CP violation
overview of CKM angles

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on the behalf of

the ***BaBar*** *Collaboration*

DIS 2004

Stbske Pleso, High Tatras, Slovakia

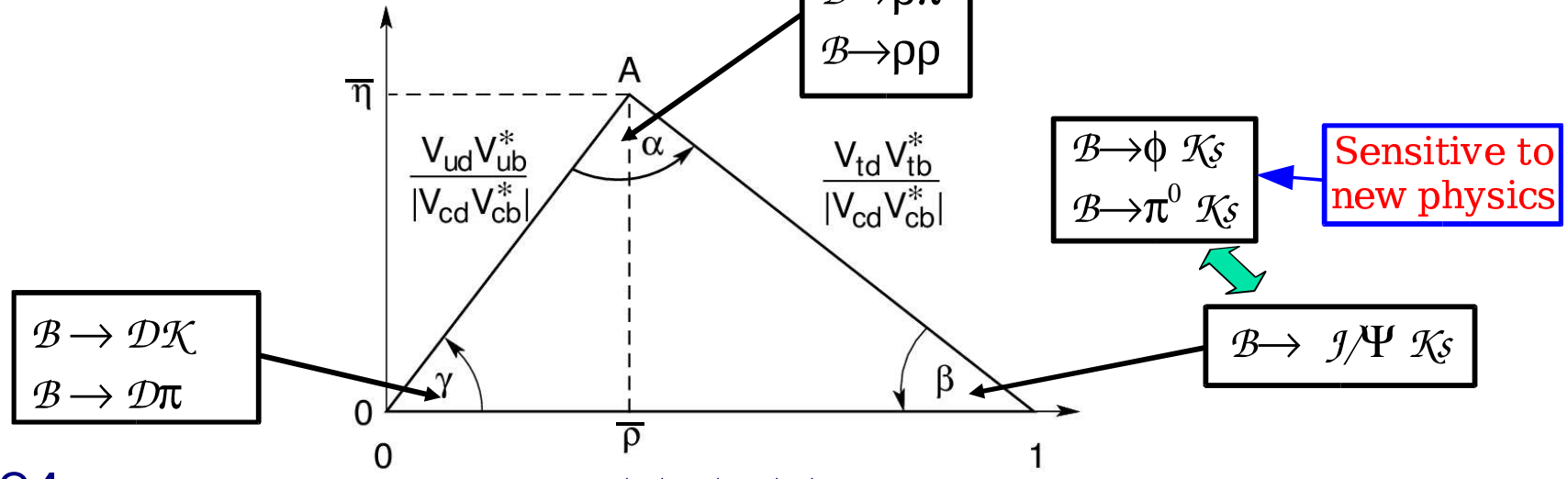
The Unitarity Triangle & B Decays

$$V_{CKM} = \begin{pmatrix} Vud & Vus & Vub \\ Vcd & Vcs & Vcb \\ Vtd & Vts & Vtb \end{pmatrix} \simeq \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\bar{\rho}-i\bar{\eta}) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\bar{\rho}-i\bar{\eta}) & -A\lambda^2 & 1 \end{pmatrix}$$

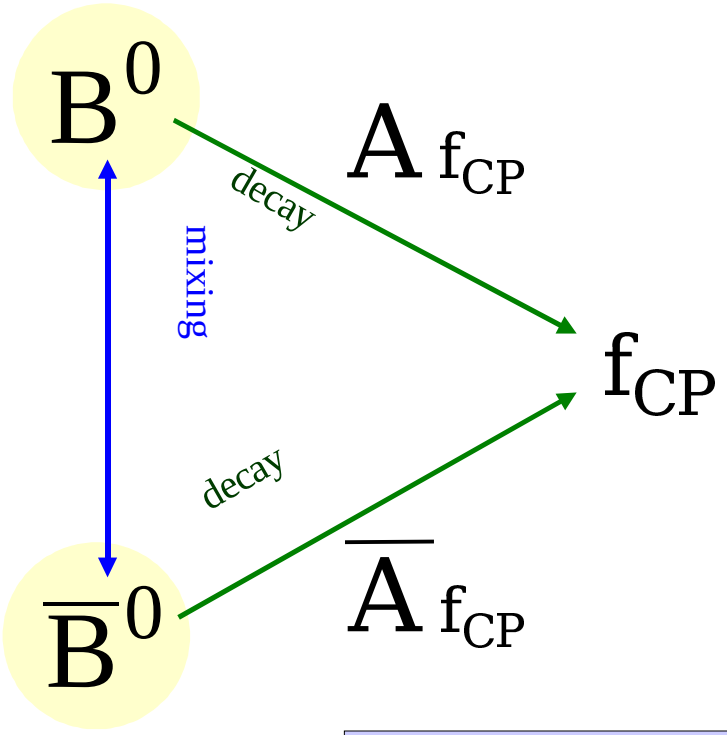
Only one parameter

$\mathcal{CP}$ in B is larger than in K system

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



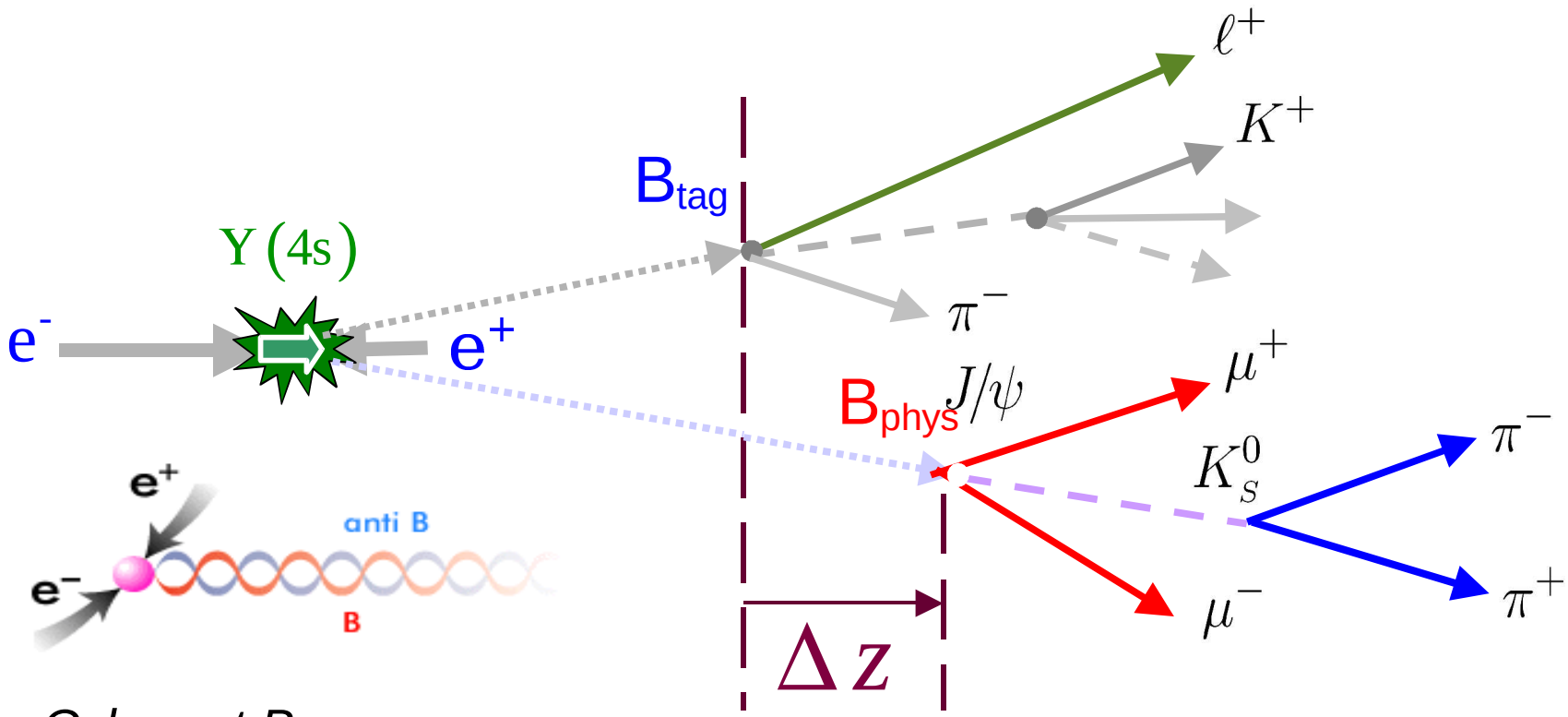
CP violation in mixing and decay



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

If $f = J/\psi\ K_S$	$C=0$	$S=\sin(2\beta)$
If $f = \pi\pi\ ,\ \rho\rho$	$C\neq 0$	$S\approx\sin(2\alpha+\Delta\alpha)$
If $f = D\ \pi$	$C\approx 1$	$S=r\ \sin(2\beta+\gamma) \ll 1$

Experimental technique

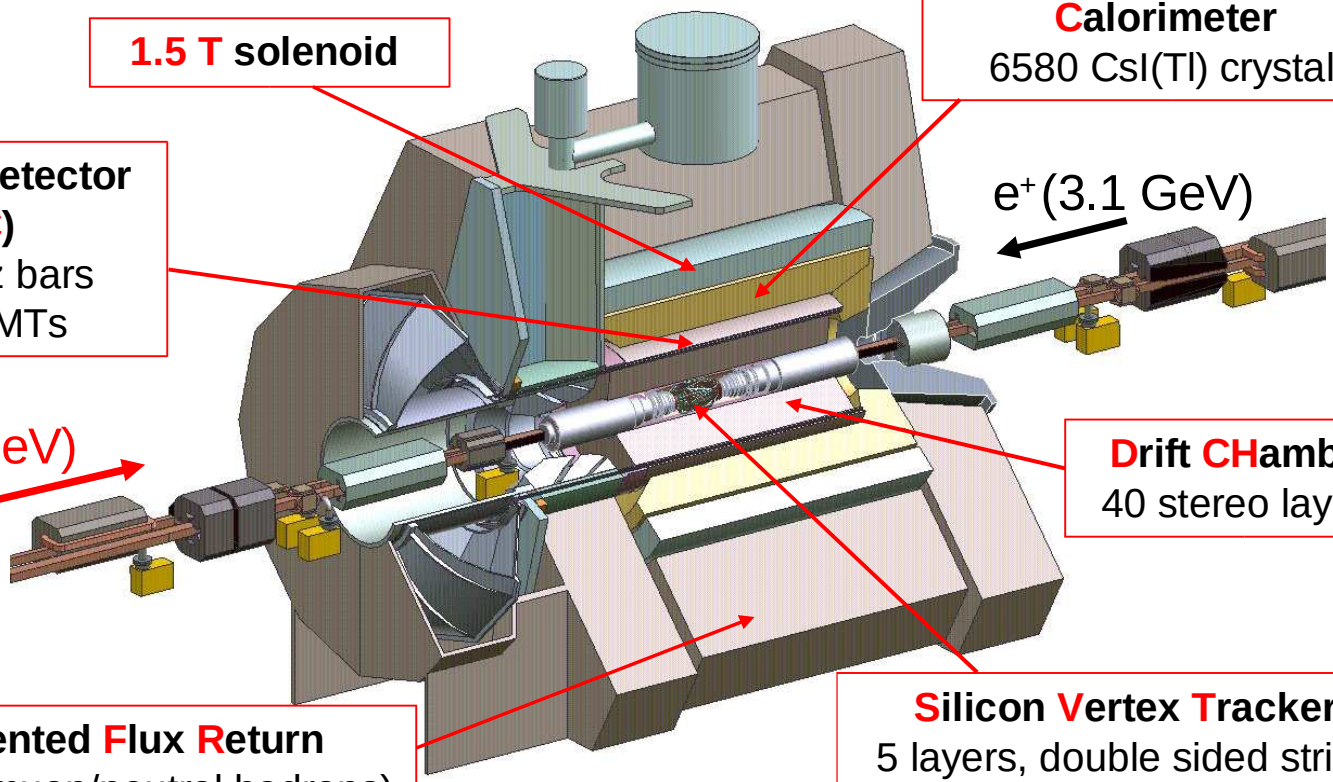


Coherent B meson pair production

$$<|\Delta z|> = <\beta\gamma c \Delta t> \sim 250\,\mu m$$

0.56 1.2 ps

The BaBar detector



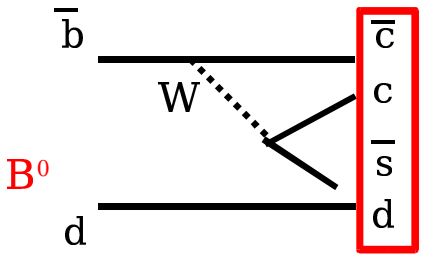
SVT: 97% efficiency, 15 μm z hit resolution (inner layers, ⊥ tracks)

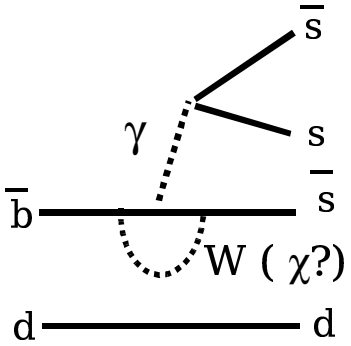
SVT+DCH: $\sigma(p_T)/p_T = 0.13\ \% \times p_T + 0.45\ \%$

DIRC: K-π separation 4.2σ @ 3.0 GeV/c → >3.0σ @ 4.0 GeV/c

EMC: $\sigma_E/E = 2.3\ \% \times E^{-1/4} \oplus 1.9\ \%$

Measurements of β





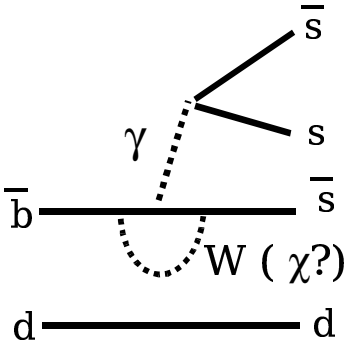
J/ψ

K0

[Charmonium K0](#)

Penguin and tree have the same weak phase

No Tree



ϕ

K0

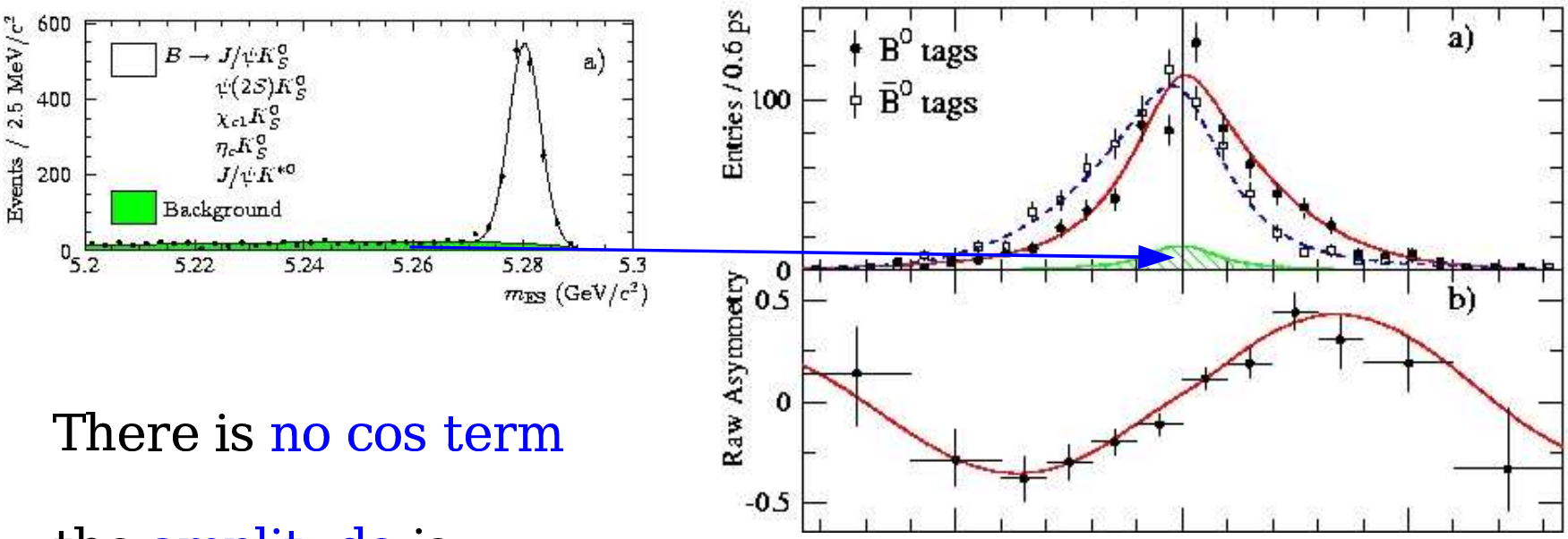
[ϕK0 / π0K0 / η(')K0](#)

[f0K0 / K+K-K0](#)

Mostly penguin. In principle measures sin2β, but sensitive to new physics

J/ψ Ks

sin2β is measured with good precision (using $b \to c\bar{c}\, s$):



There is no cos term

the amplitude is proportional to sin 2β

The asymmetry is clearly visible

sin2β=0.741±0.067 ±0.034 (BaBar, 89M BB)

New time-dependent asymmetry measurement with $B^0 \to J/\Psi\ K^{*0}(K_s\pi^0)$

cos 2β>0 @ 89%CL preliminary

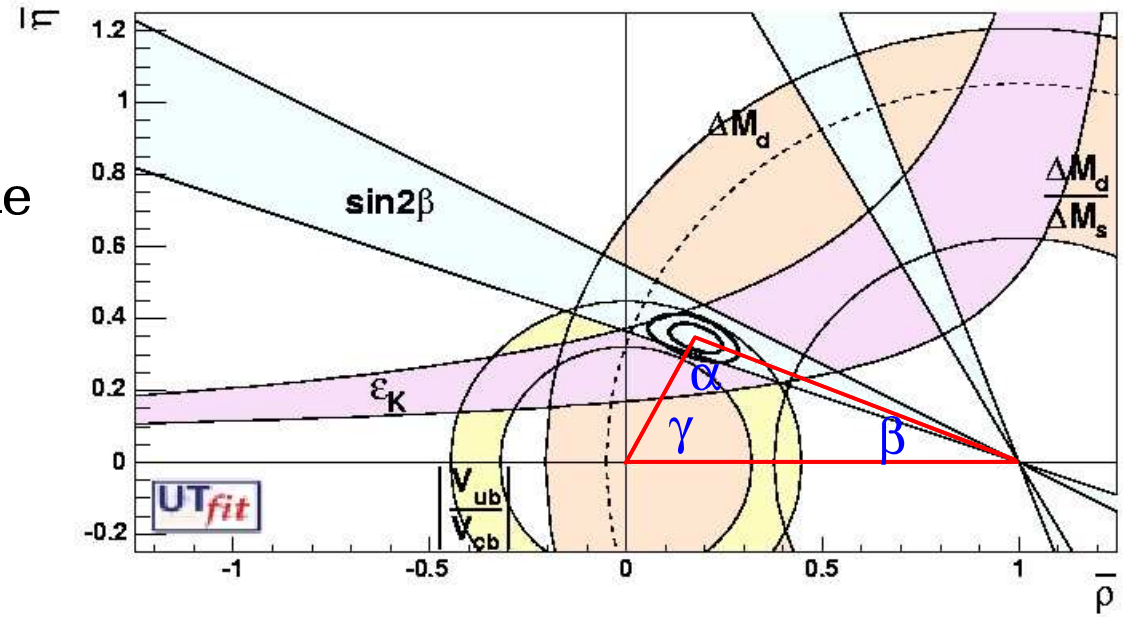
Talk from M. Pioppi

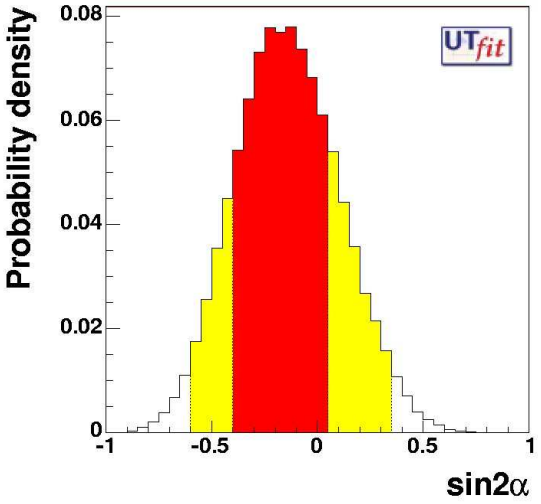
Unitarity Triangle fit

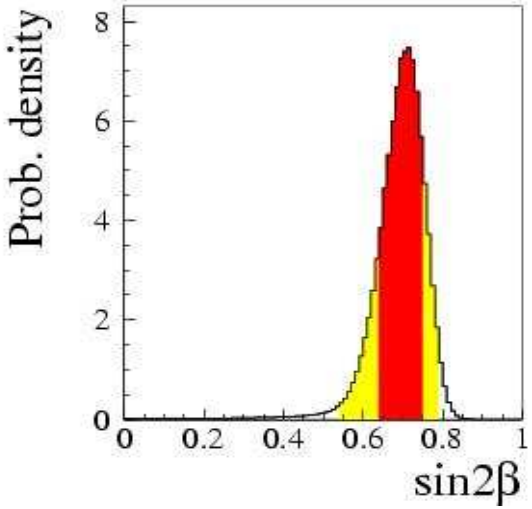
The fit results are compatible with the SM

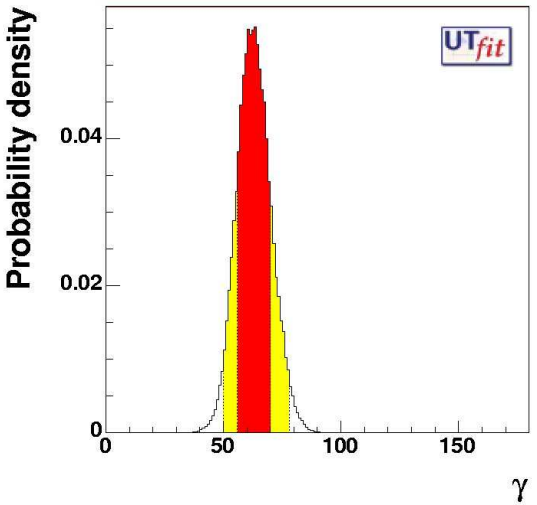
Indirect determination of the UT angles:

- Sin(2α)= –0.19±0.25
- Sin(2β)= 0.685±0.052
- γ = (61.5±7)deg



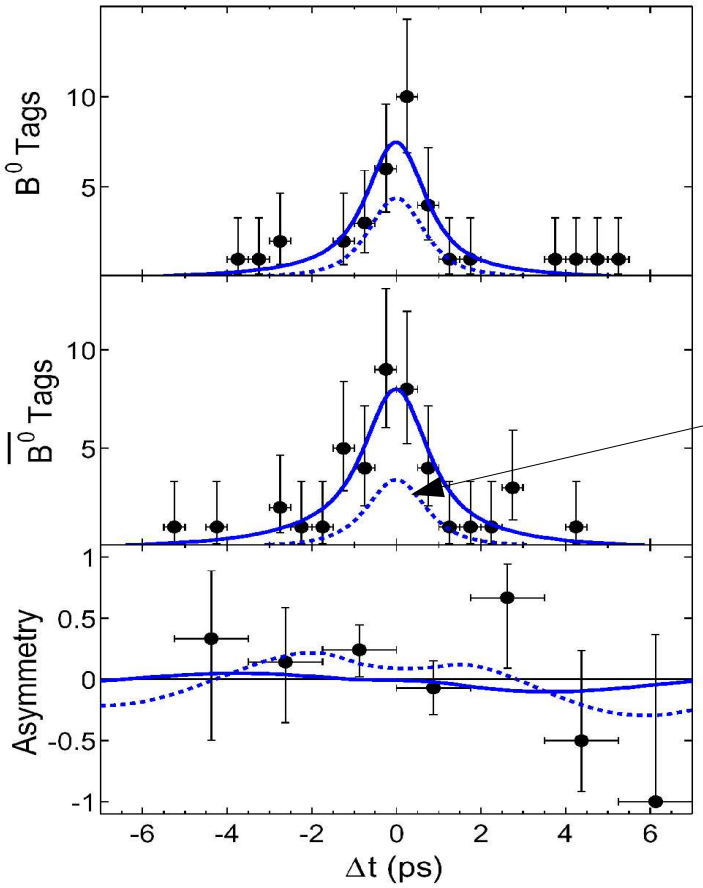


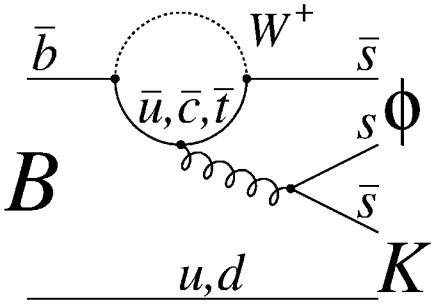




ϕK_s (BaBar)

110 fb^{-1}





ϕK_s (Belle)

140 fb^{-1}

background

SM

Hint, not very clear
of new physic

$C = 0.38 \pm 0.37 \pm 0.12$

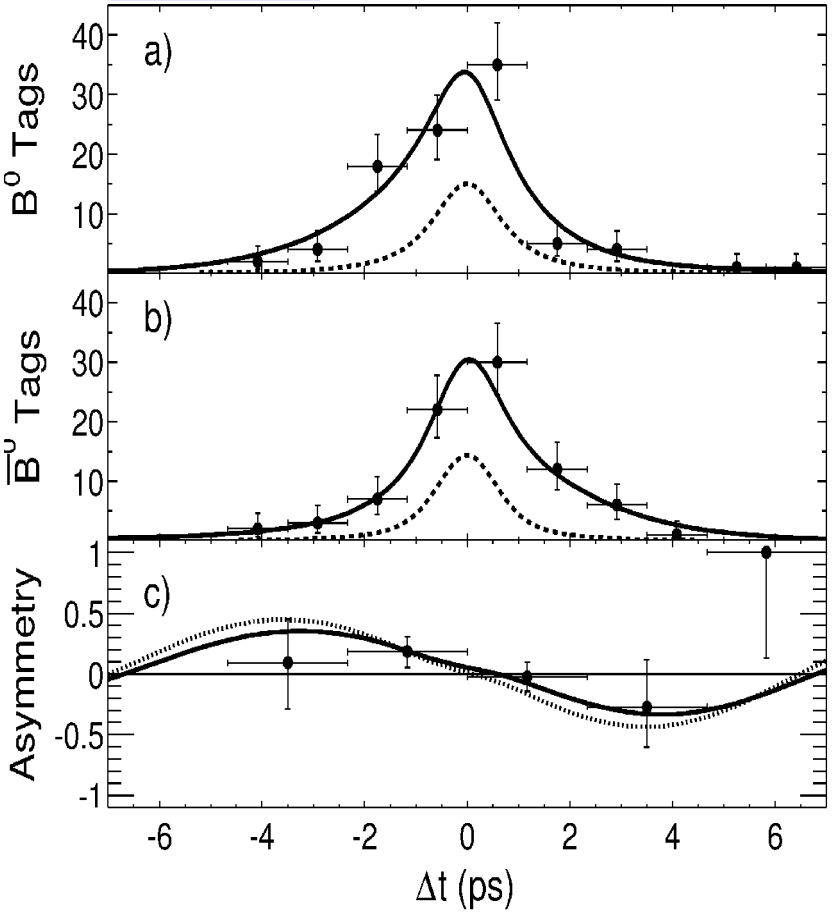
$S = 0.45 \pm 0.43 \pm 0.07$

$C = -0.15 \pm 0.29 \pm 0.07$

$S = -0.96 \pm 0.50^{+0.09}_{-0.11}$

$K^+ K^- K_s$

110 fb^{-1}

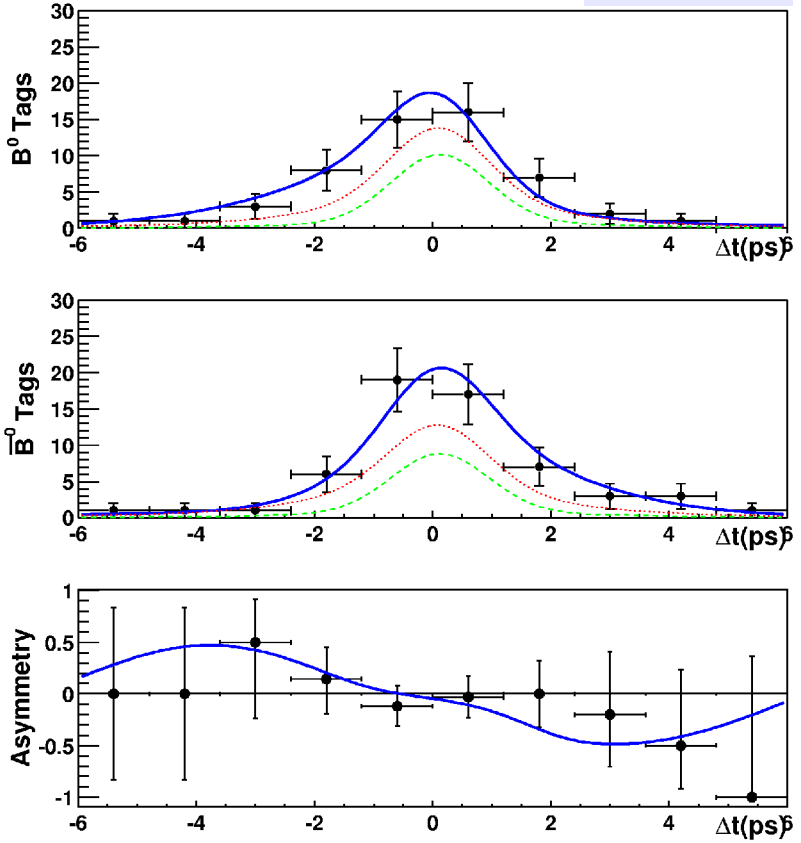


$C = -0.10 \pm 0.19 \pm 0.09$

$S = -0.56 \pm 0.25 \pm 0.04$

$f^0(980)\ K_s$

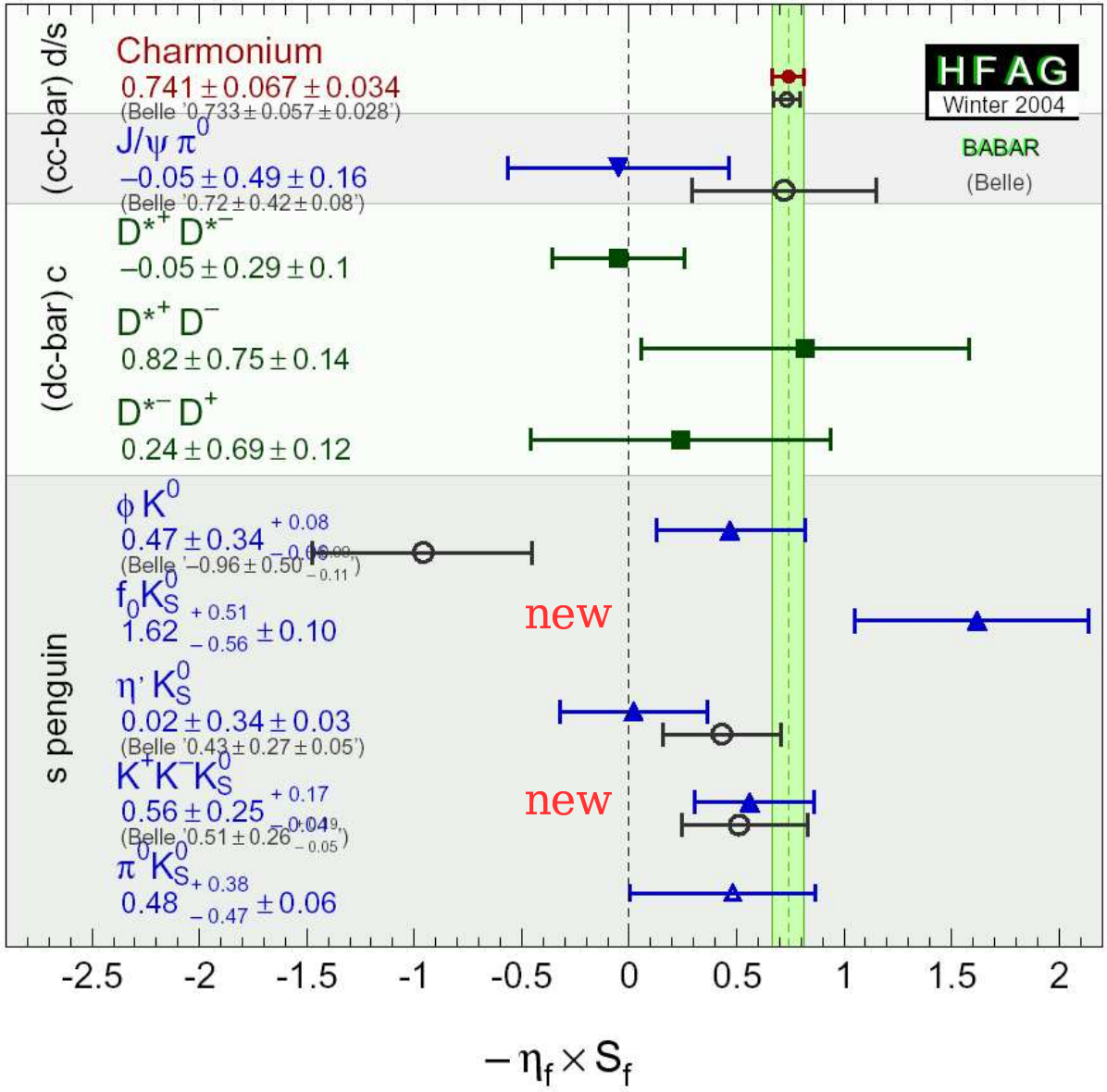
110 fb^{-1}



$C = 0.27 \pm 0.36 \pm 0.12$

$S = -1.62^{+0.56}_{-0.51} \pm 0.10$

Status of S(sin $2\beta_{eff}$) measurements



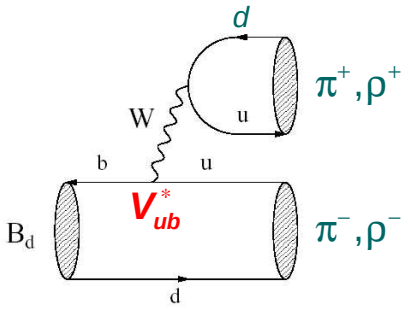
Include all sin 2β measurements from BaBar (and Belle).

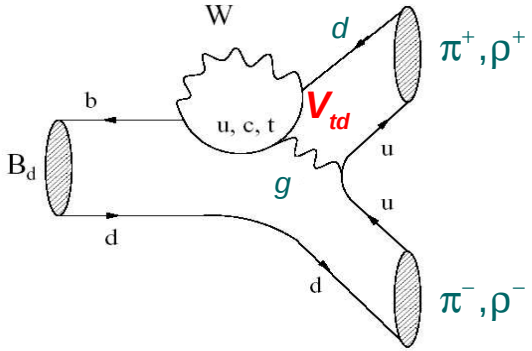
Including those not presented today.

b→s penguins give lower values

Sin(2α) from $B^0 \to \pi^+\pi^-$ ($\rho^+\rho^-$) decay

Proceeds mainly through $b \to u\bar{u}d$ tree diagram, but penguin contributions introduce additional phases.





Used channels:

$B \to \pi\pi$

$B \to \pi\rho$

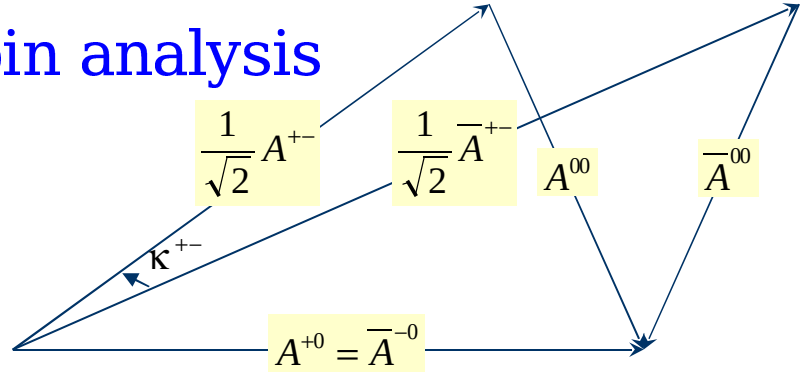
$B \to \rho\rho$

extra weak and strong phases + |P/T| modify α by κ:

$\sin 2\alpha \to \sin 2\alpha_{eff}$ $\quad 2\alpha_{eff} = 2\alpha + \kappa$

To relate α to α_{eff}:

Isospin analysis



Grossman-Quinn bound

$$\sin^2(\alpha_{eff} - \alpha) < \frac{BR(B^0 \to \pi^0\pi^0)}{BR(B^+ \to \pi^+\pi^0)} \quad \begin{matrix}\rho^0\rho^0 \\ \rho^+\rho^0\end{matrix}$$

$A^{00} \approx 0 \;\to\; \alpha_{eff} \approx \alpha$

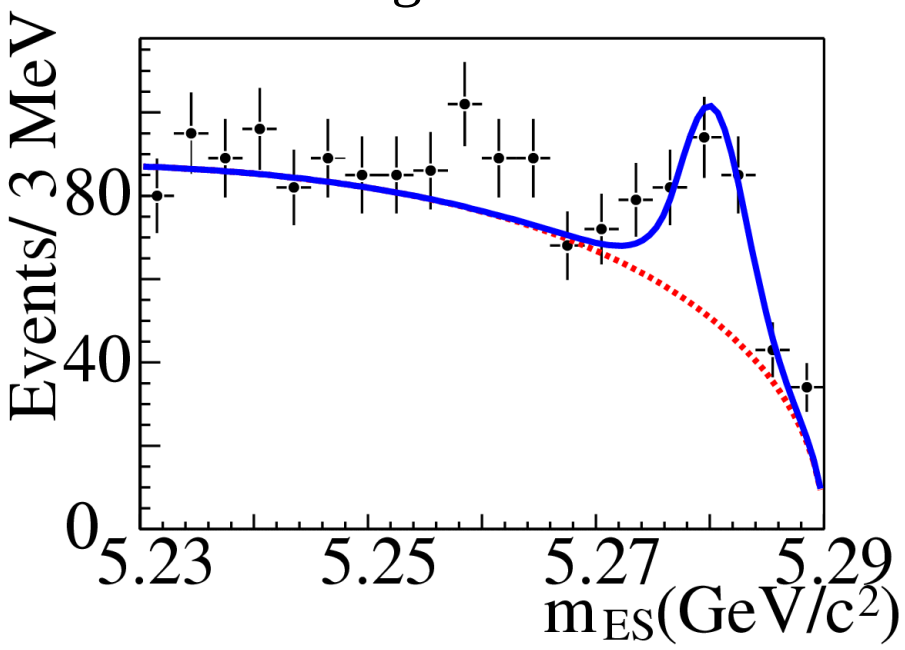
Small penguin contamination: $\rho^+\rho^-$

$BR(B^{\pm} \to \rho^{\pm}\rho^0) = (26.4 \pm 6.4)\ 10^{-4}$

$BR(B^0/\bar{B}^0 \to \rho^0\rho^0) < 2.1\ 10^{-6}$ → Small penguin contribution

We find $B \to \rho^+\rho^-$ polarized → CP even final state

220 signal events



from **ML fit** on
m_{ES}, E, NN(evt. shape), t, M, hel. Angles:

$BR(B^0 \to \rho^+\rho^-) = (30 \pm 4_{stat} \pm 5_{syst})\ 10^{-6}$

$f_{long}(\rho^+\rho^-) = (0.99 \pm 0.03^{+0.04}_{-0.03})$

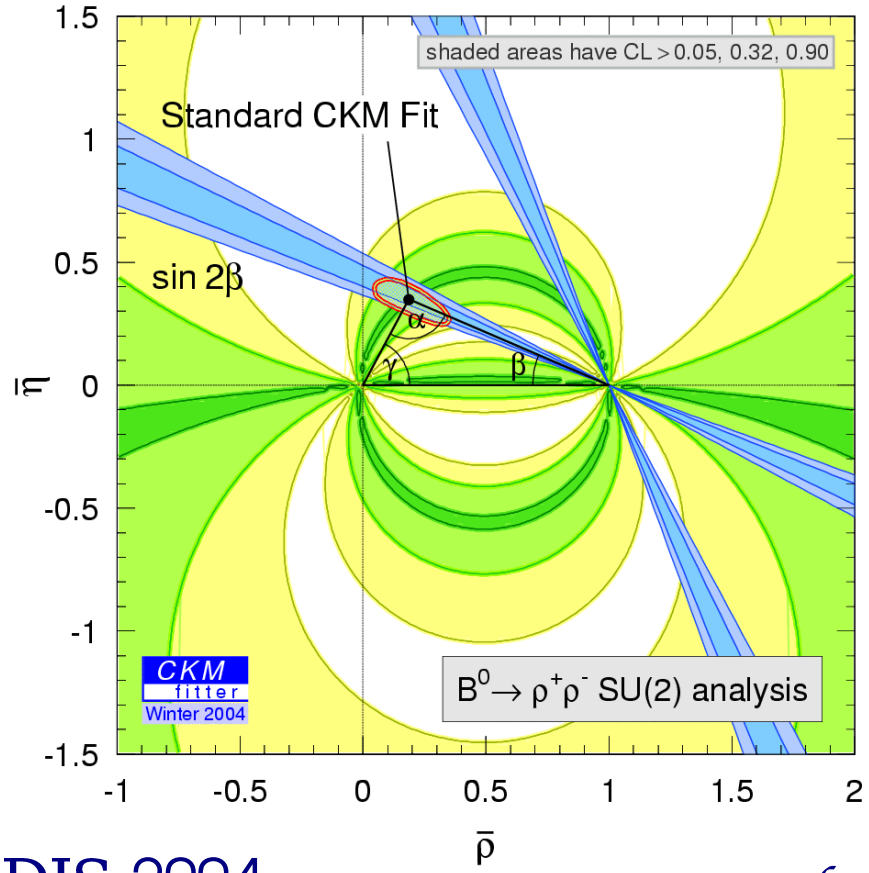
Preliminary

$\rho^+\rho^-$: results

The time-depended asymmetry:

$$C_l = -0.23 \pm 0.24 \pm 0.14$$

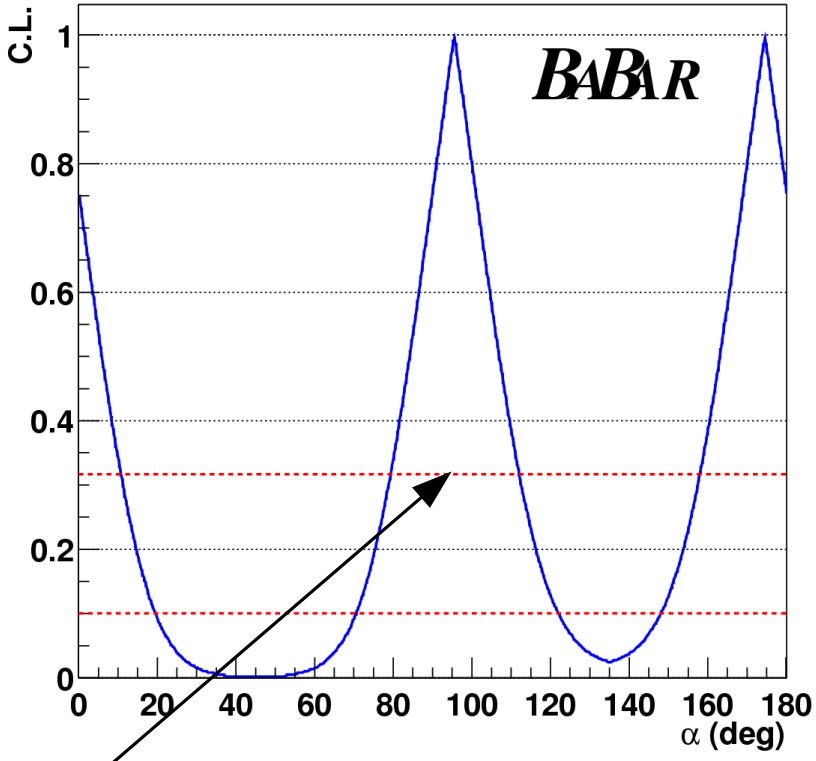
$$S_l = -0.19 \pm 0.33 \pm 0.11$$



Isospin analysis:

interference, NR contribution

I=1 amplitudes neglected



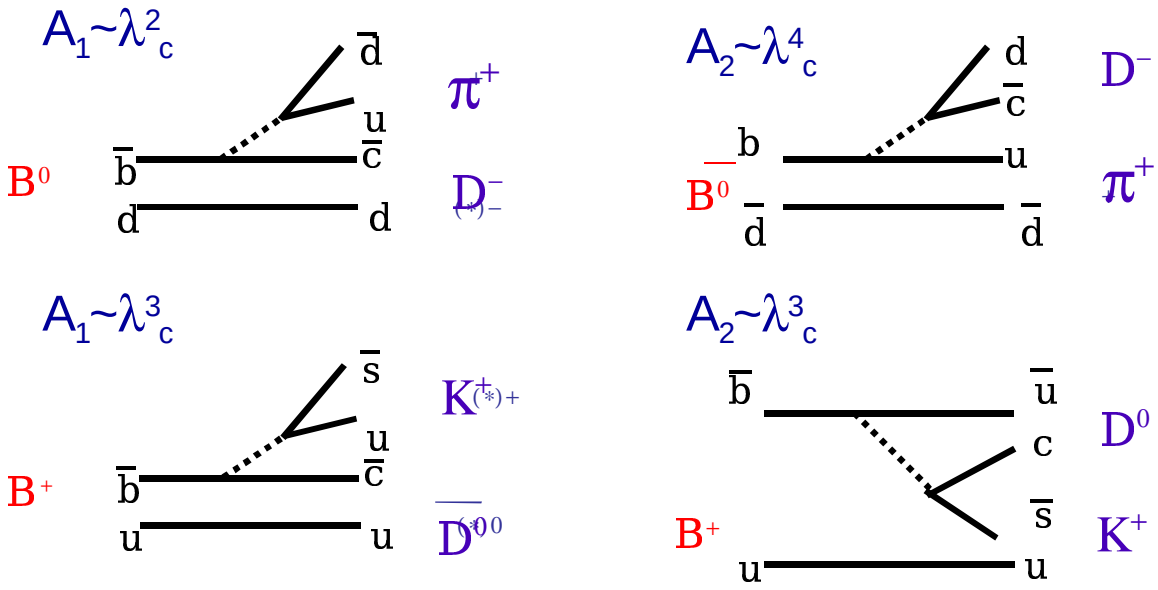
$$\alpha = (96 \pm 10_{stat} \pm 4_{syst} \pm 13_{peng})\, deg$$

Measurements of γ

Contributions from b→u transitions bring a dependence of CPV from γ

- Measure γ directly in direct CP asymmetries & B^+ decay rates
- Measure $2\beta+\gamma$ with CPV in mixing

Two cases

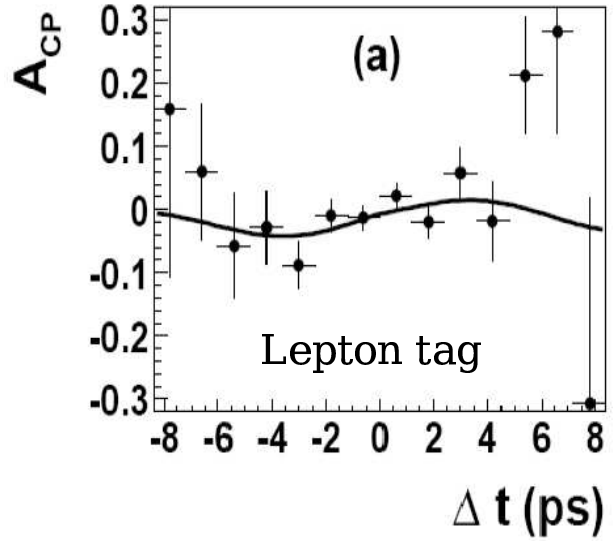


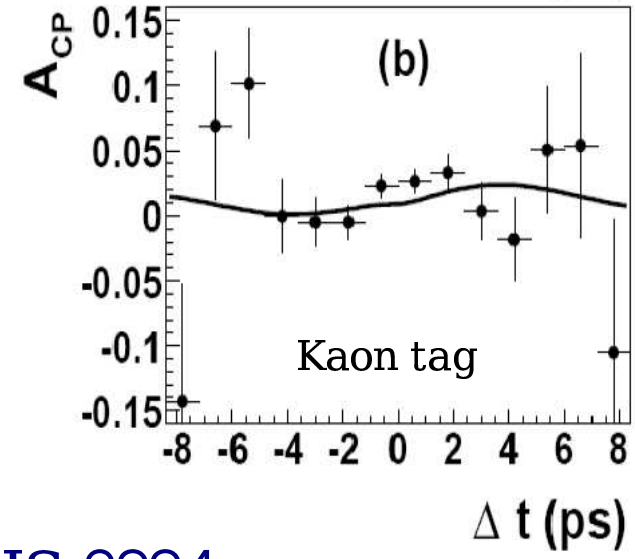
$\sin(2\beta+\gamma)$: A_2 doubly cabibbo suppressed

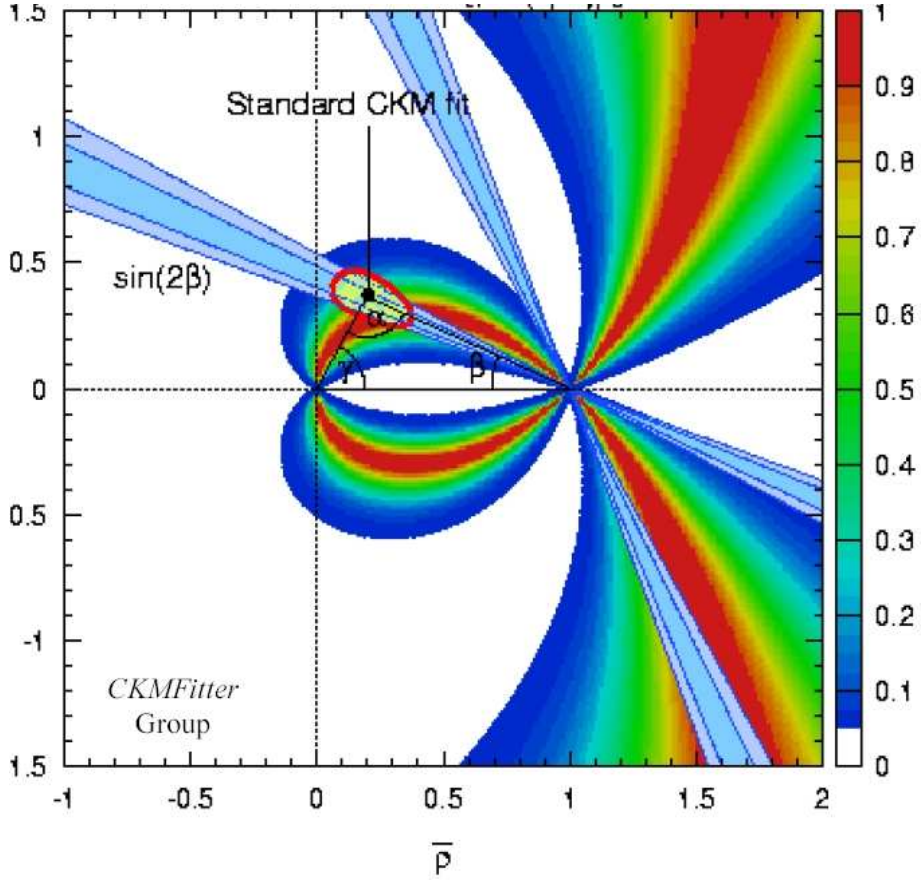
$\sin(\gamma)$: A_2 colour suppressed

ρ–η constraints from $D^{(*)}\pi$

From (small) asymmetry in $B^0 \to D^{(*)+}\pi^-$ and $B^0 \to D^{(*)-}\pi^+$ get the sensitivity to $\sin(2\beta+\gamma)$



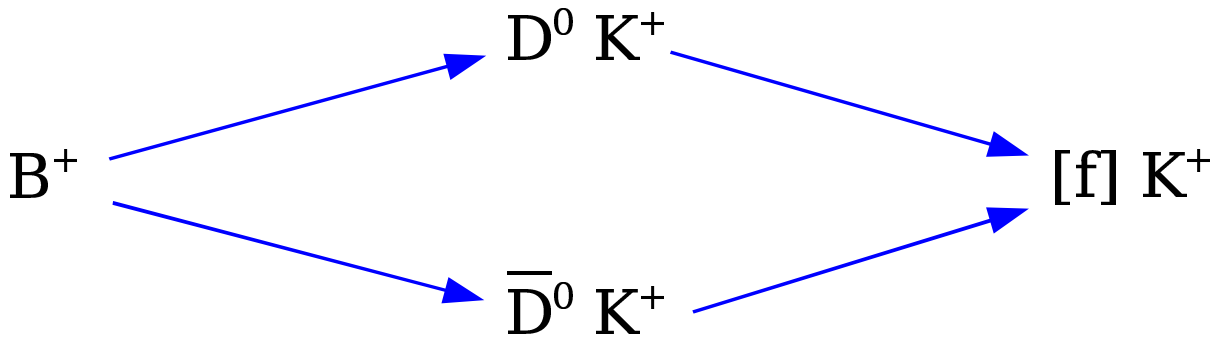




- $|\sin(2\beta+\gamma)| > 0.87$ at 68% CL
- $|\sin(2\beta+\gamma)| > 0.58$ at 95% CL

How to extract γ from B→DK decays

γ is the phase between b→u and b→c amplitudes



$$r_b \equiv \frac{|A(B^- \to \overline{D}^0 K^-)|}{|A(B^- \to D^0 K^-)|} \sim 0.1 - 0.2$$

for most methods based on B→DK, the larger r_b, the better precision on γ

exploits the interference between $B^- \to D^0 K^-$ and $B^- \to \overline{D}^0 K^-$ when $D^0/\overline{D}^0$ decays to a common final state

theoretically clean extraction of γ, but generally with discrete ambiguities
(number of ambiguities depends on the D final state)

$B^- \to [K^+\pi^-]_D K^-$: ADS method

Atwood-Dunietz-Soni: equalize the interference amplitudes

favored $B^- \to D^0 K^-$, **suppressed** $D^0 \to K^+ \pi^-$

suppressed $B^- \to \bar{D}^0 K^-$, **favored** $\bar{D}^0 \to K^+ \pi^-$

$\Rightarrow [K^+ \pi^-]_D K^-$

$$R_{ADS} = \frac{Br([K^+\pi^-]K^-) + Br([K^-\pi^+]K^+)}{Br([K^-\pi^+]K^-) + Br([K^+\pi^-]K^+)} = r_d^2 + r_b^2 + 2 r_b r_d \cos\delta \cos\gamma$$

R_{ADS}<0.026 @ 90% CL $\longrightarrow$ r_b<0.22 @ 90% CL

hep-ex/0402024 Sub. to PRL

Interference is going to be small

$\searrow$ Tough measurement of γ

The program of measuring γ

a number of decay modes give information on γ:

$B \to D^{(*)}K^{(*)}$, $D^0 \to$ CP eigenstate
$B \to D^{(*)}K^{(*)}$, $D^0 \to$ Double Cabibbo Suppressed (previous slides)
$B \to D^{(*)}K^{(*)}$, $D^0 \to$ 3body (require Dalitz analysis)
$B^0 \to D^{(*)}\ \pi, \rho$ time dependent analysis, measures $\sin(2\beta+\gamma)$)

the methods provide a theoretically clean measurement of γ,
but require very large B samples

Large effort in getting to γ ongoing

Summary and outlook

- The sin2β is already a precision measure

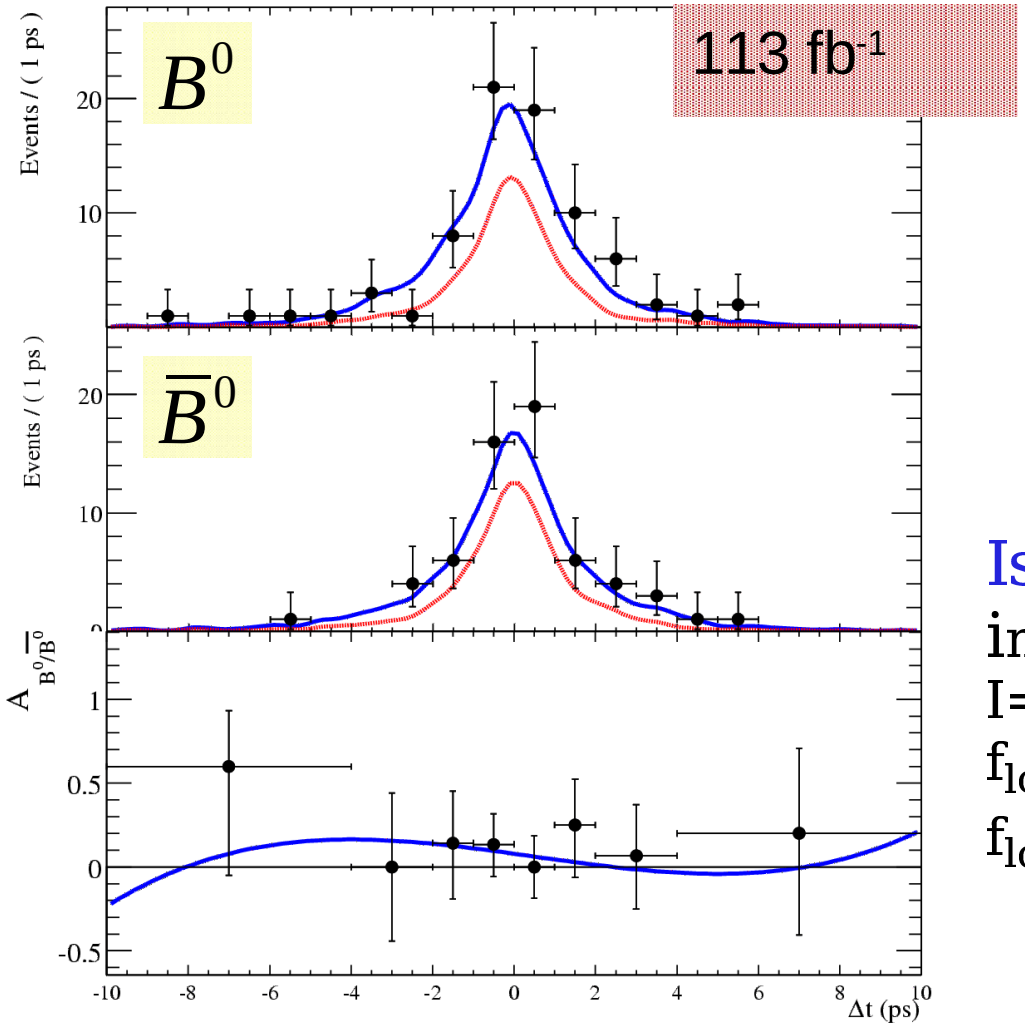
- Testing the SM:
  very good agreement in J/ψ Ks with SM
  some deviation on penguins (φ Ks)
- New penguins modes (f^0 Ks , $K^+ K^-$ Ks) studies
- α extraction need a full isospin analysis for ππ
- We have a first constraint on α with assumptions (I=1 neglected)

$$\alpha = (96 \pm 10_{stat} \pm 4_{syst} \pm 13_{peng})\, deg$$

- Lots of new measurements aiming at measuring γ

Backup slides

$\rho^+\rho^-$ time-dependent asymmetry



$$C_l = -0.23 \pm 0.24 \pm 0.14$$

$$S_l = -0.19 \pm 0.33 \pm 0.11$$

Isospin analysis:

interference, NR contribution

I=1 amplitudes neglected

$f_{long}(\rho^+\rho^0) = (0.962^{+0.049}_{-0.065})$ BaBar & Belle

$f_{long}(\rho^0\rho^0) = 1$ assumed