α and γ at Babar

Malcolm John
LPNHE – Universités Paris 6&7

On behalf of the *BABAR* collaboration

Conclusions (for those who can't wait…)

- PEP-II and *BABAR* have performed beyond expectation
- CP violation in the B system is well established
  - sin(2β) fast becoming a precision measurement

$$\sin(2\beta) = 0.722 \pm 0.046$$

- As for the other two angles (the subject of this presentation) :
  - Many analysis strategies in progress
  - The CKM angle α is measured but greater precision will come

$$\alpha = [103^{+10}_{-11}]^{\circ}$$

  - First experimental results on γ are available

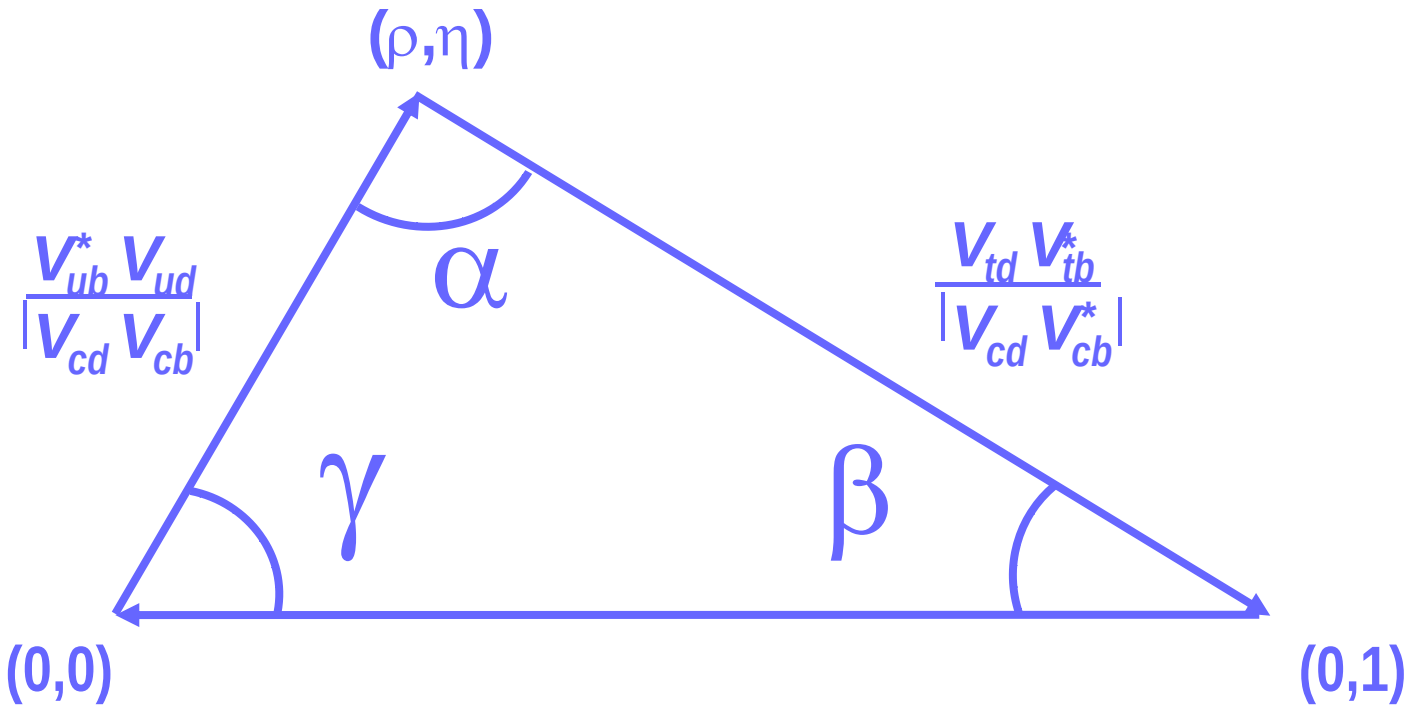
$$\gamma = [70 \pm 29]^{\circ} \quad + n\pi$$

  - First experimental results on 2β+γ are available

$$|\sin(2\beta + \gamma)| > 0.75 \quad (68\%\ C.L.)$$

- Results presented here are based on datasets up-to 227 M_{BB}
  - *BABAR* and PEP-II aim to achieve 550 M_{BB} (500 fb^{-1}) by summer 2006

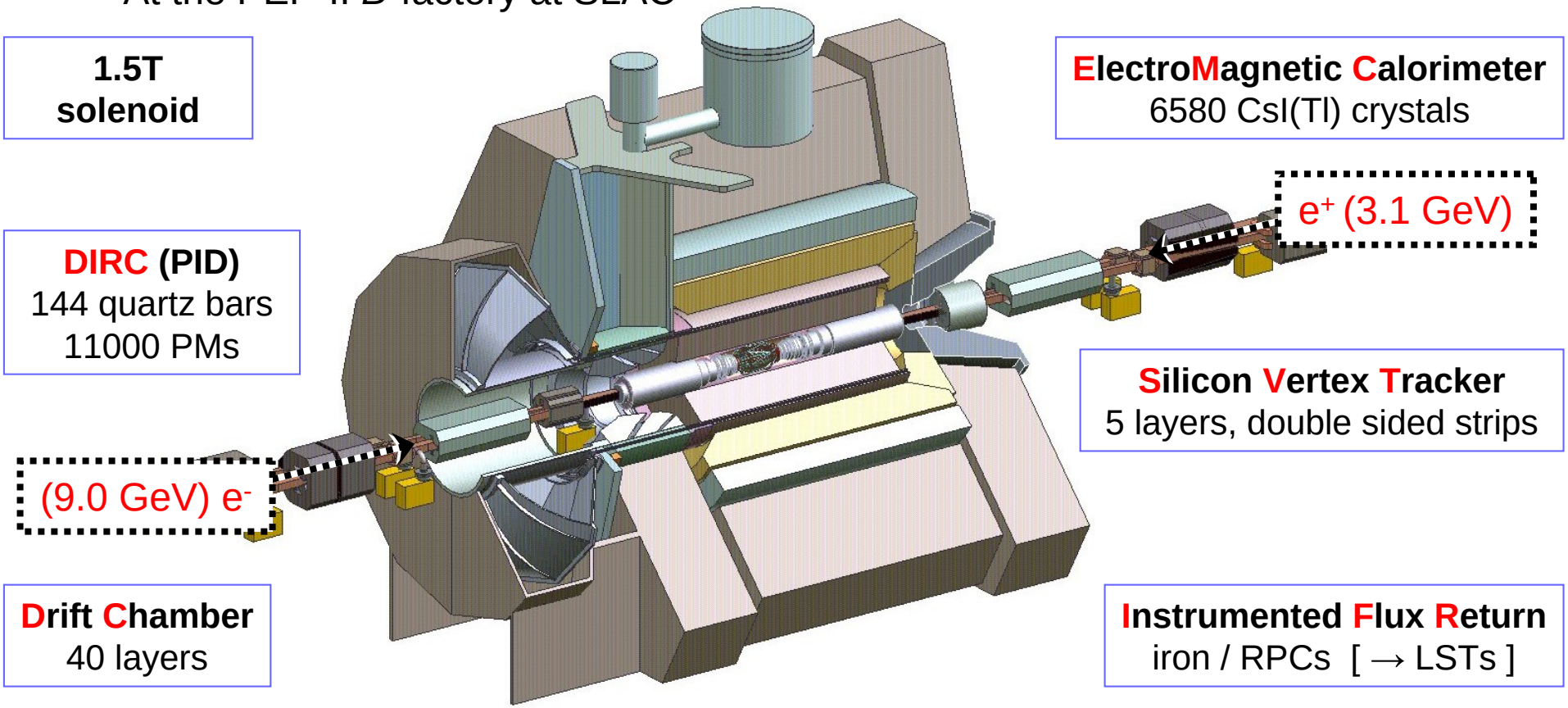
$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \approx \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1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



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

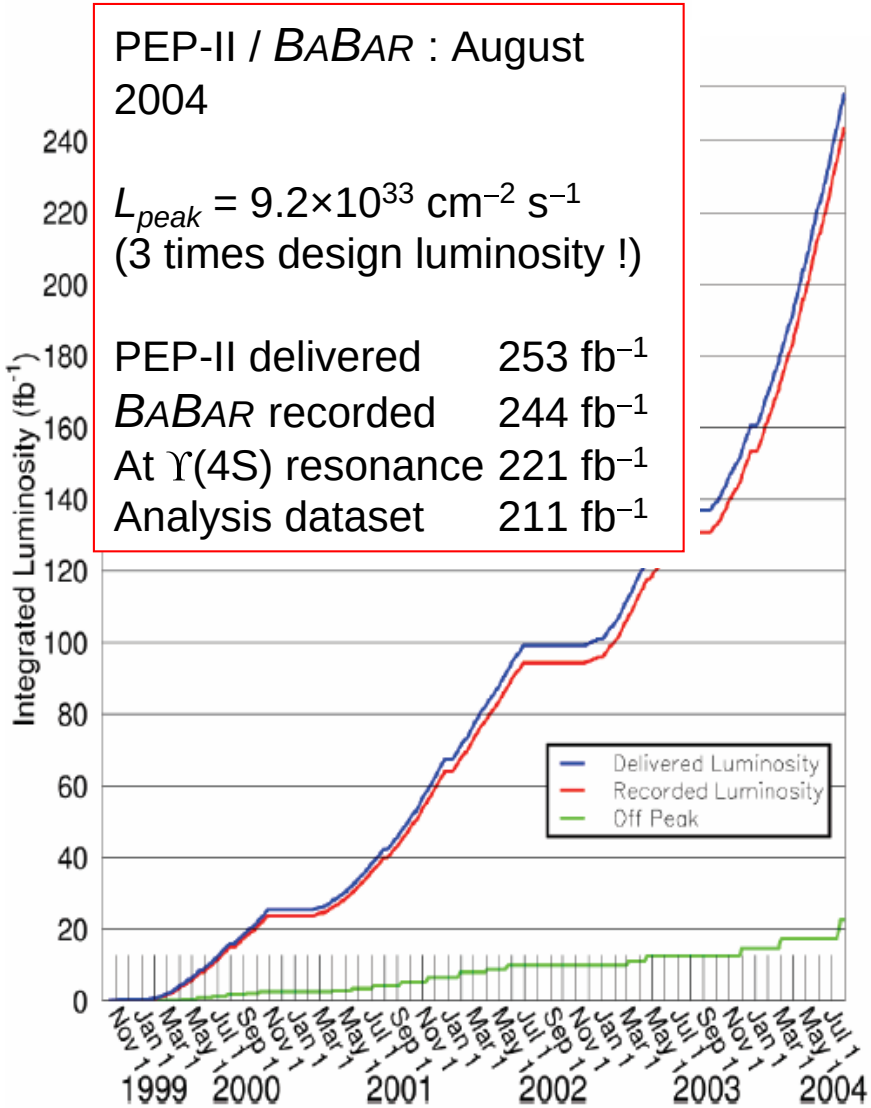
BABAR : where? what? who?

- At the PEP-II *B*-factory at SLAC



- *BABAR* collaboration consists 11 countries and ~590 physicists !

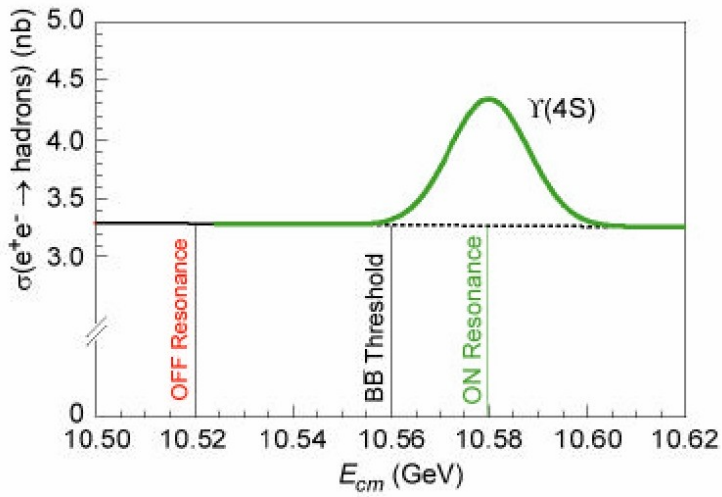
PEP-II : performance



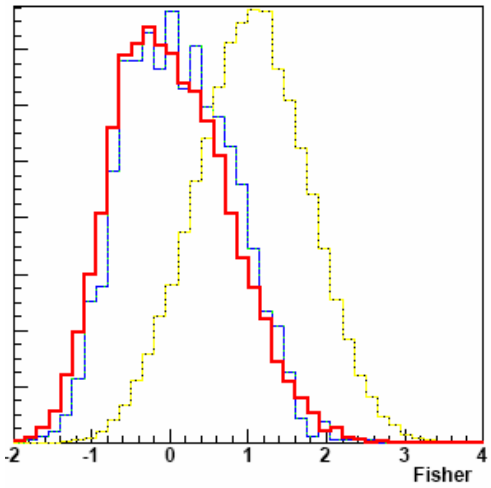
- Beams circulating in PEP-II again this month for the beginning of the 2005-2006 run.
  - Aim for 500 fb^{-1} by summer 2006
- Belle and KEKB are running well
  - Their dataset could be 600 fb^{-1} in the same time period

Analysis techniques : Continuum suppression

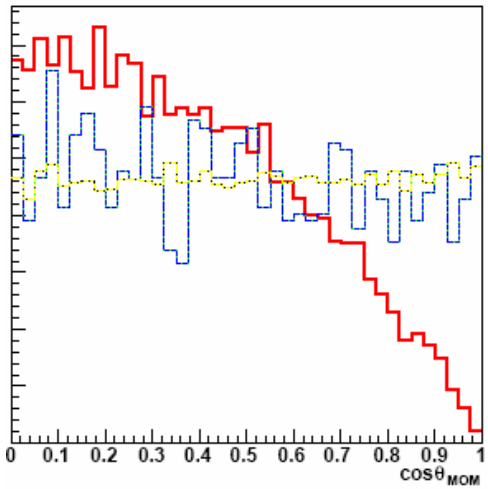
- For every $b\bar{b}$ pair-production, expect three $q\bar{q}, \quad q \in \{u, d, s, c\}$
  - *Many techniques available it fight this background.*
  - *They can be amalgamated in linear discriminators or neural networks.*



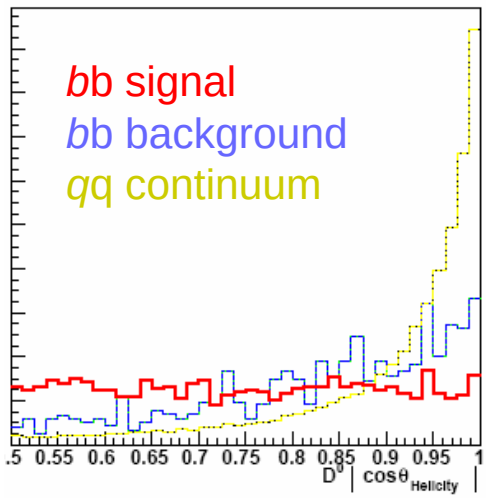
Variables that distinguish spherical B events from jet-like continuum.



Variables that distinguish $\Upsilon(4S) \rightarrow bb$ from $e^+e^- \rightarrow q\bar{q}$



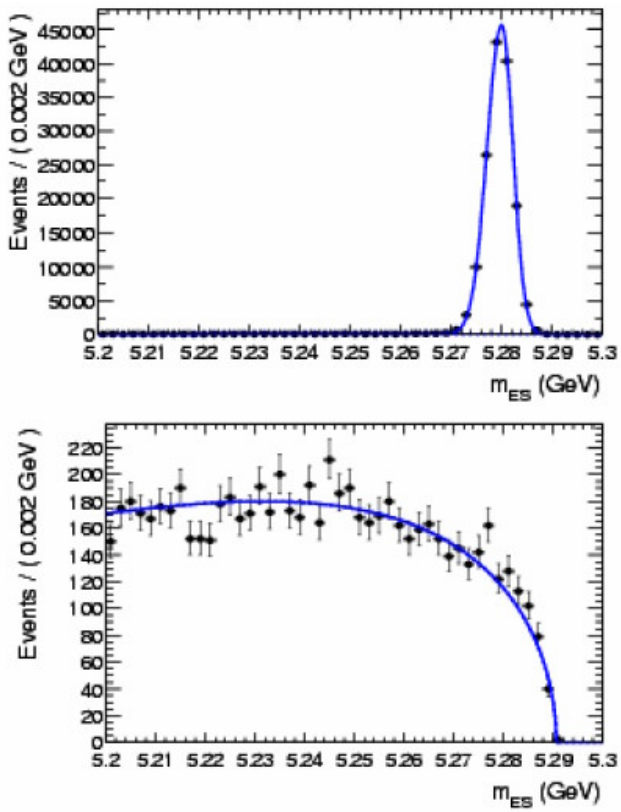
Other variables, like $\theta_H(D^0)$



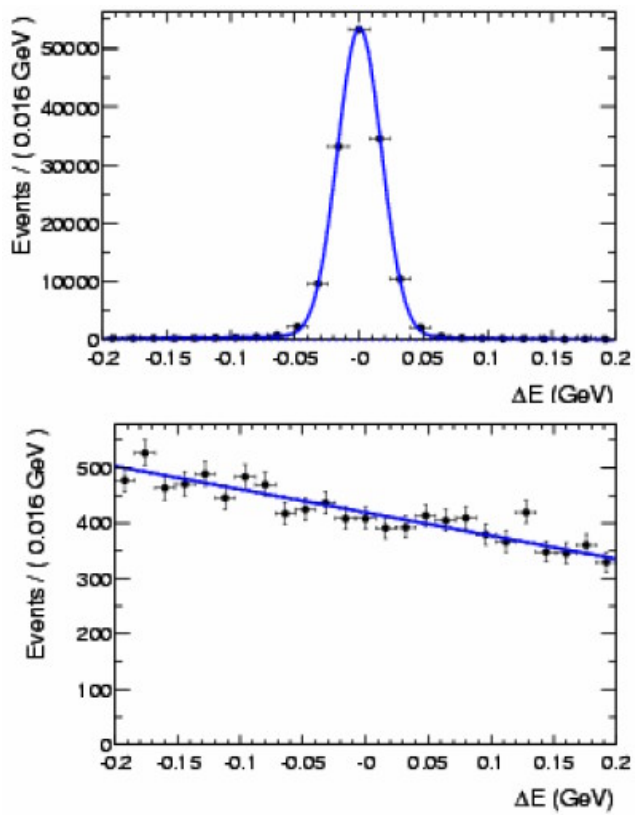
Analysis techniques : m_{ES} and ΔE

- Precise kinematics, unique to machines operating at a threshold
  - The initial energy of the system is well known from the precise tuning of the beam

$$m_{ES} = \sqrt{E_{beam}^{*2} - p_B^{*2}}$$



$$\Delta E = E_B^* - E_{beam}^*$$

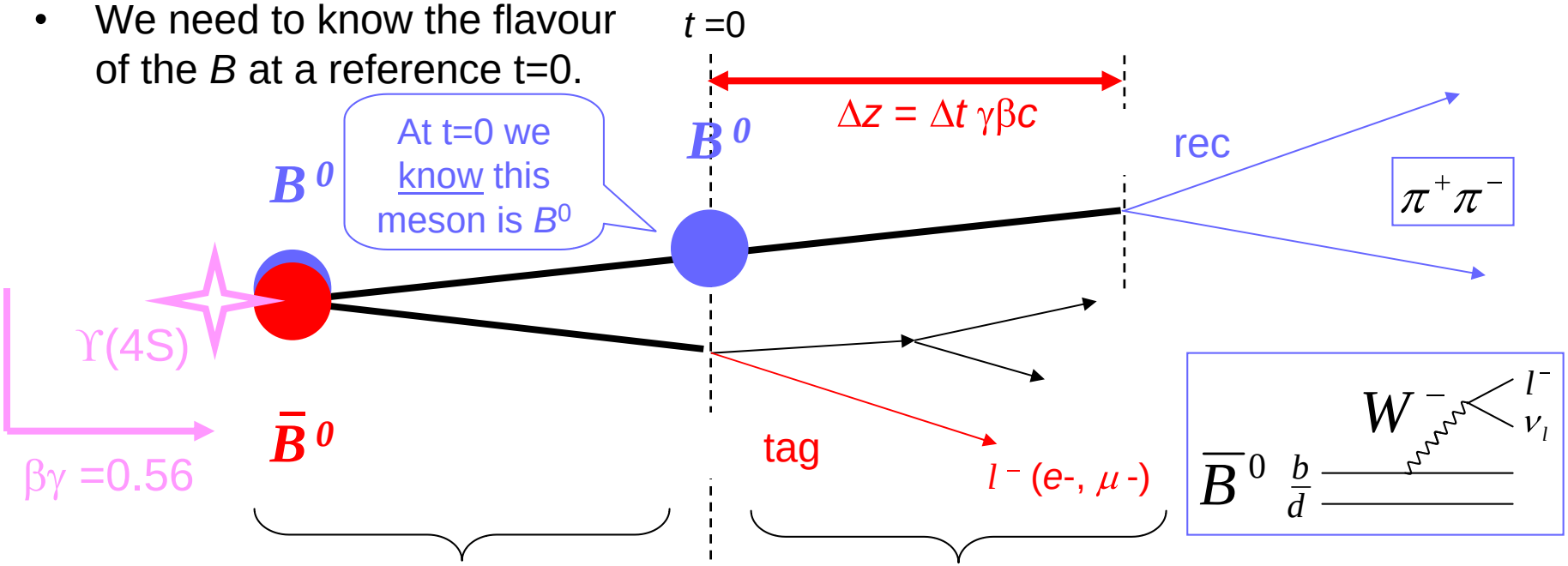


Large data sample feeds a plethora of analyses

- Precision measurement of SM CP violation : sin(2β)
- New physics searches in s-penguin decays
- SM CP violation : measurement of CKM angle α
- SM CP violation : measurement of CKM angle γ
- SM CP violation : measurement of CKM angles $2\beta+\gamma$
- Semileptonic *B* decays and the determination of $|V_{ub}|$ and $|V_{cb}|$
- Radiative penguin *B* decays
- Search for rare leptonic *B* decays
- Charm physics : D^0 mixing, precision D^0 measurements
- Tau physics : lifetime measurements, rare decay searches
- New particle searches : Pentaquarks, exotic baryons, D_{sJ}

Time-dependent analysis requires B^0 flavour tagging

- We need to know the flavour of the B at a reference t=0.



The two mesons oscillate coherently : at any given time, if one is a B^0 the other is <u>necessarily</u> a $\bar{B}^0$

In this example, the tag-side meson decays first. It decays semi-leptonically and the charge of the lepton gives the flavour of the tag-side meson : $l^- = \bar{B}^0$ $l^+ = B^0$. Kaon tags also used.

Δt picoseconds later, the B^0 (or perhaps its now a $\bar{B}^0$) decays.

Formalism of *CP* violation with *B* mesons

Time evolution of a $B^0 / \overline{B}^0$

$\Delta m_d = 0.502 \pm 0.006\,\mathrm{ps}^{-1}$

$$\Gamma(B^0 / \overline{B}^0 \to f_{CP}) = e^{-\Delta t/\tau}\left(1 + \eta S_{f_{CP}} \sin(\Delta m_d \Delta t) - \eta C_{f_{CP}} \cos(\Delta m_d \Delta t)\right)$$

$\eta = +1(-1)$ for $B^0(\overline{B}^0)$

$$S_{f_{CP}} = \frac{2\,\Im(\lambda_{f_{CP}})}{1+\lambda^2_{f_{CP}}}$$

$S \neq 0$: Indirect *CP* violation

$$C_{f_{CP}} = \frac{1-\lambda^2_{f_{CP}}}{1+\lambda^2_{f_{CP}}}$$

$C \neq 0$: Direct *CP* violation

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

Final State Amplitudes

from mixing

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

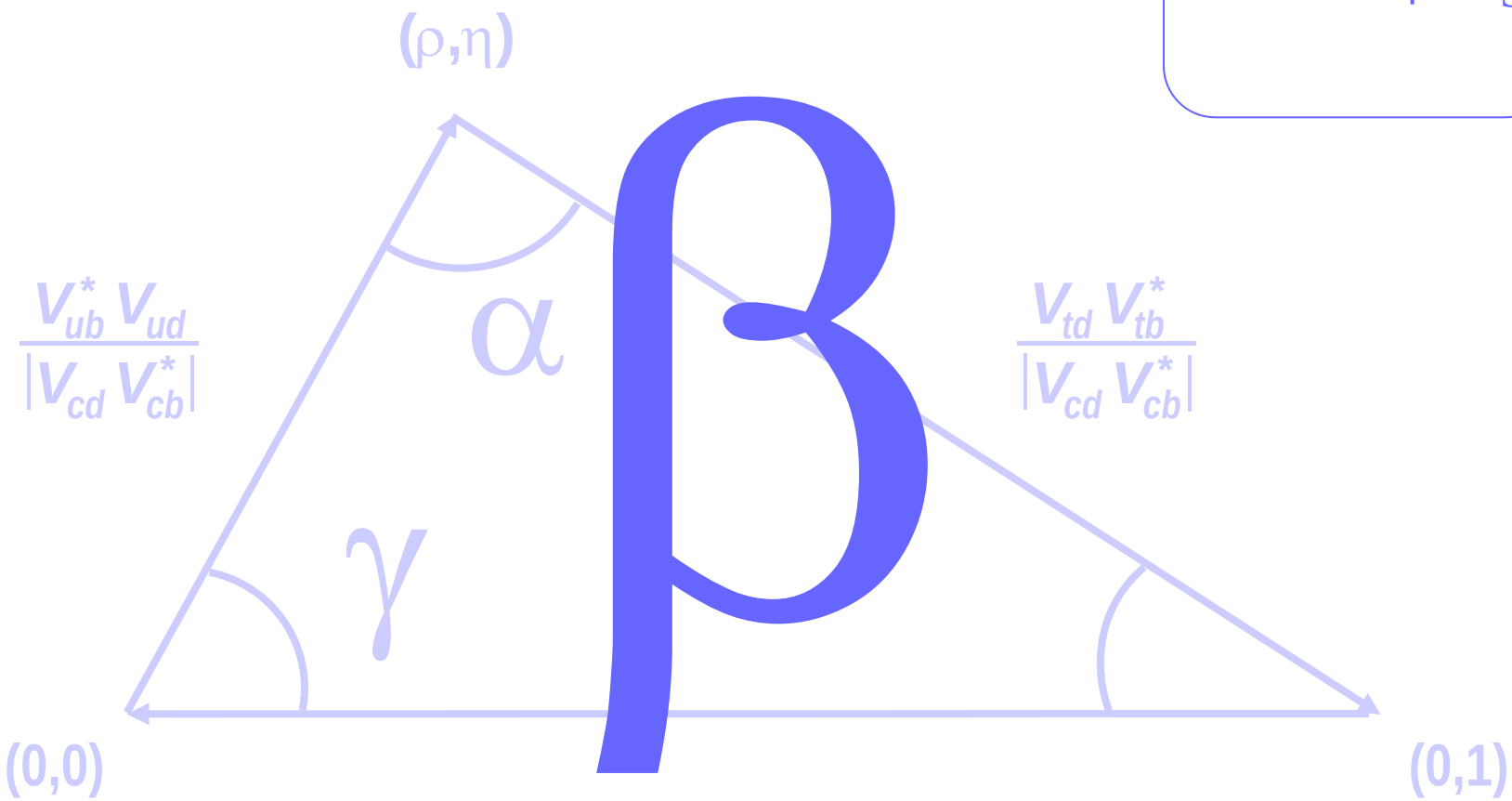
$$|B_H\rangle = p|B^0\rangle - q|\overline{B}^0\rangle$$

Time-dependent asymmetry

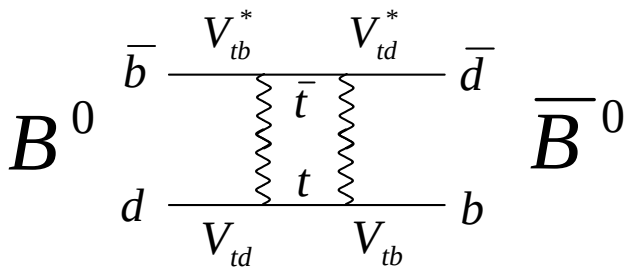
$$A_{f_{CP}}(\Delta t) = \frac{\Gamma(\overline{B}^0 \to f_{CP}) - \Gamma(B^0 \to f_{CP})}{\Gamma(\overline{B}^0 \to f_{CP}) + \Gamma(B^0 \to f_{CP})}$$

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

$B \to J/\psi\, K_S$



sin(2β) measurement with charmonium (214 M_{BB})



$$\sin(2\beta) = +0.722 \pm 0.040 \pm 0.023$$

$$|\lambda| = |\bar{A}/A| = 0.950 \pm 0.031 \pm 0.013$$

Limit on direct CPV

$$\sin(2\beta)_{WA} = +0.726 \pm 0.037$$

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

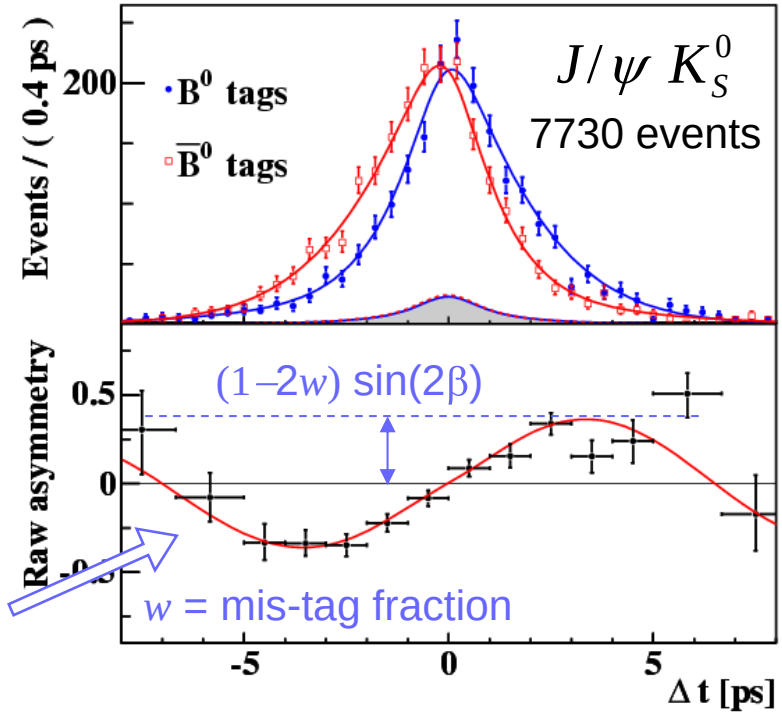
$\frac{q}{p} \approx e^{-i2\beta}$ from $B^0/\bar{B}^0$ mixing

$\frac{\bar{A}_{f_{CP}}}{A_{f_{CP}}} = \pm 1$

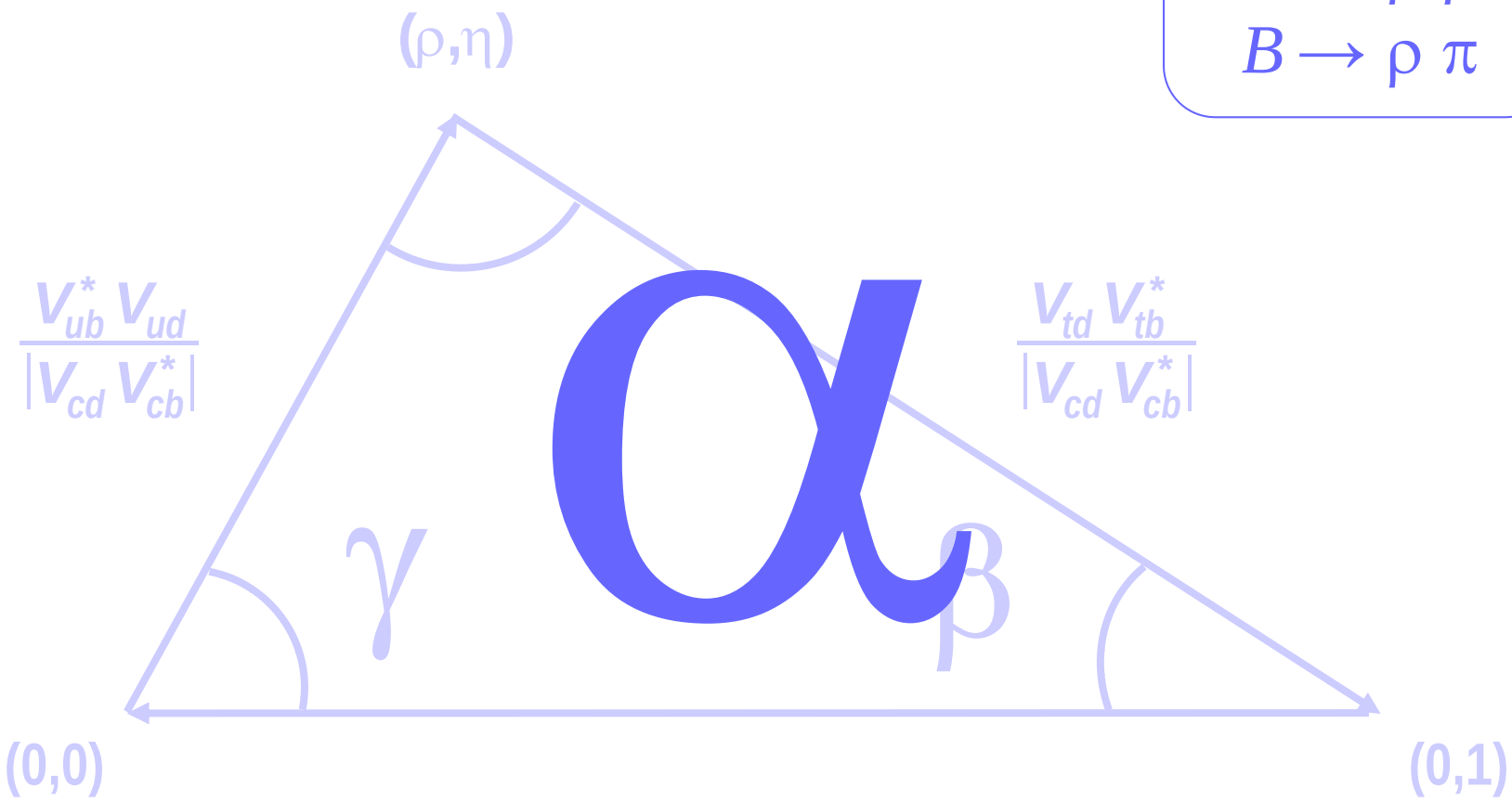
$$S_{f_{CP}} = \frac{2\,\Im(\lambda_{f_{CP}})}{1+\lambda_{f_{CP}}^2} = \sin(2\beta) \qquad C_{f_{CP}} = \frac{1-\lambda_{f_{CP}}^2}{1+\lambda_{f_{CP}}^2} = 0$$

$$A_{f_{CP}}(\Delta t) = S_{f_{CP}} \sin(\Delta m_d \Delta t)$$

Time-dependent asymmetry with an amplitude ≅ sin(2β)



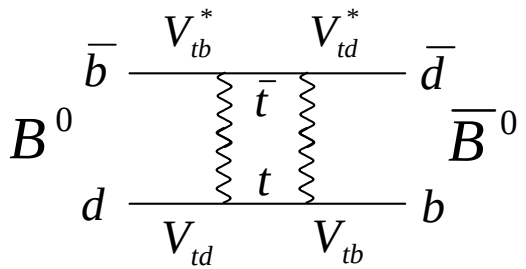
$B \to \pi\,\pi$
$B \to \rho\,\rho$
$B \to \rho\,\pi$



The route to sin(2α)

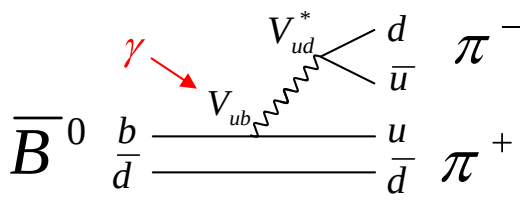
- Access to α from the interference of a *b*→*u* decay (γ) with $B^0\bar{B}^0$ mixing (β)

$B^0\bar{B}^0$ mixing



$q/p \propto V_{tb}^* V_{td} / V_{tb} V_{td}^*$

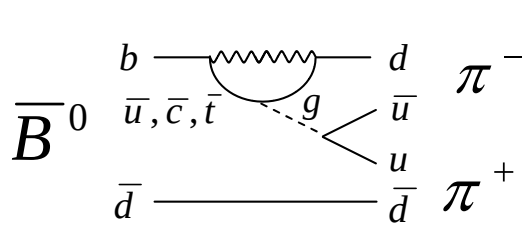
Tree decay



$A \propto V_{ud}^* V_{ub}$

⊕

Penguin decay



$A \approx V_{td}^* V_{tb}$

$$\lambda = \frac{q}{p}\frac{\bar{A}}{A} = e^{-i2\beta} e^{-i2\gamma} = e^{i2\alpha}$$

$$\lambda = e^{i2\alpha} \frac{T + P e^{+i\gamma} e^{i\delta}}{T + P e^{-i\gamma} e^{i\delta}}$$

$$S = \sin(2\alpha)$$
$$C = 0$$

$$S = \sqrt{1 - C^2}\,\sin(2\alpha_{eff})$$
$$C \propto \sin\delta$$

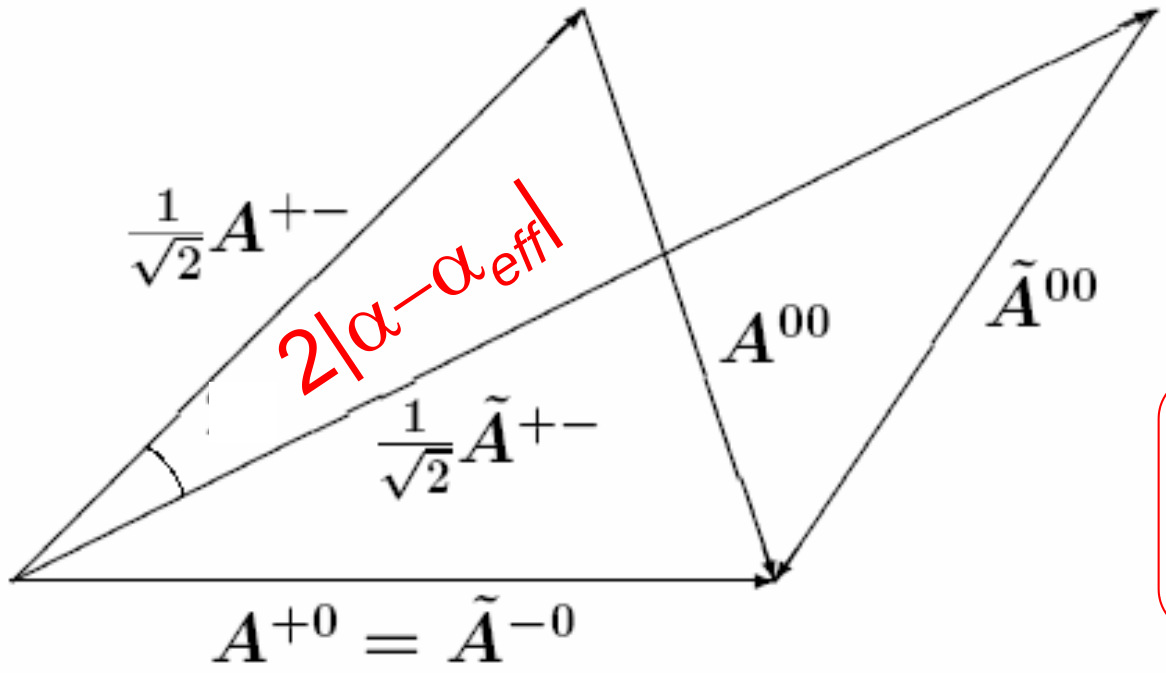
How can we obtain α from α_{eff} ?

Time-dep. asymmetry : $A_{\pi\pi}(\Delta t) = S_{\pi\pi}\sin(\Delta m_d \Delta t) - C_{\pi\pi}\cos(\Delta m_d \Delta t)$

NB : T = "tree" amplitude P = "penguin" amplitude

How to estimate $|\alpha-\alpha_{eff}|$: Isospin analysis

- Use SU(2) to relate decay rates of different *hh* final states ($h \in \{\pi,\rho\}$)
- Need to measure several related B.F.s



$$\mathbf{A}^{+-} = A(B^0 \to \pi^+\pi^-)$$
$$\tilde{\mathbf{A}}^{+-} = A(\overline{B}^0 \to \pi^+\pi^-)$$

$$\mathbf{A}^{+0} = A(B^+ \to \pi^+\pi^0)$$

$$\mathbf{A}^{00} = A(B^0 \to \pi^0\pi^0)$$
$$\tilde{\mathbf{A}}^{00} = A(\overline{B}^0 \to \pi^0\pi^0)$$

Difficult to reconstruct.
Limiting factor in analysis

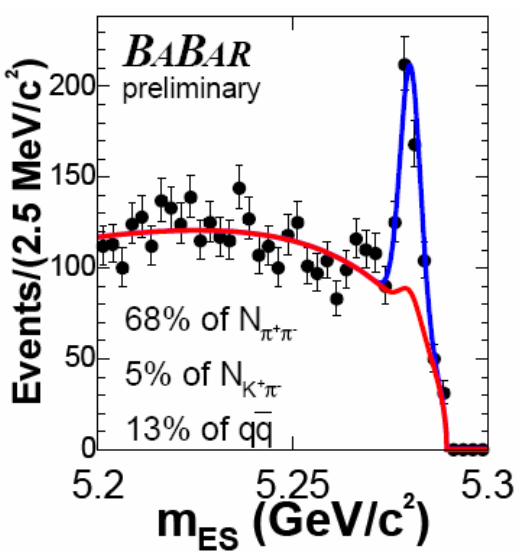
Gronau, London : PRL**65**, 3381 (1990)

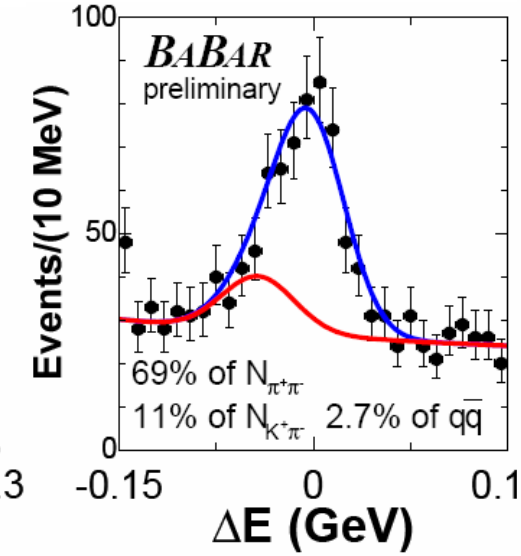
Time-dependent A_{CP} of $B^0 \to \pi^+\pi^-$

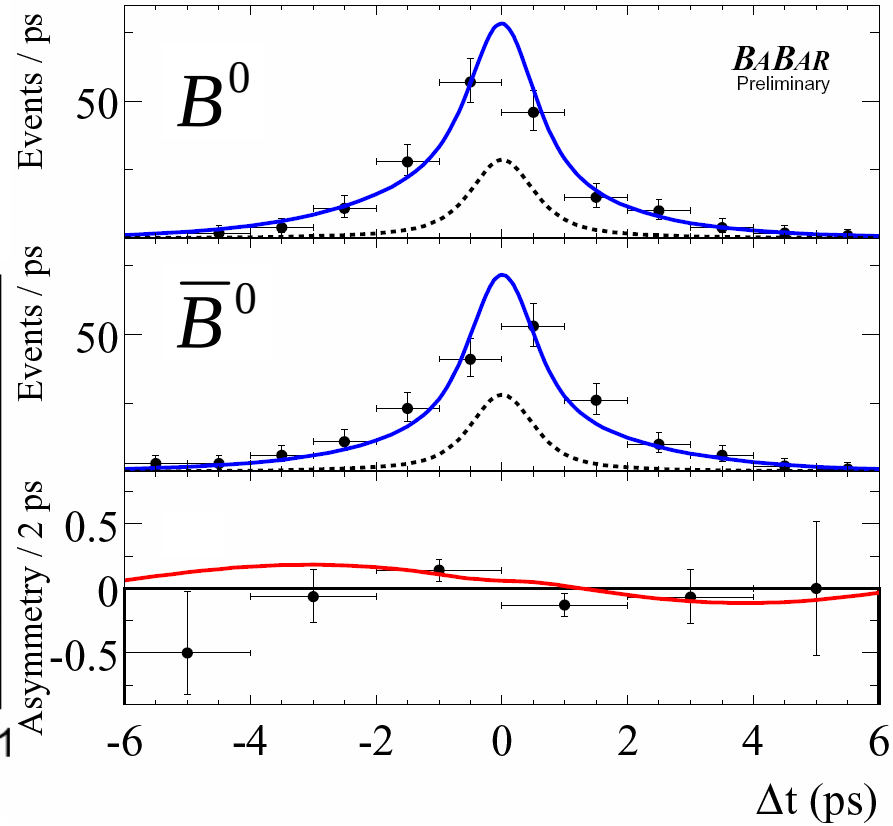
- Good π/K separation up to 4.5 GeV/c

Blue : Fit projection

Red : $q\bar{q}$ background + $B^0 \to K\pi$ cross-feed







$$N(B \to \pi^+\pi^-) = 467 \pm 33 \quad (227\mathrm{M}_{B\bar{B}})$$

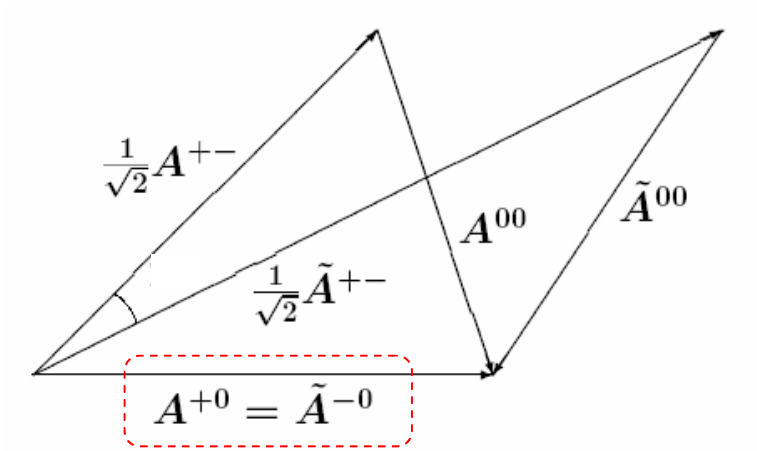
$$B(B^0 \to \pi^+\pi^-) = (4.7 \pm 0.6 \pm 0.2) \cdot 10^{-6}$$

BR result in fact obtained from $97\mathrm{M}_{BB}$

$$S_{\pi^+\pi^-} = -0.30 \pm 0.17 \pm 0.03$$

$$C_{\pi^+\pi^-} = -0.09 \pm 0.15 \pm 0.04$$

Now we need $B^+ \to \pi^+\pi^0$

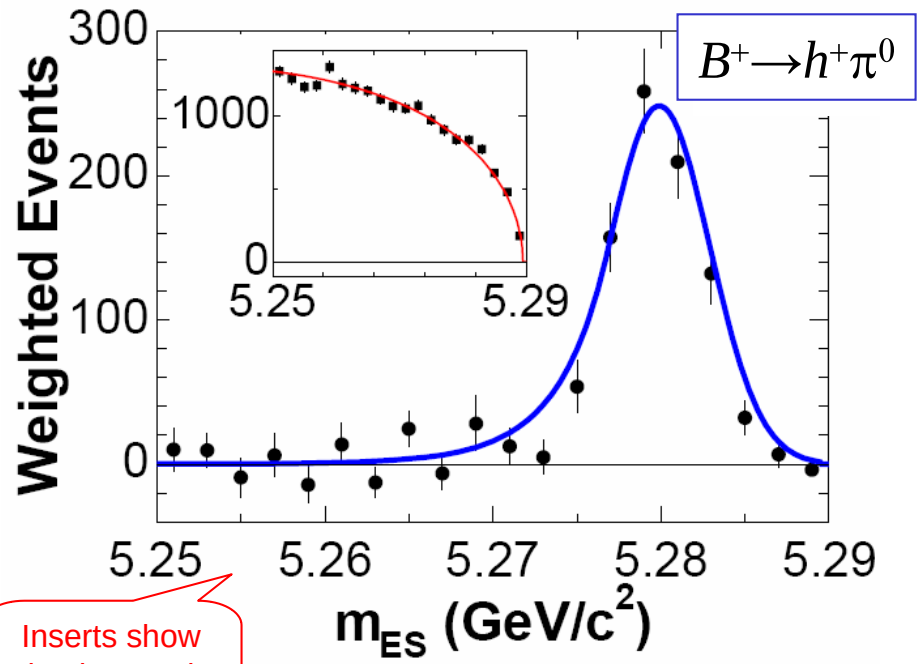


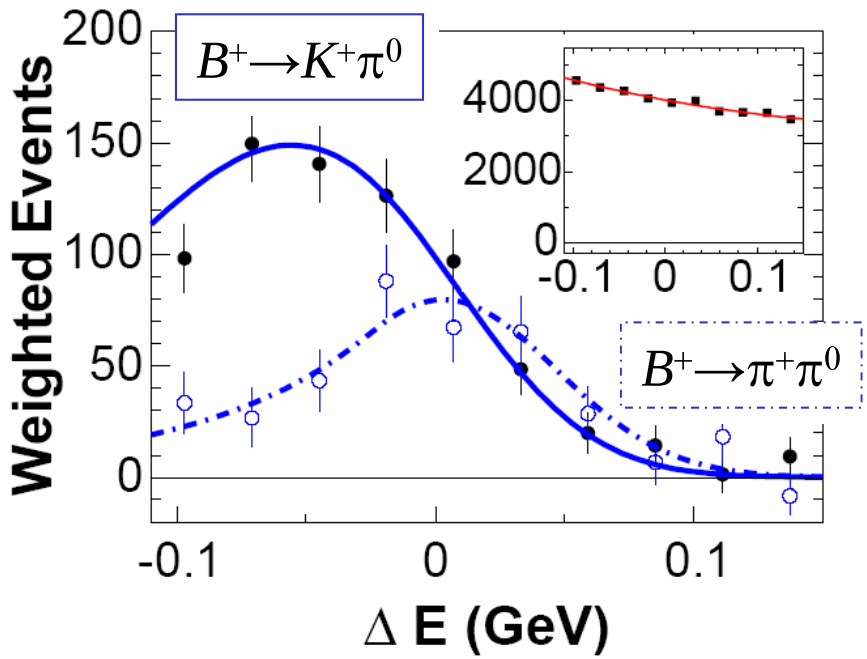
- Analysis method reconstructs and fits $B^+ \to \pi^+\pi^0$ and $B^+ \to K^+\pi^0$ together

$$B(B^+ \to K^+\pi^0) = (12.0 \pm 0.7 \pm 0.6)\cdot 10^{-6}$$

$$B(B^+ \to \pi^+\pi^0) = (5.8 \pm 0.6 \pm 0.4)\cdot 10^{-6}$$

$$A_{CP}(B^\pm \to \pi^\pm\pi^0) = -0.01 \pm 0.10 \pm 0.02$$

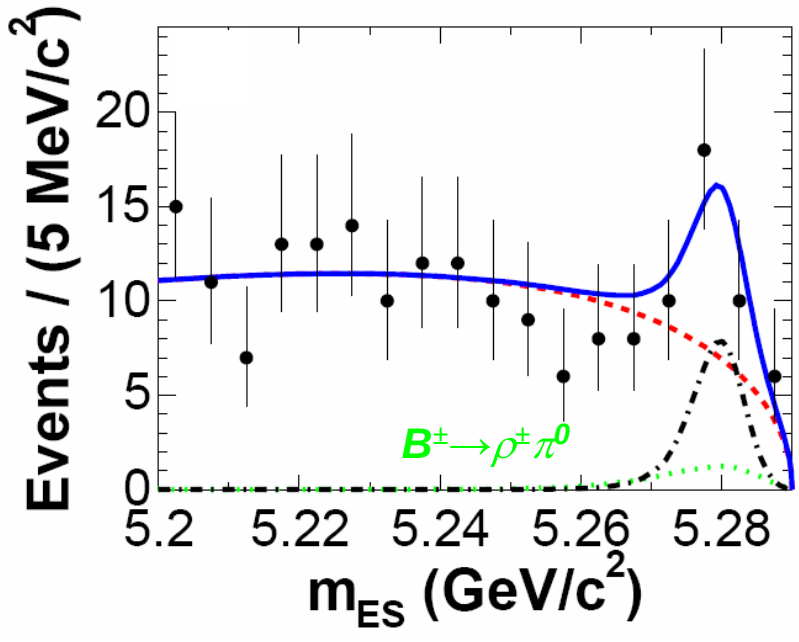




Inserts show background components

…and $B^0 \to \pi^0\pi^0$

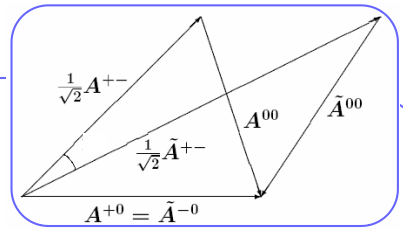
- 61±17 events in signal peak (227M$_{BB}$)
  - Signal significance = 5.0σ
  - Detection efficiency 25%



- Time-integrated result gives :

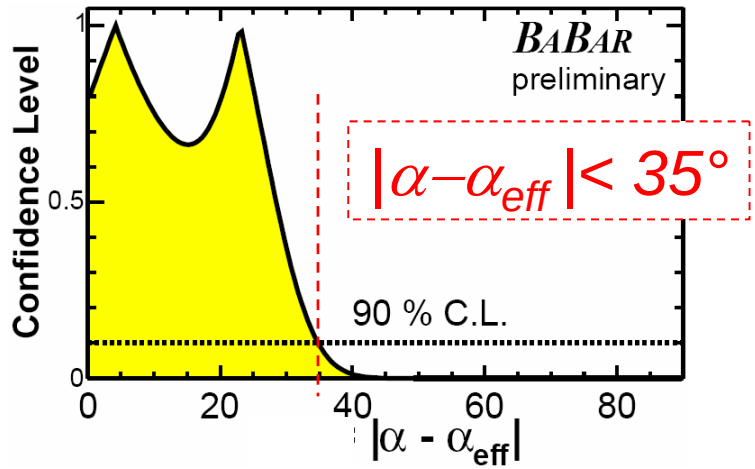
$$B(B^0 \to \pi^0\pi^0) = (1.17 \pm 0.32 \pm 0.10) \cdot 10^{-6}$$

$$C_{\pi^0\pi^0} = -0.12 \pm 0.56 \pm 0.06$$



Using isospin relations and

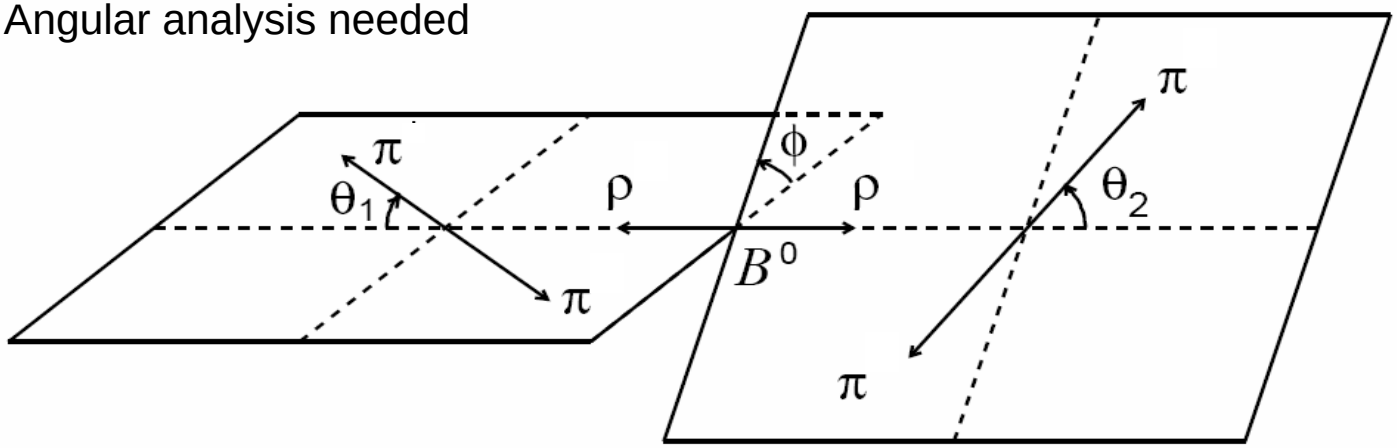
- 3 B.F.s
  - $B^0 \to \pi^+\pi^-$
  - $B^+ \to \pi^+\pi^0$
  - $B^0 \to \pi^0\pi^0$
- 2 asymmetries
  - $C_{\pi^+\pi^-}$
  - $C_{\pi^0\pi^0}$



- Large penguin pollution (*P/T*)
  - Isospin analysis not currently viable in the $B \to \pi\pi$ system

Isospin analysis using $B \to \rho\rho$

- Extraction of α follows the same logic as for the $B \to \pi\pi$ system
  - Except $\rho\rho$ is a vector-vector state
  - $\rho^+\rho^-$ is not generally a *CP* eigenstate
  - Angular analysis needed

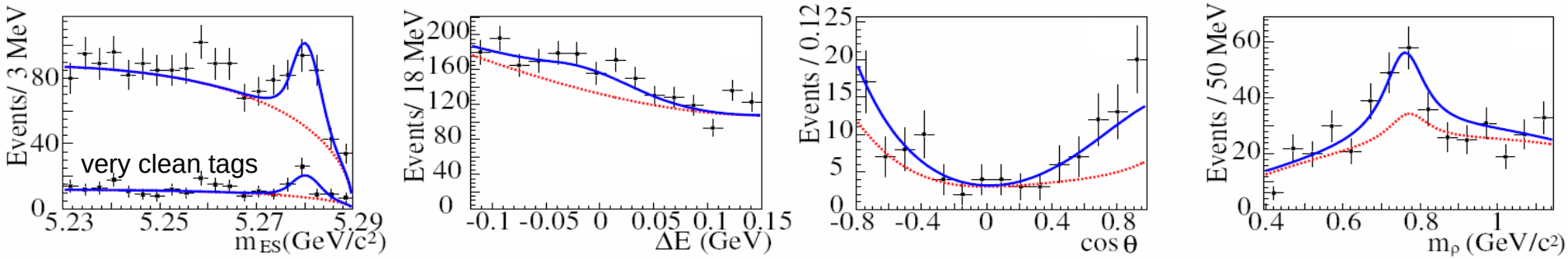


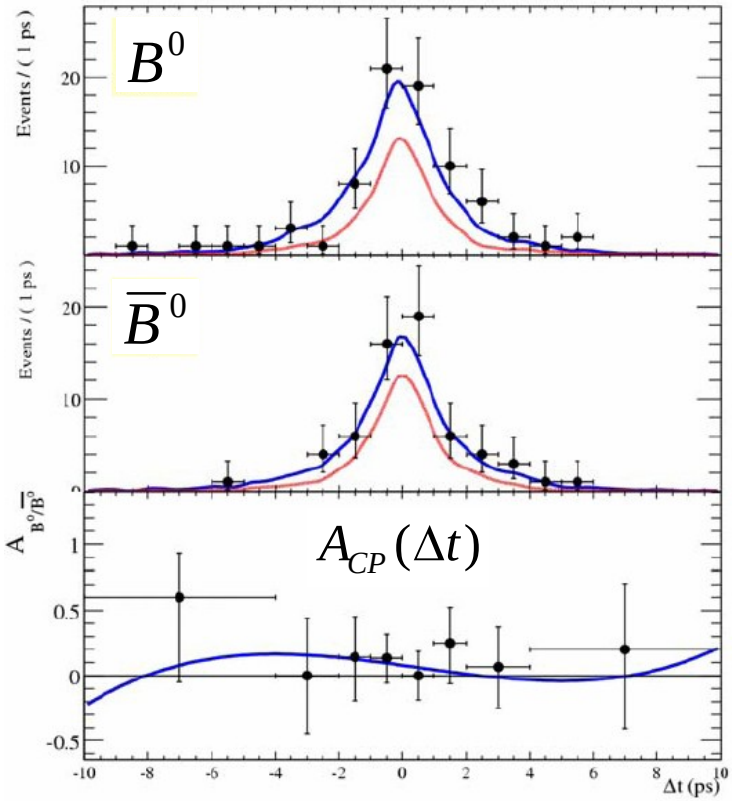
$$\frac{d^2N}{d\cos\theta_1 d\cos\theta_2} \propto \underbrace{f_L \cos^2\theta_1 \cos^2\theta_2}_{\substack{\text{Longitudinal} \\ \text{Helicity state } h=0 \\ \text{CP+1 eigenstate}}} + \underbrace{\tfrac{1}{4}(1-f_L)\sin^2\theta_1 \sin^2\theta_2}_{\substack{\text{Transverse} \\ \text{Helicity state } h=\pm 1 \\ \text{non-CP eigenstate}}}$$

- However, $f_L = \Gamma_{long}/\Gamma$ is measured to be $\cong$1 in $B \to \rho\rho$
  - Transverse component taken as zero in analysis

Time dependent analysis of $B \to \rho^+\rho^-$

- Maximum likelihood fit in 8-D variable space





(122M$_{B\overline{B}}$)

32133 events in fit sample

$$N(B \to \rho^+\rho^-) = 314 \pm 34$$

$$S_{\rho^+\rho^-} = -0.42 \pm 0.42 \pm 0.14$$

$$C_{\rho^+\rho^-} = -0.17 \pm 0.27 \pm 0.14$$

(97M$_{B\overline{B}}$)

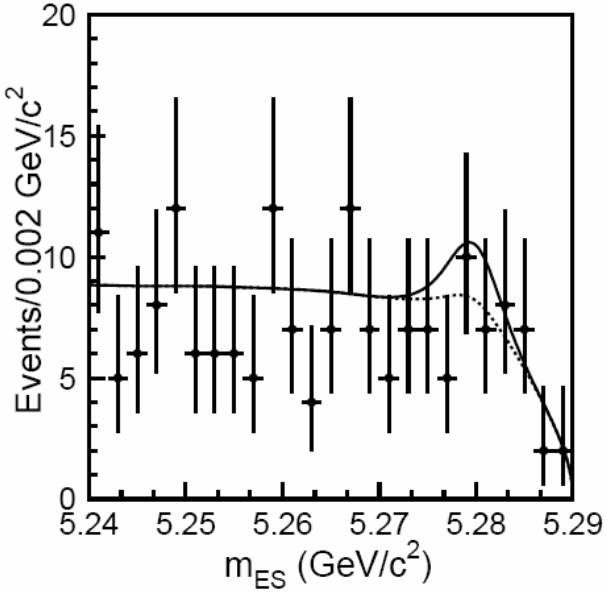
$$f_L = \Gamma_{long}/\Gamma = 0.99 \pm 0.03^{+0.04}_{-0.03}$$

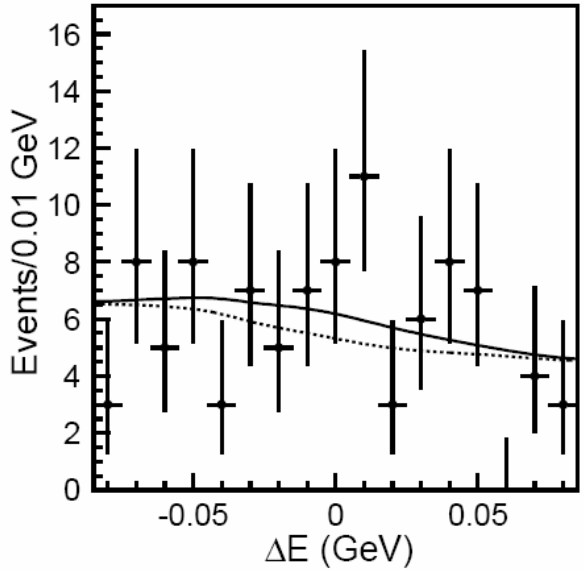
$$B(B^0 \to \rho^+\rho^-) = (30 \pm 4 \pm 5)\cdot 10^{-6}$$

$$c.f. \quad B(B^0 \to \pi^+\pi^-) = 4.7 \cdot 10^{-6}$$

Searching for $B \to \rho^0 \rho^0$

- Similar analysis used to search for $\rho^0\rho^0$
  - Dominant systematic stems from the potential interference from $B \to a_1^{\pm}\pi^{\pm}$ (~22%)





$(227\,\mathrm{M}_{B\bar{B}})$

$$N(B^0 \to \rho^0\rho^0) = 33^{+22}_{-20} \pm 12$$

$$\text{Rec. Eff.} = 27\%$$

$$B(B^0 \to \rho^0\rho^0) = (0.54^{+0.36}_{-0.32} \pm 0.19)\cdot 10^{-6}$$

$$< \; 1.1\cdot 10^{-6} \quad 90\%\ \text{C.L.}$$

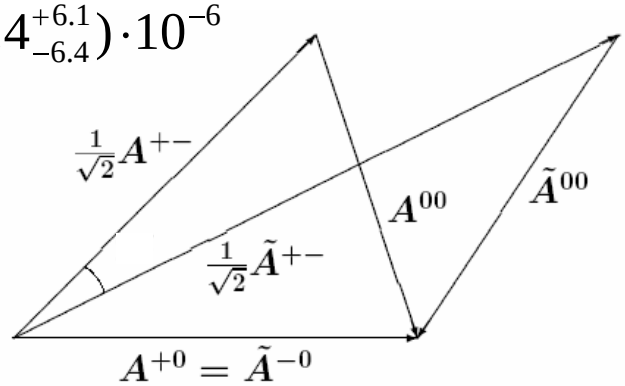
c.f. $B \to \pi^+\pi^-$ *B.F.= 4.7 x* 10^{-6} *and* $B \to \pi^0\pi^0$ *B.F.= 1.2 x* 10^{-6}

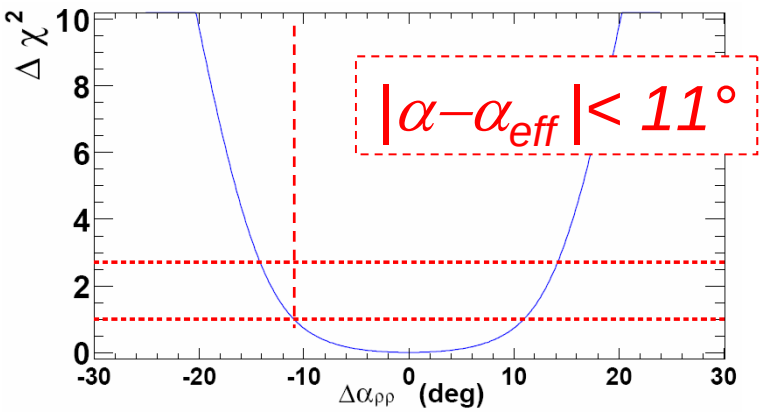
$\mathcal{B}\,(B \to \rho^+\rho^-) = 33 \times 10^{-6}$

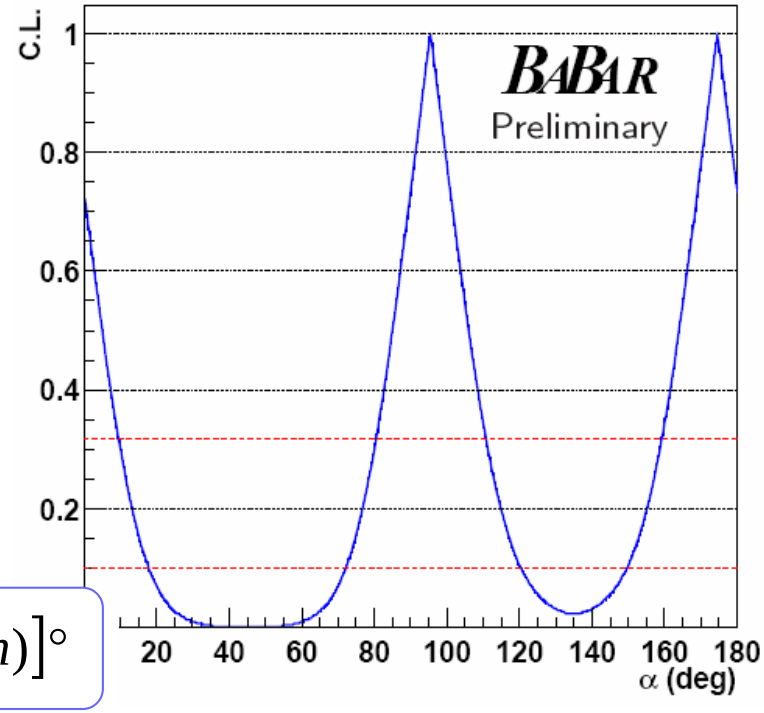
Isospin analysis using $B \to \rho\rho$

- Taking the world average $B(B^+ \to \rho^+\rho^0) = (26.4^{+6.1}_{-6.4}) \cdot 10^{-6}$ and thanks to $f_L = \Gamma_{long}/\Gamma \approx 1$ we apply the isospin analysis to $B \to \rho\rho$
- The small rate of $B^0 \to \rho^0\rho^0$ means
  - $|\alpha - \alpha_{eff}|$ is small[er]
  - P/T is small in the $B \to \rho\rho$ system

    (…Relative to $B \to \pi\pi$ system)



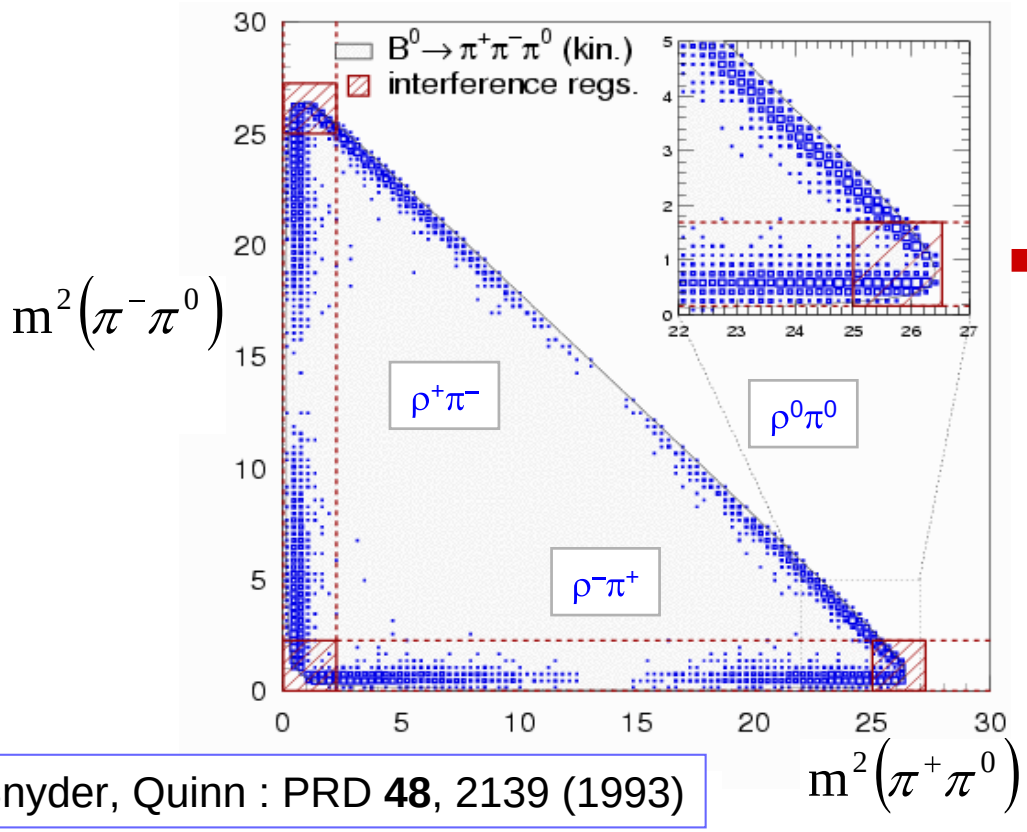




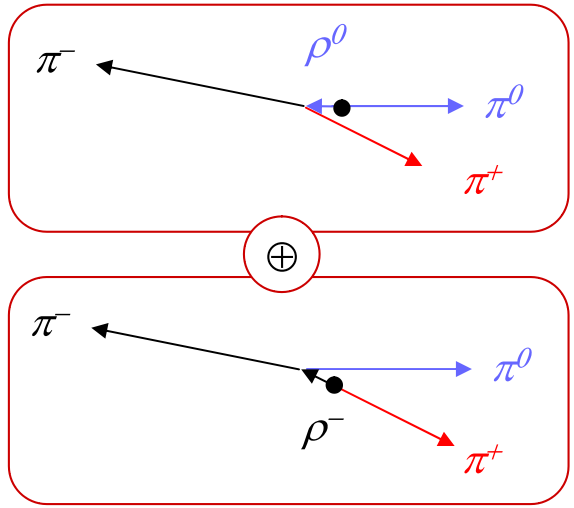
$$\alpha = [96 \pm 10(stat.) \pm 4(syst.) \pm 11(penguin)]^\circ$$

Another approach : $B \to (\rho\pi)^0$

- Unlike $\pi^+\pi^-$ and $\rho^+\rho^-$, $\rho^+\pi^-$ is not a CP eigenstate
  - Must consider 4 (flavour/charge) configurations $B^0 \to \rho^+\pi^-$ $\overline{B}^0 \to \rho^+\pi^-$ $\overline{B}^0 \to \rho^-\pi^+$ $B^0 \to \rho^-\pi^+$
  - Equivalent "isospin analysis" not viable (triangles→pentagons, 6→12 unknowns…)
- However, a full time-dependent Dalitz plot analysis of $B \to \pi^+\pi^-\pi^0$ can work!
  - Enough information to constrain α



Interference at equal masses-squared gives information on strong phases between resonances



Snyder, Quinn : PRD **48**, 2139 (1993)

Time-dependent Dalitz fit

- Extract α and strong phases using interferences between amplitudes
- Time evolution of $B \to \pi^+\pi^-\pi^0$ can be written as :

$$|\mathcal{A}^{\pm}_{3\pi}(\Delta t)|^2 = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}}\Big[|\mathcal{A}_{3\pi}|^2 + |\overline{\mathcal{A}}_{3\pi}|^2 \mp \left(|\mathcal{A}_{3\pi}|^2 - |\overline{\mathcal{A}}_{3\pi}|^2\right)\cos(\Delta m_d \Delta t) \pm 2\mathrm{Im}\left[\overline{\mathcal{A}}_{3\pi}\mathcal{A}^*_{3\pi}\right]\sin(\Delta m_d \Delta t)\Big],$$

$\mathcal{A}^+_{3\pi}$ for B^0

$\mathcal{A}^-_{3\pi}$ for $\overline{B}^0$

- Assuming amplitude $\mathcal{A}^{\pm}_{3\pi}\left(B \to \pi^+\pi^-\pi^0\right)$ is dominated by ρ^+,ρ^- and ρ^0, we write

$$\boxed{\begin{aligned} A_{3\pi} &= f_+A^+ + f_-A^- + f_0A^0 \\ \overline{A}_{3\pi} &= f_+\overline{A}^+ + f_-\overline{A}^- + f_0\overline{A}^0 \end{aligned}}$$

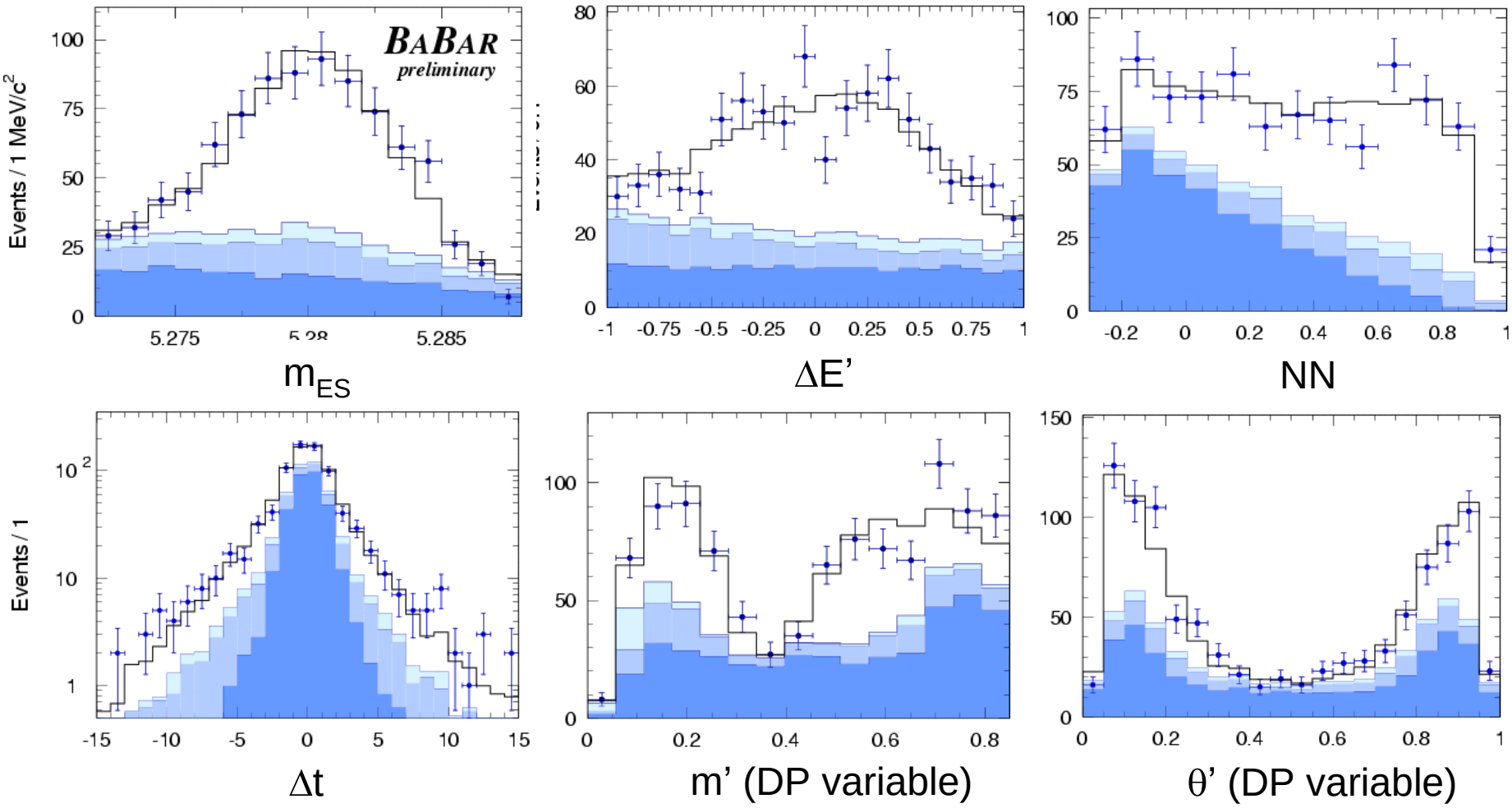
script {+,−,0} refers to {ρ^+,ρ^-,ρ^0}

  - The "f"s are functions of the Dalitz-plot and describe the kinematics of $B \to \rho\pi$ (S→VS)
  - The "A"s are the complex amplitudes containing weak and strong phases. They are independent of the Dalitz variables

- Complicated stuff!
  - At least 17 parameters to fit-for in a 6-D variable space
  - Large backgrounds. Over 80% of selected events are continuum

$B \to \pi^+\pi^-\pi^0$: data/MC, 213M$_{BB}$

- Fit finds 1184 ± 58 $B \to \pi^+\pi^-\pi^0$

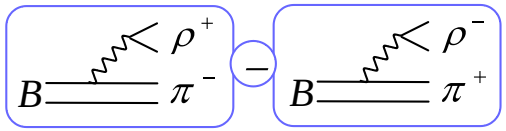


Signal
Self-crossfeed
B-background
Continuum-background

Fit result → Physics results : $B \to (\rho\pi)^0$ 213M$_{BB}$

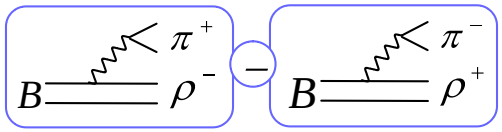
- Hint of direct *CP*-violation

$$A^{+-}_{\rho\pi} \cong$$

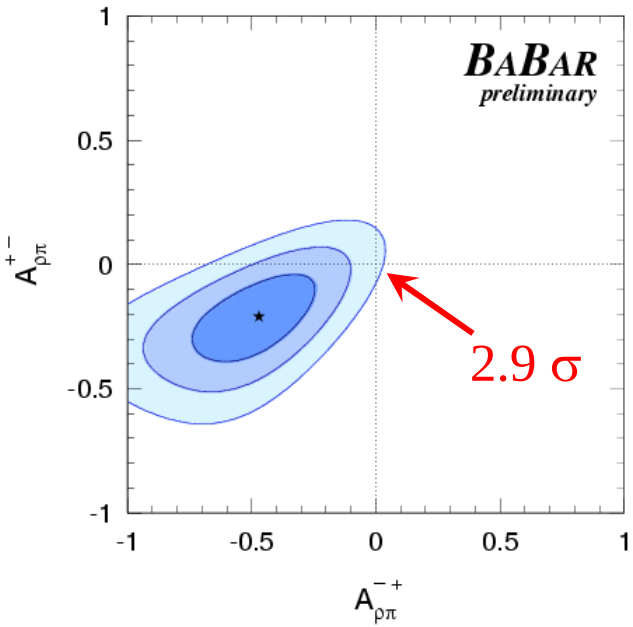


$$= -0.21 \pm 0.11 \pm 0.04$$

$$A^{-+}_{\rho\pi} \cong$$



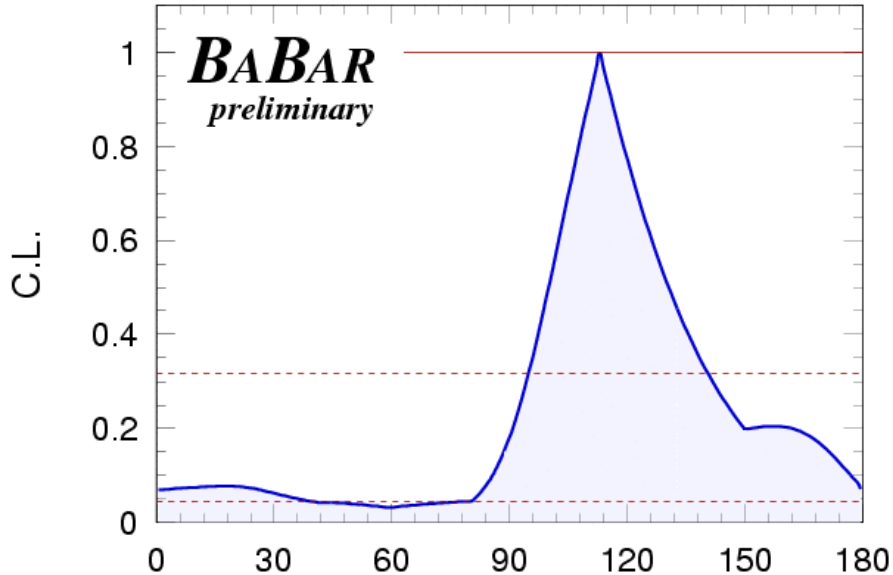
$$= -0.47^{+0.14}_{-0.15} \pm 0.06$$



- Likelihood scan of α using :

$$A^{\kappa} = T^{\kappa} e^{-i\alpha} + P^{\kappa}$$
$$\bar{A}^{\kappa} = T^{\bar{\kappa}} e^{+i\alpha} + P^{\bar{\kappa}}$$

$\kappa \in \{+,-,0\}$
T =tree amp.
P =penguin



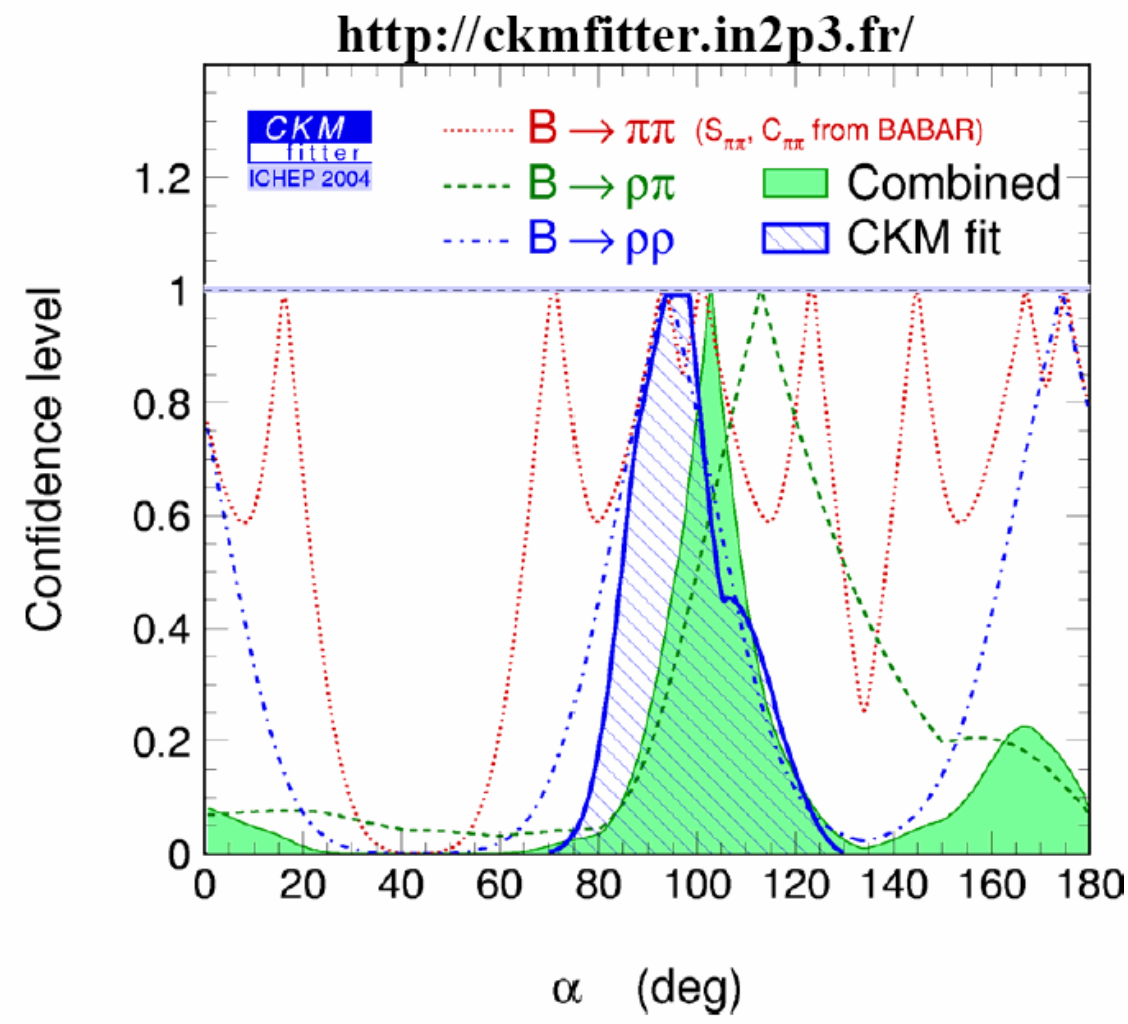
$$\alpha = \left[113^{+27}_{-17}(stat.) \pm 6(syst.)\right]^{\circ}$$

Mirror solution not shown
Weak constraint at C.L.<5%

Combining results on α

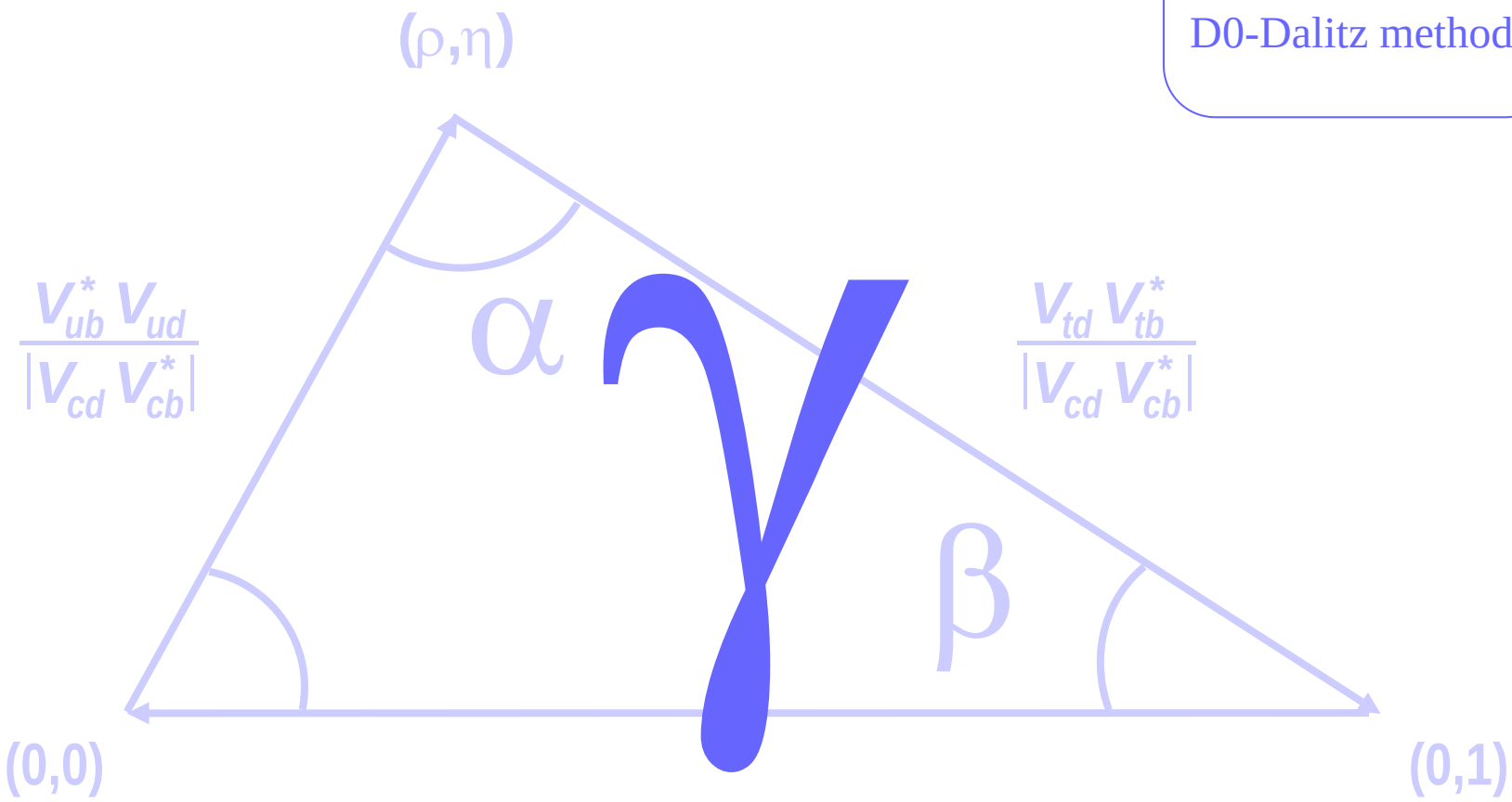
- Combining results in a global CKM fit
- Mirror solutions are clearly disfavoured
- α is measured.
  - Although improvements will come

$$\alpha = \left[103^{+10}_{-11}\right]^{\circ}$$



$B^{\pm} \longrightarrow D^{(*)}K^{(*)}$

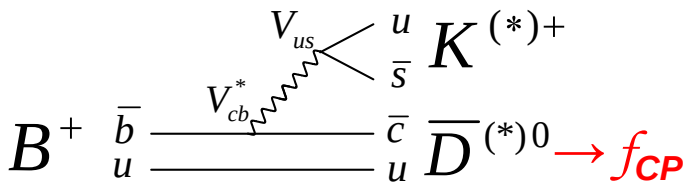
GLW, ADS and
D0-Dalitz methods

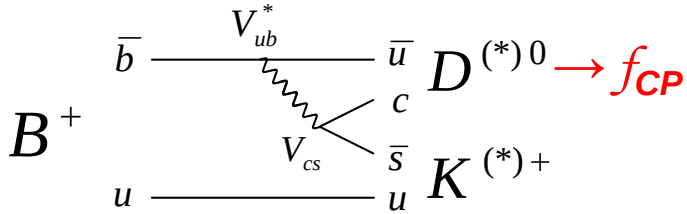


How to access γ?

- Decays where $b \to u\bar{c}s \;\; (\propto V_{ub})$ interferes with $b \to c\bar{u}s$
  - charged *B*s only (time-independent, direct CPV)
  - no penguins pollution
- Need same final state

GLW method





Colour **favoured** b→c amplitude

Colour **suppressed** b→u amplitude

$$a = A(B^+ \to \bar{D}^0 K^+) \propto V_{cb}^* V_{us}$$

$$A(B^+ \to D^0 K^+) \propto V_{ub}^* V_{cs} = a r_B \, e^{i\delta} e^{i\gamma}$$

Strong phase between diagrams

Crucial parameter :
(not well measured)

$$r_B = \frac{|A(B^+ \to D^0 K^+)|}{|A(B^+ \to \bar{D}^0 K^+)|} = \frac{|V_{ub}||V_{cs}|}{|V_{cb}||V_{us}|} \cdot f_{COL} \approx 0.15$$

$$A_{CP\pm} = \frac{\Gamma(B^- \to D_{CP\pm} K^{(*)-}) - \Gamma(B^+ \to D_{CP\pm} K^{(*)+})}{\Gamma(B^- \to D_{CP\pm} K^{(*)-}) + \Gamma(B^+ \to D_{CP\pm} K^{(*)+})} = \frac{\pm 2 r_B \sin\delta \sin\gamma}{R_{CP\pm}}$$

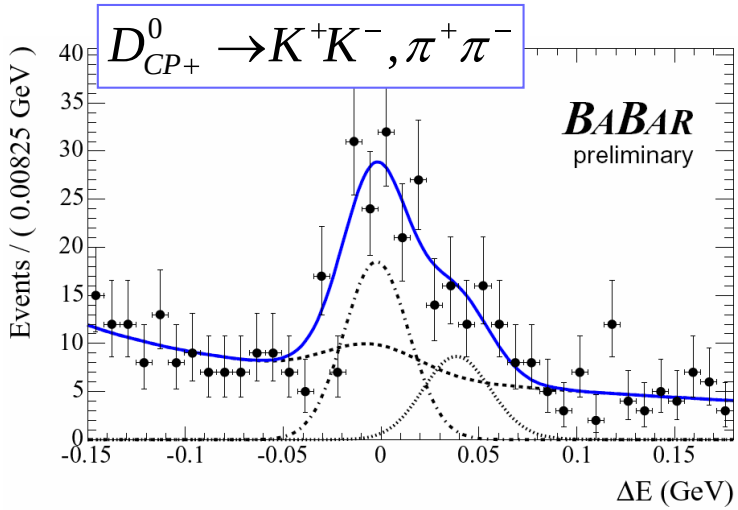
$$R_{CP\pm} = \frac{\Gamma(B^- \to D_{CP\pm} K^{(*)-}) + \Gamma(B^+ \to D_{CP\pm} K^{(*)+})}{\Gamma(B^- \to D^0 K^{(*)-})} = 1 + r_B^2 \pm 2 r_B \cos\delta \cos\gamma$$

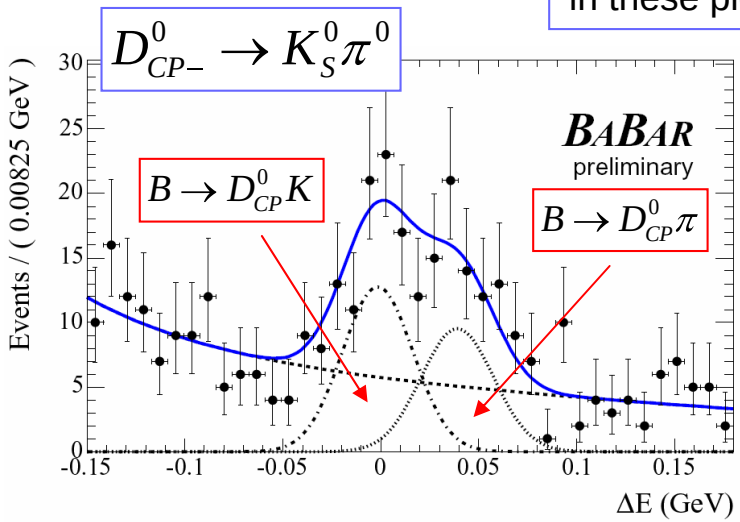
$$\boxed{A_{CP+} R_{CP+} = -A_{CP-} R_{CP-}}$$

GLW method : $B \to D^0 K$ (214 M_{BB})

- Main background from kinematically similar $B \to D^0 \pi$ which has B.F. 12x larger
  - So the signal and this main background are fitted together
  - 2D fit to DE and the Čerenkov angle of the prompt track

A 2σ cut on θ_C in these plots





$R_{CP+} = 0.87 \pm 0.14(\text{stat.}) \pm 0.06(\text{syst.})$ $\quad$ $R_{CP-} = 0.80 \pm 0.14(\text{stat.}) \pm 0.08(\text{syst.})$

$A_{CP+} = 0.40 \pm 0.15(\text{stat.}) \pm 0.08(\text{syst.})$ $\quad$ $A_{CP-} = 0.21 \pm 0.17(\text{stat.}) \pm 0.07(\text{syst.})$

$B^\pm \to D^0 K^{*\pm}$

$R_{CP+} = 1.73 \pm 0.36(\text{stat.}) \pm 0.11(\text{syst.})$ $\quad$ $R_{CP-} = 0.64 \pm 0.25(\text{stat.}) \pm 0.07(\text{syst.})$

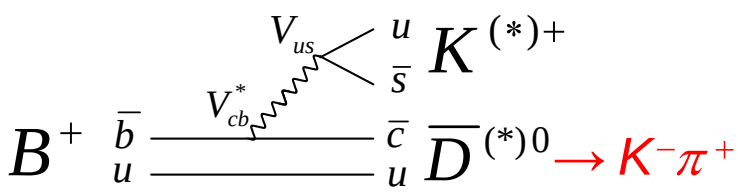
$A_{CP+} = -0.08 \pm 0.20(\text{stat.}) \pm 0.06(\text{syst.})$ $\quad$ $A_{CP-} = -0.35 \pm 0.38(\text{stat.}) \pm 0.10(\text{syst.})$

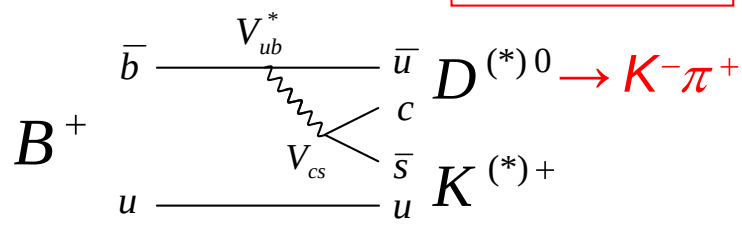
Only a loose bound on r_B with current statistics: $(r_B)^2 = 0.19 \pm 0.23$

Accessing γ without using *CP* states

- Using CP final states of the D^0 yields an expected $\mathcal{A}_{CP}$ of only ~10%
  - We can potentially do better using "wrong-sign" final states

ADS method





Colour **favoured** b→c amplitude ⊗ Cabibbo **suppressed** c→d amplitude	Colour **suppressed** b→u amplitude ⊗ Cabibbo **favoured** c→s amplitude

$$A(B^+ \to [K^-\pi^+]_{D^0} K^+) \propto r_B\, e^{i\delta_B} e^{i\gamma} + e^{i\delta_D} r_D$$

$D^0 \to K\pi$ suppression factor: r_D = 0.060±0.003
Phys.Rev.Lett. 91:17 1801

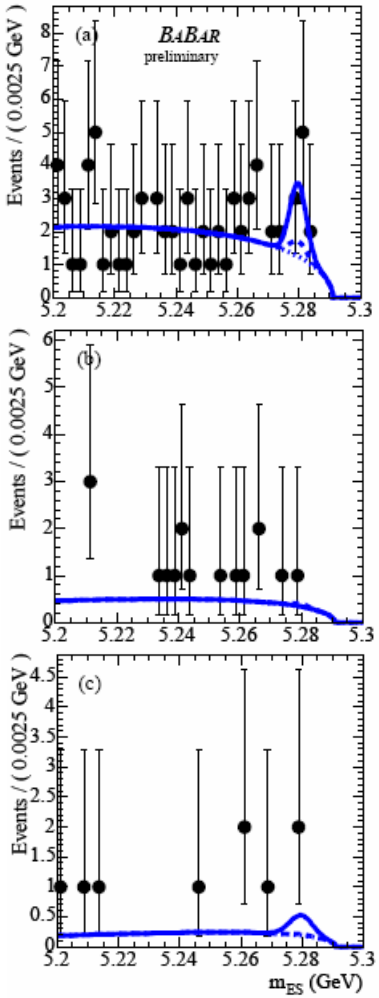
$$R_{ADS} = \frac{\Gamma(B^- \to D_{ADS} K^{(*)-}) + \Gamma(B^+ \to D_{ADS} K^{(*)+})}{\Gamma(B^- \to D^0 K^{(*)-}) + \Gamma(B^+ \to \overline{D}^0 K^{(*)+})} = r_B^2 + r_D^2 + 2 r_B r_D \cos(\delta_B + \delta_D)\cos\gamma$$

- And with enough events (*i.e.* large r_B), expect large asymmetry

$$A_{ADS} = \frac{\Gamma(B^- \to D_{ADS} K^{(*)-}) - \Gamma(B^+ \to D_{ADS} K^{(*)+})}{\Gamma(B^- \to D_{ADS} K^{(*)-}) + \Gamma(B^+ \to D_{ADS} K^{(*)+})} = \frac{2 r_B r_D \sin(\delta_B + \delta_D)\sin\gamma}{R_{ADS}}$$

ADS method : $B \to D^{(*)0}K$ (227 M_{BB})

- The number of $B^+ \to [K^-\pi^+]_{D^0} K^+$ events depends foremost on the value of r_B



$$B^+ \to D^0 K^+$$

$$N = 4.7^{+4.0}_{-3.2}$$

$$R_{ADS} = 0.013^{+0.011}_{-0.009}$$

$$B^+ \to [D^0\pi^0]_{D^*} K^+$$

$$N = -0.2^{+1.3}_{-0.8}$$

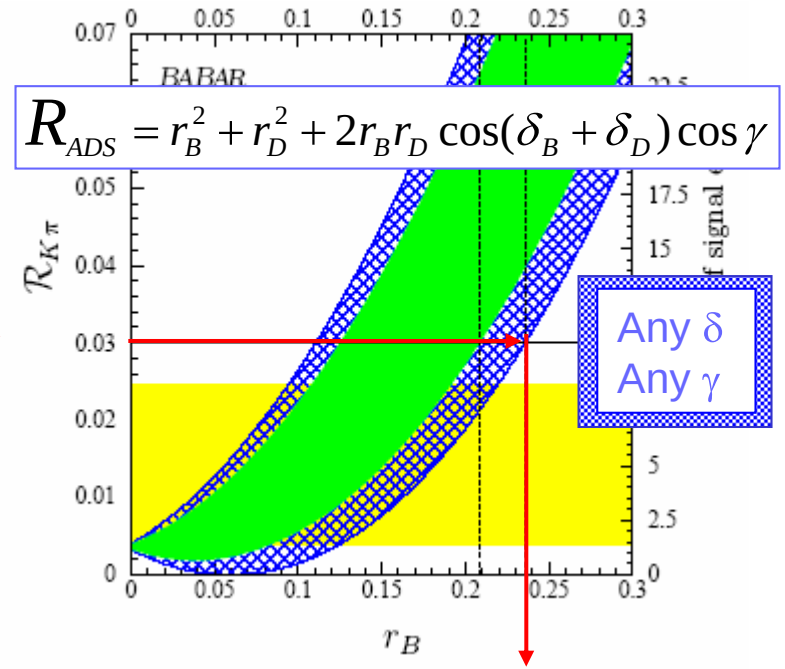
$$R_{ADS} = -0.001^{+0.010}_{-0.006}$$

$$B^+ \to [D^0\gamma]_{D^*} K^+$$

$$N = 1.2^{+2.1}_{-1.4}$$

$$R_{ADS} = 0.011^{+0.019}_{-0.013}$$

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



DK : $r_B < 0.23$

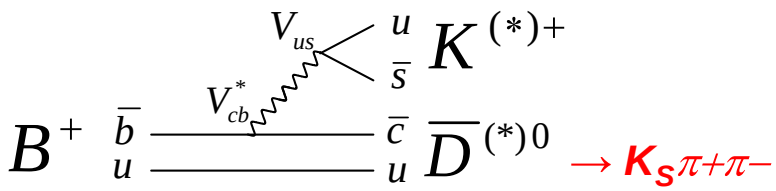
*D*K* : $(r_B)^2 < (0.16)^2$

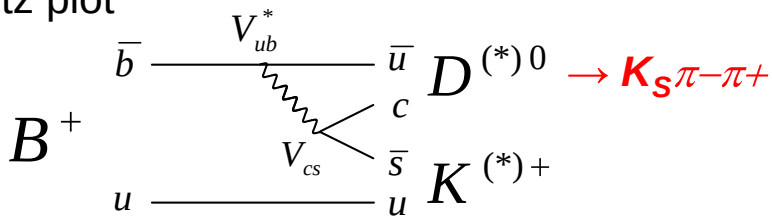
(90% C.L.)

The smallness of r_B makes the extraction of γ with the GLW/ADS methods difficult

$b \to u$ sensitivity with an unsuppressed D^0 decay

- Consider once again $B \to D^{(*)0}K$ decays, this time the with $D^0 \to K_S \pi\pi$.
  - Obtain δ_D information from a fit to the D^0 Dalitz plot





Colour **favoured** b→c amplitude

$$= A(B^+ \to \bar{D}^0 K^+)$$

Colour **suppressed** b→u amplitude

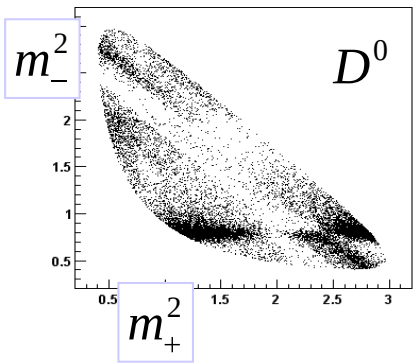
$$= \left|A(B^+ \to \bar{D}^0 K^+)\right| r_B\, e^{i\delta} e^{i\gamma}$$

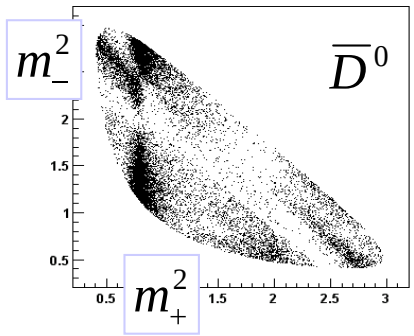
$$M_+(m_-^2, m_+^2) = \left|A(B^+ \to \bar{D}^0 K^+)\right| \left[f(m_+^2, m_-^2) + r_B\, e^{i\delta} e^{i\gamma} f(m_-^2, m_+^2)\right]$$

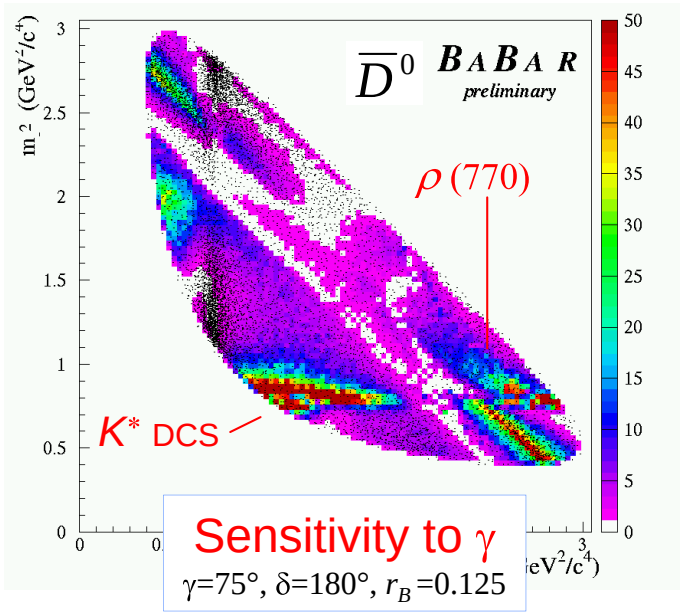
$$M_-(m_-^2, m_+^2) = \left|A(B^- \to D^0 K^-)\right| \left[f(m_-^2, m_+^2) + r_B\, e^{i\delta} e^{-i\gamma} f(m_+^2, m_-^2)\right]$$

- D^0 Dalitz model $f(m_+^2, m_-^2)$

$$m_-^2 = m(K_S^0 \pi^-)^2 \qquad m_+^2 = m(K_S^0 \pi^+)^2$$

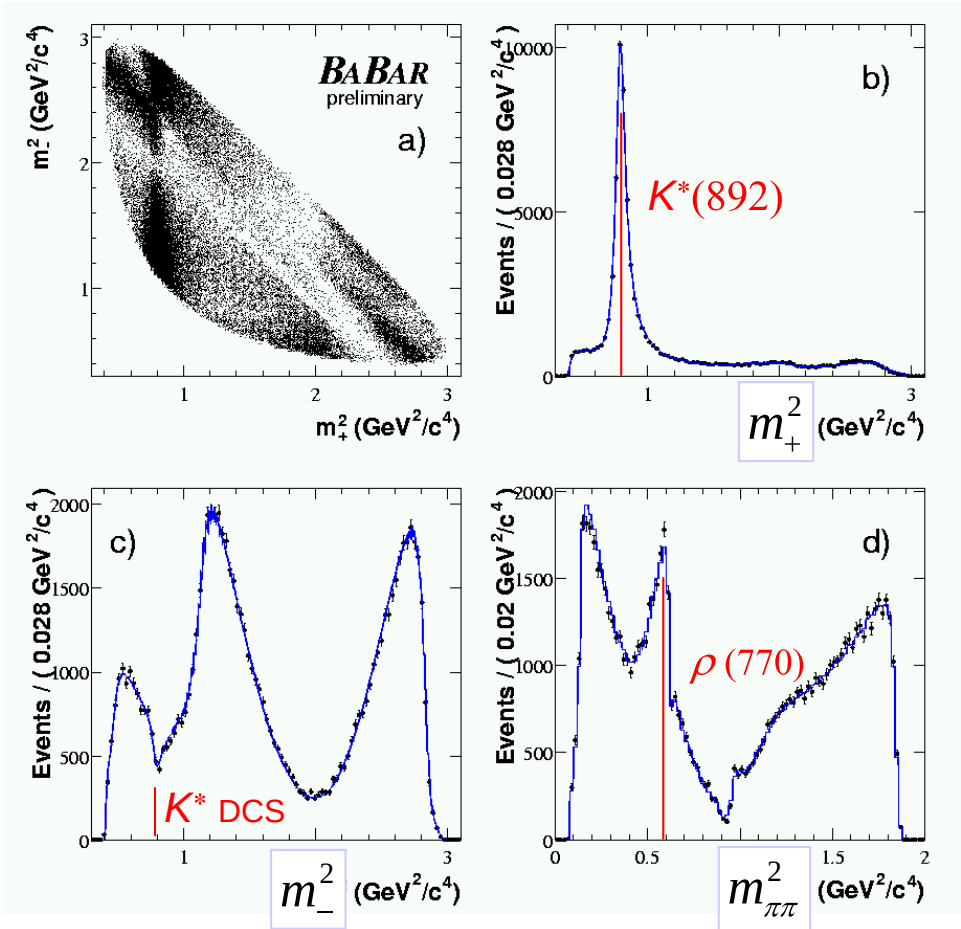






The $D^0 \to K_S \pi^+ \pi^-$ Dalitz model

- Determine on clean, high statistics sample of 81500 $D^{*+} \to D^0 \pi^+$ events
  - ASSUME no *D*-mixing or *CP* violation in *D* decays
  - Build model from 15 known resonances (+2 unidentified scalar $\pi\pi$ resonances)

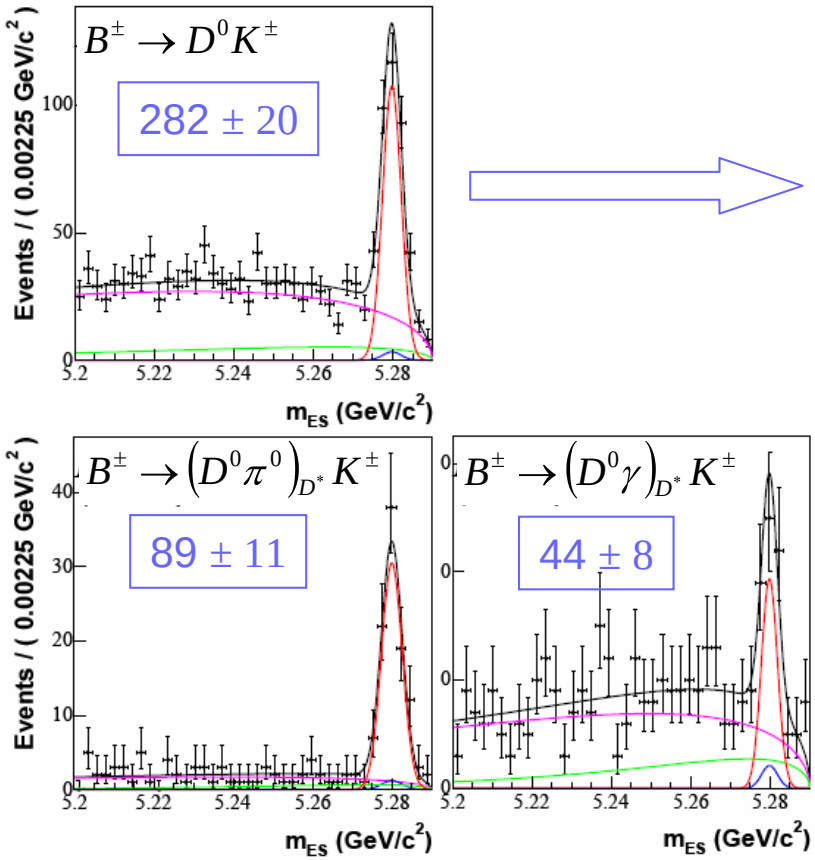


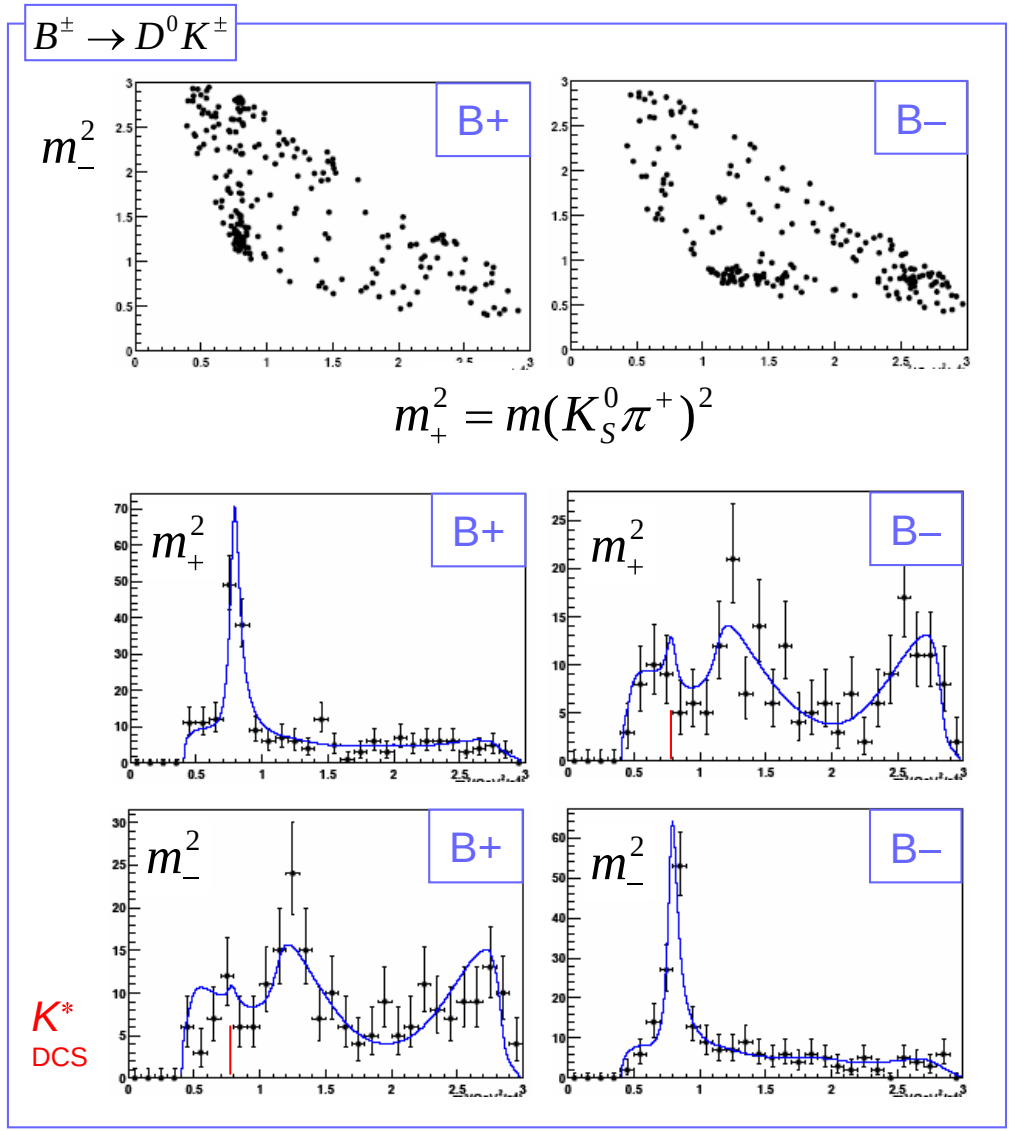
Resonance	Amplitude	Phase (degrees)	Fraction (%)
$K^*(892)$	1.777 ± 0.018	131.0 ± 0.81	58.51
$\rho^0(770)$	1 (fixed)	0(fixed)	22.33
$K^*(892)$ DCS	0.1789 ± 0.0080	-44.0 ± 2.4	0.59
$\omega(782)$	0.0391 ± 0.0016	114.8 ± 2.5	0.56
$f_0(980)$	0.469 ± 0.011	213.4 ± 2.2	5.81
$f_0(1370)$	2.32 ± 0.31	114.1 ± 4.4	3.39
$f_2(1270)$	0.915 ± 0.041	-22.0 ± 2.9	2.95
$K_0^*(1430)$	2.454 ± 0.074	-7.9 ± 2.0	8.37
$K_0^*(1430)$ DCS	0.350 ± 0.069	$-344. \pm 10.$	0.60
$K_2^*(1430)$	1.045 ± 0.045	-53.1 ± 2.6	2.70
$K_2^*(1430)$ DCS	0.074 ± 0.038	-98 ± 30	0.01
$K^*(1410)$	0.524 ± 0.073	-157 ± 10	0.39
$K^*(1680)$	0.99 ± 0.31	-144 ± 18	0.35
$\rho(1450)$	0.554 ± 0.097	$35 \pm 12.$	0.28
σ_1	1.346 ± 0.044	-177.5 ± 2.5	9.11
σ_2	0.292 ± 0.025	-206.8 ± 4.3	0.98
Non resonant	3.41 ± 0.48	-233.9 ± 5.0	6.82

χ^2 / **d.o.f.** = 3824/(3054-32) = **1.27**

D^0 Dalitz method : $B \to D^{(*)0}K$ (227 M_{BB})

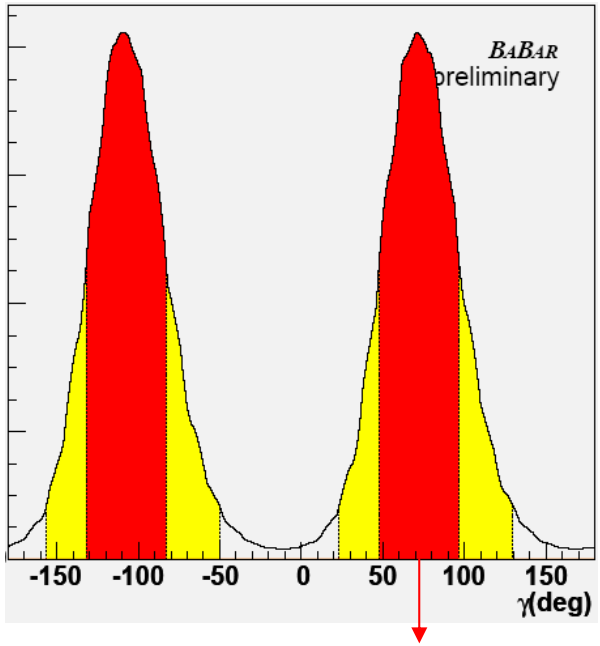
- Maximum likelihood fit extracts $r_B^{(*)}$, γ, $\delta^{(*)}$ from a fit to m_{ES}, ΔE, *Fisher* and the $D^0 \to K_S\pi+\pi-$ Dalitz model.



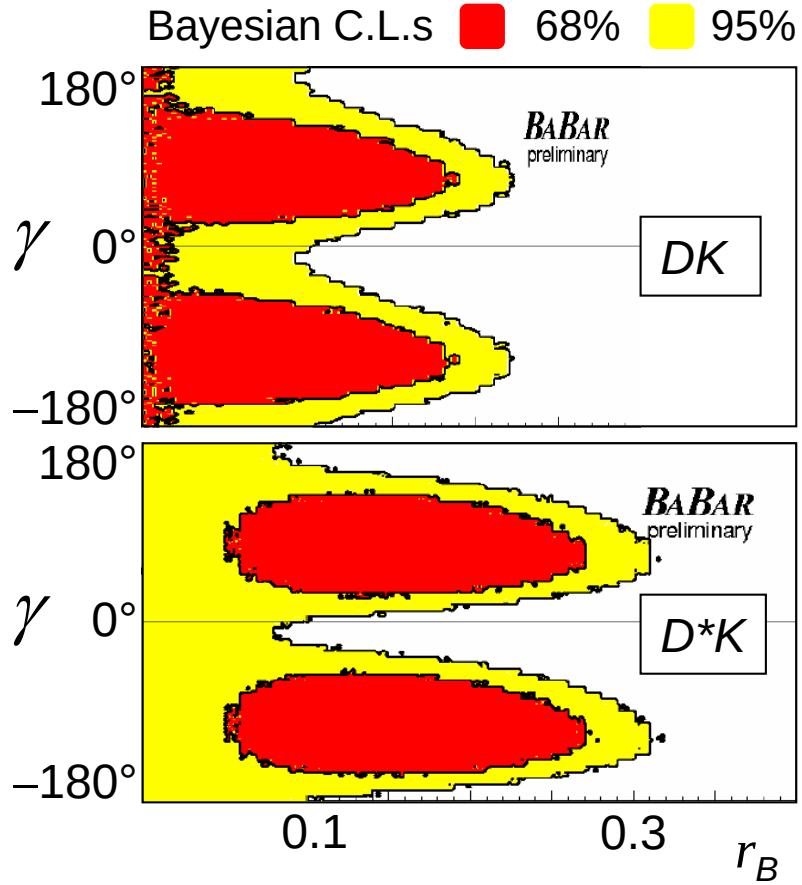


D^0 Dalitz method : $B \to D^{(*)0}K$: result

- Measurement of gamma
  - Twofold ambiguity in γ extraction



γ = 70°±26°±10°±10° (+nπ)



DK : r_B < 0.19 (90% C.L.)

δ_B = 114°±41°±8°±10° (+nπ)

*D*K* : $r_B = 0.155^{+0.070}_{-0.077} \pm 0.040 \pm 0.020$

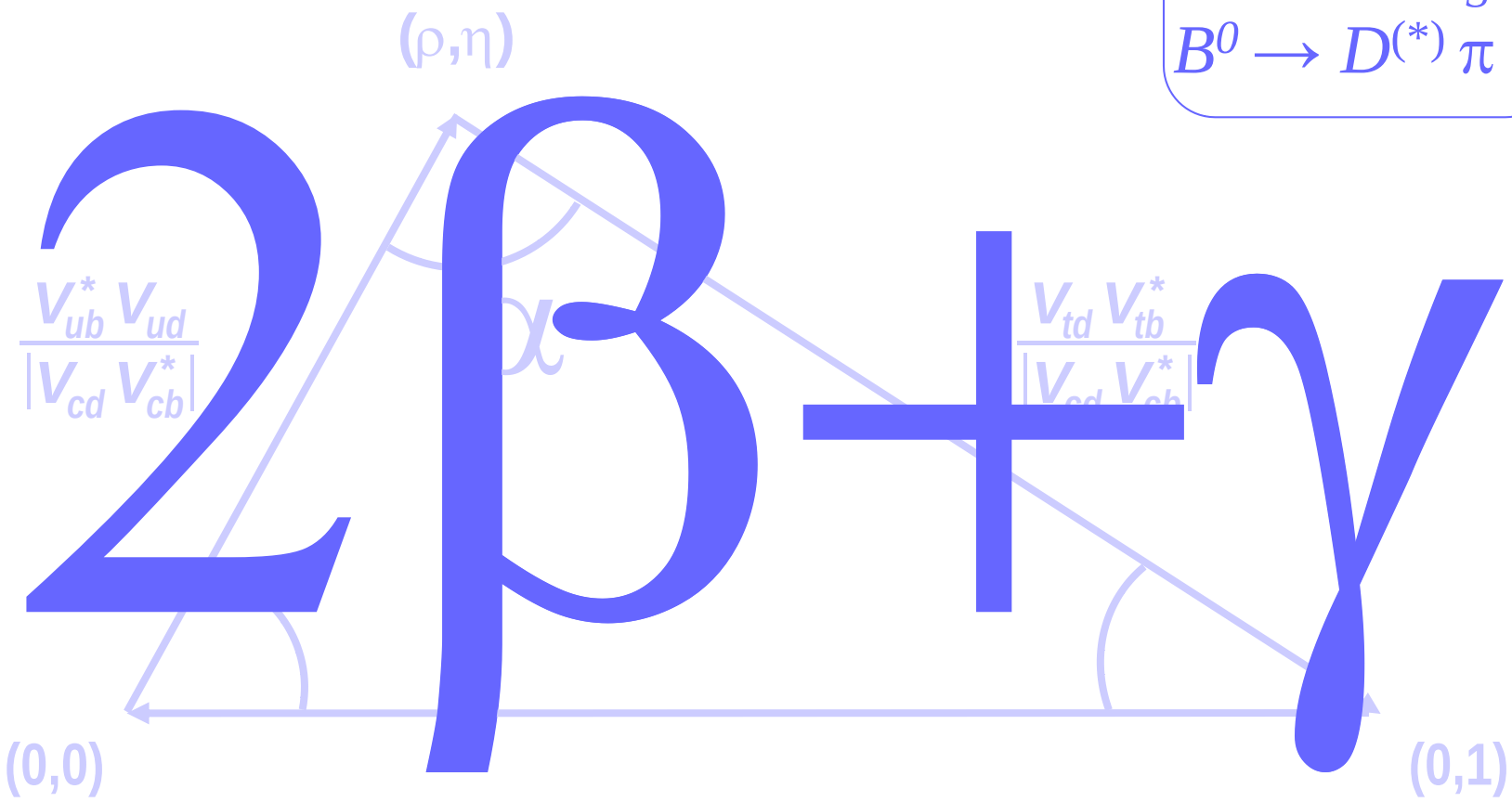
δ_B = 303°±34°±14°±10° (+nπ)

3rd error is due attributed to the Dalitz model

$B^0 \to D^{(*)} K^{(*)}$

$B^0 \to D^{\pm} K_S \pi$

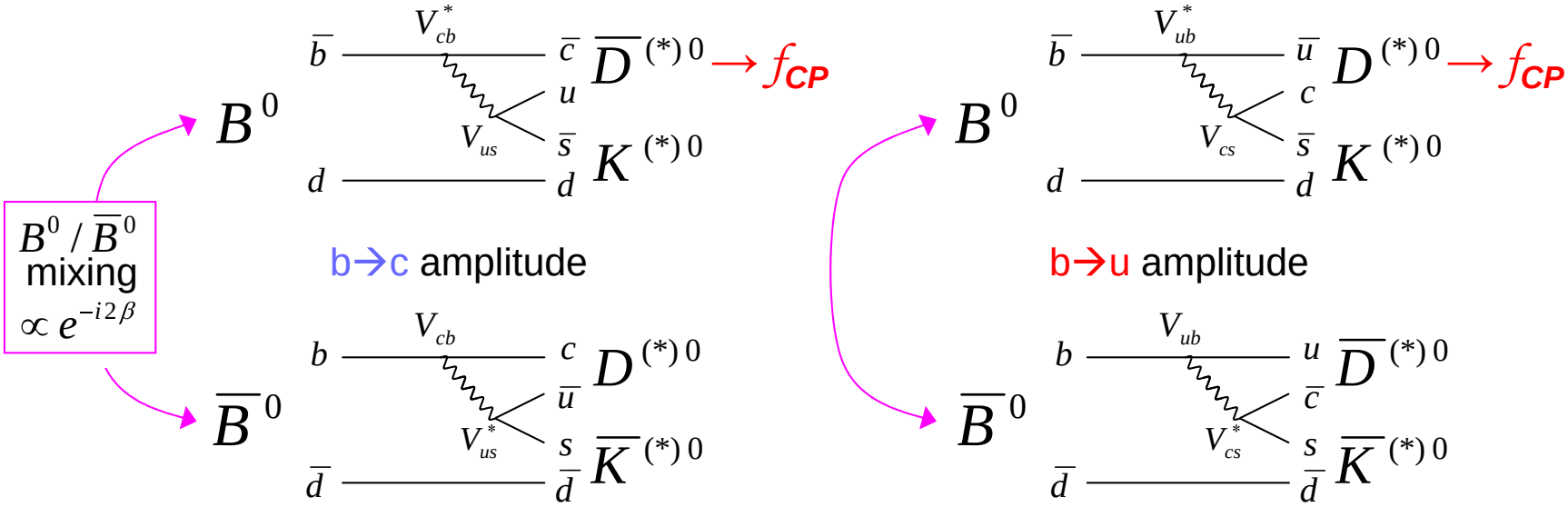
$B^0 \to D^{(*)} \pi$



$$2\beta + \gamma$$

Other ways to access $b \to u$

- So, what happens if we start with a neutral B^0?



$$a = A(B^0 \to \overline{D}^0 K^0)$$

$$= a\, r_0\, e^{i\delta} e^{i\gamma} e^{i2\beta}$$

$$r_0 = \frac{|A(B^0 \to D^0 K^0)|}{|A(B^0 \to \overline{D}^0 K^0)|} \approx 0.45$$

- Eventually this will be a time-dependent analysis
  - Early days yet though. Using non-*CP* modes of the D^0, we search for :

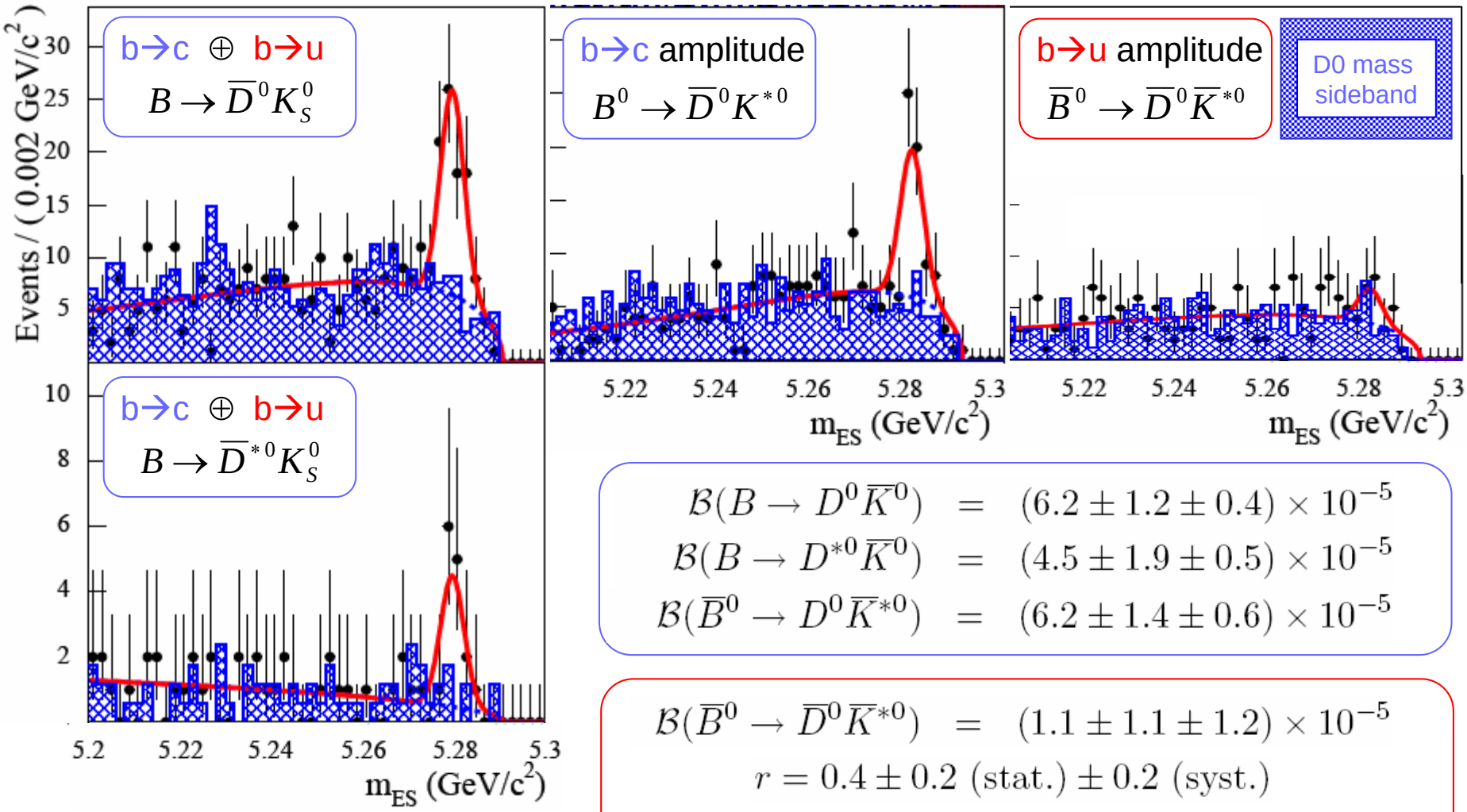
$(B/\overline{B}^0) \to \overline{D}^0\ K_S^0$

$(B/\overline{B}^0) \to \overline{D}^{*0} K_S^0$ AND $B^0 \to \overline{D}^0 K^{*0} \quad K^{*0} \to K^+\pi^-$ AND $\overline{B}^0 \to \overline{D}^0 \overline{K}^{*0} \quad \overline{K}^{*0} \to K^-\pi^+$

self tagging b→c amplitude

self tagging b→u amplitude

$B^0 \to \overline{D}^{(*)0} K^{(*)0}$ (124 M_{BB})



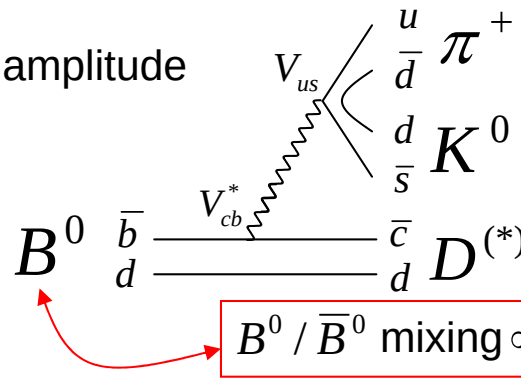
$$\mathcal{B}(B \to D^0 \overline{K}^0) = (6.2 \pm 1.2 \pm 0.4) \times 10^{-5}$$
$$\mathcal{B}(B \to D^{*0} \overline{K}^0) = (4.5 \pm 1.9 \pm 0.5) \times 10^{-5}$$
$$\mathcal{B}(\overline{B}^0 \to D^0 \overline{K}^{*0}) = (6.2 \pm 1.4 \pm 0.6) \times 10^{-5}$$

$$\mathcal{B}(\overline{B}^0 \to \overline{D}^0 \overline{K}^{*0}) = (1.1 \pm 1.1 \pm 1.2) \times 10^{-5}$$
$$r = 0.4 \pm 0.2\ (\text{stat.}) \pm 0.2\ (\text{syst.})$$
$$r < 0.8 \text{ at the } 90\% \text{ C.L}$$

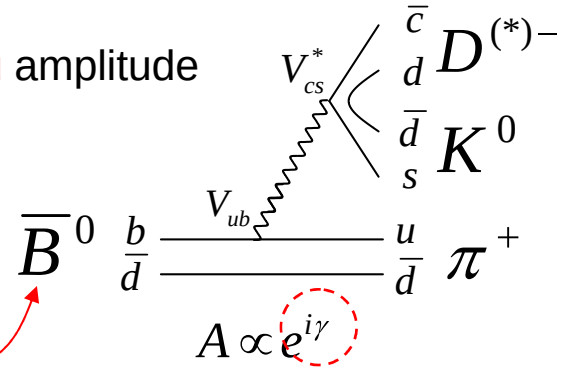
- Very challenging for 2β+γ

Avoiding colour suppression : $B^0 \to D^{\pm} K_S \pi^{\pm}$ (88 M_{BB})

b→c amplitude

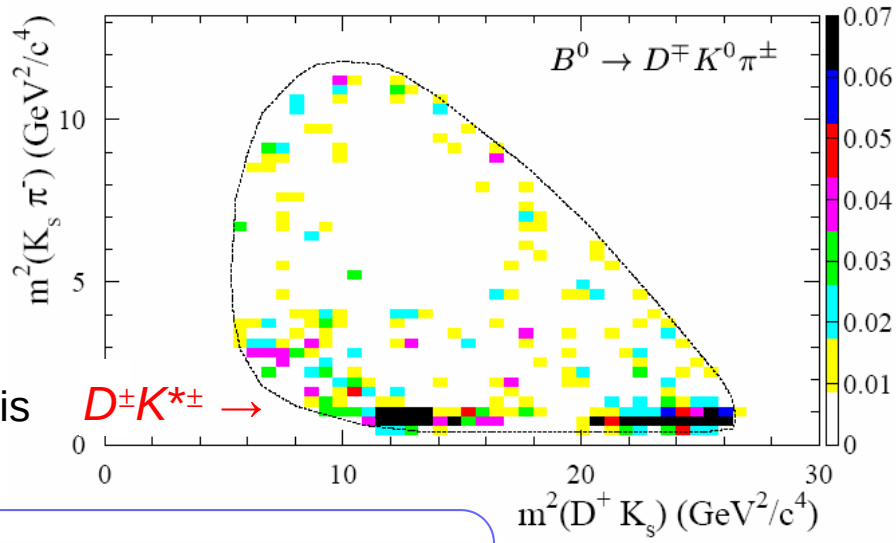


b→u amplitude



$B^0 / \bar{B}^0$ mixing $\propto e^{-i2\beta}$

- Method has two advantages :
  - Avoids colour suppression in $b \to u$
  - Integrating over Dalitz plane removes ambiguities in eventual γ extraction
- First experimental step complete :
  - Branching fraction measurement
  - Currently, Too few events for TD analysis
  - ≅1/3 of events are <u>NOT</u> in the K* region

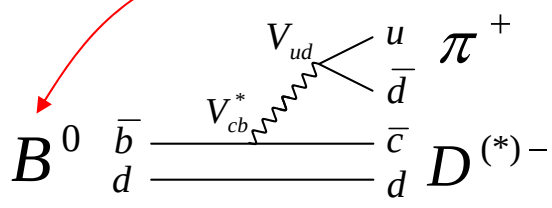


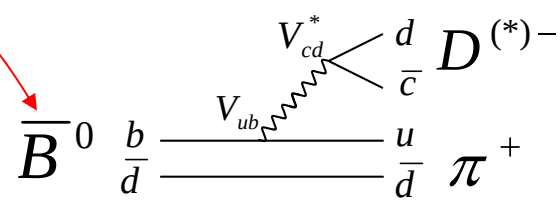
$$\mathcal{B}(B^0 \to D^{\mp} K^0 \pi^{\pm}) = (4.9 \pm 0.7_{\text{stat}} \pm 0.5_{\text{syst}}) \times 10^{-4}$$
$$\mathcal{B}(B^0 \to D^{*\mp} K^0 \pi^{\pm}) = (3.0 \pm 0.7_{\text{stat}} \pm 0.3_{\text{syst}}) \times 10^{-4}$$

Another way to sin(2β+γ) : $B^0 \to D^{*-}\pi^+$

- Both B^0 and $\overline{B}^0$ decay to $D^{(*)-}\pi^+$, neither with a colour-suppressed diagram

$B^0 / \overline{B}^0$ mixing $\propto e^{i2\beta}$





favoured b→c amplitude $\sim\lambda^2$

suppressed b→u amplitude $\sim\lambda^4$

$$a = A(B^0 \to D^{(*)-}\pi^+) \propto V^*_{cb}V_{ud}$$

$$A(\overline{B}^0 \to D^{(*)-}\pi^+) \propto V_{ub}V^*_{cd} = a\left|r^{(*)}\right|e^{i\delta}e^{i\gamma}$$

$$P_\eta(B^0,\Delta t) \propto 1+\eta C\cos(\Delta m_d\Delta t)+S^\eta\sin(\Delta m_d\Delta t)$$

$$P_\eta(\overline{B}^0,\Delta t) \propto 1-\eta C\cos(\Delta m_d\Delta t)-S^\eta\sin(\Delta m_d\Delta t)$$

$$\eta = +\text{ for } D^{*-}\pi^+, \quad \eta = -\text{ for } D^{*+}\pi^-$$

$$S^\pm = \frac{2r^{(*)}}{1+r^{(*)2}}\sin(2\beta+\gamma\pm\delta)$$

$$C = \frac{1-r^{(*)2}}{1+r^{(*)2}} \approx 1$$

Input

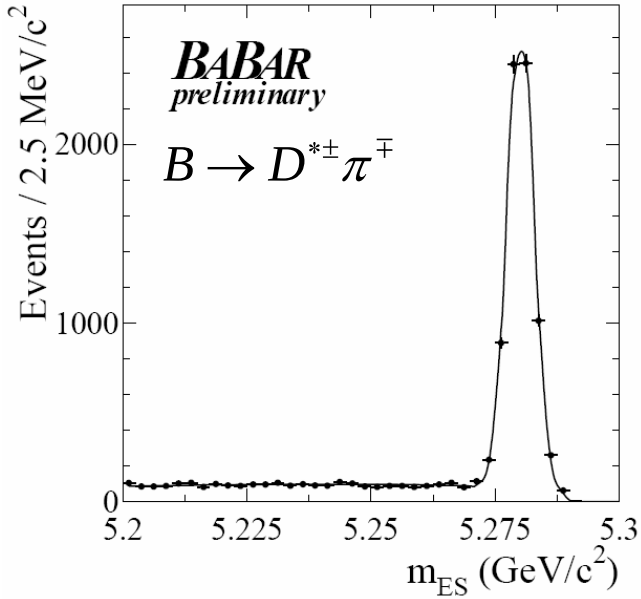
$|r^{(*)}|$ is estimated from $\overline{B}^0 \to D_s^{(*)-}\pi^+$

- SU(3) symmetry used

$$|r^{(*)}| = \frac{\left|A\left(\overline{B}^0 \to D^{(*)-}\pi^+\right)\right|}{\left|A\left(B^0 \to D^{(*)-}\pi^+\right)\right|} = 1.5^{+0.4}_{-0.6}\,\%$$

$B^0 \to D^{*-}\pi^+$: very small A_{CP} offset by copious statistics

Full reconstruction (110M$_{BB}$)



Total yields (all tags)

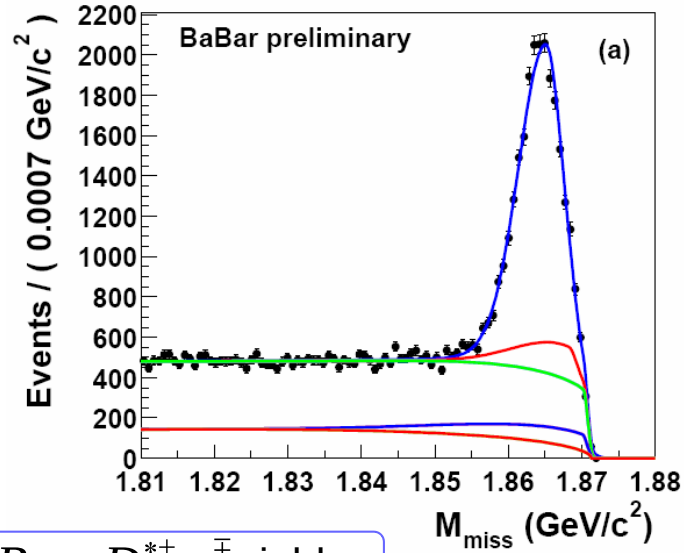
7611 ± 97	$B \to D^{\pm}\pi^{\mp}$
7068 ± 89	$B \to D^{*\pm}\pi^{\mp}$
4400 ± 79	$B \to D^{\pm}\rho^{\mp}$

Partial reconstruction (178 M$_{BB}$)

$$B^0 \to D^{*-}\pi^+$$
$$\hookrightarrow \overline{D}^0\pi^-_{soft}$$
$$\hookrightarrow X$$

Find events with two pions and examine the missing mass X

D*ρ
Combinat. BB
Peaking BB
Continuum



$B \to D^{*\pm}\pi^{\mp}$ yields

16060 ± 210	*lepton tags*
57480 ± 540	*kaon tags*

sin(2β+γ) results

Full reconstruction (110M$_{BB}$)

$B \to D^{\pm}\pi^{\mp}$

$2r\sin(2\beta+\gamma)\cos\delta = -0.032 \pm 0.031 \pm 0.020$

L $2r\cos(2\beta+\gamma)\sin\delta = -0.059 \pm 0.055 \pm 0.033$

$B \to D^{*\pm}\pi^{\mp}$

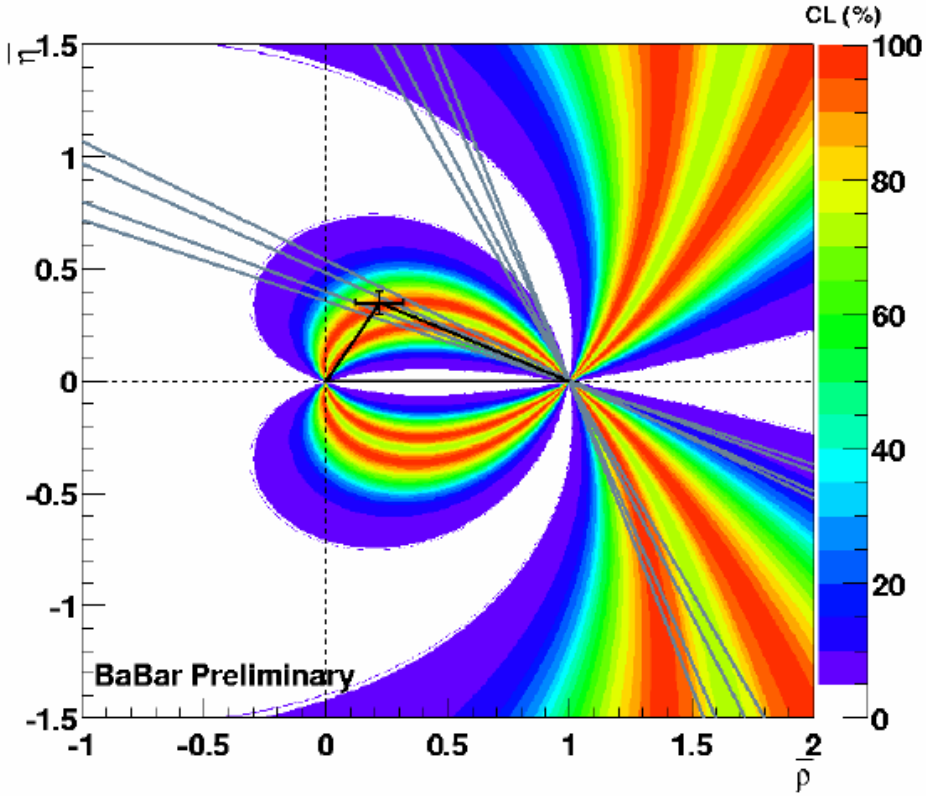
$2r_*\sin(2\beta+\gamma)\cos\delta_* = -0.049 \pm 0.031 \pm 0.020$

L $2r_*\cos(2\beta+\gamma)\sin\delta_* = 0.044 \pm 0.054 \pm 0.033$

$B \to D^{\pm}\rho^{\mp}$

$2r_\rho\sin(2\beta+\gamma)\cos\delta_* = -0.005 \pm 0.044 \pm 0.021$

L $2r_\rho\cos(2\beta+\gamma)\sin\delta_* = -0.147 \pm 0.074 \pm 0.035$



Partial reconstruction (178 M$_{BB}$)

$B \to D^{*\pm}\pi^{\mp}$

$2r_*\sin(2\beta+\gamma)\cos\delta_* = -0.041 \pm 0.016 \pm 0.010$

L $2r_*\cos(2\beta+\gamma)\sin\delta_* = -0.015 \pm 0.036 \pm 0.019$

$|\sin(2\beta+\gamma)| > 0.75 \quad (68\%\ C.L.)$

L : result uses lepton tags only

Conclusions

- PEP-II and *BABAR* have performed beyond expectation
- CP violation in the B system is well established
  - sin(2β) fast becoming a precision measurement

$$\sin(2\beta) = 0.722 \pm 0.046$$

- As for the other two angles (the subject of this presentation) :
  - Many analysis strategies in progress
  - The CKM angle α is measured but greater precision will come

$$\alpha = [103^{+10}_{-11}]^{\circ}$$

  - First experimental results on γ are available

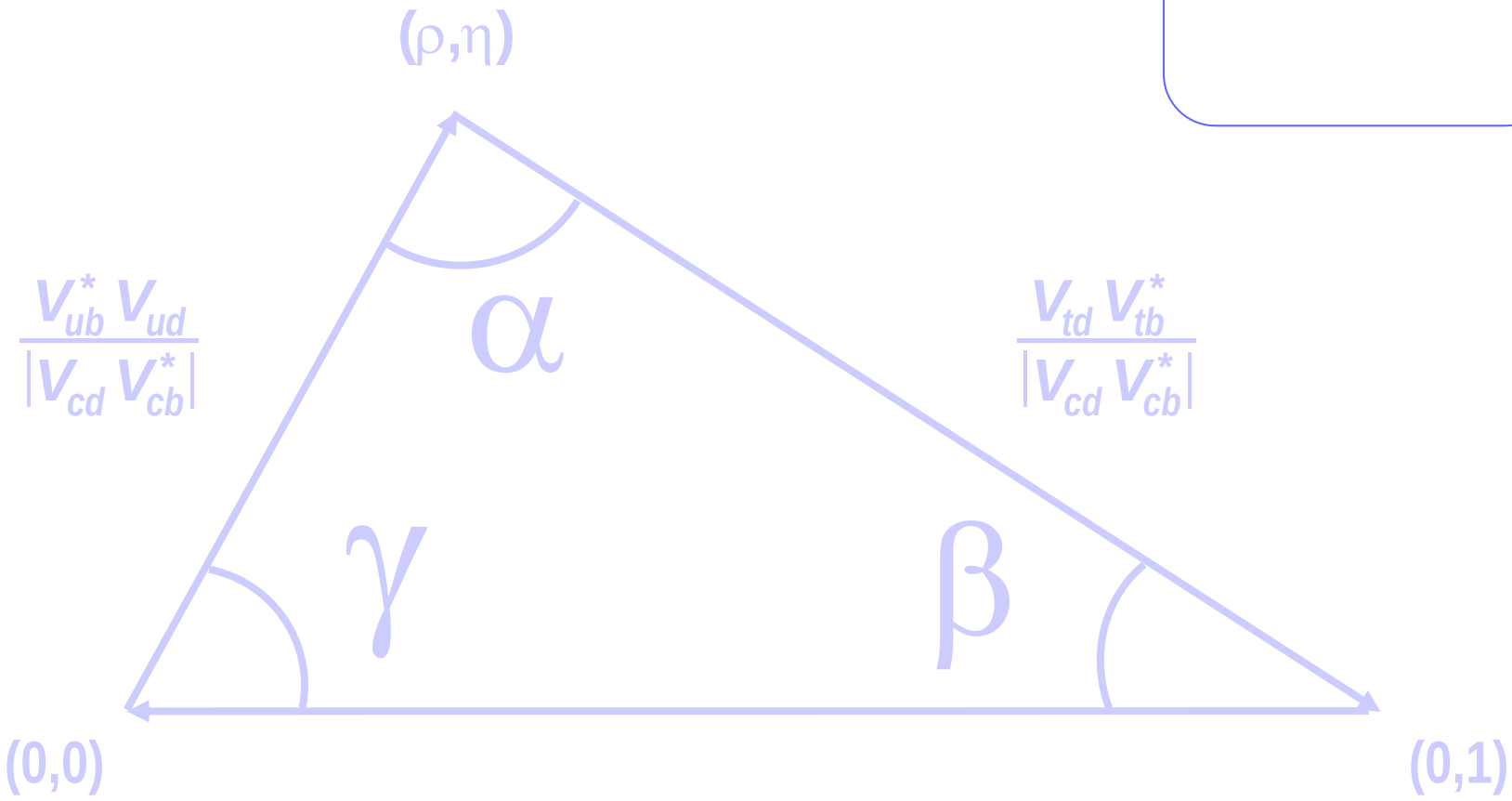
$$\gamma = [70 \pm 29]^{\circ} \quad + n\pi$$

  - First experimental results on 2β+γ are available

$$|\sin(2\beta + \gamma)| > 0.75 \quad (68\%\ C.L.)$$

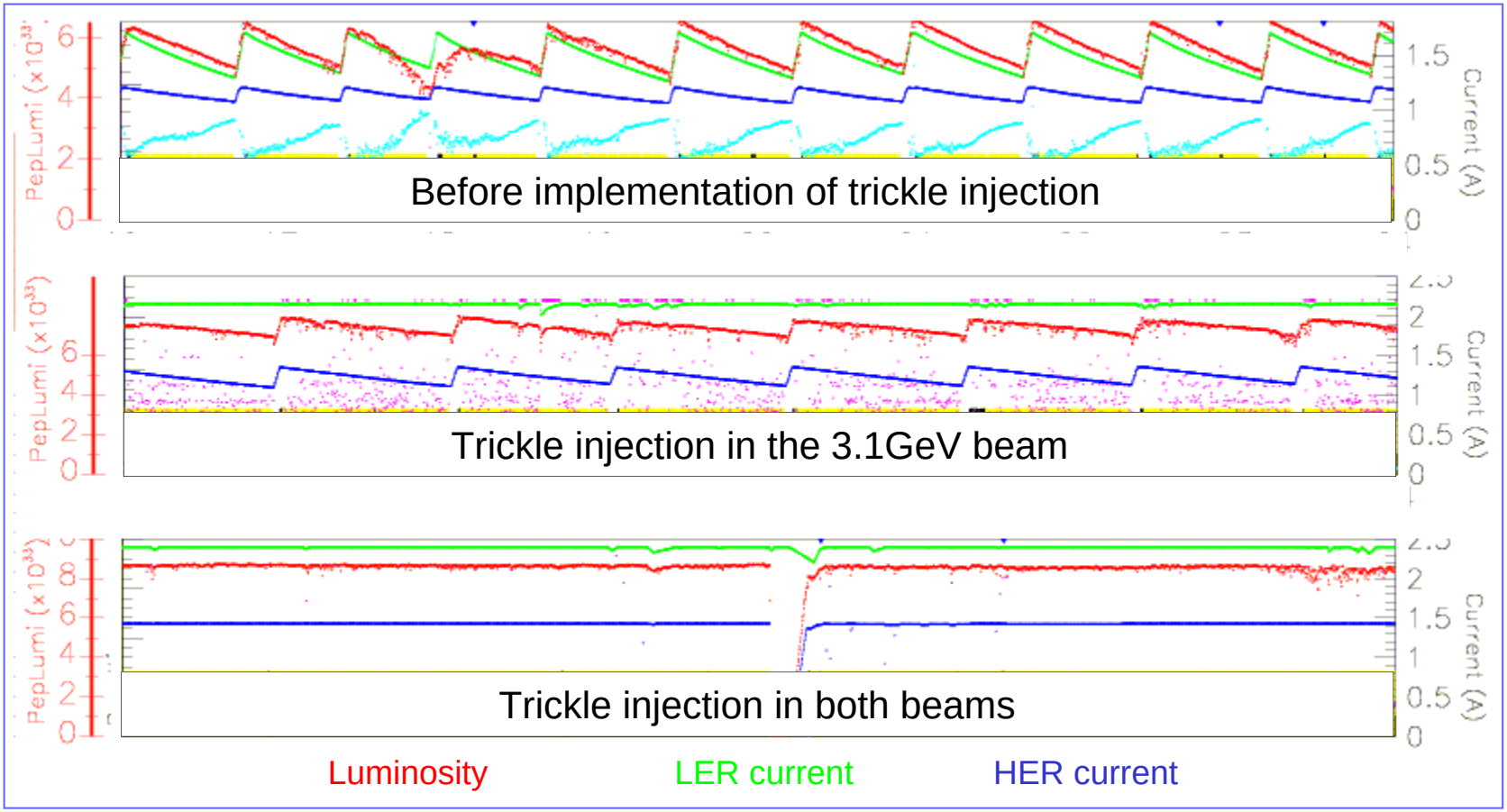
- Results presented here are based on datasets up-to 227 M_{BB}
  - *BABAR* and PEP-II aim to achieve 550 M_{BB} (500 fb^{-1}) by summer 2006

BACK-UP

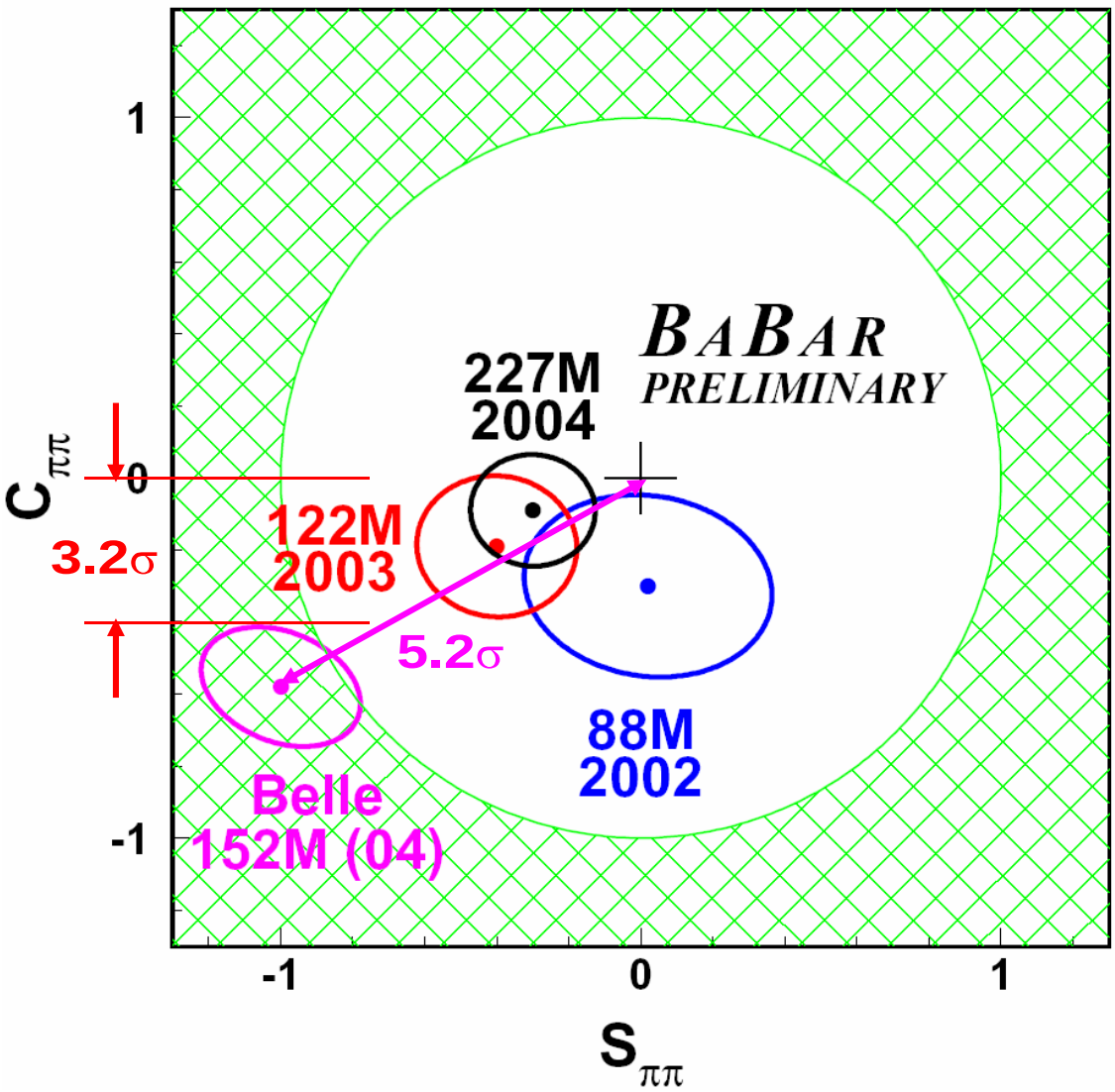


PEP-II : performance

- 5Hz "trickle" injection used in 2004



Comparison with Belle : CPV in $B^0 \to \pi^+\pi^-$



Belle report observation of CPV in $B^0 \to \pi^+\pi^-$

>3σ discrepancy between *BABAR* & Belle

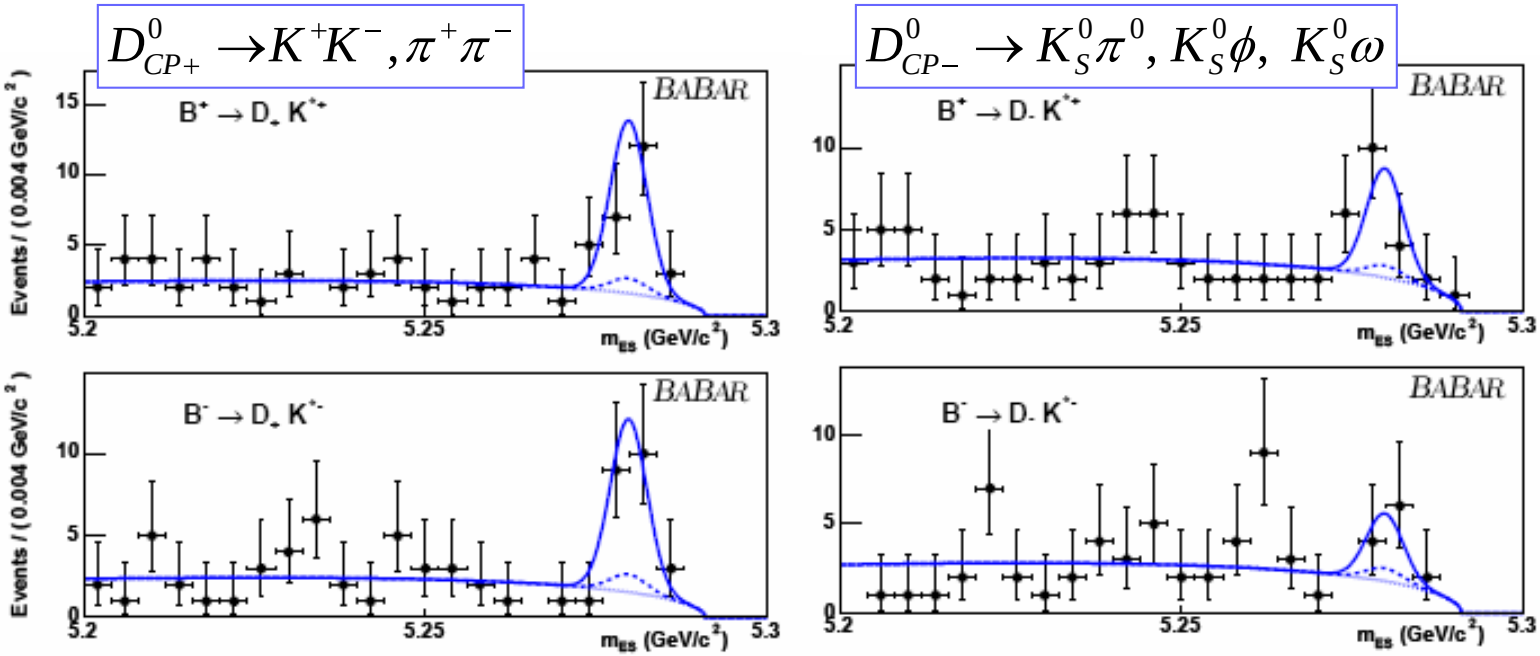
Belle 3.2σ evidence for Direct *CP* violation <u>not supported</u> by *BABAR* measurements

GLW method : $B \to D^0 K^*$ (227 M_{BB})

- Recontruct $K^* \to K_S \pi$.
  - Clean, no kinematically similar background
  - Lower B.F. and lower efficiency : Fewer events than D^0K analysis

B^+

B^-



$R_{CP+} = 1.73 \pm 0.36(\text{stat.}) \pm 0.11(\text{syst.})$ $\quad R_{CP-} = 0.64 \pm 0.25(\text{stat.}) \pm 0.07(\text{syst.})$

$A_{CP+} = -0.08 \pm 0.20(\text{stat.}) \pm 0.06(\text{syst.})$ $\quad A_{CP-} = -0.35 \pm 0.38(\text{stat.}) \pm 0.10(\text{syst.})$

$B \to \left(D^0\pi^0\right)_{D*} K$ $\quad R_{CP+} = 1.09 \pm 0.26(\text{stat.}) \pm 0.09(\text{syst.})$

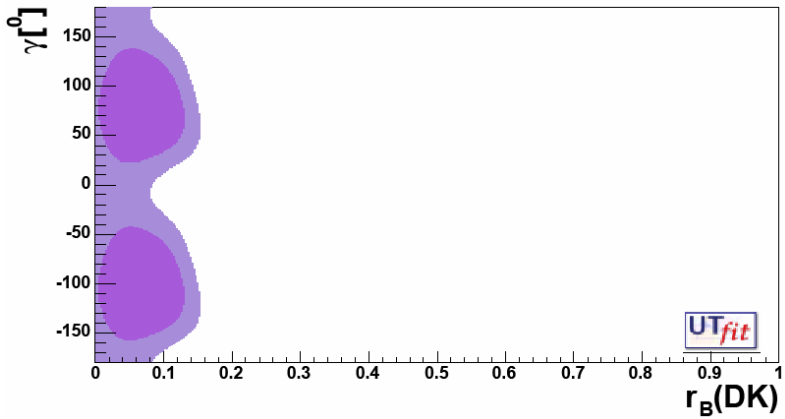
Similar analysis, 121 M_{BB} $\quad A_{CP+} = -0.02 \pm 0.24(\text{stat.}) \pm 0.05(\text{syst.})$

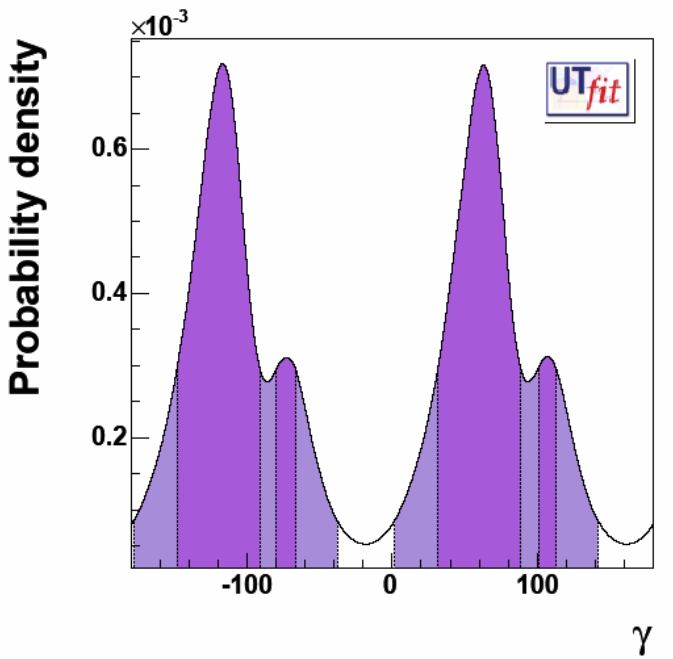
$(r_B)^2 = 0.19 \pm 0.23$

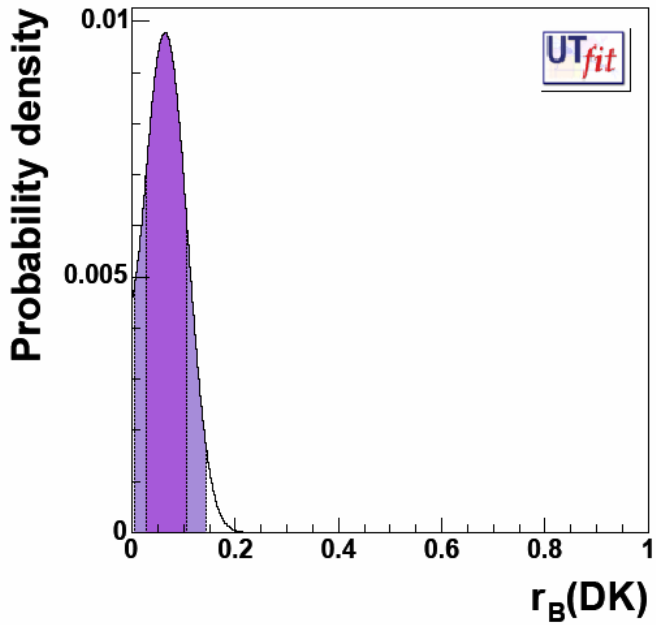
γ from B→DK

- **Combining results from GLW, ADS and D0-Dalitz methods**
  - **UTFit collaboration**
  - **hep-ph/0501199**

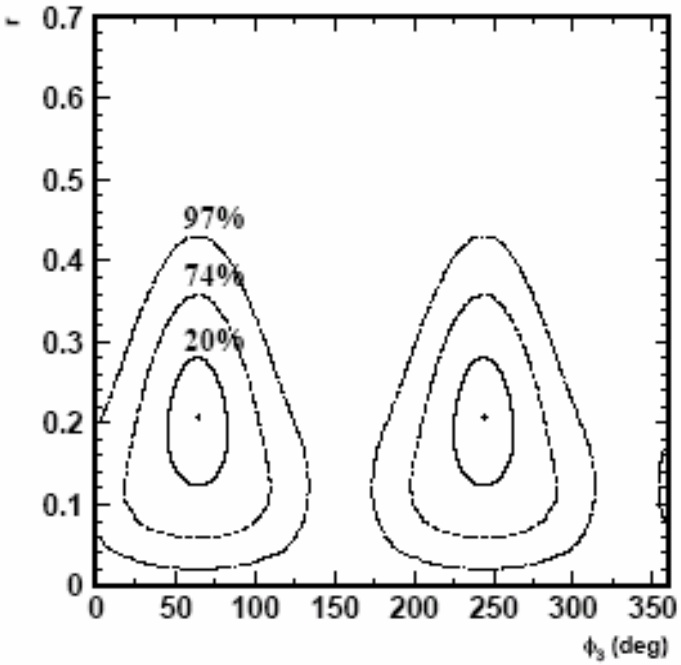
$\gamma = 60° \pm 28° \quad (+n\pi)$

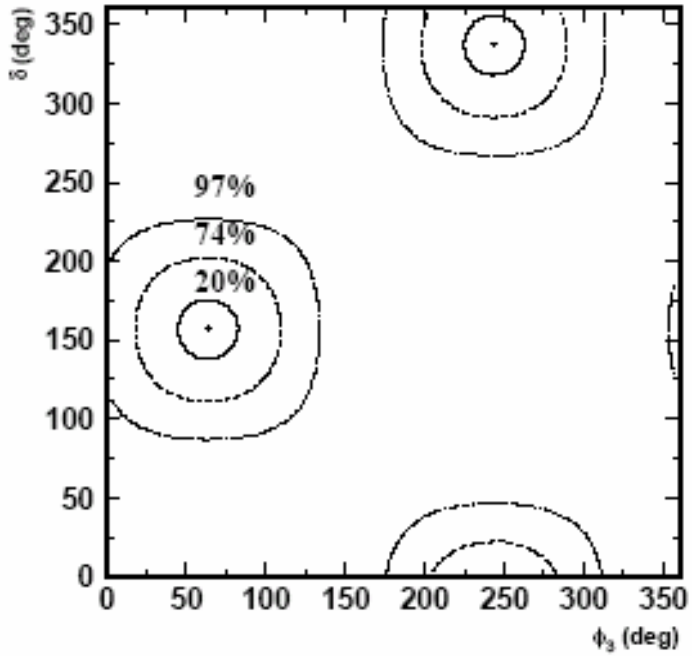






γ from Belle





$B^{\pm} \to \left(K_S\pi^+\pi^-\right)_D K^{\pm}$: PRELIMINARY

$\phi_3 = 64^\circ \pm 19^\circ(\text{stat}) \pm 13^\circ(\text{syst}) \pm 11^\circ(\text{model})$

$r = 0.21 \pm 0.08(\text{stat}) \pm 0.03(\text{syst}) \pm 0.04(\text{model})$

$\delta = 157^\circ \pm 19^\circ(\text{stat}) \pm 11^\circ(\text{syst}) \pm 21^\circ(\text{model})$

$r > 0$ @ 99.3% CL

CPV @ 94% CL

This document was created with Win2PDF available at http://www.daneprairie.com.
The unregistered version of Win2PDF is for evaluation or non-commercial use only.