{+0.0056}_{-0.0077}$$

$$\lambda = 0.22513^{+0.00028}_{-0.00031}$$

(68% CL)

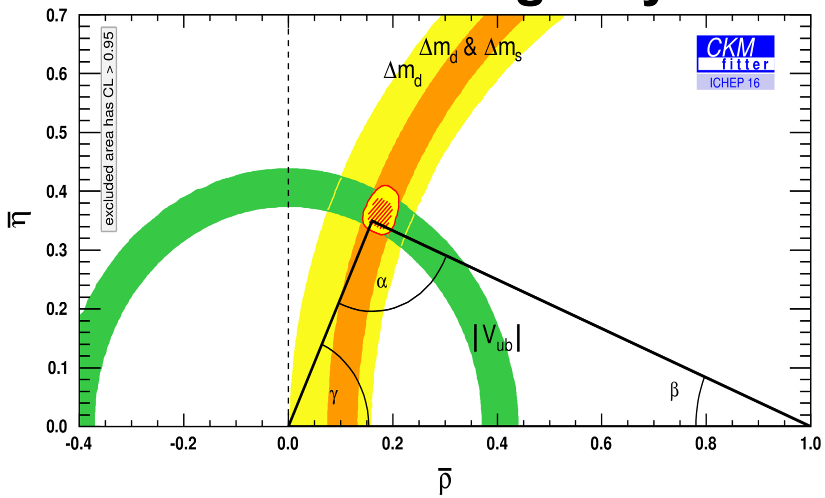
$$\bar{\rho} = 0.1602^{+0.0066}_{-0.0064}$$

$$\bar{\eta} = 0.3501^{+0.0059}_{-0.0063}$$

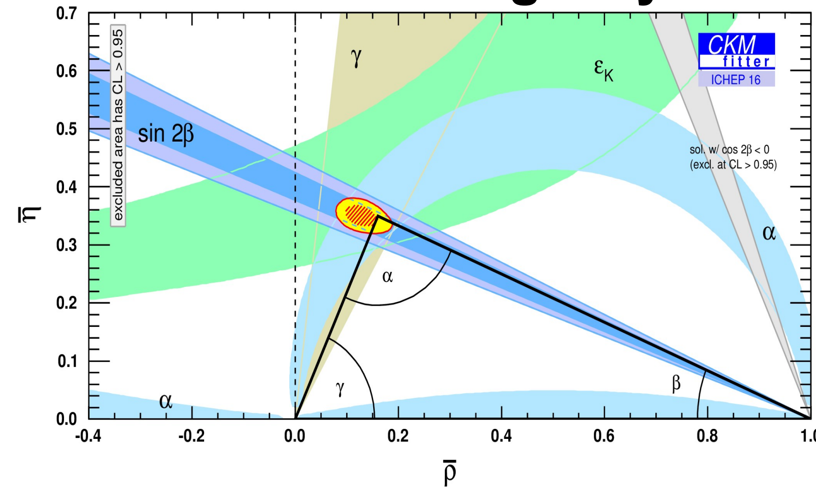
# Latest global CKM fit: Consistency with CKM picture

- **Validity of Kobayashi-Maskawa picture of CP violation**

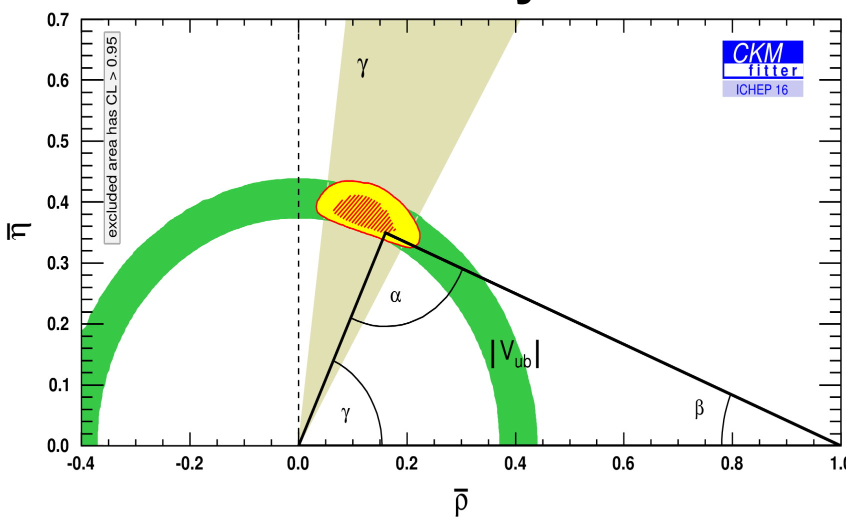
## CP conserving only



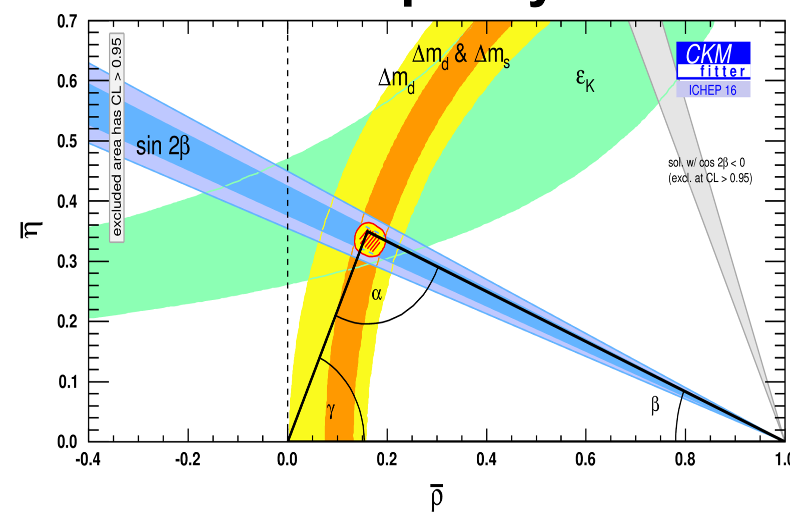

## CP violating only




## Tree only




## Loop only



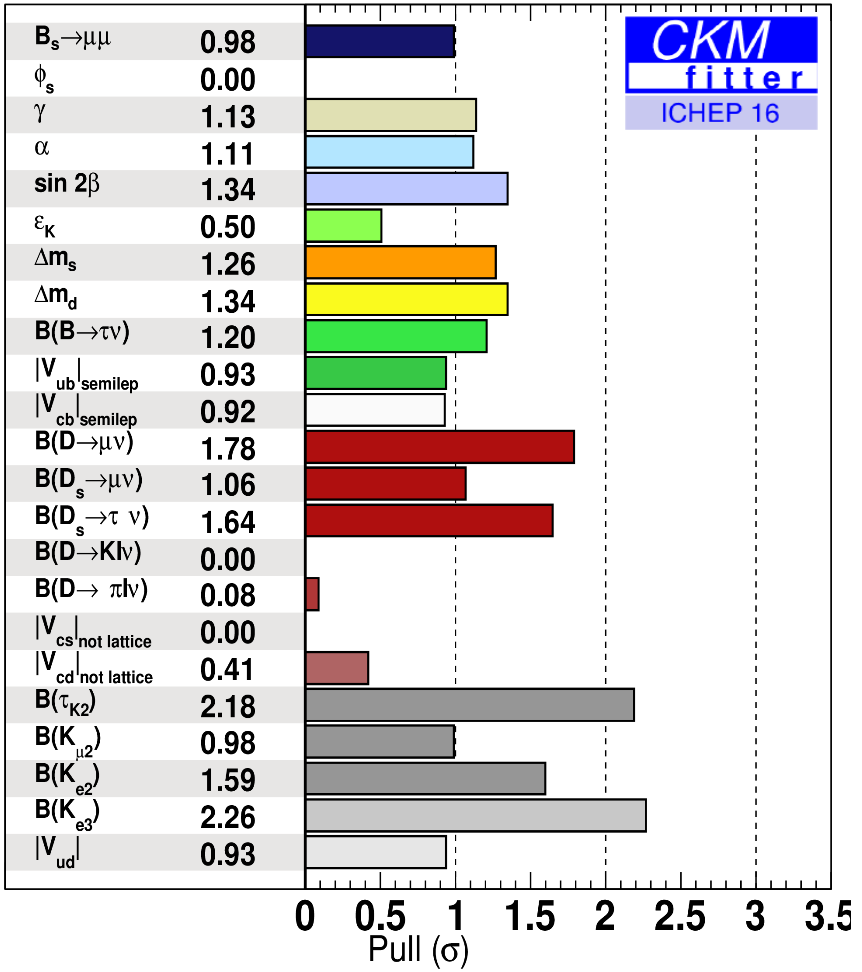
# Latest global CKM fit: Pulls

- Pulls for various observables (included in the fit or not)
- For 1D, pull obs =

$$\sqrt{\chi^2_{\text{min; with obs}} - \chi^2_{\text{min; w/o obs}}}$$

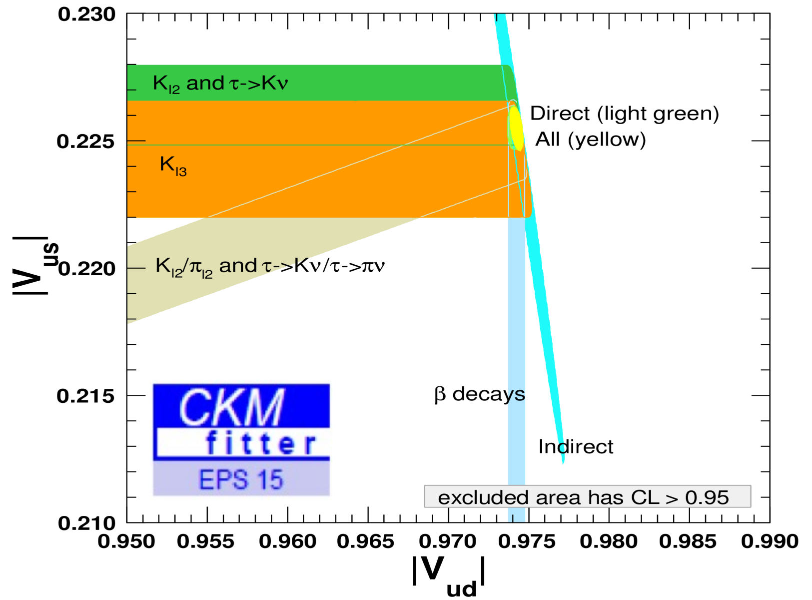
- If Gaussian errors, uncorrelated, random vars of mean 0 and variance 1
- Here correlations, and some pulls = 0 due to Rfit model th. Errors

- Slight discrepancy within $|V_{us}|$ obs (~2.3σ)



# Latest global CKM fit: $|V_{us}|$ and $|V_{ud}|$ 2015→ 2016

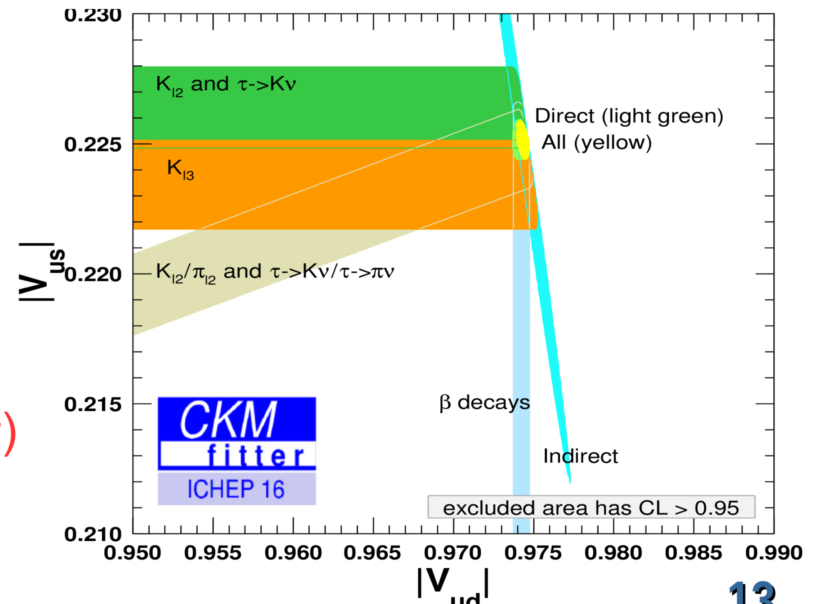
- **"Direct" (semi-lep & lep) vs "indirect (other sectors)**
- **$|V_{ud}|,|V_{us}|$:** nuclear β + lep K, π and τ decays
- **Similar accuracy for exp and lattice inputs**
- **$|V_{ud}|$ from super-allowed β decays 10 times more precise**




- **$|V_{us}|$ from $K\to\pi l\nu$ in discrepancy with that of $K\to l\nu$ & $\tau\to K\nu_\tau$ due new $f_+^{K\to\pi}(0)$ from lattice**

  (FLAG16, ETM16, MILC13, RBC-UKQCD15)

  ⇒ Culprit of new tension in global fit (pull ~2.3σ)



# Latest global CKM fit: $|V_{ub}|$, $|V_{cb}|$ excl. vs incl.

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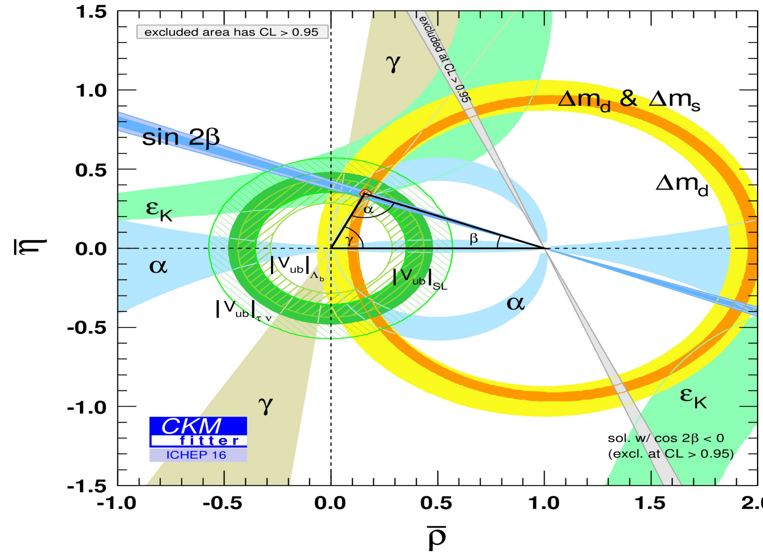
- **Previous fit uses particular average of exclusive & inclusive SL B-decays**
- **Using only exclusive SL B-decays to fix $|V_{ub}|$ (and $|V_{cb}|$) changes $\varepsilon_K$ contour**
- **But not the best fit point**

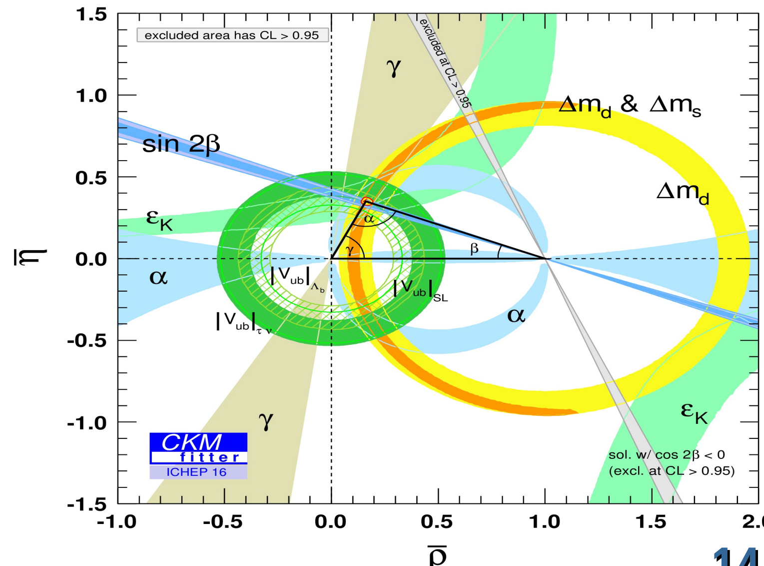
- **When using inclusive SL B-decays, more agreement with $B^+ \to \tau^+ \nu$**
- **Notice $\Delta m_s$ ring stops closing**

- **Overall agreement between various constrains remains excellent in both excl. and incl. fits**
  - Little variation of p-value of best fit point
  - Little variation of Wolfenstein parameters

**Exclusive SL**



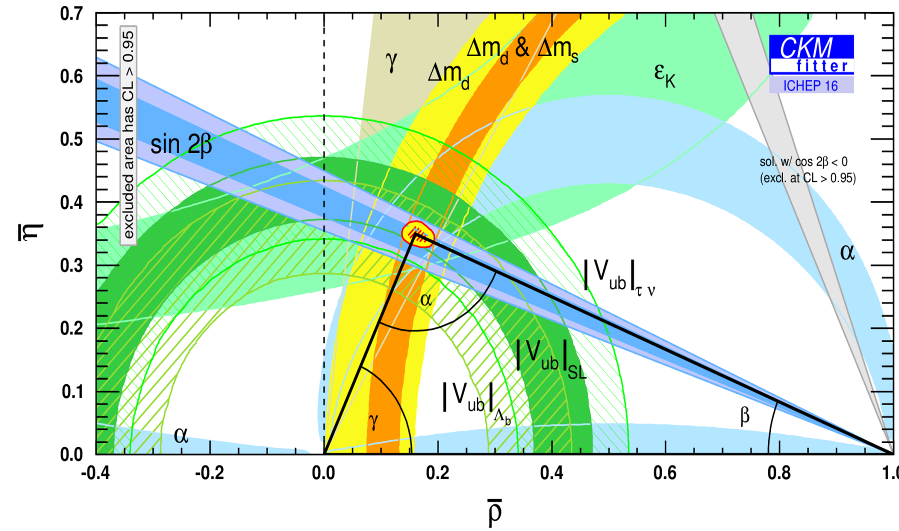

**Inclusive SL**

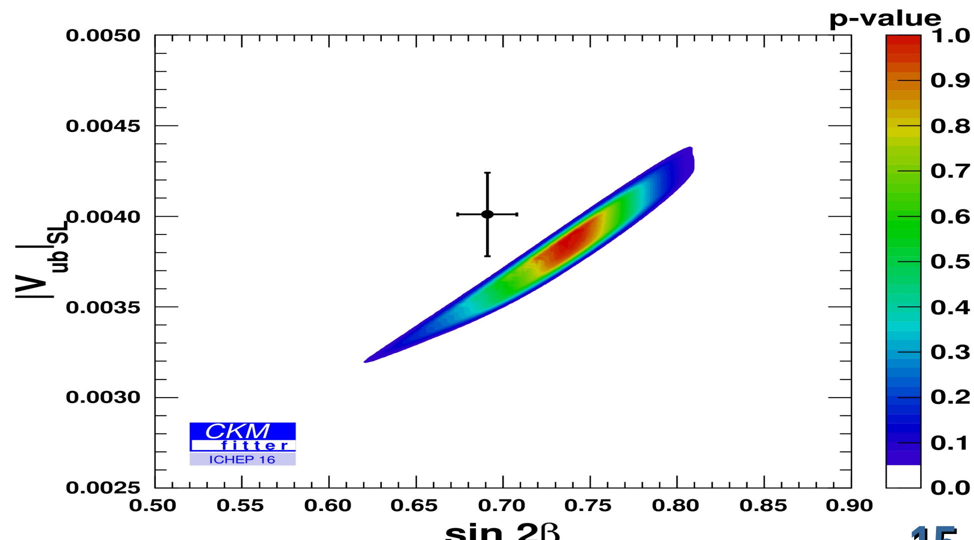


# Latest global CKM fit: $|V_{ub}|_{SL}$ vs $\sin(2\beta)$ correlation

CKM fitter ICHEP 16

- **Increase in the average used as input for $|V_{ub}|_{SL}$**
- **Slight tension between $|V_{ub}|_{SL}$ and $\sin(2\beta)$ (1.5σ for 2D hypothesis)**
- **Reducing uncertainty on CKM parameters (mostly $\bar{\eta}$-bar)**



# Latest global CKM fit: $B_s$ triangle

- $\bar{\rho}_{B_s} + i\bar{\eta}_{B_s} = -\frac{V_{us}V_{ub}^*}{V_{cs}V_{cb}^*}$ **provides the $B_s$ Unitarity triangle ($\lambda^4$,$\lambda^2$,$\lambda^2$)**

- **Information on $B_s$ mixing angle**

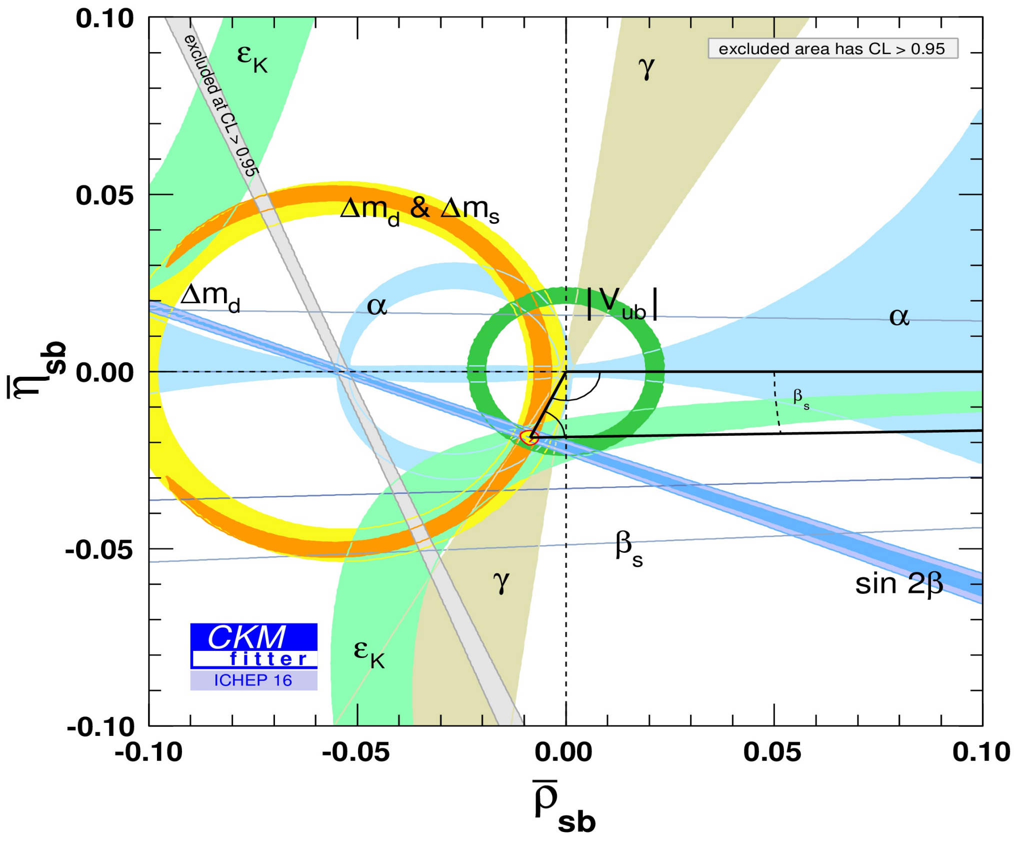
  **$\beta_s$ from $B_s \to J/\psi\ \phi$**

- **Not relevant for SM determination of CKM parameters**

$$\bar{\rho}_{Bs} = -0.00855^{+0.00037}_{-0.00035}$$

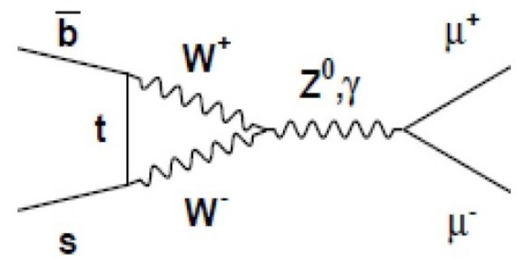
$$\bar{\eta}_{Bs} = -0.0167^{+0.00033}_{-0.00032}$$

(68% CL)



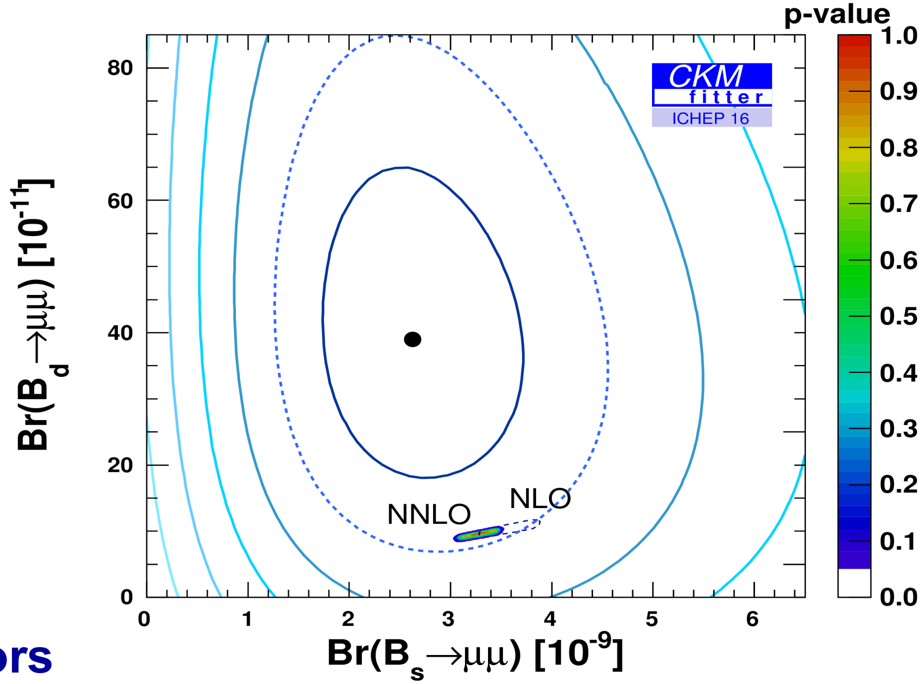
# FCNC $\Delta F = 1$: $B_{s,d} \to \mu^+\mu^-$

- **Measured by LHCb and CMS**
- **Sensitive to pseudo/scalar contributions**
- **Theoretical progress**
  - Inclusion of $B_s$ mixing in experimental time-integrated rate $\langle Br(B_s \to \mu\mu)\rangle \simeq 1.1\, Br_{t=0}$
  - NLO+LO EW $\to$ NNLO + NLO EW




- **SM (and MFV) correlation between $Br(B_d \to \mu^+\mu^-)$ and $Br(B_s \to \mu^+\mu^-)$, driven by $\Delta m_d/\Delta m_s$**

$$Br(B_d \to \mu\mu)_{t=0}/Br(B_s \to \mu\mu)_{t=0} = 0.0298^{+0.0008}_{-0.0010}$$




- **Further tests of pseudo/scalar operators**

$$Br(B_d \to \tau\tau)_{t=0} \times 10^8 = 2.05^{+0.13}_{-0.15} \qquad Br(B_s \to \tau\tau)_{t=0} \times 10^7 = 6.98^{+0.38}_{-0.43}$$

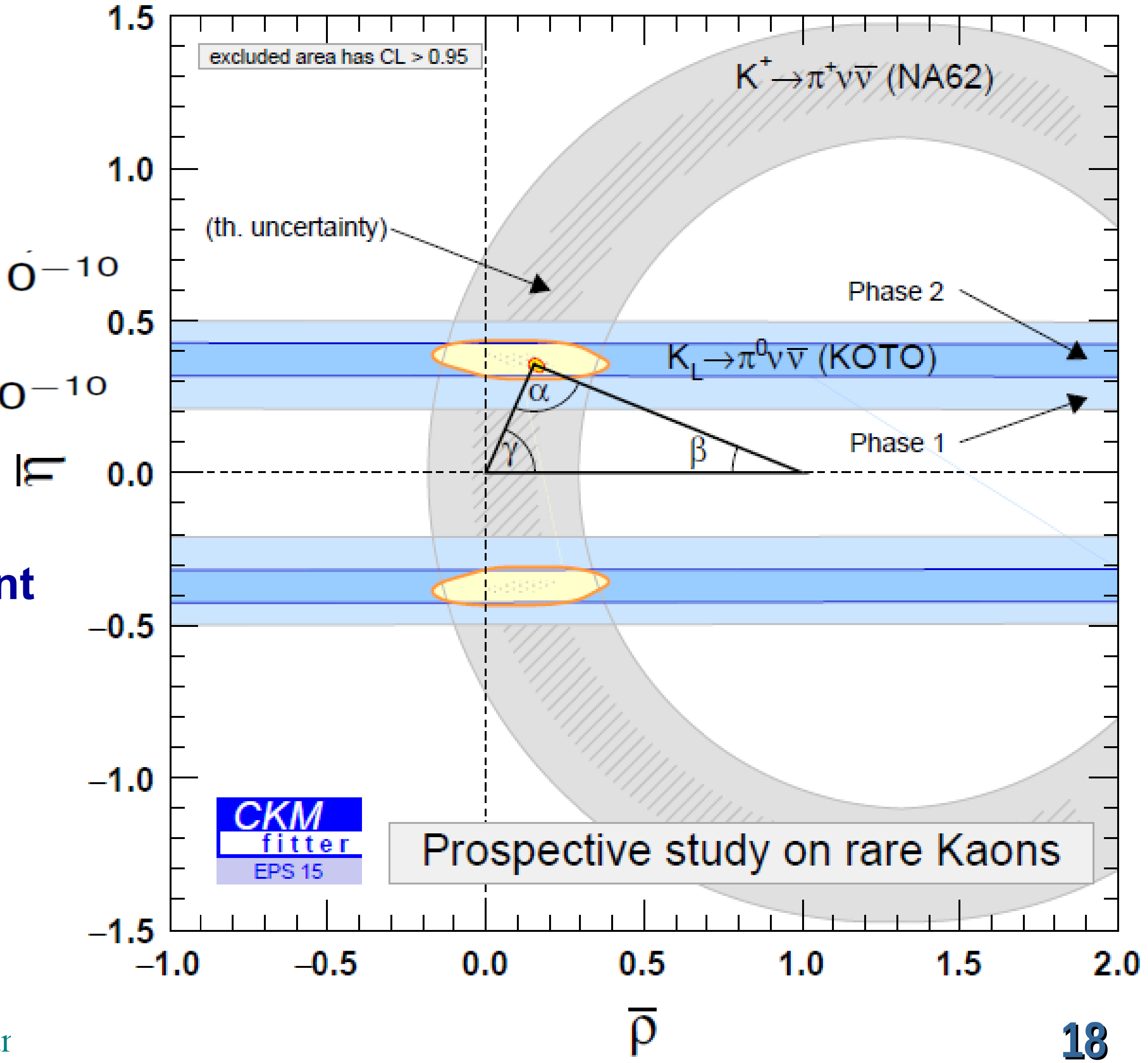
# FCNC ΔF = 1: $K \to \pi\nu\nu$ future impact

- **$K \to \pi\nu\nu$ rare decays very clean probes of Z penguin and boxes**

$$Br(K^+ \to \pi^+ \nu\bar{\nu}) = (0.88^{+0.09}_{-0.10}) \times 10^{-10}$$

$$Br(K_L \to \pi^0 \nu\bar{\nu}) = (0.31^{+0.02}_{-0.02}) \times 10^{-10}$$

- **NA62 and KOTO expect a 10% precision measurement for charged and neutral modes, respectively**



# FCNC $\Delta F = 2$: observables and NP

- **Neutral-meson mixing described by** $i\frac{d}{dt}\begin{pmatrix} |B_q(t)\rangle \\ |\bar{B}_q(t)\rangle \end{pmatrix} = \left(M^q - \frac{i}{2}\Gamma^q\right)\begin{pmatrix} |B_q(t)\rangle \\ |\bar{B}_q(t)\rangle \end{pmatrix}$
  - M and $\Gamma$ are hermitian
  - Mixing due to non-diagonal terms $M^q_{12} - (i/2)\Gamma^q_{12}$
  - Diagonalisation gives $|B^q_{H,L}\rangle = p|B_q\rangle \mp q|\bar{B}_q\rangle$ of masses and widths $M^q_{H,L}$ & $\Gamma^q_{H,L}$
- **Observables (in terms of $M^q_{12}$ and $\Gamma^q_{12}$)**
  - Mass and width difference: $\Delta m_q = M^q_H - M^q_L$ and $\Delta\Gamma_q = \Gamma^q_H - \Gamma^q_L$
  - Semi-leptonic asymmetry $a^q_{SL} = \frac{\Gamma(\bar{B}_q(t)\to\ell^+\nu X)-\Gamma(B_q(t)\to\ell^-\nu X)}{\Gamma(\bar{B}_q(t)\to\ell^+\nu X)+\Gamma(B_q(t)\to\ell^-\nu X)}$
  - Mixing phase in time-dependent analyses
- **NP potential**
  - $\Gamma_{12}$ dominated by tree decays into charm: NP if changes in tree-level decays
  - $M_{12}$ dominated by (virtual) top boxes: NP if heavy particle in the box
  - Assume generic and independent NP contributions $M^d_{12}$ and $M^s_{12}$ only

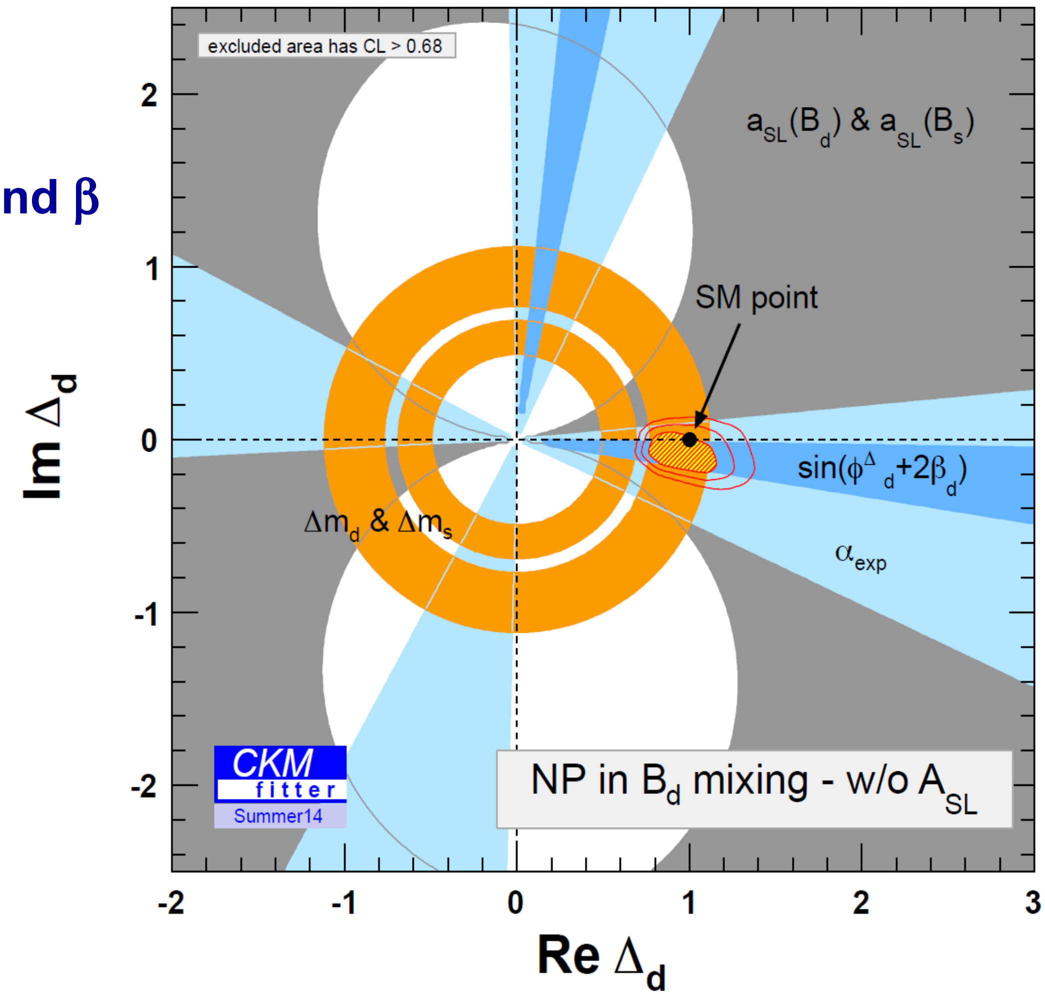
$$M^q_{12} = (M^q_{12})_{SM} \times \Delta_q \quad \Delta_q = |\Delta_q|e^{i\phi^\Delta_q} = (1 + h_q e^{2i\sigma_q})$$

**Can use $\Delta m_d$, $\Delta m_s$, $\beta$, $\phi_s$, $a^d_{SL}$, $a^s_{SL}$, $\Delta\Gamma_s$ to constrain $\Delta_d$ and $\Delta_s$**

# FCNC $\Delta F = 2$: $B_d$ mixing

Summer 2014

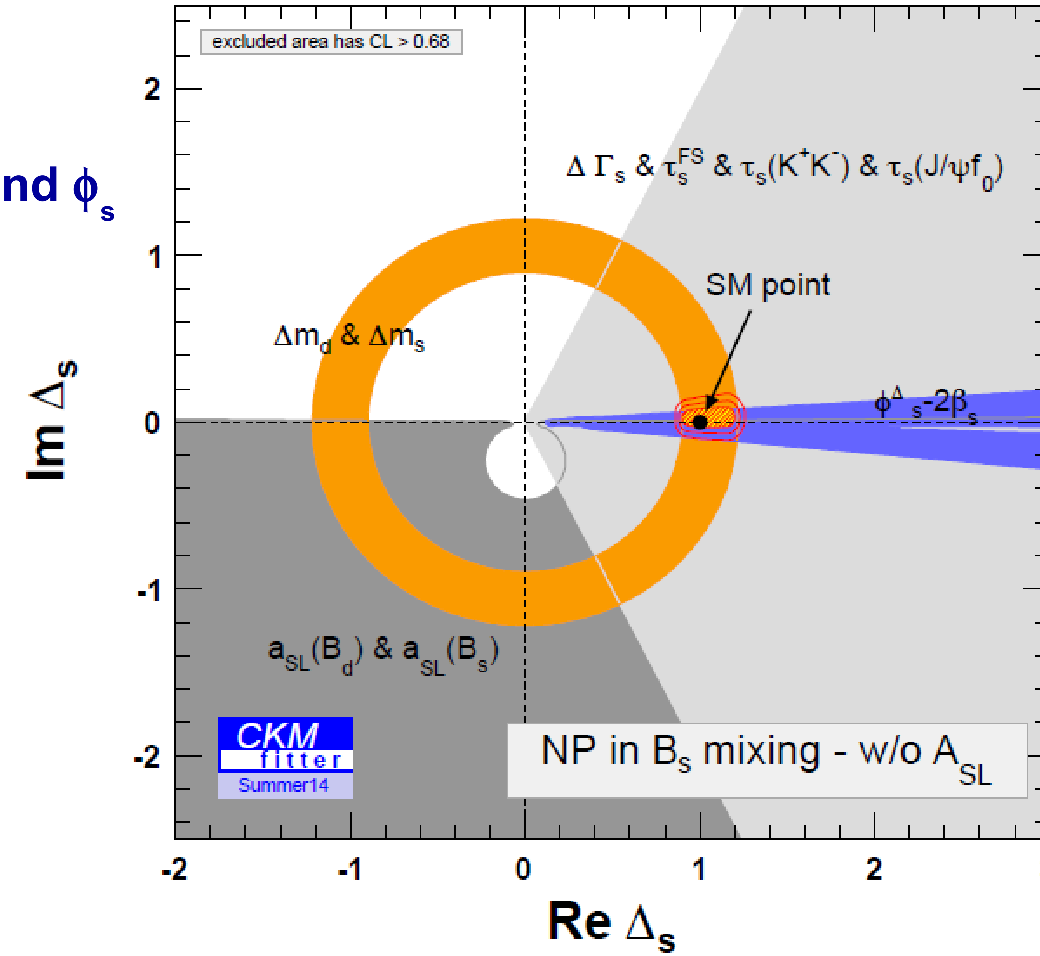
- **Constraints @ 68% CL**
- **Dominant constraints from $\Delta m_d$ and $\beta$**
- **Good agreement with other constraints**
- **Compatible with SM**
  - $\Delta_d = 0.94^{+0.18}_{-0.15} + i\,(-0.11^{+0.11}_{-0.05})$
  - 2D SM hyp. ($\Delta_d = 1 + i0$): $0.9\sigma$
- **Still room for NP in $\Delta_d$**



# FCNC $\Delta F = 2$: $B_s$ mixing

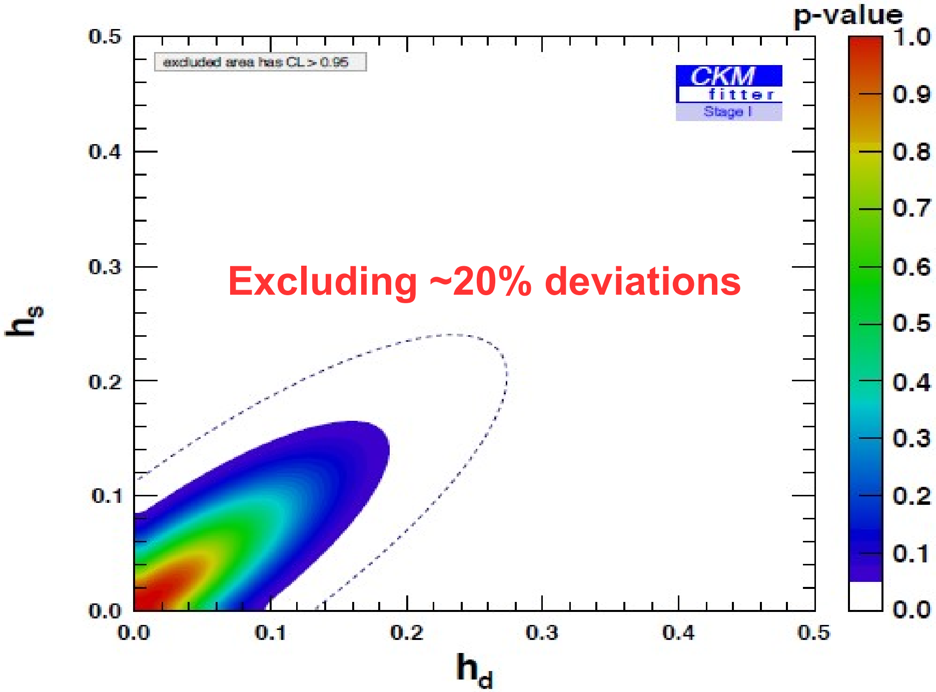
Summer 2014

- **Constraints @ 68% CL**
- **Dominant constraints from $\Delta m_s$ and $\phi_s$**
- **$\phi_s$ favours SM**
- **$A_{SL}$ (combination of $a^d_{SL}$ & $a^s_{SL}$) measured by DØ not included**
- **Compatible with SM**
  - $\Delta_s = 1.05^{+0.14}_{-0.13} + i\,(-0.03^{+0.04}_{-0.04})$
  - 2D SM hyp. ($\Delta_s = 1 + i0$): $0.3\sigma$
- **Still room for NP in $\Delta_s$**

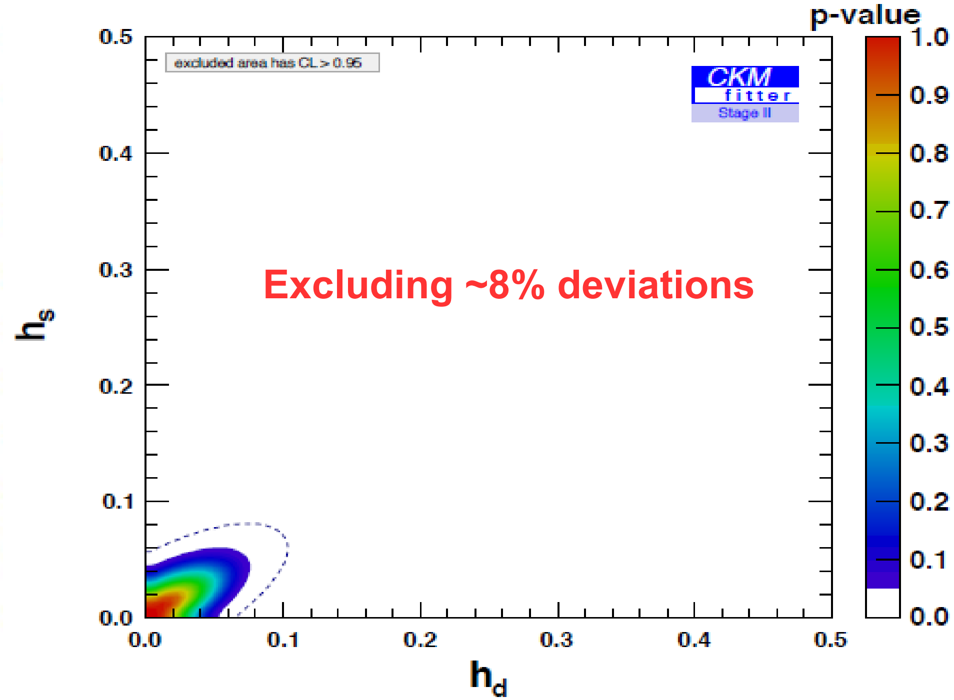


# Prospects of FCNC $\Delta F = 2$: bounds on Energy Scale

**Stage I: 7 $fb^{-1}$ LHCb + 5 $ab^{-1}$ Belle II (2018)**




**Stage II: 50 $fb^{-1}$ LHCb + 50 $ab^{-1}$ Belle II (2023)**




From $C_{ij}^2/\Lambda^2 \times (\bar{b}_L \gamma^\mu q_{j,L})^2$

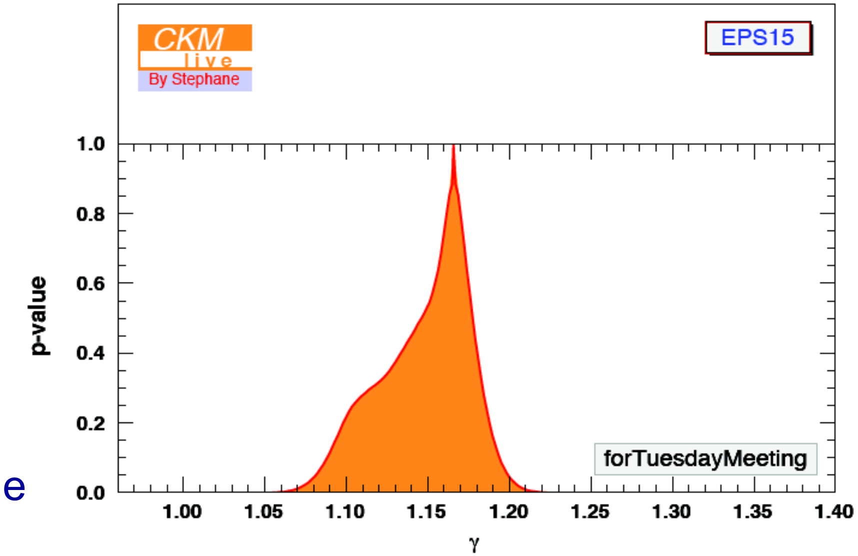
$$h \simeq 1.5 \frac{|C_{ij}|^2}{|V_{ti}V_{tj}|^2} \frac{(4\pi)^2}{G_F \Lambda^2}$$

| Couplings | NP loop order | Scales (in TeV) probed by $B_d$ mixing | $B_s$ mixing |
|---|---|---|---|
| $\lvert C_{ij}\rvert = \lvert V_{ti}V_{tj}^*\rvert$ (CKM-like) | tree level | 17 | 19 |
| | one loop | 1.4 | 1.5 |
| $\lvert C_{ij}\rvert = 1$ (no hierarchy) | tree level | $2 \times 10^3$ | $5 \times 10^2$ |
| | one loop | $2 \times 10^2$ | 40 |

# CKM*live* project

- **CKMlive project**
  - Web application which allows to configure CKM analysis with CKMfitter package
  - Analysis card send to calculus server with results send back to user with e-mail notification

- **What can be done with CKMlive (so far)?**
  - Global CKM fit of SM hypothesis (CKM parameters metrology)
  - User can use inputs proposed by CKMfitter group or set its own
  - SM predictions of most CKM-related flavour observables
  - **NOTE:** application could be extended to include model-independent NP in $\Delta F = 2$ quark transitions depending on the interest




$$\gamma_{\rm SM} = 1.166^{+0.051}_{-0.105} \ @ \ 3\ \sigma$$

- **CKMlive application is here:** ckmlive.in2p3.fr
- **Contact mail:** ckmlive@clermont.in2p3.fr

# Summary and outlook

- **Flavour Physics**
  - Potential to unravel NP beyond energy scale of direct searches
  - Analysis of flavour processes crucial

- **Determination of CKM matrix elements**
  - High precision era of determination of CKM parameters
  - Precise theoretical inputs (Lattice QCD & others..) are of major importance
  - No signs of deviation from CKM picture
  - $|V_{us}|$ from $K\to\pi l\nu$ brings tension to global fit due to new $f_+^{K\to\pi}(0)$ from lattice
  - $V_{ub}$ and $V_{cb}$ inclusive vs exclusive issue still not resolved
  - Others processes to include?

- **FCNC and NP**
  - $\Delta F = 1$: $B_s\to\mu^+\mu^-$, $K\to\pi\nu\nu$
  - $\Delta F = 2$: NP potential from mixing observables (still room for NP)

# CKMfitter group & page

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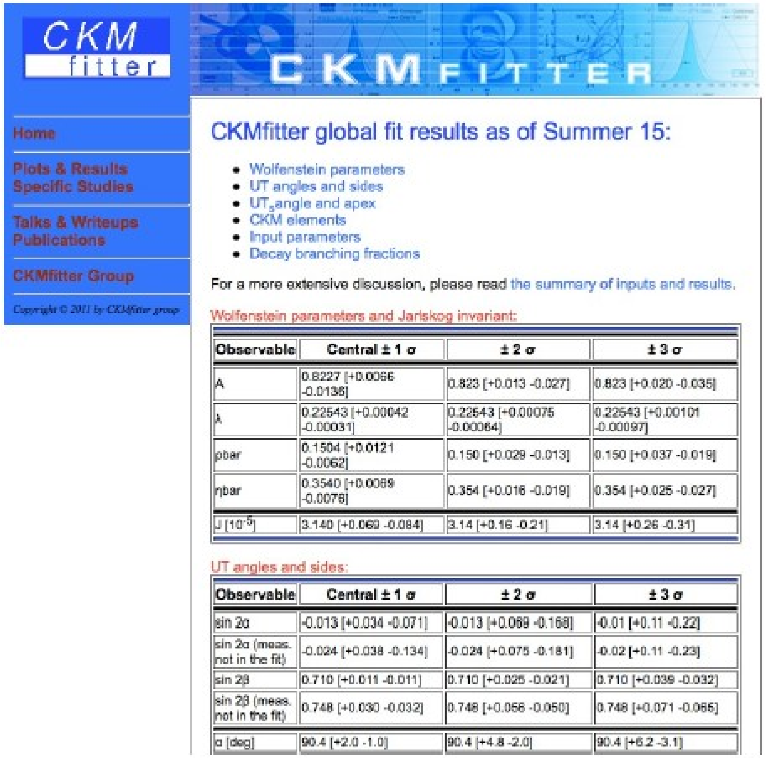
**More at:** [http://ckmfitter.in2p3.fr](http://ckmfitter.in2p3.fr)



CKM fitter

CKMFITTER

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CKMfitter Group

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CKMfitter global fit results as of Summer 15:

- Wolfenstein parameters
- UT angles and sides
- $UT_s$ angle and apex
- CKM elements
- Input parameters
- Decay branching fractions

For a more extensive discussion, please read the summary of inputs and results.

Wolfenstein parameters and Jarlskog invariant:

| Observable | Central ± 1 σ | ± 2 σ | ± 3 σ |
|---|---|---|---|
| A | 0.8227 [+0.0066 -0.0136] | 0.823 [+0.013 -0.027] | 0.823 [+0.020 -0.035] |
| λ | 0.22543 [+0.00042 -0.00031] | 0.22543 [+0.00075 -0.00064] | 0.22543 [+0.00101 -0.00097] |
| ρbar | 0.1504 [+0.0121 -0.0062] | 0.150 [+0.029 -0.013] | 0.150 [+0.037 -0.019] |
| ηbar | 0.3540 [+0.0069 -0.0078] | 0.354 [+0.016 -0.019] | 0.354 [+0.025 -0.027] |
| J [$10^{-5}$] | 3.140 [+0.069 -0.084] | 3.14 [+0.16 -0.21] | 3.14 [+0.26 -0.31] |

UT angles and sides:

| Observable | Central ± 1 σ | ± 2 σ | ± 3 σ |
|---|---|---|---|
| sin 2α | -0.013 [+0.034 -0.071] | -0.013 [+0.069 -0.168] | -0.01 [+0.11 -0.22] |
| sin 2α (meas. not in the fit) | -0.024 [+0.038 -0.134] | -0.024 [+0.075 -0.181] | -0.02 [+0.11 -0.23] |
| sin 2β | 0.710 [+0.011 -0.011] | 0.710 [+0.025 -0.021] | 0.710 [+0.039 -0.032] |
| sin 2β (meas. not in the fit) | 0.748 [+0.030 -0.032] | 0.748 [+0.056 -0.050] | 0.748 [+0.071 -0.065] |
| α [deg] | 90.4 [+2.0 -1.0] | 90.4 [+4.8 -2.0] | 90.4 [+6.2 -3.1] |

CKM live

**Application at:** [ckmlive.in2p3.fr](ckmlive.in2p3.fr)
**Contact:** ckmlive@clermont.in2p3.fr

# Back up Slides

# Averaging lattice results

Collecting lattice results

- follow FLAG to exclude limited results
- supplement with more recent published results with error budget

Splitting error estimates into stat and syst

- Stat : essentially related to size of gauge conf
- Syst : fermion action, $a \to 0$, $L \to \infty$, mass extrapolations...
  added linearly using error budget

"Educated Rfit" used to combine the results

- no correlations assumed
- product of (Gaussian + Rfit) likelihoods for central value
- product of Gaussian (stat) likelihoods for stat uncertainty
- syst uncertainty of the combination = most precise method
  - the present state of art cannot allow us to reach a better theoretical accuracy than the best of all estimates
  - best estimate should not be penalized by less precise methods

# $|V_{ub}|$ from semileptonic $B$ decays

Two ways of getting $|V_{ub}|$:

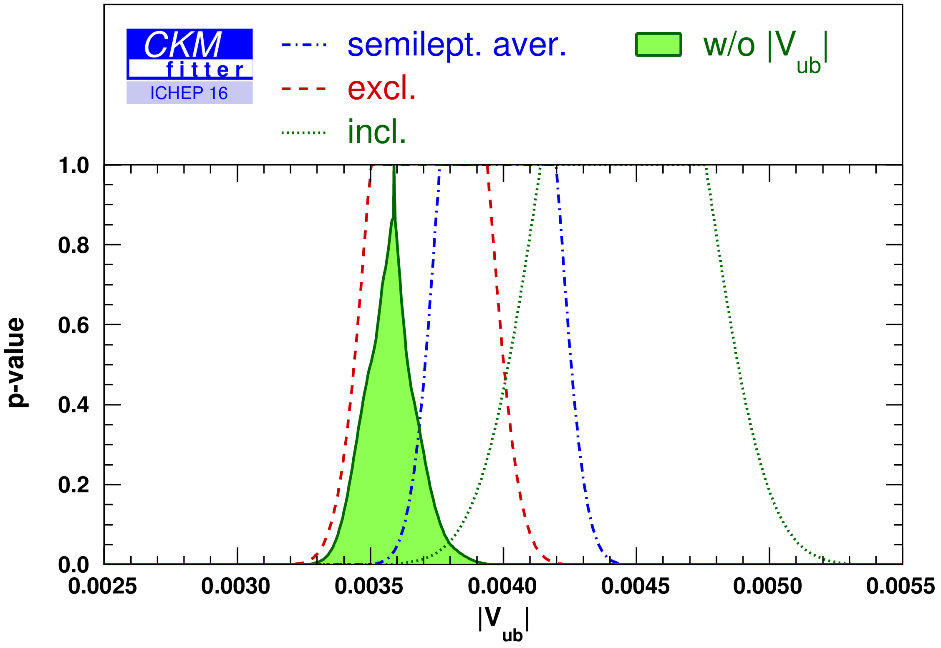
- Inclusive : $b \to u\ell\nu$ + Operator Product Expansion [HFAG BLNP]
- Exclusive : $B \to \pi\ell\nu$ + Form factors [J. A. Bailey et al., Fermilab-MILC]

$$|V_{ub}|_{inc} = 4.45 \pm 0.18 \pm 0.31$$
$$|V_{ub}|_{exc} = 3.72 \pm 0.09 \pm 0.22$$

$$|V_{ub}|_{ave} = 4.01 \pm 0.08 \pm 0.22$$

with all values $\times 10^{-3}$

- HFAG, with theory errors added linearly
- systematics combined using Educated Rfit




Indirect det. from global fit: $|V_{ub}|_{fit} = 3.57^{+0.15}_{-0.14}$ (4%)

# $|V_{cb}|$ from semileptonic $B$ decays

Two ways of getting $|V_{cb}|$:

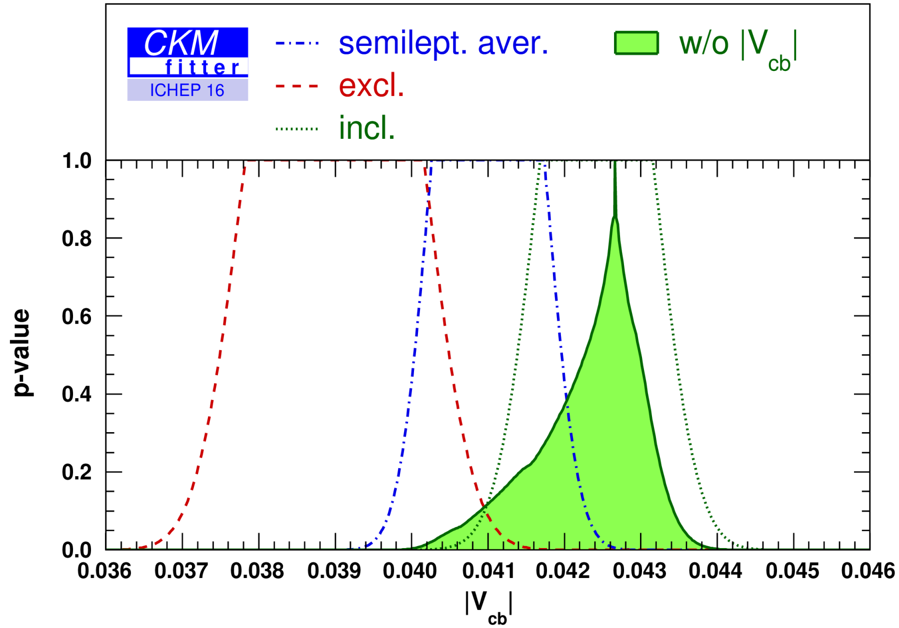
- Inclusive : $b \to c\ell\nu$ + OPE for moments [HFAG, Gambino and Schwanda]
- Exclusive : $B \to D(^*)\ell\nu$ + Form factors [J. A. Bailey et al., Fermilab-MILC]

$$|V_{cb}|_{inc} = 42.42 \pm 0.44 \pm 0.74$$
$$|V_{cb}|_{exc} = 38.99 \pm 0.49 \pm 1.17$$

$$|V_{cb}|_{ave} = 41.00 \pm 0.33 \pm 0.74$$

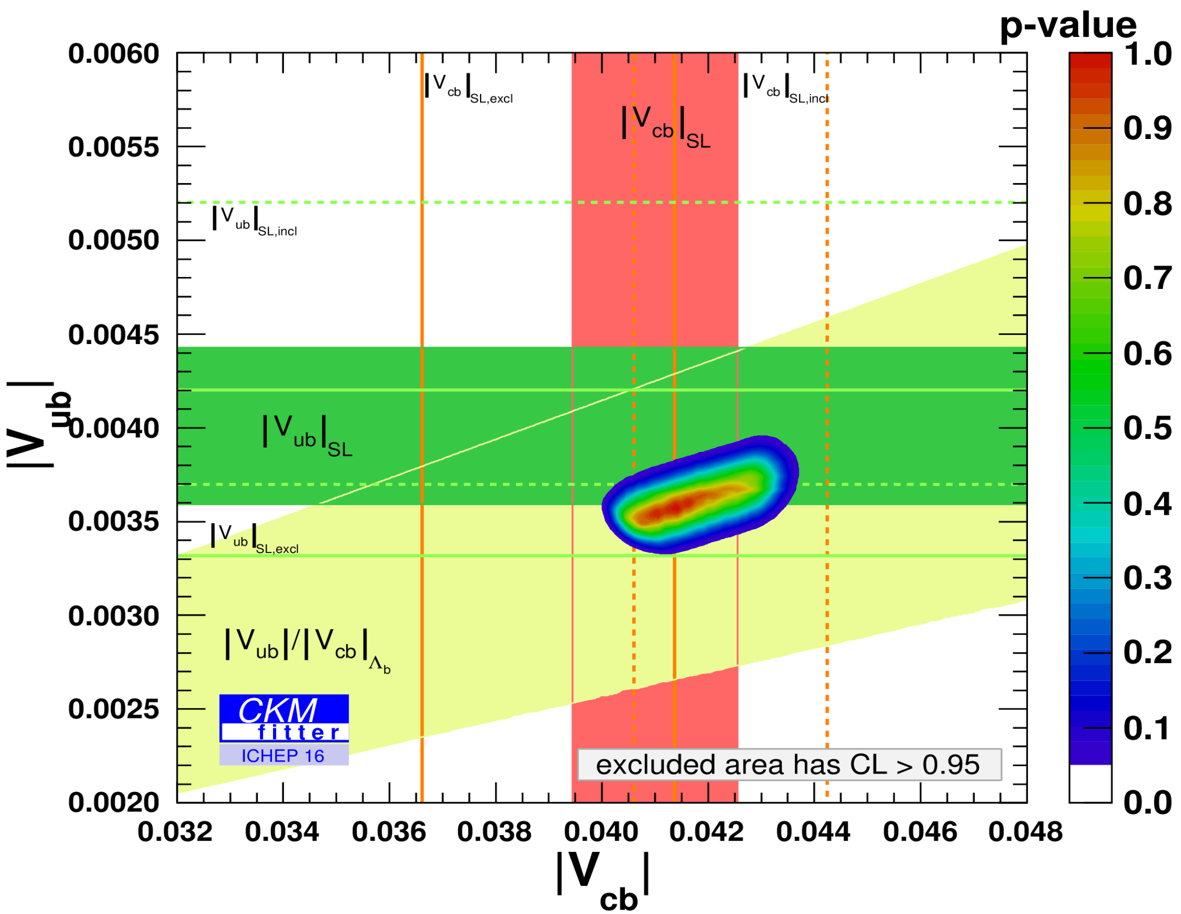
with all values $\times 10^{-3}$

- HFAG, with theory errors added linearly
- systematics combined using Educated Rfit




Indirect det. from global fit: $|V_{cb}|_{fit} = 43.0^{+0.4}_{-1.4}$ (4%)

# $|V_{ub}|, |V_{cb}|$




- Information on $|V_{ub}|$ from $Br(B \to \tau\nu)$
- New LHCb result on $|V_{ub}/V_{cb}|$ from $\Gamma(\Lambda_b \to p\mu\nu)/\Gamma(\Lambda_b \to \Lambda_c\mu\nu)$ at high $q^2$

  [Detmold, Lehner and Meinel]
- Global fit favours exclusive $|V_{ub}|_{SL}$ but inclusive $|V_{cb}|_{SL}$