The CKM matrix
Status and some Outlook

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FPCP'03 , Paris
3rd of June, 2003

The next 25 minutes contain:

Introductory remarks

Unitarity violation in the first family

The Standard CKM fit: inputs and results

Some interesting topics beyond that

Concluding remarks

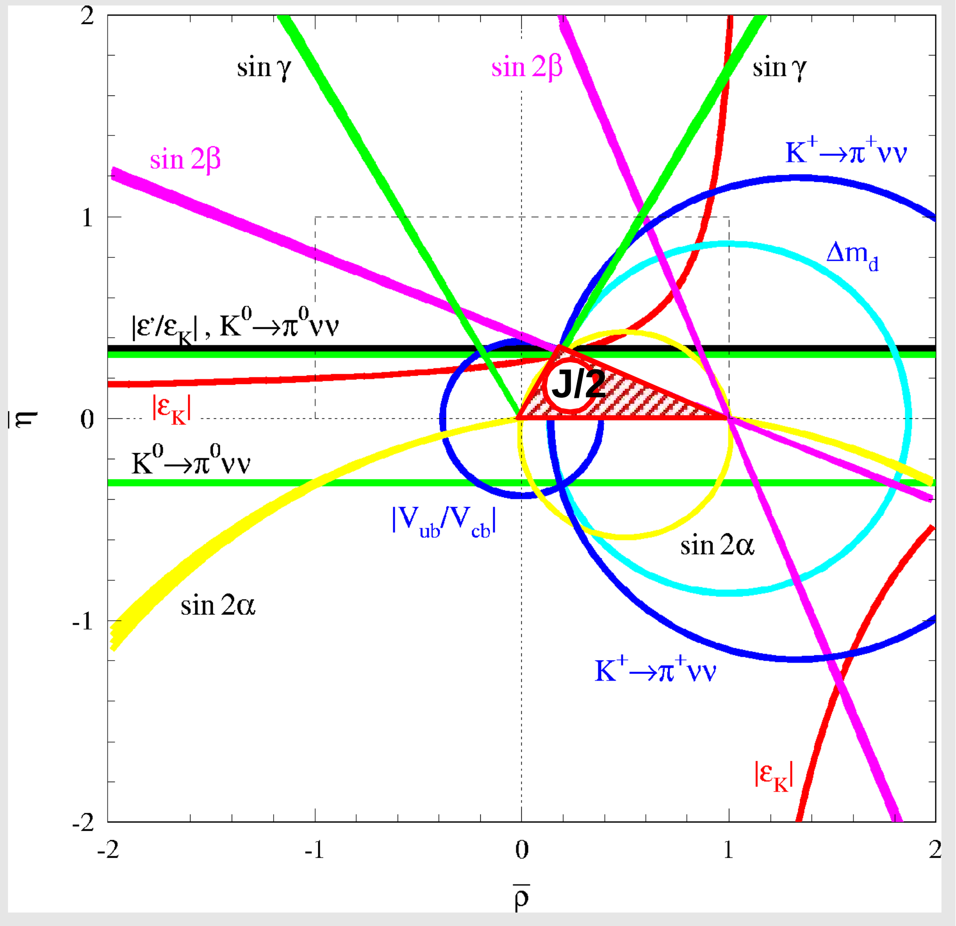
Constraining the CKM matrix

1. Consistency between data & SM

   UT: Not the whole story!

2. Constrain the four independent real parameters of the CKM matrix
   => CP violation in the SM (J)

3. Probing for New Physics



We follow here the Rfit approach:

Theoretical uncertainties: constant likelihood

Addition of theoretical errors: "linear"

In this way, CL's can be obtained (dependent on the theoretical error range chosen)!

A. Höcker, H. L., S. Laplace, F. Le Diberder
EPJ C21 (2001) 225, [hep-ph/0104062]

Further reference: http://ckmfitter.in2p3.fr

Other approaches (not considered in this talk):

Bayesian approach (e.g. M. Ciuchini et al., JHEP 0107:013,2001)
Scan Method (BABAR Physics Book)
Likelihood fit (Schubert, Nogowski, CKM WS 2003)

See also: The CKM matrix and the unitarity triangle hep-ph/0304132

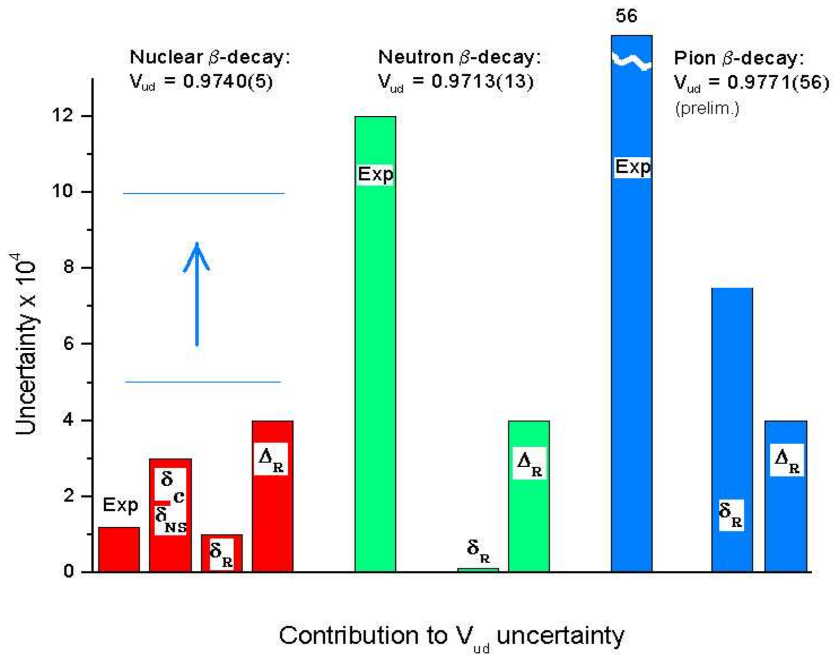
The Unitarity Problem in the first family: |V$_{ud}$|

1. Superallowed nuclear β-decays

$$ft(1-\delta_c)(1-\delta_R)=\frac{k}{2G_F^2|V_{ud}|^2(1+\Delta_R)}$$

|V$_{ud}$| = 0.9740 ± 0.0001 ± 0.0008(5)(10)?

(Towner and Hardy, 2003)



2. Neutron β-decay

$$\tau^{-1}=C|V_{ud}|^2 f^R(1+3\lambda^2)(1+\Delta_R)$$

|V$_{ud}$| = 0.9717 ± 0.0012 ± 0.0004

(PERKEO-II, 2003)

|V$_{ud}$| = 0.9725 ± 0.0012 ± 0.0004

(PDG, 2002)

3. Pion β-decay

$$|V_{ud}|^2=\frac{(K/\ln 2)BR(\pi\to\pi^0 e\nu_e)}{2G_F^2(1+\Delta_R)f_1 f_2 f(1+\delta_R)\tau_\pi}$$

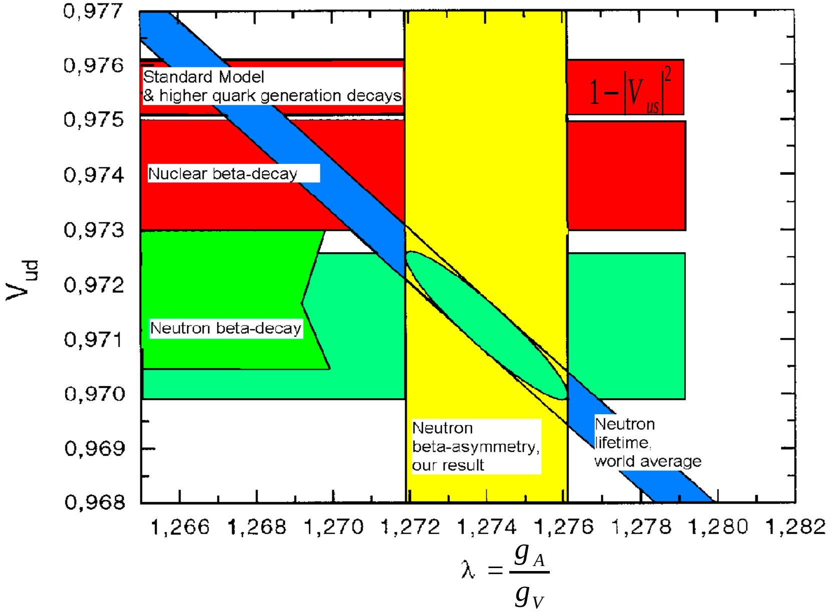
$BR(\pi^+\to\pi^0 e^+\nu)=(1.026\pm0.039)\times10^{-8}$ **(Macfarlane et al. 85)**

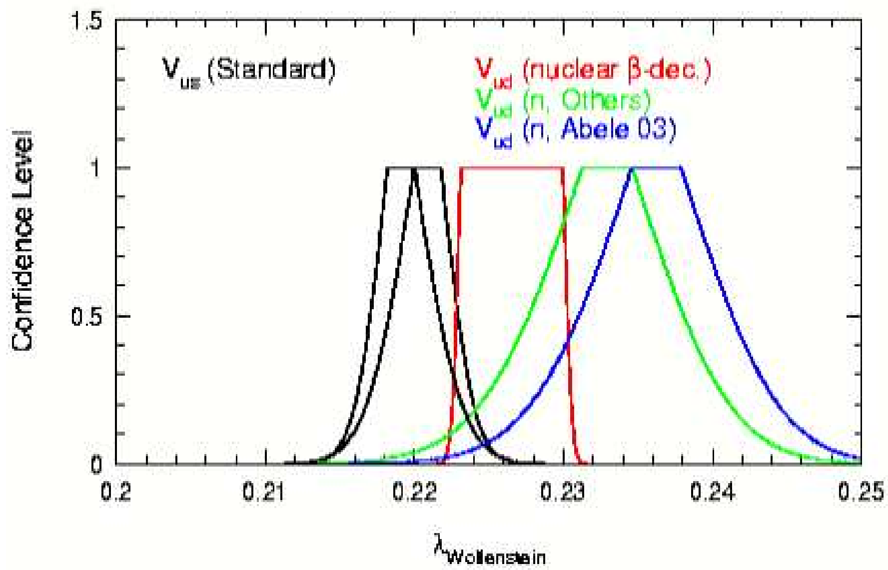
$BR(\pi^+\to\pi^0 e^+\nu)=(1.044\pm0.007_{stat}\pm0.009_{sys})\times10^{-8}$ **(PIBETA 2003 Preliminary)**

|V$_{ud}$| = 0.9765 ± 0.0055 ± 0.0005

The Unitarity Problem in the first family: $|V_{ud}|$

$$1-\Delta=|V_{ud}|^2+|V_{us}|^2+|V_{ub}|^2$$



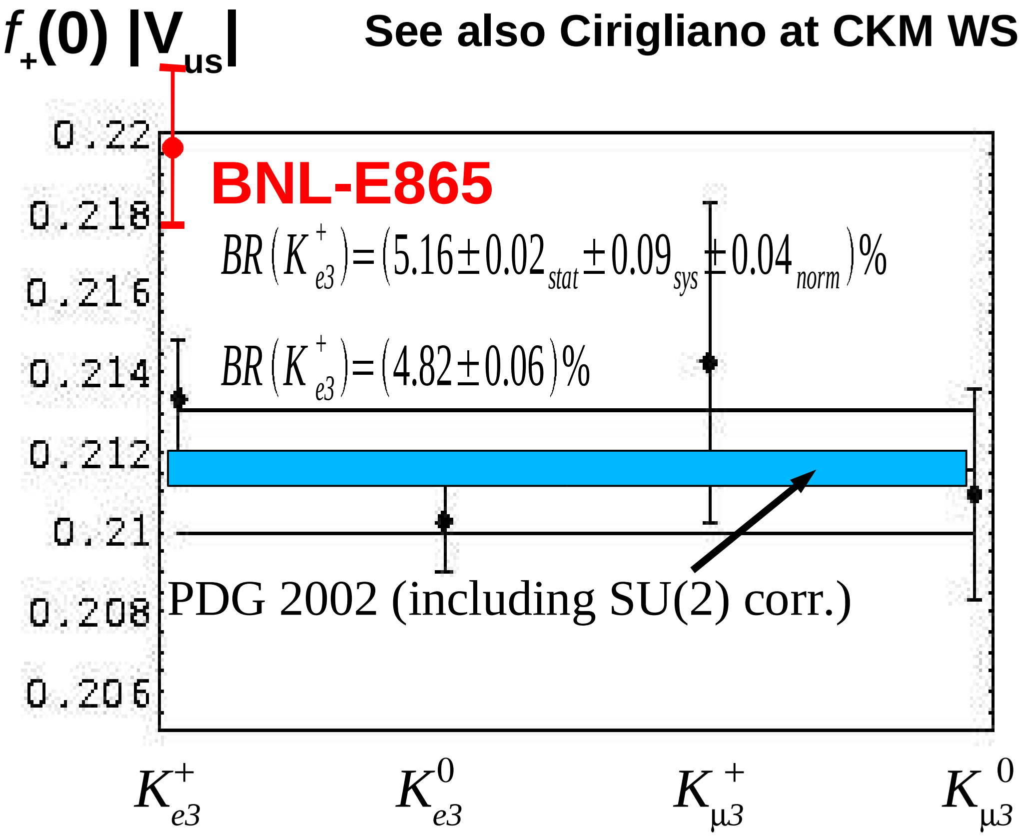


<u>How to quantify the deviation from the unitarity condition?</u>

$\lvert V_{us}\rvert$ \ $\lvert V_{ud}\rvert$	0.9717 ±0.0013	0.9717 ±0.00126 ±0.0004	0.9740 ±0.0005	0.9740 ±0.0001 ±0.0008
0.2201 ±0.0024	0.72 ±0.08 %	0.71 ±0.08 %	4.40 ±0.21 %	10.26 ± 0.30%
0.2201 ±0.0016 ±0.0018	0.60 ±0.08 %	1.07 ±0.10 %	4.31 ±0.20 %	23.37 ± 0.42%

The Unitarity Problem solved: $|V_{us}|$?

See also Cirigliano at CKM WS 2003

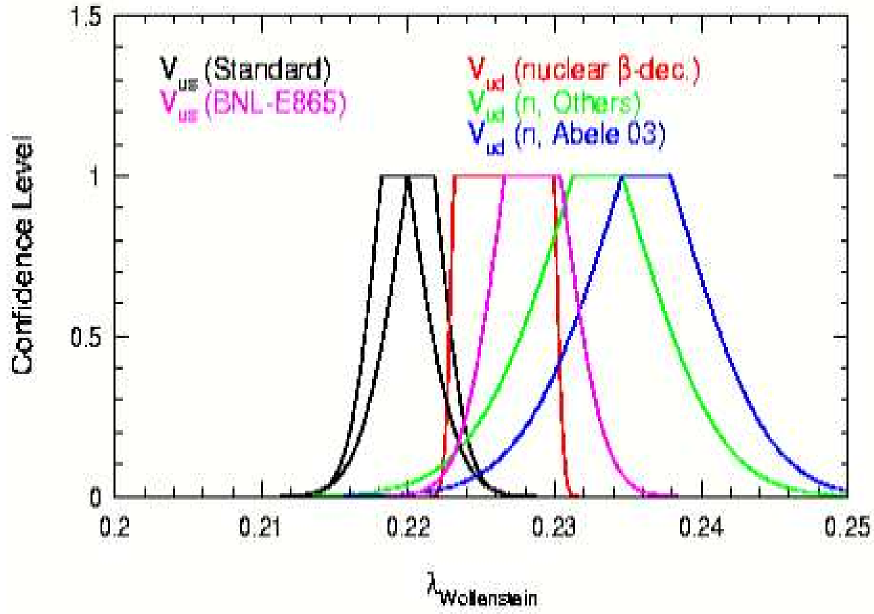


BNL-E865:

$$|V_{us}| = (0.2285 \pm 0.0023_{exp} \pm 0.0019_{theo,\,f_4})$$

Combined K_{l3} (PDG2002) & f_4 (Leutwyler-Roos):

$$|V_{us}| = (0.2201 \pm 0.0016_{exp} \pm 0.0018_{theo,\,f_4})$$



Deviation between BNL-E865 and $BR(K^+_{e3})(PDG2002)$: 2.9-σ

BNL-E865 correct => K^0_{e3}-BR's?

What to choose for $|V_{us}|$ now?

Possible solution: Wait for e.g. NA48 & KLOE and use a weighted mean with a rescaling factor:
$|V_{us}| = 0.2228 \pm 0.0039 \pm 0.0018$

The Standard CKM fit: Inputs

Note	Parameter	Value	Source
	$\|V_{ud}\|$	$0.9721 \pm 0.0009 \pm 0.0004$	neutron β decay (my average)
		$0.9740 \pm 0.0001 \pm 0.0008$	nuclear β decay (my proposal)
	$\|V_{us}\|$	$0.2228 \pm 0.0039 \pm 0.0018$	$K \to \pi l \nu$, my proposal
Not used for the global fit → Averaging Problem, see e.g. Ed Thorndike	$\|V_{ub}\|$	$(4.12 \pm 0.13 \pm 0.42) \times 10^{-3}$	Inclusive, my average
		$(3.17 \pm 0.17 \pm 0.17 \pm 0.03^{+0.53}_{-0.39}) \times 10^{-3}$	Exclusive ($\pi + \rho$), CLEO'03
		$(3.64 \pm 0.22 \pm 0.25^{+0.39}_{-0.56}) \times 10^{-3}$	Exclusive (ρ), BABAR'02
		$(3.11 \pm 0.13 \pm 0.24 \pm 0.61) \times 10^{-3}$	Exclusive (π, UKQCD), Belle'03
Z.Ligeti, N. Uraltsev, M. Calvi, M. Artuso	$\|V_{cb}\|$	$(42.6 \pm 1.1 \pm 2.1) \times 10^{-3}$	Exclusive: PDG 2003
		$(40.7 \pm 0.6 \pm 0.8) \times 10^{-3}$	Inclusive: HFAG, Winter 2003
	ε_K	$(2.271 \pm 0.017) \times 10^{-3}$	PDG 2002
	Δm_d	$(0.502 \pm 0.006)\ ps^{-1}$	HFAG, Winter 2003
V. Jain	Δm_s	Amplitude Spectrum	HFAG, Winter 2003
	$\sin 2\beta$	0.734 ± 0.055	HFAG, Winter 2003
	$m_t(\overline{MS})$	$(167 \pm 5)\ GeV/c^2$	CDF, D0, PDG 2002
	η_B	0.55 ± 0.01	
D. Becirevic, C. Davies, A. Le Yaouanc	$f_{Bd}\sqrt{B_d}$	$(223 \pm 33 \pm 12)\ MeV$	ICHEP 2002, L. Lellouch
	ξ	$1.24 \pm 0.04 \pm 0.06$	ICHEP 2002, L. Lellouch
	B_K	$0.86 \pm 0.06 \pm 0.14$	ICHEP 2002, L. Lellouch
	m_c	1.2 ± 0.2	PDG 2002
	η_{cc}	1.46 ± 0.41	CKM WS 2002, U. Nierste
	η_{ct}	0.47 ± 0.04	CKM WS 2002, U. Nierste
	η_{tt}	0.5765 ± 0.0065	CKM WS 2002, U. Nierste

Metrology: the Unitarity Triangle (w/o $|V_{ub}|$!!!)

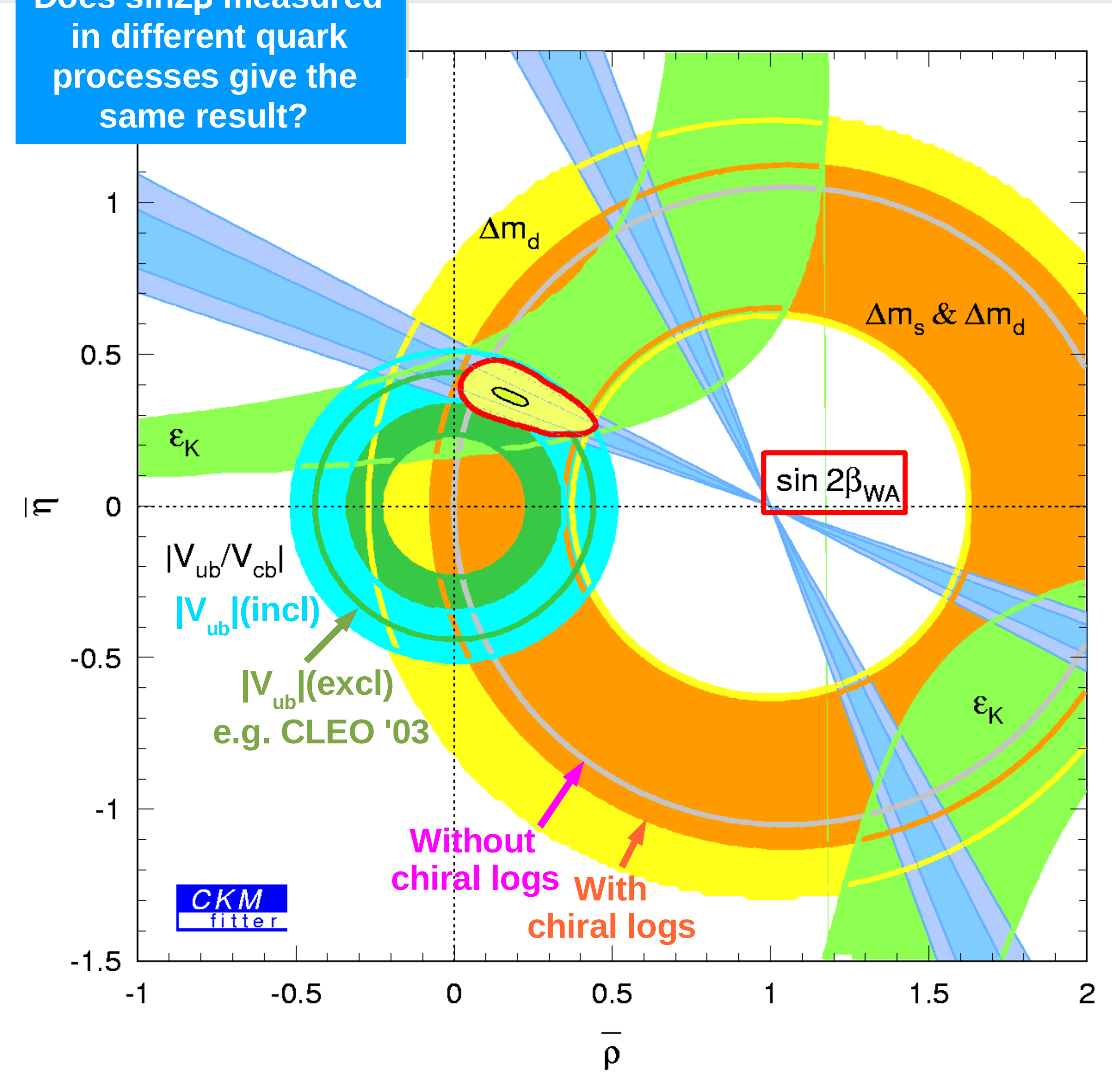
Sin2β: most precise and robust constraint

Which one is the correct ambiguity?

Additional constraints and constraints on α and γ ?

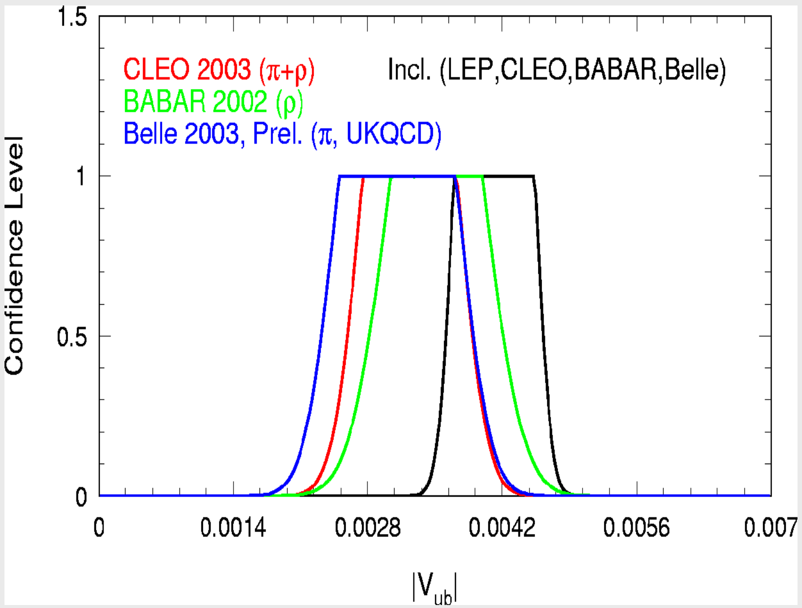
Does sin2β measured in different quark processes give the same result?

Constraints in global fit:
$\sin 2\beta$, Δm_d & Δm_s, ε_K
$|V_{ub}|$ overlaid



Which constraints can be improved?
Good prospects: $|V_{ub}|$ & $|V_{cb}|$

How to combine the different results for $|V_{ub}|$ (Excl.)?
Comparing Apples with Pies!



Inclusive and exclusive results consistent?

Selected Numerical Results (|V_{ub}| not in the fit!)

CKM and UT Parameters

Parameter	95% CL region
λ	0.2288 ± 0.0058
A	0.73 - 0.84
ρ	0.04 - 0.42
η	0.24 - 0.46
J	$(2.2 – 4.0) \times 10^{-5}$
$\sin(2\alpha)$	-0.95 - 0.54
$\sin(2\beta)$	0.62 - 0.84
α	73º – 125º
β	19.2º – 28.7º
γ	32º – 83º

Rare Branching Fractions

Observable	95% CL region
$BR(K_L \to \pi^0 \nu\nu)$	$(1.4 – 5.9) \times 10^{-11}$
$BR(K^+ \to \pi^+ \nu\nu)$	$(2.6 – 9.3) \times 10^{-11}$
$BR(B^+ \to \tau^+ \nu)$	$(6.2 – 31.5) \times 10^{-5}$
$BR(B^+ \to \mu^+ \nu)$	$(2.4 – 12.3) \times 10^{-7}$

Theory Parameters(*)

Observable	95% CL region (limit)
m_t	> 95 GeV/c^2
$f_{Bd}\sqrt{B_d}$	> 180 MeV
B_K	0.46 – 1.62

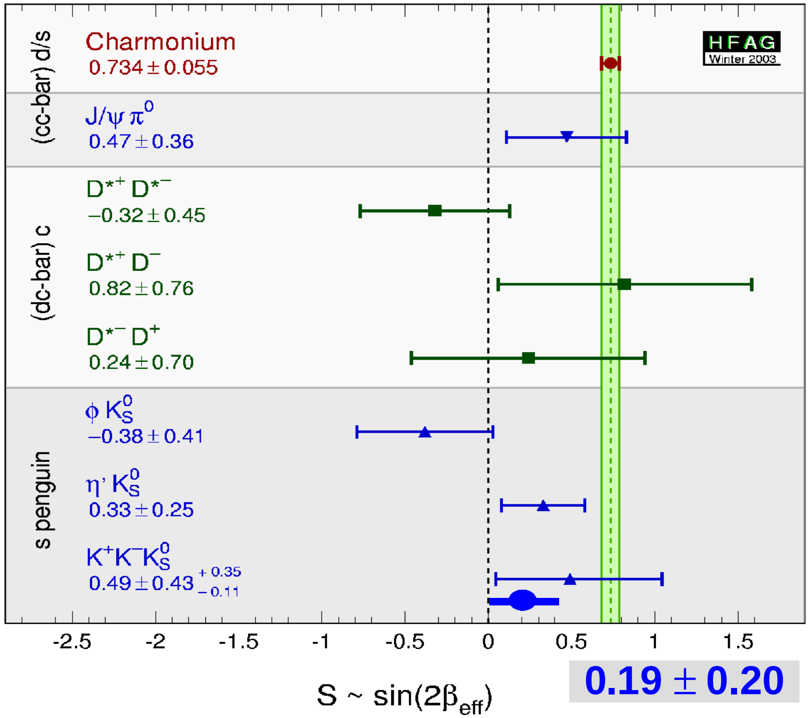
(*) Without using a priori information

Observable	95% CL region
$\|V_{ub}\|$	$(3.2 – 4.9) \times 10^{-3}$
Δm_s	$(15 – 41)\ ps^{-1}$

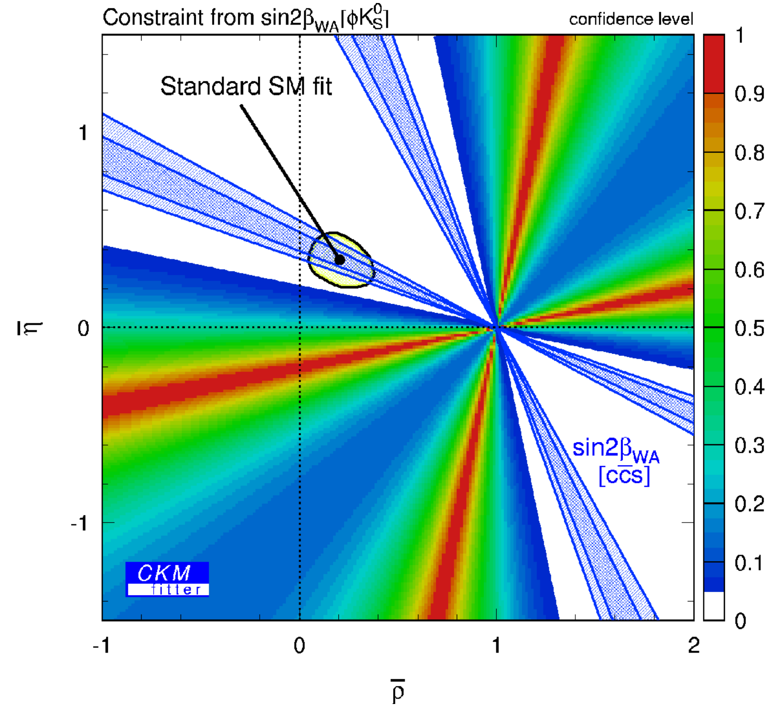
p-value (SM): 11%

→ $|V_{ud}|$ & $|V_{us}|$

Time dependent CP asymmetries in $b \rightarrow s s \bar{s}$



0.19 ± 0.20

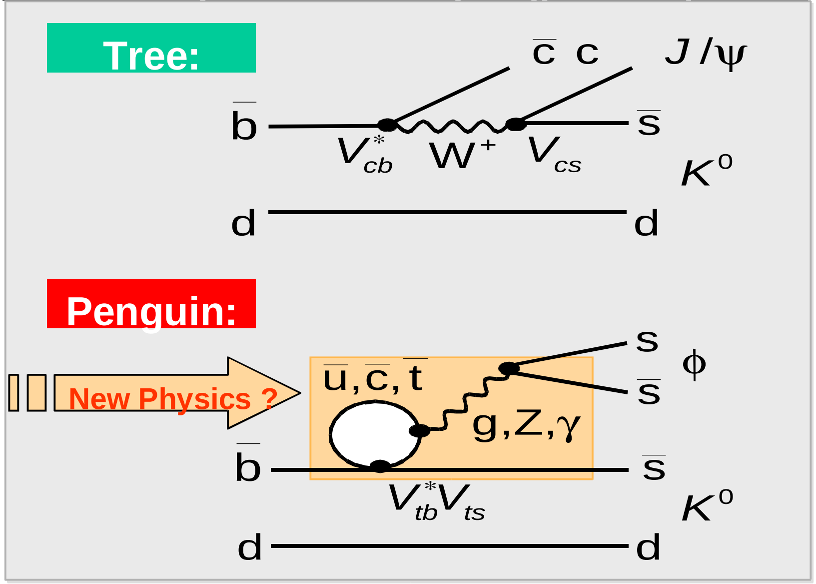


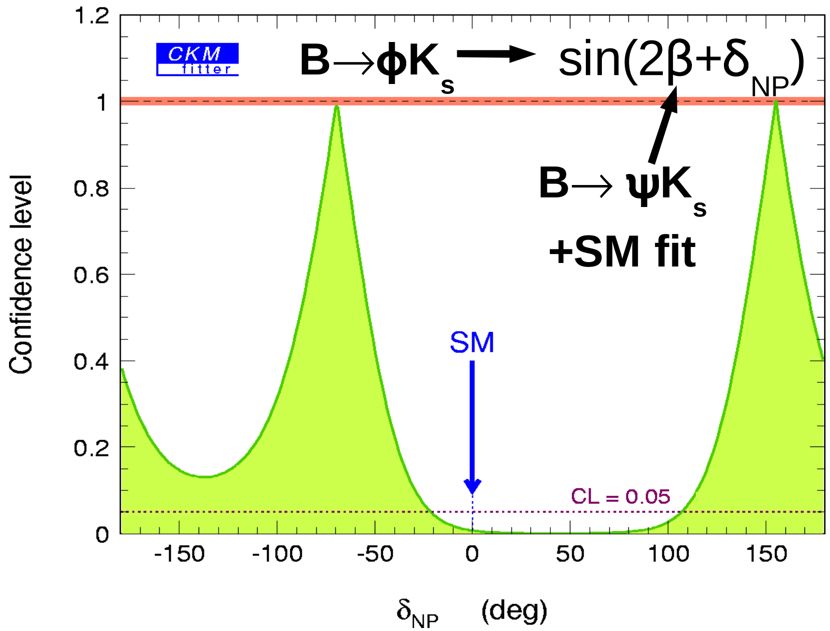
Exciting effect ?

CAVEAT!

Statistics can be mean!

Both decays dominated by single weak phase

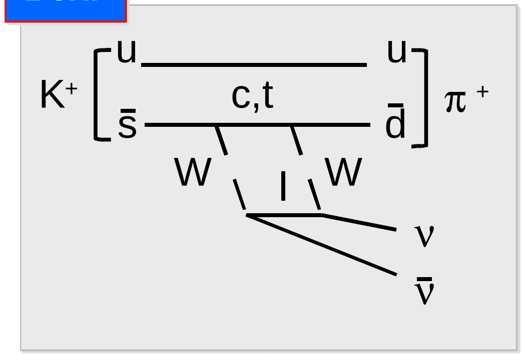




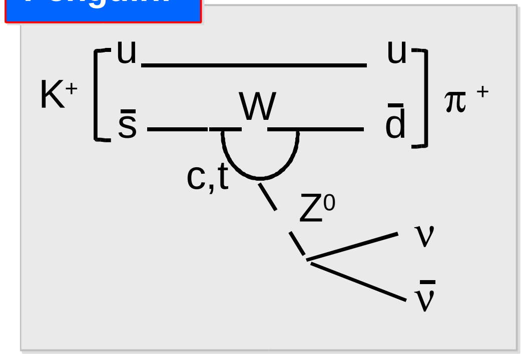
See also talks by Bill Ford and Gudrun Hiller

Constraint from Rare Kaon Decays: $K^+ \rightarrow \pi^+ \nu\bar{\nu}$

Box:



Penguin:



Buchalla, Buras, Nucl.Phys. B548 (1999) 309

You again?

$$BR\left(K^+ \rightarrow \pi^+ \nu\bar{\nu}\right) \propto \frac{BR\left(K^+ \rightarrow \pi^0 e^+ \nu\right)}{|V_{us}|^2} \sum_{l=e,\mu,\tau} \left| V_{cs}^* V_{cd} X_{NL}^l + V_{ts}^* V_{td} X(x_t) \right|^2$$

top contribution *charm contribution*

$$BR\left(K^+ \rightarrow \pi^+ \nu\bar{\nu}\right) \propto \lambda^8 A^4 X^2(x_t) \frac{1}{\sigma} \left[(\sigma\bar{\eta})^2 + (\rho_0 - \bar{\rho})^2 \right]$$

ellipse

Main theoretical uncertainty:
Charm contribution (m_c, scale dependence)

Parametric uncertainties: $|V_{cb}|$, m_t (=> Tevatron)

Experiment:

Two events observed at BNL (E787), yielding:

$$B\left(K^+ \rightarrow \pi^+ \nu\bar{\nu}\right) = \left(1.57\,^{+1.75}_{-0.82}\right) \times 10^{-10}$$

E787 (BNL-68713)
PRL 88:041803, 2002

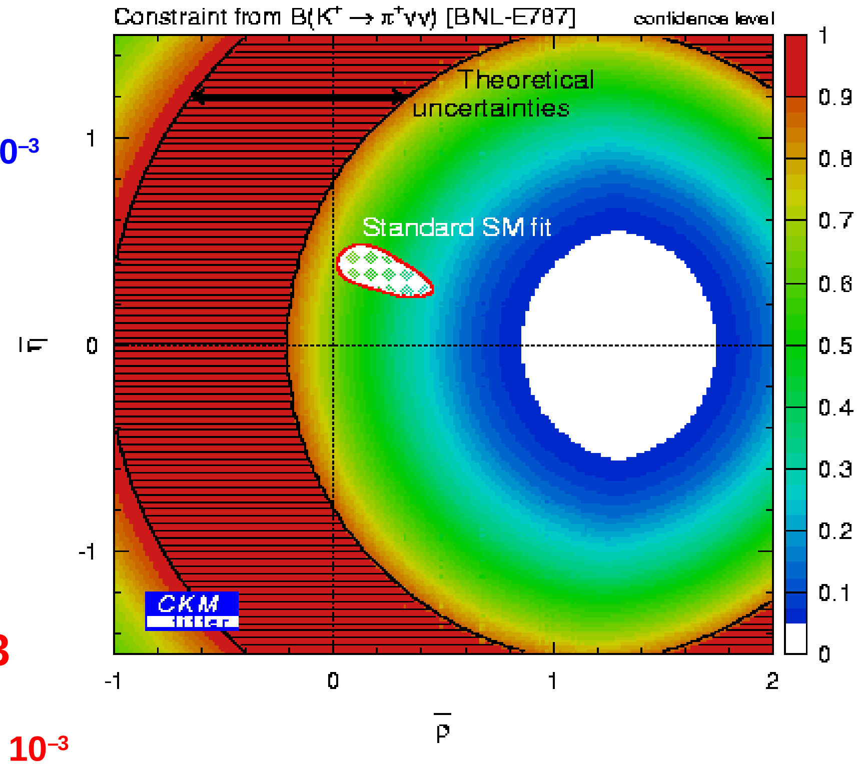
Constraint from Rare Kaon Decays: $K^+ \to \pi^+ \nu\bar{\nu}$

At present dominated by experimental uncertainties.

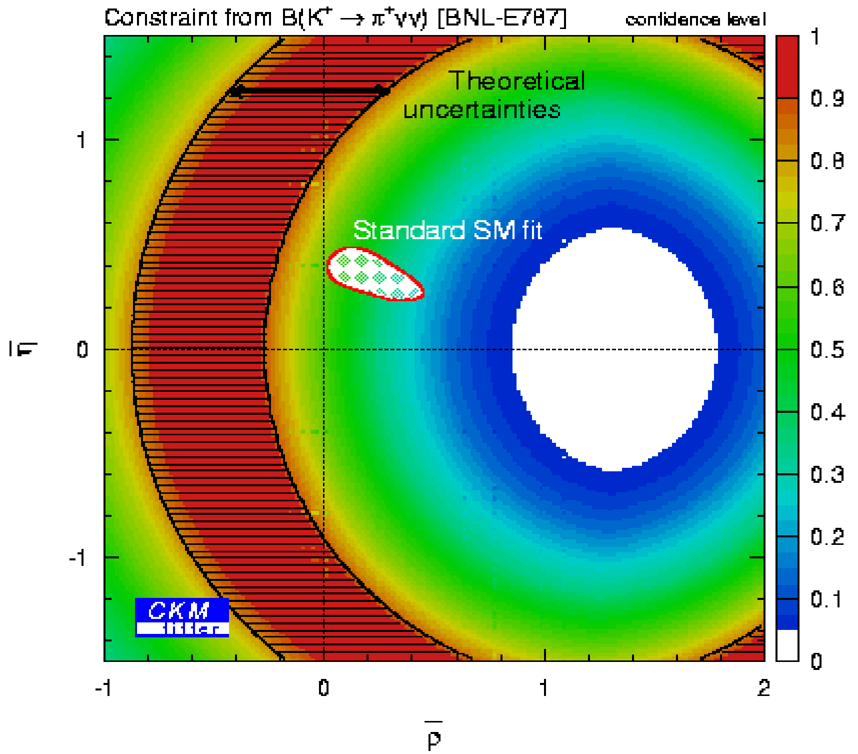
Uncertainties on $|V_{cb}|^4 = \lambda^8 A^4$ are important for constraints in the ρ-η plane ! (For $K_L \to \pi^0 \nu\bar{\nu}$ as well!)

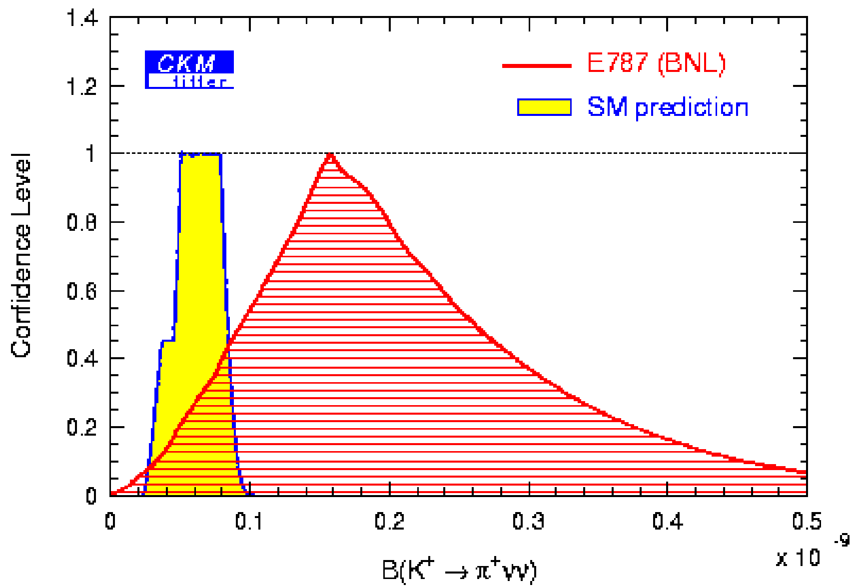
Improvement during the last year!

Spring'02
$|V_{cb}|$
$(40.7 \pm 0.5 \pm 2.0)\ 10^{-3}$



Spring'03
$|V_{cb}|$
$(40.7 \pm 0.6 \pm 0.8)\ 10^{-3}$





Talks on rare Kaon decays:
Marco Sozzi, KTeV
Guido Martinelli

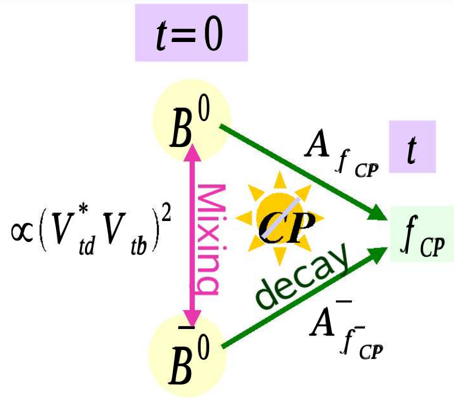
CP Violation in $B^0 \to \pi^+\pi^-$ Decays

$$\lambda_{f_{CP}} = \eta_{f_{CP}} \frac{q}{p} \frac{\bar{A}_{\bar{f}_{CP}}}{A_{f_{CP}}}$$

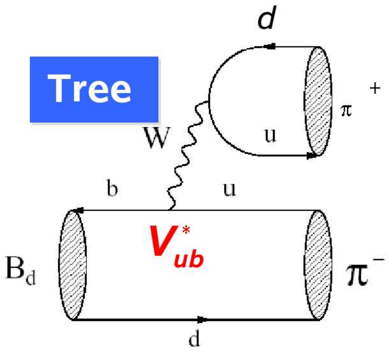
$$A_{f_{CP}}(t) \propto S_{f_{CP}} \sin(\Delta m_d t) - C_{f_{CP}} \cos(\Delta m_d t)$$

$$C_{f_{CP}} = \frac{1 - |\lambda_{f_{CP}}|^2}{1 + |\lambda_{f_{CP}}|^2}$$

$$S_{f_{CP}} = \frac{2\,\mathrm{Im}\lambda_{f_{CP}}}{1 + |\lambda_{f_{CP}}|^2}$$

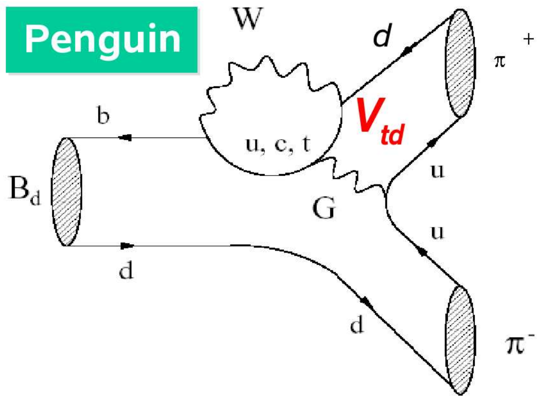


	BABAR	Belle
$S_{\pi\pi}$	$+0.02 \pm 0.34$	-1.23 ± 0.42
$C_{\pi\pi}$	-0.30 ± 0.25	-0.77 ± 0.28
ρ	-0.10	0.024



$$A(B^0 \to \pi^+\pi^-) = R_u e^{i\gamma} T_{\pi\pi} + R_c P_{\pi\pi}$$

$$\lambda_{\pi\pi} = e^{-2i\beta} \frac{e^{-i\gamma} + (R_c/R_u)(P_{\pi\pi}/T_{\pi\pi})}{e^{i\gamma} + (R_c/R_u)(P_{\pi\pi}/T_{\pi\pi})}$$



For a single weak phase (tree):

$$\lambda = \frac{q}{p}\frac{\bar{A}_{\bar{f}}}{A_f} = \eta_f e^{-2i(\beta+\gamma)} = \eta_f e^{2i\alpha}$$

$C_{\pi\pi} = 0$, $S_{\pi\pi} = \sin(2\alpha)$

For additional phases:

$|\lambda| \neq 1 \Rightarrow$ must fit for direct *CP*

$\mathrm{Im}(\lambda) \neq \sin(2\alpha) \Rightarrow$ need to know $|P_{\pi\pi}/T_{\pi\pi}|$, $\delta = \arg(P_{\pi\pi}/T_{\pi\pi})$

$C_{\pi\pi} \neq 0$, $S_{\pi\pi} \sim \sin(2\alpha_{eff})$

Numerical analysis within different theoretical frameworks (far from complete)

1. Isospin symmetry SU(2) (GL)

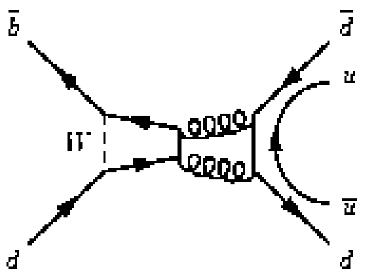
$$\frac{A^{+-}}{\sqrt{2}} + A^{00} = A^{+0}$$

EW-Penguins neglected

CP-averaged BR($B\to\pi\pi$) only
$B\to\pi^0\pi^0$ not seen yet
=> Bounds (GQ, Ch, GLSS)

2. Flavor symmetry SU(3) (SW)

a) $|P_{\pi\pi}| = |P_{K0K0}|$ (BF,Ch)
EW-Penguins neglected
b) $|P_{\pi\pi}| = |P_{K\pi}|$ (Ch)
OZI-suppressed Annihilation-Penguins neglected
No correction for SU(3) breaking



3. $|P_{\pi\pi}|$ from $B\to K^0\pi$ (FM, Ch, GR)

SU(3) + no EW-Penguins => $|P_{K0\pi}|=|P_{K\pi}|$
No $|V_{us}V_{ub}^*|$ contribution => $|P_{K0\pi}|=|A(B\to K^0\pi)|$

Here we use: $$|P_{\pi\pi}| \approx \sqrt{\frac{\tau_0}{\tau_+}}\frac{f_\pi}{f_K}\frac{1}{R_{th}}|P_{K^0\pi}|$$ **(HLPR)**

taken from GR **taken from BBNS**

GL: Gronau, London, Phys.Rev.LettD65:3381,1990
GQ: Grossman, Quinn, Phys.Rev.D58, (1998) 017504
Ch: Charles, Phys.Rev.D59:054007,1999
GLSS: Gronau, London, Sinha, Sinha, Phys.Lett.B514 (2001) 315
SW: Silva, Wolfenstein, Phys.Rev.D49(1994) 1151
BF: Buras,Fleischer, **Phys.Lett.B360**:138,1995
FM: Fleischer, Mannel, Phys.Lett. B397(1997)269
GR: Gronau, Rosner, Phys.Rev.D65:013004,2002+other papers
BBNS: Beneke et al., Nucl.Phys.B606:245-321,2001
HLPR: Höcker, Lacker, Pivk, Roos, LAL-02-103

See also talk by Michael Gronau

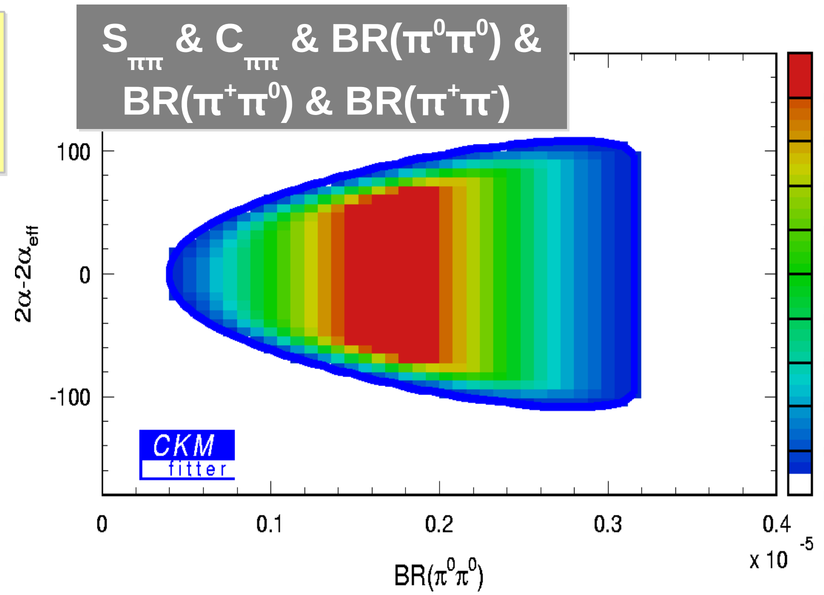
$\sin(2\alpha_{eff})$ & SU(2) symmetry

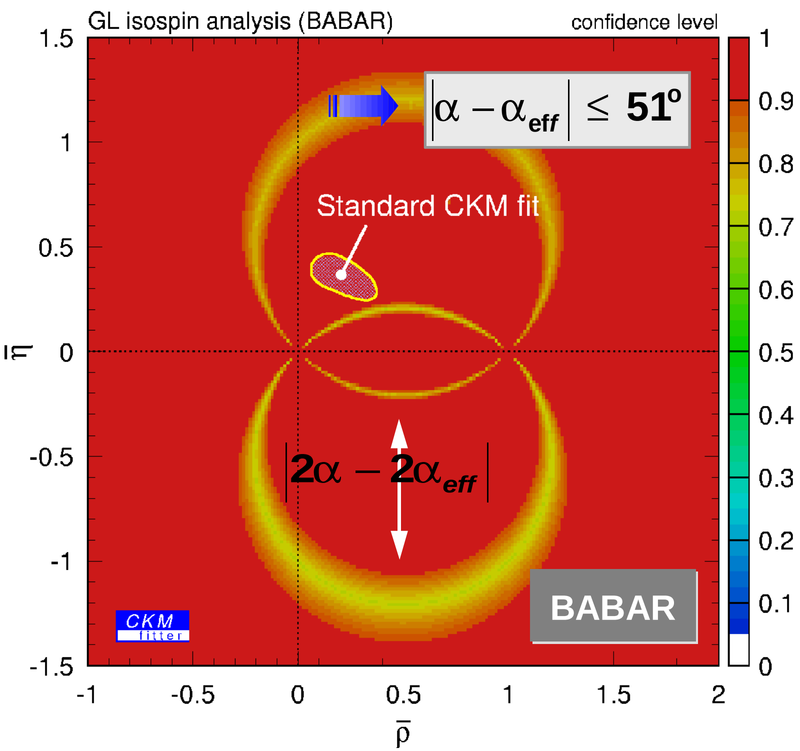
Using the BR's : $\pi^+\pi^-$, $\pi^\pm\pi^0$, $\pi^0\pi^0$ (limit)

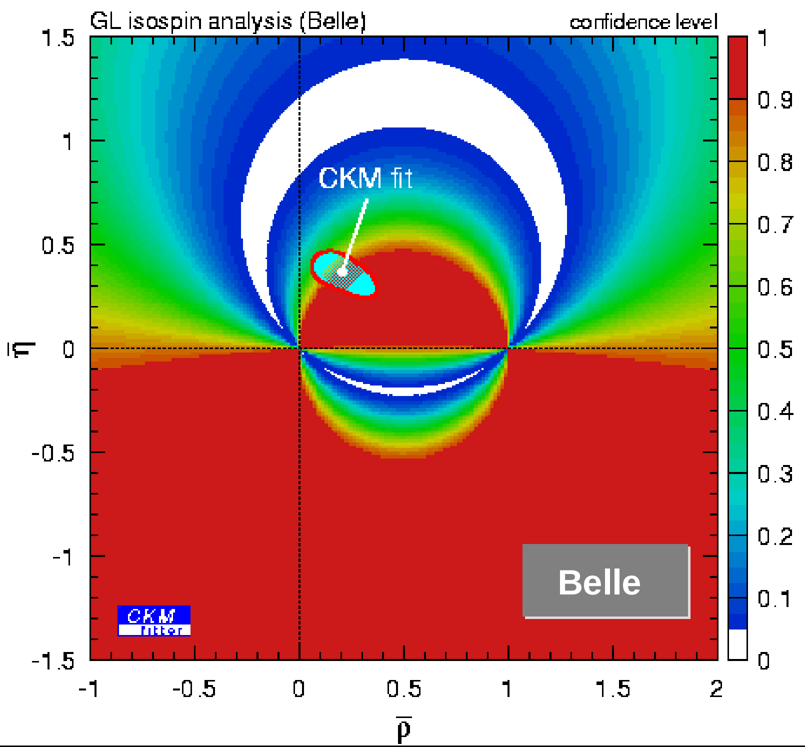
and CP asymmetries : $A_{CP}(\pi^\pm\pi^0)$, $S_{\pi\pi}$, $C_{\pi\pi}$

$$\cos(2\alpha - 2\alpha_{eff}) \geq \frac{1 - 2B^{00}/B^{+0}}{\sqrt{1 - C_{\pi\pi}^2}}$$

Grossman-Quinn 98; Charles 99;
Gronau-London-Sinha-Sinha 01

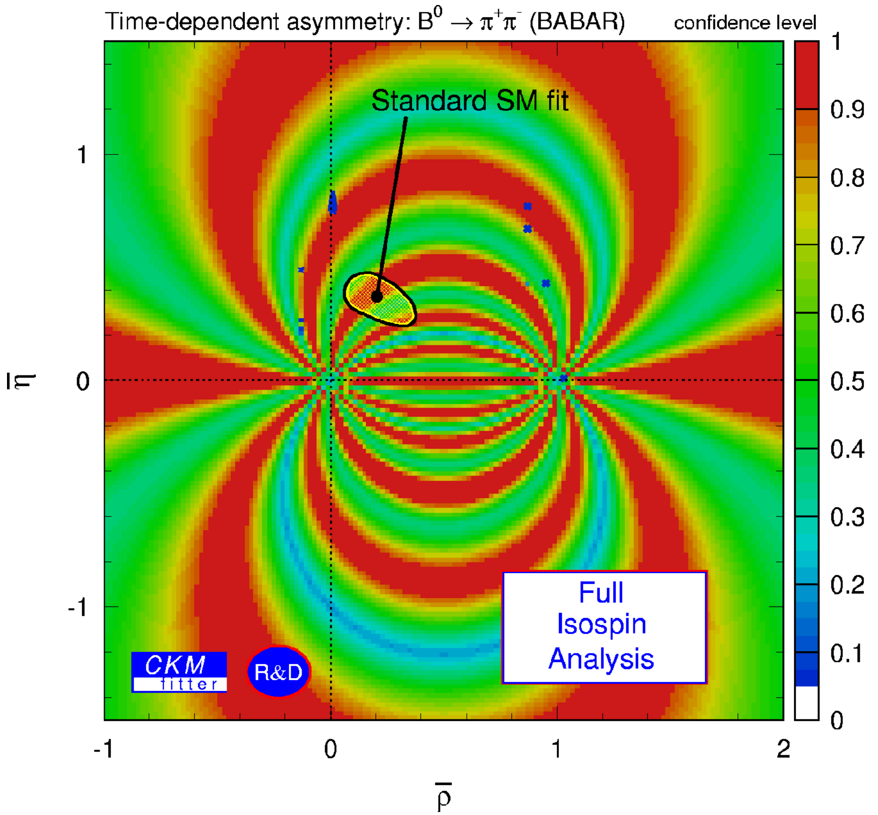




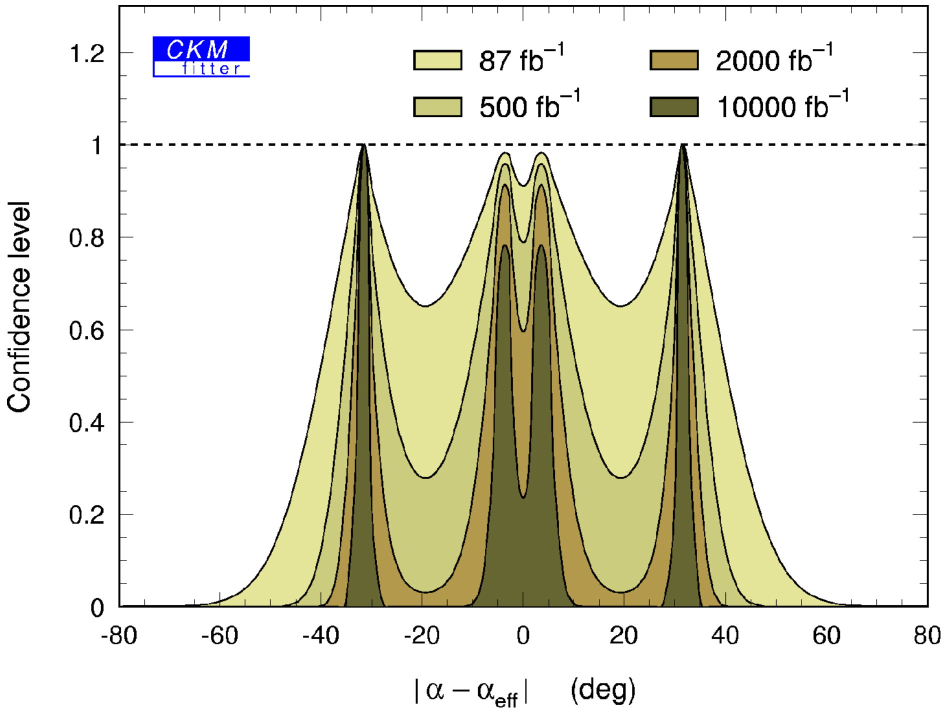


How about More Statistics?

Isospin analysis for present central values, but 500 fb^{-1}



And even more...



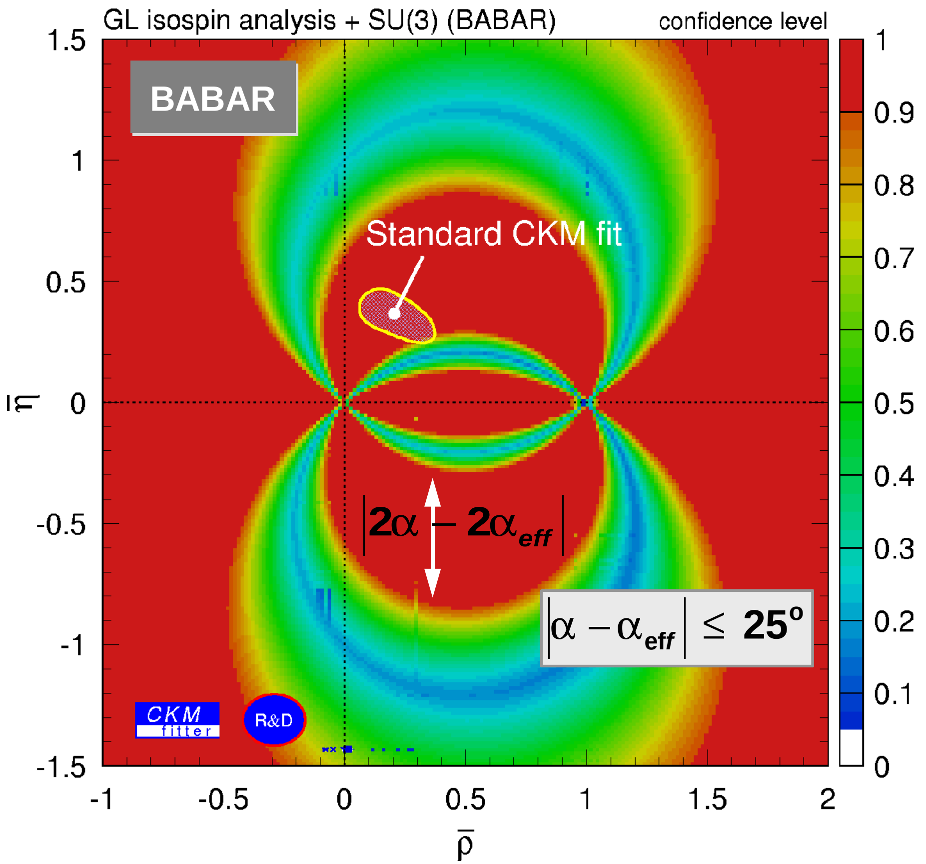
If central value of BR($\pi^0\pi^0$) stays large, full isospin analysis is impossible for first generation B factories

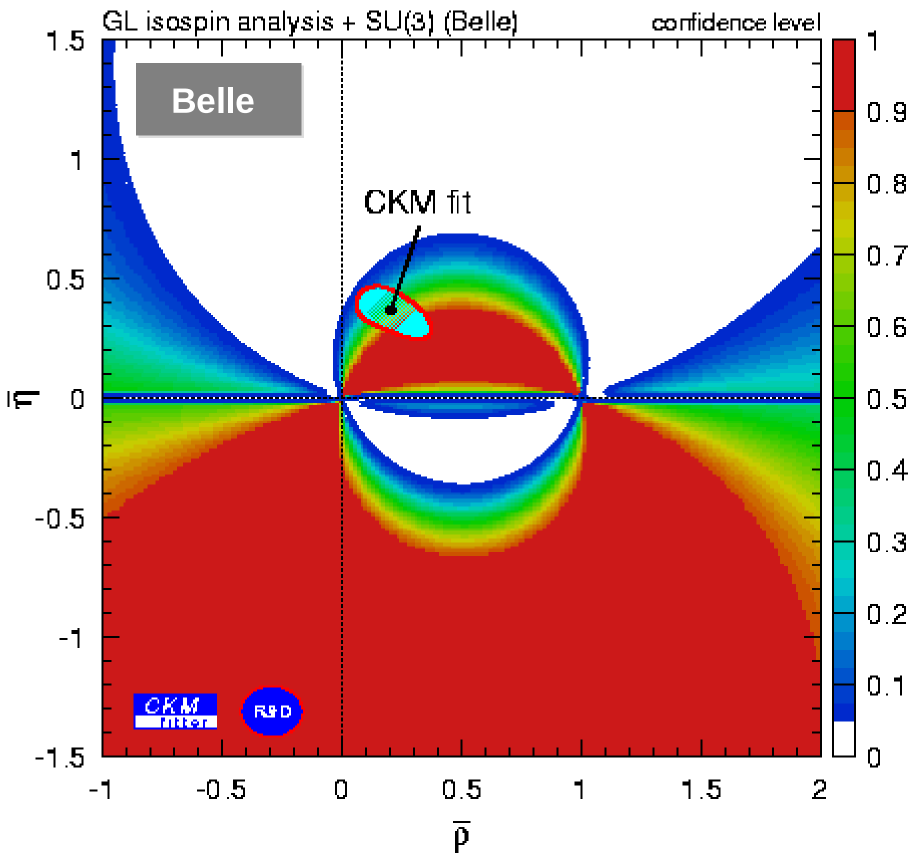
We might be lucky: Compensation between $C_{\pi\pi}$ and 1-2B^{00}/B^{+0}?

$\sin(2\alpha_{eff})$ & SU(3): $|P_{\pi+\pi-}| = |P_{K+\pi-}|$

Using in addition the BR: $K^+\pi^-$

$$\cos(2\alpha - 2\alpha_{eff}) \geq \frac{1 - 2\lambda^2 B_{K\pi}^{+-} / B^{+-}}{\sqrt{1 - C_{\pi\pi}^2}}$$



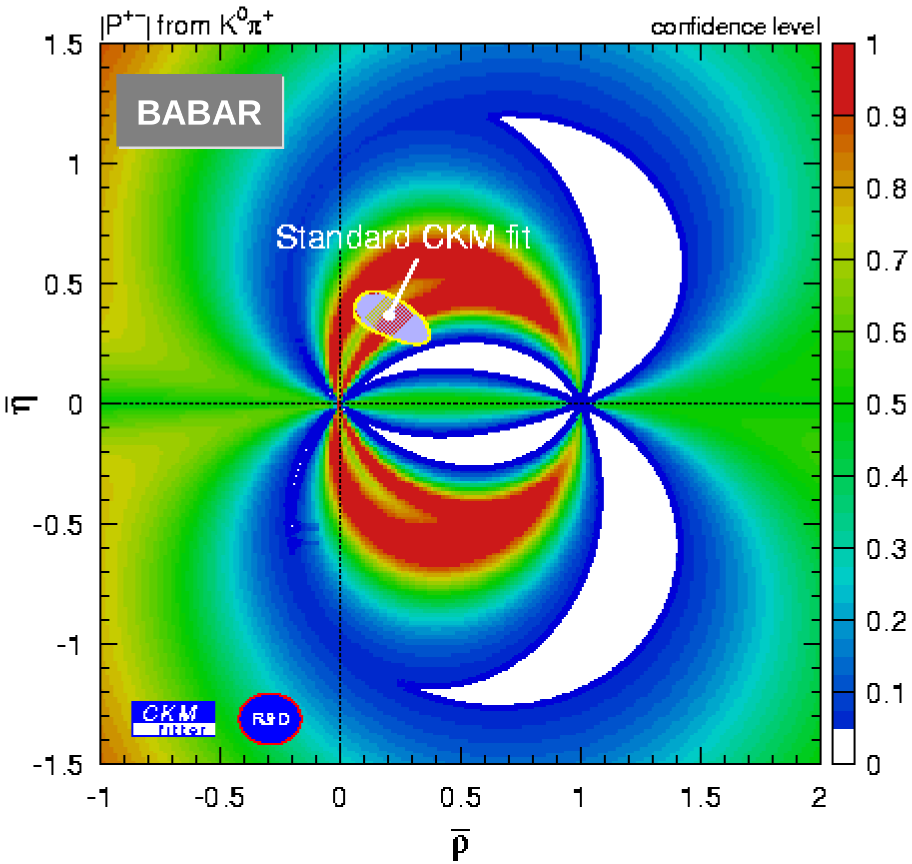


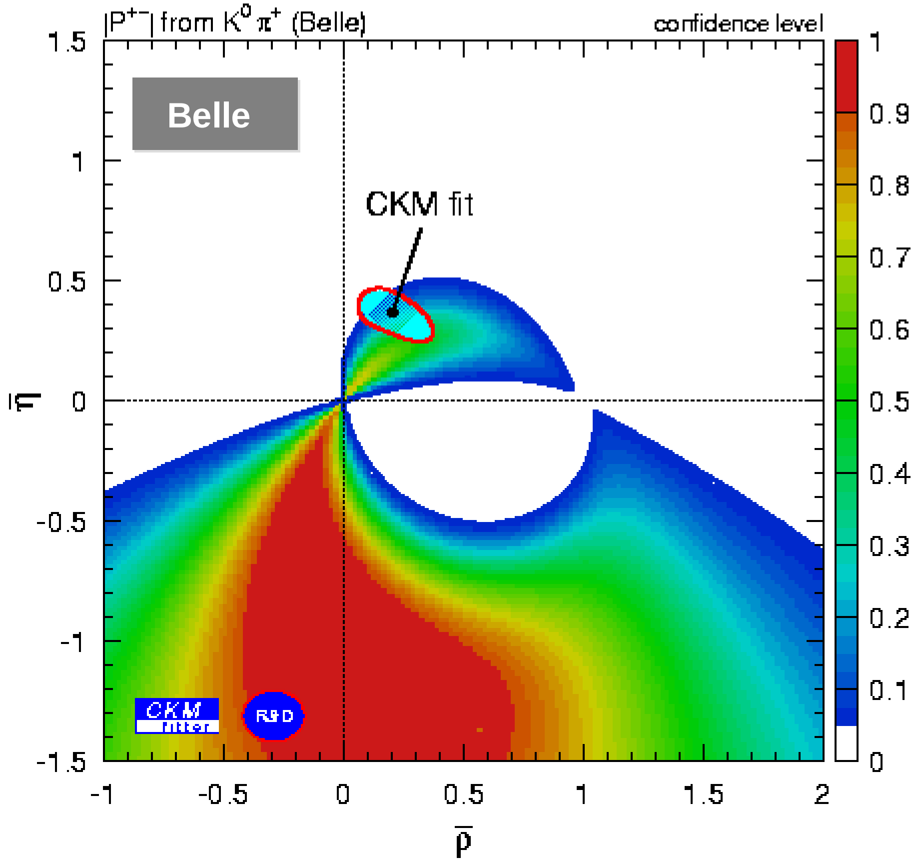
No significant constraints. However:
$C_{\pi\pi} \approx 0.75$ => dramatic improvement

$\sin(2\alpha_{eff})$ & SU(3): $|P_{\pi+\pi-}|$ from $B^{\pm} \to K^0\pi^{\pm}$

Using in addition the BR: $K^0\pi^{\pm}$

$$|P_{\pi\pi}| = \sqrt{\frac{\tau_0}{\tau_+}}\frac{f_\pi}{f_K}\frac{1}{R_{th}}|P_{K^0\pi}|$$

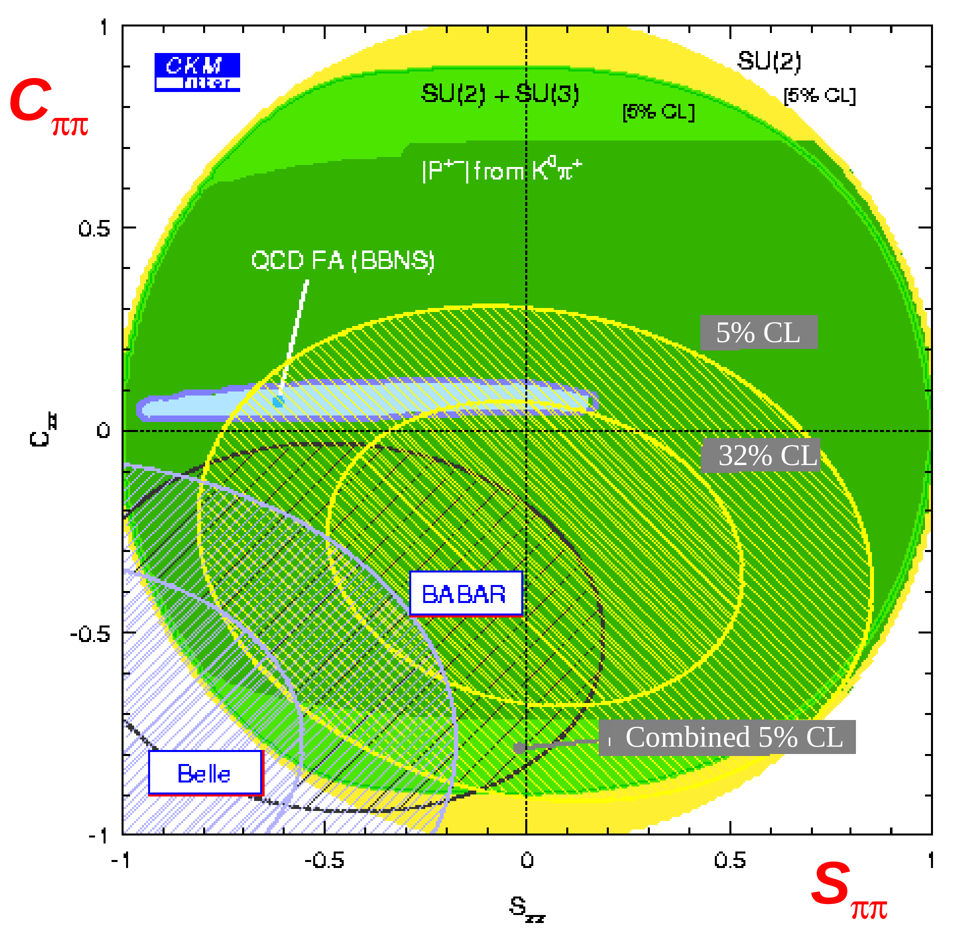




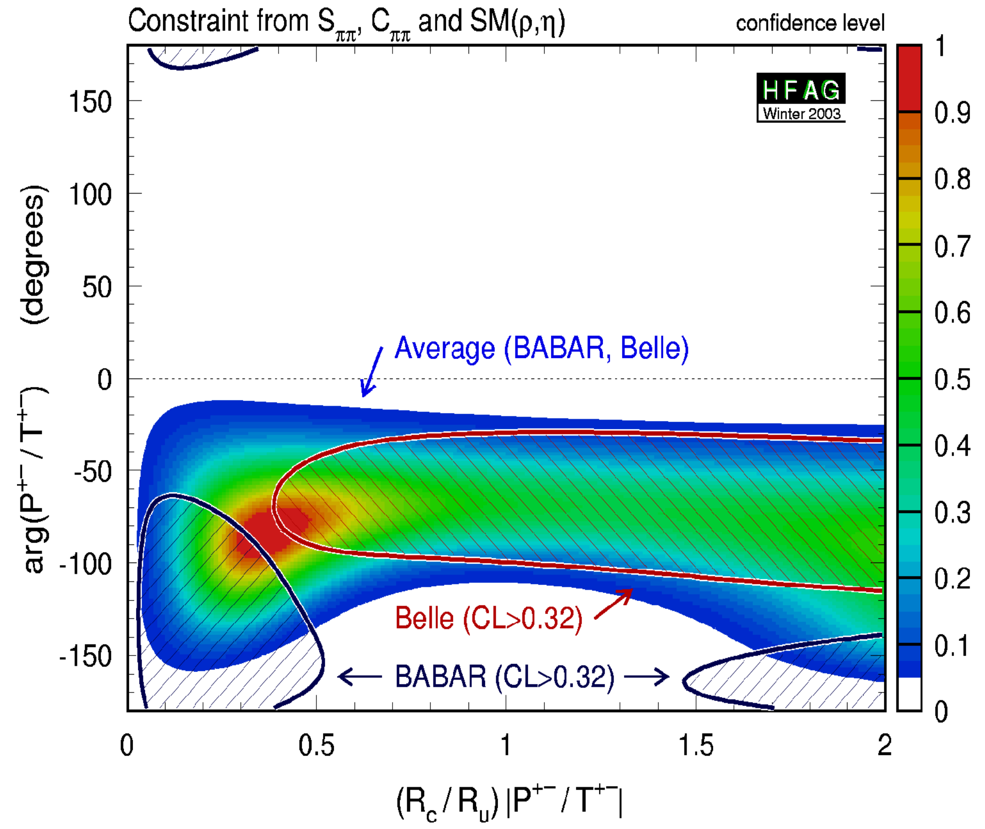
Constraint significantly improved.
However, uncertainties still too large!

Experimental Observables & Theoretical Unkowns

·Prediction of $S_{\pi\pi}$ and $C_{\pi\pi}$ within different frameworks if the CKM phase is constrained by the global CKM fit:



·What are the constraints on |P/T| and δ if the CKM phase is constrained by the global CKM fit:



$K^+ \to \pi^+ \nu\nu$

α from $B^0 \to \rho\pi$: SU(3) constraints

J. Charles, LPT-Orsay99-31: SU(3) & neglect OZI-suppressed annihilation penguins
A. Höcker, M.Laget, S. Laplace, J. von Wimmersperg-Toeller, LAL-03-17

$$\cos(2\alpha - 2\alpha_{eff}^{+-}) = 1 - 2\lambda^2 \frac{BR_{K^*\pi}^{+-}}{BR_{\rho\pi}^{+-}}$$

$$\rightarrow |\alpha - 2\alpha_{eff}^{+-}| < 18.8\ deg.$$

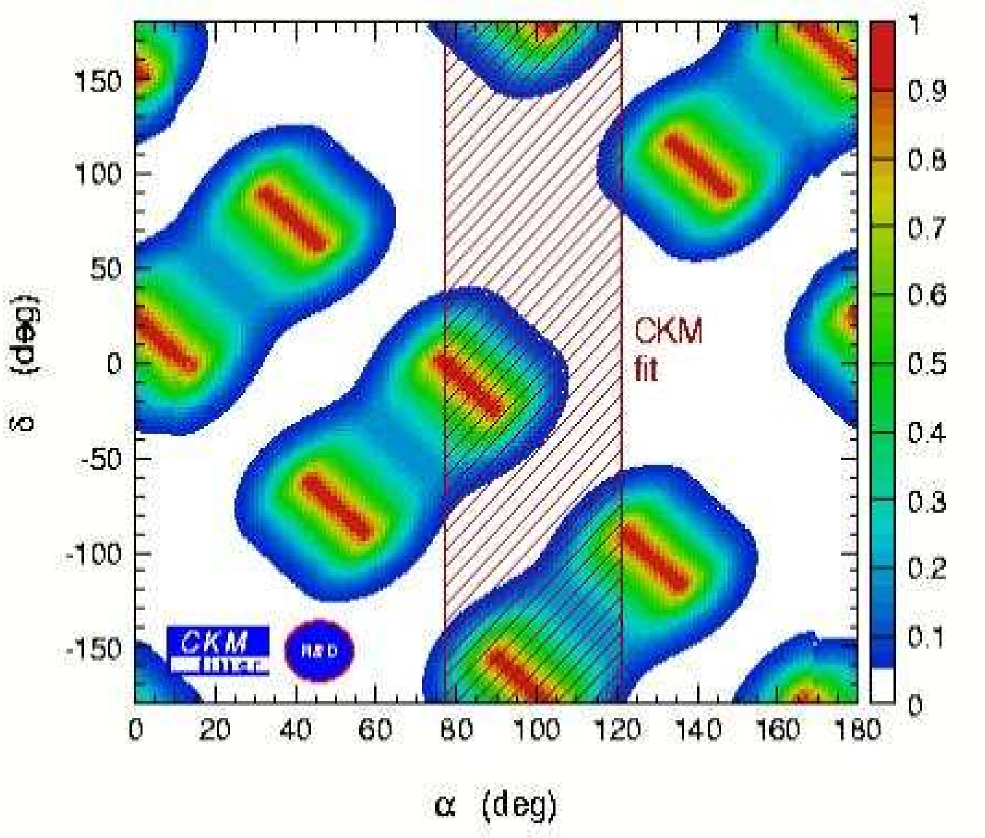
$$\cos(2\alpha - 2\alpha_{eff}^{-+}) = 1 - 2\lambda^2 \frac{BR_{\rho K}^{-+}}{BR_{\rho\pi}^{-+}}$$

$$\rightarrow |\alpha - 2\alpha_{eff}^{-+}| < 13.9\ deg.$$

$$\delta = arg(A^{-+} A^{+-*})$$

If δ were measured in a Dalitz-analysis there would an interesting constraints on α even with the present statistics !!!

From the five CP-observables measured by BABAR one infers:



Some Concluding Remarks

1) Unitarity problem: "What actually is a theoretical error?"
   - $|V_{ud}|$: Unitarity problem again on the table! (H. Abele, CKM WS 2003)
   - $|V_{us}|$: Does BNL-E865 solve the problem? (NA48, KLOE,τ-decays(Jamin))

2) We definitely do need (expert's) averages for $|V_{ub}|$! => HFAG !

3) Moment measurements are of great importance ! ($|V_{cb}|$, $|V_{ub}|$, OPE)

4) We are suffering from large theoretical errors !
   - Is there any hope to improve B_K?
   - What about the chiral logs ?

5) We are eagerly awaiting larger statistics for "sin2β"(ϕK_s) !

6) The quest for α has just started. The penguin is (by far) not tamed (yet) !
   - $BR(\pi^0\pi^0) \approx O(2*10^{-6})$? (=> Isospin analysis?)
   - $C_{\pi\pi}$ small or large ? (=> Factorisation, SU(2)&SU(3) bounds)
   - $BR(B \rightarrow K^0 \bar{K}^0) < 1.6*10^{-6}$ (M.Bona) => $|\alpha-\alpha_{eff}| < 35^\circ$ (SU(3), Buras & Fleischer, Charles)
   - Interesting constraints on α in $B \rightarrow \rho\pi$ using SU(3) and neglecting OZI-suppressed annihilation penguins once δ has been measured in the Dalitz-analysis !

Many thanks to:

CKMfitter: J. Charles, A. Höcker, S. Laplace, F. Le Diberder, J. Ocariz, M. Pivk, L. Roos

In addition: U. Langenegger, Z. Ligeti, K. Schubert, L. Wilden

Last but not least: The contributors to the CKM workshops 2002/03 and the HFAG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