Angle averages from B-factories

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KM unitarity triangle and CPV parameter convention

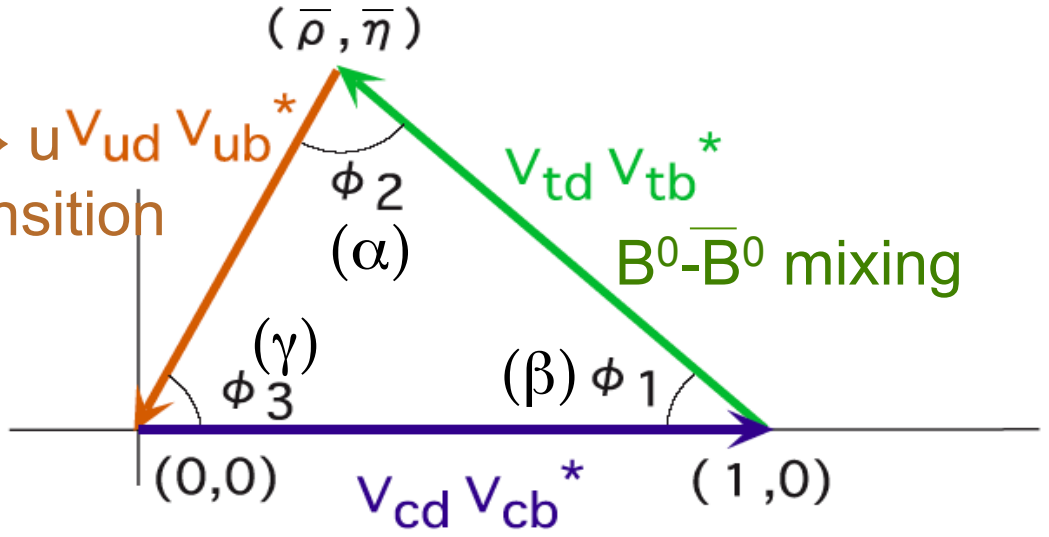
$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho - i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

by Wolfenstein parametrization

Irreducible complex phase causes CP Violation (CPV)!

Comprehensive test; measure all the angles and sides.

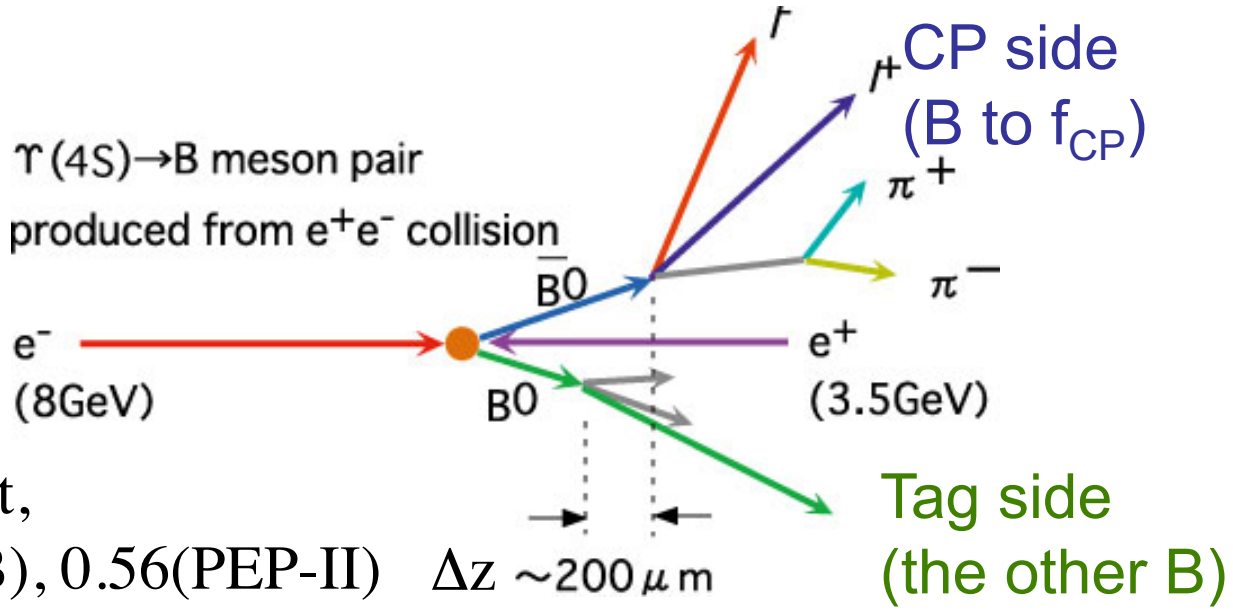
B system : very good place, all the angles are *O*(0.1)!



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

Time-dependent CPV

In order to see CPV by interference between decay and mixing.



$\Delta z = \beta\gamma c \Delta t$,

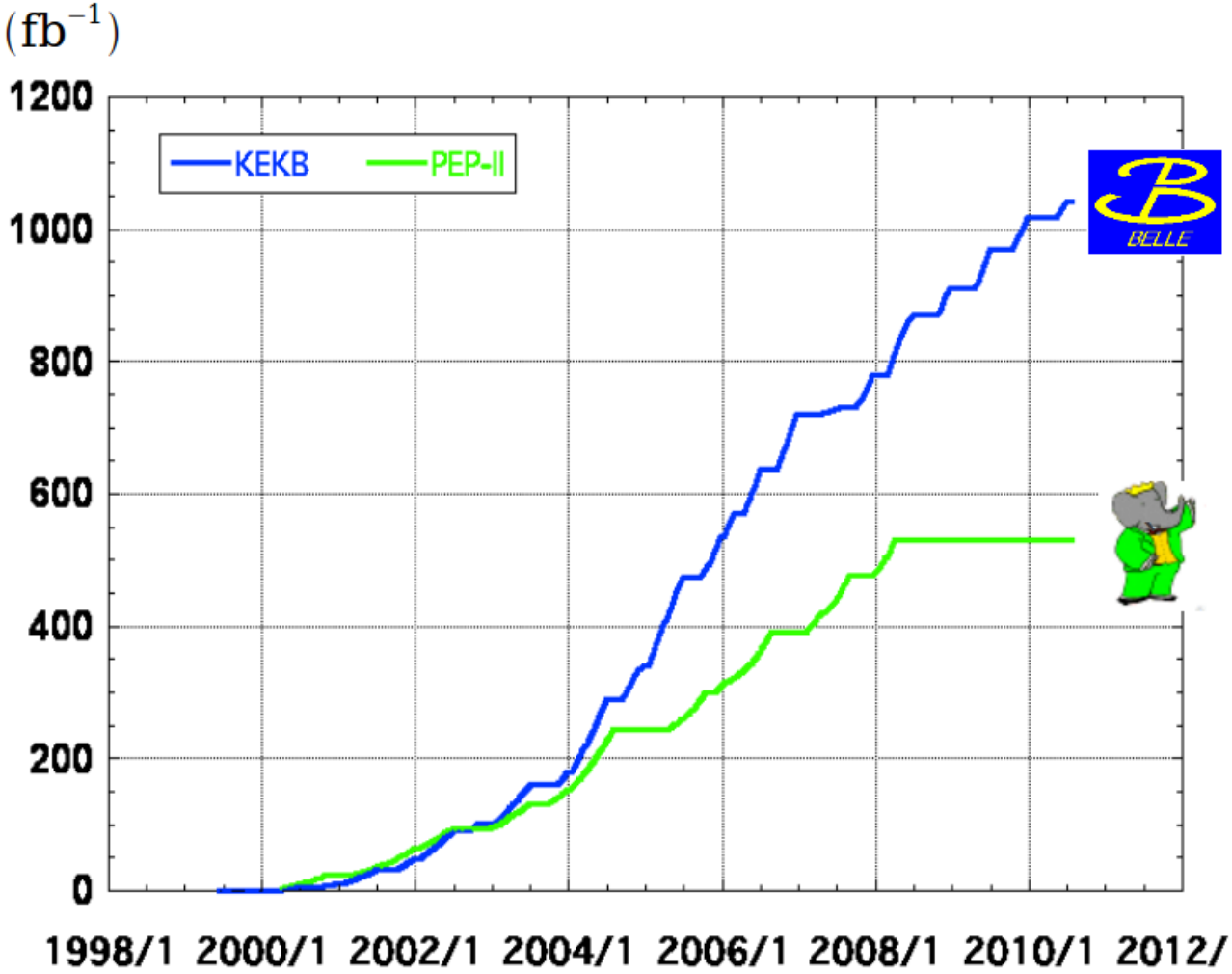
$\beta\gamma = 0.425(\mathrm{KEKB}), 0.56(\mathrm{PEP\text{-}II})$

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

$$S_{f_{CP}} = \frac{2\,Im(\lambda)}{|\lambda|^2 + 1} \qquad A_{f_{CP}} = \frac{|\lambda|^2 - 1}{|\lambda|^2 + 1} \qquad \lambda = \frac{q}{p}\frac{\bar{A}(f_{CP})}{A(f_{CP})}$$

$$-C_{f_{CP}} = A_{f_{CP}} \qquad |\lambda| = 1 \text{ if no DCPV}$$

Integrated luminosity of B factories

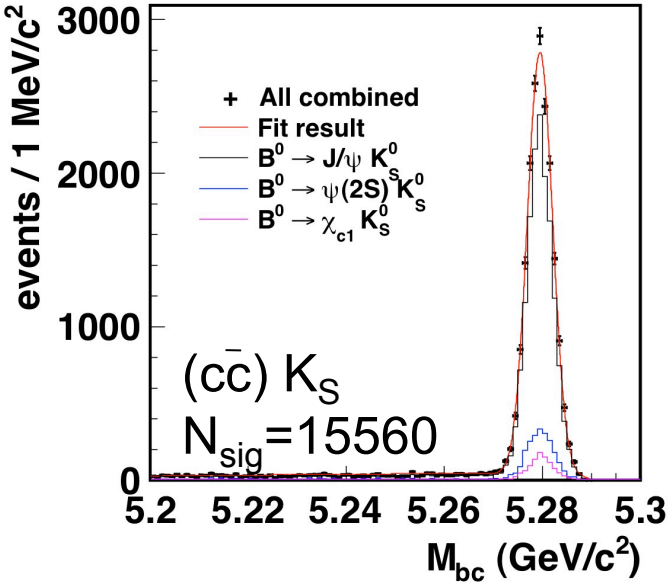


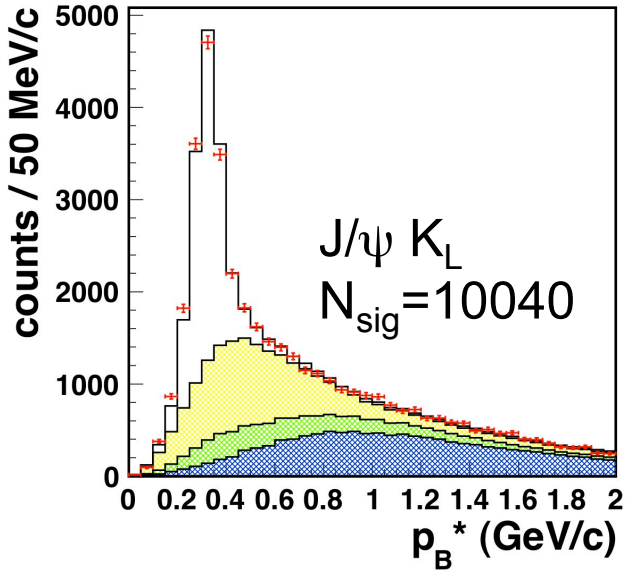
$> 1\ ab^{-1}$
On resonance:
$\Upsilon(5S)$: 121 fb^{-1}
$\Upsilon(4S)$: 711 fb^{-1} 772M $B\bar{B}$
$\Upsilon(3S)$: 3 fb^{-1}
$\Upsilon(2S)$: 25 fb^{-1}
$\Upsilon(1S)$: 6 fb^{-1}
Off reson./scan:
~ 100 fb^{-1}

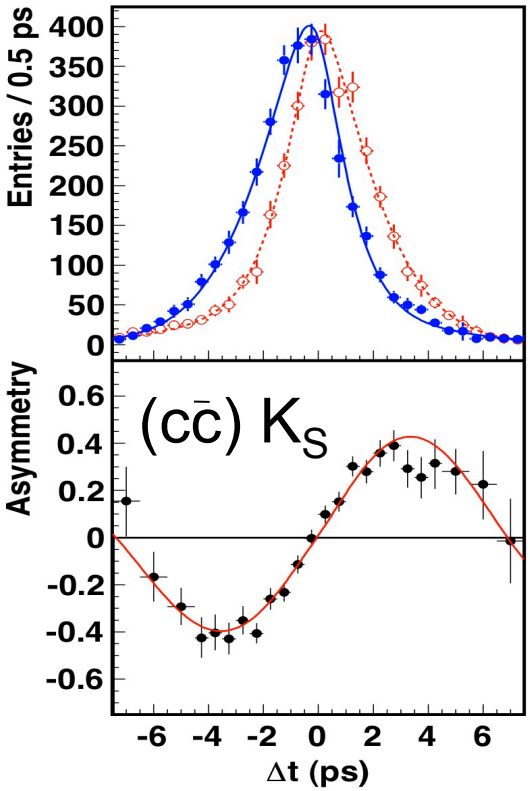
~ $550\ fb^{-1}$
On resonance:
$\Upsilon(4S)$: 433 fb^{-1} 470M $B\bar{B}$
$\Upsilon(3S)$: 30 fb^{-1}
$\Upsilon(2S)$: 14 fb^{-1}
Off resonance:
~ 54 fb^{-1}

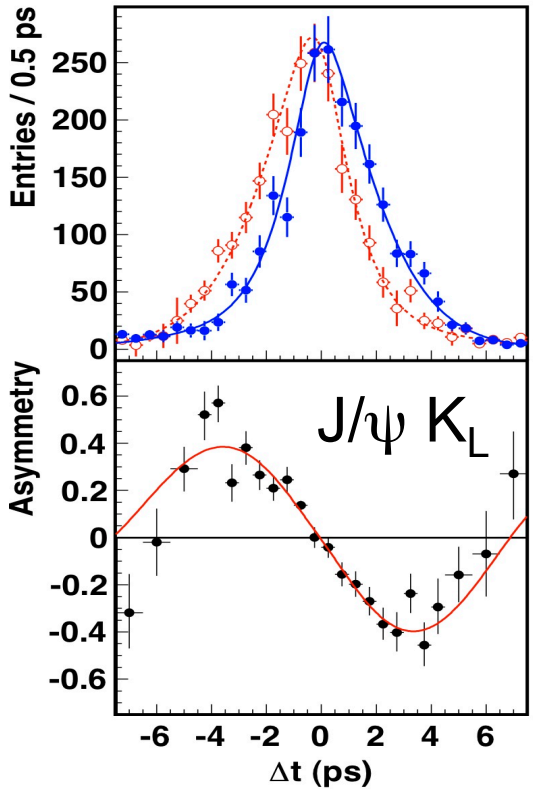
In total, more than 1G $B\bar{B}$ pairs are recorded at B-factories and used to measure angles.

sin2ϕ_1(=sin2β) at Belle (772M $B\bar{B}$)







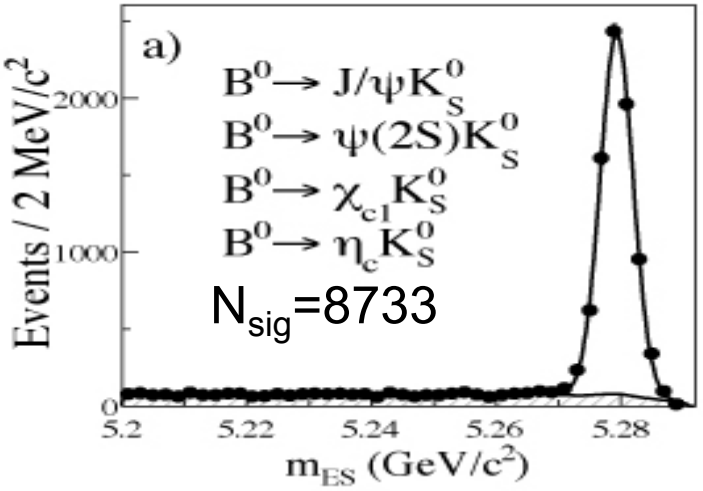


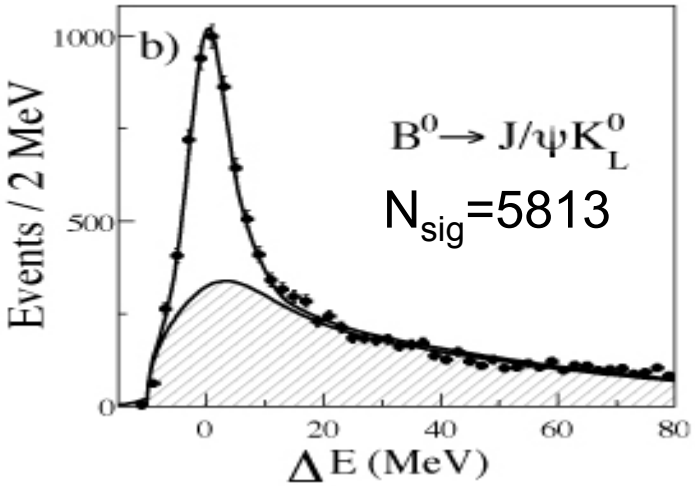
sin2ϕ_1=0.668±0.023±0.012

-C_{fCP}= A_{fCP}=0.007±0.016±0.012

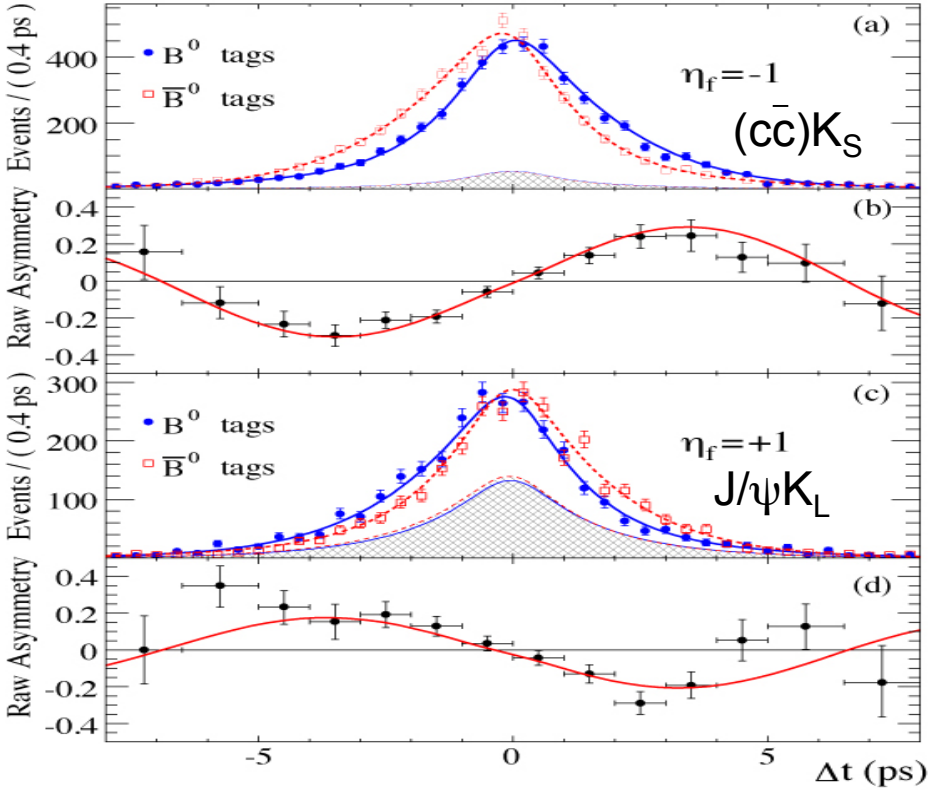
PRL108,171802(2012)

$\sin 2\phi_1 (=\sin 2\beta)$ at BaBar (465M $B\bar{B}$)





$E_B - E_{CM}/2$

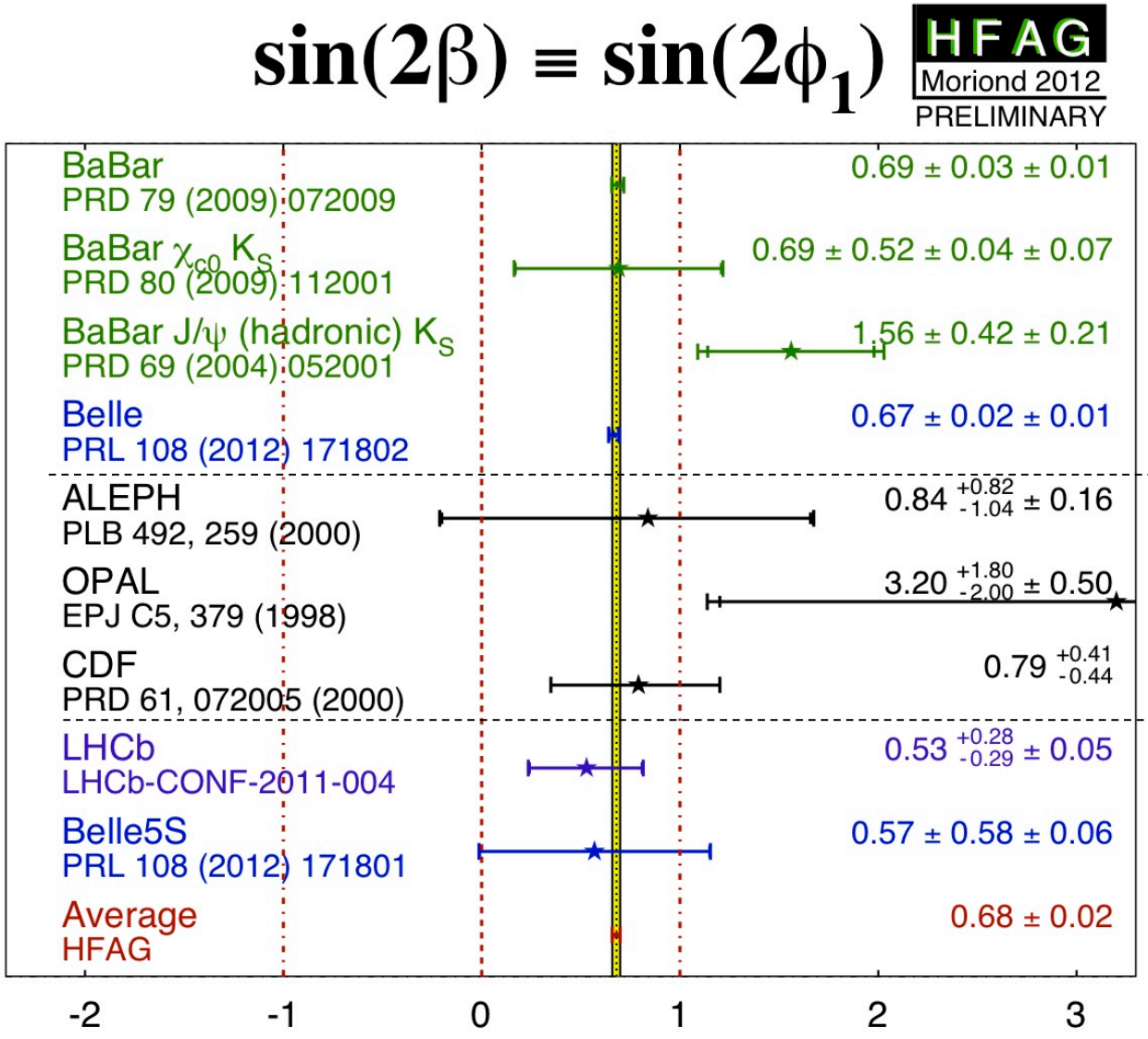


$\sin 2\phi_1 = 0.687 \pm 0.028 \pm 0.012$

$-C_{fCP} = A_{fCP} = -0.024 \pm 0.020 \pm 0.016$

PRD79,072009(2009)

Known as a firm SM reference.



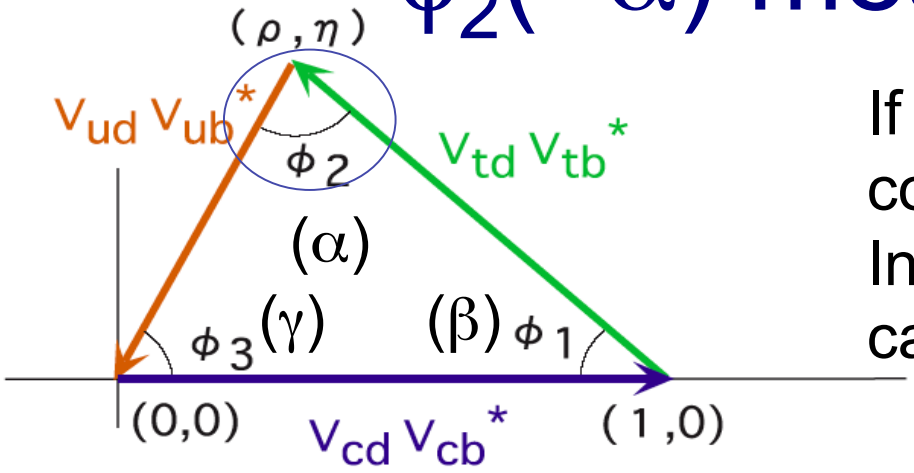
Measurements by B-factories

Measurements before B-factories

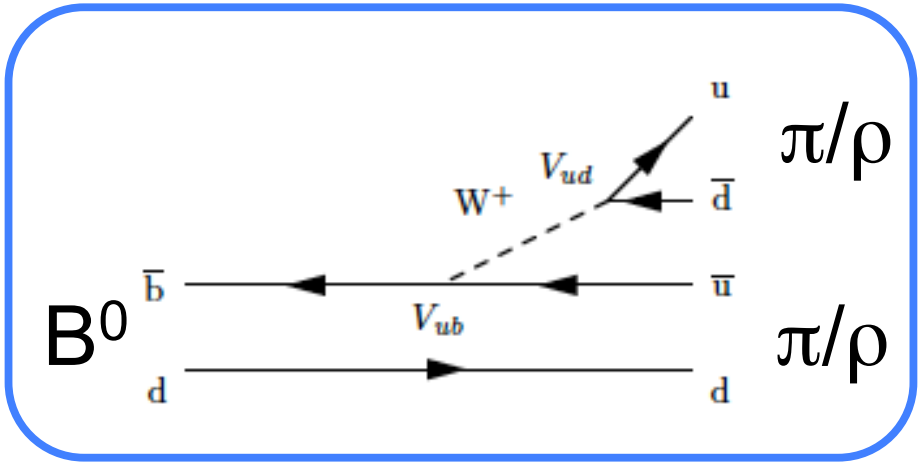
Sorry, this LHCb result ($35pb^{-1}$, A_{fCP}=0 assumed.) became obsolete.

(See Julian Wishahi's talk on Saturday.)

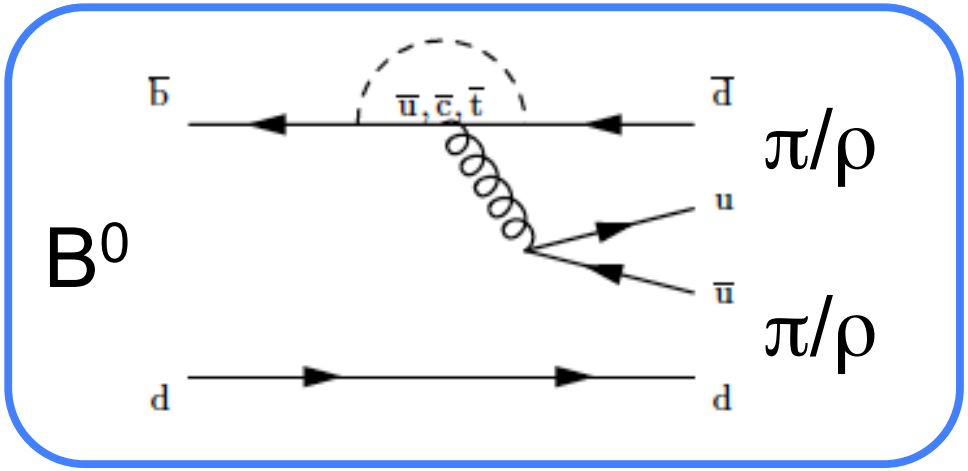
$\phi_2(=\alpha)$ measurement



If tree only, S_f is directly connected to $\sin 2\phi_2$ and $A_f=0$. Interference with $b\rightarrow d$ penguin can be solved by isospin analysis.



Decay diagram (tree)



Decay diagram (penguin)

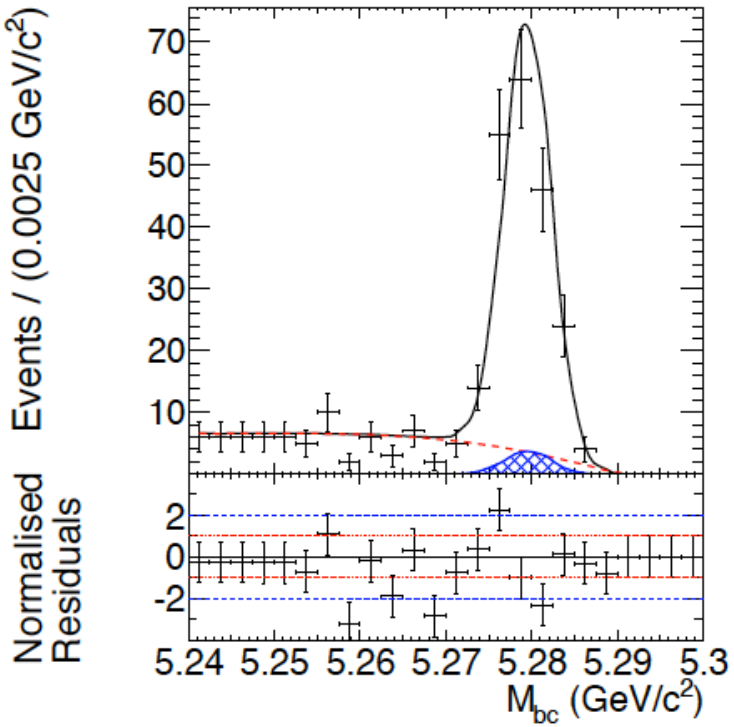
This time, new $\pi^+\pi^-$, $\rho^0\rho^0$(Belle) and $(\rho\pi)^0$ (BaBar) results come.

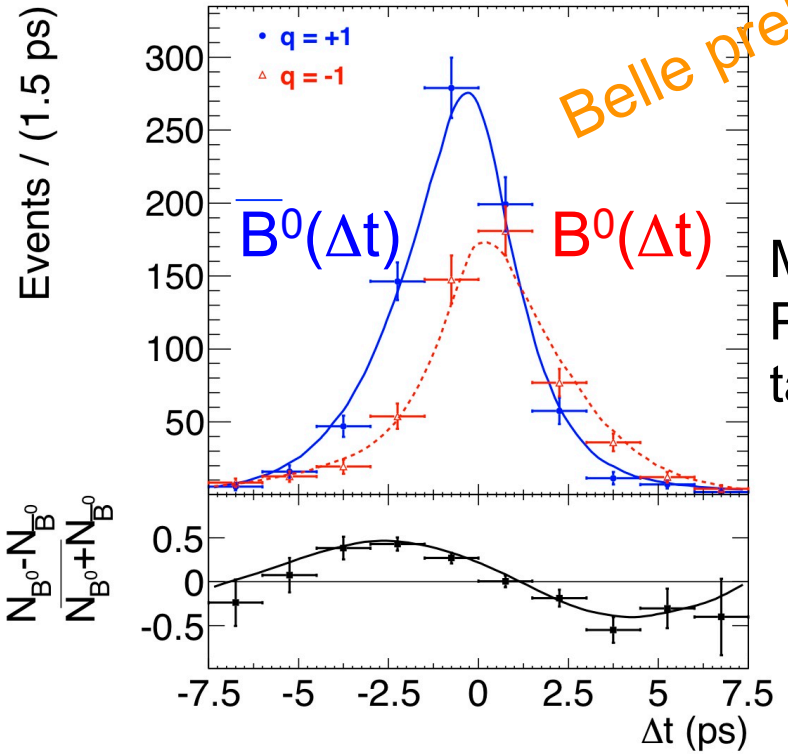
$B^0 \to \pi^+\pi^-$ CPV at Belle (772M $B\bar{B}$)

New

ΔE, M_{bc}, Δt, $L_{K\pi}^{\pm}$, $F_{S/B}$ for $K\pi$, $\pi\pi$, KK simultaneous 6D fit.
$B^0 \to \pi^+\pi^-$ signal yield : 2886±82 events.

Signal enhanced sample with very tight cuts



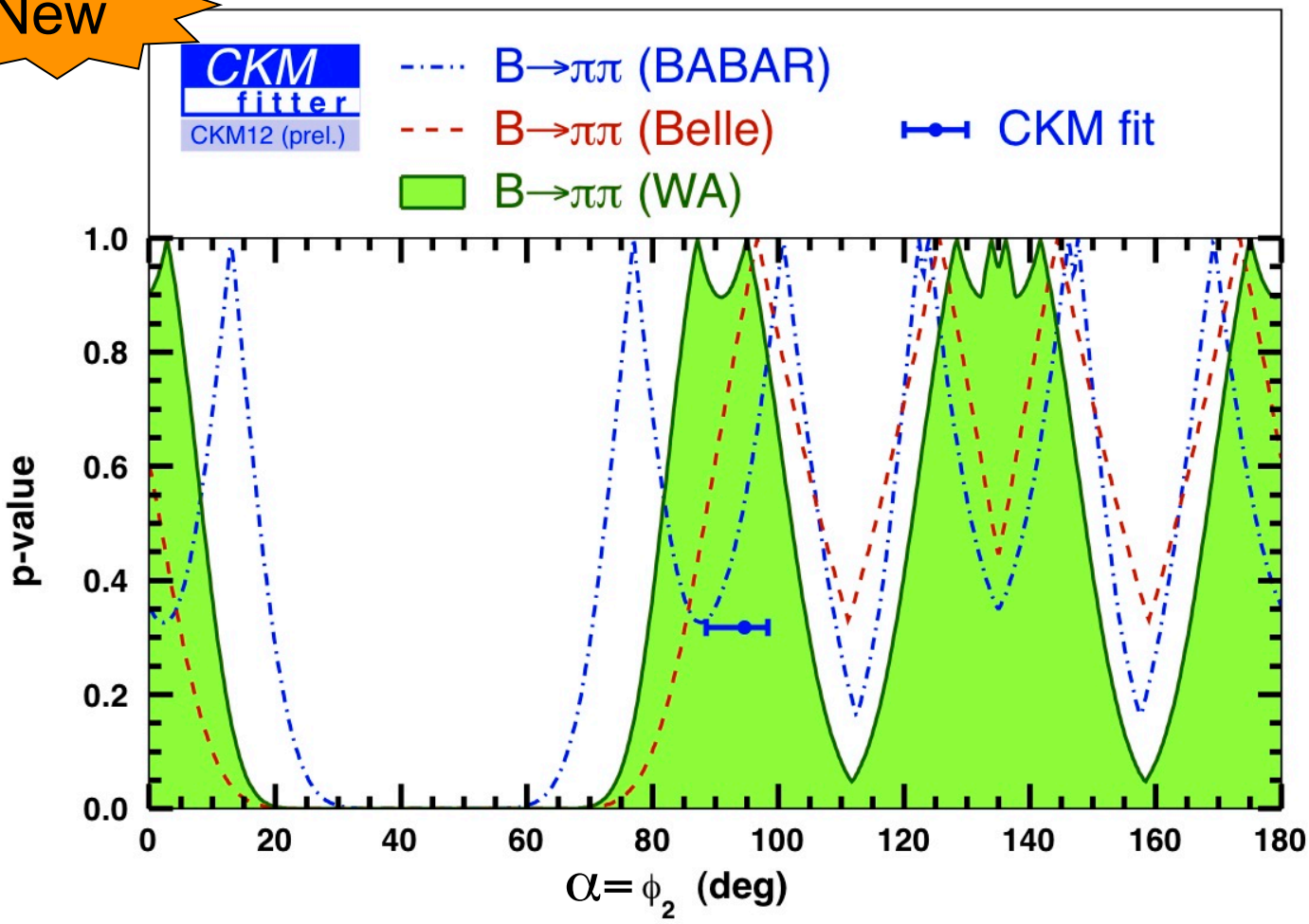


More detail: see Pit Vanhoefer's talk on Saturday

S_{fCP}=-0.636±0.082±0.027
$-C_{fCP}=A_{fCP}$=+0.328±0.061±0.027

New constraint by ππ modes

New



For ππ, isospin triangle is found to properly close.

Thanks to CKMfitter friends, especially Olivier Deschamps and Karim Trabelsi for plots including other relevant ones.

$B^0 \to \rho^0\rho^0$ search at Belle (772M $B\bar{B}$)

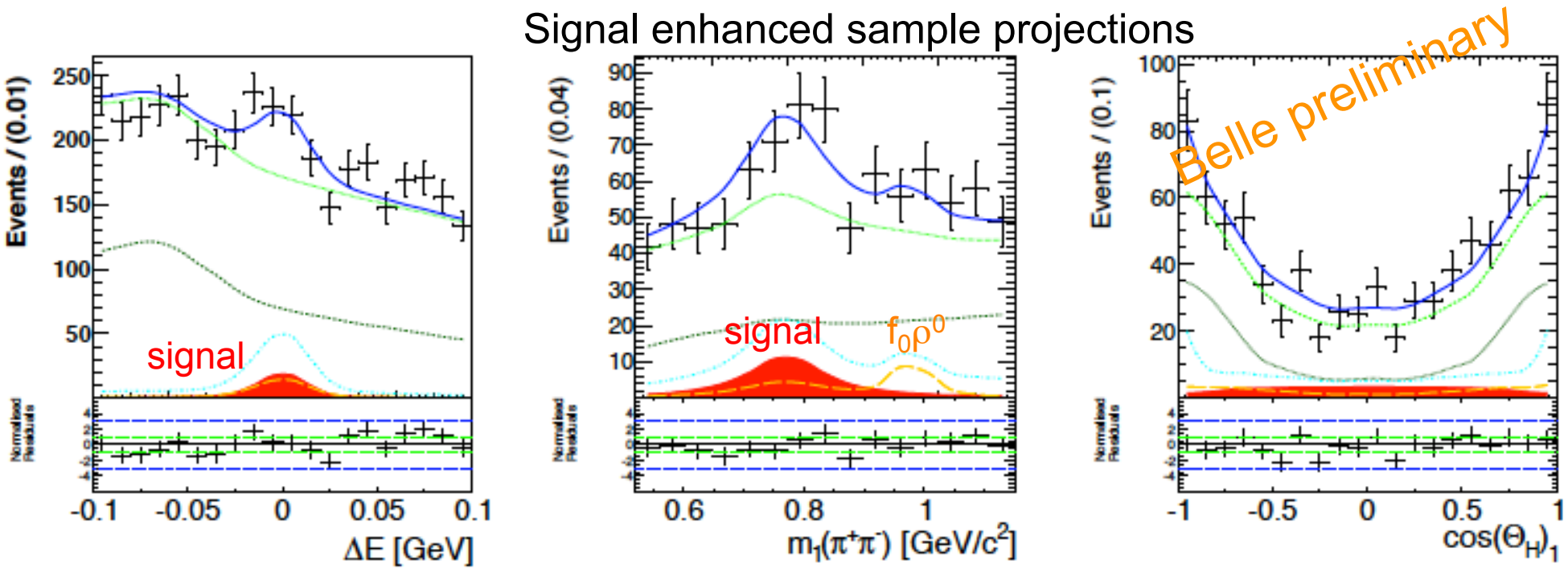
New

ΔE, $M_{1,2}$, $\cos\theta_{H1,2}$, $F_{S/B}$ 6D fit.

$B^0 \to \rho^0\rho^0$ stat. significance : 2.9σ (including syst.)

More detail: see Pit Vanhoefer's talk on Saturday

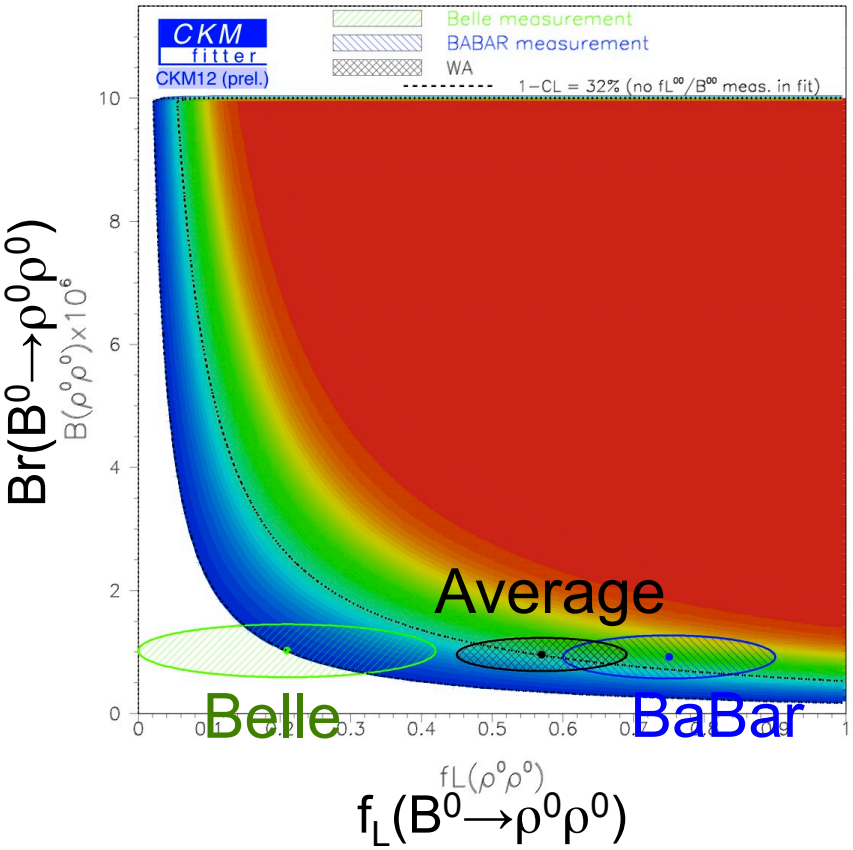
Signal enhanced sample projections

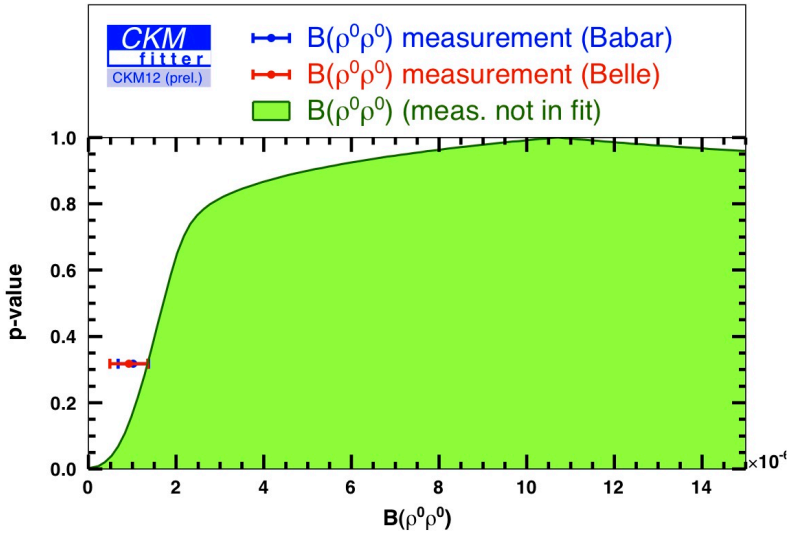


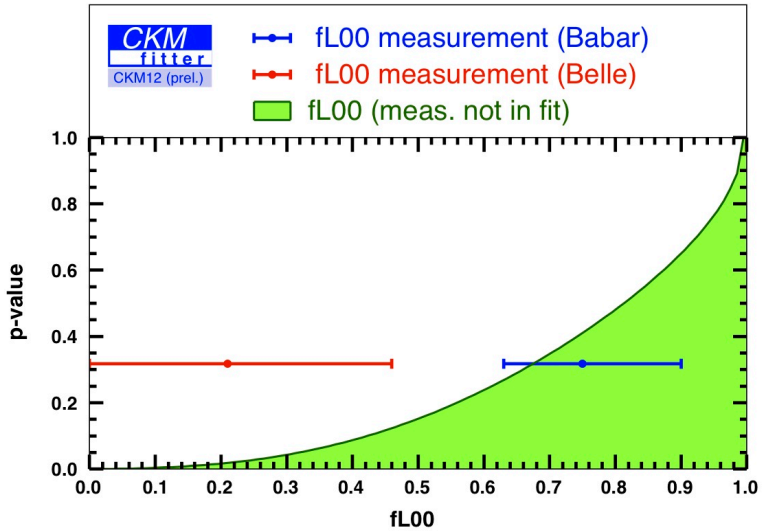
$Br(B^0 \to \rho^0\rho^0) = (1.02 \pm 0.30 \pm 0.22) \times 10^{-6}$, $< 1.5 \times 10^{-6}$@90%C.L.

$f_L = 0.21\ ^{+0.22}_{-0.18} \pm 0.11$

$B^0 \to \rho^0\rho^0$ Belle & BaBar



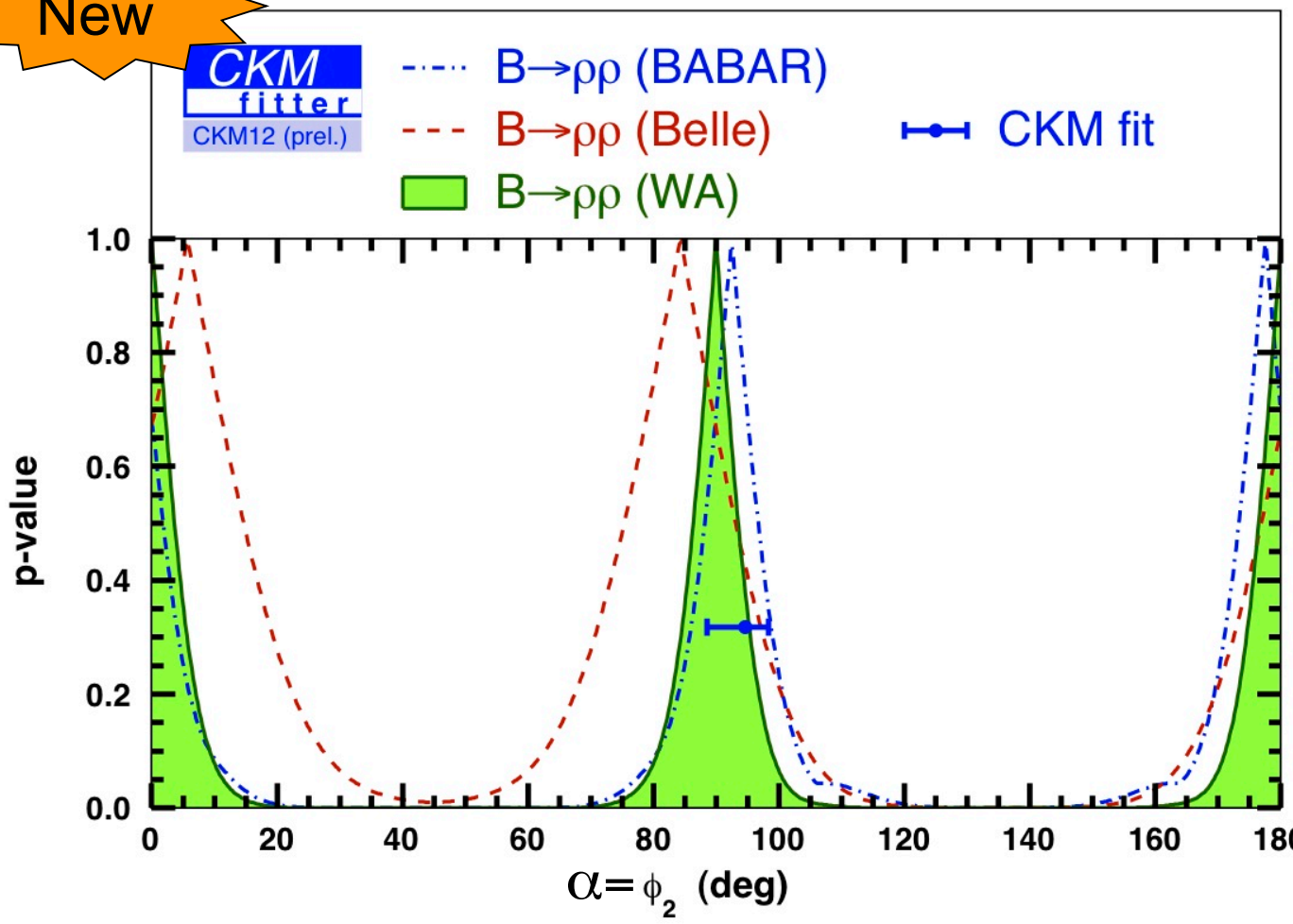




More precise measurements are necessary.

New constraint by ρρ modes

New



For ρρ, isospin triangle is flat, thus no plateau in p-value plot.

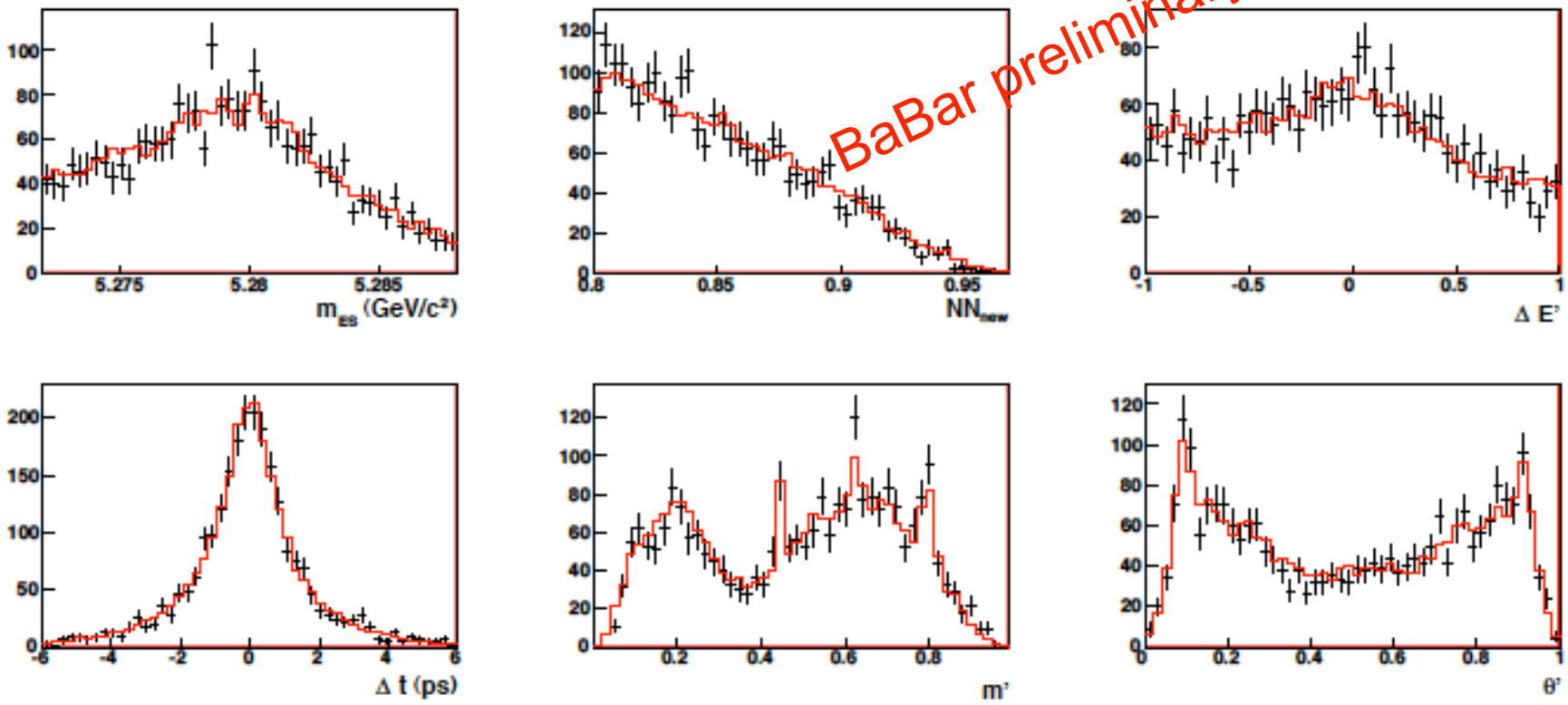
$Br(B^+ \to \rho^+\rho^0)$ improvement is also important. Belle update awaited.

$\phi_2=\alpha=(89.9\ +5.4/-5.3)°$

BaBar $B^0 \to (\rho\pi)^0$ result

New

M_{bc}, ΔE, NN_{output}, Δt, m' θ' 6D time-dep. Dalitz fit.



Signal yield : 2940±100 events.

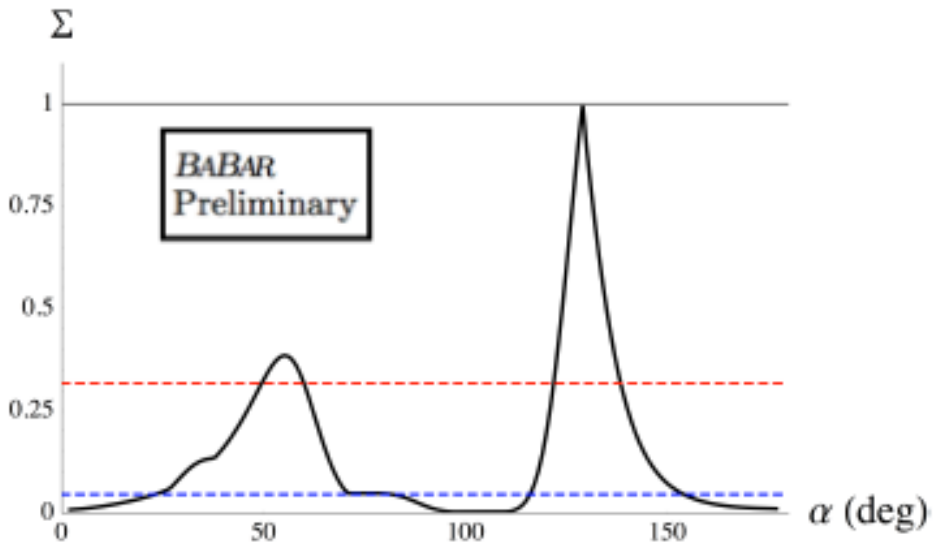
$\alpha=\phi_2$ scan is performed.

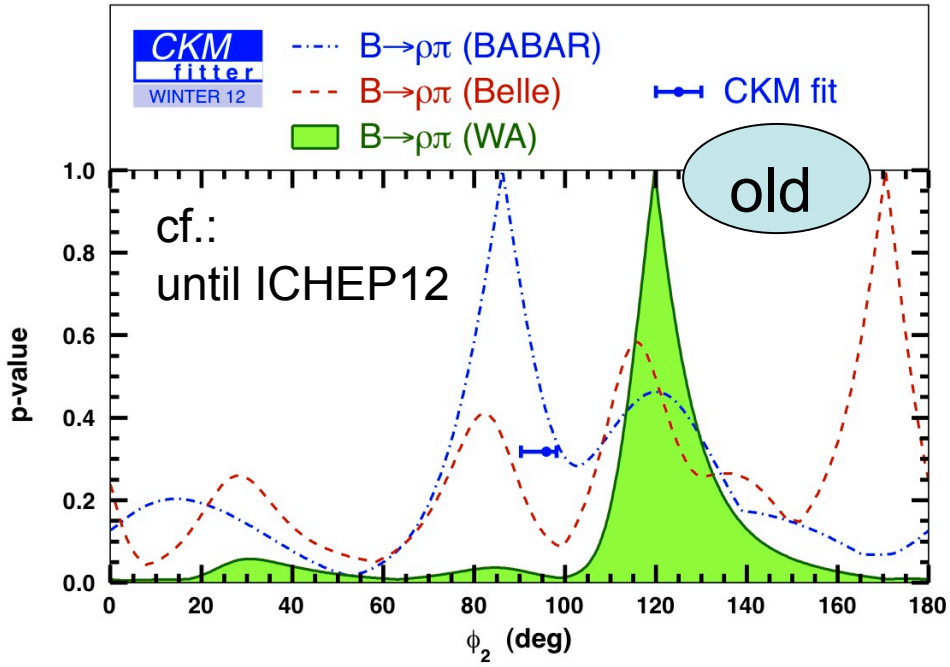
More detail : see Tomo Miyashita's talk in Sunday morning

$\alpha=\phi_2$ scan in $(\rho\pi)^0$ mode in BaBar

New

More detail : see Tomo Miyashita's talk in Sunday morning



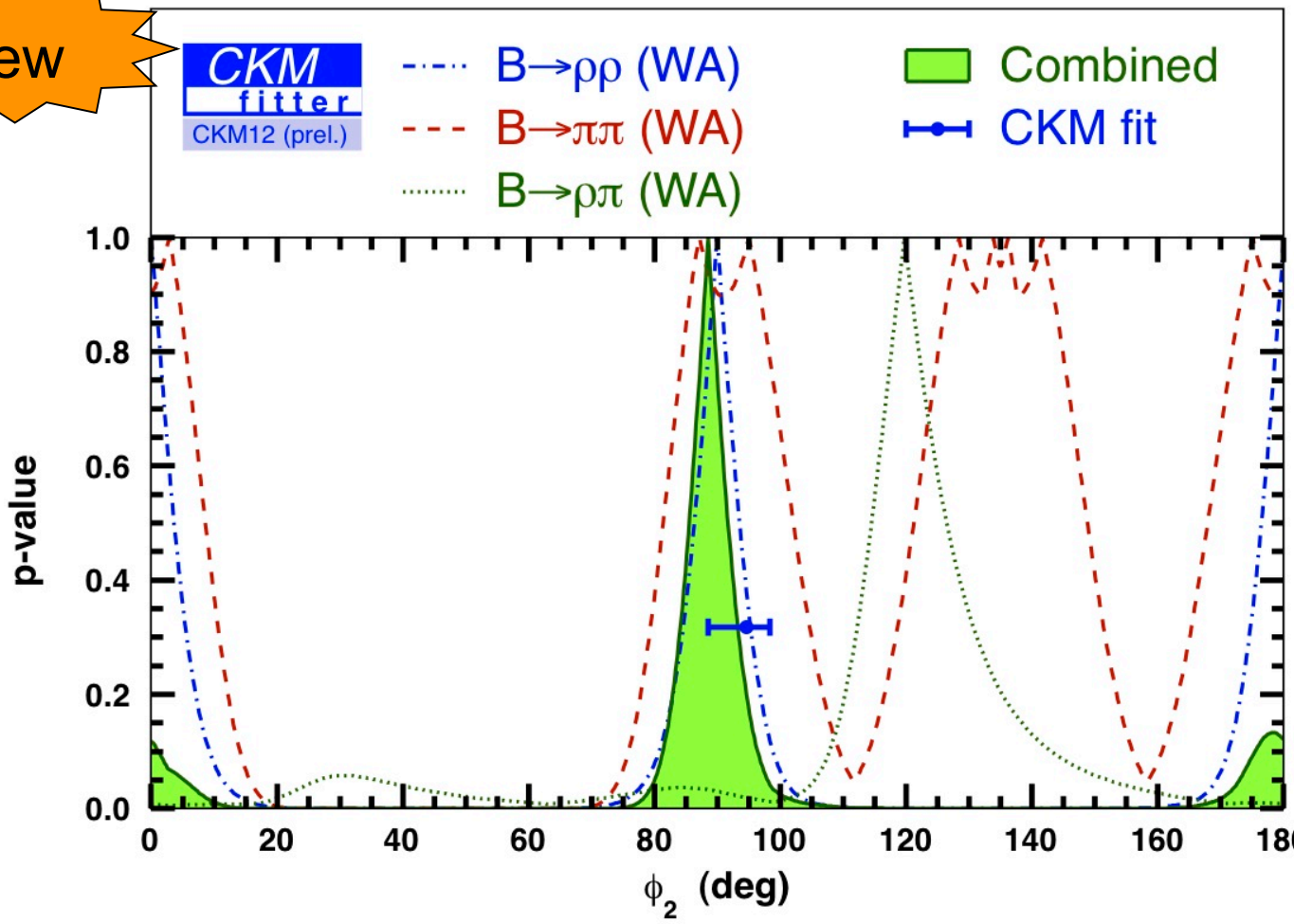


Result behavior is non-Gaussian. At 2σ level, most of the region is still allowed in $\rho\pi$ case in general.

New BaBar most favored $\alpha=\phi_2$ value moves to the one by old average.

New constraint by ππ/ρρ/ρπ modes

New

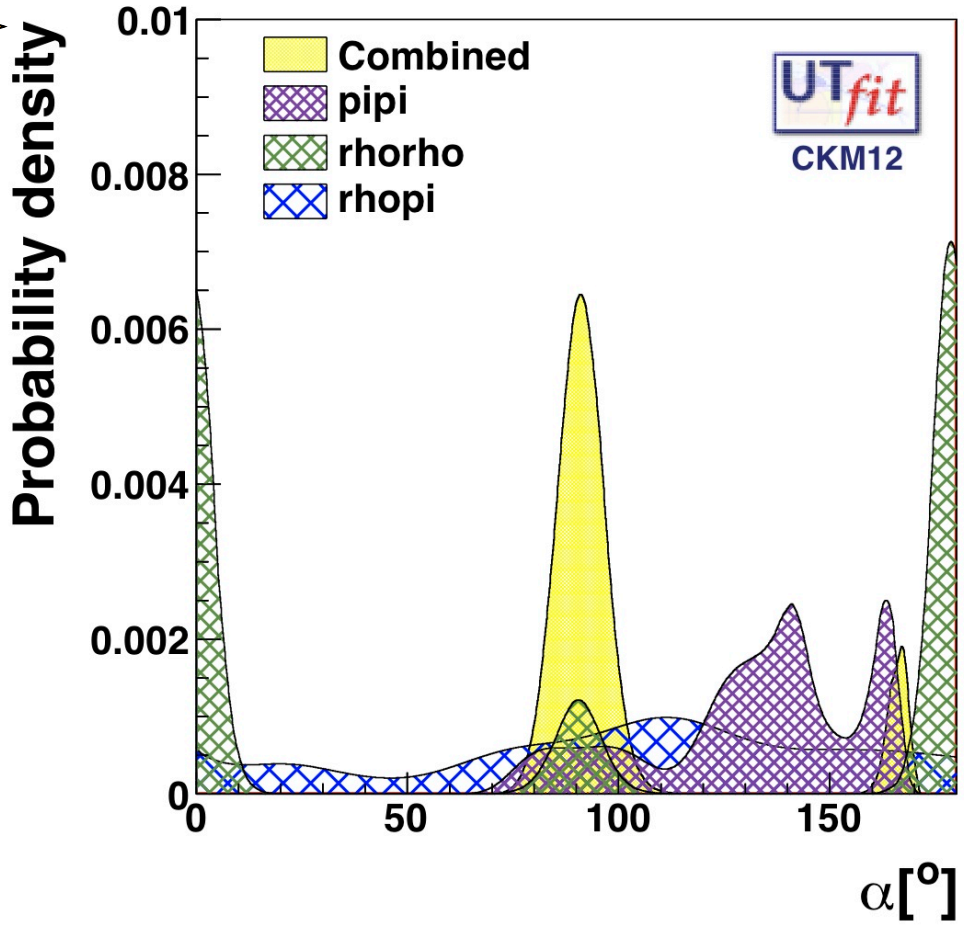


Disclaimer: BaBar new $(\rho\pi)^0$ result could not be included, though ρπ modes don't constrain so strongly compared with ρρ and ππ.

$\alpha=\phi_2=(88.5\ +4.7/-4.4)°$

Another approach

New



$\phi_2=\alpha=(91.9\pm6.9)°$

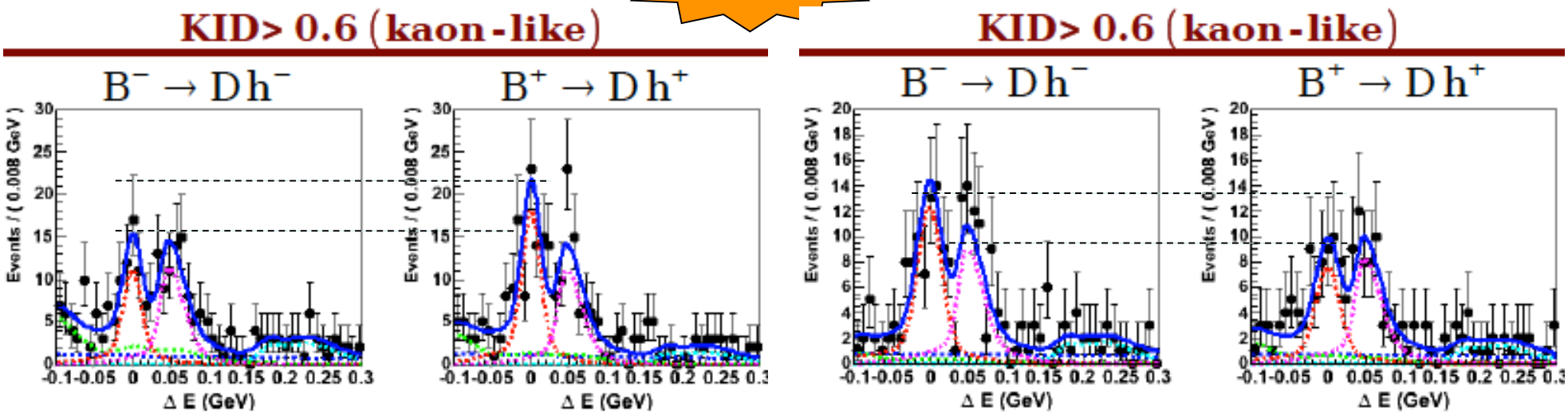
$\phi_3=\gamma$ constraint

Principle	Method Name and reference
D^0 or $D^{*0} \rightarrow$ CP eigenstate	GLW, PLB253,483(1991), PLB265,172(1991)
Enhance CP asymmetry by suppressed D decay	ADS, PRL78,3357(1997), PRD63,036005(2001)
Dalitz distribution in three-body D decay ($K_S p^+ p^-$, etc)	GGSZ, PRD68,054018(2003), Belle Dalitz Analysis meeting proceedings

Use all available information to get $\phi_3=\gamma$.

Belle GLW by D^{*0} K (772M $B\bar{B}$)

$D^{*0} \to D^0\pi^0$, $D^0 \to K^+K^-$, $\pi^+\pi^-$ New $D^{*0} \to D^0\pi^0$, $D^0 \to K_S\pi 0$, $K_S\,\eta$



A_{CP+}=-0.23±0.11 A_{CP-}=+0.20±0.13

CP asymmetry central values support expectation of sign flip according to the CP eigenvalue of D^0 decay final state.

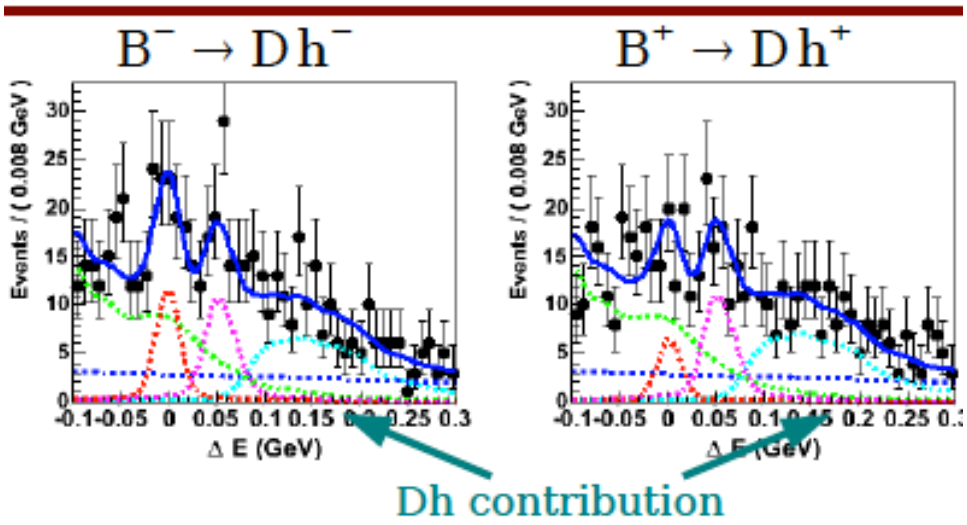
More detail : see Karim Trabelsi talk on Sunday afternoon.

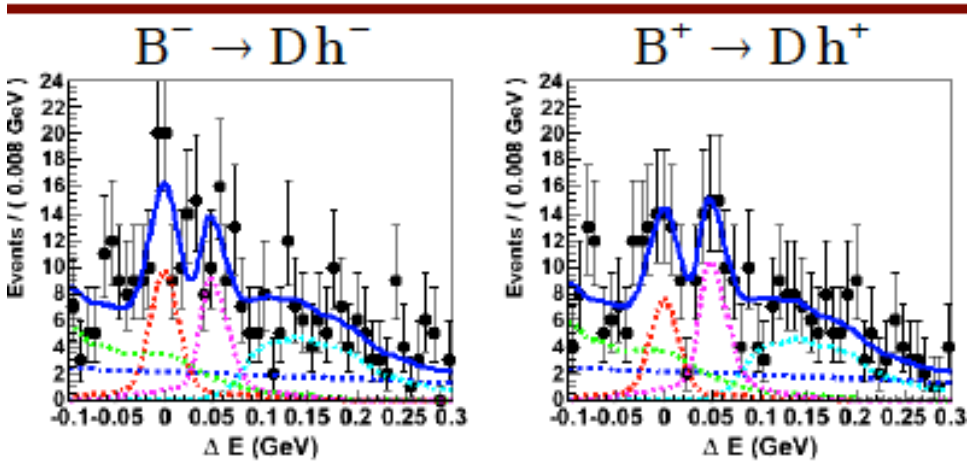
Belle GLW by D^{*0} K (cont.)

$D^{*0} \to D^0\gamma$, $D^0 \to K^+K^-$, $\pi^+\pi^-$

New

$D^{*0} \to D^0\gamma$, $D^0 \to K_S\pi 0$, $K_S\,\eta$





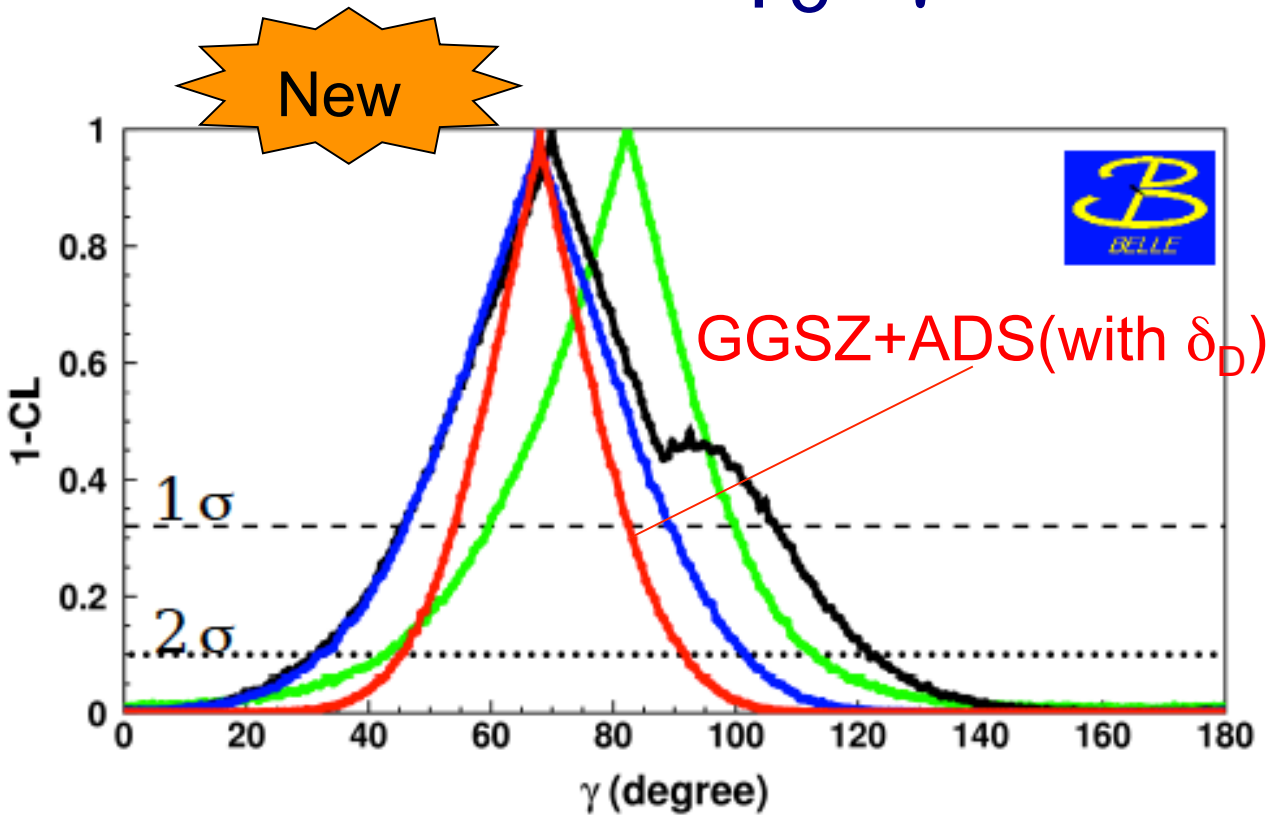
A_{CP-}=+0.28±0.23

A_{CP-}=+0.13±0.19

CP asymmetry central values still does not contradict expectation of sign flip by CP eigenvalue.

More detail : see Karim Trabelsi talk on Sunday afternoon.

Belle $\phi_3=\gamma$ constraint



GGSZ+ADS(with δ_D)+GLW

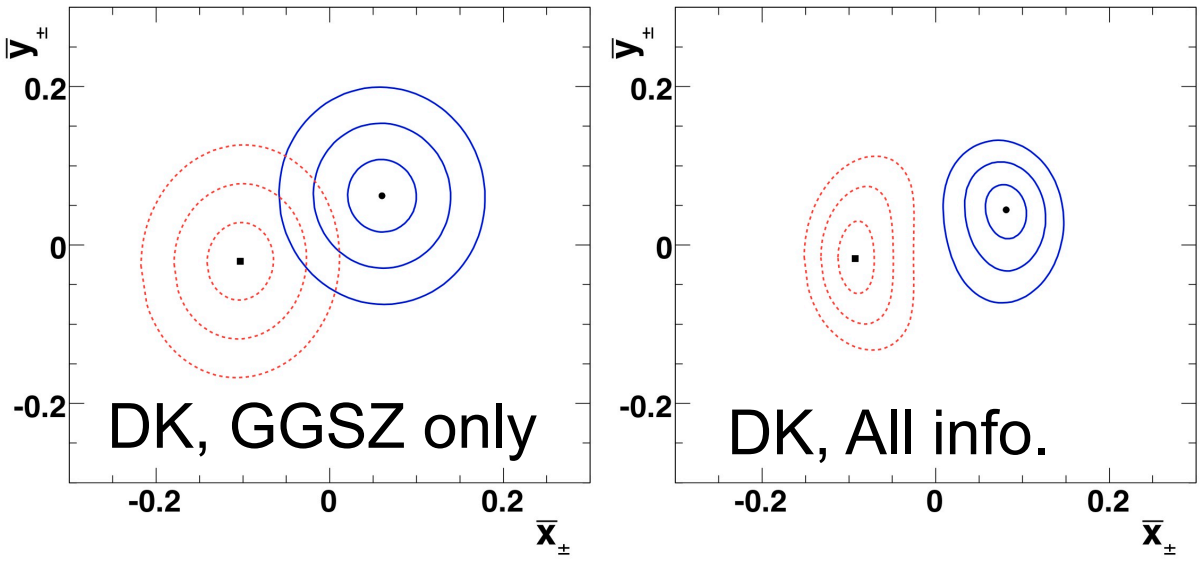
$\phi_3=\gamma=(68\ +15/-14)°$

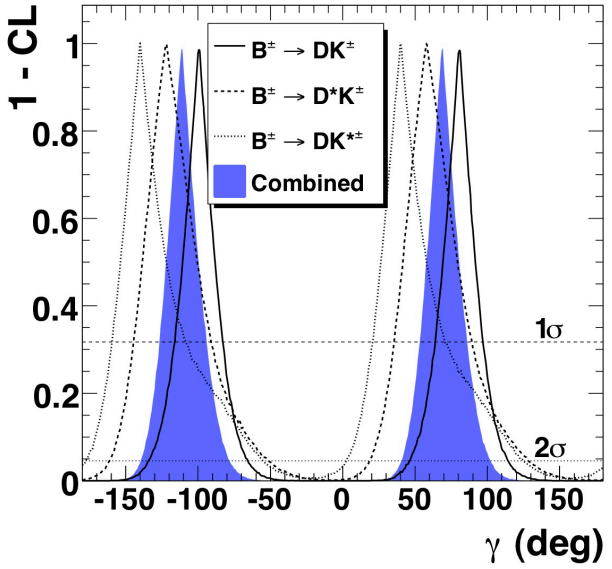
More detail : see Karim Trabelsi talk on Sunday afternoon.

New

BaBar $\phi_3=\gamma$ constraint

Translate ADS&GLW measurements into GGSZ-familiar cartesian variables, $x_{\pm i}=r_{Bi}\cos(\delta_{Bi}\pm\phi_3)$, $y_{\pm i}=r_{Bi}\sin(\delta_{Bi}\pm\phi_3)$, where i=DK, DK* and D*K.





$\phi_3=\gamma=(69\ +17/-16)°$

More detail : see Denis Derkach's talk on Sunday afternoon.

Summary

- $\sin 2\phi_1 = \sin 2\beta = 0.68 \pm 0.02$ in World Average.
  - It is a firm SM reference point.
- Constraint on $\phi_2 = \alpha$: (88.5 +4.4/-4.2)°
  - Belle new $B^0 \to \pi^+\pi^-$, $\rho^0\rho^0$ results shown.
  - BaBar new $B^0 \to (\rho\pi)^0$ result shown.
  - Still several not updated analyses from Belle : awaited.
- Belle and BaBar come up with each $\phi_3 = \gamma$ constraint.
  - Belle new $B \to D^{*0}$ K GLW results shown.
  - Belle : (68 +15/-14)°
  - BaBar : (69 +17/-16)°
- We see still relevant CPV measurements are active at B-factories.