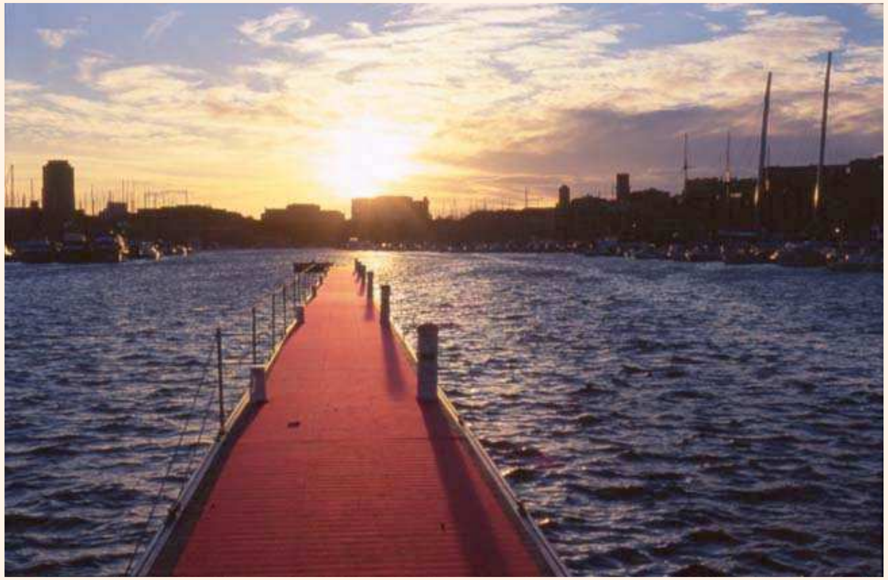
Status of the CKMfitter project

BES-Belle-CLEO-BaBar WS, Beijing, november 26-27th 2007



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http://ckmfitter.in2p3.fr

The statistical framework

we use a standard frequentist approach: likelihood maximization (χ^2 minimization)

where necessary, we try to treat non Gaussian behavior by Monte-Carlo simulation of virtual experiments

theoretical errors

no model-independent treatment available, due to lack of precise definition; we use the Rfit model: a theoretical parameter that has been computed (e.g. B_K) is assumed to lie within a definite range, without any preference inside this range

the best fit will thus be searched by moving uniformly in the theoretical parameter space

references: A. Höcker *et al.*, EPJC 21 (2001); JC *et al.*, EPJC 41 (2005); http://ckmfitter.in2p3.fr

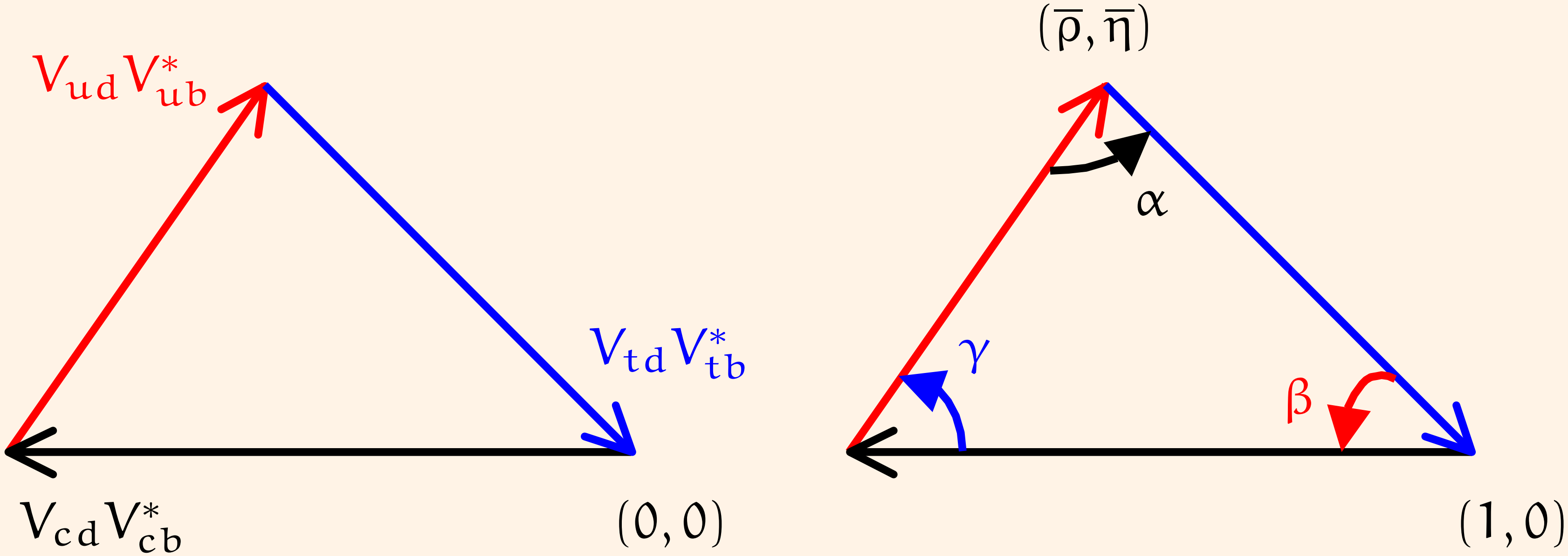
The Unitarity Triangle in short

unitary-exact and convention-independent version of the Wolfenstein parametrization

$$\lambda^2 \equiv \frac{|V_{us}|^2}{|V_{ud}|^2 + |V_{us}|^2} \qquad A^2\lambda^4 \equiv \frac{|V_{cb}|^2}{|V_{ud}|^2 + |V_{us}|^2}$$

there is no need to stop at $\mathcal{O}(\lambda^4)$!

$$\bar\rho + i\bar\eta \equiv -\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}$$



The global CKM fit

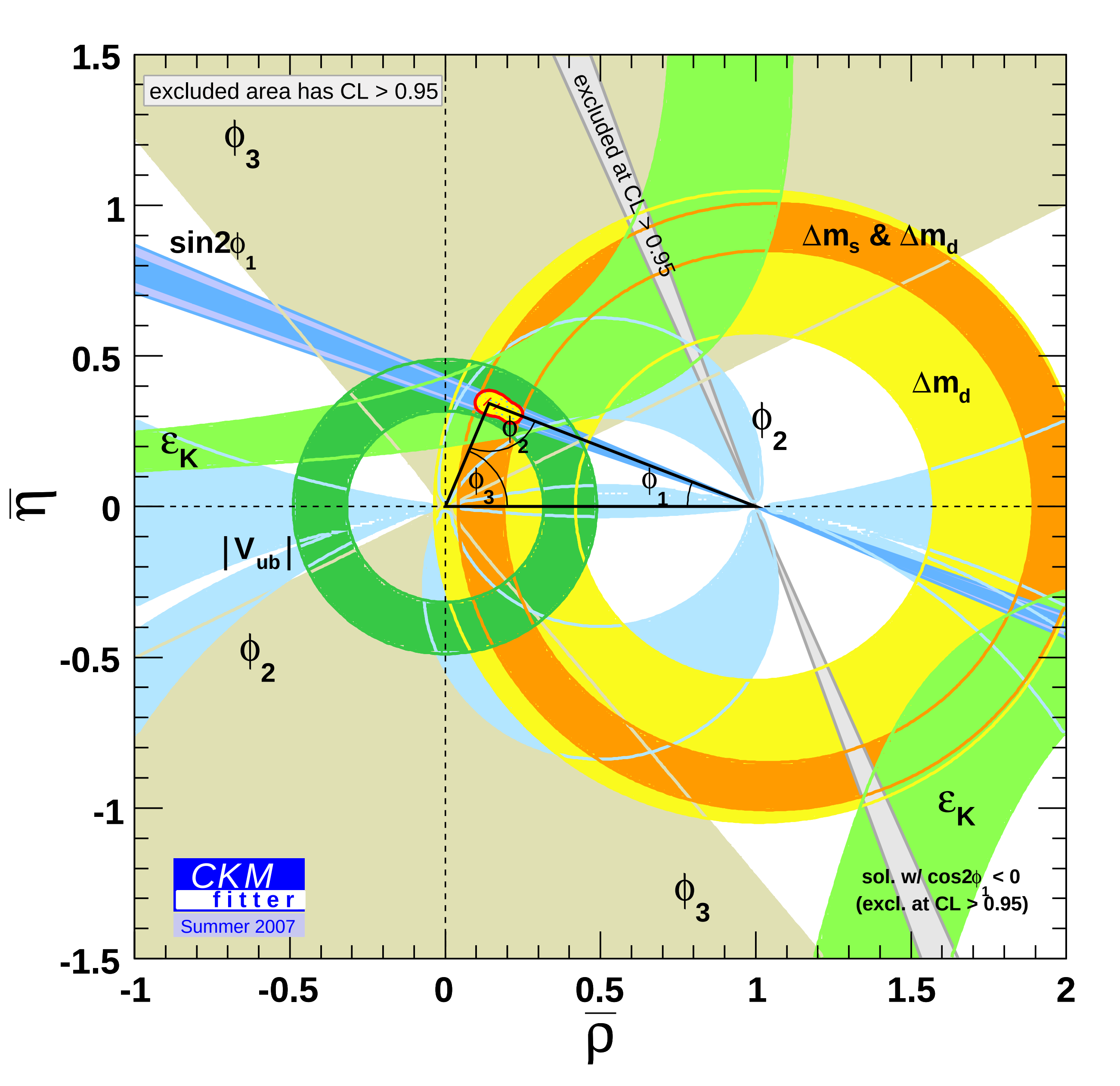
uses all constraints on which we think we have a good theoretical control

$\lvert V_{ud}\rvert$, $\lvert V_{us}\rvert$, $\lvert V_{cb}\rvert$	PDG, HFAG and Flavianet WG
ε_K	exp: KTeV/KLOE, theo: CKM06
$\lvert V_{ub}\rvert$	our average
Δm_d	exp: last WA, theo: CKM06
Δm_s	dominated by CDF, theo: CKM06
β	last WA
α	exp: last $\pi\pi$, $\rho\pi$, $\rho\rho$ WA, theo: SU(2)
γ	exp: last $B \to DK$ WA, theo: GLW/ADS/GGSZ
$B \to \tau\nu$	exp: last WA, theo: CKM06

(more details can be found on http://ckmfitter.in2p3.fr)

The global CKM fit: results

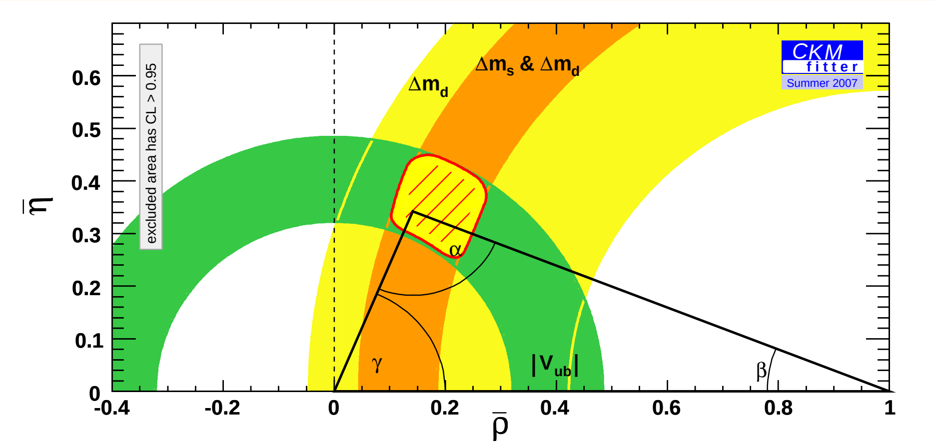
The global CKM fit: results (the plot of Supreme Harmony)



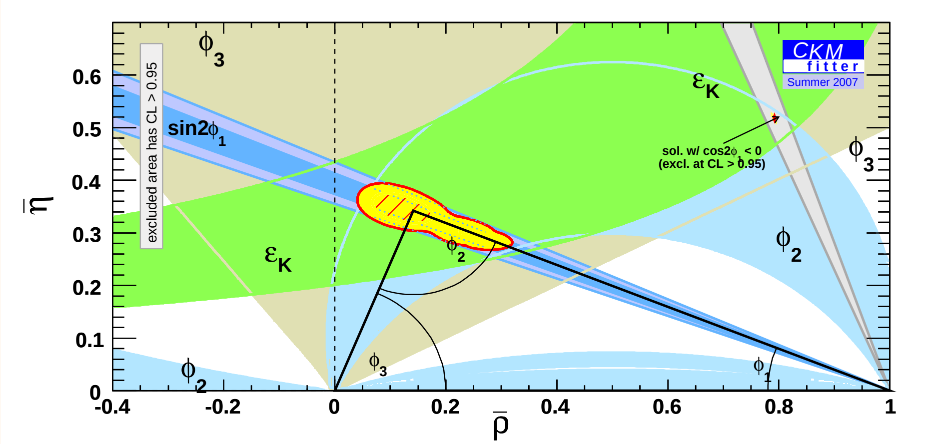
Summer 07

all constraints together

Testing the CKM paradigm (the plots of Celestial Agreement)



CP-conserving...



...vs. CP-violating

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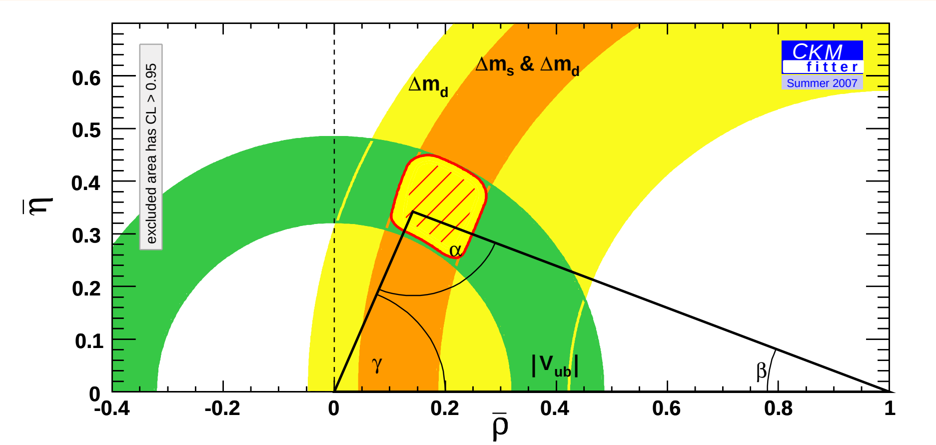

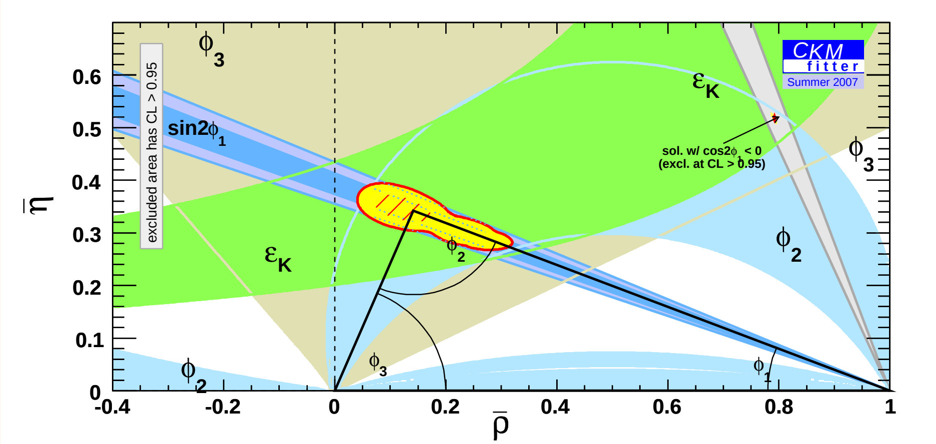

CP-conserving...

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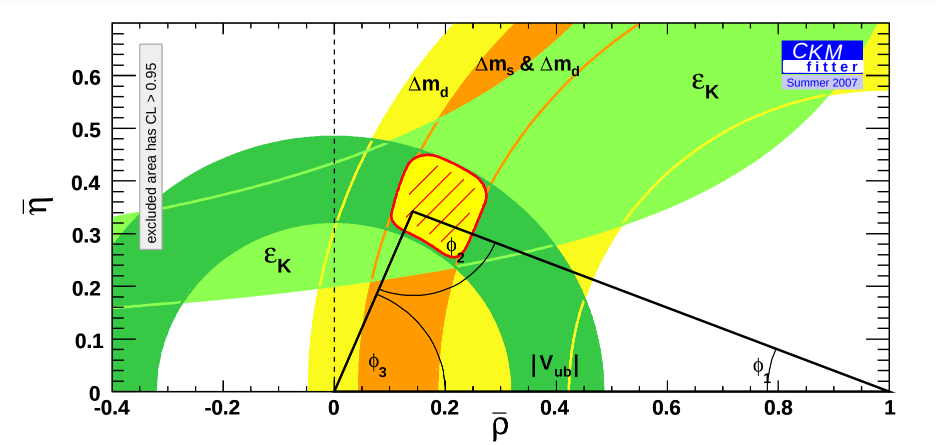
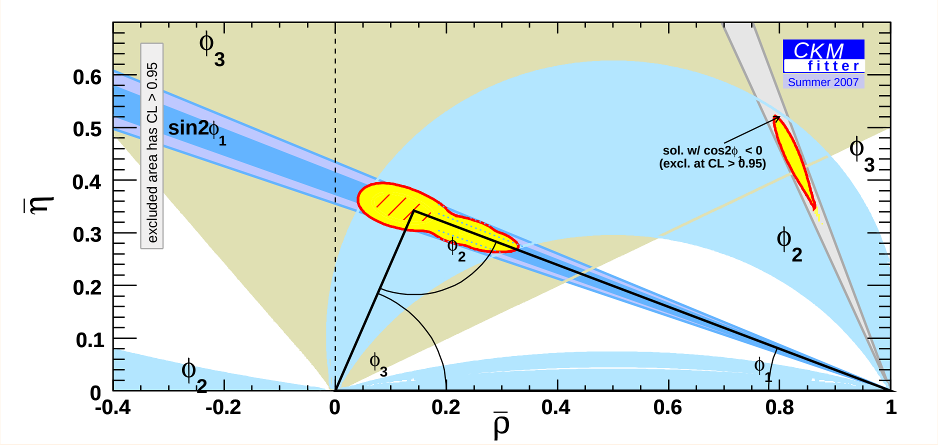
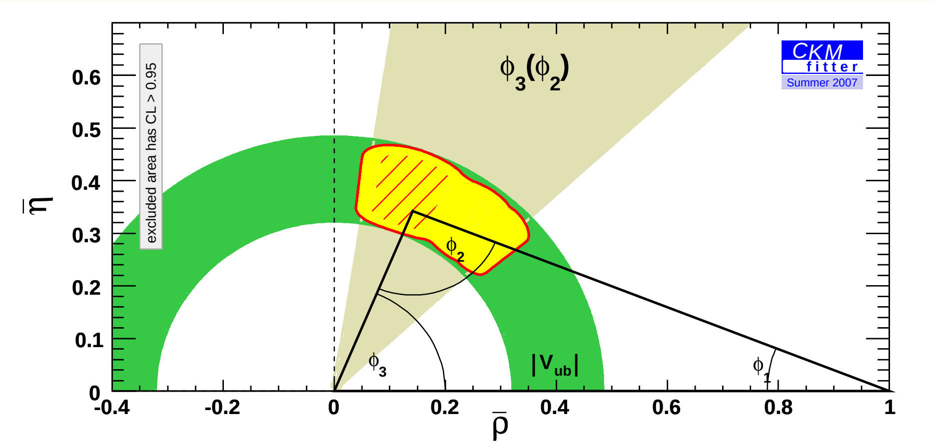


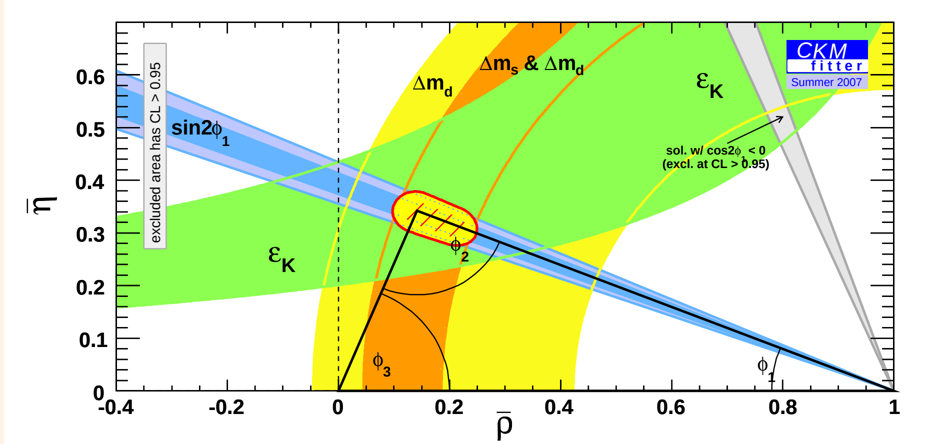


no angles (with theory)...

...vs. angles (without theory)

Testing the CKM paradigm (the plots of Celestial Agreement)





tree… …vs. loop

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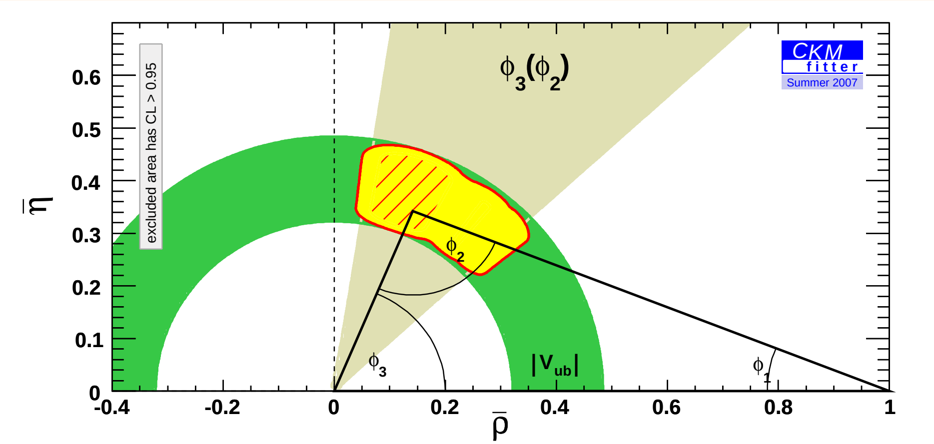

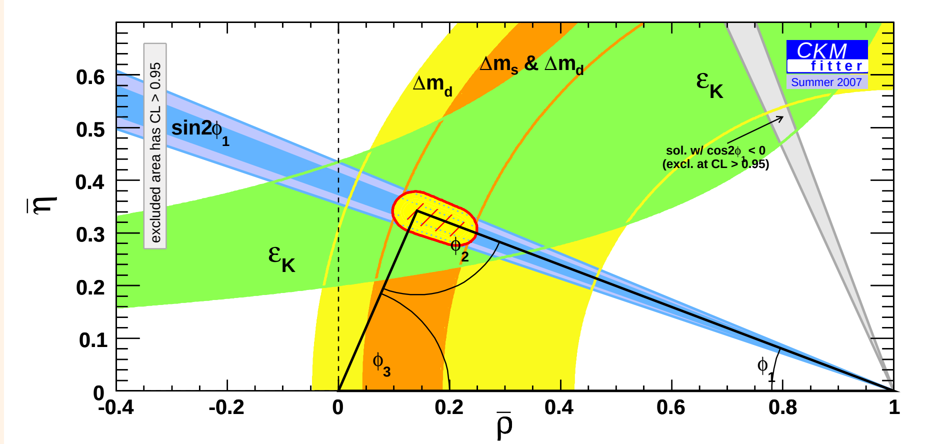

tree… …vs. loop

the $(\bar{\rho}, \bar{\eta})$ plane is not the whole story, still the overall agreement is impressive !

Depuzzling $B \to K\pi$

a long story:

Silva and Wolfenstein, 1993

Gronau *et al.*, 1994-1995 and 2004

JC; Pirjol; Fleischer, 1999

JC *et al.*, 2004

Buras *et al.* (BFRS), 2003-2005

many other works !

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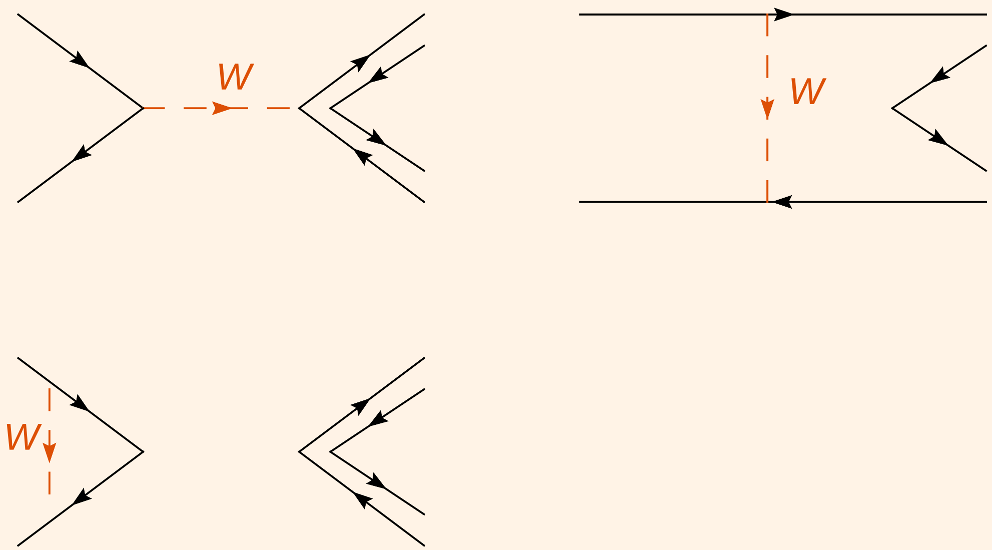
however due to lack of information on B_s decays, most of these works assume in addition that some or all of the following annihilation/exchange topologies are negligible (exception: Wu and Zhou, 2005)



Annihilation/exchange diagrams in heavy meson decays

these topologies are power-suppressed

the amplitude ratios

$$\left|\frac{A(D^0 \to K^0\overline{K^0})}{A(D^0 \to K^+K^-)}\right| \quad \text{and} \quad \left|\frac{A(B^0 \to D_s^- K^+)}{A(B^0 \to D^-\pi^+)}\right|$$

are both formally of order $(1/N_c)(\Lambda/m_Q)$;

but the first one is $\sim 43\%$ while the second one is $\sim 12\%$!

in charmless B-decays the only direct constraint is

$$\left|\frac{A(B^0 \to K^+K^-)}{A(B^0 \to \pi^+\pi^-)}\right| < 0.24$$

General parametrization in the strict SU(3) limit

$$
\begin{aligned}
A(K^+\pi^-) &= V_{us}V_{ub}^{*}T^{+-} + V_{ts}V_{tb}^{*}P \\
A(K^0\pi^+) &= V_{us}V_{ub}^{*}N^{0+} + V_{ts}V_{tb}^{*}(-P + P_C^{EW}) \\
\sqrt{2}A(K^+\pi^0) &= V_{us}V_{ub}^{*}(T^{+-} + T^{00} - N^{0+}) + V_{ts}V_{tb}^{*}(P + P^{EW} - P_C^{EW}) \\
\sqrt{2}A(K^0\pi^0) &= V_{us}V_{ub}^{*}T^{00} + V_{ts}V_{tb}^{*}(-P + P^{EW}) \\
A(\pi^+\pi^-) &= V_{ud}V_{ub}^{*}(T^{+-} + \Delta T) + V_{td}V_{tb}^{*}(P + PA) \\
\sqrt{2}A(\pi^0\pi^0) &= V_{ud}V_{ub}^{*}(T^{00} - \Delta T) + V_{td}V_{tb}^{*}(-P - PA + P^{EW}) \\
\sqrt{2}A(\pi^+\pi^0) &= V_{ud}V_{ub}^{*}(T^{+-} + T^{00}) + V_{td}V_{tb}^{*}P^{EW} \\
A(K^+K^-) &= V_{ud}V_{ub}^{*}\Delta T + V_{td}V_{tb}^{*}PA \\
A(K^0\overline{K}^0) &= V_{ud}V_{ub}^{*}\Delta P + V_{td}V_{tb}^{*}(-P - PA + P_C^{EW} - \frac{1}{3}P_{K\overline{K}}^{EW}) \\
A(K^+\overline{K}^0) &= V_{ud}V_{ub}^{*}N^{0+} + V_{td}V_{tb}^{*}(-P + P_C^{EW})
\end{aligned}
$$

Electroweak penguins

the $Q_{7,8}$ operators are suppressed by their Wilson coefficients with respect to $Q_{9,10}$ (Neubert and Rosner; Buras and Fleischer; Gronau, Pirjol and Yan) so that their $\Delta I = 3/2,\ 1$ hadronic matrix elements are not independent parameters in the SU(3) limit

$$
\begin{aligned}
P^{EW} &= R^{+}(T^{+-} + T^{00}) \\
P_C^{EW} &= \frac{R^{+}}{2}(T^{+-} + T^{00} + N^{0+} - \Delta T - \Delta P) \\
&- \frac{R^{-}}{2}(T^{+-} - T^{00} + N^{0+} + \Delta T + \Delta P) \\
P_{K\overline{K}}^{EW} &= R^{+}(N^{0+} - \Delta T - \Delta P)
\end{aligned}
$$

with

$$
R^{\pm} = -\frac{3}{2}\frac{c_9 \pm c_{10}}{c_1 \pm c_2} = (1.35 \pm 0.13)10^{-2}
$$

Parameter counting

neglecting annihilation/exchange diagrams would imply $\Delta T = PA = N^{0+} - \Delta P = 0$, in which case there are 7 hadronic parameters (+$(\bar{\rho}, \bar{\eta})$) and 15 independent measured observables

the exact SU(3) limit need 6 additional parameters but introduces only 4 new measured observables (among which one upper limit)

Parameter counting

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this seems hopeless ! however it is not...

in addition there are useful constraints coming from ratios of BR's by CDF (among which two new independent observables, $B_s \to K^+K^-$ and $B_s \to K^+\pi^-$, and one upper limit, $B_s \to \pi^+\pi^-$)

in total we have 13+2 parameters for 24 independent observables

SU(3) breaking

dominant factorizable SU(3) breaking is easy to identify, it is related to ratios of decay constants; we normalise $B \to K\pi$, $B_s \to K^+K^-$ and $B_s \to K^+\pi^-$ with respect to $B \to \pi\pi$ through the factors $N_{K\pi} \sim f_K/f_\pi$, $N_{K\bar{K}} \sim (f_{B_s}/f_B)(f_K/f_\pi)^2$ and $N^s_{K\pi} = (f_{B_s}/f_B)(f_K/f_\pi)$; take conservative theoretical errors

$$N_{K\pi} = 1.22 \pm 0.22$$
$$N_{K\bar{K}} = 1.81 \pm 0.34$$
$$N^s_{K\pi} = 1.48 \pm 0.28$$

remaining factorizable SU(3) breaking, such as $(f_\pi\, F^{B\to K})/(f_K\, F^{B\to\pi})$ is much smaller (a few %) and is neglected

non factorizable Λ/m_b-suppressed SU(3) breaking effects are neglected

Notation

in the tree dominance approximation, $B^0(t) \to \pi^+\pi^-$ measures α, so write the time-dependent CP-asymmetry

$$\begin{aligned} a_{CP}(t) &= C\cos\Delta m t + S\sin\Delta m t \\ &= C\cos\Delta m t + \sqrt{1-C^2}\sin 2\alpha_{\mathrm{eff}}\sin\Delta m t \end{aligned}$$

in the penguin dominance approximation, $B^0(t) \to K_S\pi^0$ measures β, so write the time-dependent CP-asymmetry

$$a_{CP}(t) = C\cos\Delta m t + \sqrt{1-C^2}\sin 2\beta_{\mathrm{eff}}\sin\Delta m t$$

Understanding the constraint shape in the $(\bar{\rho}, \bar{\eta})$ plane: the "α" subsystem

the subsystem $B \to \pi^+\pi^-$, $B \to K^\pm\pi^\mp$, $B \to K^+K^-$ approximately measures α

neglecting annihilation and exchange, there is a simple analytical solution

$$\sqrt{1 - C^2_{\pi\pi}}|\mathcal{D}| \cos(2\alpha - 2\alpha_{\text{eff}} - \epsilon) = (1 + \lambda^2)^2 - 2\lambda^2 \sin^2\gamma \left[1 + \frac{BR(K^+\pi^-)}{BR(\pi^-\pi^+)}\right]$$

and $BR(K^+\pi^-)C(K^+\pi^-) + BR(\pi^+\pi^-)C(\pi^+\pi^-) = 0$

where $\mathcal{D} \equiv |\mathcal{D}|e^{i\epsilon} = (1 + \lambda^2)(1 + \lambda^2 e^{i\gamma})$

taking power-suppressed contributions into account, the system of equations remain closed and solvable, and can be approximately viewed as a bound on $|\alpha - \alpha_{\text{eff}}|$.

the bound would become an equality if the time-dependent CP-asymmetry in $B \to K^+K^-$ is measured

the "β" subsystem

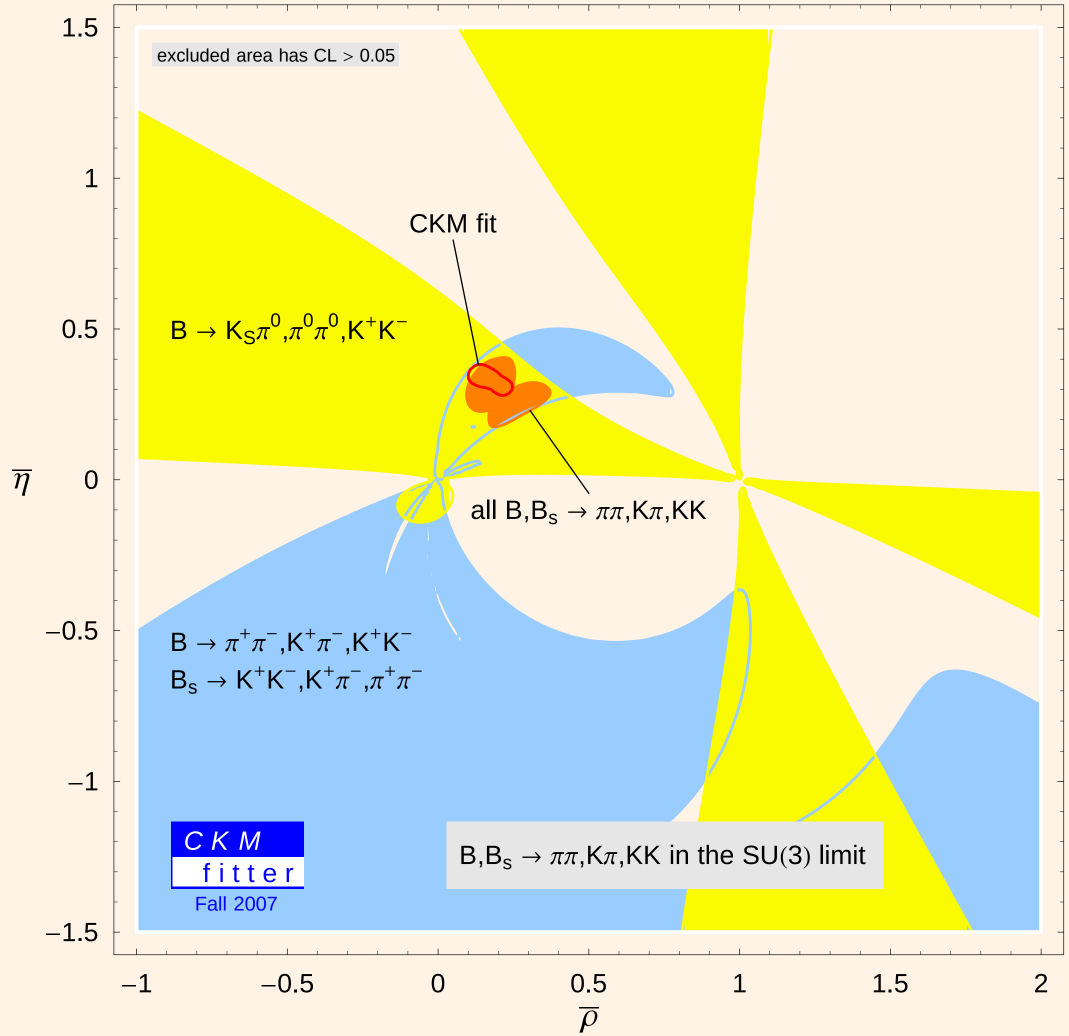
replace $B \to \pi^+\pi^-$ by $B \to K_S\pi^0$, $B \to K^\pm\pi^\mp$ by $B \to \pi^0\pi^0$, and α by β

$$\sqrt{1 - C^2_{K_S\pi^0}}|\mathcal{D}|\cos(2\beta - 2\beta_{\text{eff}} + \epsilon) = (1+\lambda^2)^2 - 2\lambda^2\sin^2\gamma\left[1 + \frac{BR(\pi^0\pi^0)}{BR(K_s\pi^0)}\right]$$

and $BR(K_S\pi^0)C(K_S\pi^0) + BR(\pi^0\pi^0)C(\pi^0\pi^0) = 0$

taking annihilation/exchange into account, this translates into a bound that improves the result of Gronau, Grossman and Rosner that is not optimal

Constraint in the $(\bar{\rho}, \bar{\eta})$ plane from the partial and full input sets



combination of constraints stronger than the naïve product $\alpha \otimes \beta$: the correlation comes mainly from the electroweak penguin coefficients $R^{\pm}$

the α and β subsystems dominate the constraint; other inputs help in disfavouring mirror solutions

The pValue of the analysis within the Standard Model

in frequentist statistics, the pValue is a well-defined interpretation of χ^2_{min}/N_{dof}; assuming a given theory (here, $(\bar{\rho},\bar{\eta})_{SM}$+SU(3)), the pValue is the probability that one obtains a less good fit if one performs many similar experiments

the larger the pValue, the better the compatibility of the observed data with respect to the assumed theory

here the pValue if of order 30–40% and thus the compatibility of the data with the SM+SU(3) hypothesis is very good

more information can be obtained by comparing the indirect fit prediction for a given observable with the direct experimental measurement (on the way...)

Outlook

in the near future, thanks to CDF and LHCb, there may be up to 38 measured observables depending on the very same 13+2 parameters; this will allow to fit part of SU(3) breaking and to study different New Physics scenarios

New Physics in $B\overline{B}$ mixing
Model-independent parametrization

$$\langle B_q \,|\, \mathcal{H}^{\mathrm{SM+NP}}_{\Delta B=2} \,|\, \bar{B}_q \rangle \equiv \langle B_q \,|\, \mathcal{H}^{\mathrm{SM}}_{\Delta B=2} \,|\, \bar{B}_q \rangle \times (1 + x_q^{\mathrm{NP}} + i y_q^{\mathrm{NP}})$$

(SM is thus located at $(x_d^{\mathrm{NP}}, y_d^{\mathrm{NP}}) = (0, 0)$)

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(SM is thus located at $(x^{NP}_d, y^{NP}_d) = (0, 0)$)

Strategy and inputs

assume that tree-level transitions are 100% SM

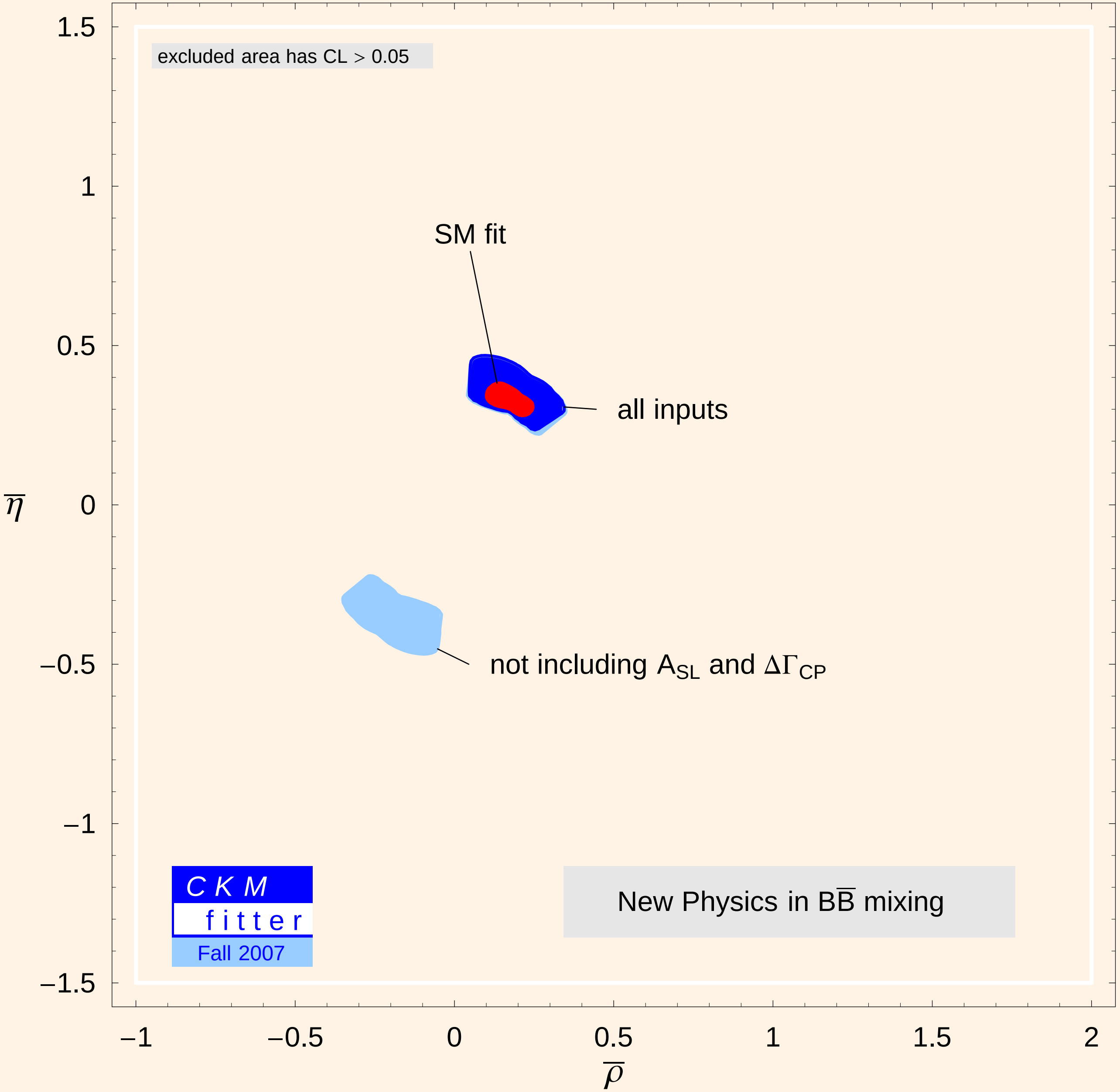
fix SM parameters with $|V_{ud}|$,$|V_{us}|$, $|V_{cb}|$, $|V_{ub}|$, γ and $\alpha = \pi - \gamma - \beta_{\text{eff}}(\Psi K_S)$

(x^{NP}_d, y^{NP}_d) are then constrained by Δm_d (circle)
and by $2\beta_{\text{eff}}(\Psi K_S) = 2\beta + \arg(1 + x^{NP}_d + i y^{NP}_d)$ (straight line)

(x^{NP}_s, y^{NP}_s) are constrained by Δm_s (circle) (no phase measurement up to now)

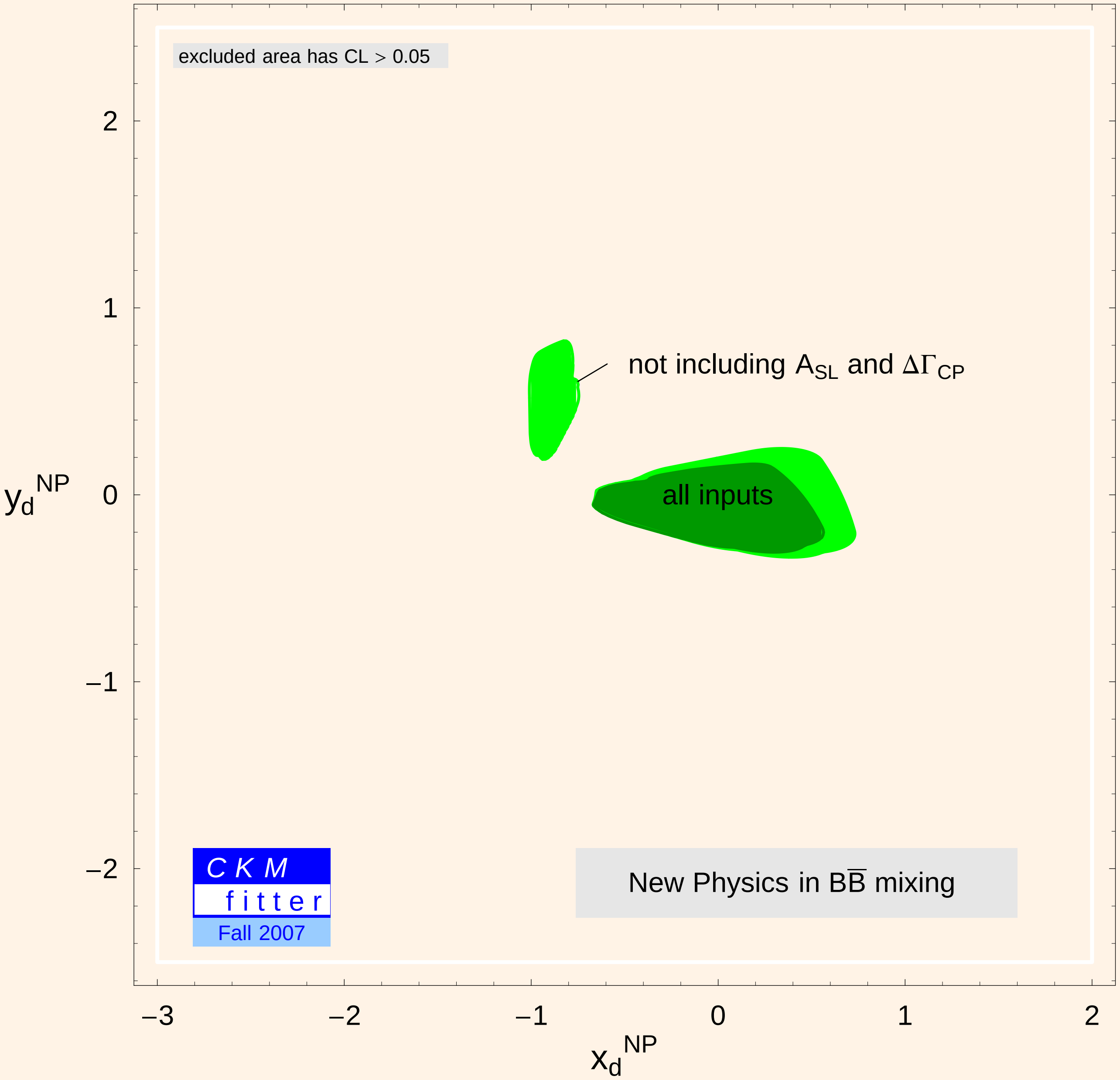
additional information is brought by the measurement of the semileptonic asymmetries A^d_{SL}, A^s_{SL} and by $\Delta\Gamma_{s,CP} = \frac{(x^{NP}_s)^2}{(x^{NP}_s)^2 + (y^{NP}_s)^2} \Delta\Gamma_{s,SM}$

Results in the $(\bar{\rho}, \bar{\eta})$ plane



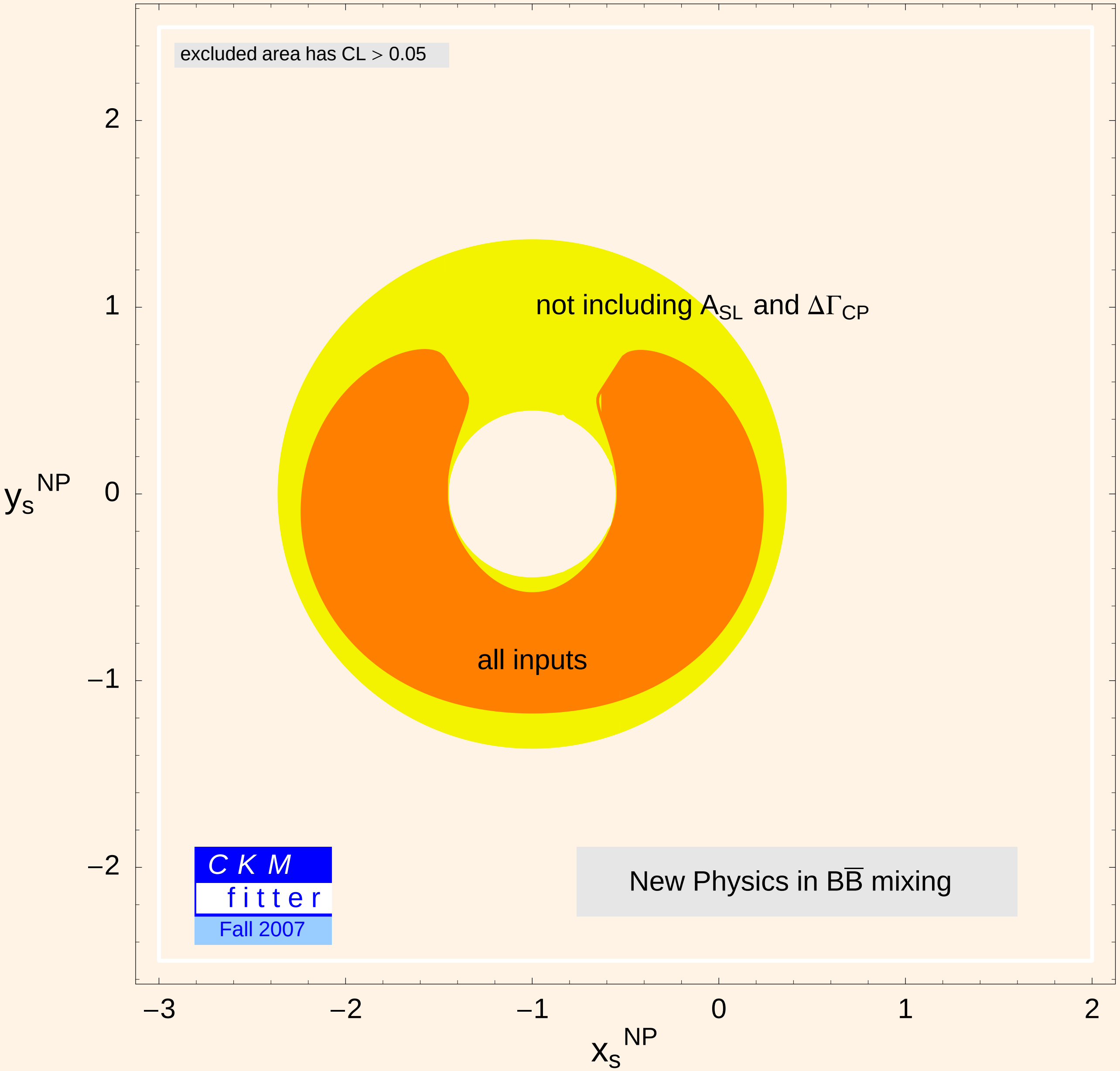
no evidence for New Physics...

Results in the x_d^{NP}, y_d^{NP} plane



no evidence for New Physics, but sizable contributions are allowed

Results in the x_s^{NP}, y_s^{NP} plane



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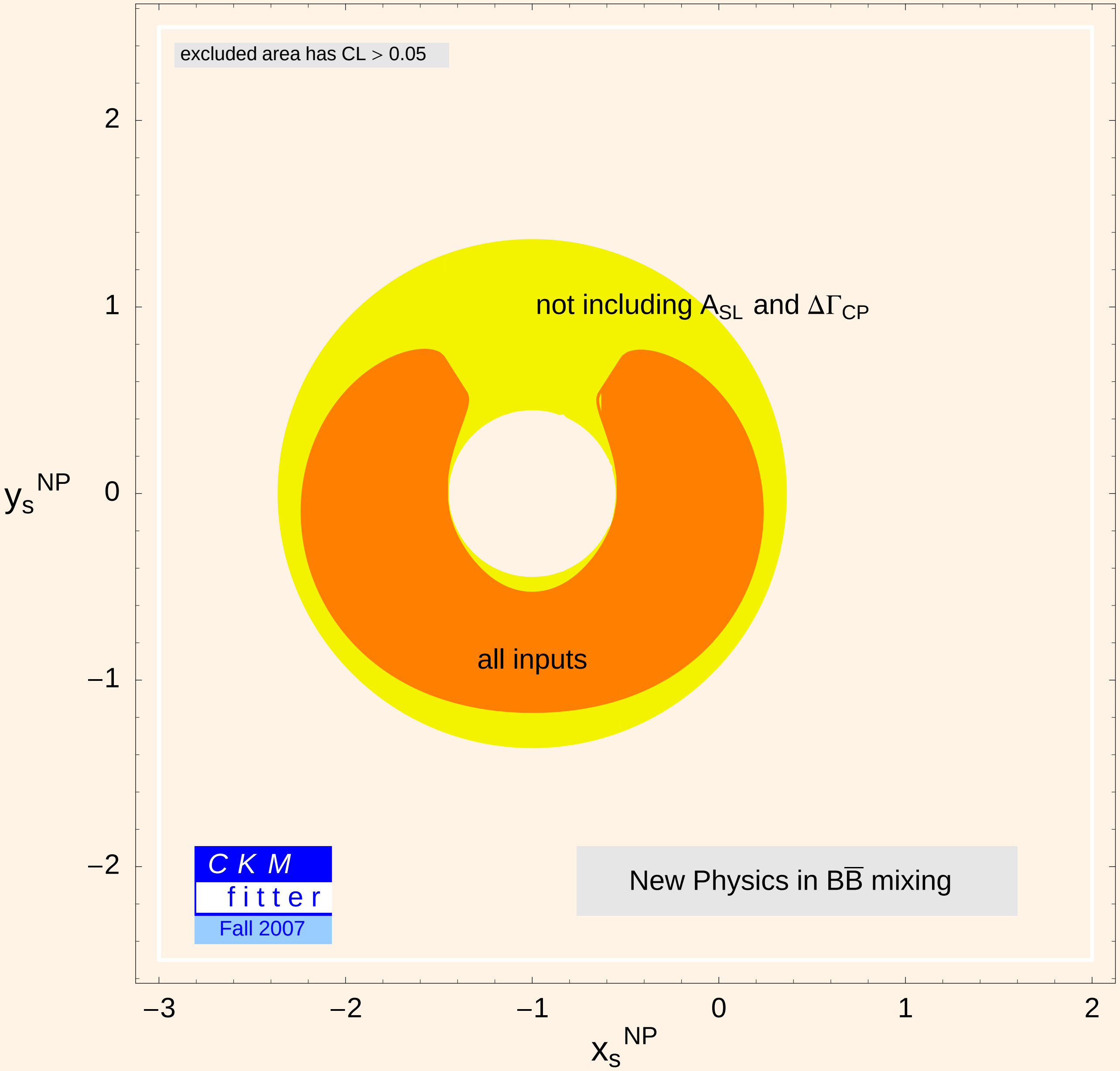

no evidence for New Physics, but sizable contributions are allowed

wait for the measurement of the $B_s\overline{B}_s$ mixing phase !

Outlook

what we have done so far:

- the traditional inputs to the global CKM fit
- generic NP contributions to $B\overline{B}$ mixing, including the $\Delta B = 2$ amplitude at NLO
- $B \to \pi\pi, \rho\pi, \rho\rho$ in the SU(2) limit for the extraction of α
- the $B \to DK$-like decays (ADS/GLW/GGSZ) for the extraction of γ
- the $B \to D\pi$-like decays for the extraction of $\sin(2\beta + \gamma)$
- $B \to PP$ in the SU(3) limit
- QCD factorization approach to $B \to PP$ (to be updated)
- rare decays such as $K \to \pi\nu\bar{\nu}$ (to be updated) and $B \to \ell^+\ell^-$

Outlook

for the future:

- $B \to V\gamma$ at NLO (almost done)
- $B \to P(V)\ell^+\ell^-$
- the inclusive versions $b \to s\gamma$, $b \to s\ell^+\ell^-$
- $B \to VP, VV, PPP$ in the SU(3) limit
- the $b \to s$ non leptonic penguin decays
- charm physics...
- $\ldots$

on the statistical side, we are implementing the tools that are needed to systematically study non asymptotic (non Gaussian) effects by toy Monte-Carlo frequentist approaches

Conclusion

the global CKM fit, which uses well controlled inputs only, does confirm the CKM mechanism as the dominant contribution to flavor- and CP-violating transitions

the three main FCNC transitions ($s \to d$, $b \to d$ and $b \to s$) have now been tested and are in good to excellent agreement with SM predictions

some important observables (very rare kaon and B decays, CP violation in B_s decays ...) remain to be measured and interpreted: will be done at future experiments !

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the overall pattern of B decays to two light pseudoscalars is reasonably described by simple phenomenological approaches, but its details and dynamics challenges the theory

present understanding makes unclear the disentanglement of statistical fluctuations, hadronic effects (flavor symmetry breaking) and possible New Physics effects

however due to the large number of experimentally accessible observables, new information from non leptonic B decays is expected in a close future

New Physics in $\Delta B = 2$ transitions can be parametrized model-independently and constrained with non trivial results: non standard contributions are not necessary to describe the data but ae allowed up to sizable values

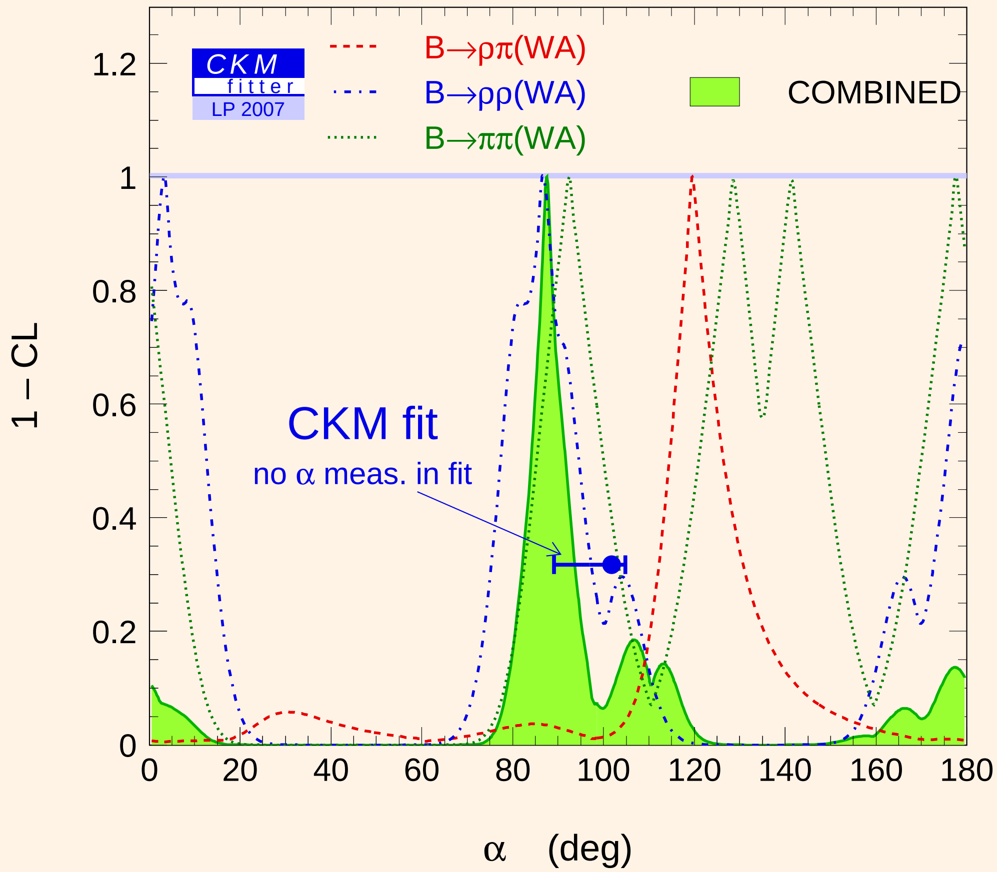
we have still a lot of work to do within CKMfitter !

Backup

More on selected inputs...

the angle α

the best constraint comes from the $\rho\pi$ and $\rho\rho$ modes, which show a tendency to different central values



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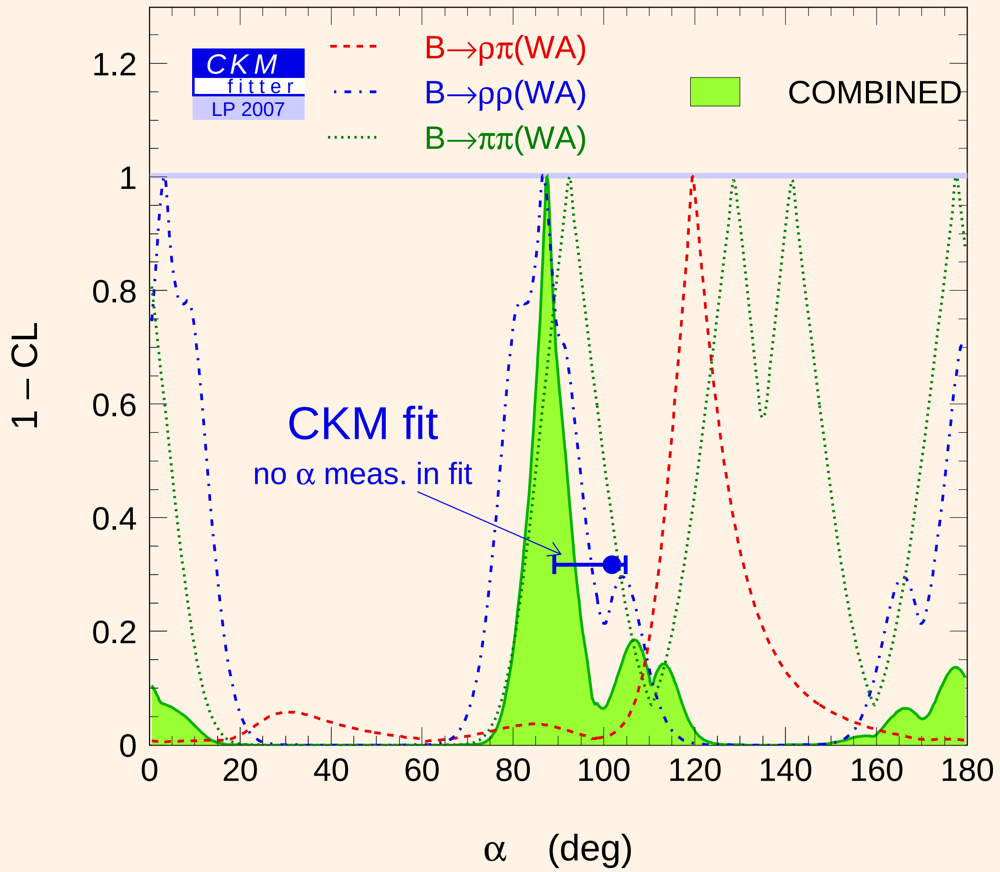

new average $\alpha = (87.7^{+6.4}_{-5.3})^\circ$

…more on selected inputs…

the angle γ (preliminary)

the analysis is non trivial: naive interpretation of χ^2 in terms of the error function underestimates the error on γ because of the bias on r_B due to r_B compatible with 0; both Babar and Belle use their own frequentist approach, while we use a different one

meanwhile the central value of r_B has decreased

...more on selected inputs...

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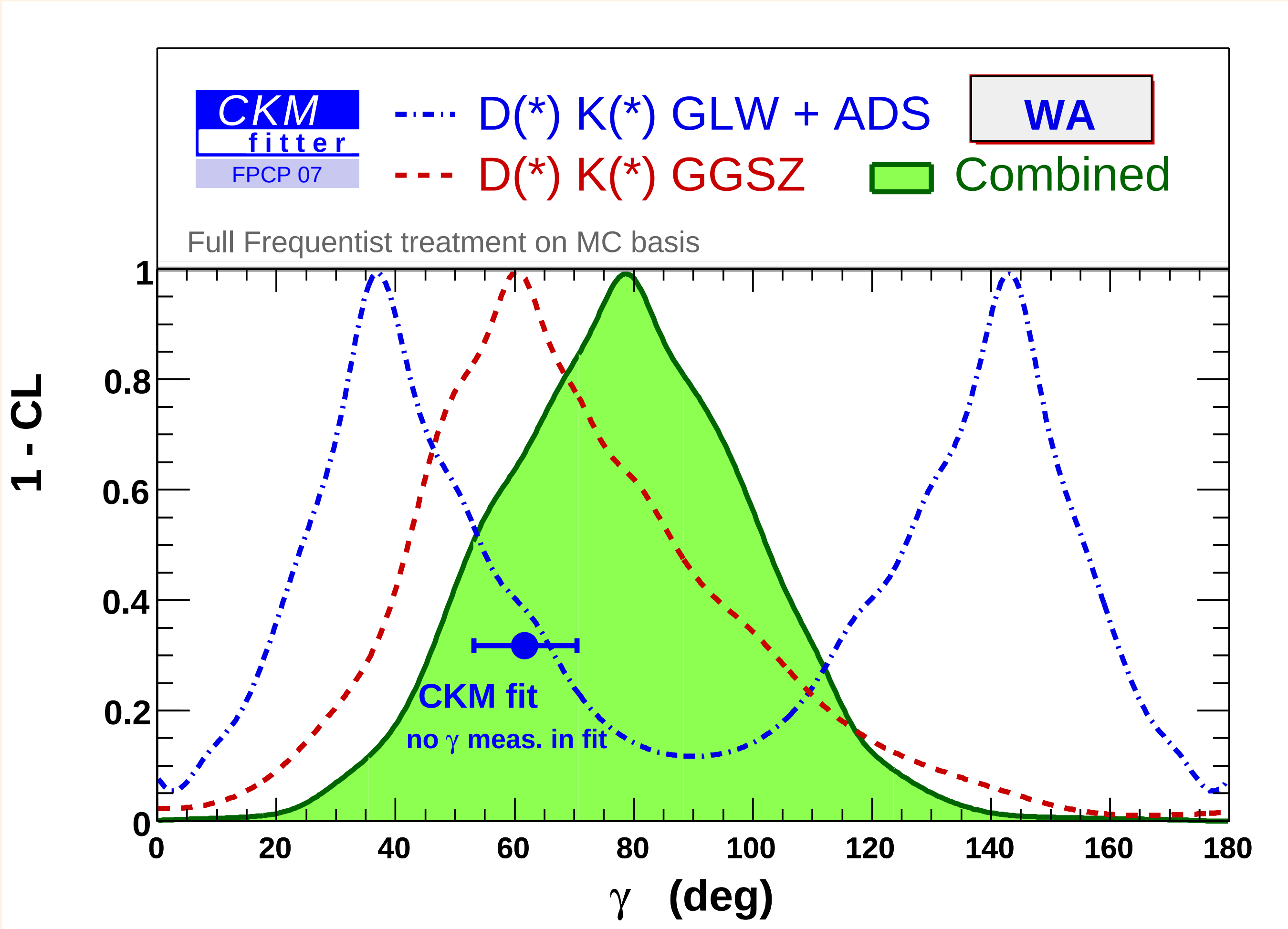
meanwhile the central value of r_B has decreased

we find a somewhat loose constraint, with $\gamma = (77^{+30}_{-32})^\circ$



Challenge: nuisance parameters in toy analyses

asymptotically (small Gaussian errors), when one repeats a large number of times the same experiment, the distribution of $\Delta\chi^2(\bar\rho,\bar\eta) = \mathrm{Min}_\mu\,\chi^2(\bar\rho,\bar\eta;\mu) - \chi^2_{min}$ follows a $N_{dof} = 2$ χ^2-distribution and does not depend on the true (unknown) value of the SM parameters μ

however in presence of physical boundaries and/or large non-linearities, the above statement is no longer true, one must compute numerically the actual distribution and study the dependence wrt to μ

this is technically very demanding, but is mandatory to get a sensible answer for specific analyses: γ from $B \to DK$, α from $B \to \rho\pi$, among others

we are implementing these techniques within a general algorithm in CKMfitter so that virtually any problem can be treated transparently

The statistical method to extract γ

the observables depend on γ and μ where $\mu = (r_B, \delta)$

1. minimize $\chi^2(\gamma, \mu)$ with respect to μ and substract the minimum $\rightarrow \Delta\chi^2(\gamma)$
2. assume that the true value of μ is $\mu_t \rightarrow \mathrm{PDF}\left[\Delta\chi^2(\gamma)\,|\,\gamma, \mu_t\right]$
3. compute $(1-\mathrm{CL})_{\mu_t}(\gamma)$ via toy Monte-Carlo
4. maximize with respect to $\mu_t \rightarrow (1-\mathrm{CL})(\gamma)$

this is a quite general, but very expensive, procedure; coverage must be (and is being) checked

another possibility is to assume that the best value of μ corresponds to the one that minimizes $\Delta\chi^2(\gamma, \mu)$ for the fixed γ

A side remark: direct tests of SU(3) in heavy meson observables

decay constants: f_{D_s}/f_D (exp, latt) and f_{B_s}/f_B (latt) are of the same order as f_K/f_π

once dominant sources are identified (phase space, pole contribution to the form factor), $D \to \pi$ and $D \to K$ semileptonic decays do not indicate large corrections (Fajfer)

still, information is incomplete and one cannot exclude new mechanisms of SU(3) breaking

A few words on statistics

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- theoretical uncertainties for the quantities that are computed within QCD
- discrete ambiguities that correspond to physical maxima of the Likelihood
- physical bounds, e.g. $|\sin 2\beta| < 1$
- nuisance parameters, that is you may want $(1 - \mathrm{CL})(\gamma)$ while the Likelihood depends on many other parameters

Bayesian vs. frequentist inference

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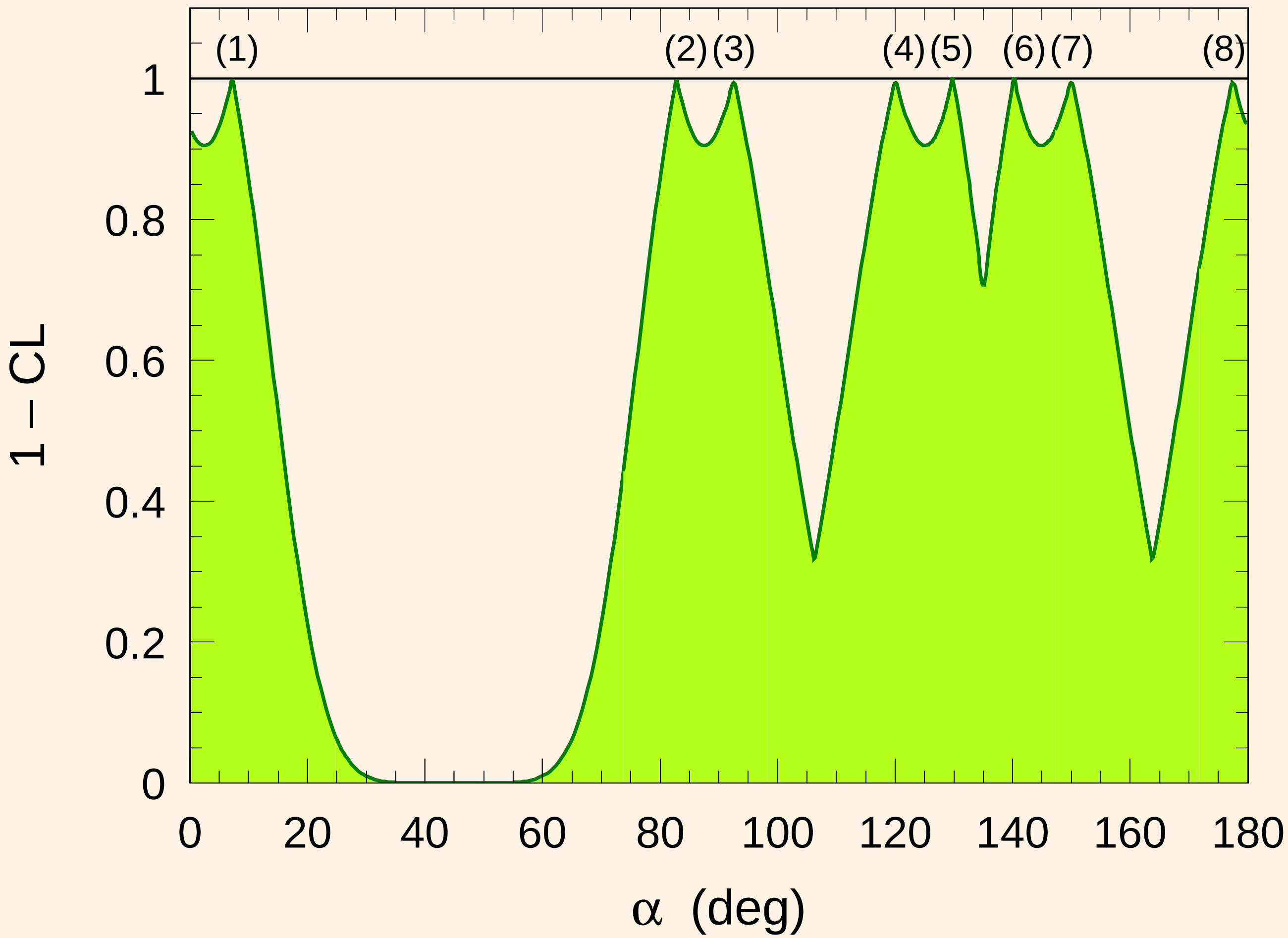
Bayesian statistics is technically simpler (no minimization), and solves in part the difficulties mentioned in the previous slide. However the drawback is the non invariance with respect to the parametrization, and the possible violation of the symmetries of the problem !

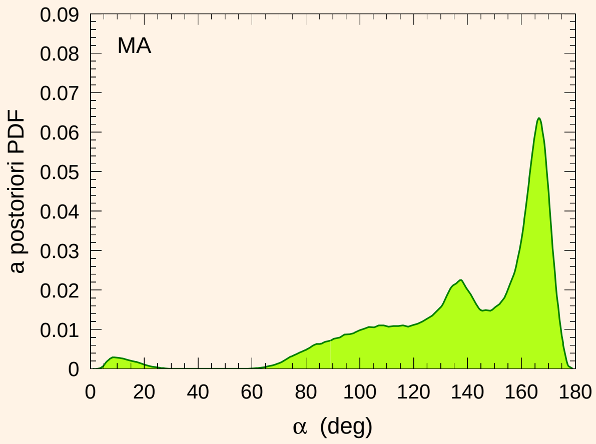
Frequentist result for the $B \to \pi\pi$ isospin analysis



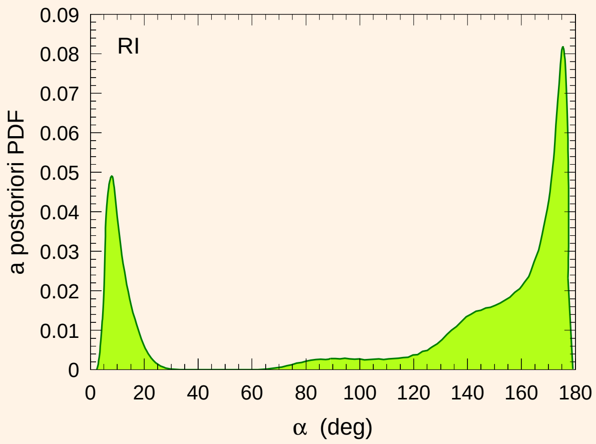
frequentist analysis is invariant with respect to the parametrization, and shows explicitly the eight-fold discrete ambiguity that can be computed analytically

Bayesian result(s)

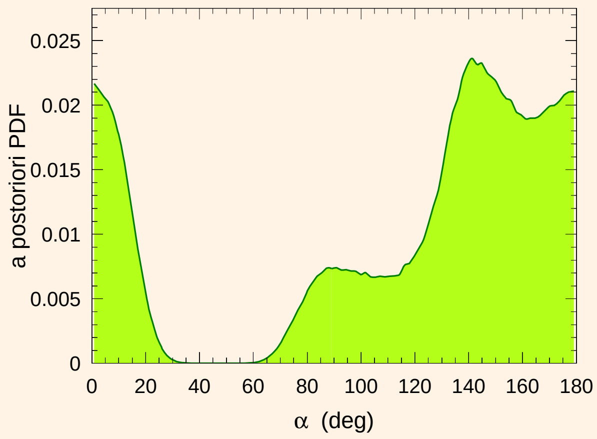
Modulus and Argument parametrization



Real and Imaginary part parametrization)



yet another parametrization



cf. discussion in hep-ph/0607246, hep-ph/0701204, hep-ph/0703073

CMKfitter historics

first CKM fit in 1992 by Schubert and Schmidtler

during the BaBar workshop (1996-1997) the need for a specific tool and method was stressed, and finally was fulfilled by the frequentist "Scan Method" (Schune and Plaszczynski)

meanwhile a Bayesian treatment appeared (Rome group, 2000)

the CKMfitter project started in 2001 (Höcker, Lacker, Laplace and Le Diberder) to advocate frequentist statistics and a well-defined (Rfit) model for theoretical uncertainties

Strategy and goals of CKMfitter

try to state clearly the various assumptions

try to be conservative, or a least careful

try to be transparent on the methods; keep historics on the Web site; let the tools available to the community

try to answer the requests from the community, even if some of them (10 two-dimensional plots the night before the conference) are not reasonable

try to perform not only updates of well-known analyses, but also develop new physics approaches

try to be appealing

try to be exhaustive

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of course there is fun only because none of these goals is fully reached !