Rare Charmless Decays and Measurements of α and β in Penguins

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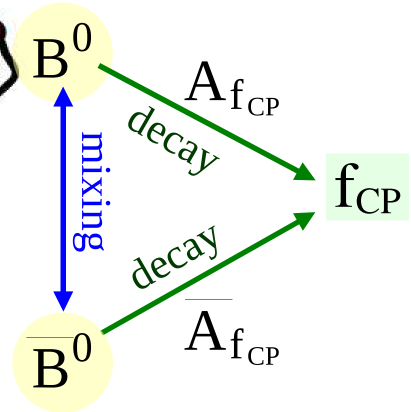
on behalf of *BABAR* Collaboration

Time dependent CP asymmetry



$$\lambda_{f_{CP}} = \frac{q}{p} \cdot \frac{\overline{A}_{f_{CP}}}{A_{f_{CP}}} = |\lambda_{f_{CP}}| \cdot e^{-2i\phi_{CP}}$$

mixing *decay*

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

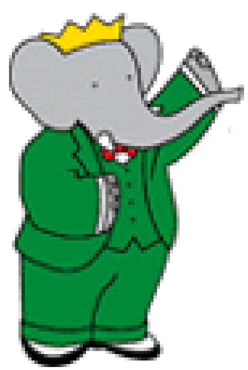
$$C_{f_{CP}} = \frac{1-|\lambda_{f_{CP}}|^2}{1+|\lambda_{f_{CP}}|^2}$$

$$A_{f_{CP}} = \frac{\Gamma(\overline{B}^0_{phys}(t)\rightarrow f_{CP}) - \Gamma(B^0_{phys}(t)\rightarrow f_{CP})}{\Gamma(\overline{B}^0_{phys}(t)\rightarrow f_{CP}) + \Gamma(B^0_{phys}(t)\rightarrow f_{CP})}$$
$$= C_{f_{CP}}\cos(\Delta m_d \Delta t) + S_{f_{CP}}\sin(\Delta m_d \Delta t)$$

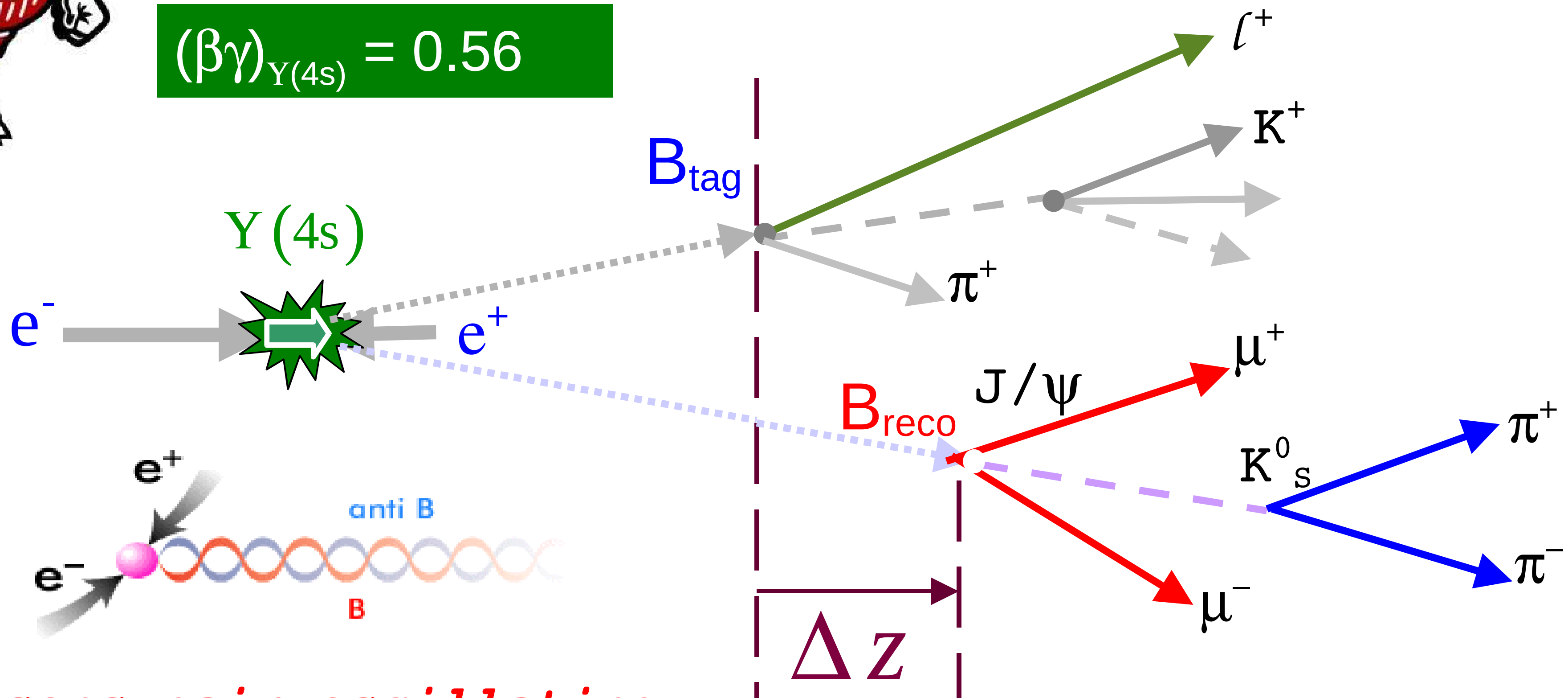
With only one CKM term in the decay ($A = \overline{A}$)

$$C = 0 \quad ; \quad S = \sin(2\beta)$$

Standard Model predictions



Vertex Reconstruction



B mesons pair oscillating in a coherent state

$$<|\Delta z|> \sim 200\,\mu m$$

$$\Delta t \approx \frac{\Delta z}{<\beta\gamma> c}$$

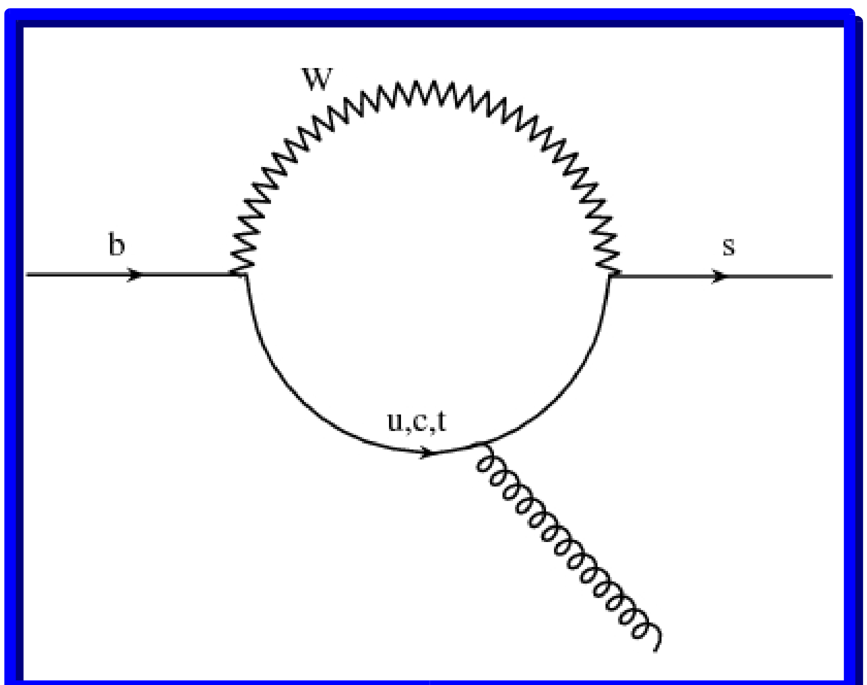
Testing b→s: Time Dependent A_{CP}

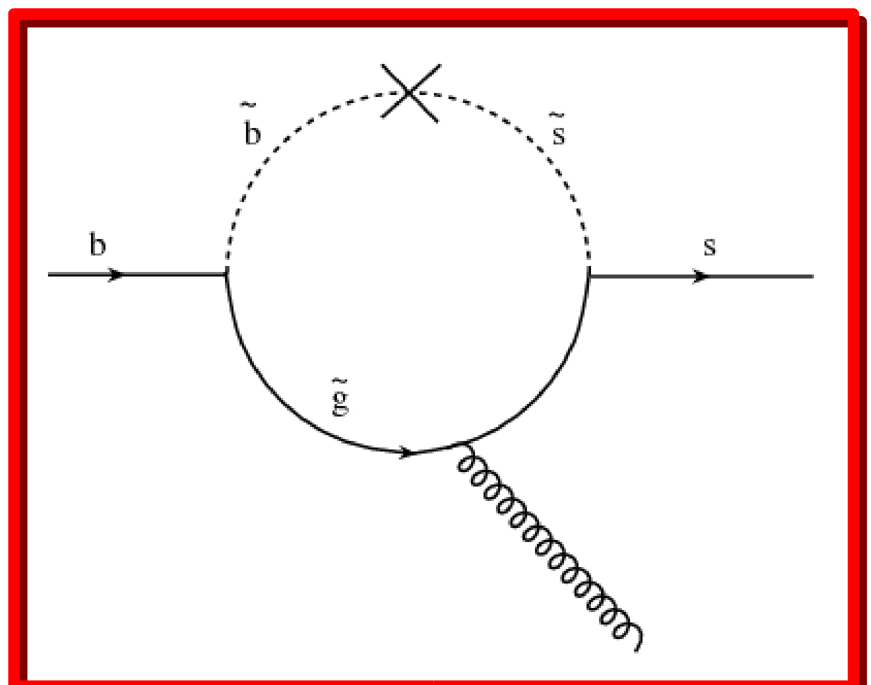
From an experimental point of view

- Same approach as sin2β analysis for $J/\psi K^0$
- Take special care to additional background sources (these are rare decays, $BR \sim 10^{-5}$)

From a theoretical point of view

- SM predicts $S \sim \sin 2\beta$ and $C \sim 0$ if only one amplitude is present
- For b→s channels, the **dominant SM amplitude is a penguin**. **NP can enter at the leading order**





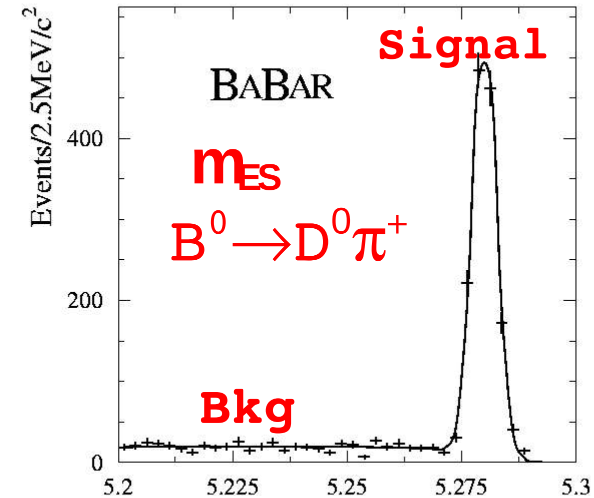
Experimental strategy(I)

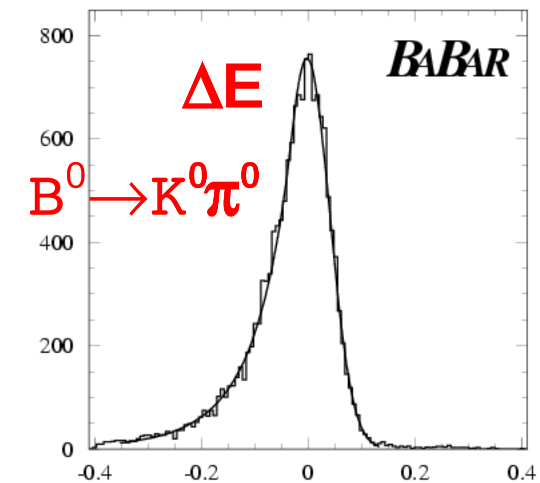
We reduce background by

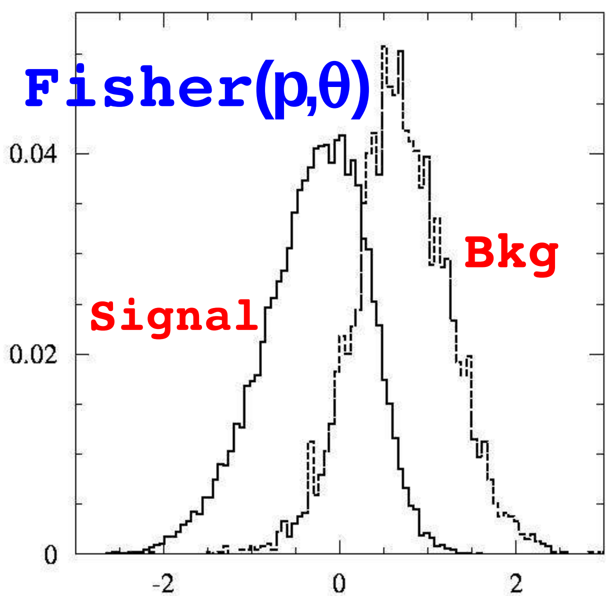
- Using kinematic variables

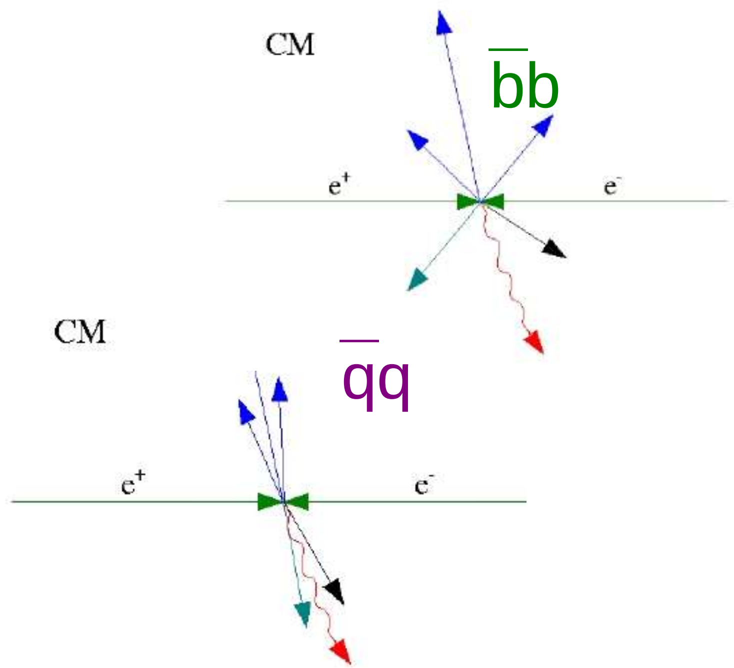
$$m_{ES}=\sqrt{(\sqrt{s}/2)^2-p_B^{*2}} \qquad \Delta E=E_B^*-\sqrt{s}/2$$

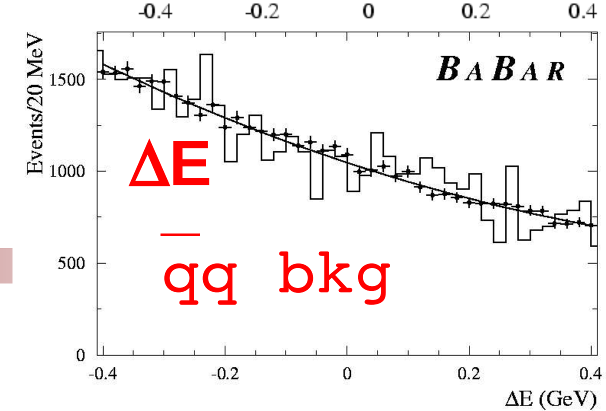
- Exploiting the different topology (isotropic vs jet-like)







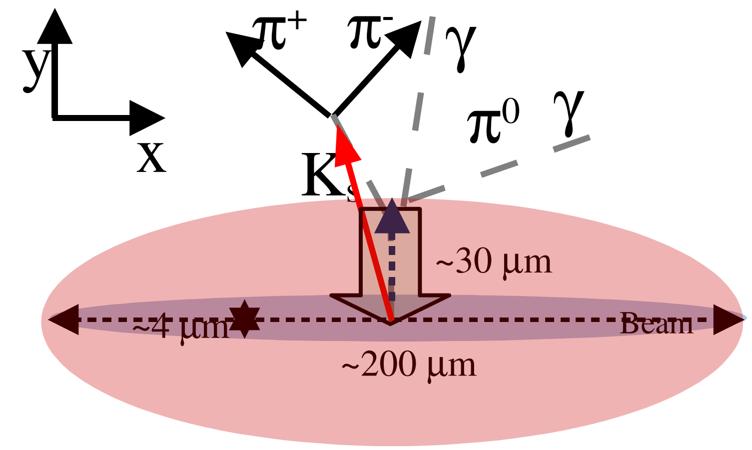


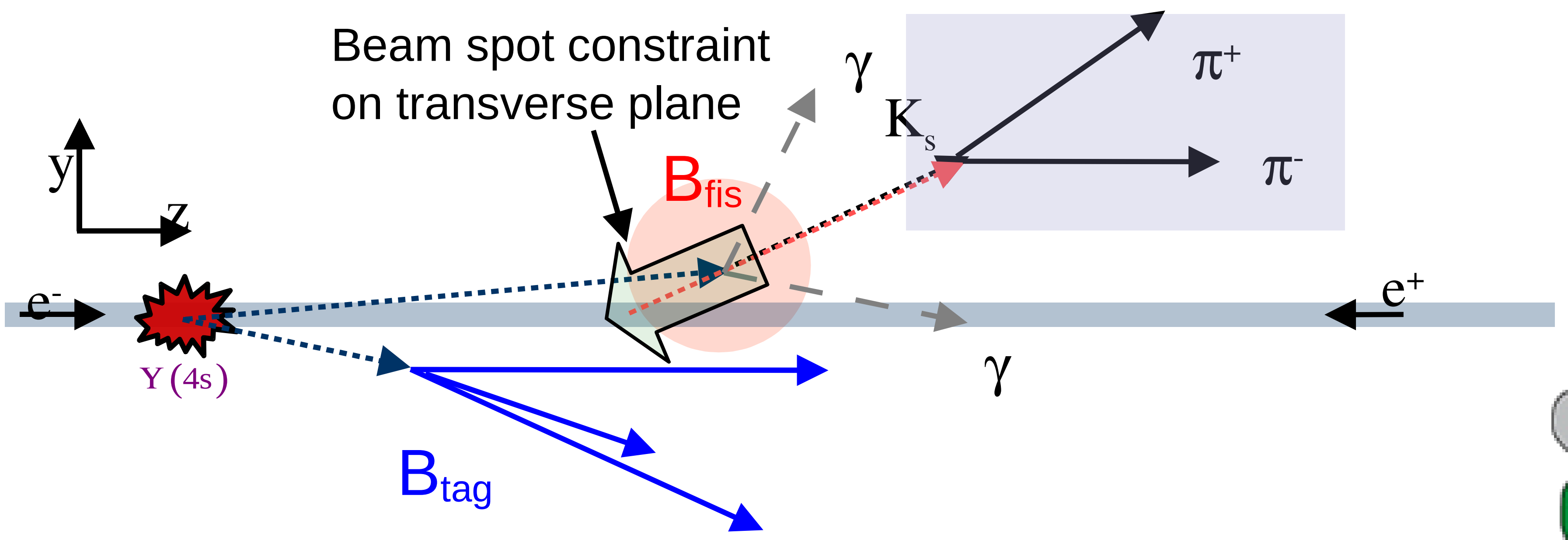


Experimental strategy(II)

Several of these channels do not have charged tracks from the vertex. But we can extrapolate back the K_S:

- Using the constraint of the beam spot on the transverse plane
- Requiring the K_S to decay in the inner part of the SVT



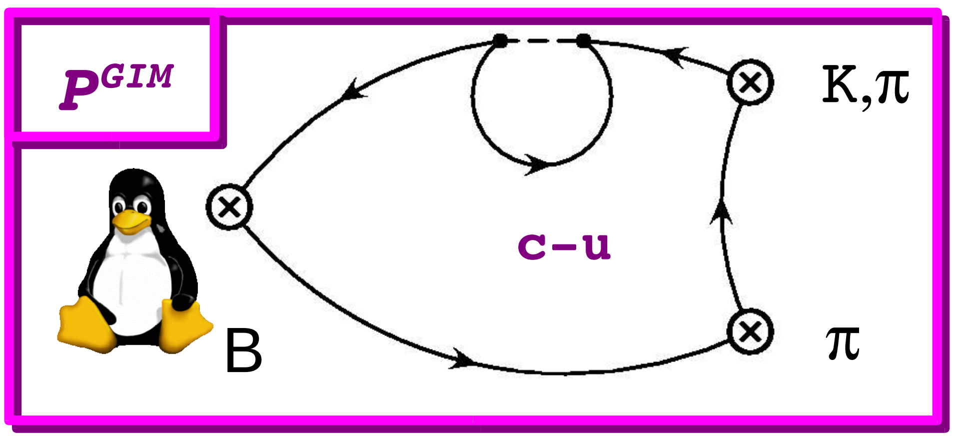


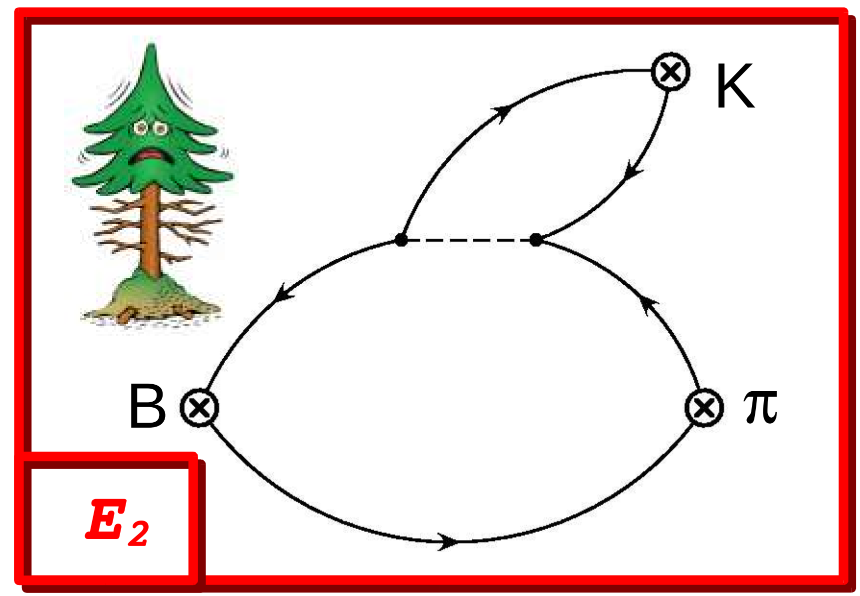
Theory problem: CKM suppressed terms

CKM enhanced $(\sim \lambda^2)$ CKM suppressed $(\sim \lambda^4)$

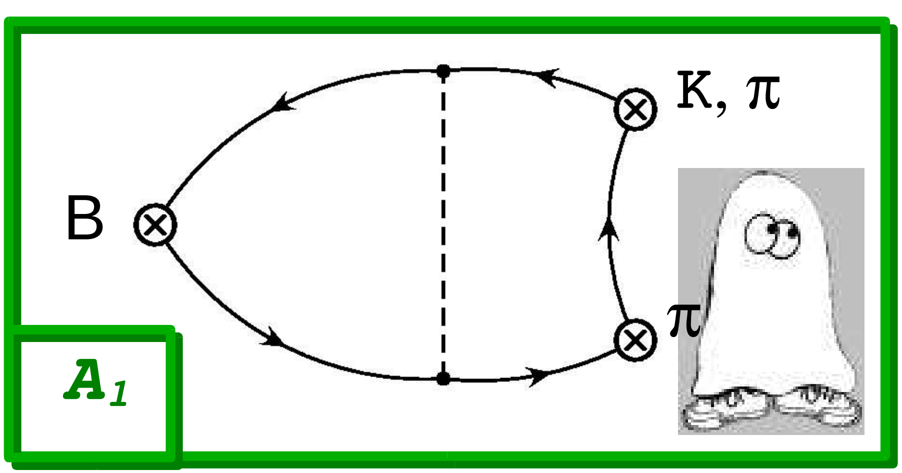
$$\mathcal{A}(B^0 \to f^s{}_{CP}) = V_{ts} V_{tb}^* \times \boldsymbol{P} - V_{us} V_{ub}^* \times \{\ldots\}$$

GIM penguins (c–u)

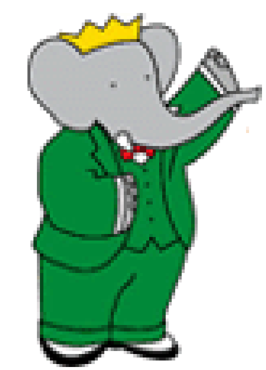




"Color suppressed" tree

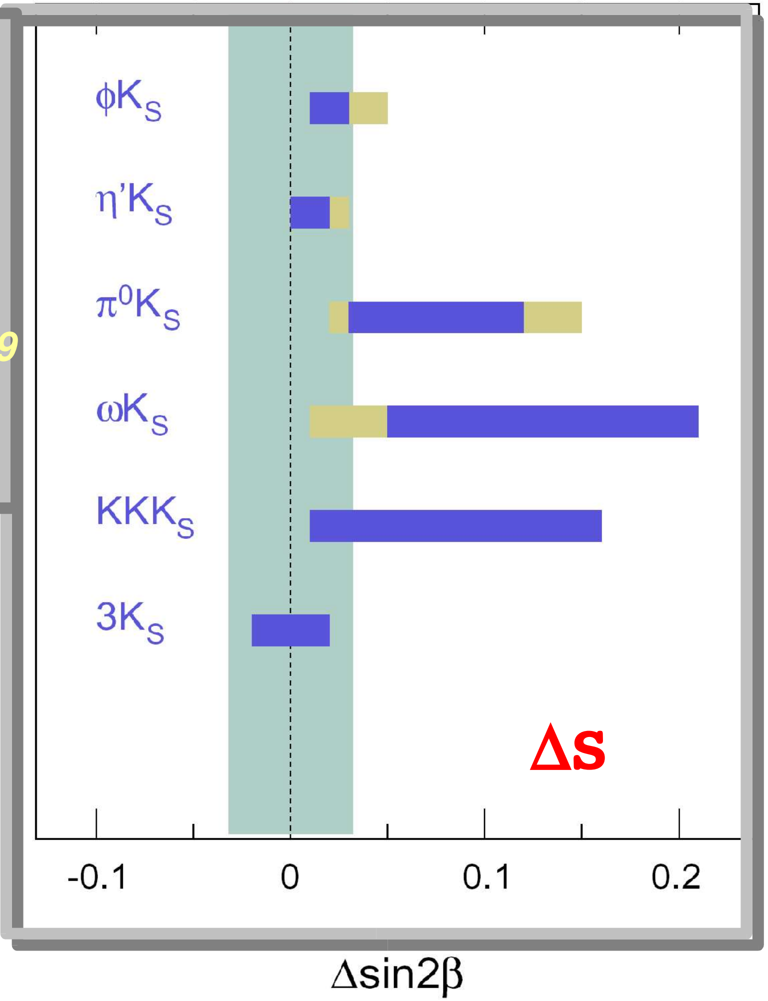


Connected Annihilation



ΔS: Calculation vs flavor symmetry

Beneke, Phys.Lett. B620, 143 (2body),
Cheng,Chua,Soni hep-ph/0506268(3body)
Grossman et al. Phys. Rev. D68 015004
Gronau et al. Phys. Lett. B579, 331,
Gronau et al. Phys. Lett. B596, 107
Gronau and Rosner, Phys. Rev. D71 074019
Engerlhard and Raz, hep-ph/0508046
Raz, hep-ph0509125



The corrections can be calculated (for example with QCD fact) or can be extracted from data, for example with SU(3). Open issues:

- Do the penguins factorize (i.e, are **charming penguins** important?)
- What is the error associated to **SU(3) breaking**?
- Can we follow a **“data driven” approach** to reduce the uncertainties?

How can experiments help?

Also BF provide information on decay amplitude.
We can measure them with high precision

Neutral decays are not well reproduced

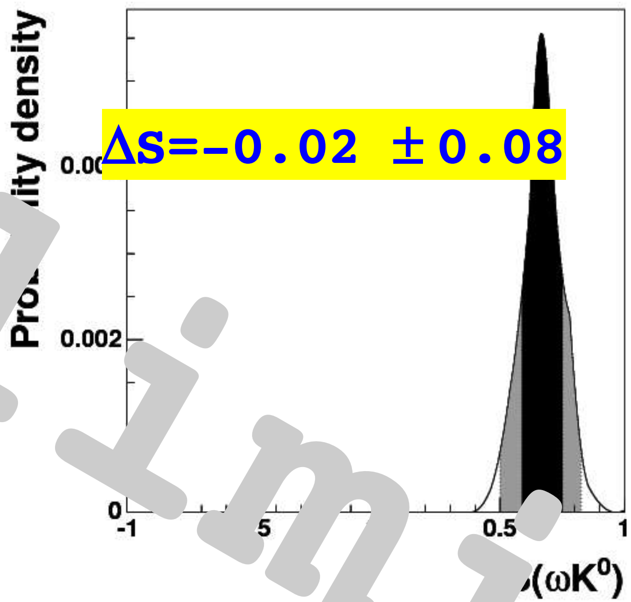
Mode	*BABAR*	Belle	World Average	QCD FA	pQCD
$\pi^+\pi^-$	$4.7 \pm 0.6 \pm 0.2$	$4.4 \pm 0.6 \pm 0.3$	4.5 ± 0.4	$4.6 - 9.5$	$5.9 - 11.0$
$\pi^0\pi^0$	$1.17 \pm 0.32 \pm 0.10$	$2.3^{+0.4+0.2}_{-0.5-0.3}$	1.45 ± 0.29	$0.4 - 0.9$	$0.1 - 0.7$
$\pi^+\pi^0$	$5.8 \pm 0.6 \pm 0.4$	$5.0 \pm 1.2 \pm 0.5$	5.5 ± 0.6	$5.1 - 6.0$	$2.7 - 4.8$
$K^+\pi^-$	$17.9 \pm 0.9 \pm 0.7$	$18.5 \pm 1.0 \pm 0.7$	18.2 ± 0.8	$18.4 - 20.0$	$12.6 - 19.3$
$K^0\pi^0$	$11.4 \pm 0.9 \pm 0.6$	$11.7 \pm 2.3^{+1.2}_{-1.3}$	11.5 ± 1.0	$6.5 - 9.3$	$4.4 - 8.1$
$K^0\pi^+$	$26.0 \pm 1.3 \pm 1.0$	$22.0 \pm 1.9 \pm 1.1$	24.1 ± 1.3	$18.8 - 24.8$	$14.4 - 26.3$
$K^+\pi^0$	$12.0 \pm 0.7 \pm 0.6$	$12.0 \pm 1.3^{+1.3}_{-0.9}$	12.1 ± 0.8	$11.7 - 14.0$	$7.8 - 14.3$
K^+K^-	< 0.6	$0.06^{+0.12+0.03}_{-0.10-0.02}$	$0.06^{+0.12}_{-0.10}$	< 0.08	0.06
$K^0\overline{K^0}$	$1.19^{+0.40}_{-0.35} \pm 0.13$	$0.8 \pm 0.3 \pm 0.1$	$0.96^{+0.25}_{-0.24}$	$1.5 - 2.2$	1.4
$K^+\overline{K^0}$	$1.45^{+0.53}_{-0.46} \pm 0.11$	$1.0 \pm 0.4 \pm 0.1$	$1.19^{+0.32}_{-0.30}$	$1.4 - 2.2$	1.4

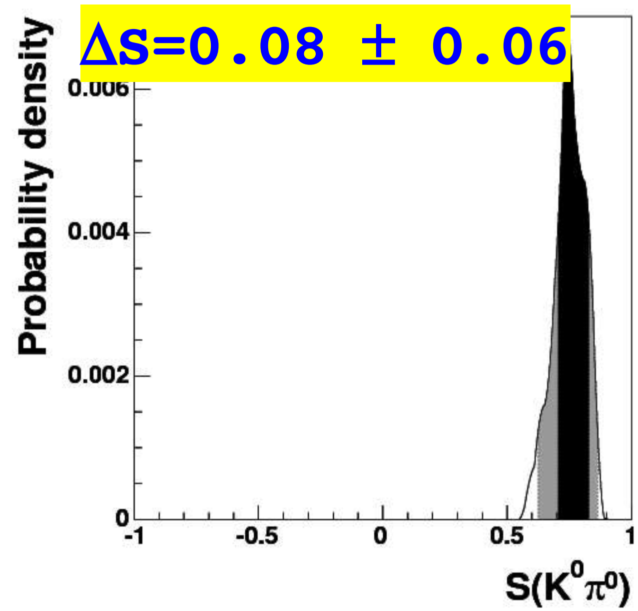
With precise measurements we will be able to test the models and improve the knowledge on ΔS.

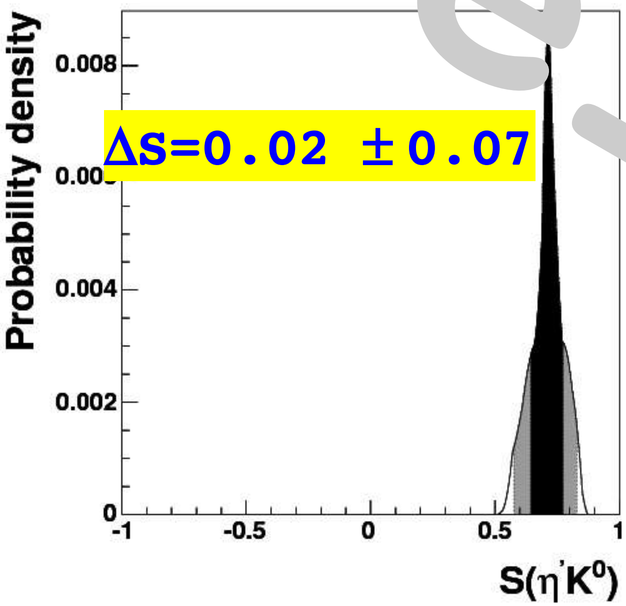
Mode	σ (stat)	σ (syst)	σ (tot)	σ (WA)
$\pi^+\pi^-$	3.5	2	4	3
$\pi^0\pi^0$	14	6	15	11
$\pi^+\pi^0$	5.5	3	6	4
$K^+\pi^-$	1.5	2	2.5	2
$K^0\pi^0$	4	3	5	4
$K^0\pi^+$	2.5	3	4	3
$K^+\pi^0$	3	3	4	3
K^+K^-	–	–	–	$< 10^{-7}$
$K^0\overline{K^0}$	17	6	18	13
$K^+\overline{K^0}$	15	3	15	11

% error with 1ab^{-1} data

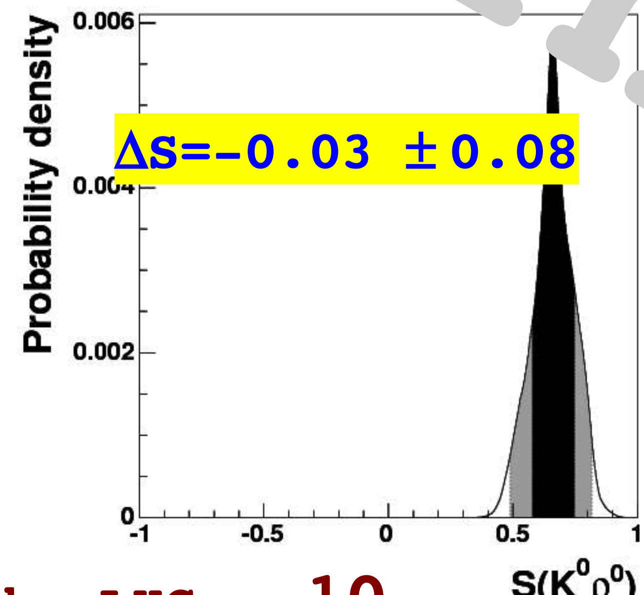
ΔS with Charming Penguins

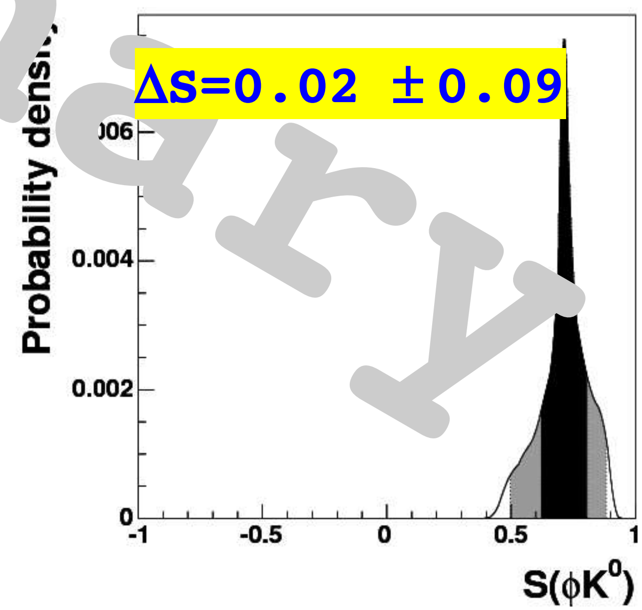




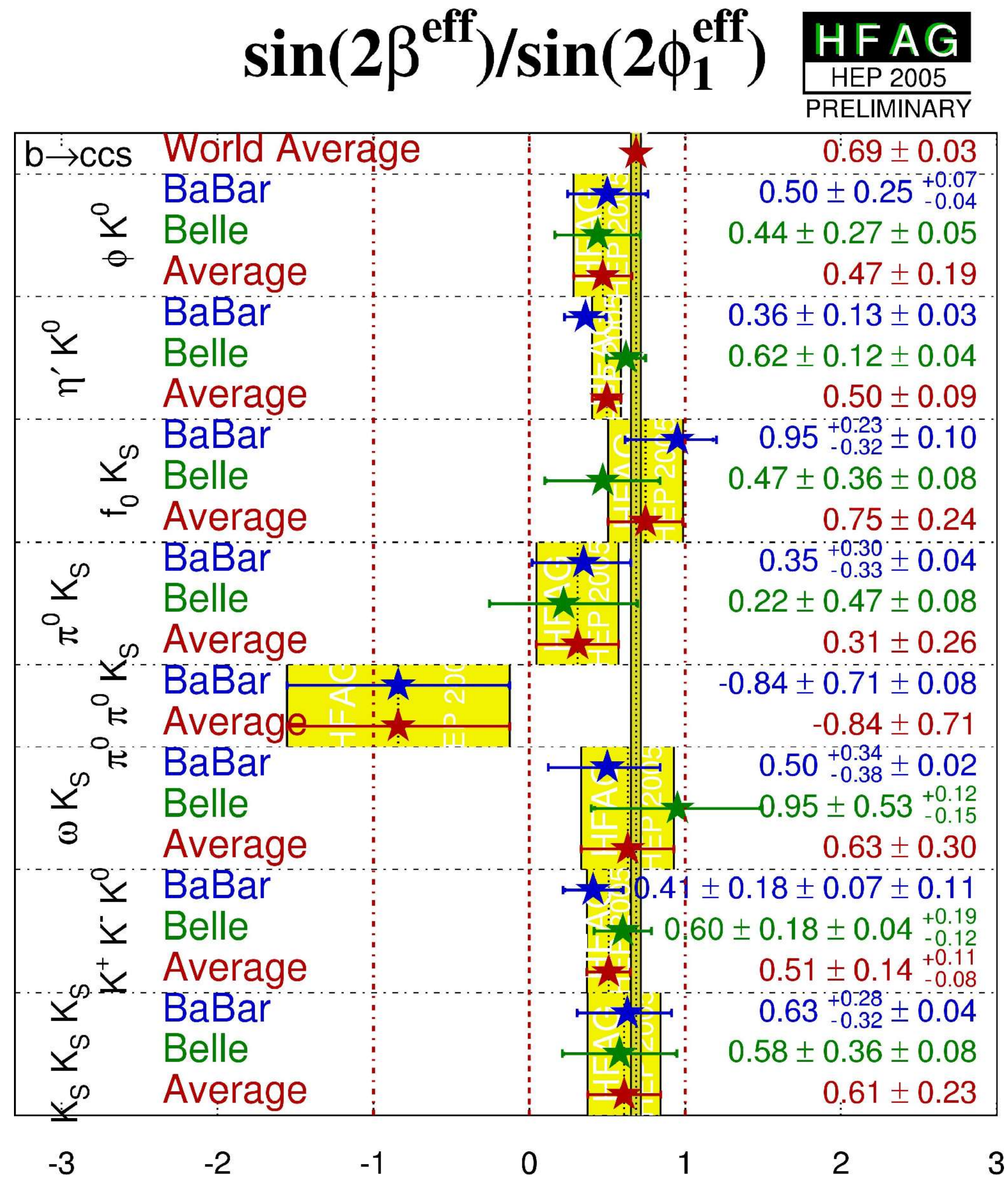


Ciuchini et al., in preparation (see hep-ph/0407073 as a reference)





Current Experimental Status



Good agreement between BaBar and Belle

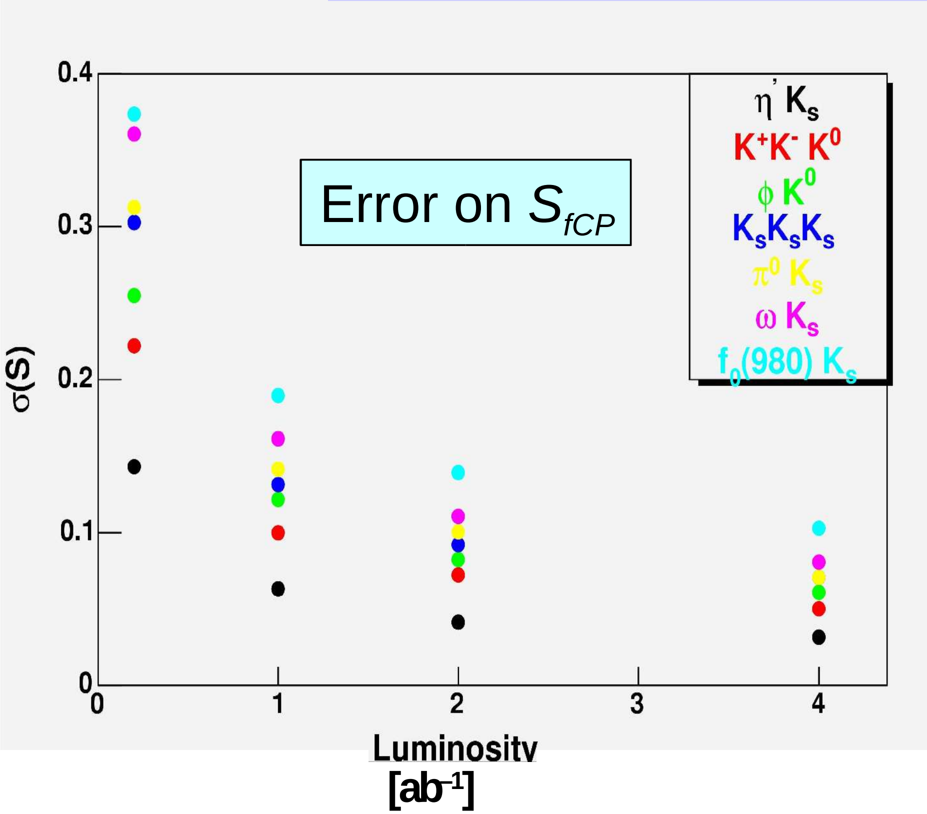
Consistency among different channels

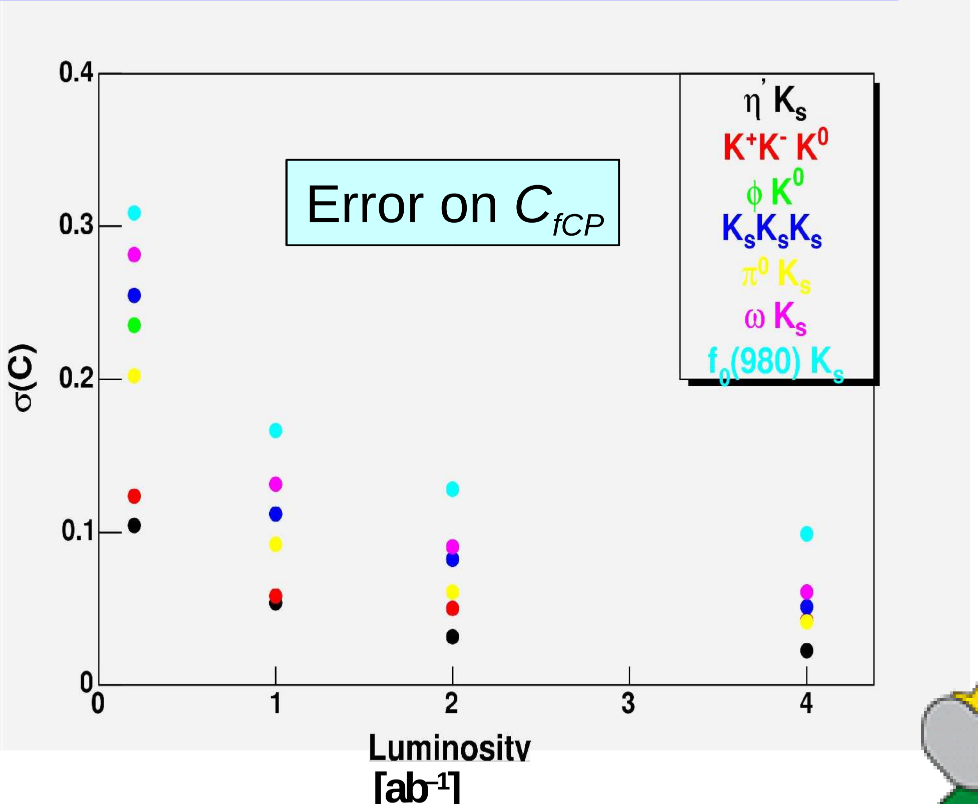
S error vs. luminosity

Expect >2 ab^{-1} dataset from combined B Factories by end 2008

⇒ ~0.1 errors on S_{fCP} and C_{fCP} from individual $b \to s\bar{s}s$, $q\bar{q}s$ modes

⇒ potential to discover significant deviation from $b \to c\bar{c}s$ modes





SUSY Mass Insertions

$$\begin{pmatrix} m_{11} & m_{21} & m_{31} \\ m_{12} & m_{22} & m_{32} \\ m_{13} & m_{23} & m_{33} \end{pmatrix} \rightarrow \begin{pmatrix} m_d & 0 & 0 \\ 0 & m_s & 0 \\ 0 & 0 & m_b \end{pmatrix}$$

quark rotation (generating CKM matrix)

$$\begin{pmatrix} \tilde{m}^2_{11} & \tilde{m}^2_{21} & \tilde{m}^2_{31} \\ \tilde{m}^2_{12} & \tilde{m}^2_{22} & \tilde{m}^2_{32} \\ \tilde{m}^2_{13} & \tilde{m}^2_{23} & \tilde{m}^2_{33} \end{pmatrix}_{AB} \rightarrow \begin{pmatrix} m^2_{\tilde{d}} & 0 & 0 \\ 0 & m^2_{\tilde{s}} & 0 \\ 0 & 0 & m^2_{\tilde{b}} \end{pmatrix}_{AB} + m^2_{\tilde{q}} \begin{pmatrix} 0 & \delta^{*BA}_{12} & \delta^{*BA}_{13} \\ \delta^{AB}_{12} & 0 & \delta^{*BA}_{23} \\ \delta^{AB}_{13} & \delta^{AB}_{23} & 0 \end{pmatrix}$$

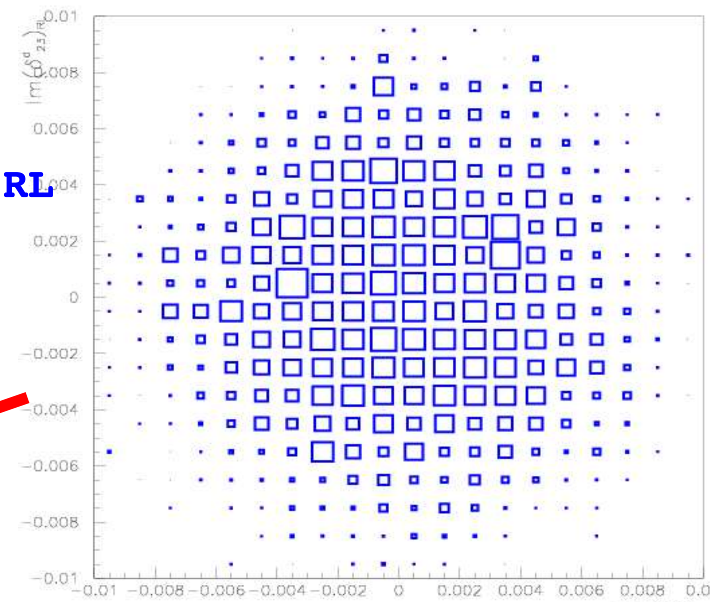
average squark mass

chirality of incoming and outgoing squark (**LL,LR,RL,RR**)

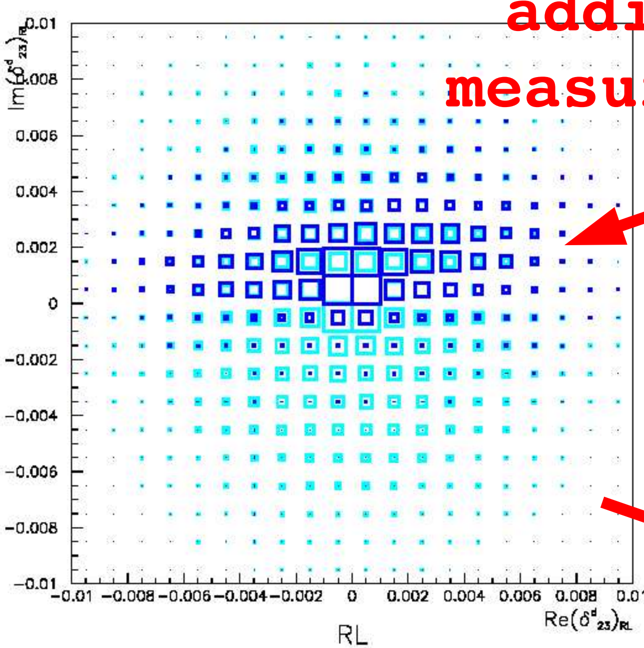
Effective interaction (mass insertion) between second and third family

And how A_{CP} will help

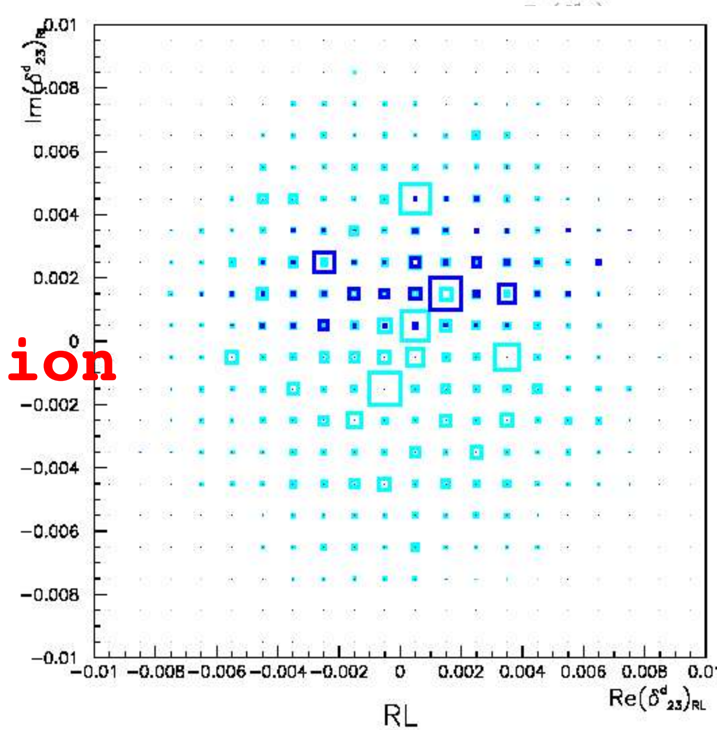
$Re(\delta^d_{23})_{RL}$ vs $Im(\delta^d_{23})_{RL}$



adding S measurements



extrapolation to 2008



No b→s time dep.
With b→s time dep.

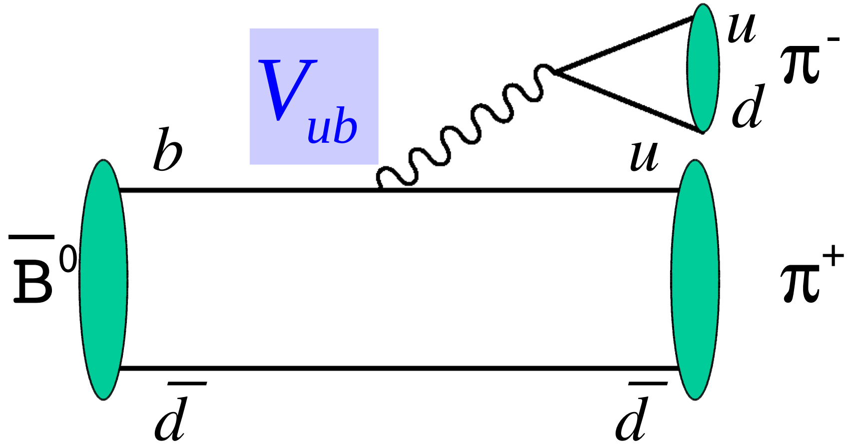
α from B→ρρ and B→ππ

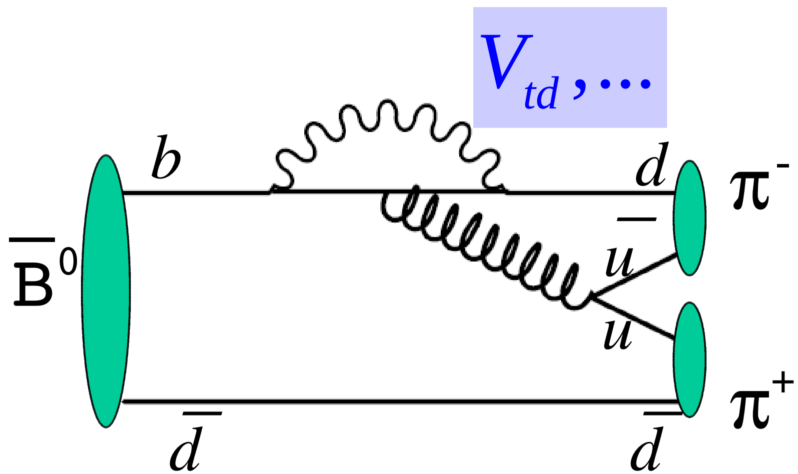
Original idea: if $B^0\to\pi^+\pi^-$ amplitude is dominated by the $b\to u$ tree process, it is just like measuring sin2β

$$\lambda_{\pi^+\pi^-}=\frac{q}{p}\cdot\frac{\bar{A}_{\pi^+\pi^-}}{A_{\pi^+\pi^-}}=\eta_{CP}^{\pi^+\pi^-}e^{-2i\beta}e^{-2i\gamma}=e^{2i\alpha}$$

$$S_{\pi^+\pi^-}=\frac{2\Im(\lambda_{\pi^+\pi^-})}{1+|\lambda_{\pi^+\pi^-}|^2}=\sin 2\alpha \qquad C_{\pi^+\pi^-}=\frac{1-|\lambda_{\pi^+\pi^-}|^2}{1+|\lambda_{\pi^+\pi^-}|^2}=0$$

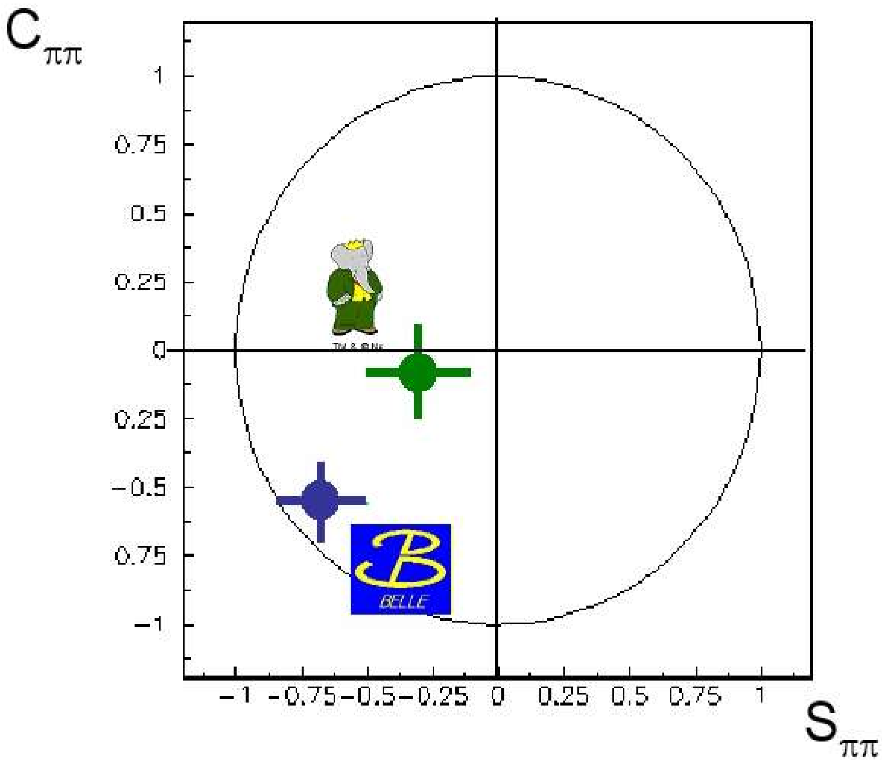
If penguins were negligible, we could extract α directly from the time-dependent CP asymmetry for $B^0\to\pi^+\pi^-$. But penguins are there

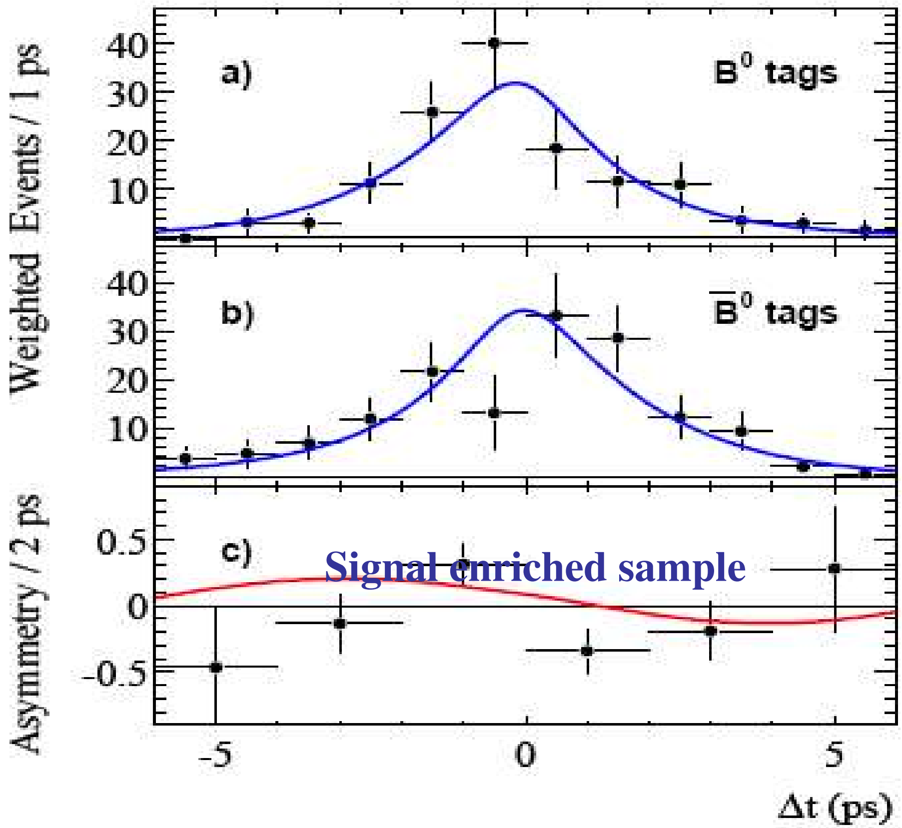




Time dependent $A_{CP}(\pi\pi)$

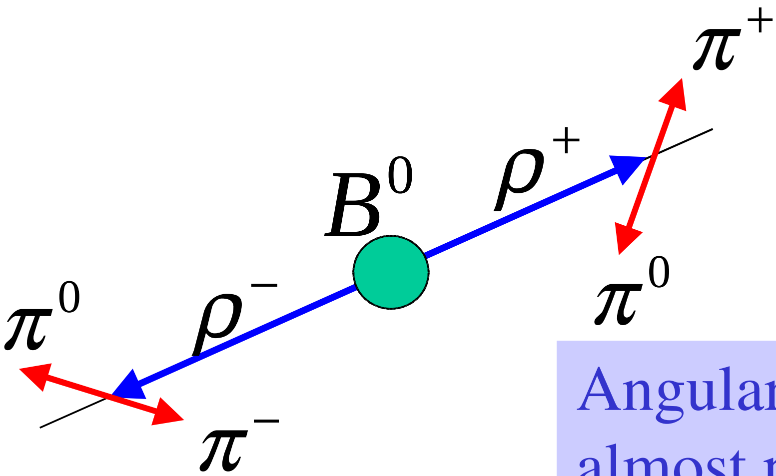
	BABAR	BELLE
$S_{\pi\pi}$	$-0.30 \pm 0.17 \pm 0.03$	$-0.67 \pm 0.16 \pm 0.06$
$C_{\pi\pi}$	$-0.09 \pm 0.15 \pm 0.04$	$-0.56 \pm 0.12 \pm 0.06$





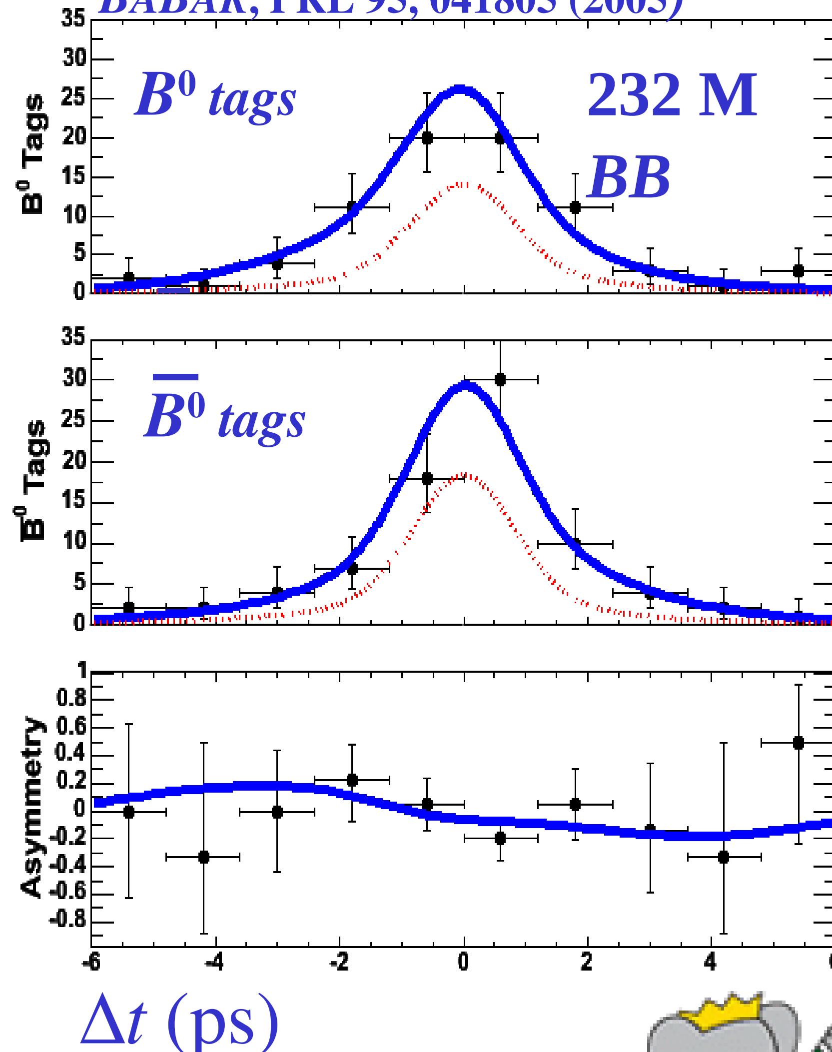
Time dependent $A_{CP}(\rho\rho)$

3 polarizations→mixed CP state
We are lucky (there is just one).
No additional dilution, even if it's a VV decay



Angular analysis → almost pure CP=+1 !

BABAR, PRL 95, 041805 (2005)



	BABAR	BELLE (LP2005)
f_L	$0.978 \pm 0.014^{+0.021}_{-0.029}$	$0.951^{+0.033+0.029}_{-0.039-0.031}$
$S_{\rho\rho}$	$-0.33 \pm 0.24^{+0.08}_{-0.14}$	$0.09 \pm 0.42 \pm 0.08$
$C_{\rho\rho}$	$-0.03 \pm 0.18 \pm 0.09$	$0.00 \pm 0.30^{+0.09}_{-0.10}$

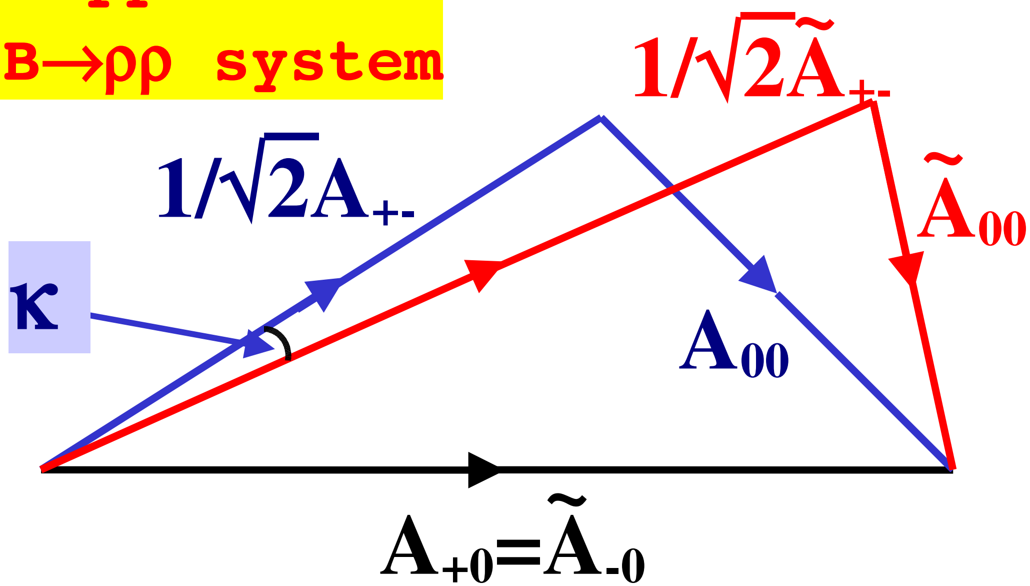
Would like to see *S*, *C* with 5x data!

Isospin Analysis(I)

$B^+ \to \pi^+\pi^0$ is pure tree (no gluonic penguin)$\to$triangles have common side after rescaling one set by $e^{2i\gamma}$:

$$A(B^+ \to \pi^+\pi^0) = \tilde{A}(B^- \to \pi^-\pi^0) \equiv e^{2i\gamma} A(B^- \to \pi^-\pi^0)$$

The same approach also for $B \to \rho\rho$ system



- If penguin amp=0, triangles coincide.
- 4-fold discrete ambiguity (can flip both triangles)
- take worst case as "penguin error"

Grossman & Quinn, PRD 58, 017504 (1998)

$$\sin^2\kappa < \frac{BR(B^0 \to \pi^0\pi^0) + BR(\bar{B} \to \pi^0\pi^0)}{BR(B^+ \to \pi^+\pi^0) + BR(B^- \to \pi^-\pi^0)}$$

Isospin Analysis(II)

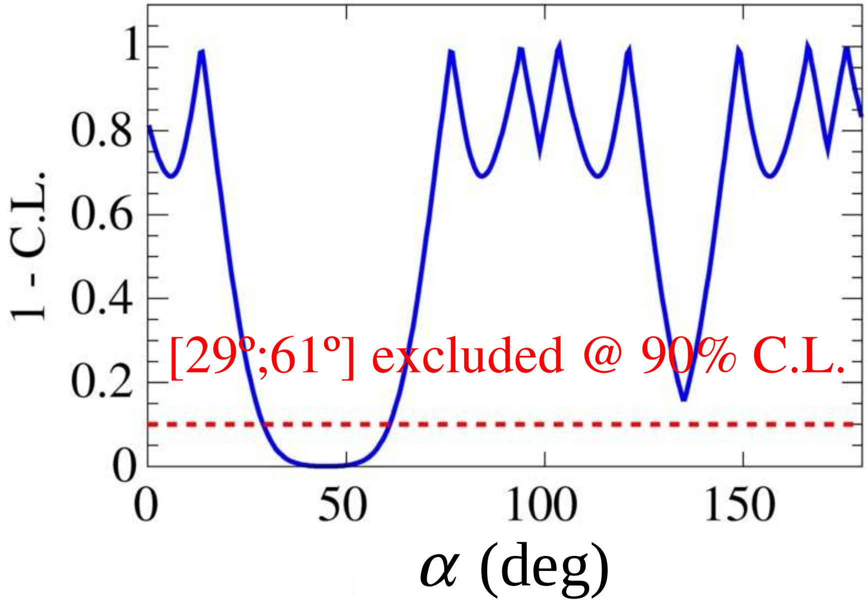
Mode	$B/10^{-6}$ (*BABAR*)	$B/10^{-6}$ (Belle)
$B^0 \to \pi^0\pi^0$	$1.17 \pm 0.32 \pm 0.10$	$2.3^{+0.4+0.2}_{-0.5+0.3}$
$B^+ \to \pi^+\pi^0$	$5.8 \pm 0.6 \pm 0.4$	$5.0 \pm 1.2 \pm 0.5$
$B^0 \to \pi^+\pi^-$	$5.5 \pm 0.4 \pm 0.3$	$4.4 \pm 0.6 \pm 0.3$
$C_{\pi^0\pi^0}$	$-0.12 \pm 0.56 \pm 0.06$	

Mode	$B/10^{-6}$ (*BABAR*)		$B/10^{-6}$ (Belle)	
$B^0 \to \rho^0\rho^0$	<1.1(@90%C.L.)	[230 M $\bar{B}B$]	–	
$B^+ \to \rho^+\rho^0$	$23^{+5}_{-6} \pm 6$	[89 M $\bar{B}B$]	$32 \pm 7^{+4}_{-7}$	[85 M $\bar{B}B$]
$B^0 \to \rho^+\rho^-$	$30 \pm 4 \pm 5$	[89 M $\bar{B}B$]	$24.4 \pm 2.2^{+3.8}_{-4.1}$	[275 M $\bar{B}B$]

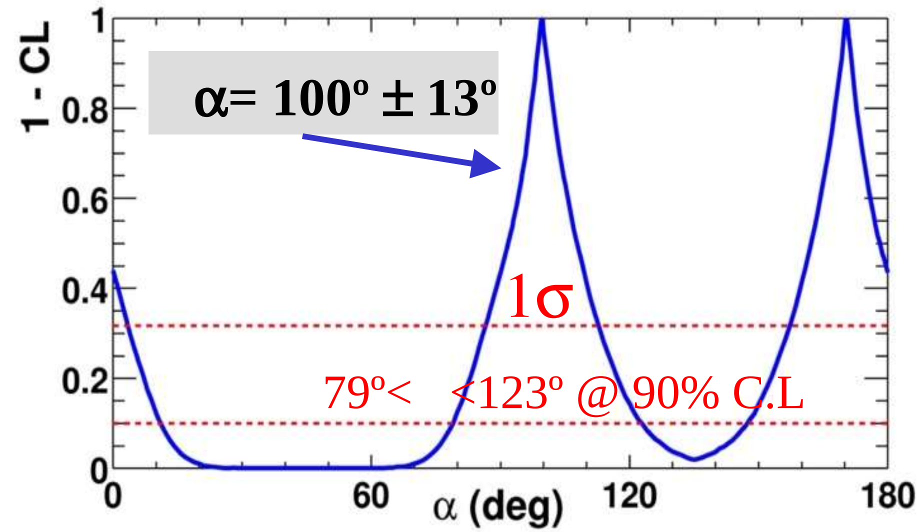
$\pi^0\pi^0$ amp. isn't small compared to the others, while $\rho^0\rho^0$ is small. This means that $\rho\rho$ is better
$|\Delta\alpha_{\pi\pi}|<35°$(90%CL) vs $|\Delta\alpha_{\rho\rho}|<14°$(90%CL)

Isospin Analysis(III)

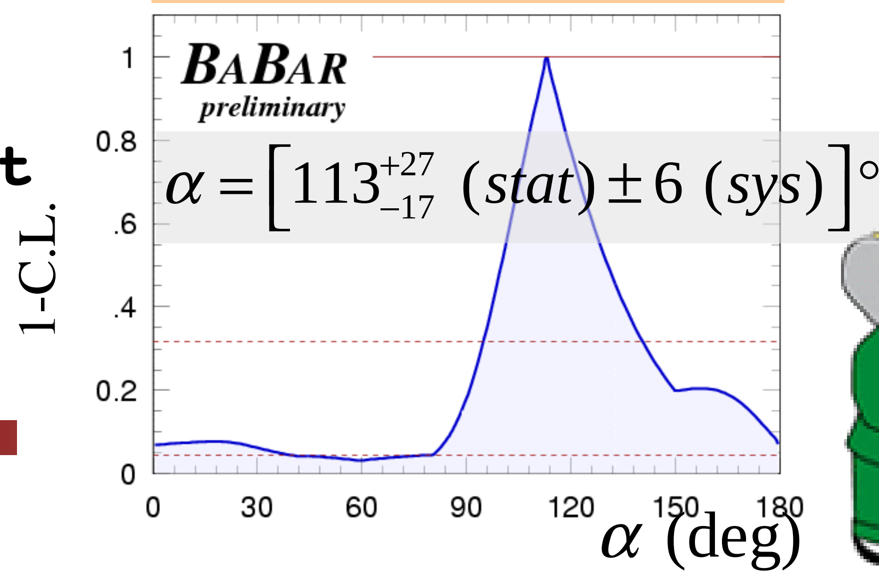
$B \to \pi\pi$ PRL, 94, 181802 (2005)



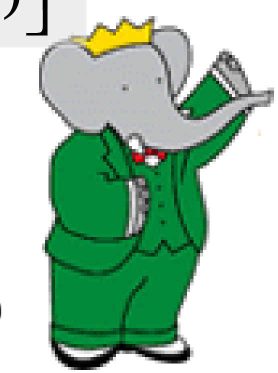
$B \to \rho\rho$ PRL 95, 041805 (2005)



$B \to \pi^+\pi^-\pi^0$ Dalitz hep-ex/0408089

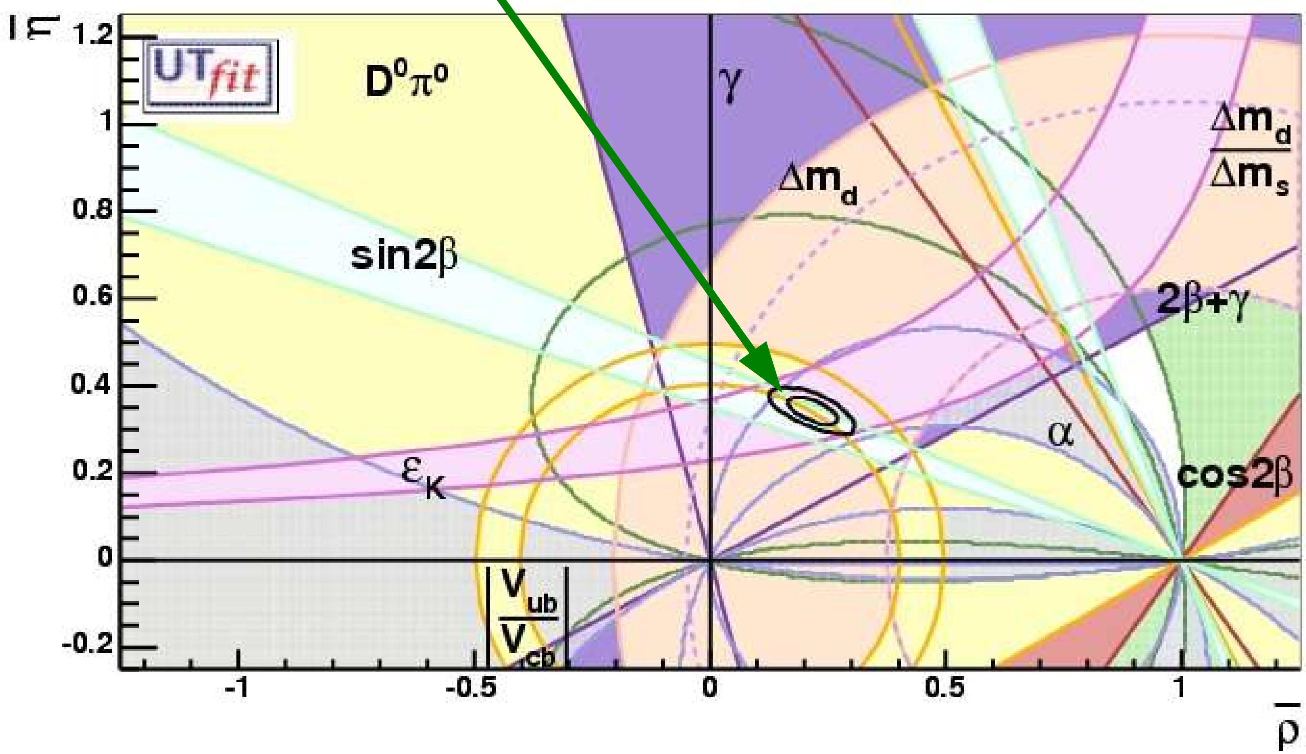


Complementary information from $B \to \pi^+\pi^-\pi^0$ time dependent Dalitz analysis

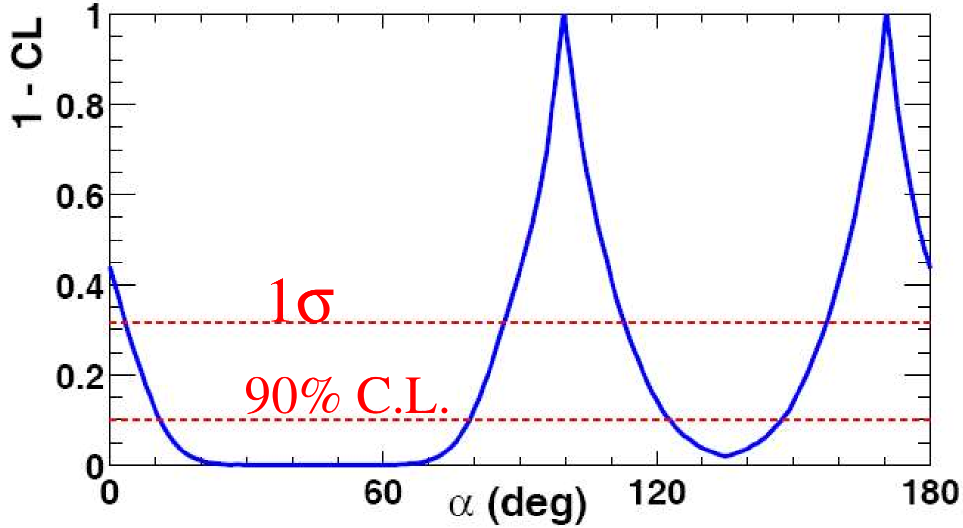


Present Impact on UT_{fit}

α is cutting the total area in the same way Δm_s will do one day (which does not replace Δm_s in searching for NP but helps a lot in determining the CKM)

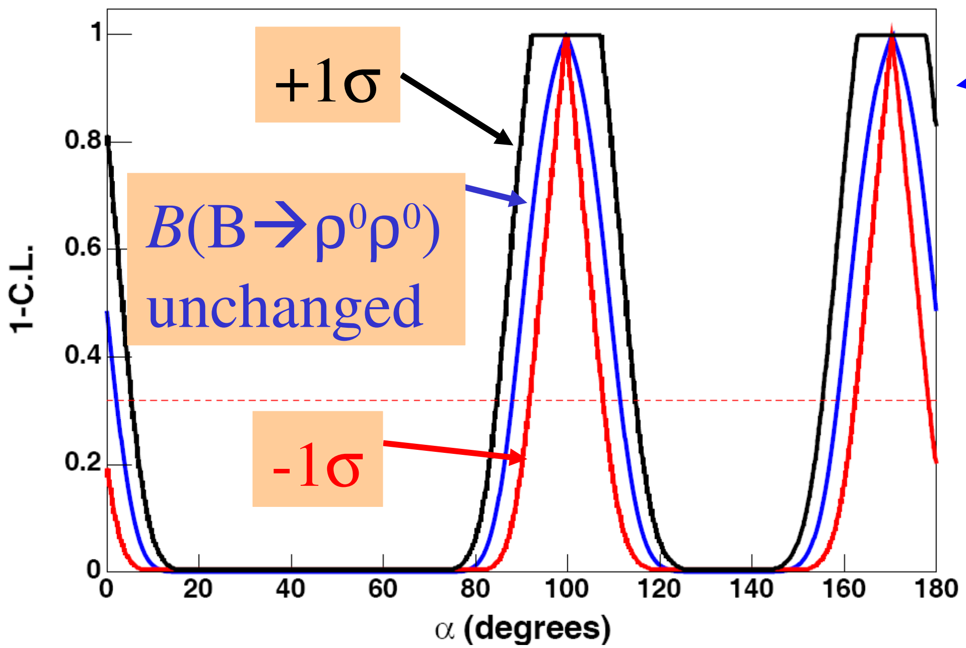


Projections for α from $B \to \rho^+\rho^-$



Current α measurement from $B \to \rho\rho$

Multiple unresolved solutions within each peak.



Projected α measurements from $B \to \rho\rho$ for 1 ab^{-1}

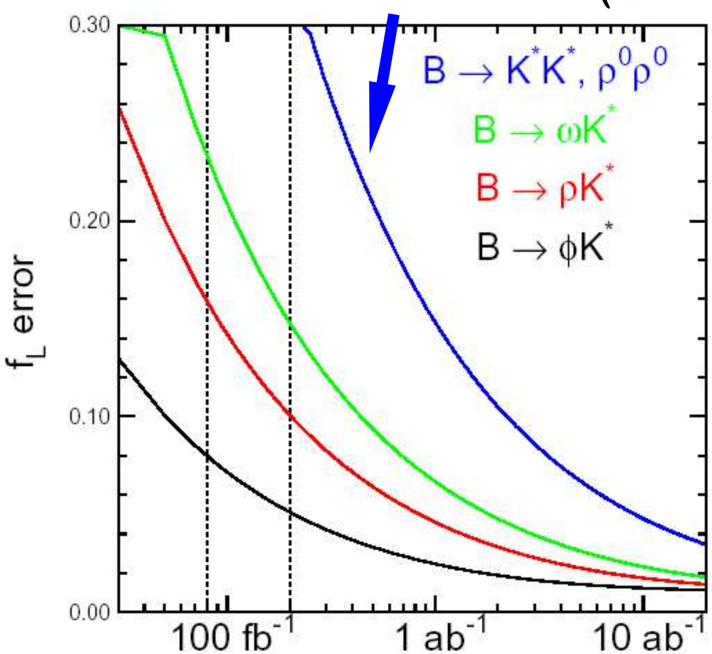
The uncertainty on α depends critically on $\mathcal{B}(B \to \rho^0\rho^0)$. Scenarios:

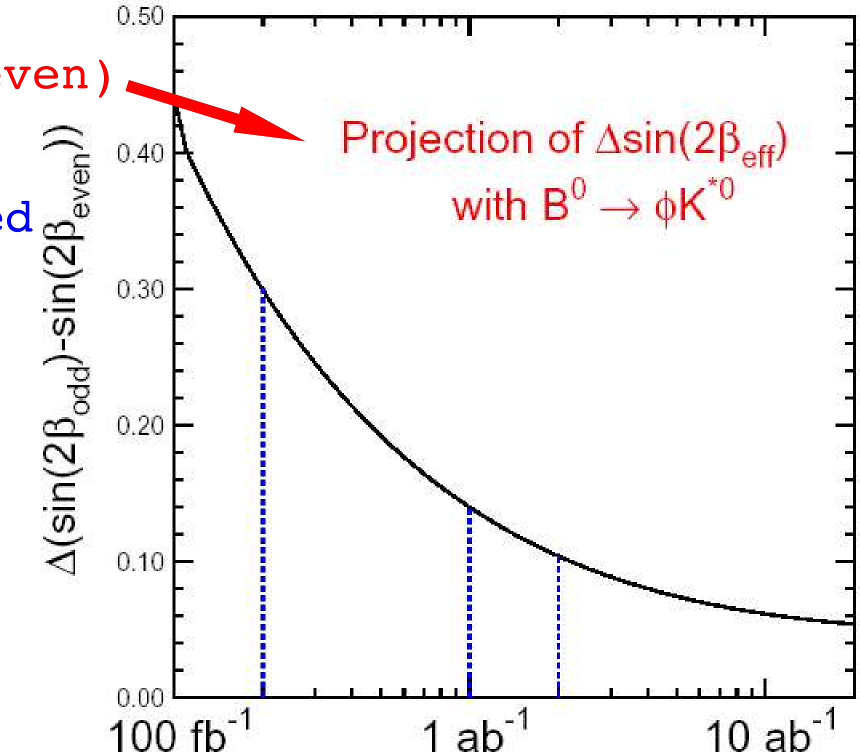
4. use current central value
5. $+1\sigma$ (black line)
6. -1σ (red line)

Study of $B \to V_s V$ Decays

A rich set of new observables

- Theoretically clean access to phases
  - Measure $\Delta S = \sin 2\beta(odd) - \sin 2\beta(even)$
- Triple-product asymmetries
  - Able to separate right handed currents (which are null in SM)



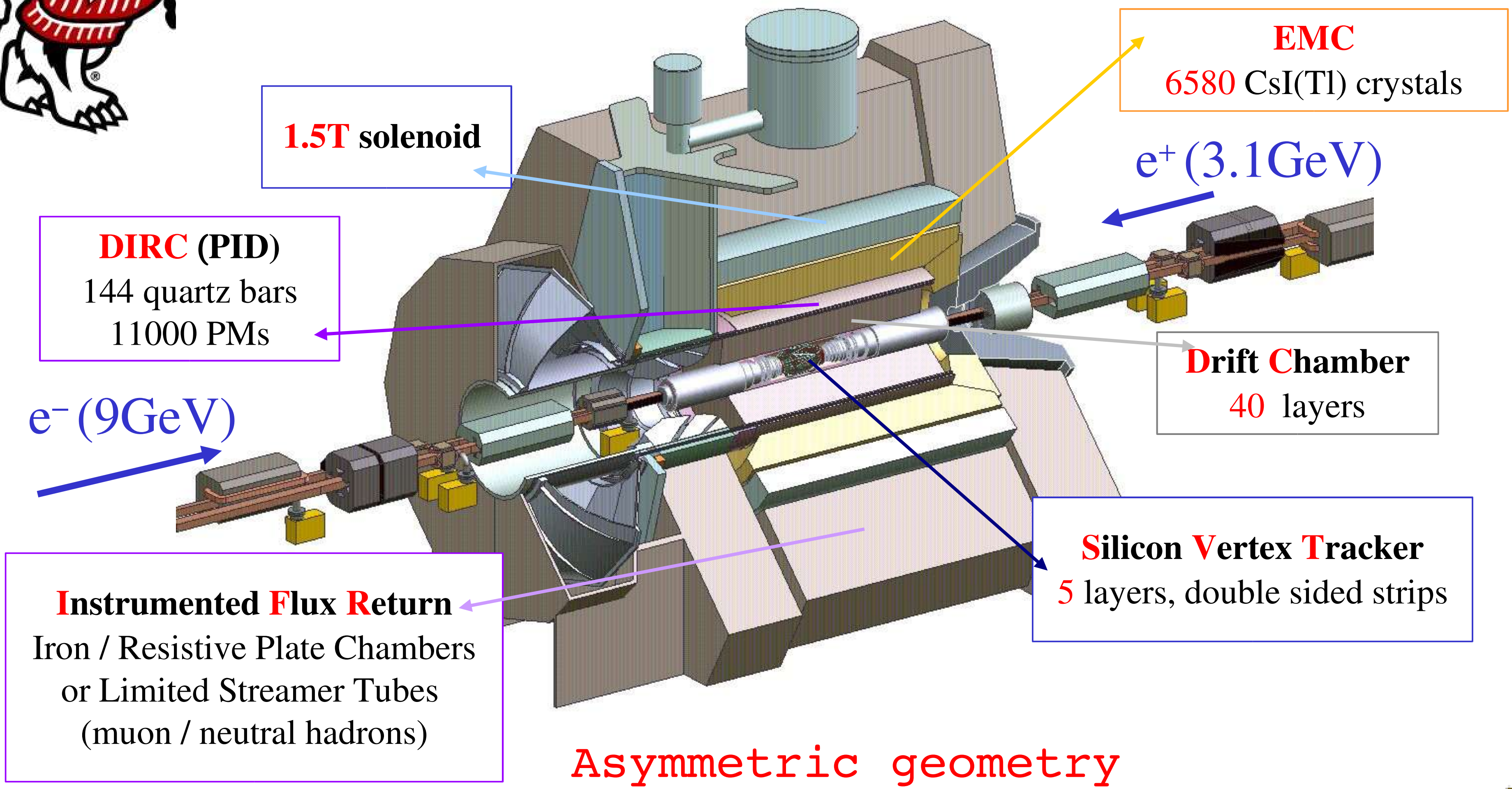


Conclusion

- The B-factories are in the era of high precision measurements
- We can access both α and quantities sensitive to NP applying well tested experimental techniques to charmless B decays
- With ~1ab^{-1} in 2008, BaBar will test CKM mechanism and the presence of NP in a statistically significant way (~0.1 for S and C, ~10°-15° for α from $\rho\rho$ alone)
- Even in the case of small deviations, we will obtain very useful information from the combination of constraints from several decay modes
- We can also help theorists to improve the models and reduce the theoretical errors, by providing a large set of precise measurements on similar channels (BR and CP asymmetries)
- We can use additional ways to test $b\to s$ decays, such as $B\to VV$ modes

Backup Slides

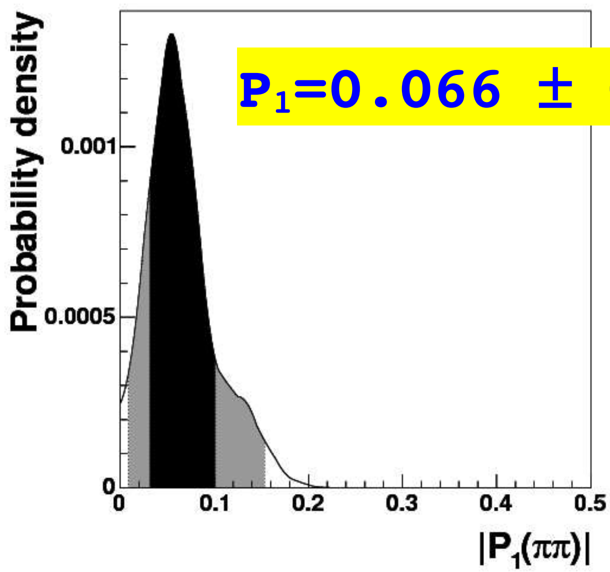
BABAR Detector

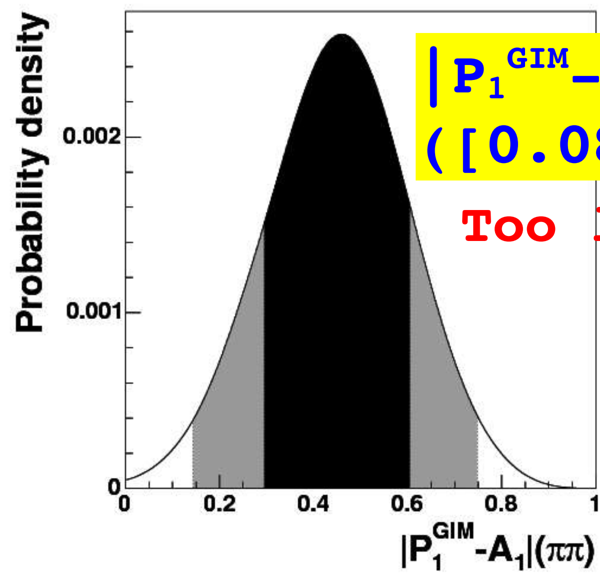


Asymmetric geometry
(inorder to optimize peformances for the boost of the rest-frame respect to LAB)

Fit to B→ππ

Channel	$BR^{th}\times 10^6$	$BR^{exp}\times 10^6$	$\mathcal{A}^{th}_{CP}$	$\mathcal{A}^{exp}_{CP}$	$\mathcal{S}^{th}$	$\mathcal{S}^{exp}$
$\pi^+\pi^-$	5.5 ± 0.4	5.4 ± 0.4	0.33 ± 0.11	0.37 ± 0.10	-0.54 ± 0.12	-0.50 ± 0.12
$\pi^+\pi^0$	5.7 ± 0.6	5.8 ± 0.6	0	0.01 ± 0.06	-	-
$\pi^0\pi^0$	1.42 ± 0.29	1.45 ± 0.29	0.07 ± 0.24	0.28 ± 0.39	-	-





$|P_1^{GIM}-A_1|=0.45 \pm 0.15$
([0.08,0.90] at 95%)

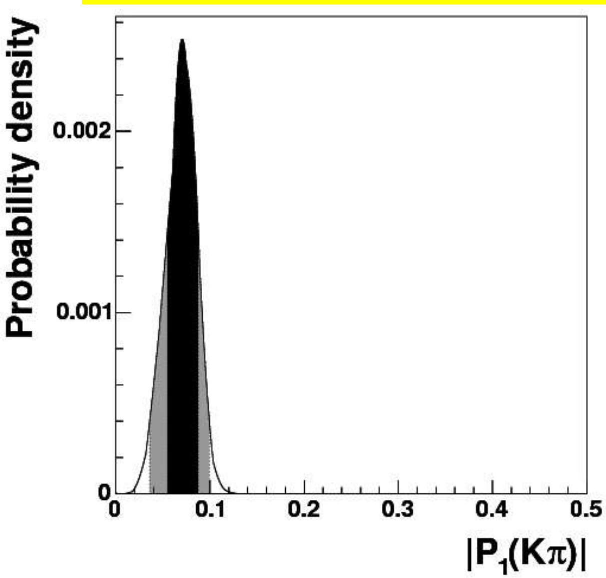
Too large to be Λ_{QCD}/m_b.
Problems with factorization?

- **Values are given in units of E_1**
- We will use [0.0,0.90] for the Kπ fit (to be conservative)

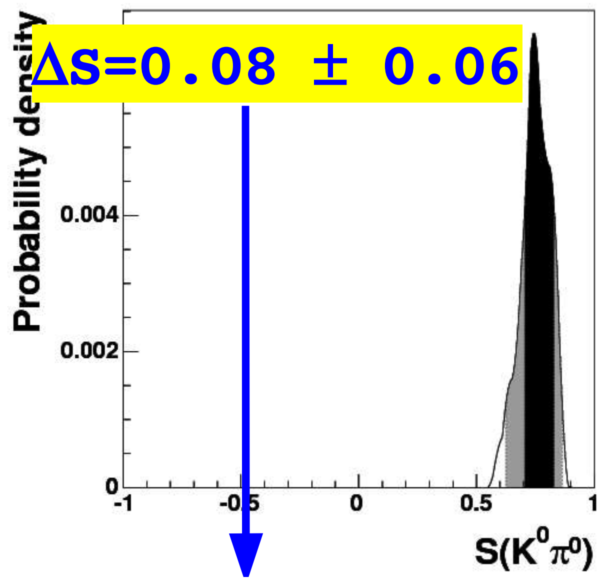
Fit to $B \to K\pi$

Channel	$BR^{th} \times 10^6$	$BR^{exp} \times 10^6$	$\mathcal{A}_{CP}^{th}$	$\mathcal{A}_{CP}^{exp}$
$K^+\pi^-$	20.1 ± 0.6	19.7 ± 0.7	-0.107 ± 0.018	-0.115 ± 0.018
$K^+\pi^0$	12.9 ± 0.5	12.2 ± 0.8	0.00 ± 0.04	0.04 ± 0.04
$K^0\pi^+$	24.9 ± 1.0	25.3 ± 1.4	0.00 ± 0.04	-0.02 ± 0.02
$K^0\pi^0$	9.9 ± 0.4	11.5 ± 1.0	-0.09 ± 0.06	0.02 ± 0.13

P_1=0.071 ± 0.016



ΔS=0.08 ± 0.06



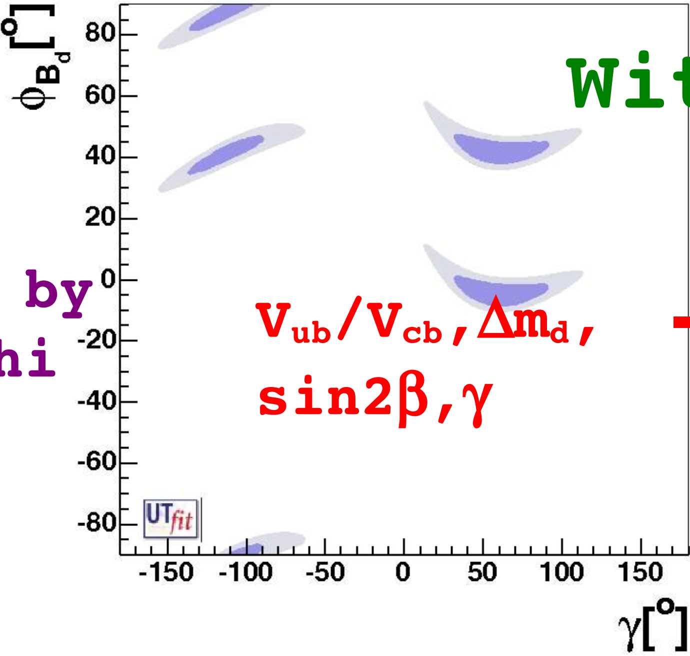
Prediction in the Standard Model (exp error on sin2β not included)

Including the radiative corrections, the discrepancy in the BR is gone. **No more $K\pi$ puzzle!!!!**

What we learn from α

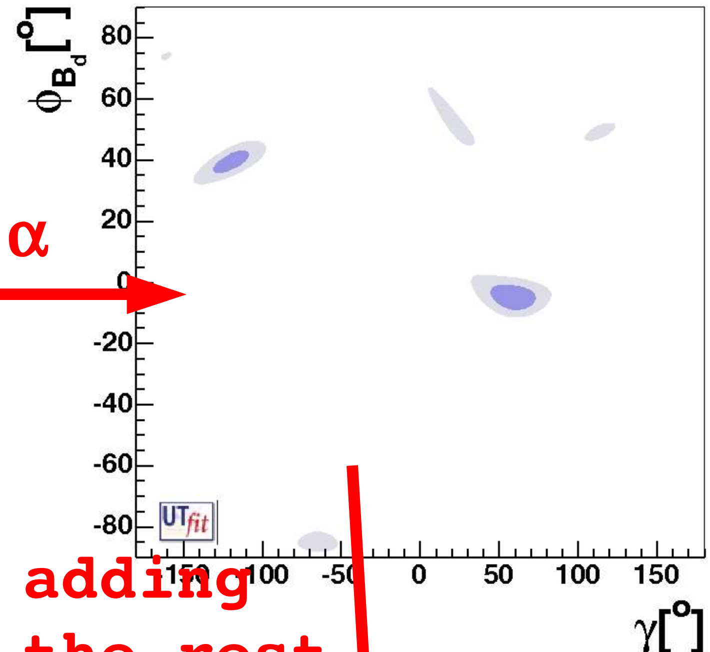
See talk by A.Stocchi

With NP

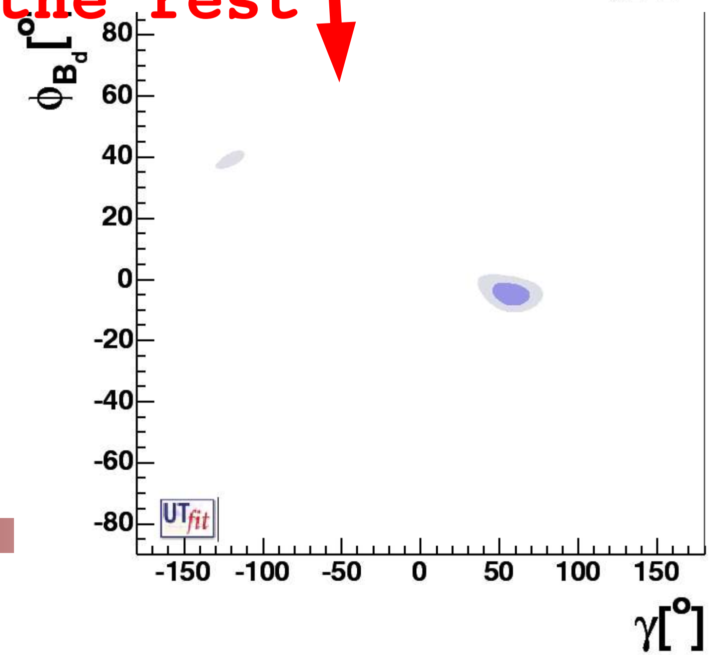


$V_{ub}/V_{cb}, \Delta m_d,$ $\sin 2\beta, \gamma$

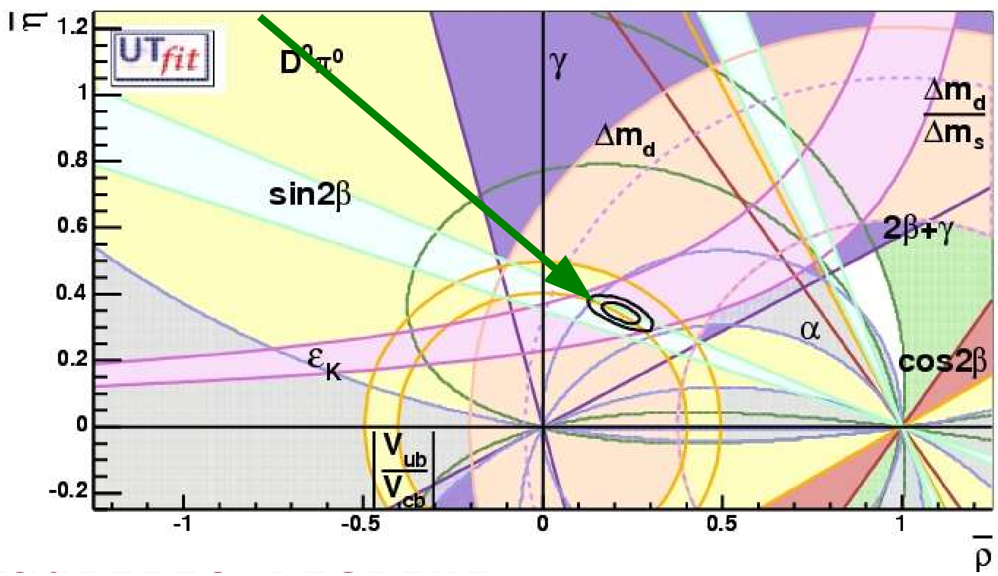
adding α



adding the rest

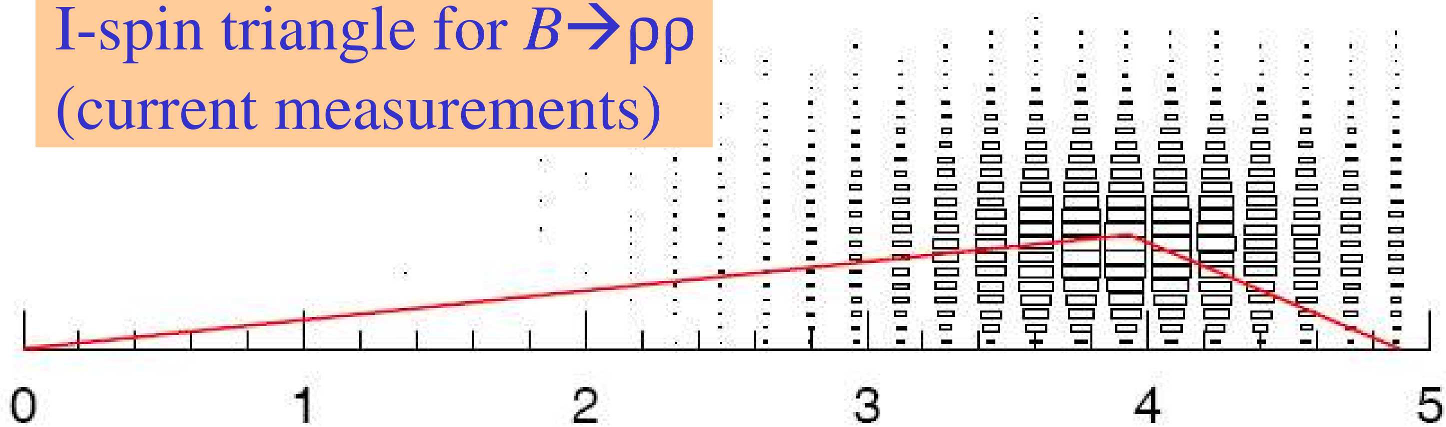


With SM

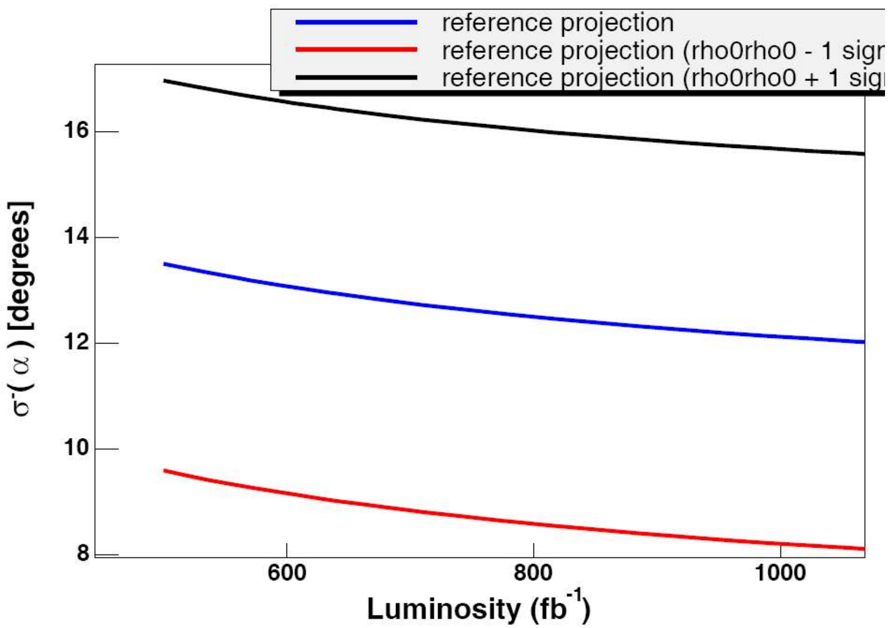


Critical issue for α: $B \to \rho^0\rho^0$

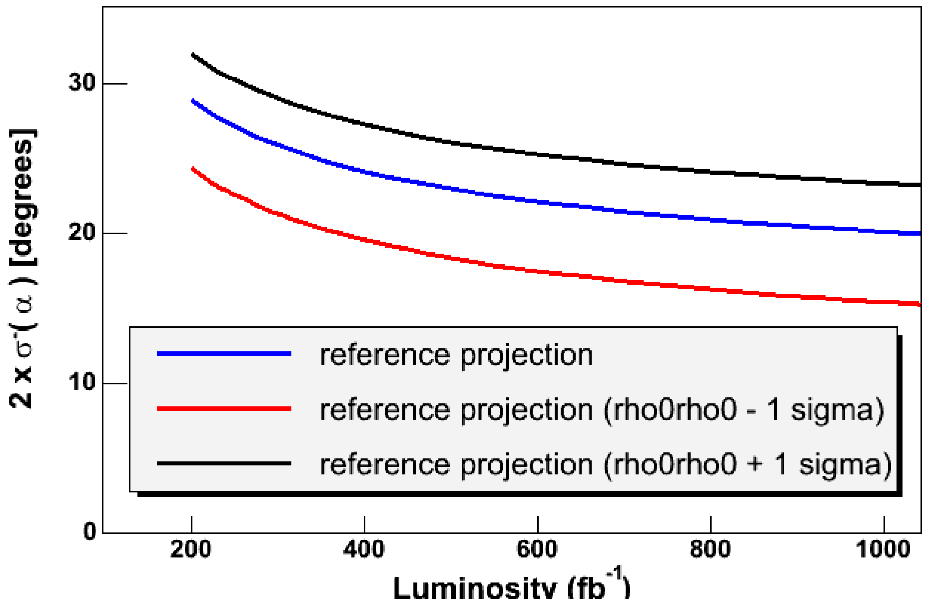
I-spin triangle for $B \to \rho\rho$ (current measurements)



Projected 1σ uncertainties on α



Projected 2σ uncertainties on α



Generalizing the UT_{fit}

Now that we have so many informations, we can fit CKM and NP parameters together (not possible before α and γ measurements)

- $|\varepsilon_K|^{EXP} = C_\varepsilon \cdot |\varepsilon_K|^{SM}$
- $\Delta m_s^{EXP} = C_s \cdot \Delta m_s^{SM}$
- $\alpha^{EXP} = \alpha^{SM} - \phi_{Bd}$
- $\Delta m_d^{EXP} = C_d \cdot \Delta m_d^{SM}$
- $A_{CP}(J/\psi K^0) = \sin(2\beta + 2\phi_{Bd})$

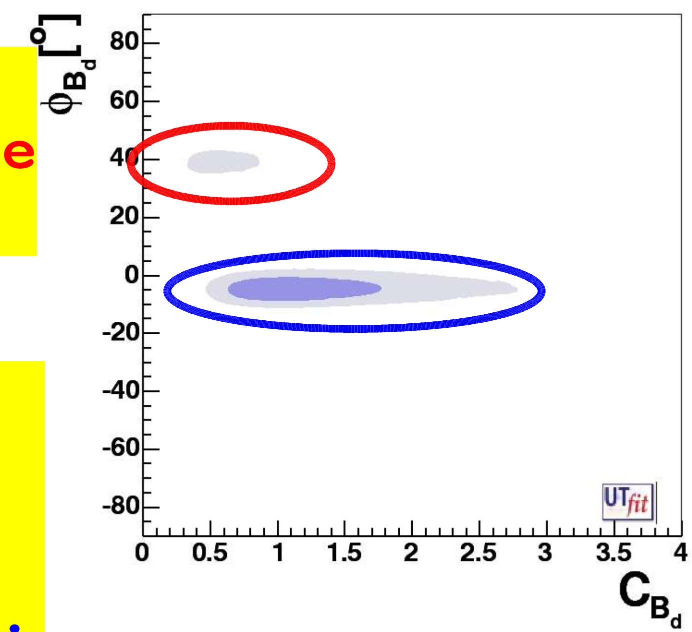
5 unknowns

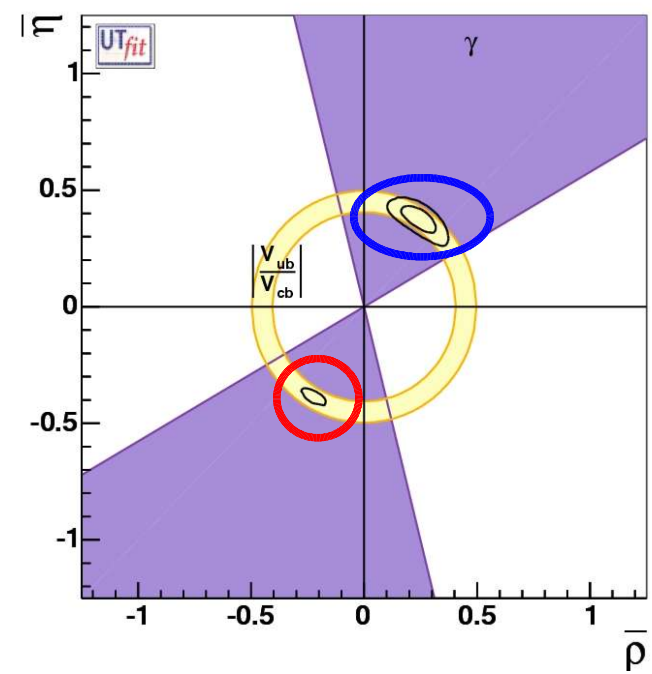
"SM" $\bar{\rho} = 0.246 \pm 0.053$
"NP" [-0.230, -0.212] @ 95% Prob.

"SM" $\bar{\eta} = 0.379 \pm 0.039$
"NP" [-0.398, -0.381] @ 95% Prob.

large NP with arbitrary phase ~4.3% Prob.

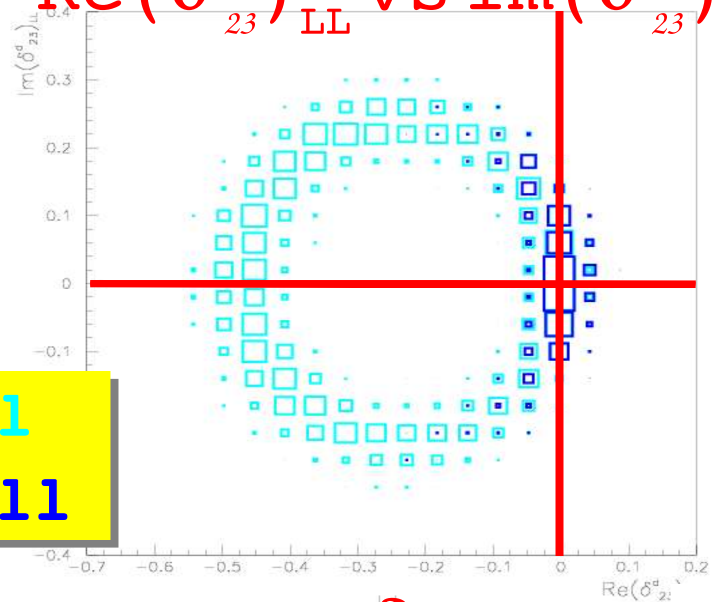
SM, or small NP with arbitrary phase, or large NP with SM phase ~95.7% Prob.



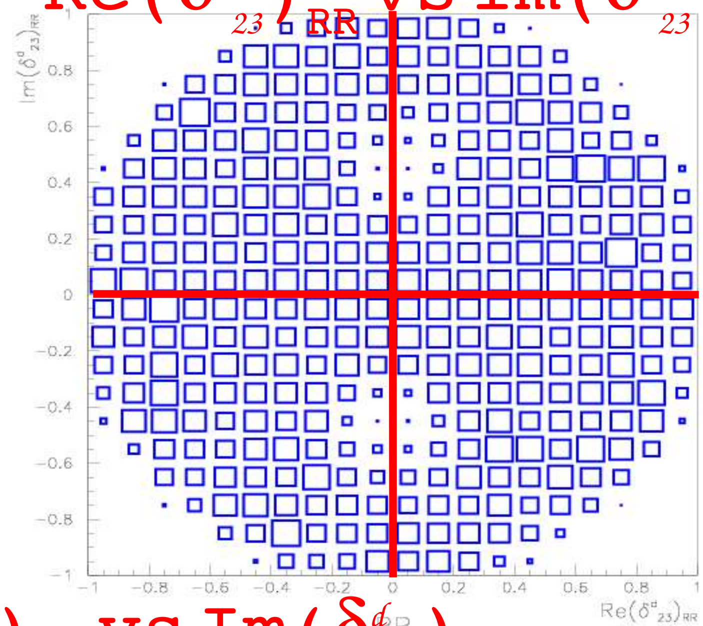


NP in b→s processes

$Re(\delta^d_{23})_{LL}$ vs $Im(\delta^d_{23})_{LL}$



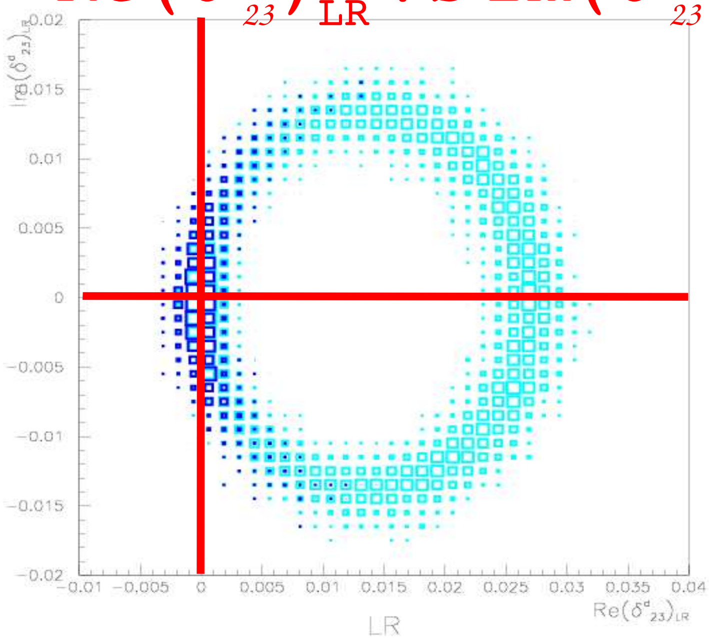
$Re(\delta^d_{23})_{RR}$ vs $Im(\delta^d_{23})_{RR}$



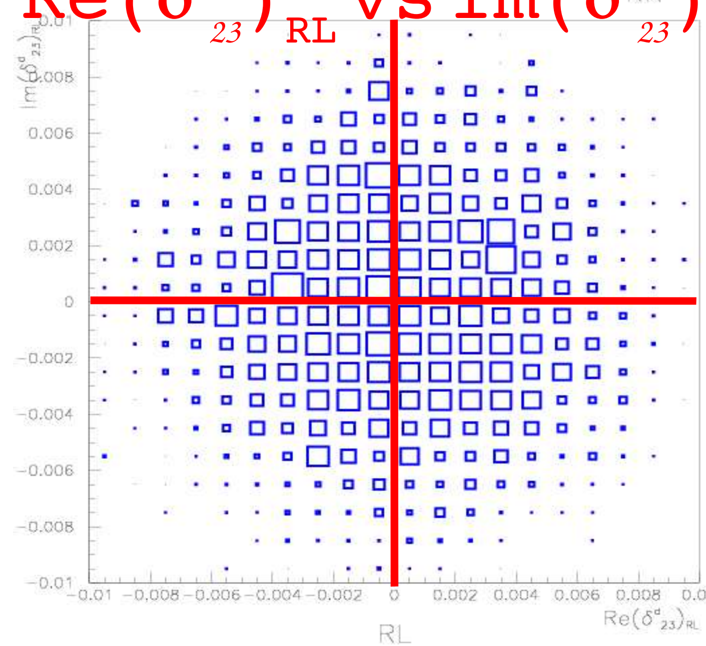
No b→sll

With b→sll

$Re(\delta^d_{23})_{LR}$ vs $Im(\delta^d_{23})_{LR}$



$Re(\delta^d_{23})_{RL}$ vs $Im(\delta^d_{23})_{RL}$



α from $B \to \pi^+\pi^-\pi^0$

Not a CP eigenstates $\Rightarrow$ pentagonal relations

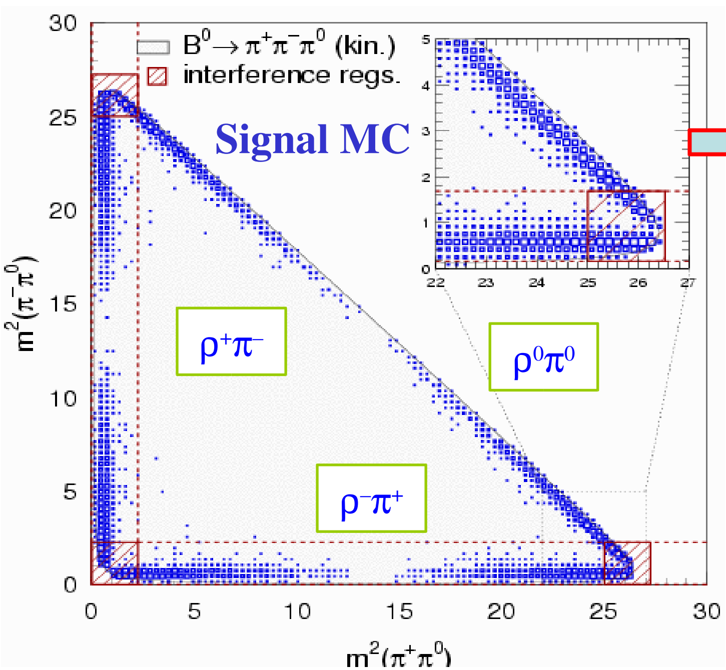
A. Snyder and H. Quinn, PRD, 48, 2139 (1993)

EWP neglected: 12 unknowns for 13 observables $\Rightarrow$ in principle possible

Unfruitful with the present statistics: current data does not constraint α

Time dependent Dalitz analysis assuming Isospin symmetry

use relativistic Breit-Wigner form factors



Interference between the ρ resonances at equal masses-squared gives information on **strong phases** between resonances $\Rightarrow$ **α can be constrained without ambiguity**

Direct CP asymmetries:

$$A_{\rho\pi}^{+-} = \frac{|\kappa^{+-}|^2 - 1}{|\kappa^{+-}|^2 + 1}$$

$$A_{\rho\pi}^{-+} = \frac{|\kappa^{-+}|^2 - 1}{|\kappa^{-+}|^2 + 1}$$

$$\kappa^{+-} = (q/p)(\overline{A}^-/A^+)$$

$$\kappa^{-+} = (q/p)(\overline{A}^+/A^-)$$