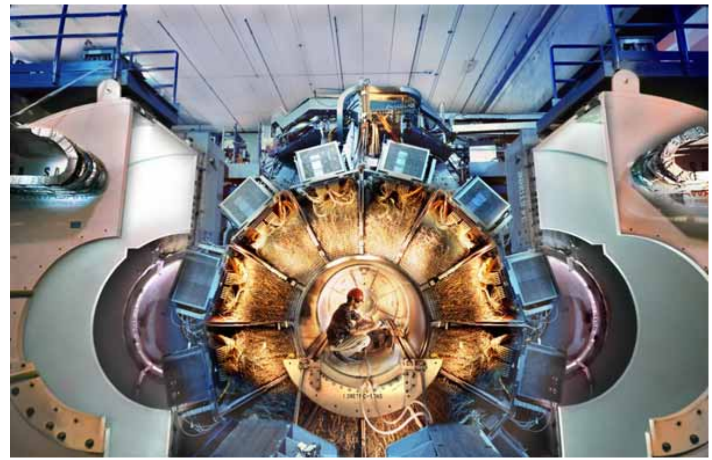
Measurements of the Unitarity Triangle angles at the B factories



Marcella Bona

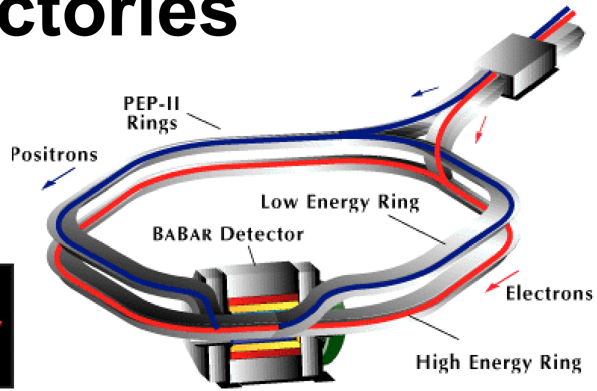
CERN

CERN Seminar
May 27th, 2008

Outline

- very briefly: on detectors and luminosities
- $\sin 2\beta$ from charmonium final states: a precision measurement
  - time for studying the theory error
- α from charmless two-body B decays
  - more complicated: penguins are conspiring
  - BRs and asymmetries of $\pi\pi$ decays
  - also $\rho\rho$ and $\rho\pi$ (direct extraction of α)
- γ from DK tree decays:
  - (almost) new physics free
  - unexpected precision from the B factories
- using the angles to constrain NP

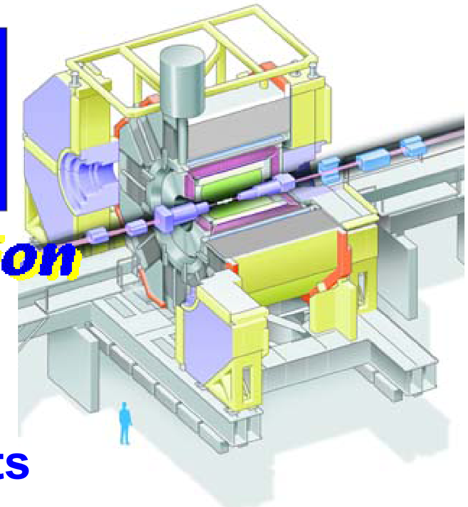
B factories



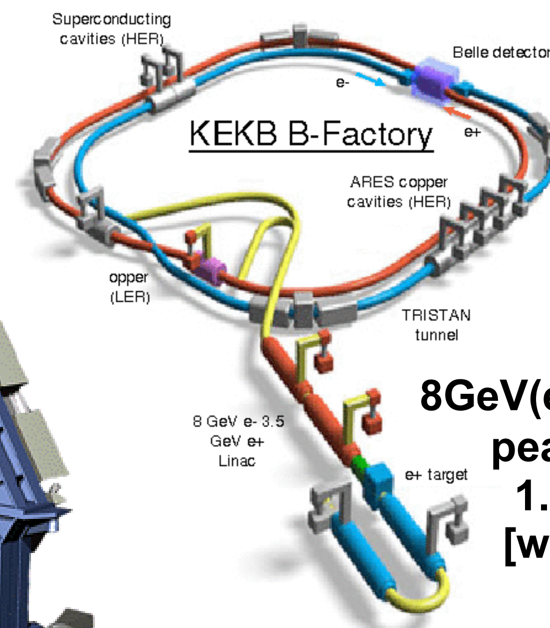
PEP-II
ASYMMETRIC B FACTORY
SLAC/LBL/LLNL

9GeV(e^-) →← 3.1GeV(e^+)
peak luminosity
1.2 10^{34} $cm^{-2}s^{-1}$

BELLE
Belle Collaboration



13 countries
57 institutes
~400 physicists



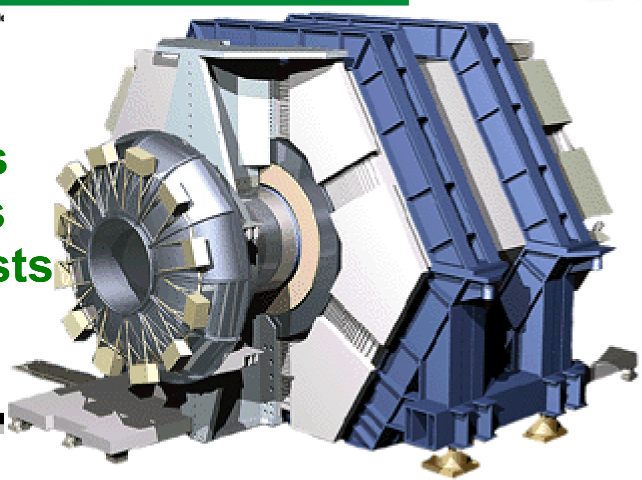
KEKB
uest for CPV
kekb.jp

8GeV(e^-) →← 3.5GeV(e^+)
peak luminosity
1.7 10^{34} $cm^{-2}s^{-1}$
[world record]

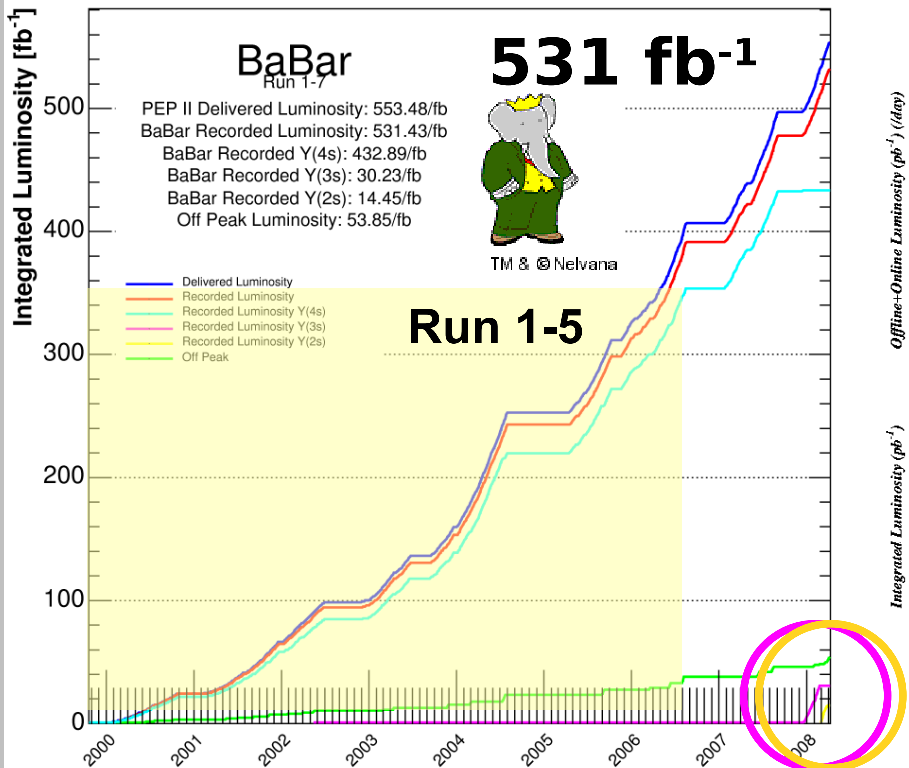
BABAR

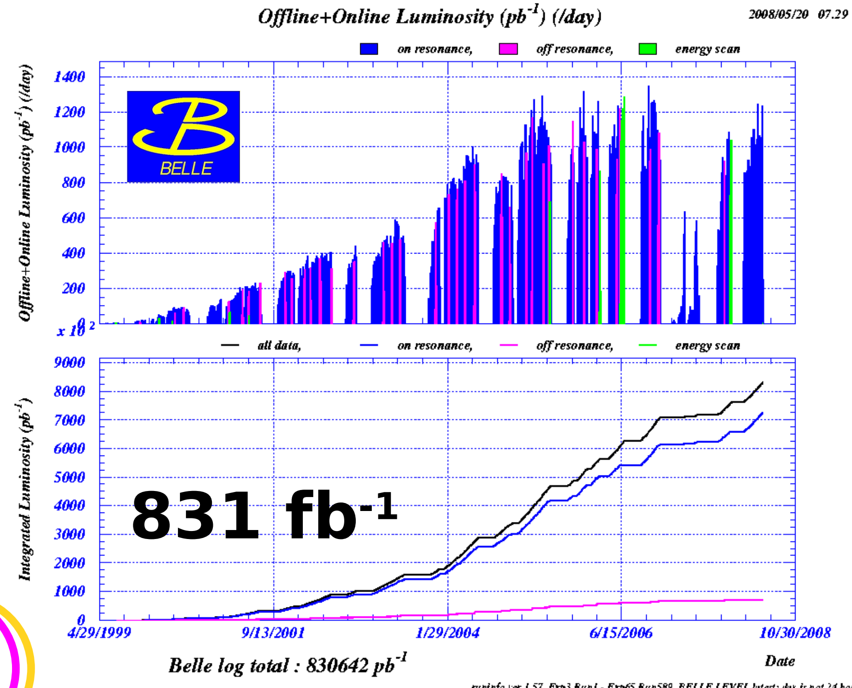
™ and © Ne

11 countries
80 institutes
623 physicists



B factory data



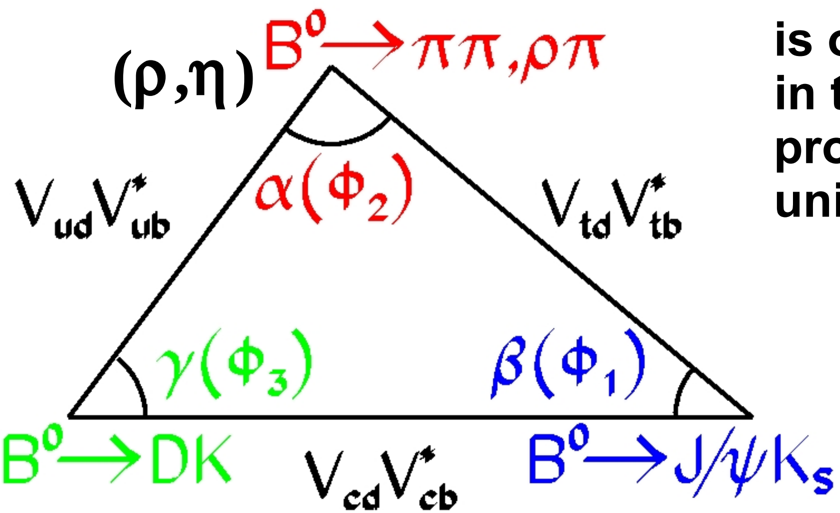


- **BaBar** Υ(4S) run concluded on December 21st 2007
  - then scan on Υ(3S) and Υ(2S)
- final collision at 12:43pm Monday 7 April 2008
  - after almost 9 years and more than 345 papers

CP violation in the Standard Model

- The CP symmetry is violated in any field theory having in the Lagrangian at least one phase that cannot be re-absorbed
- The mass eigenstates are not eigenstates of the weak interaction. This feature of the Standard Model Hamiltonian produces the (unitary) mixing matrix V_{CKM}.

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \approx \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\bar{\rho}-i\bar{\eta}) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\bar{\rho}-i\bar{\eta}) & -A\lambda^2 & 1 \end{pmatrix}$$



- With three families of quarks, there is one phase that allows CP violation in the SM. All the flavour mixing processes are related (through the unitarity of the V_{CKM}) to this phase.

Unitarity Triangle

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

All the angles are related to the CP asymmetries of specific B decays

Three types of CP violation

- Three interference effects can be observed:
  - CP violation in the mixing ($|q/p| \neq 1$)
  - (direct) CP violation in the decays ($|\bar{A}/A| \neq 1$)
  - (indirect) CP violation in interference between mixing and decay ($\mathrm{Im}\lambda \neq 0$)

$$|B_L\rangle = p|B^0\rangle + q|\overline{B}^0\rangle$$
$$|B_H\rangle = p|B^0\rangle - q|\overline{B}^0\rangle$$

both neutral and charged B's

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

neutral B's

Direct CP violation

- both charged and neutral B's
- tagging not always necessary (charged and *self-tagging* modes)
  - higher efficiency
- interference between (*at least*) two amplitudes contributing to the same final state

$$A_f = a_1 \exp\left[i(\delta_1 + \phi_1)\right] + a_2 \exp\left[i(\delta_2 + \phi_2)\right]$$

$$\bar{A}_{\bar{f}} = a_1 \exp\left[i(\delta_1 - \phi_1)\right] + a_2 \exp\left[i(\delta_2 - \phi_2)\right]$$

δ_i: strong phase
CP even

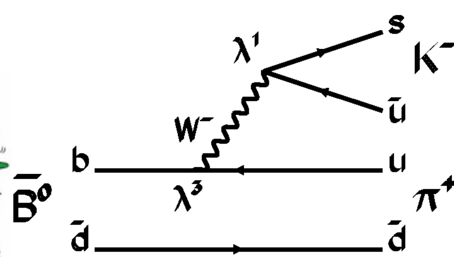
ϕ_i: weak phase
CP odd

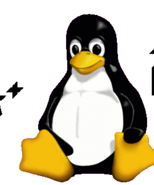
- measured asymmetry is:

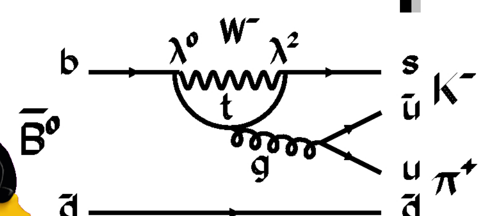
$$A_{CP} \equiv \frac{|\bar{A}_{\bar{f}}|^2 - |A_f|^2}{|\bar{A}_{\bar{f}}|^2 + |A_f|^2} \sim \sum_{i,j} a_i\, a_j \sin(\phi_i - \phi_j) \sin(\delta_i - \delta_j)$$

interesting modes

- $K^+\pi^-$: tree + penguin
- $K^0\pi^+$: pure penguin

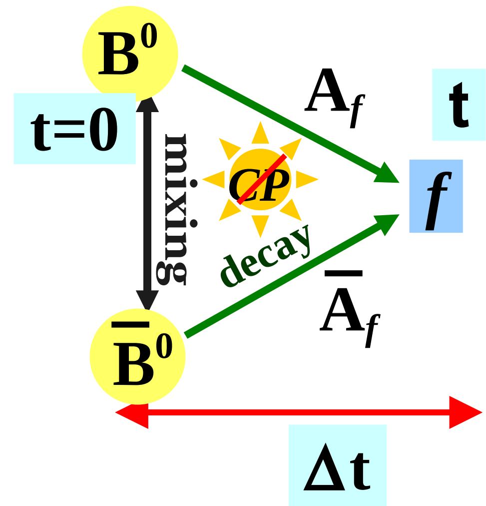






CP violation in interference between mixing and decay

I.Bigi, A.Sanda
Nucl.Phys.B193:85,1981



- decays to a final state f accessible to both B and $\bar{B}$ (f are not necessarily CP eigenstate)
- if Im$\lambda \neq 0$ then $\rightarrow$ CP violation

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

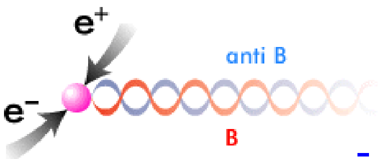
$$\lambda = \frac{q}{p}\frac{A(\bar{B} \rightarrow f)}{A(B \rightarrow f)} = \frac{V_{td}^* V_{tb}}{V_{td} V_{tb}^*}\frac{\bar{A}}{A} \sim e^{-i2\beta}\frac{\bar{A}}{A}$$

β = mixing phase

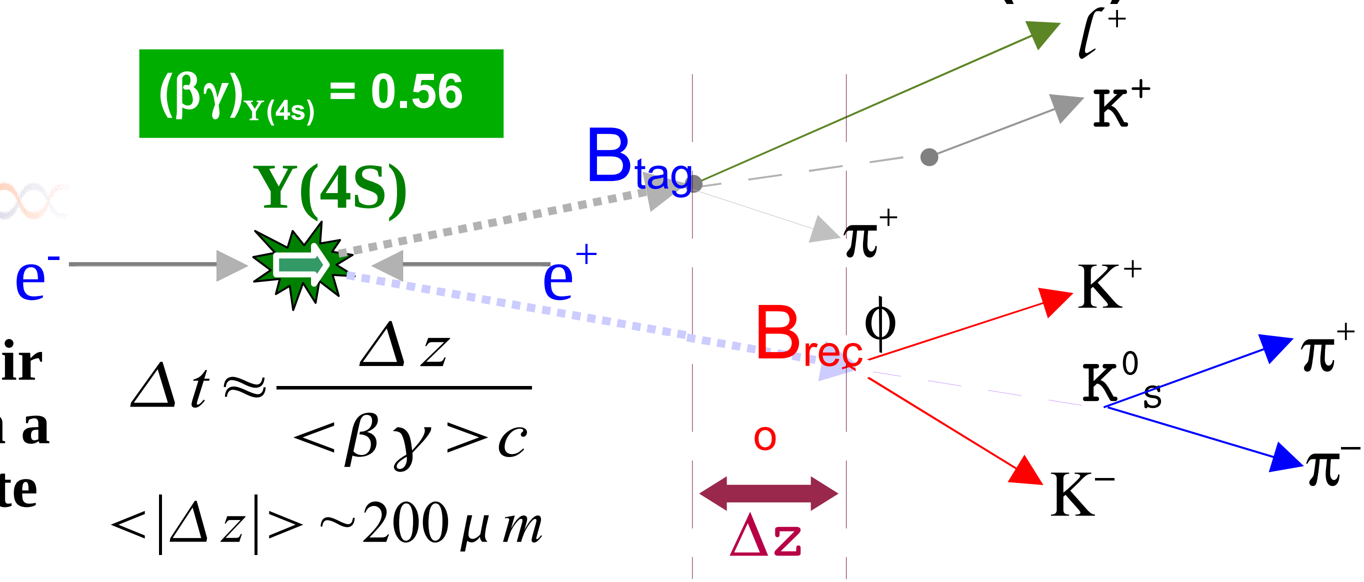
examples

	f	$\mathrm{Arg}(\frac{\bar{A}}{A})$	$\lvert\lambda\rvert$	parameter
mixing	$B^0 \rightarrow l\nu X, D^{(*)}\pi(\rho, a_1)$	0	~ 0	ΔM_{B^0}
"sin 2β"	$B^0 \rightarrow J/\psi K^0$, ...	0	1	$\sin 2\beta$
"sin 2α"	$B^0 \rightarrow \pi\pi$, rr, $\pi\pi\pi$	$\sim(-2\gamma)$	~ 1	$\sin 2\alpha$
"$\sin(2\beta+\gamma)$"	$B^0 \rightarrow D^{(*)}\pi$	$\sim(-\gamma)$	~ 0.02	$\sin(2\beta+\gamma)$

Observation of CP violation at Υ(4S)



B mesons pair oscillating in a coherent state



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

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

Time evolution of the $\bar{B}B$ system (assuming $\Delta\Gamma = 0$)

$$f(\bar{B}^0_{phys} \to f_{CP}, \Delta t) = \frac{\Gamma}{4} e^{-\Gamma|\Delta t|}\left[1 + S_{f_{CP}} \sin(\Delta m_d \Delta t) - C_{f_{CP}} \cos(\Delta m_d \Delta t)\right]$$

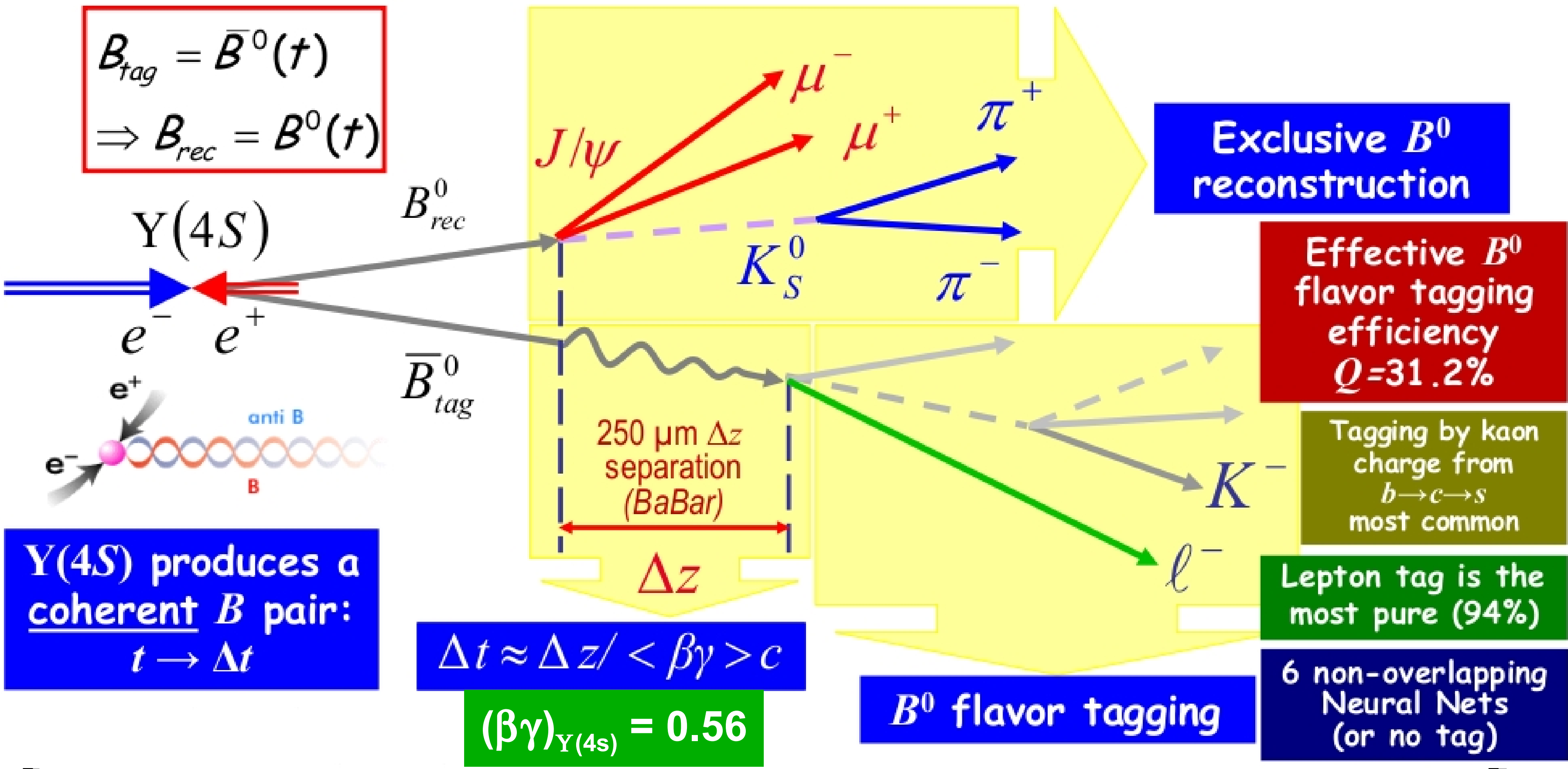
$$f(B^0_{phys} \to f_{CP}, \Delta t) = \frac{\Gamma}{4} e^{-\Gamma|\Delta t|}\left[1 - S_{f_{CP}} \sin(\Delta m_d \Delta t) + C_{f_{CP}} \cos(\Delta m_d \Delta t)\right]$$

- direct CP violation $C \neq 0$
- indirect CP violation $S \neq 0$

$$C_f(= -A_f) = \frac{1 - |\lambda_{f_{CP}}|^2}{1 + |\lambda_{f_{CP}}|^2}$$

$$S_f = \frac{2 Im \lambda_{f_{CP}}}{1 + |\lambda_{f_{CP}}|^2}$$

Time-dependent CP analysis



- $B^0_{rec} = B^0_{flav}$ (flavour eigenstates) ⇒ lifetime, mixing analysis
- $B^0_{rec} = B^0_{flav}$ (CP eigenstates) ⇒ CP analysis

Analysis strategy

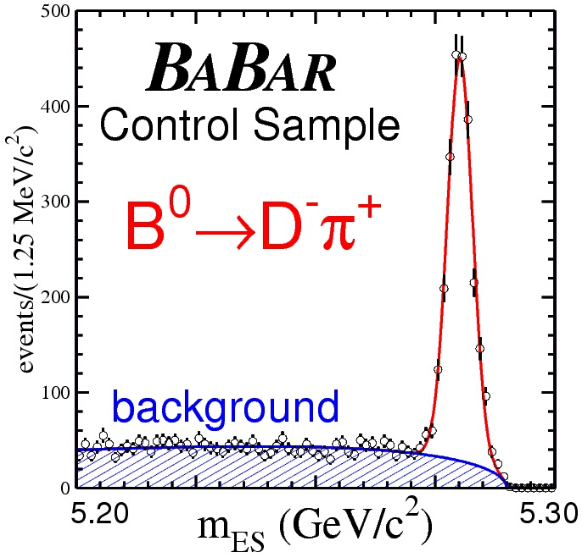
- B-candidate selection through kinematic variables (ΔE, m_{ES})
- background fighting: against continuum light-quark production
  - ➔ topological variables
- particle identification: K/π separation
- maximum likelihood fits

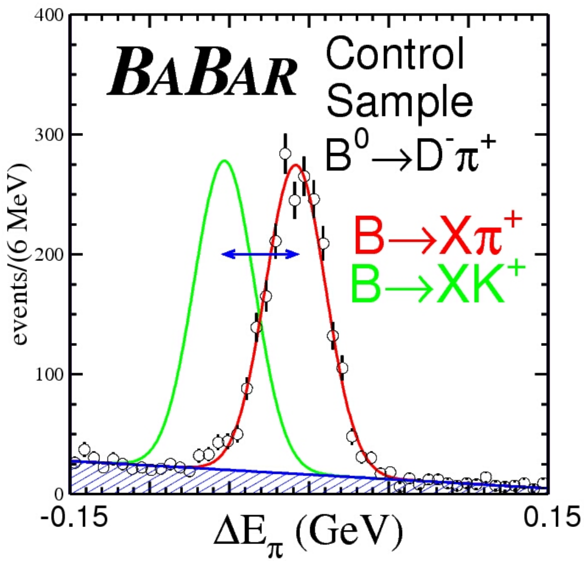
- signal BRs ranging from ~ 10^{-3} for $J/\psi K^0$
  to ~ 10^{-6} for $\pi\pi$ decays

- main background contamination from light-quark pair production from the continuum
  - ➔ $\bar{u}u$, $\bar{d}d$, $\bar{s}s$, $\bar{c}c$: total cross section ~ 3.4 nb^{-1} to be compared to 1.1 nb^{-1} for $\Upsilon(4S)$
- background from $\tau\tau$ production or two photons is mainly negligible
- background from other B decays can be important depending on the considered mode

Experimental issues: B selection

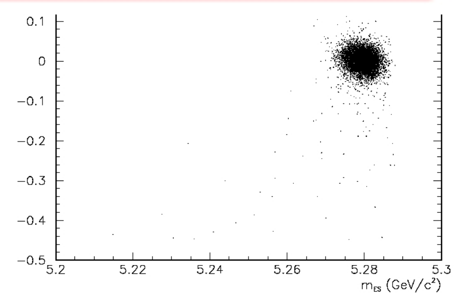
- kinematic variables:
  - ΔE and m_{ES} to be used in the likelihood
  - check the correlation of the variables
  - for example: the presence of a π^0 in the final state requires 2D parameterizations





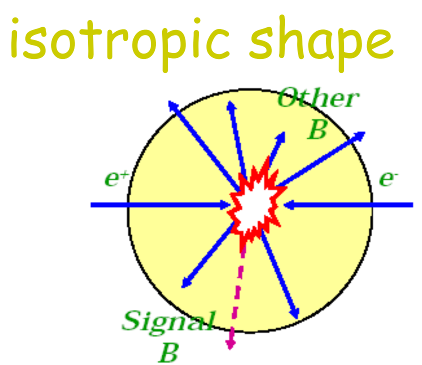
$$m_{ES} = \sqrt{E^{*2}_{\text{beam}} - p^{*2}_B}$$

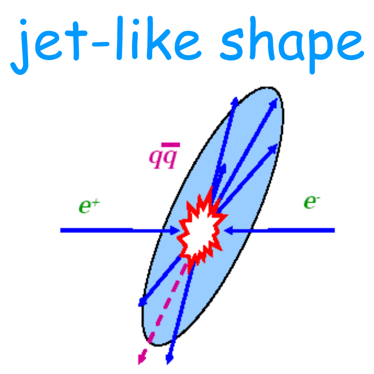
$$\Delta E = E^*_B - \frac{\sqrt{s}}{2}$$

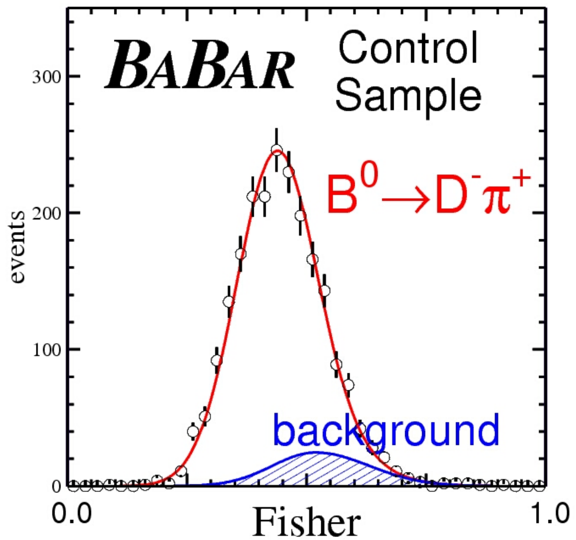


Experimental issues: background

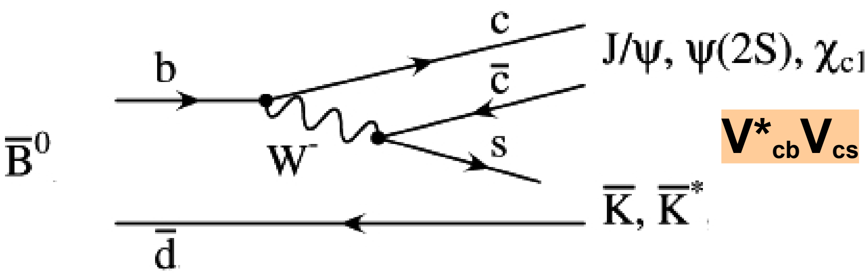
- to isolate the background:
  variables representing the shape of the event:
  - signal: spherical
  - light continuum component: jet-like
  - shape variables are used in linear combination (Fisher discriminant) or Neural Network.
  - We can cut on the final variable or parameterize it to be included in the likelihood



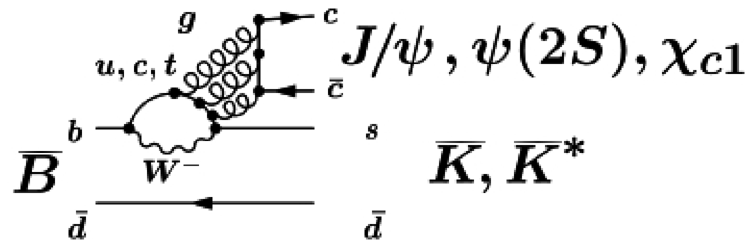




sin2β in golden b → ccs modes



$V^*_{cb}V_{cs}$



- branching fraction: $\mathcal{O}$ (10^{-3})
  the colour-suppressed tree dominates and the t penguin has the same weak phase of the tree

$$A_{CP}(t) = \frac{\Gamma(\bar{B}^0(t) \to f_{CP}) - \Gamma(B^0(t) \to f_{CP})}{\Gamma(\bar{B}^0(t) \to f_{CP}) + \Gamma(B^0(t) \to f_{CP})} = S \sin\Delta m t - C \cos\Delta m t$$

S ~ sin2β
C ~ 0

- theoretical uncertainty:

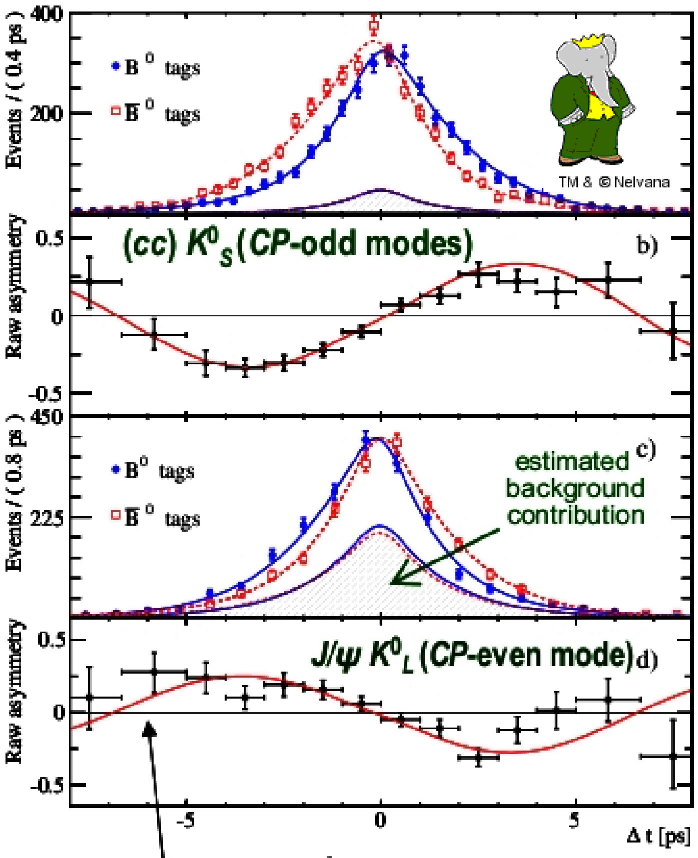
M.Ciuchini, M.Pierini, L.Silvestrini
Phys. Rev. Lett. 95, 221804 (2005)

  - model-independent data-driven estimation from $J/\psi\pi^0$ data:
    $\Delta S_{J/\psi K0} = S_{J/\psi K0} - \sin2\beta = 0.000 \pm 0.012$
  - model-dependent estimates of the u- and c- penguin biases
    $\Delta S_{J/\psi K0} = S_{J/\psi K0} - \sin2\beta \sim \mathcal{O}(10^{-3})$
    $\Delta S_{J/\psi K0} = S_{J/\psi K0} - \sin2\beta \sim \mathcal{O}(10^{-4})$

H.Li, S.Mishima
JHEP 0703:009 (2007)

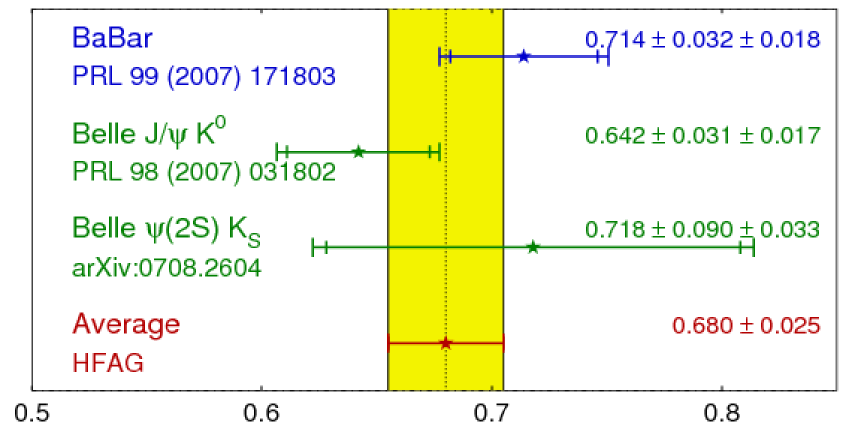
H.Boos et al.
Phys. Rev. D73, 036006 (2006)

Latest sin2β results



raw asymmetry $\frac{N(\overline{B}^0)-N(B^0)}{N(\overline{B}^0)+N(B^0)}$ as function of Δt

$\sin(2\beta) \equiv \sin(2\phi_1)$ HFAG LP 2007 PRELIMINARY



BABAR Collaboration
Phys.Rev.Lett.99:171803(2007)

BaBar with 384 10^6 $\overline{B}B$ pairs

$\sin 2\beta = 0.714 \pm 0.032 \pm 0.018$

Belle with 535 10^6 $\overline{B}B$ pairs

$\sin 2\beta = 0.642 \pm 0.031 \pm 0.017$

Belle Collaboration
Phys.Rev.Lett.98:031802(2007)

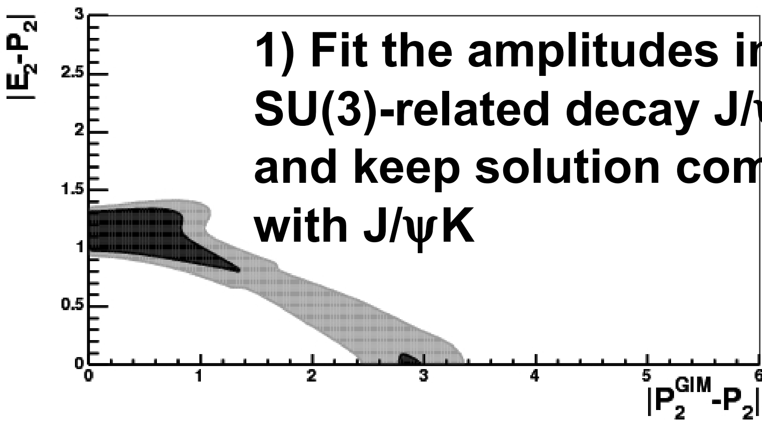
Theory error on sin2β

A.Buras, L.Silvestrini
Nucl.Phys.B569:3-52(2000)

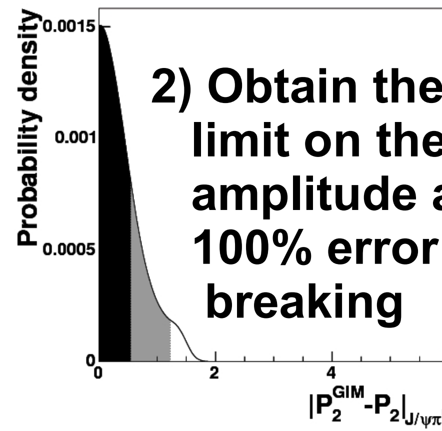
Channel	Cl.	E_1	E_2 $\frac{1}{N}$	EA_2 $\frac{1}{N^2}$	A_2 $\frac{1}{N}$	P_1 $\frac{1}{N}$	P_2 $\frac{1}{N^2}$	P_3	P_1^{GIM} $\frac{1}{N}$	P_2^{GIM} $\frac{1}{N^2}$	P_3^{GIM}	P_4 $\frac{1}{N^3}$	P_4^{GIM} $\frac{1}{N^3}$
$B_d \to J/\psi K^0$	C	–	λ^2	–	–	–	λ^2	–	–	λ^4	[illegible]	–	–
$B_d \to \pi^0 J/\psi$	D	[illegible]	λ^3	λ^3	–	–	λ^3	[illegible]	–	λ^3	[illegible]	$[\lambda^3]$	$[\lambda^3]$

$V^*_{cb}V_{cs}$ $V^*_{tb}V_{ts}$ $V^*_{ub}V_{us}$

$V^*_{cb}V_{cd}$ $V^*_{tb}V_{td}$ $V^*_{ub}V_{ud}$

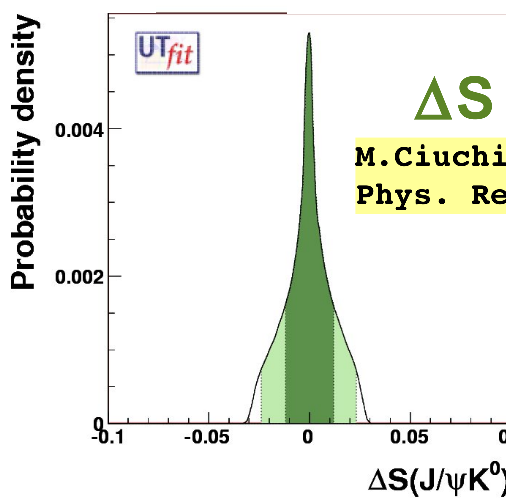


1) Fit the amplitudes in the SU(3)-related decay $J/\psi\pi^0$ and keep solution compatible with $J/\psi K$



2) Obtain the upper limit on the penguin amplitude and add 100% error for SU(3) breaking

3) Fit the amplitudes in $J/\psi K^0$ imposing the upper bound on the CKM suppressed amplitude and extract the error on sin2β

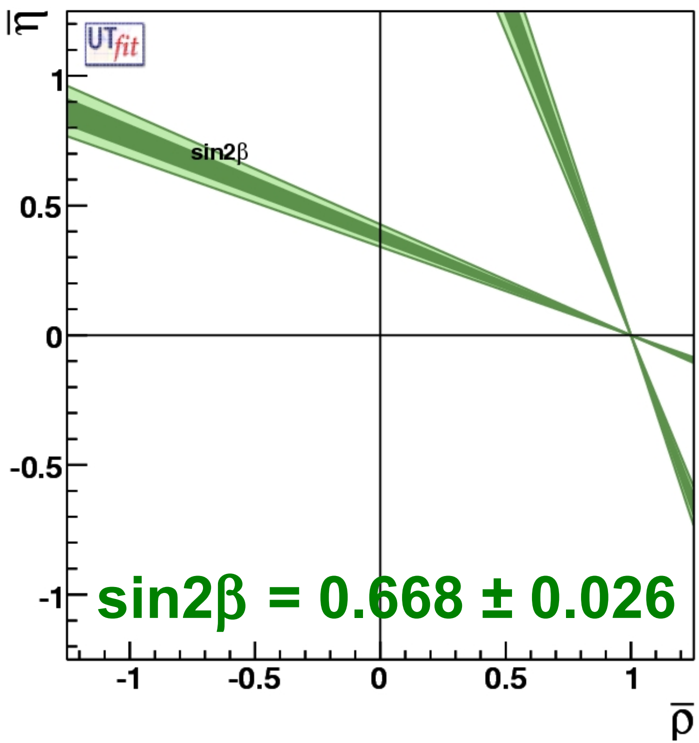


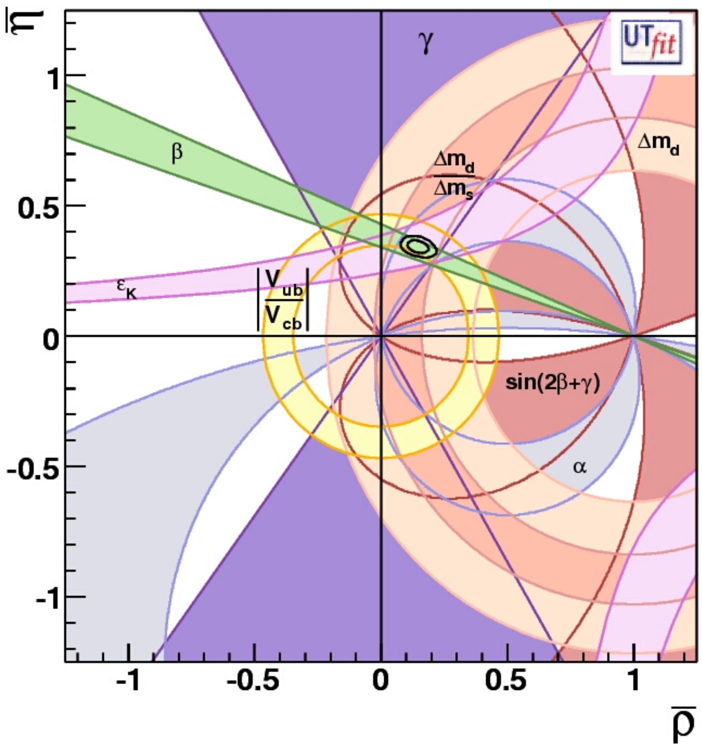
$\Delta S = 0.000 \pm 0.012$

M.Ciuchini, M.Pierini, L.Silvestrini
Phys. Rev. Lett. 95, 221804 (2005)

sin2β from J/ψK⁰ is the most effective constraint

UTfit Collaboration
http://wwww.utfit.org





- only $J/\psi K^0$ is included
- the estimate on the theory error from Ciuchini *et al* is used

Kill the ambiguity: cos2β measurements

- measurements of (sign)cos2β in:
  - $B^0 \to J/\psi K^{*0}$ **BABAR Collaboration Phys.Rev.D71:032005(2005)**

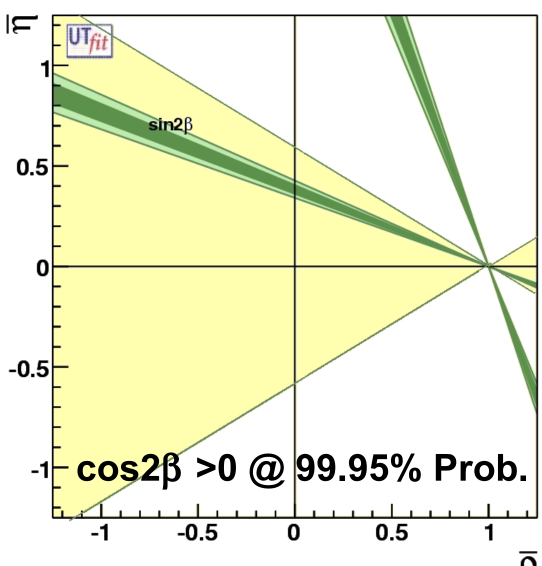
    cos2β >0 @ 86.6% CL
  - $B^0 \to D^{(*)0}h^0$ **BABAR Collaboration Phys.Rev.Lett.99:231802(2007)**

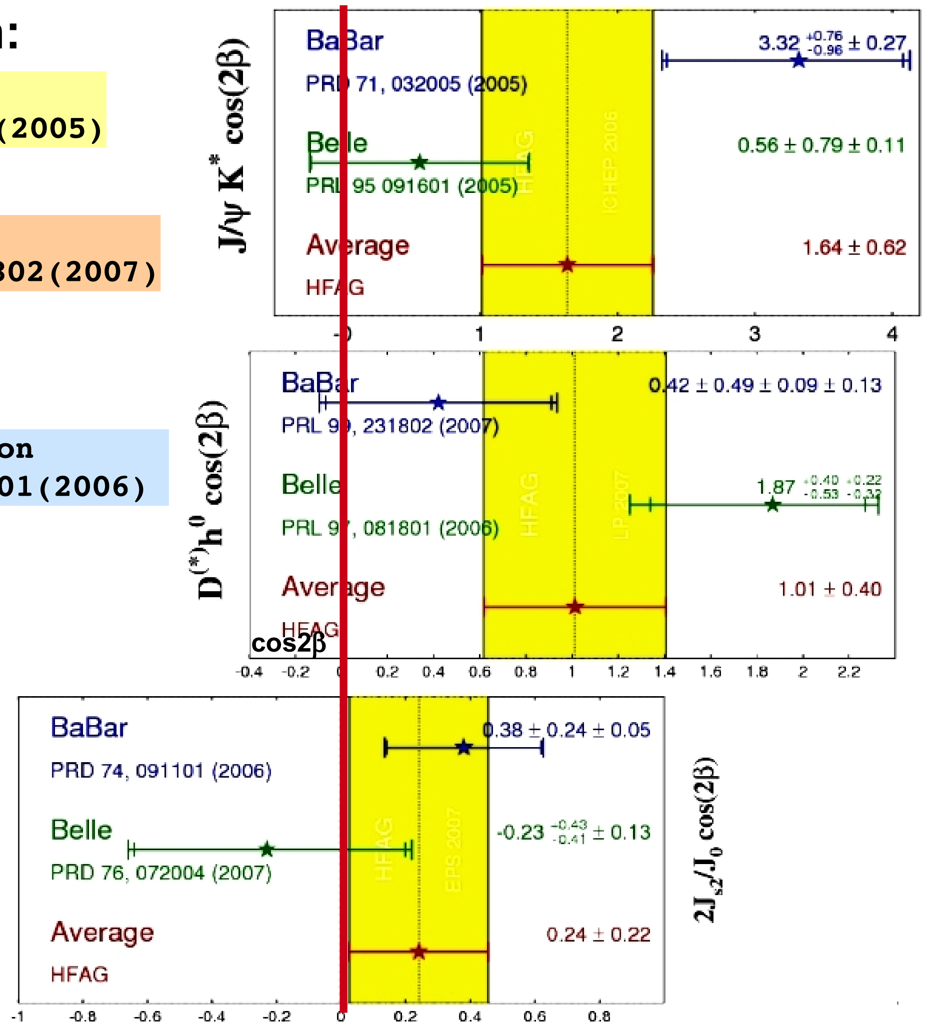
    with h = π^0, η, η', ω

    cos2β >0 @ 87% CL
  - $B^0 \to D^{*+}D^{*-}K^0_S$ **BABAR Collaboration Phys.Rev.D74:091101(2006)**

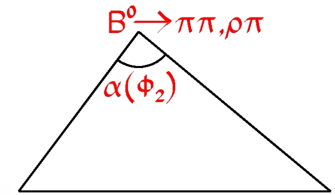
    cos2β >0 @ 94% CL

TM & © Nelvana





α: CP violation in $B^0 \rightarrow \pi^+\pi^-$



- considering the tree (T) only:

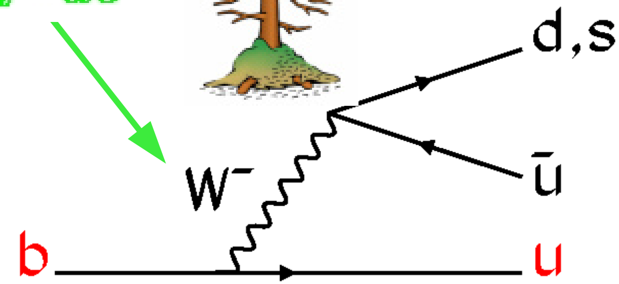
  $\lambda_{\pi\pi} = e^{2i\alpha}$

  $C_{\pi\pi} = 0$

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

$$\lambda_{\pi\pi} = \frac{V_{tb}^* V_{td}}{V_{tb} V_{td}^*} \frac{V_{ud}^* V_{ub}}{V_{ud}^* V_{ub}}$$

mixing

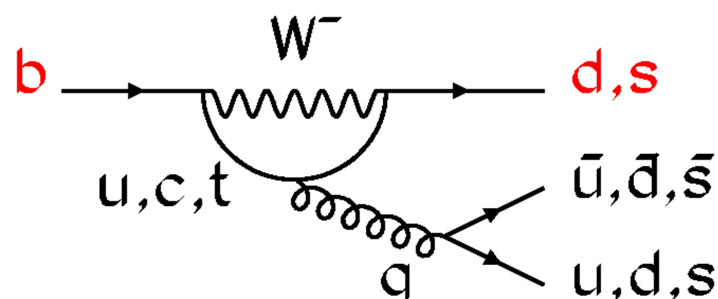


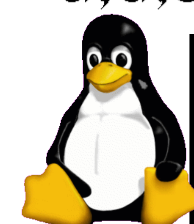
- adding the penguins (P):

$$\lambda_{\pi\pi} = e^{2i\alpha} \frac{1 + |P/T| e^{i\delta} e^{i\gamma}}{1 + |P/T| e^{i\delta} e^{-i\gamma}}$$

$$C_{\pi\pi} \propto \sin(\delta)$$

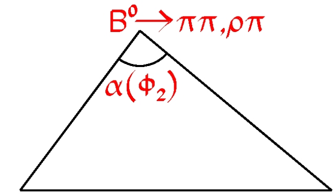
$$S_{\pi\pi} = \sqrt{1 - C_{\pi\pi}^2} \sin(2\alpha_{eff})$$





ππ and ρρ from the same diagrams

α: collecting the ingredients

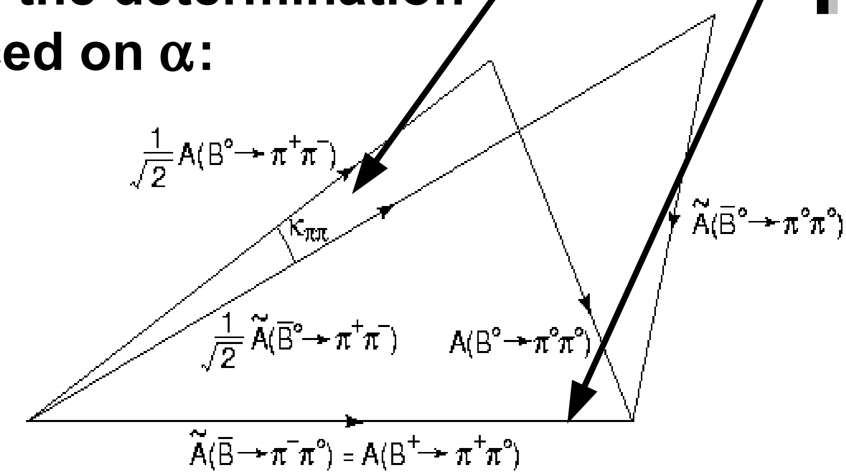


from $\alpha_{eff} \to$ to α: isospin analysis

- $B \to \pi^+\pi^-$, $\pi^+\pi^0$, $\pi^0\pi^0$ decays are connected from isospin relations
- ππ states can have I = 2 or I = 0
  - the gluonic penguins contribute only to the I = 0 state (ΔI=1/2)
  - $\pi^+\pi^0$ is a pure I = 2 state (ΔI = 3/2) and it gets contribution only from the tree diagram
  - triangular relations allow for the determination of the phase difference induced on α:

$$2\alpha_{eff} = 2\alpha + \kappa_{\pi\pi}$$

$$|A^{+0}| = |A^{-0}|$$



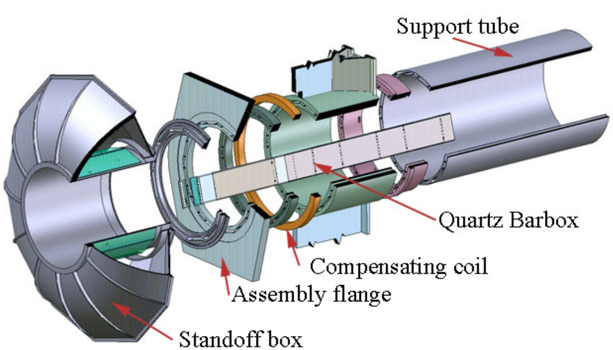
Both BR(B^0) and BR($\bar{B}^0$) have to be measured in all the ππ channels

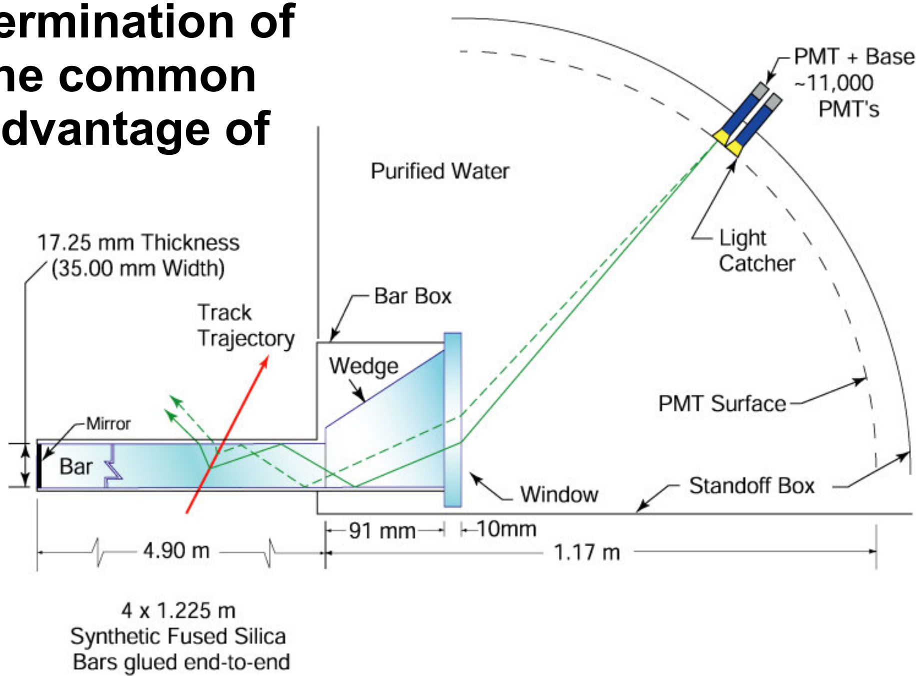
Analysis addendum for charmless two-body decays

- in BaBar: for charmless two-body decays, simultaneous ML fit to all the final states that differ only of a charged kaon or pion:
  - e.g: $\pi^+\pi^-$, $K^+\pi^-$, $K^-\pi^+$, K^+K^-
- this allows for a better determination of both the background and the common signal parameters, taking advantage of the mode with more statistics (e.g.: $K\pi$)

TM & © Nelvana

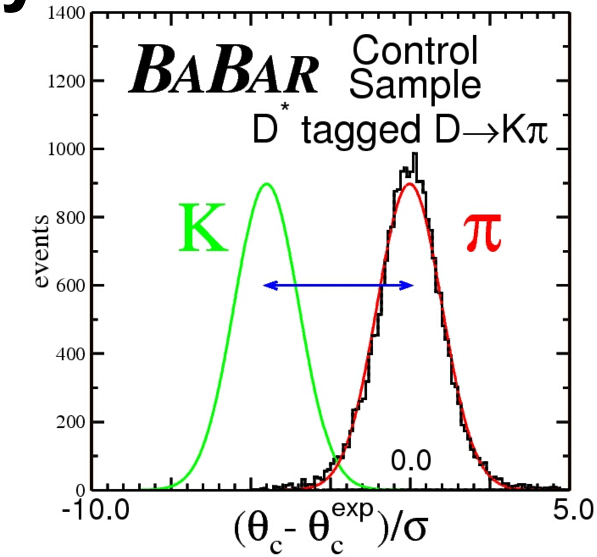
Detector of Internally Reflected Cherenkov light (DIRC)

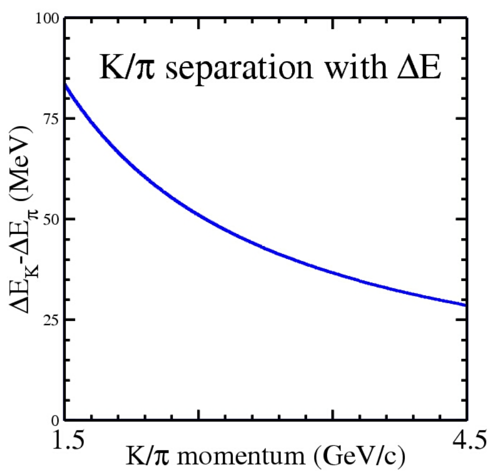


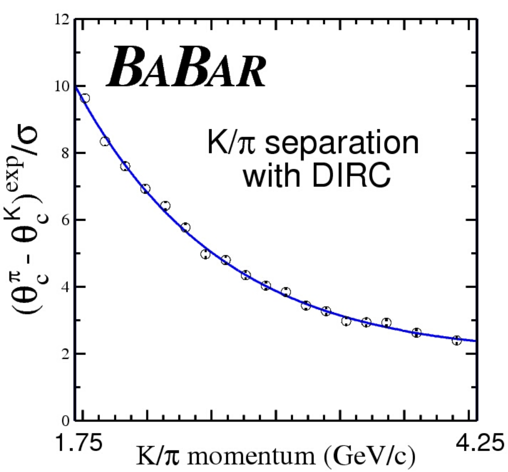


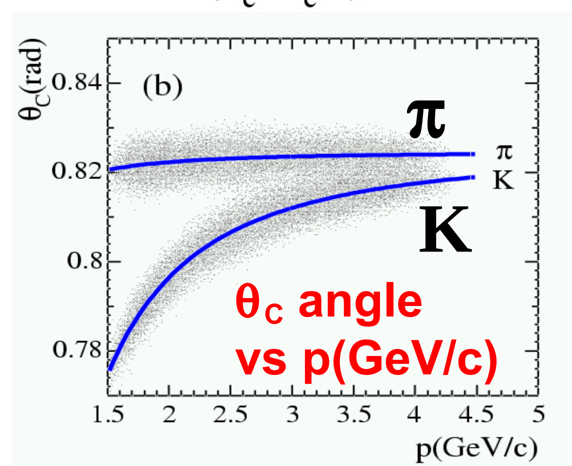
Analysis addendum for charmless two-body decays

- K/π separation is therefore essential: the DIRC is key in these analyses
  - hh: momentum region [1.5, 4.5] GeV/c
  - 13σ separation at 1.5 GeV/c
    2.5σ separation at 4.5 GeV/c
  - the dE/dx information from the Drift Chamber is used outside the DIRC acceptance [hh: 35% yield increase]



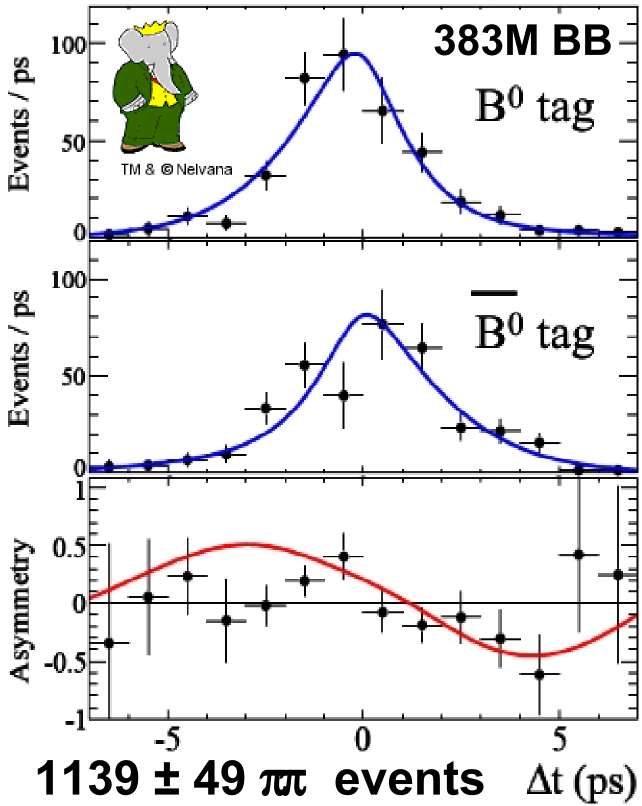




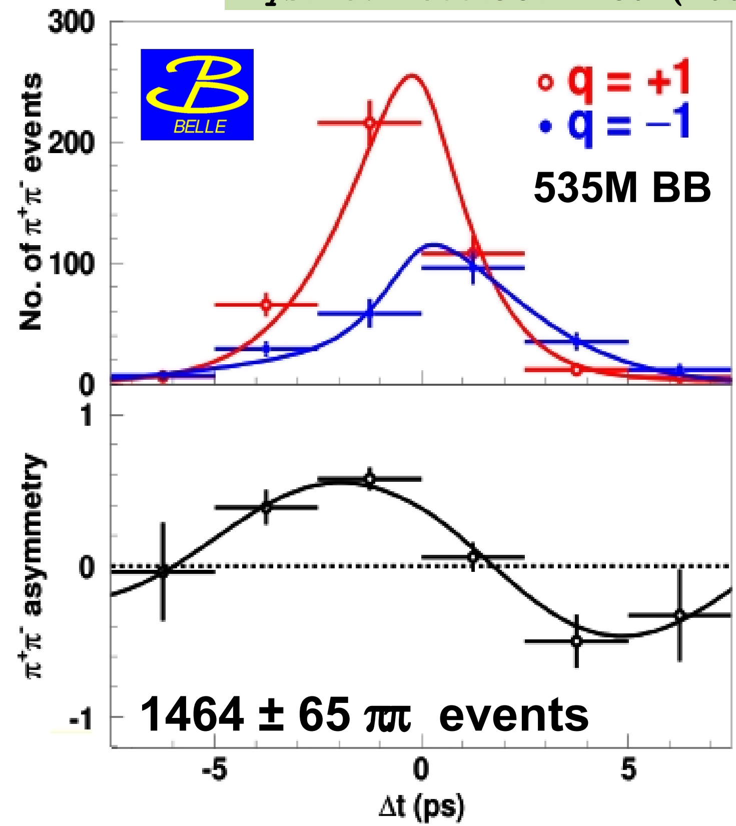


Towards α: time-dependent analysis of ππ

BABAR Collaboration
Phys.Rev.Lett.99:021603(2007)



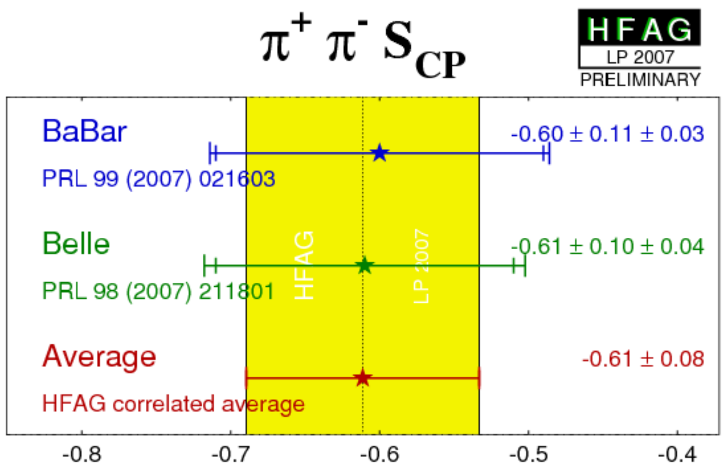
Belle Collaboration
Phys.Rev.Lett.98:211801(2007)

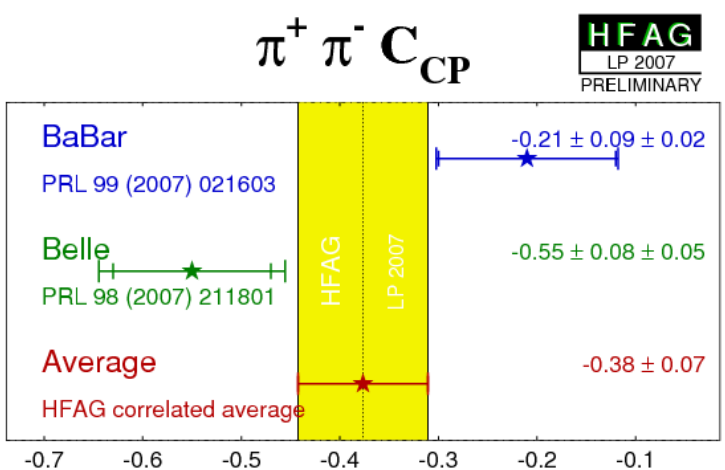


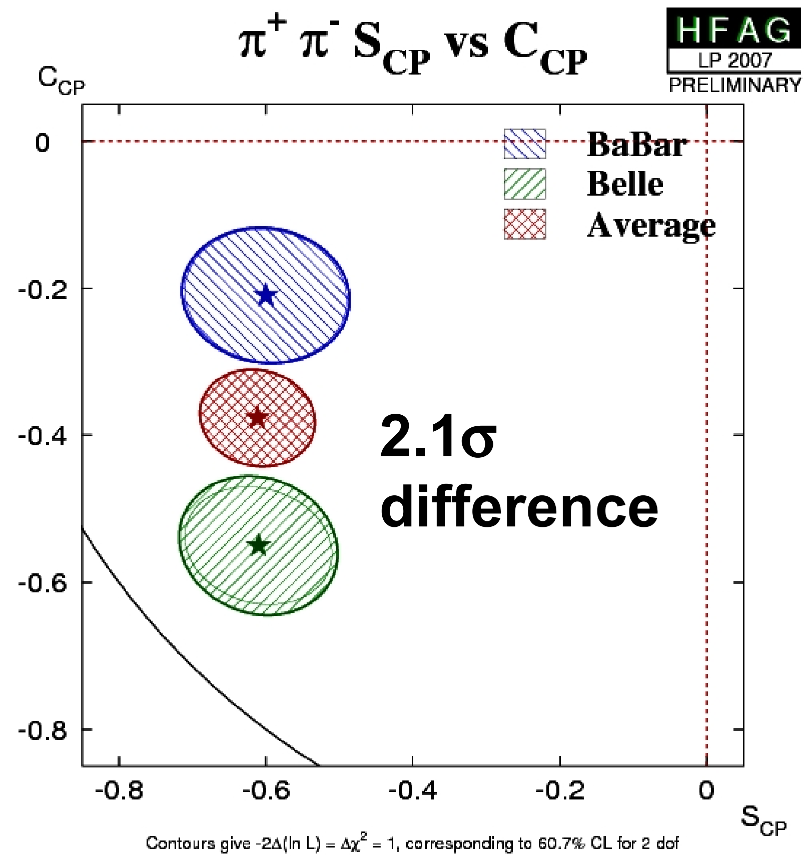
$S_{\pi\pi} = -0.60 \pm 0.11 \pm 0.03$ (5.1σ)
$C_{\pi\pi} = -0.21 \pm 0.09 \pm 0.02$ (2.2σ)

$S_{\pi\pi} = -0.61 \pm 0.10 \pm 0.04$ (5.3σ)
$C_{\pi\pi} = -0.55 \pm 0.08 \pm 0.05$ (5.5σ)

Towards α: the world average for ππ

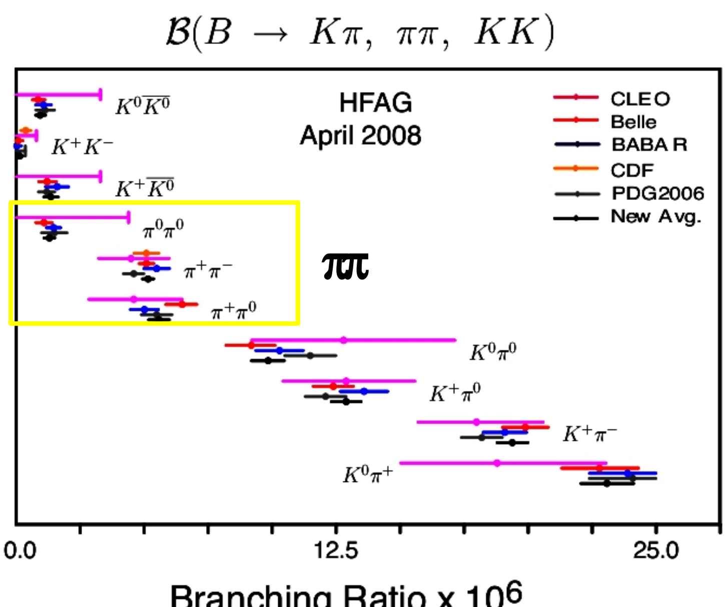


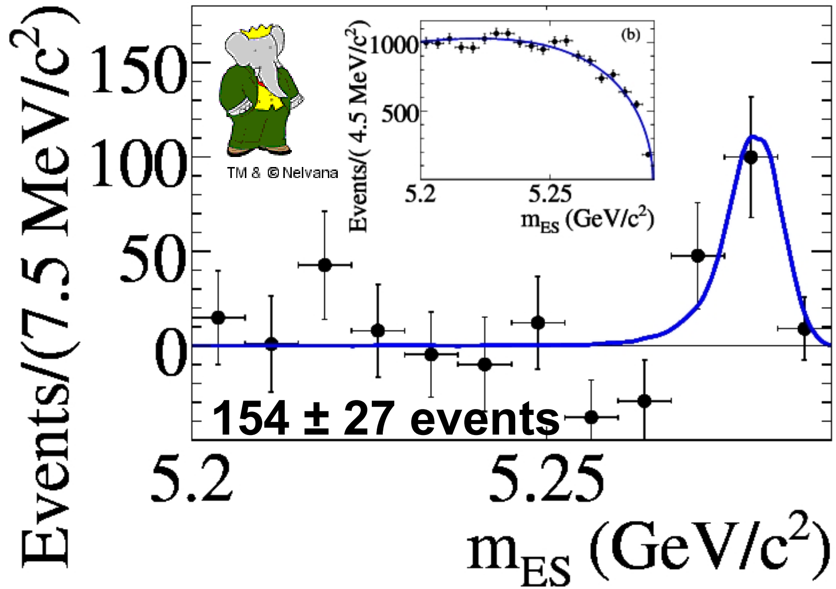




Towards α: isospin-related ππ decays

- simultaneous ML fit to:
  - $B^+ \to \pi^+\pi^0$, $K^+\pi^0$ (and cc)
- π^0 recovery: (4%+6%)
  - merged π^0: when the two photons are too close in the calorimeter to be reconstructed individually
  - $\gamma \to e^+e^-$ conversion: from interaction with detector



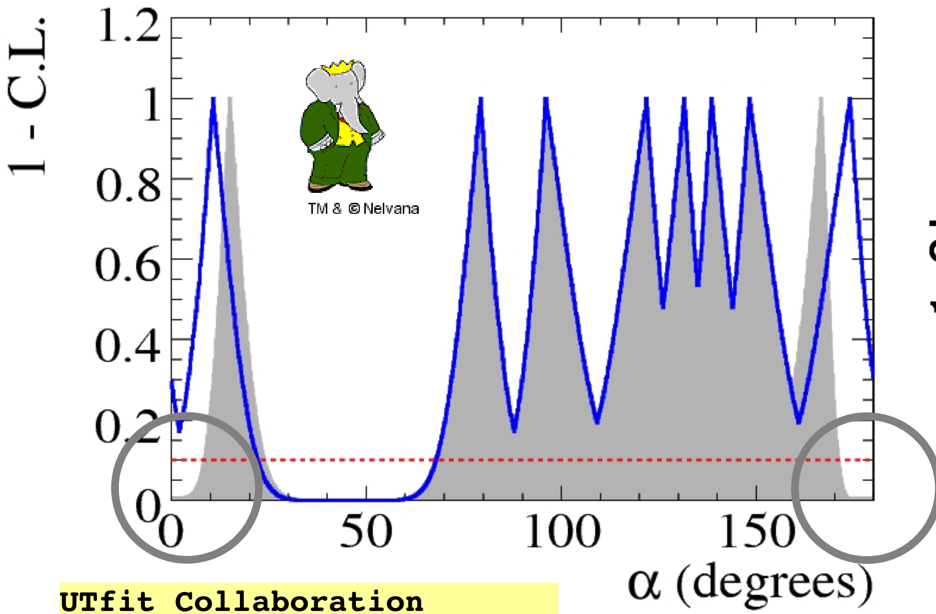


$BR(\pi^+\pi^-) = (5.2 \pm 0.2) \cdot 10^{-6}$
$BR(\pi^+\pi^0) = (5.6 \pm 0.4) \cdot 10^{-6}$
$BR(\pi^0\pi^0) = (1.3 \pm 0.2) \cdot 10^{-6}$

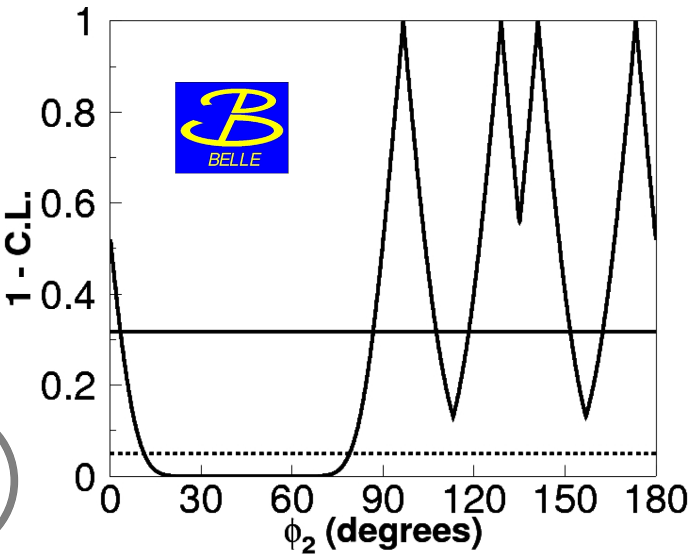
BABAR Collaboration
Phys.Rev.D76:091102(2007)

Belle Collaboration
Phys.Rev.Lett.99:121601(2007)

At last: α from ππ decays



UTfit Collaboration
Phys.Rev.D76:014015(2007)

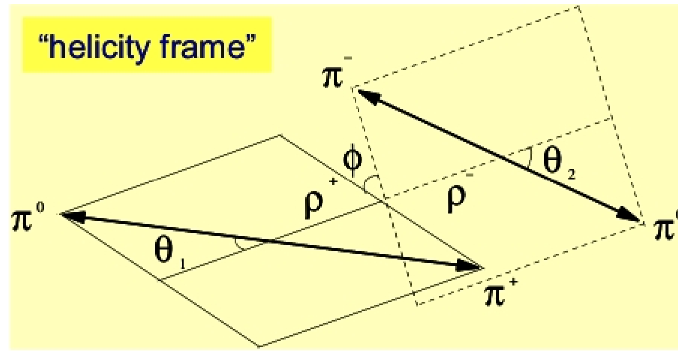


BaBar: 25° < α < 66° excluded @ 90% CL

Belle: 11° < α < 79° excluded @ 95% CL

But there is more: α from $\rho\rho$ decays

- Vector-Vector modes: angular analysis required to determine the CP content. L=0,1,2 partial waves:
  - longitudinal: CP-even state
  - transverse: mixed CP states
- +-: two π^0 in the final state
- wide ρ resonance



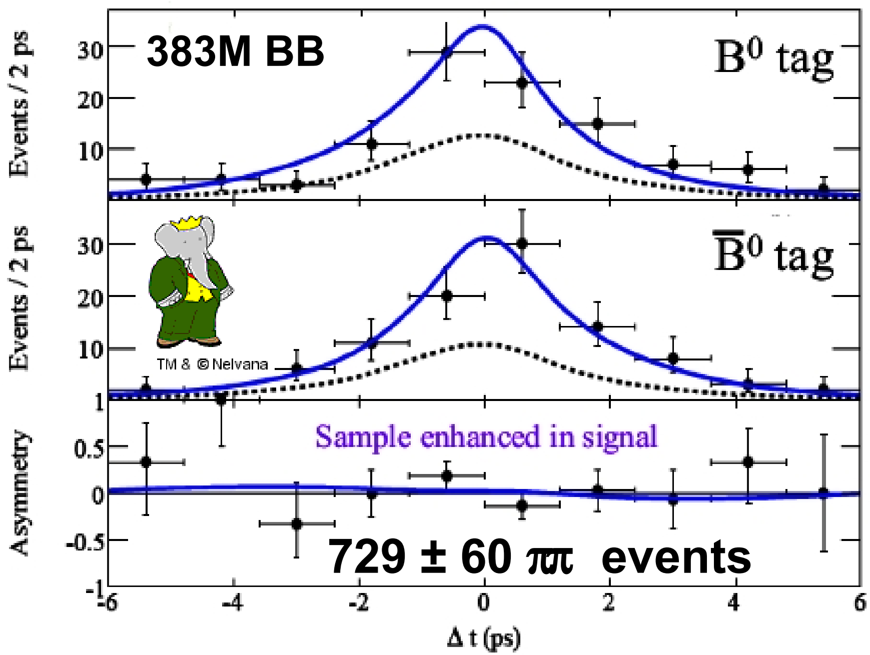
but

- BR 5 times larger with respect to $\pi\pi$
- penguin pollution might be smaller than in $\pi\pi$
- ρ are almost 100% polarized:
  - almost a pure CP-even state

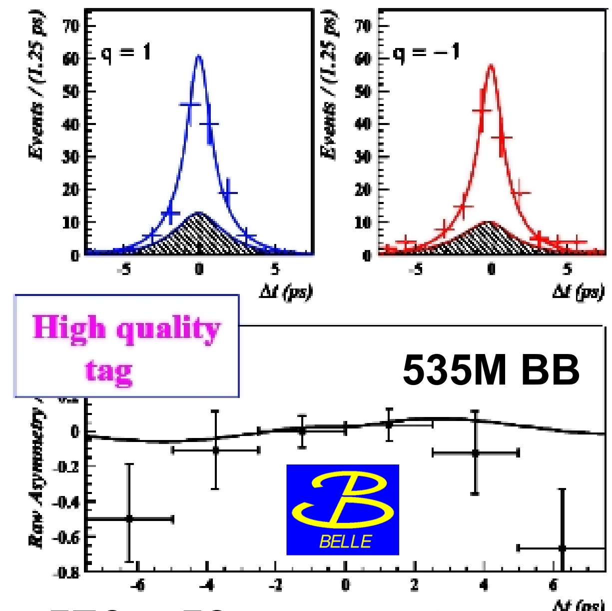
- world average longitudinal fraction:
  - $f_{long}(\rho^+\rho^-) = 0.978 \pm 0.025$
  - $f_{long}(\rho^\pm\rho^0) = 0.912 \pm 0.045$
  - $f_{long}(\rho^0\rho^0)$ still to be measured

Time-dependent analysis in $\rho^+\rho^-$ decays

BABAR Collaboration
Phys.Rev.D76:052007(2007)



Belle Collaboration
Phys.Rev.D76:011104(2007)



576 ± 53 ππ events

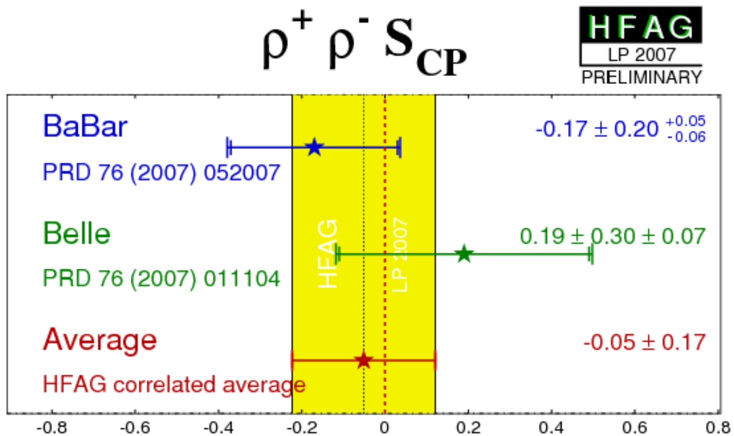
$S_{long}(\rho^+\rho^-) = -0.17 \pm 0.20 \pm 0.06$

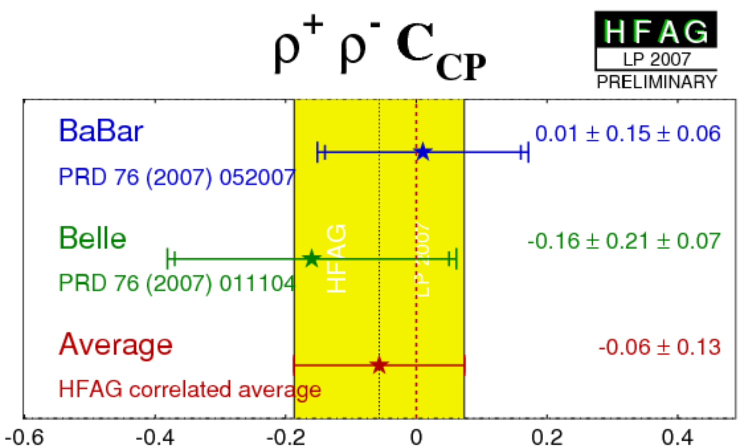
$C_{long}(\rho^+\rho^-) = 0.01 \pm 0.15 \pm 0.06$

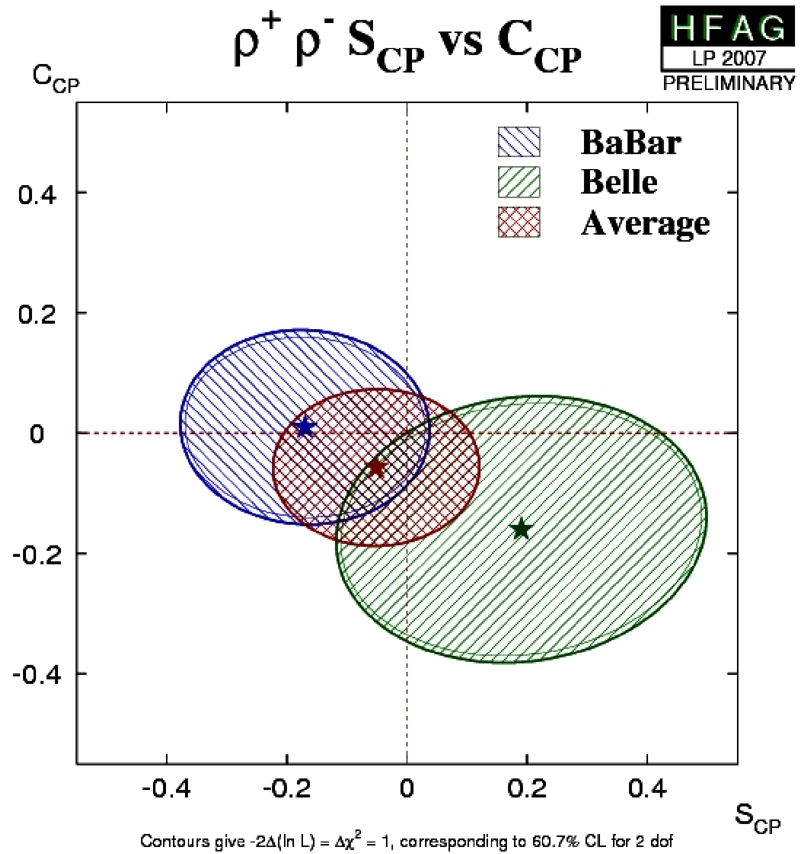
$S_{long}(\rho^+\rho^-) = 0.19 \pm 0.21 \pm 0.08$

$C_{long}(\rho^+\rho^-) = -0.16 \pm 0.21 \pm 0.08$

World averages in $\rho^+\rho^-$ decays





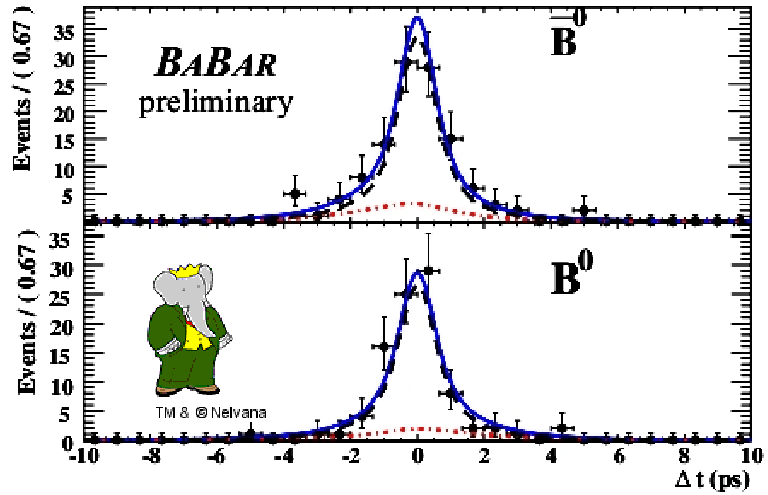


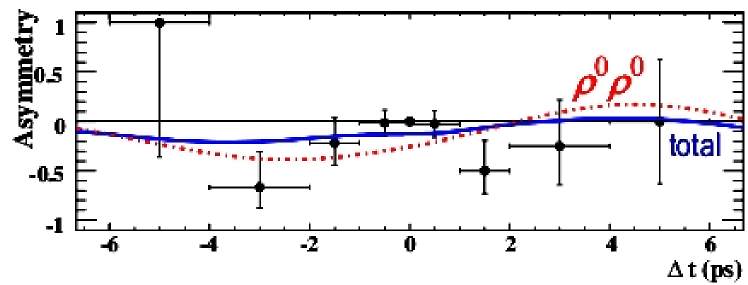
Isospin-related $\rho\rho$ decays

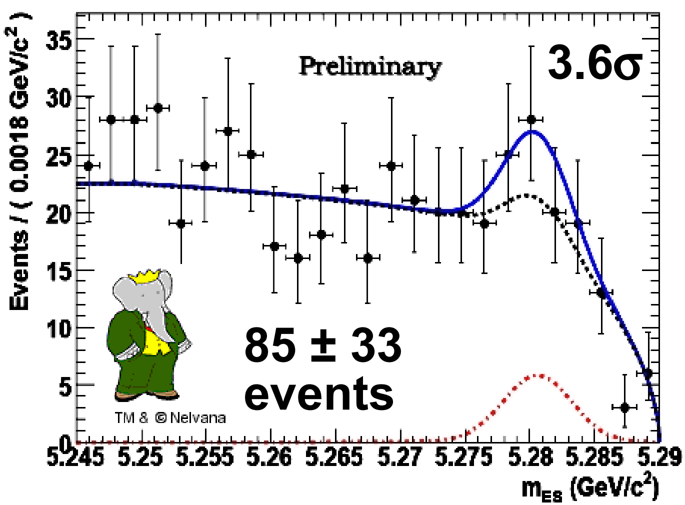
BABAR Collaboration
arXiv:0708.1630 [hep-ex]

- for the $\rho^0\rho^0$ decay:
  - small BR: penguins less important in $\rho\rho$ than in $\pi\pi$

but:
  - all charged particles final state: the vertex can be reconstructed so the time-dependent analysis feasible



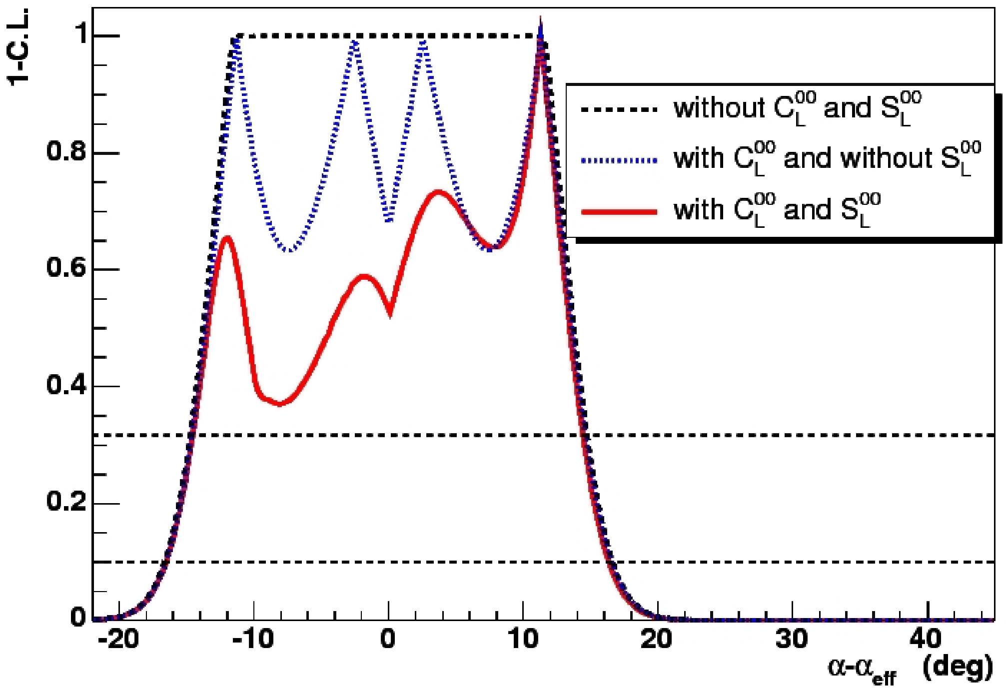


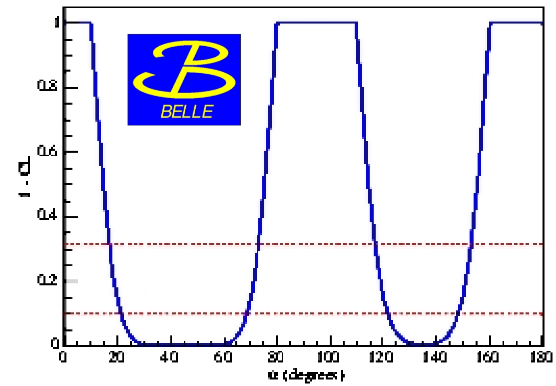


$BR(\rho^0\rho^0) = (0.84 \pm 0.29 \pm 0.17) \cdot 10^{-6}$
$f(\rho^0\rho^0) = 0.70 \pm 0.14 \pm 0.05$
$S_{long}(\rho^0\rho^0) = 0.5 \pm 0.9 \pm 0.2$
$C_{long}(\rho^0\rho^0) = 0.4 \pm 0.9 \pm 0.2$

from Belle:
$BR(\rho^0\rho^0) < 1.0 \cdot 10^{-6}$ @ 90% CL

Preliminary ρρ isospin analysis

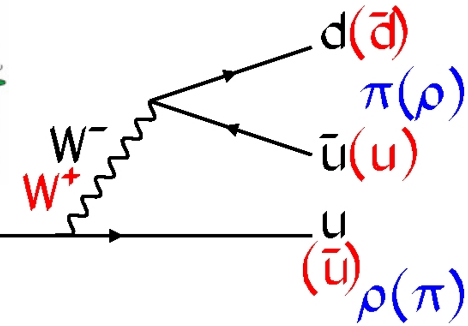




using BaBar $\rho^0\rho^0$:
$|\alpha - \alpha_{eff}| < 16.5°$ @ 90% CL

in ππ :
$|\alpha - \alpha_{eff}| < 39°$ @ 90% CL

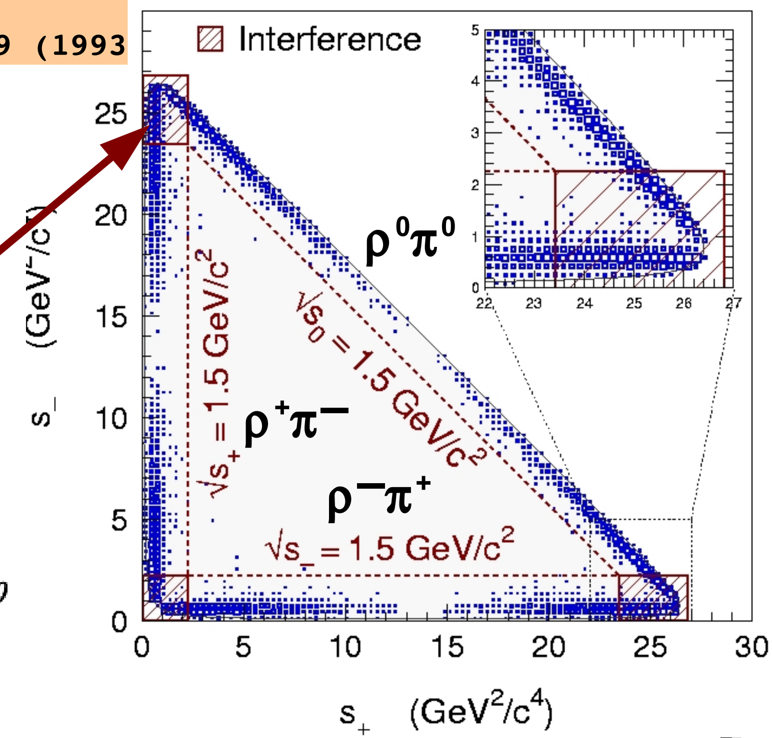
Still α: Dalitz plot analysis with $(\rho\pi)^0$

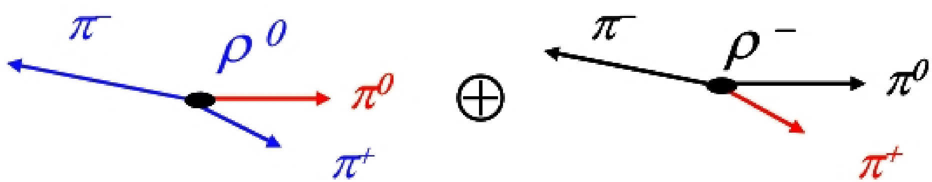


- dominant decay $\rho^+\pi^-$ is not a CP eigenstate
- 5 amplitudes need to be considered:
  - $B^0 \to \rho^+\pi^-, \rho^-\pi^+, \rho^0\pi^0$ and $B^+ \to \rho^+\pi^0, \rho^0\pi^+$
  - Isospin pentagon

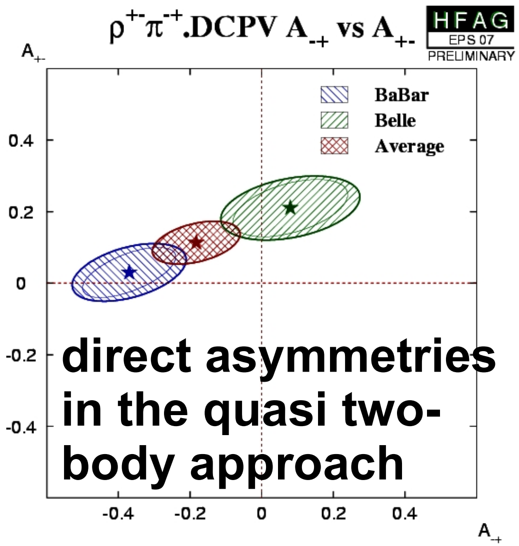
A.Snyder, H,Quinn
Phys. Rev. D48 2139 (1993

- or time-dependent dalitz analysis: α extraction together with the strong phases exploiting the amplitude interference
  - interference at equal masses-squared give information on the strong phases between resonances

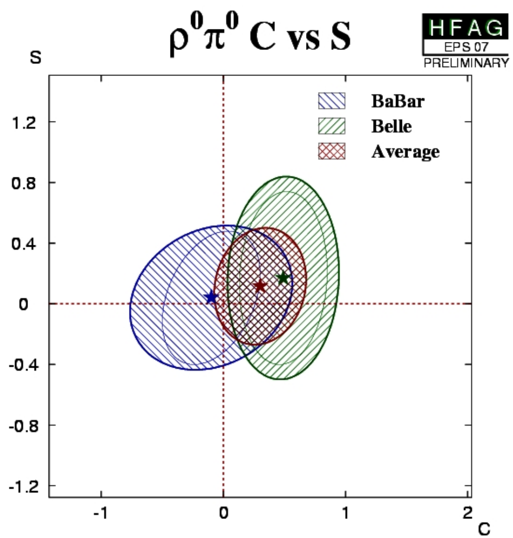




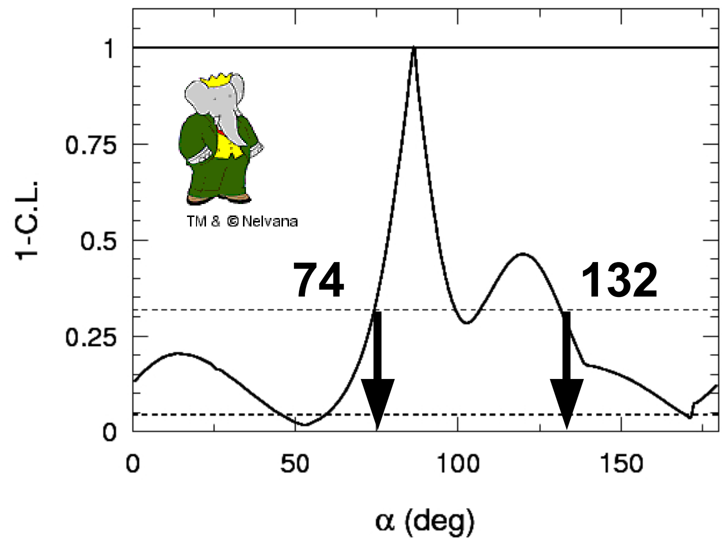
Results from $(\rho\pi)^0$

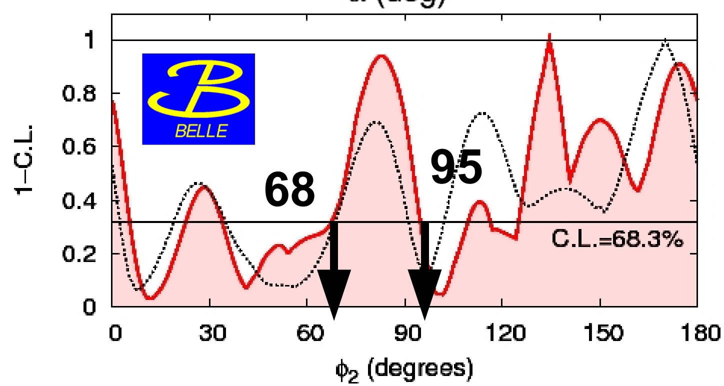


direct asymmetries in the quasi two-body approach



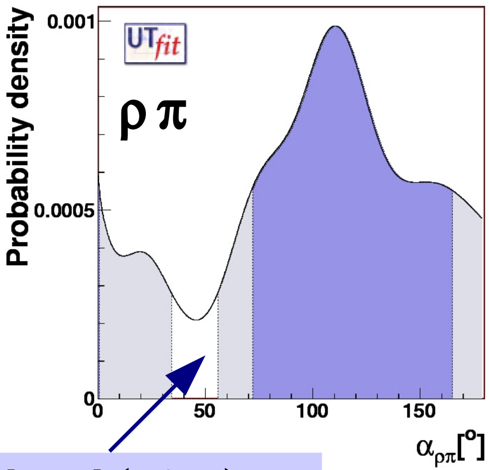
- this analysis allows for a direct determination of α without ambiguities

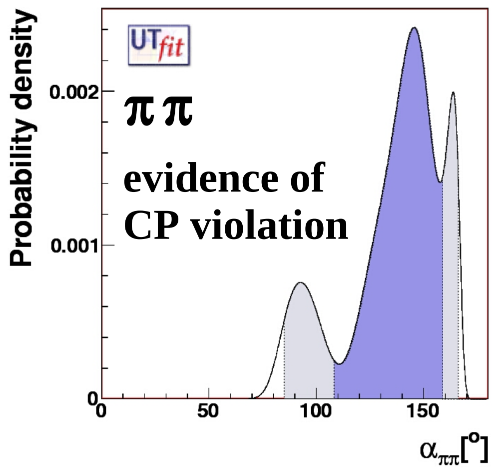


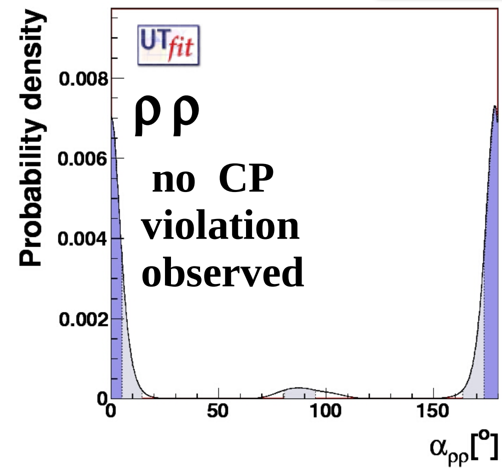


no values excluded, no values selected *yet*

α extraction from the three analyses



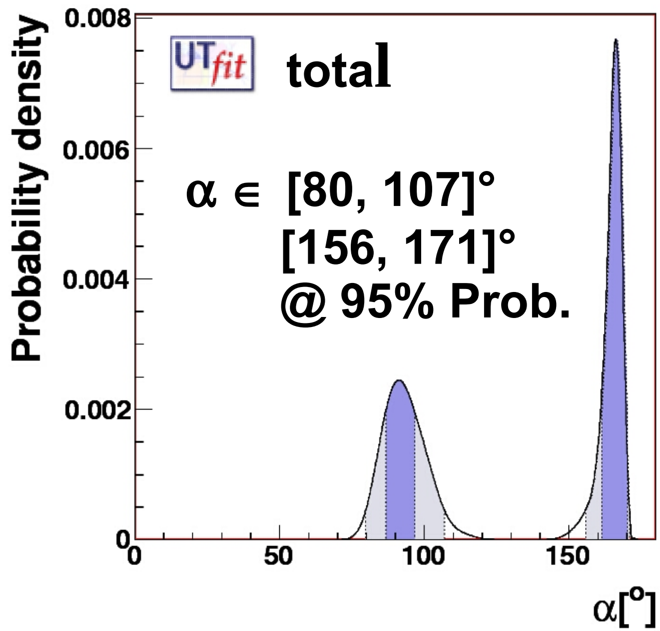


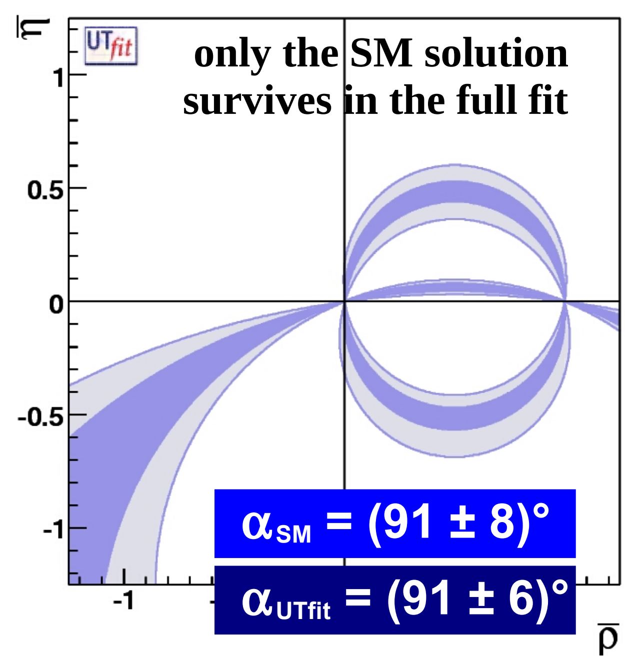


$A = A(\rho^+\pi^-)$
$\quad + A(\rho^-\pi^+)$
$\quad + 2A(\rho^0\pi^0)$
$= (T^{+-} + T^{-+} + 2T^{00})\, e^{2i\alpha}$

→ $R = \bar{A}/A = e^{2i\alpha}$

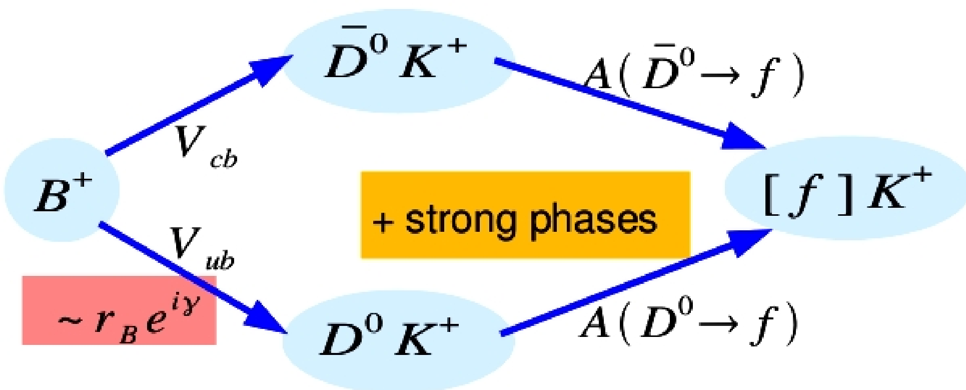
no parameterization involved

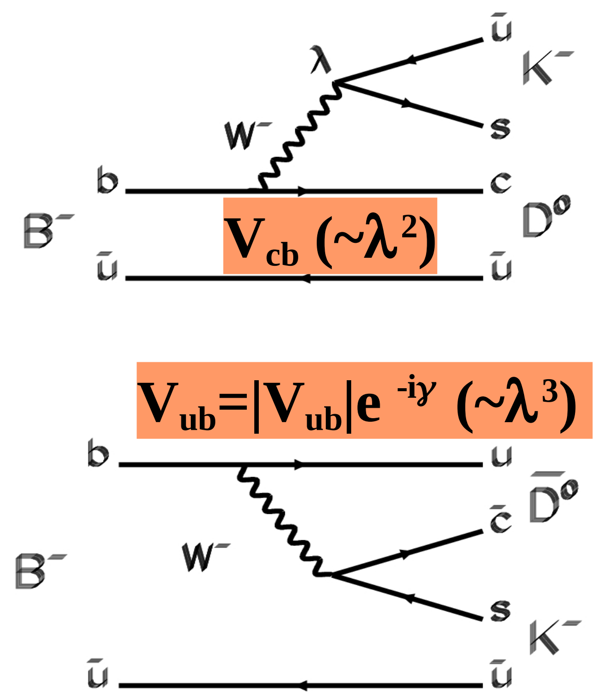




Last but not least: γ and DK trees

- $D^{(*)}K^{(*)}$ decays: from BRs and BR ratios, no time-dependent analysis, just rates
- the phase γ is measured exploiting interferences: two amplitudes leading to the same final states
- some rates can be really small: ~ 10^{-7}

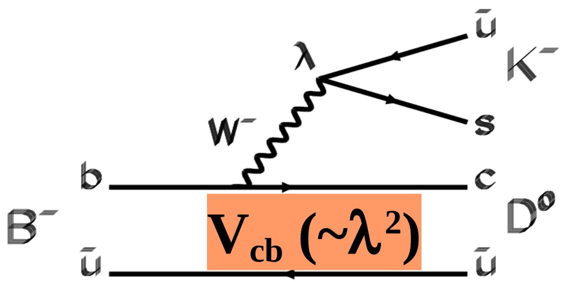




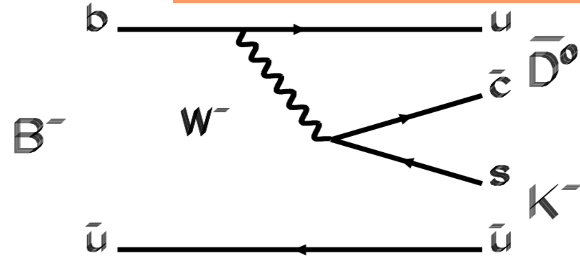
Theoretically clean (no penguins *neglecting the D^0 mixing*)

Sensitivity to γ: the ratio r_B

$V_{ub} = |V_{ub}| e^{-i\gamma}$ $(\sim\lambda^3)$



V_{cb} $(\sim\lambda^2)$



δ_B = strong phase diff.

$$A(B^- \to D^0 K^-) = A_B \qquad A(B^- \to \bar{D}^0 K^-) = A_B r_B e^{i(\delta_B - \gamma)}$$

$$A(B^+ \to \bar{D}^0 K^+) = A_B \qquad A(B^+ \to D^0 K^+) = A_B r_B e^{i(\delta_B + \gamma)}$$

r_B = amplitude ratio

$$r_B = \left| \frac{B^- \to \bar{D}^0 K^-}{B^- \to D^0 K^-} \right| = \sqrt{\bar{\eta}^2 + \bar{\rho}^2} \times F_{CS}$$

~0.36 hadronic contribution channel-dependent

- in $B^+ \to D^{(*)0} K^+$: r_B is ~0.1
- while in $B^0 \to D^{(*)0} K^0$ r_B could be ~0.4
- to be measured: $r_B(DK)$, $r^*_B(D^*K)$ and $r^s_B(DK^*)$

Three ways to make DK interfere

- GLW(*Gronau, London, Wyler*) method:
  uses the CP eigenstates $D^{(*)0}_{CP}$ with final states:
  K^+K^-, $\pi^+\pi^-$ (CP-even), $K_s\pi^0$ (ω,ϕ) (CP-odd)

$$R_{CP\pm} = 1 + r_B^2 \pm 2r_B \cos\gamma \cos\delta_B \qquad A_{CP\pm} = \frac{\pm 2r_B \sin\gamma \sin\delta_B}{1 + r_B^2 \pm 2r_B \cos\gamma \cos\delta_B}$$

- ADS(*Atwood, Dunietz, Soni*) method: B^0 and $\bar{B}^0$ in the same final state with $D^0 \rightarrow K^+\pi^-$(suppressed) and $\bar{D}^0 \rightarrow K^+\pi^-$ (favorite)

$$R_{ADS} = r_B^2 + r_{DCS}^2 + 2r_B r_{DCS} \cos\gamma \cos(\delta_B + \delta_D)$$

more sensitive to r_B

- D^0 Dalitz plot with the decays $B^- \rightarrow D^{(*)0}[K_S\pi^+\pi^-]\, K^-$

  the most sensitive way to γ

three free parameters to extract: γ , r_B and δ_B

γ measurement: GLW method

Observables:

- ratio of BF for CP/non-CP
- asymmetry B-/B+ for CP=+1/-1

Clean but statistically limited:
$BF(B^- \to D^0K^-) \cdot BF(D^0 \to f_{CP}) \sim 10^{-6}$

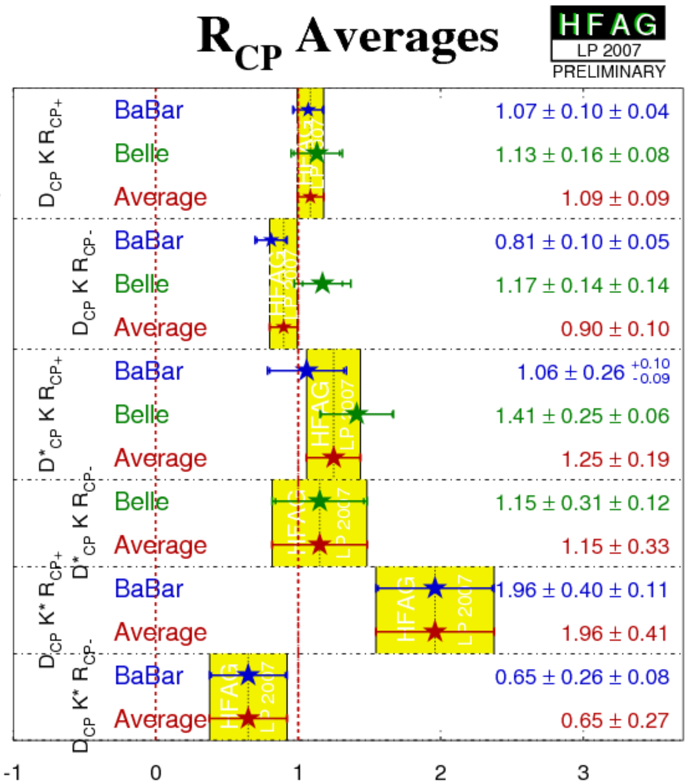
$$R_{CP\pm} = \frac{BF(B^- \to D^0_\pm K^-) + BF(B^+ \to D^0_\pm K^+)}{BF(B^- \to D^0 K^-) + BF(B^+ \to D^0 K^+)} = 1 + r_B^2 \pm 2 r_B \cos\delta \cos\gamma$$

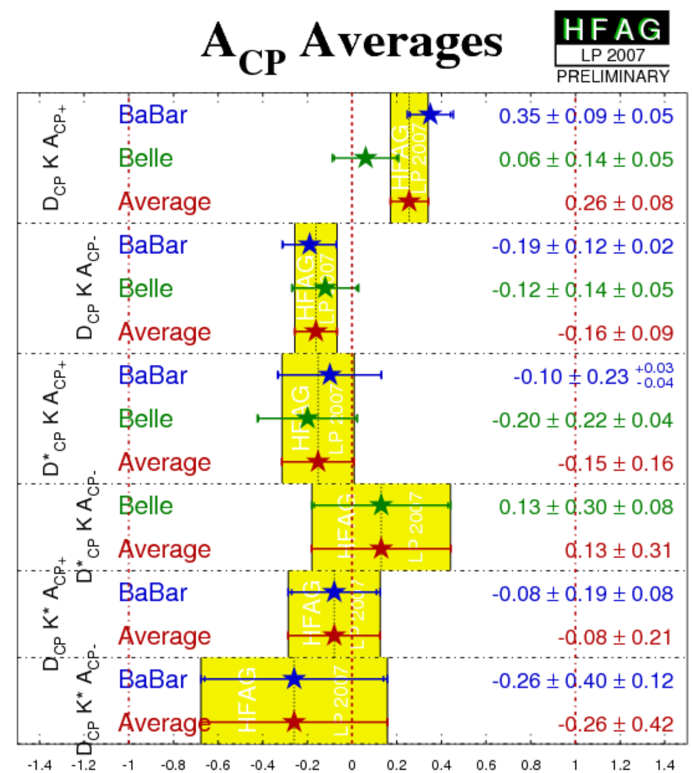
$$A_{CP\pm} = \frac{BF(B^- \to D^0_\pm K^-) - BF(B^+ \to D^0_\pm K^+)}{BF(B^- \to D^0_\pm K^-) + BF(B^+ \to D^0_\pm K^+)} = \pm 2 r_B \sin\delta \sin\gamma / R_{CP\pm}$$

$$R(K/\pi) \equiv \frac{BF(B^- \to D^0 K^-)}{BF(B^- \to D^0 \pi^-)}$$

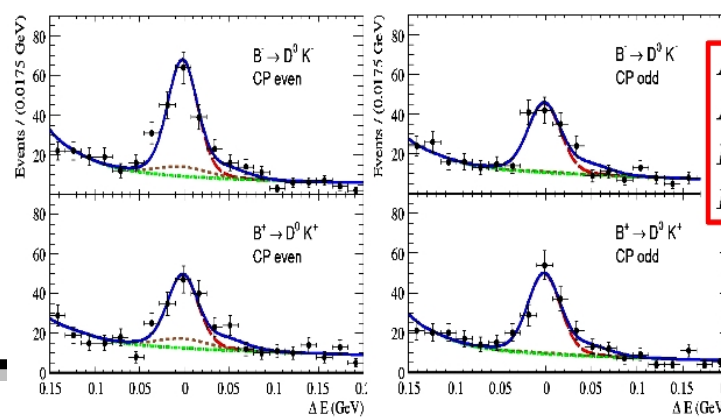
- for $D^{(*)0}K$, the $D\pi$ channel is used for normalization
- reconstruct $B^+ \to D^0h^+$ with $D^0 \to K\pi$ [non-CP], $D^0 \to K^+K^-$, $\pi^+\pi^-$ [CP+] and $D^0 \to K^0_s\pi^0$ ($K^0_s\omega$, $K^0_s\phi$) [CP-]
- eliminate background from light-quark or $c\bar{c}$ events using Neural Net or Fisher Discriminants based on event shape variables
- fit of the $R(K/\pi)$ based on kinematic variable ΔE and PID

GLW results





- cut on m_{ES} and event shape variables, then fit to the ΔE and Cerenkov distribution



$$
\begin{aligned}
A_{CP+} &= 0.27 \pm 0.09(\text{stat}) \pm 0.04(\text{syst}) \\
A_{CP-} &= -0.09 \pm 0.09(\text{stat}) \pm 0.02(\text{syst}) \\
R_{CP+} &= 1.06 \pm 0.10(\text{stat}) \pm 0.05(\text{syst}) \\
R_{CP-} &= 1.03 \pm 0.10(\text{stat}) \pm 0.05(\text{syst})
\end{aligned}
$$

TM & © Nelvana

382M $B\bar{B}$

γ measurement: ADS method

Combine dominant $b \to c$ transition with doubly-Cabibbo suppressed (DCS) D^0 decay

A₁: favoured $B^- \to D^0 K^-$ — suppressed $D^0 \to K^+\pi^-$

δ_B δ_D → $[K^+\pi^-]_D K^-$

A₂: suppressed $B^- \to \bar{D}^0 K^-$ — favoured $\bar{D}^0 \to K^+\pi^-$

small BF($\sim 10^{-7}$)
but $A_2 = O(A_1)$
large CPV possible

$$A(B^- \to [K^+\pi^-]_D K^-) \propto r_B\, e^{i(\delta_B - \gamma)} + r_D\, e^{-i\delta_D}$$

need to measure the rates:
$[K^+\pi^-]_D K^-$ and $[K^-\pi^+]_D K^-$

Observables:

$$R_{ADS} = \frac{BF([K^+\pi^-]K^-) + BF([K^-\pi^+]K^+)}{BF([K^-\pi^+]K^-) + BF([K^+\pi^-]K^+)} = r_D^2 + r_B^2 + 2 r_D r_B \cos(\delta_D + \delta_B) \cos\gamma$$

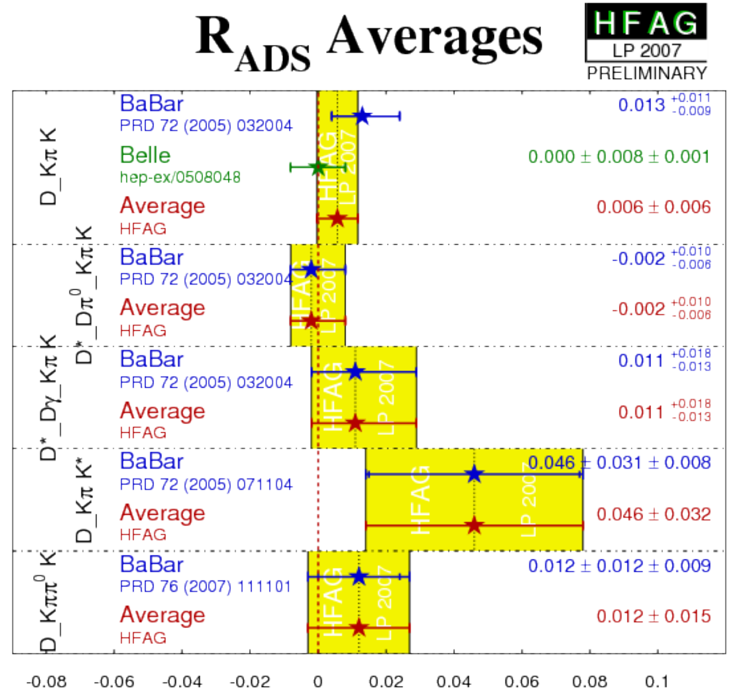
$$A_{ADS} = \frac{BF([K^+\pi^-]K^-) - BF([K^-\pi^+]K^+)}{BF([K^+\pi^-]K^-) + BF([K^-\pi^+]K^+)} = 2 r_D r_B \sin(\delta_D + \delta_B) \sin\gamma / R_{ADS}$$

Inputs:

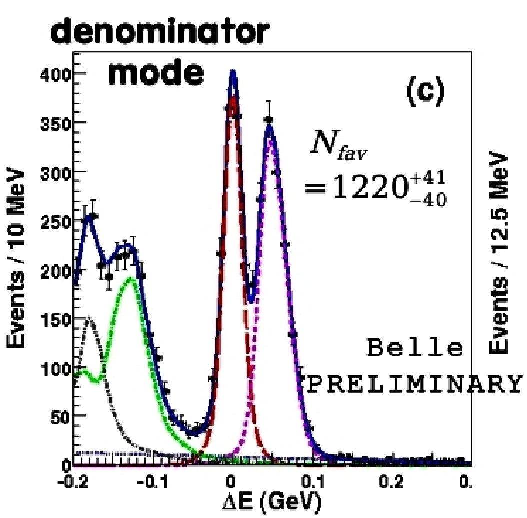
$$r_D = \left| \frac{A(D^0 \to K^+\pi^-)}{A(D^0 \to K^-\pi^+)} \right| = 0.060 \pm 0.003$$

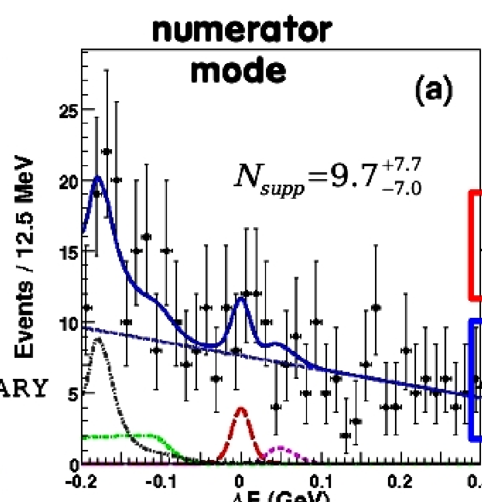
in $D^{*+} \to D^0(K\pi)\pi^+$
PRL 91, 171801 (2003)

ADS results



- **Belle: cut on m_{ES} and event shape variables, then fit to the ΔE distribution**
- **still no event found even in Belle's 657M $B\bar{B}$ sample**





no significant ADS signal found

$$R_{ADS} = (8.0^{+6.3+2.0}_{-5.7-2.8})\,10^{-3}$$

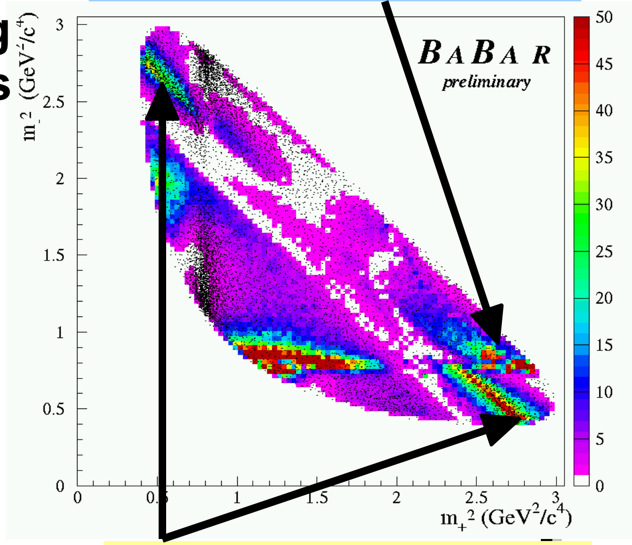
$$A_{ADS} = -0.13^{+0.97}_{-0.88} \pm 0.26$$

$$r_B < 0.19 \;@90\%\; C.L.$$

γ measurement: Dalitz method

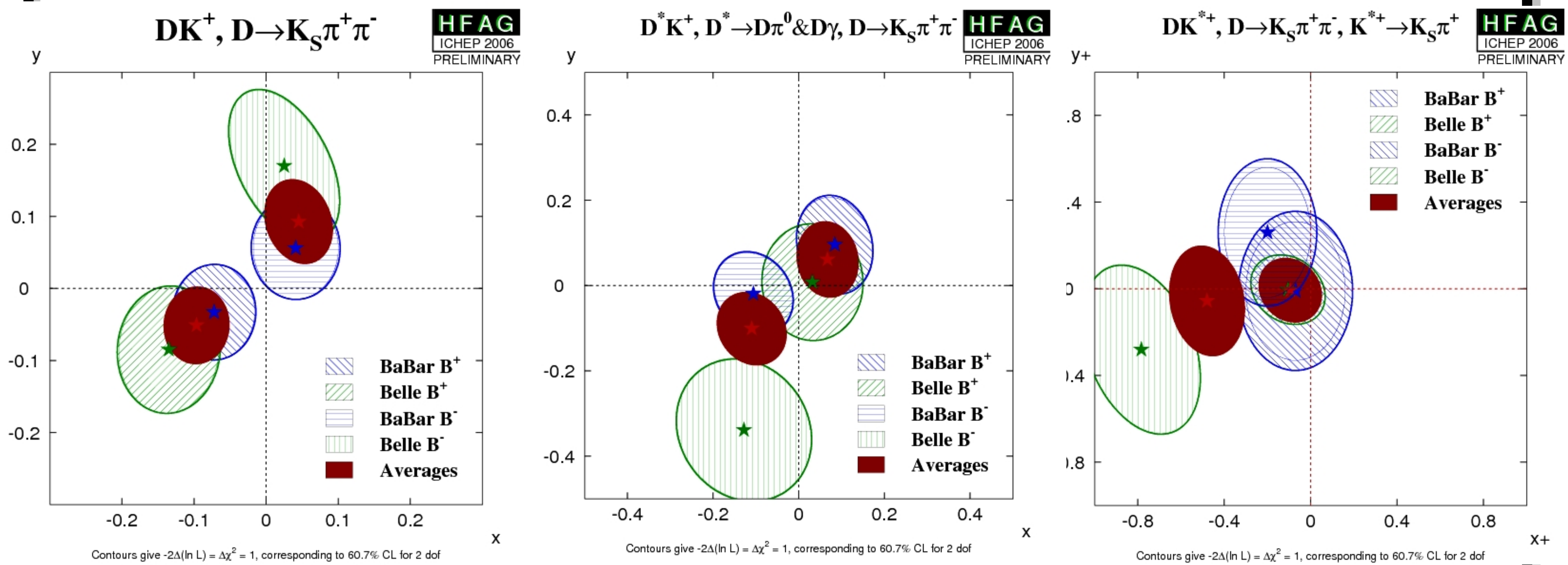
- neutral D mesons reconstructed in three-body CP-eigenstate final states (typically $D^0 \to K_S\pi^-\pi^+$)
- the complete structure (amplitude and strong phases) of the D^0 decay in the phase space is obtained on independent data sets and used as input to the analysis
- use of the cartesian coordinate:
  - $x_\pm = r_B \cos(\delta \pm \gamma)$
  - $y_\pm = r_B \sin(\delta \pm \gamma)$
- γ , r_B and δ_B are obtained from a simultaneous fit of the $K_S\pi^+\pi^-$ Dalitz plot density for B^+ and B^-
- need a model for the Dalitz amplitudes
- 2-fold ambiguity on γ

Interference of
$B^- \to D^0K^-$, $D^0 \to K^{*+}\pi^-$
(suppressed) with
$B^- \to \overline{D}^0K^-$, $\overline{D}^0 \to K^{*+}\pi^-$
~ ADS like



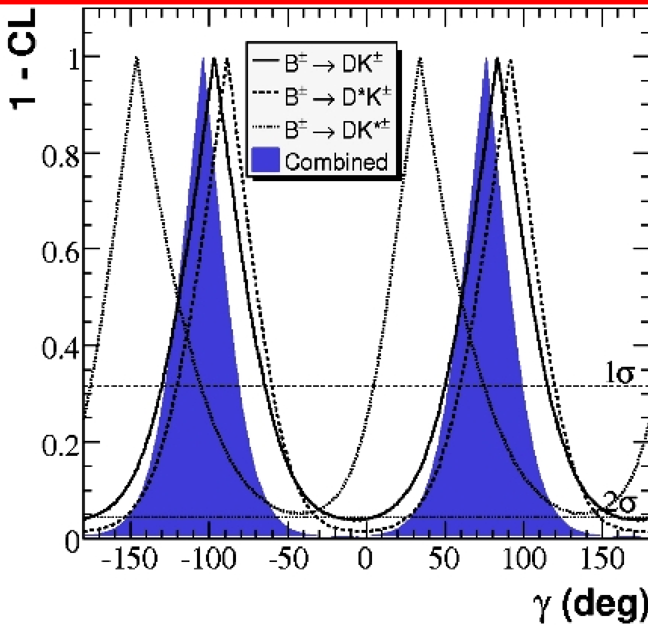
Interference of
$B^- \to D^0K^-$, $D^0 \to K^0_S\rho^0$
with
$B^- \to \overline{D}^0K^-$, $\overline{D}^0 \to K^0_S\rho^0$
~ GLW like

Dalitz results



- m_{ES}, ΔE and shape variable used in the maximum likelihood fit
- D^0 Dalitz distributions determined on independent data samples and used as input to the fit
- CP fit in Cartesian coordinate
  - approximately Gaussian distributions (no unphysical zones), small correlation and unbiased behaviour on the physics boundaries

Dalitz results: latest updates



383M $\overline{B}B$

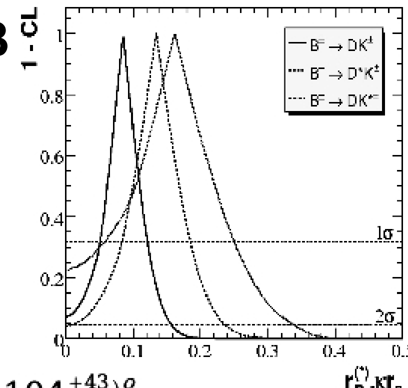
$\gamma/\phi_3=(76^{+23}_{-24})^o (mod.\, 180^o)$

$r_B(DK)=0.086\pm0.035$

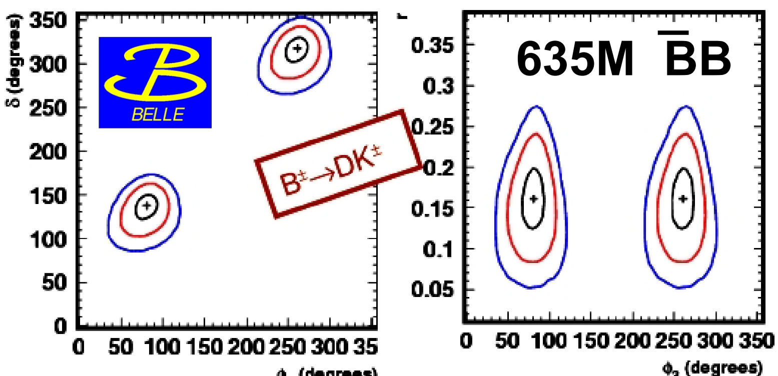
$r_B(D*K)=0.135\pm0.051$

$r_S(DK*)=0.181^{+0.100}_{-0.118}$

TM & © Nelvana



$\delta(DK)=(109^{+28}_{-31})^o,\quad \delta(D^*K)=(-63^{+28}_{-30})^o,\quad \delta(DK^*)=(104^{+43}_{-41})^o$



model error estimate is the same as in previous analysis

$\gamma/\phi_3=(76^{+12}_{-13}\pm4\pm9)^o (mod.\, 180^o)$

$r_B(DK)=0.16\pm0.04\pm0.01\pm0.05$

$r_B(D*K)=0.21\pm0.08\pm0.02\pm0.05$

$\delta(DK)=(136^{+14}_{-16}\pm4\pm23)^o$

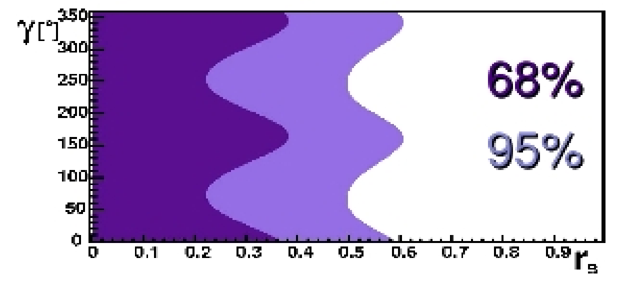
$\delta(D^*K)=(343^{+20}_{-22}\pm4\pm23)^o$

More ways to γ

- with neutral B's in the final states D^0K^{*0} with $D^0 \to K_S\pi^-\pi^+$ and $K^* \to K^-\pi^+$,
  - the charge of the K from the K* tags the flavour of the B^0 so no time-dependent analysis
  - first analysis to extract γ from neutral $B \to DK$
  - BaBar performed it with 371M $\bar{B}B$

    $\gamma = (162 \pm 56)^\circ$ (mod.180°)

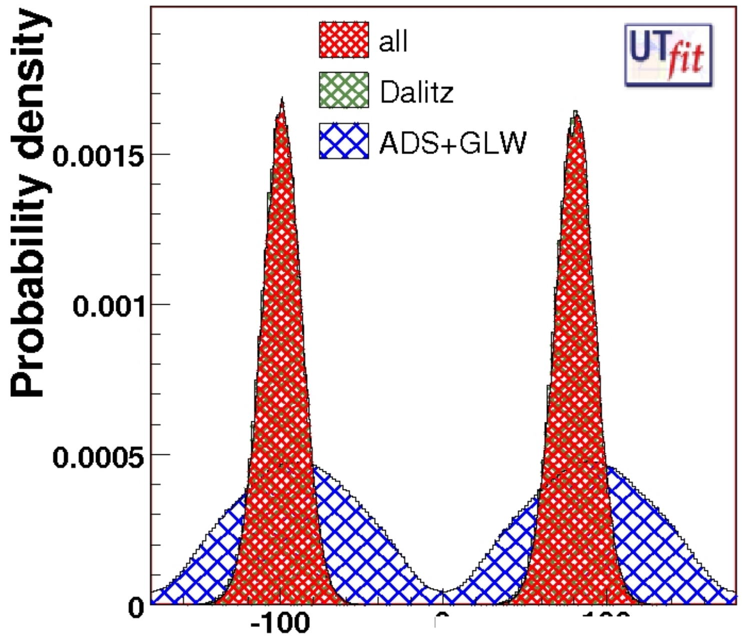
    $r_s (D^0K^{*0}) < 0.55$ @ 95% Prob.

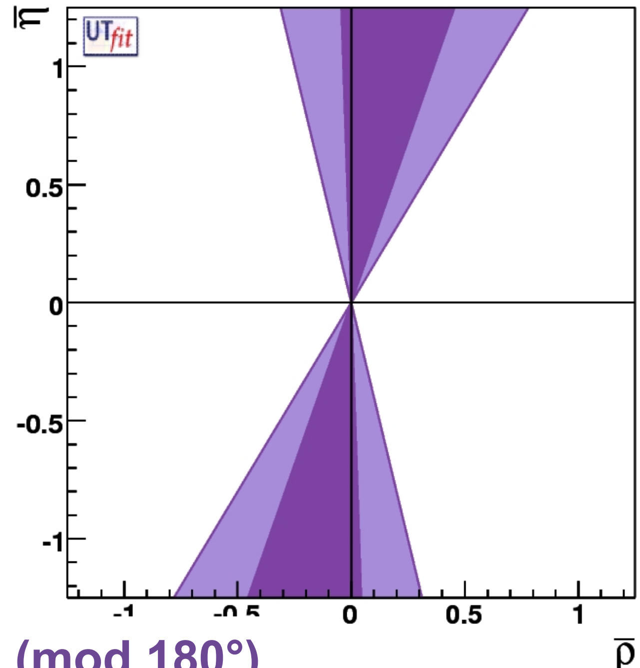


- again with neutral B's, time-dependent Dalitz plot analysis of the three-body final state $B^0 \to D^-K^0\pi^+$
  - interference between $b \to u$ and $b \to c$ transitions through the mixing: sensitivity to $2\beta+\gamma$
  - BaBar performed it with 347M $\bar{B}B$

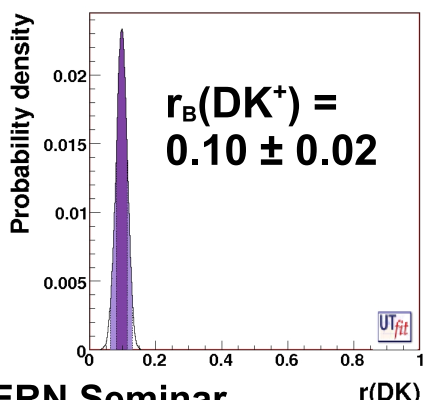
    $2\beta+\gamma = (83 \pm 53 \pm 20)^\circ$ (mod.180°)

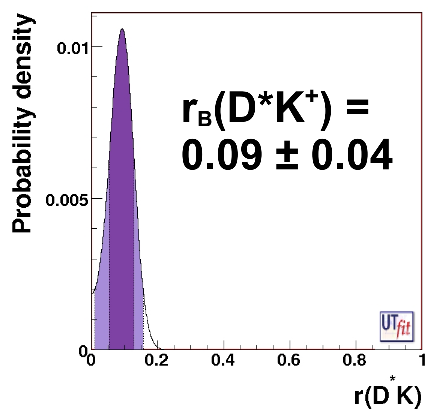
Combining the methods for γ

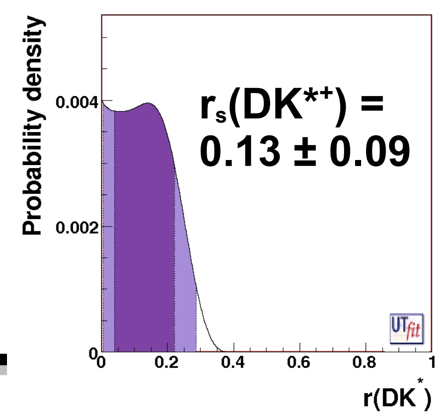




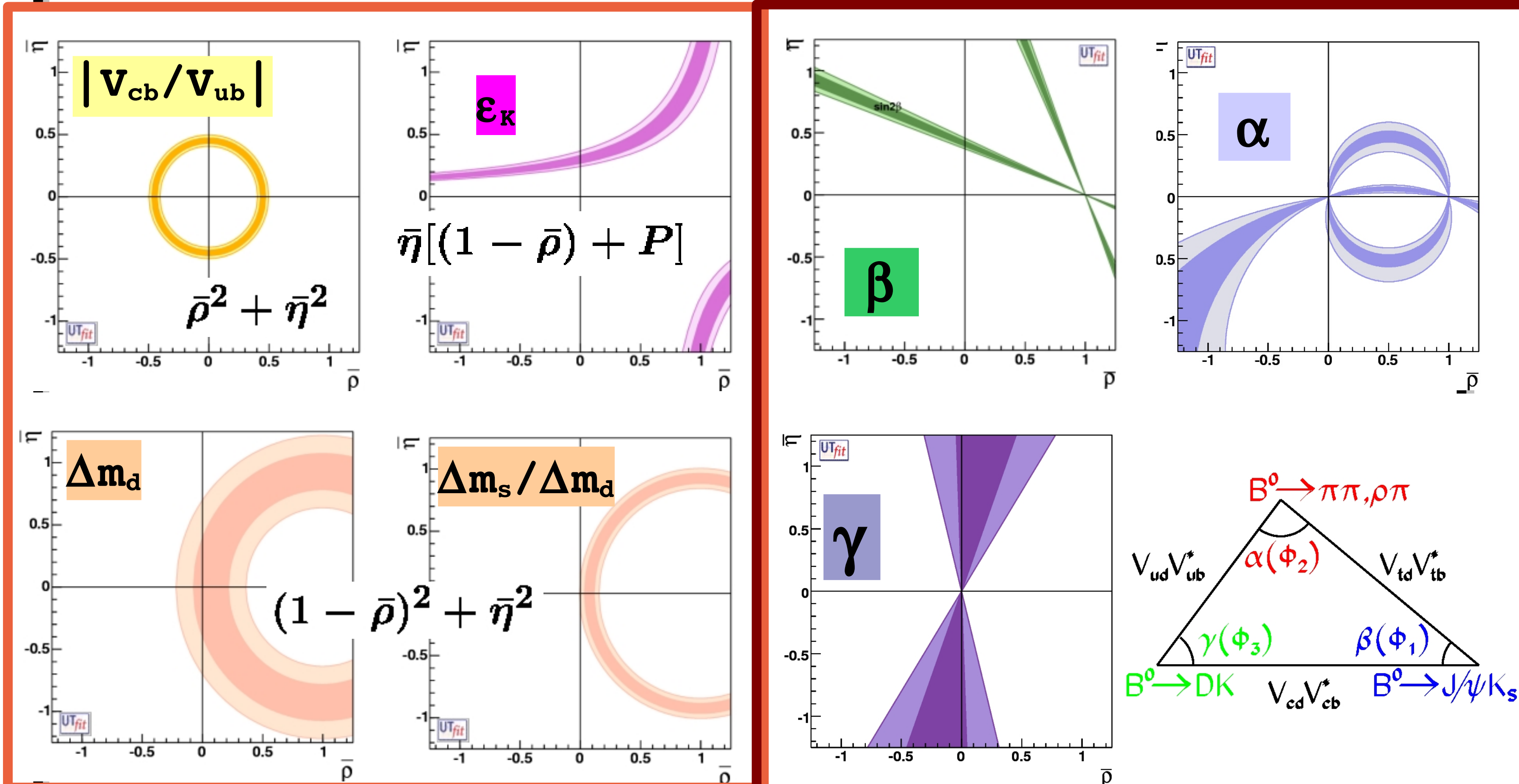
$\gamma = (80 \pm 13)°$ (mod.180°)



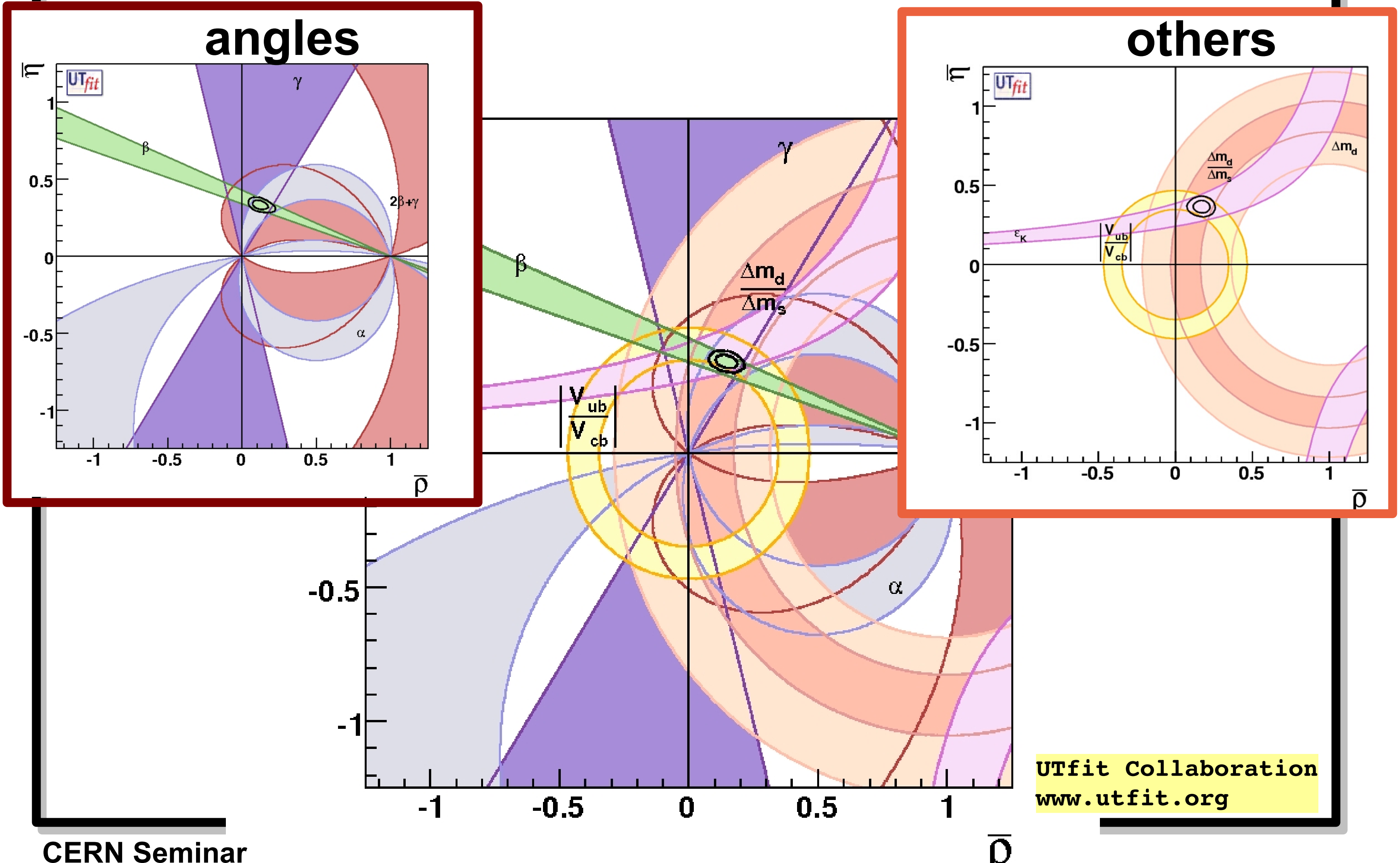




Unitarity Triangle analysis in the SM



Unitarity Triangle analysis in the SM



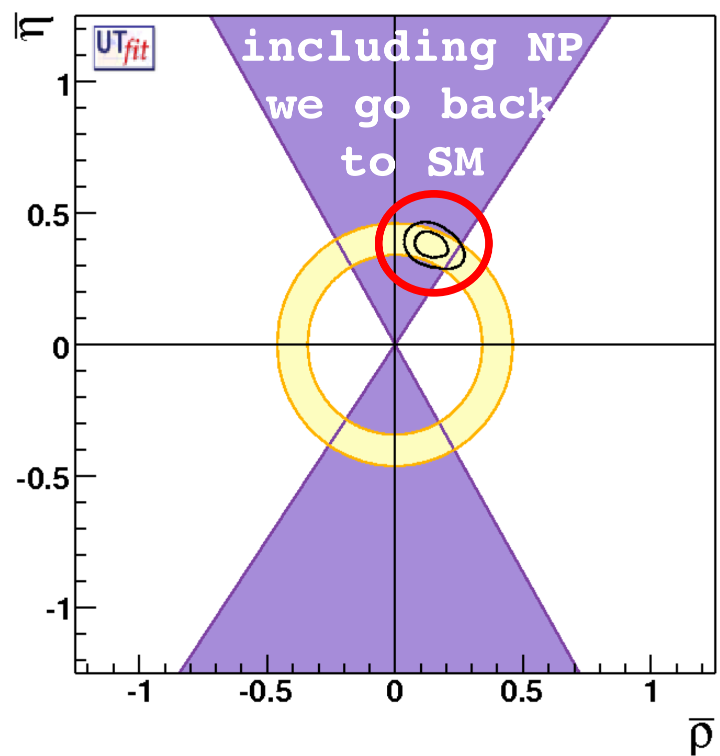
UTfit Collaboration
www.utfit.org

Including NP in Unitarity Triangle analysis

All NP effects can be parameterized in terms of one complex parameter for each meson mixing, to be determined in a simultaneous fit with the CKM parameters (now there are enough experimental constraints to do so).

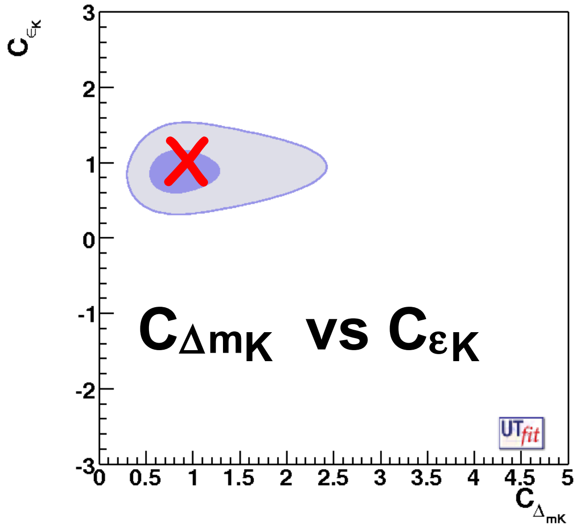
$$C_{B_s} e^{-2i\phi_{B_s}} = \frac{\langle \overline{B}_s | H_{eff}^{SM} + H_{eff}^{NP} | B_s \rangle}{\langle \overline{B}_s | H_{eff}^{SM} | B_s \rangle} = 1 + \frac{A_{NP} e^{-2i\phi_{NP}}}{A_{SM} e^{-2i\beta_s}}$$

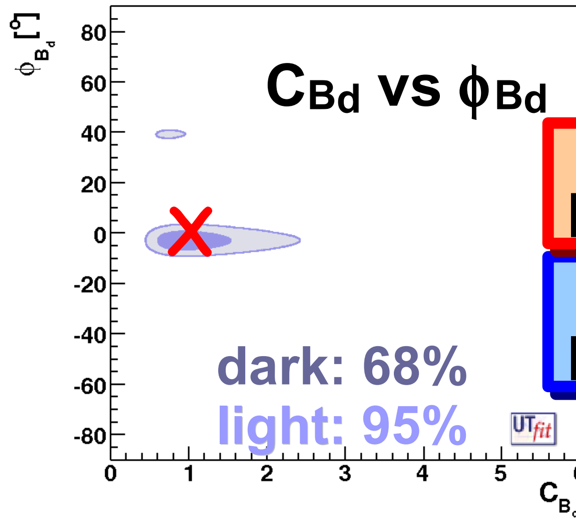
SM	SM+NP
tree level	
$(V_{ub}/V_{cb})^{SM}$	$(V_{ub}/V_{cb})^{SM}$
γ^{SM}	γ^{SM}
Bd Mixing	
β^{SM}	$\beta^{SM}+\phi_{Bd}$
α^{SM}	$\alpha^{SM}-\phi_{Bd}$
Δm_d	$C_{Bd}\Delta m_d$
Bs Mixing	
Δm_s^{SM}	$C_{Bs}\Delta m_s^{SM}$
β_s^{SM}	$\beta_s^{SM}+\phi_{Bs}$
K Mixing	
ε_K^{SM}	$C_{\varepsilon_K}\varepsilon_K^{SM}$



The UT*fit* beyond the SM

UTfit Collaboration
arXiv:0803.0659 [hep-ph]

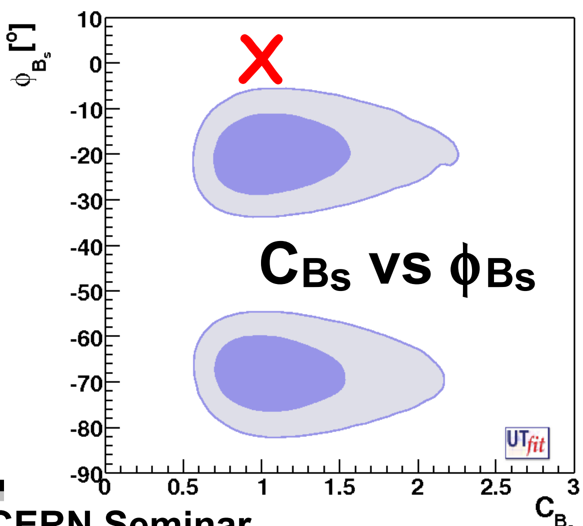




$C_{Bd} = 1.00 \pm 0.32$
[0.51, 1.94] @ 95% Prob.

$\phi_{Bd}=(-3.0 \pm 2.2)°$
[-7.8°, 1.7°] @ 95% Prob.

X SM expectation



1 – 2: strong suppression
1 – 3: < *O* (10%)
2 – 3: ~ *O* (1)

$C_{Bs} = 1.07 \pm 0.29$
[0.62, 1.93] @ 95% Prob.

$\phi_{Bs}=(-19.9 \pm 5.6)° \cup (-68.2 \pm 4.9)°$
[-30°, -9°] U [-78°, -58°]@ 95% Prob.

The future of CKM fits

LHCb reach from: O. Schneider, 1st LHCb Collaboration Upgrade Workshop

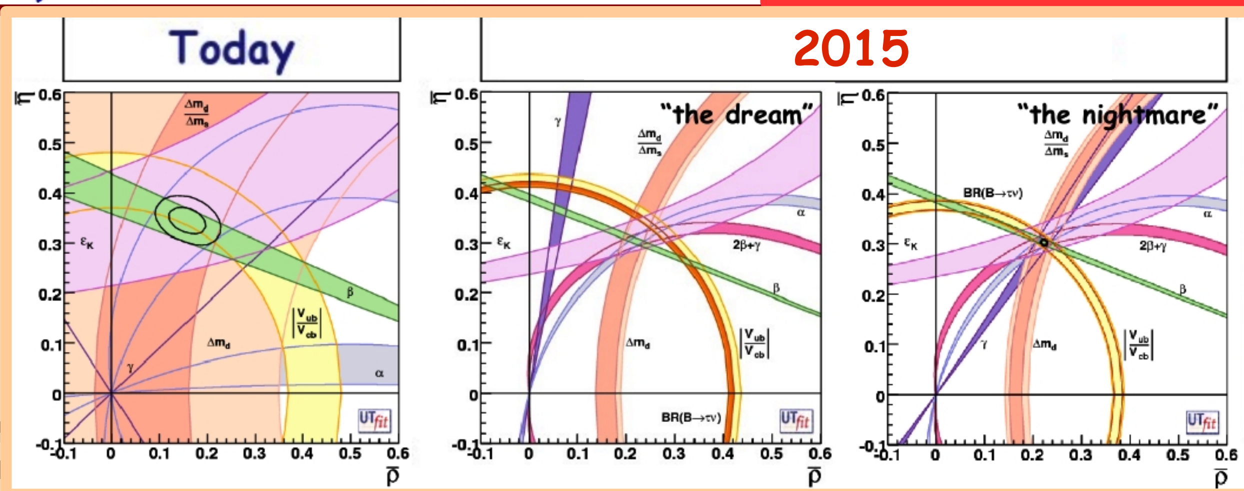
SuperB reach from: SuperB Conceptual Design Report, arXiv:0709.0451

	LHCb 2015	SuperB
	10/fb (5 years)	1/ab (1 month at Υ(5S))
Δm_s	0.07%(+0.5%)	no
A^s_{SL}	?	0.006
ϕ_s ($J/\psi\ \phi$)	0.01+syst	0.14
		75/ab (5 years)
$\sin 2\beta$ ($J/\psi\ K_s$)	0.010	0.005
γ (all methods)	2.4°	1-2°
α (all methods)	4.5°	1-2°
$\lvert V_{cb}\rvert$ (all methods)	no	< 1%
$\lvert V_{ub}\rvert$ (all methods)	no	1-2%

©2007 V. Lubicz

Hadronic matrix element	Current lattice error	60 TFlop Year [2011 LHCb]	1-10 PFlop Year [2015 SuperB]
$f_+^{K\pi}(0)$	0.9% (22% on 1-f_+)	0.4% (10% on 1-f_+)	< 0.1% (2.4% on 1-f_+)
$\hat{B}_K$	11%	3%	1%
f_B	14%	2.5 - 4.0%	1 – 1.5%
$f_{B_s} B_{B_s}^{1/2}$	13%	3 - 4%	1 – 1.5%
ξ	5% (26% on ξ-1)	1.5 - 2 % (9-12% on ξ-1)	0.5 – 0.8 % (3-4% on ξ-1)
$\mathcal{F}_{B\to D/D^* l\nu}$	4% (40% on 1-$\mathcal{F}$)	1.2% (13% on 1-$\mathcal{F}$)	0.5% (5% on 1-$\mathcal{F}$)
$f_+^{B\pi}, \ldots$	11%	4 - 5%	2 – 3%
$T_1^{B\to K^*/\rho}$	13%	----	3 – 4%

S. Sharpe @ Lattice QCD: Present and Future, Orsay, 2004 and report of the U.S. Lattice QCD Executive Committee



Summary and conclusions

- β is a precision measurement: time to be careful with the calculation of the SM expectation
- α is still limited statistically and by the uncertainty of the hadronic picture.
  Still we currently have → σ = ~10°
- Tree level: γ extraction still statistical dominated and plenty of room for improvements, new channels, new techniques
  The current knowledge still better that expected → σ = ~13°
- All these constraints are precious for the now precise extraction of $\bar{\rho}$ and $\bar{\eta}$ parameters
- but above all for the overconstraining of the UTfit: very interesting constraints on NP quantities

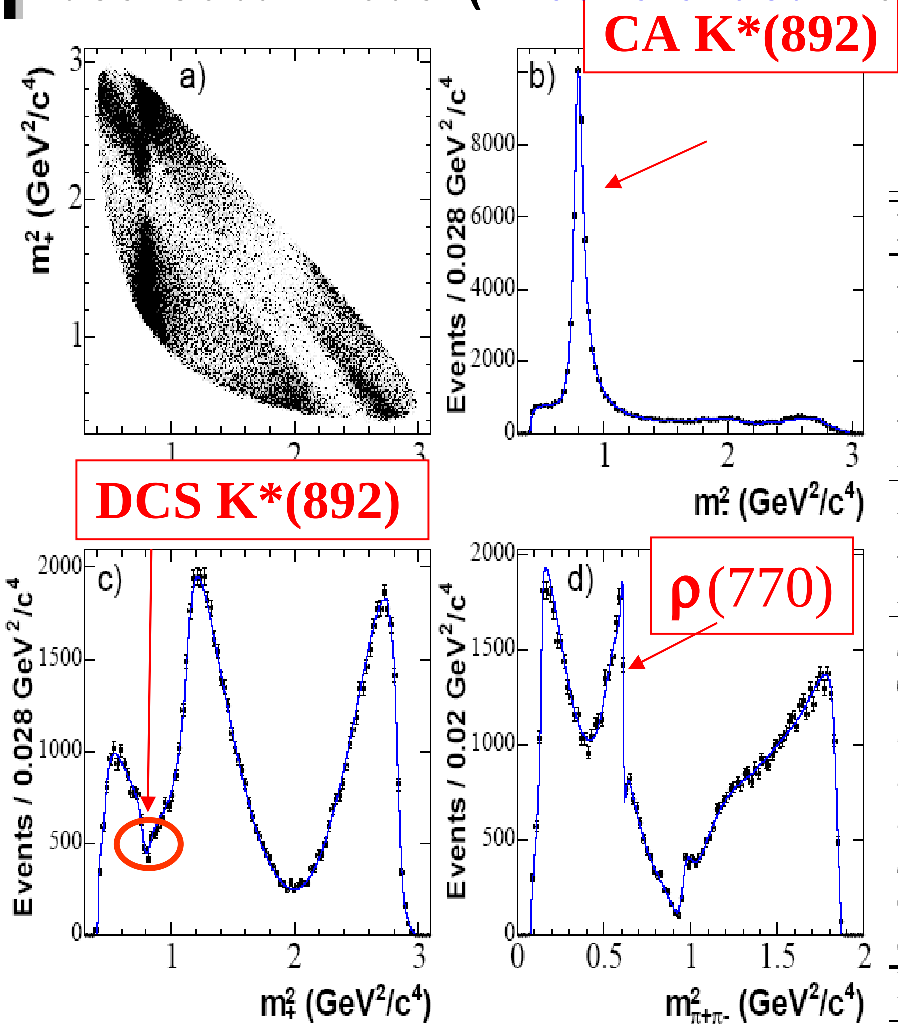
Back up slides

Marcella Bona

Dalitz method: the amplitude model

extract $A(m_-^2,m_+^2)$ from high-purity tagged $D^{*+}\rightarrow D^0\pi^+$, $D^0\rightarrow K^0\pi^+\pi^-$ sample

use isobar model (≡ coherent sum of Breit-Wigner (BW) amplitudes)



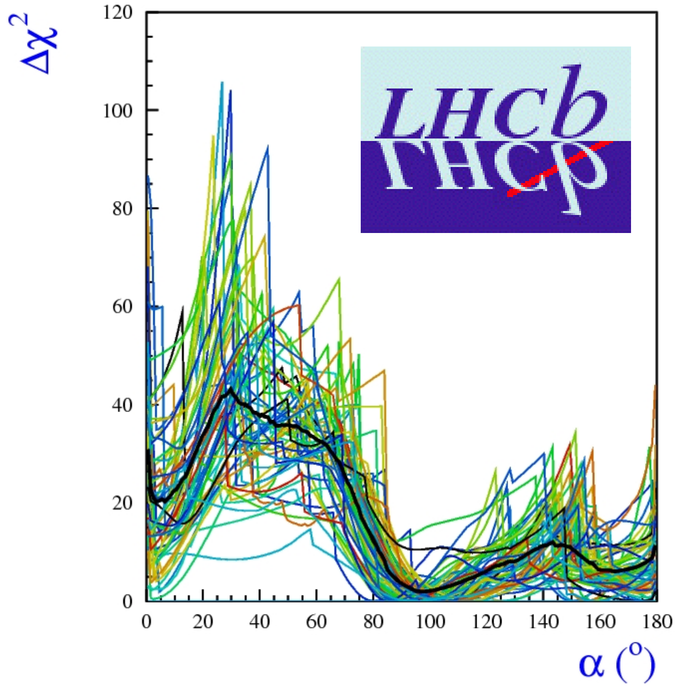
16 resonances (3 WS DCS)
+ 1 NR component

χ^2/d.o.f = 1.27

Resonance	Amplitude	Phase (deg)	Fit fraction
$K^*(892)^-$	1.781 ± 0.018	131.0 ± 0.82	0.586
$K_0^*(1430)^-$	2.447 ± 0.076	-8.3 ± 2.5	0.083
$K_2^*(1430)^-$	1.054 ± 0.056	-54.3 ± 2.6	0.027
$K^*(1410)^-$	0.515 ± 0.087	154 ± 20	0.004
$K^*(1680)^-$	0.89 ± 0.30	-139 ± 14	0.003
$K^*(892)^+$	0.1796 ± 0.0079	-44.1 ± 2.5	0.006
$K_0^*(1430)^+$	0.368 ± 0.071	-342 ± 8.5	0.002
$K_2^*(1430)^+$	0.075 ± 0.038	-104 ± 23	0.000
$\rho(770)$	1 (fixed)	0 (fixed)	0.224
$\omega(782)$	0.0391 ± 0.0016	115.3 ± 2.5	0.006
$f_0(980)$	0.4817 ± 0.012	-141.8 ± 2.2	0.061
$f_0(1370)$	2.25 ± 0.30	113.2 ± 3.7	0.032
$f_2(1270)$	0.922 ± 0.041	-21.3 ± 3.1	0.030
$\rho(1450)$	0.516 ± 0.092	38 ± 13	0.002
σ	1.358 ± 0.050	-177.9 ± 2.7	0.093
σ'	0.340 ± 0.026	153.0 ± 3.8	0.013
Non Resonant	3.53 ± 0.44	127.6 ± 6.4	0.073

Dalitz method: carthesian coordinates

- from previous studies, we know that (γ , δ_B and r_B) are not a good choice from the fit point of view
  - no sensitivity to γ if $r_B < 0.10$ (underestimation of the errors)
  - fit bias on r_B for $r_B \sim 0.10$ (physical bound + low statistics)
- fit for cartesian coordinates instead: x_0 , y_0
  - $x_\pm = \mathrm{Re}[r_B\, e^{i(\delta \pm \gamma)}]$, $y_\pm = \mathrm{Im}[r_B\, e^{i(\delta \pm \gamma)}]$
  - gaussian errors: no unphysical zones
  - (x+, y+), (x-, y-) uncorrelated
  - unbiased results for all possible r_B
- also in the GLW:
  - $x_\pm = [R_{CP+}(1 \mp A_{CP+}) - R_{CP-}(1 \mp A_{CP-})]/4$



Decay Mode	Signal	Background
$B^\pm \to D(K^+K^-)K^\pm$	2800, 3200	3700 ± 1000
$B^\pm \to D(\pi^+\pi^-)K^\pm$	900, 1100	3800 ± 1500
$B^\pm \to D(K^\pm\pi^\mp)K^\pm$	28000, 28300	17500 ± 1000
$B^\pm \to D(K^\mp\pi^\pm)K^\pm$	10, 400	800 ± 500
$B^\pm \to D(K^\pm\pi^\mp\pi^+\pi^-)K^\pm$	30400, 30700	20200 ± 2500
$B^\pm \to D(K^\mp\pi^\pm\pi^+\pi^-)K^\pm$	20, 410	1200 ± 360
$B^\pm \to D(K^0_S\pi^+\pi^-)K^\pm$	5000	$1000 - 5000$ (90% C.L.)
$B^\pm \to D(K^0_S K^+K^-)K^\pm$	1000	/
$B^\pm \to D(K^+K^-\pi^+\pi^-)K^\pm$	1700	1500 ± 600
$B^\pm \to (D\pi^0)(K^\pm\pi^\mp)K^\pm$	16800, 16600	34300 ± 11500
$B^\pm \to (D\pi^0)(K^\mp\pi^\pm)K^\pm$	350, 100	4800 ± 3800
$B^\pm \to (D\gamma)(K^\pm\pi^\mp)K^\pm$	9400, 9300	34300 ± 11500
$B^\pm \to (D\gamma)(K^\mp\pi^\pm)K^\pm$	10, 140	4800 ± 3800
$B^0, \overline{B}^0 \to D(K^+K^-)K^{*0}, \overline{K}^{*0}$	240, 450	< 1000 (90% C.L.)
$B^0, \overline{B}^0 \to D(\pi^+\pi^-)K^{*0}$	70, 140	< 1000 (90% C.L.)
$B^0, \overline{B}^0 \to D(K^\pm\pi^\mp)K^{*0}, \overline{K}^{*0}$	1750, 1670	< 1700 (90% C.L.)
$B^0, \overline{B}^0 \to D(K^\mp\pi^\pm)K^{*0}, \overline{K}^{*0}$	350, 260	< 1700 (90% C.L.)

M.Bona, A.Soni, K.Trabelsi, G.Wilkinson
"UT angles from tree decays"
arXiv:0801.1833 [hep-ph]

	BF (Now)	BF(End '08)	LHCb	LHCb	SBF	ITE
$\int \mathcal{L}dt$	~ 1 ab^{-1}	2 ab^{-1}	2 fb^{-1}	10 fb^{-1}	50 ab^{-1}	
$\sigma(\alpha)$	10° (11%)	7° (8%)	8.1° (9%)	4.6° (5%)	1.5° (1.6%)	O(few %)
$\sigma(\sin 2\beta)$	0.026 (4%)	0.023 (3.3%)	0.015 (2.1%)	0.007 (1%)	0.013 (2%)	$\lesssim 1\%$
$\sigma(\gamma)$	30° (46%)	15° (23%)	4.5° (7%)	2.4° (4%)	2° (3%)	O(0.1%)

and a zoo of amplitudes

Buras & Silvestrini
hep-ph/9812392

Charming Penguin $\sim \lambda^2$ — $V_{us} V_{ub}^* \sim \lambda^4$

$$A(B^0 \to K^+ \pi^-) = V_{ts} V_{tb}^* \times P_1(c) - V_{us} V_{ub}^* \times \{E_1 - P_1^{GIM}(u-c)\}$$

$$A(B^+ \to K^0 \pi^+) = -V_{ts} V_{tb}^* \times P_1(c) + V_{us} V_{ub}^* \times \{A_1 - P_1^{GIM}(u-c)\}$$

$$\sqrt{2} \cdot A(B^+ \to K^+ \pi^0) = V_{ts} V_{tb}^* \times P_1(c) - V_{us} V_{ub}^* \times \{E_1 + E_2 + A_1 - P_1^{GIM}(u-c$$

$$\sqrt{2} \cdot A(B^0 \to K^0 \pi^0) = -V_{ts} V_{tb}^* \times P_1(c) - V_{us} V_{ub}^* \times \{E_2 + P_1^{GIM}(u-c)\}$$

Charming Penguin $\sim \lambda^3$ — $V_{ud} V_{ub}^* \sim \lambda^3$

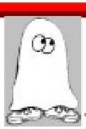
$$A(B^0 \to \pi^+ \pi^-) = V_{td} V_{tb}^* \times P_1(c) - V_{ud} V_{ub}^* \times \{E_1 + A_2 - P^{GIM}(u-c)\}$$

$$\sqrt{2} \cdot A(B^+ \to \pi^+ \pi^0) = - V_{ud} V_{ub}^* \times \{E_1 + E_2\}$$

$$\sqrt{2} \cdot A(B^0 \to \pi^0 \pi^0) = -V_{td} V_{tb}^* \times P_1(c) - V_{ud} V_{ub}^* \times \{E_2 - A_2 + P_1^{GIM}(u-c)\}$$

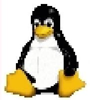
Charming Penguin $\sim \lambda^3$ — $V_{ud} V_{ub}^* \sim \lambda^3$

$$A(B^0 \to K^+ K^-) = - V_{ud} V_{ub}^* \times A_2$$



$$A(B^+ \to K^+ K^0) = -V_{td} V_{tb}^* \times P_1(c) + V_{ud} V_{ub}^* \times \{A_1 - P_1^{GIM}(u-c)\}$$

$$A(B^0 \to \bar{K}^0 K^0) = -V_{td} V_{tb}^* \times P_1(c) - V_{ud} V_{ub}^* \times \{P_1^{GIM}(u-c)\}$$



BaBar results: ππ, Kπ and KK

227 million $\bar{B}B$
BaBar-PUB-06/047

- improved statistics asks for radiative corrections
  - to extract the non-radiative BR:

$E_\gamma^{max} = M_B - m_{h+} - m_{h-}$

$$\Gamma^{incl}_{P_1P_2}(E^{max}) = \Gamma(H \to P_1 P_2 + n\gamma)|_{\sum E_\gamma < E^{max}} = \Gamma_{P_1P_2} + \Gamma_{P_1P_2+n\gamma}(E^{max})$$

$$\Gamma^{incl}_{P_1P_2}(E^{max}) = \Gamma^0_{P_1P_2} G_{P_1P_2}(E^{max})$$

where E_γ^{max} is the intrinsic energy resolution, or else the minimum energy for which we can distinguish the photon

- in MC: PHOTOS produces $h^+h^- + n\gamma$, E_γ^{max} depends on phase space
- efficiency from MC, we obtain BR($B \to h^+h^- + n\gamma$)
  - not useful for phenomenology: extrapolation of non-radiative BR clear only for small E_γ [scalar QED valid up to $O(E_\gamma^{max}/M_B)$]
  - not clean from the experimental point of view: is PHOTOS able to reproduce the whole phase space?
- ΔE is related to E_γ^{max} so we consider events with $|\Delta E| < X$:
  - we obtain BR($B \to h^+h^- + n\gamma$)$|_{E_\gamma < E_{max}}$ since $X = f(E_\gamma^{max})$

Baracchini, Isidori Phys.LettB633 309-313, 2006

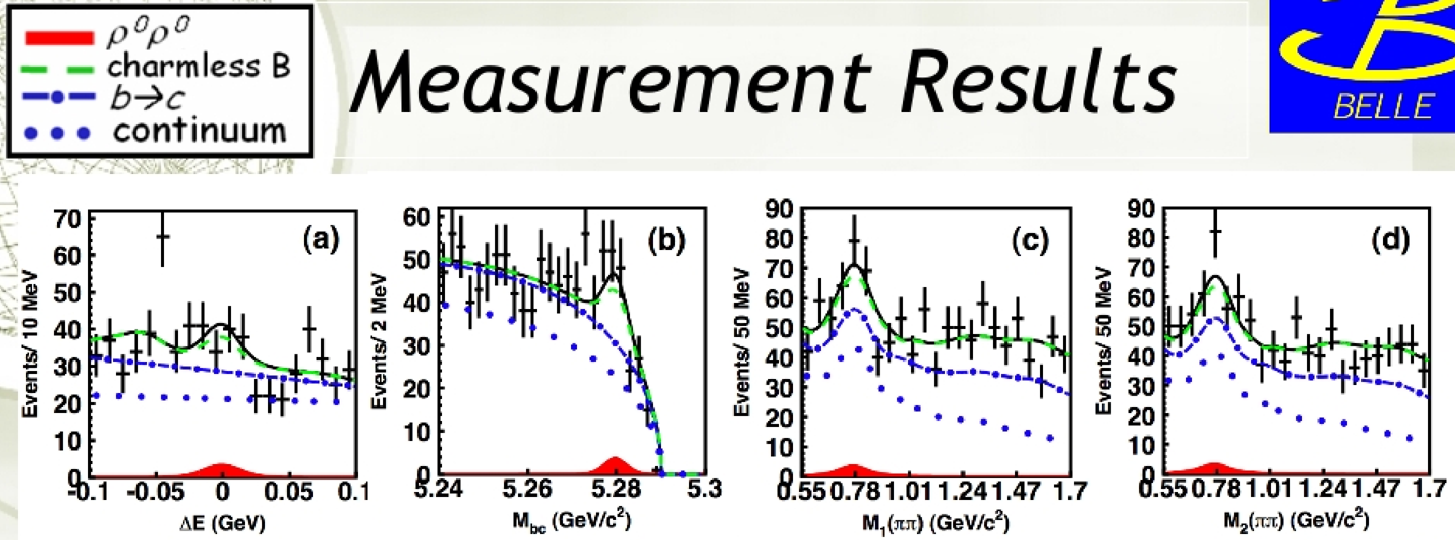
- from MC: estimate of difference between a ΔE cut and a E_γ cut **1.0-2.6%**

Mode	$BR_{E_\gamma(MeV)}(10^{-6})$	$G(E_\gamma^{max})$	$BR^0(10^{-6})$
$\pi^+\pi^-$	$5.4 \pm 0.4 \pm 0.3_{\|150}$	0.935 ± 0.005	$5.8 \pm 0.4 \pm 0.3$
$K^+\pi^-$	$18.6 \pm 0.6 \pm 0.6_{\|105}$	0.944 ± 0.005	$19.7 \pm 0.6 \pm 0.6$
K^+K^-	$< 0.40_{\|59}$	0.952 ± 0.005	< 0.40

BELLE measurement: (2008)

New Result with 657M $B\overline{B}$

Measurement Results

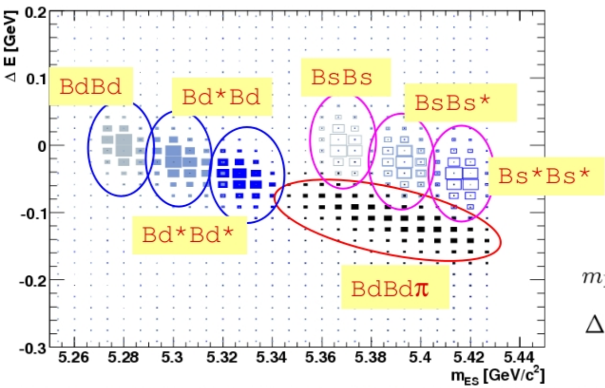


Mode	Yield	Eff.(%)	Σ	BF (x10^{-6})	UL (x10^{-6})
$\rho^0\rho^0$	$24.5^{+23.6+9.7}_{-22.1-9.9}$	9.16	1.0	0.4 ± 0.4 ± 0.2	<1.0 (assume f_L=1)
$\rho^0\pi\pi$	$161.2^{+61.2+26.0}_{-59.4-28.5}$	2.90	1.3	$5.9^{+3.5+2.7}_{-3.4-2.8}$	<11.9
4π	$112.5^{+67.4+51.5}_{-65.6-53.7}$	1.98	2.5	$12.4^{+4.7+2.0}_{-4.6-2.2}$	<19.0
$\rho^0 f_0$	$-11.8^{+14.5+4.9}_{-12.9-3.6}$	5.10	0.0	0.0	<0.6
$f_0 f_0$	$-7.7^{+4.7+3.0}_{-3.5-2.9}$	2.75	0.0	0.0	<0.4
$f_0\pi\pi$	$6.3^{+37.0+18.0}_{-34.7-18.1}$	1.55	0.0	$0.6^{+3.6}_{-3.4} \pm 1.8$	<7.3

2008/02/28 La Thuile, Italy 11

Event reconstruction

- Reconstruction techniques inherited from current B-*factories*:
  - We don't reconstruct the additional particles (π,γ) produced in the Υ(5S) decay chain;
  - separation of different components using kinematic variables.



- Good separation between Bd and Bs in mES
- BBπ discriminated by the (continuum like) mES shape

$$m_{\rm ES} = \sqrt{(s/2 + \mathbf{p}_i \cdot \mathbf{p}_B)^2/E_i^2 + p_B^2}$$

$$\Delta E = E_B^* - \sqrt{s}/2$$

E.Baracchini, M.B. et al. JHEP 0708:005,2007.

B pairs coherence

- B pairs at the Υ(5S) mainly produced in association with photons;
- What about the coherence of the B pairs?
- It can be shown that:

In the $B_{s,d}{}^*B_{s,d}{}^*$ case and in the $B_{s,d}B_{s,d}$ case the final pair is in an antisymmetric state → the time evolution of the B pair is the same than at the Y(4S);

⇩

B_d TD analyses still possible

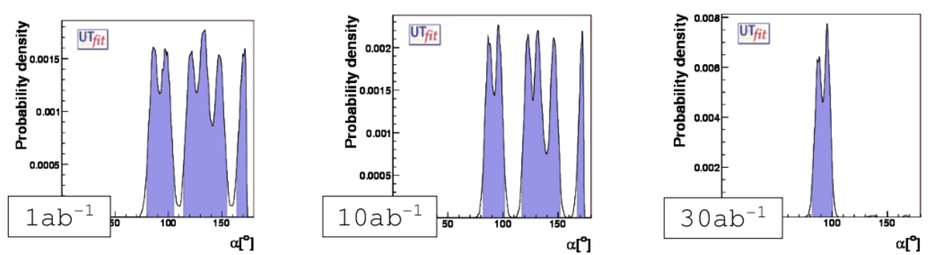
$B_{s,d}{}^*B_{s,d}$ the state is symmetric → different time evolution;

⇩

New $B_{s,d}$ Time Integrated measurement

Time Integrated Analysis

- $B_d \rightarrow \pi^0\pi^0$:
  - Rate and asymmetry used to determine a through an isospin analysis → ambiguity;
  - TD analysis at the Y(4S) not enough sensitive to extract both Re(λ) and Im(λ) (or equivalently S and C);
  - Time Integrated Analysis with B*B events at the Y(5S) allow to constraint Im(λ) and reduce the ambiguity.



Gronau-London method:

$$A^{+-} = e^{-i\alpha}\, T^{+-} + P$$
$$A^{00} = 1/\sqrt{2}\,(e^{-i\alpha}\, T^{00} - P)$$
$$A^{+0} = 1/\sqrt{2}\, e^{-i\alpha}\,(T^{+-} + T^{00})$$

CP: $\alpha \rightarrow -\alpha$

6 parameters: $|T^{+-}|$, $|T^{00}|$, $|P|$, δ^{00}, δ^{P}, α

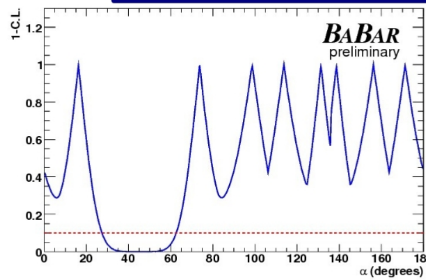
6 observables: B^{+-}, B^{00}, B^{+0}, C^{+-}, S^{+-}, C^{00}

$$B_{\pi\pi}^{+-,00} = \frac{1}{2}\left(\left|A^{+-,00}\right|^2 + \left|\bar{A}^{+-,00}\right|^2\right) \quad , \quad B_{\pi\pi}^{+0} = \frac{\tau_{B^+}}{\tau_{B^0}}\frac{1}{2}\left(\left|A^{+0}\right|^2 + \left|\bar{A}^{+0}\right|^2\right)$$

$$C_{\pi\pi}^{ij} = \frac{\left|A^{ij}\right|^2 - \left|\bar{A}^{ij}\right|^2}{\left|A^{ij}\right|^2 + \left|\bar{A}^{ij}\right|^2} \quad , \quad S_{\pi\pi}^{ij} = \frac{\mathrm{Im}\ A^{ij}\bar{A}^{ij*}}{\left|A^{ij}\right|^2 + \left|\bar{A}^{ij}\right|^2}$$

8 or 0 solutions

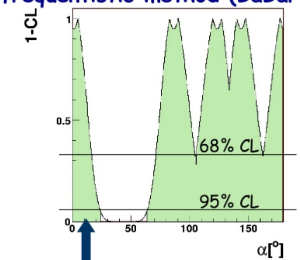
interpretation of the results



frequentistic method (BaBar paper)

"some of the solutions, and the region around a=0 can be disfavoured by other physics information"

frequentistic method (BaBar+Belle)



The region around α =0 is not excluded, despite the experimental observation of CP violation.

what kind of "other information"?

The GL method already requires some a priori "minimal assumptions" on strong interactions, namely:

- Flavour blind and CP conserving strong interactions
- Negligible isospin symmetry breaking effects, including e.m. corrections

This is because we believe that:

- QCD is the theory of strong interactions
- QCD is a renormalizable theory with a dimensionless coupling constant and a natural scale Λ_{QCD} ~ 1 GeV

$\langle M_1 M_2 | O | M\rangle \sim (\Lambda_{QCD})^3$ case of a single scale

Therefore we do not expect: $\langle \pi\pi | O | B\rangle \sim (1\ \text{TeV})^3$ or $(M_{Planck})^3$

scales and dimensions

In our case: two scales enter in the process, M_B and Λ_{QCD}

so we expect: $\langle\pi\pi|\hat{O}|B\rangle \sim f_\pi M_B^2 f^+(0) \sim f_\pi M_B^2 \left(\frac{\Lambda_{QCD}}{M_B}\right)^{3/2} \sim M_B^{1/2}\Lambda_{QCD}^{5/2}$

Note: the scaling law has a more general validity than factorization

➔ This gives: $T^{ij} \sim 1$ [We use "natural units": the BR x 10^6 are simply given by the squared amplitude]

But we can think of other considerations:

- using strict factorization

$$|T^{+-}|^2 = \frac{G_F^2 \tau_B |V_{ub}V_{ud}^*|^2}{32\pi M_B}|C_1(M_B)\langle\pi^+\pi^-|O_1|B_d^0\rangle + C_2(M_B)\langle\pi^+\pi^-|O_2|B_d^0\rangle|^2 \times 10^6$$
$$= \frac{G_F^2 \tau_B |V_{ub}V_{ud}^*|^2}{32\pi M_B}\left|\frac{C_1(M_B)}{3} + C_2(M_B)\right|^2 \times |M_B^2 f_\pi f^+(0)|^2 \times 10^6$$

several theoretical predictions exist(ed)

[17] Ciuchini et al.'98
[18] BBNS'99
[19] Keum et al.'02

➔ This gives: $|T^{+-}| = 3.2$

BR($\pi^+\pi^0$)

ref. [17]	ref. [18]	ref. [19]	Exp.
3.6 – 5.3	4.3 (1 ± 0.3)	$3.7^{+1.3}_{-1.1}$	5.5 ± 0.6

further considerations

- scaling between B and D decays

In the heavy quark limit, the dependence on M_H cancels in the decay rate.

$$R = \frac{|T^{+-}(B_d^0 \to \pi^+\pi^-)|^2}{|T^{+-}(D^0 \to \pi^+\pi^-)|^2} \sim \frac{|V_{ub}V_{ud}^*|^2}{|V_{cd}V_{ud}^*|^2}$$

$$|T^{+-}|^2 = BR(D^0 \to \pi^+\pi^-) \times 10^6 \, \frac{\tau_{B_d^0}}{\tau_{D^0}} R$$

➜ This gives: $|T^{+-}| = 1.3$

- extract P from the $B_s \to K^+K^-$ decay

Up to DCS terms

$$|P|^2 = BR(B_s \to K^+K^-) \times 10^6 \, \frac{\tau_{B_d^0}}{\tau_{B_s^0}} \frac{|V_{td}V_{tb}^*|^2}{|V_{ts}V_{tb}^*|^2} \; : \; |P_s|^2 \overset{SU(3)}{\longrightarrow} |P|^2$$

$|P_s| = 1.1$ → (SU(3)) → $|P| \le 2.5$ → ($\pi\pi$) → $|T^{+-}| \approx 1$

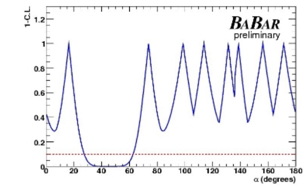
assuming that SU(3) breaking effects are not larger than 100%

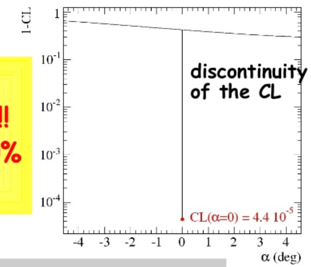
some consequences

- solution for $\alpha \to 0$

in order to reproduce the experimental values of $BR(\pi^+\pi^-)$ and $BR(\pi^0\pi^0)$ we may have |T|>>1 and |P|>>1, but |T| ~ |P|

$\alpha < 2°$ → |T+-|>30
→ |P|~30 → SU(3) breaking~3000% !!
→ m_s/m_d ~10 → SU(2) breaking~300%
(Gronau-London??)





the results are contradicting the assumptions

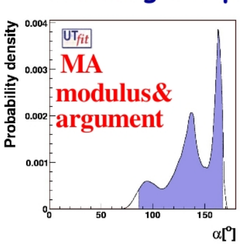
using the available information (priors)

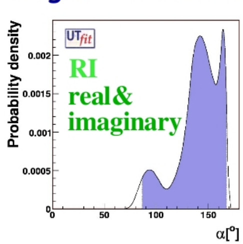
In previous UTfit analyses: $|T^{ij}| \le 10$, $|P| \le 10$

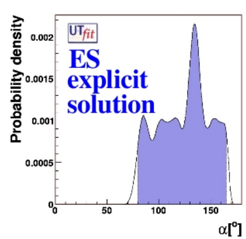
Now: $|T^{ij}| \le 10$, $|P| \le 2.5$, arbitrary phases ← SU(3) breaking ≤ 100%

$|T^{ij}|$ will be automatically limited

1) The information on the matrix elements has the effect of eliminating some of the eight solutions, including the pathological solution at α ~0





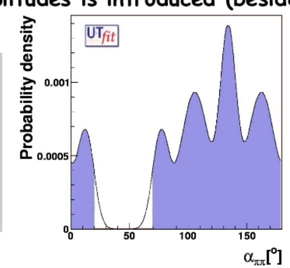


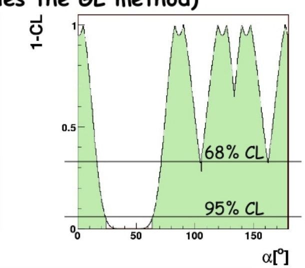
Bayesian vs Frequentistic analysis

Compare the 2 methods using the same assumptions

- In the Bayesian approach: extract BR's and CP parameters with gaussian p.d.f. according with their experimental values and errors
- In the frequentistic analysis: no additional information on the hadronic amplitudes is introduced (besides the GL method)

Caveat: these are two different quantities: p.d.f. or CL

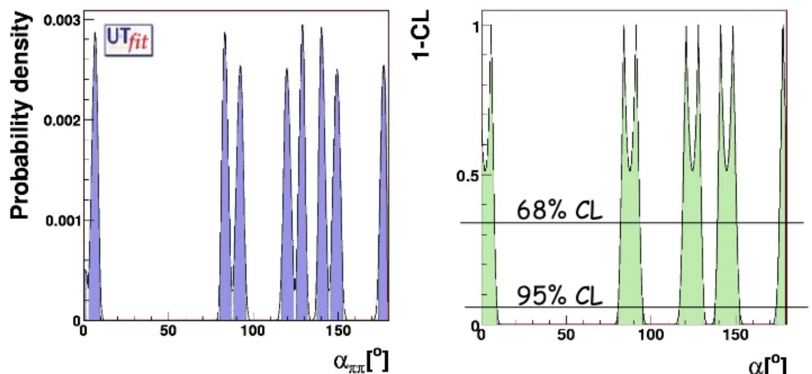




The two approaches give equivalent results at a meaningful CL/Prob.

further comparison:

Reducing the experimental errors by
a factor of 10 at fixed central values



Not yet really separated at a meaningful CL

The eight solutions "start" to be separated both in the Bayesian and frequentistic case

Provided the same assumptions are done, the two approaches lead to similar results

BaBar-Belle comparison:

For S:

1. **The average per event errors are about the same for Belle and BaBar; there are some specific cases where BaBar has better errors, e.g. p0K0, because of the 5-layer SVT**
2. **The yields are generally much higher for BaBar vs Belle, due to the use of multivariate maximum likelihoods instead of cuts**
3. **The product of same per event errors times higher yields gives much better performance, typically 20-50% and averaging around 43%.**

For C:

1. **The average per event errors are worse for BaBar than for Belle; there are some specific cases where BaBar has better errors, e.g. p0K0**
2. **The yields are generally much higher for BaBar vs Belle, same as for S**
3. **The product of smaller per event errors times higher yields still gives better performance in most cases, although it is less of an advantage. This ends up being about a 9% advantage on average.**