B Factory Results

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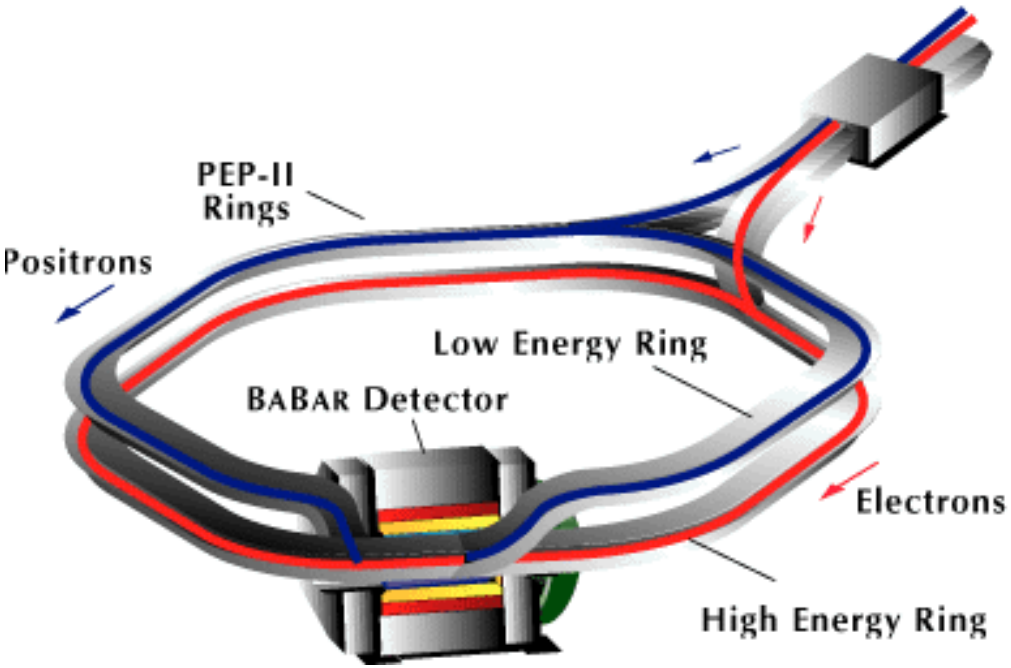
Contents

- The B factories
- B factory physics
- Results
  - Unitarity Triangle angles measured in various ways
  - Rare B decays
  - Other interesting recent highlights
- Summary

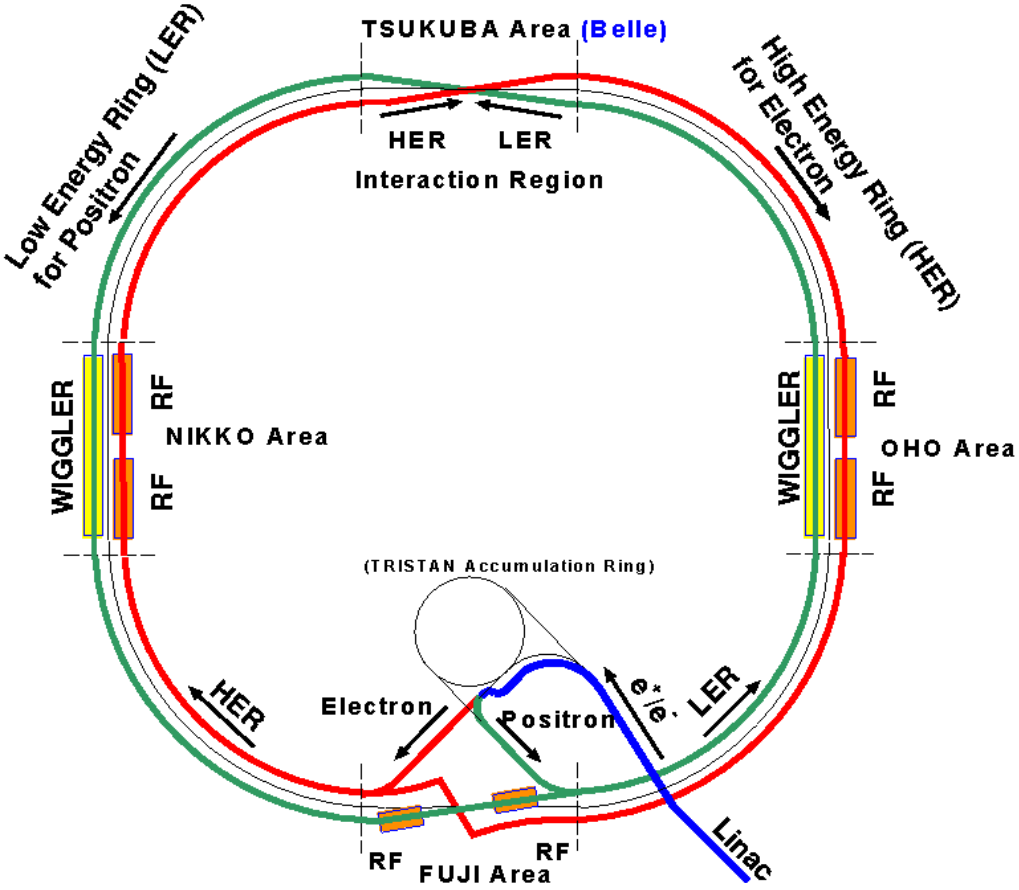
NB. All results are preliminary unless published reference given

The Asymmetric B Factories

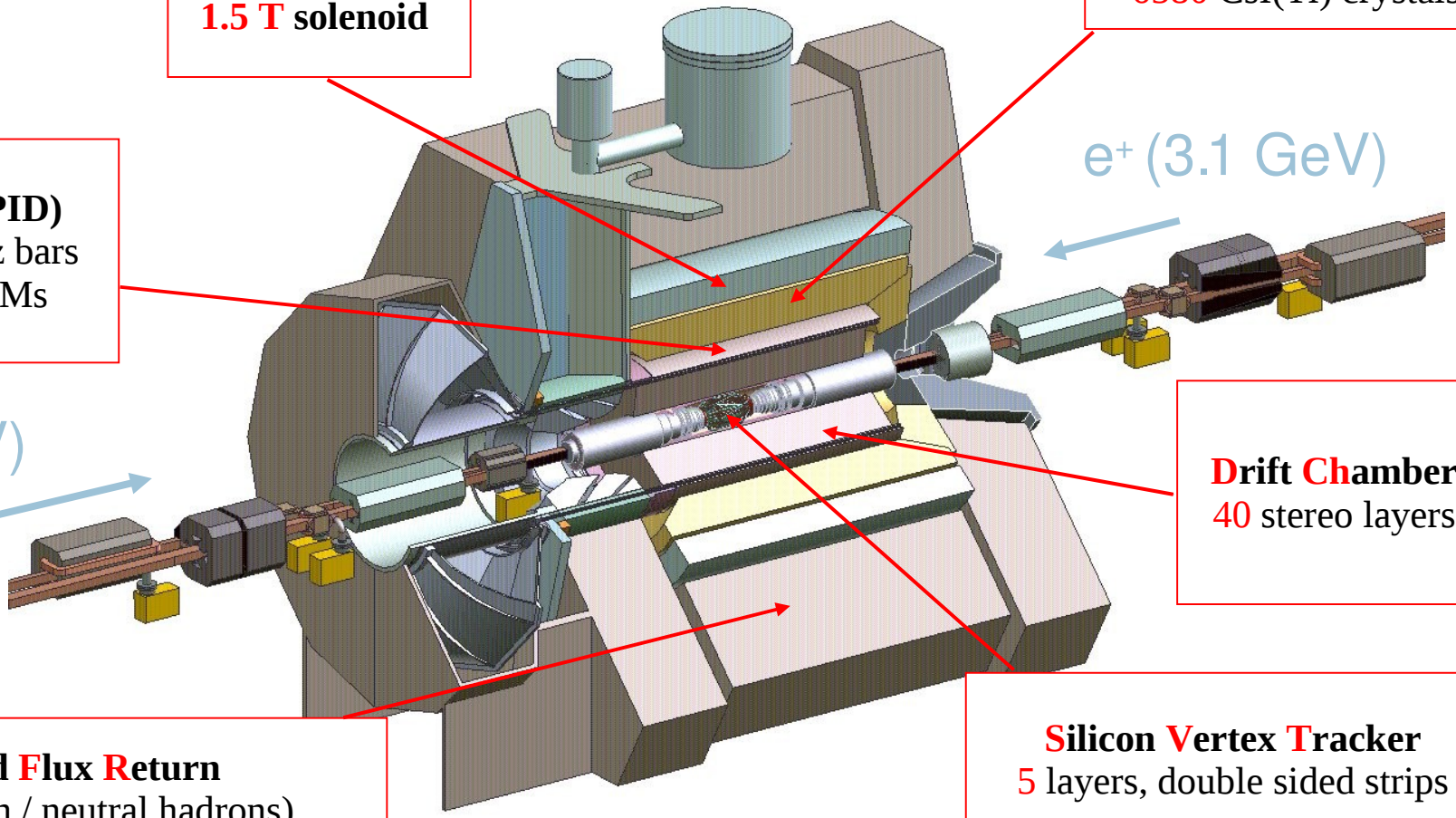
PEPII at SLAC
9.0 GeV e^- on 3.1 GeV e^+



KEKB at KEK
8.0 GeV e^- on 3.5 GeV e^+



BABAR Detector



1.5 T solenoid

EMC
6580 CsI(Tl) crystals

DIRC (PID)
144 quartz bars
11000 PMs

e^+ (3.1 GeV)

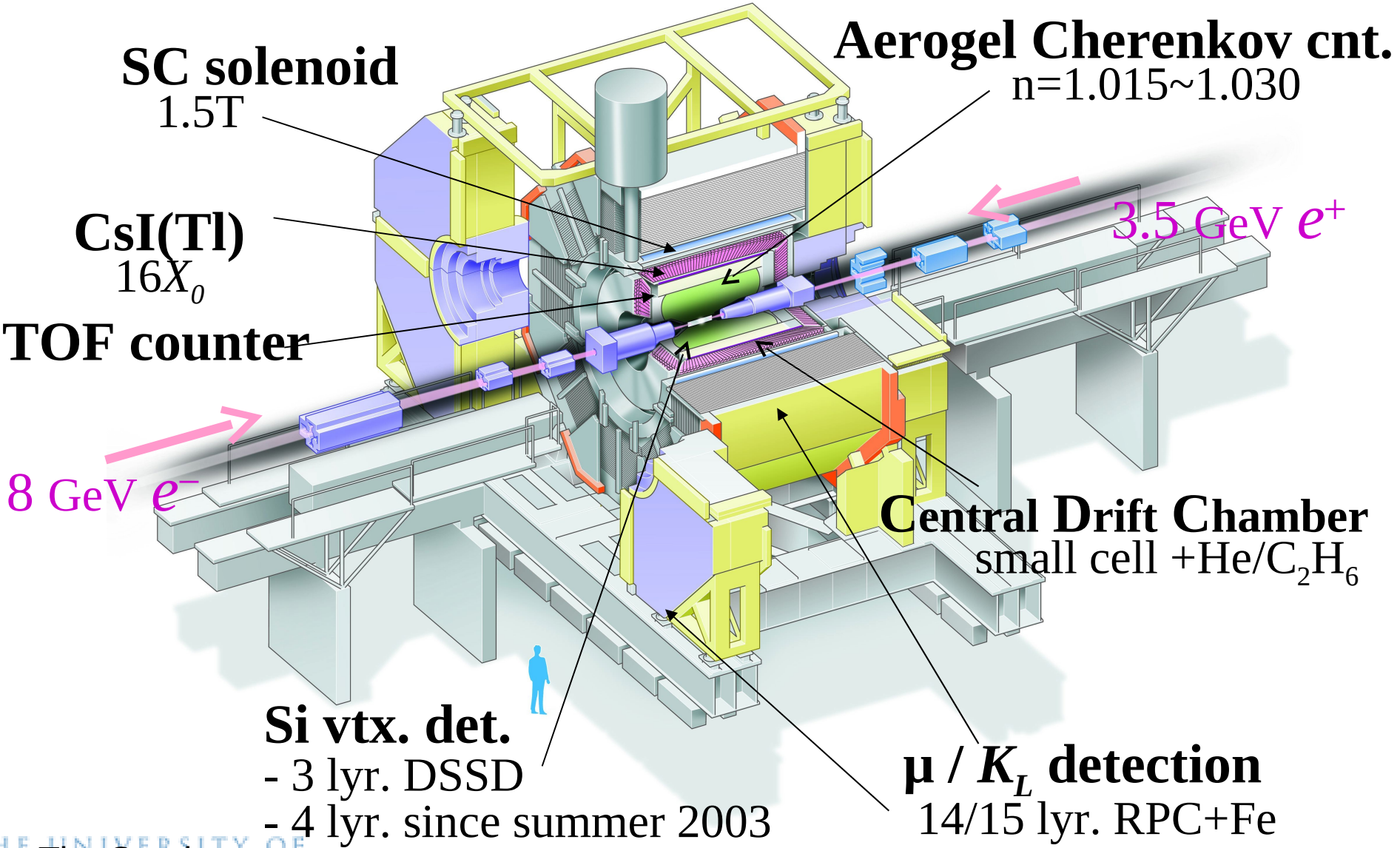
e^- (9 GeV)

Drift Chamber
40 stereo layers

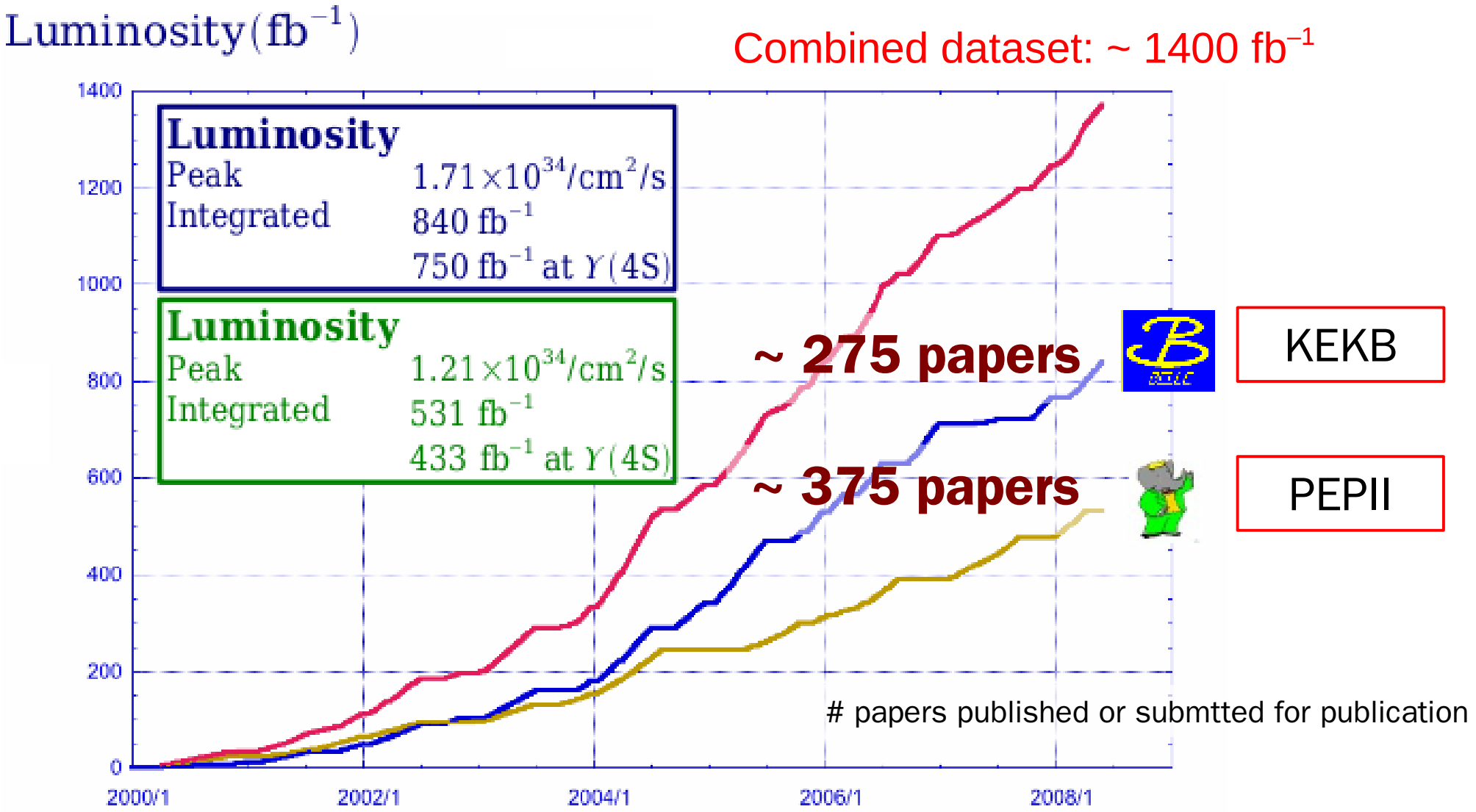
Silicon Vertex Tracker
5 layers, double sided strips

Instrumented Flux Return
iron / RPCs (muon / neutral hadrons)
2/6 replaced by LST in 2004
Rest of replacement in 2006

Belle Detector



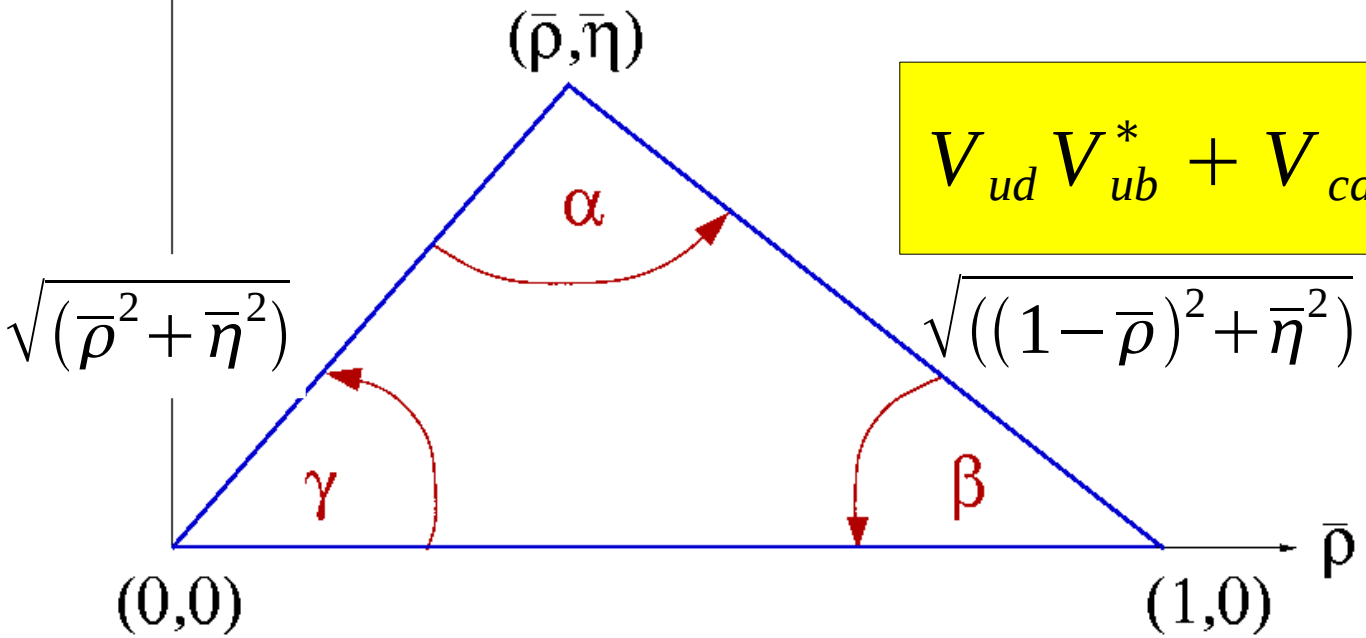
B factories – World Record Luminosities



The Cabibbo-Kobayashi-Maskawa Matrix & The Unitarity Triangle

Quark couplings to W boson described by 3x3 unitary matrix (4 free parameters, inc. 1 phase)

$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$



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

$$\alpha \equiv \phi_2 = \arg\left[-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right], \quad \beta \equiv \phi_1 = \arg\left[-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right], \quad \gamma \equiv \phi_3 = \arg\left[-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right]$$

B Factory Physics Programme

- Test the Standard Model mechanism for flavour changing quark interactions
  - Multiple measurements of sides and angles of the Unitarity Triangle
  - Studies of rare decays
- Exploit huge data samples to probe several complementary sectors
  - charm, tau, Upsilon, spectroscopy, ...

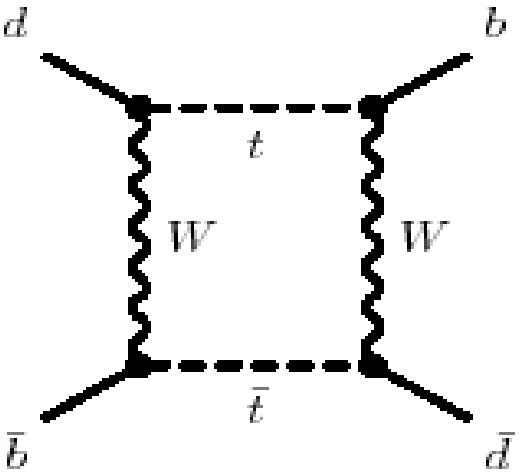
Measurement of sin(2β)

Carter & Sanda, PRD23 (1981) 1567; Bigi & Sanda, NP193 (1981) 85

- Sensitivity to CP violation between B^0 decays to $J/\psi\, K^0$ with and without mixing
  - B^0–$\bar{B}^0$ mixing phase:

$$arg\left(\frac{V_{td}^{*}V_{tb}}{V_{td}V_{tb}^{*}}\right) = -2\beta$$

(usual phase convention)



- Exploit quantum correlations in $\Upsilon(4S) \rightarrow B^0\bar{B}^0$
  - Energy asymmetry + vertexing ⇒ precise Δt measurement
  - Lepton & hadron identification ⇒ performant flavour tagging

$$\Gamma_{B\to J/\psi K^0}(\Delta t) \propto e^{-|\Delta t|/\tau_B}\left(1 \pm (S\sin(\Delta m \Delta t) - C\cos(\Delta m \Delta t))\right)$$

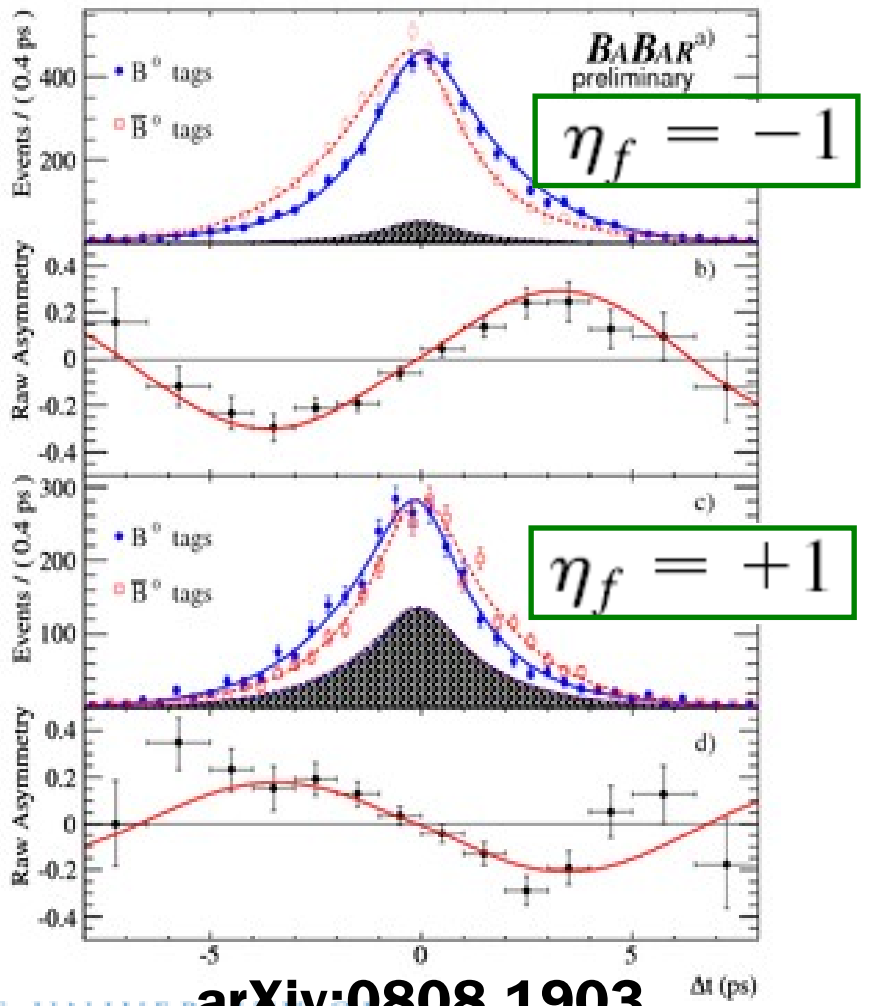
$+ : \text{tag}\, B = B^0$

$- : \text{tag}\, B = \bar{B}^0$

$$\text{Standard Model} : S = -\eta\sin(2\beta) \quad C = 0$$

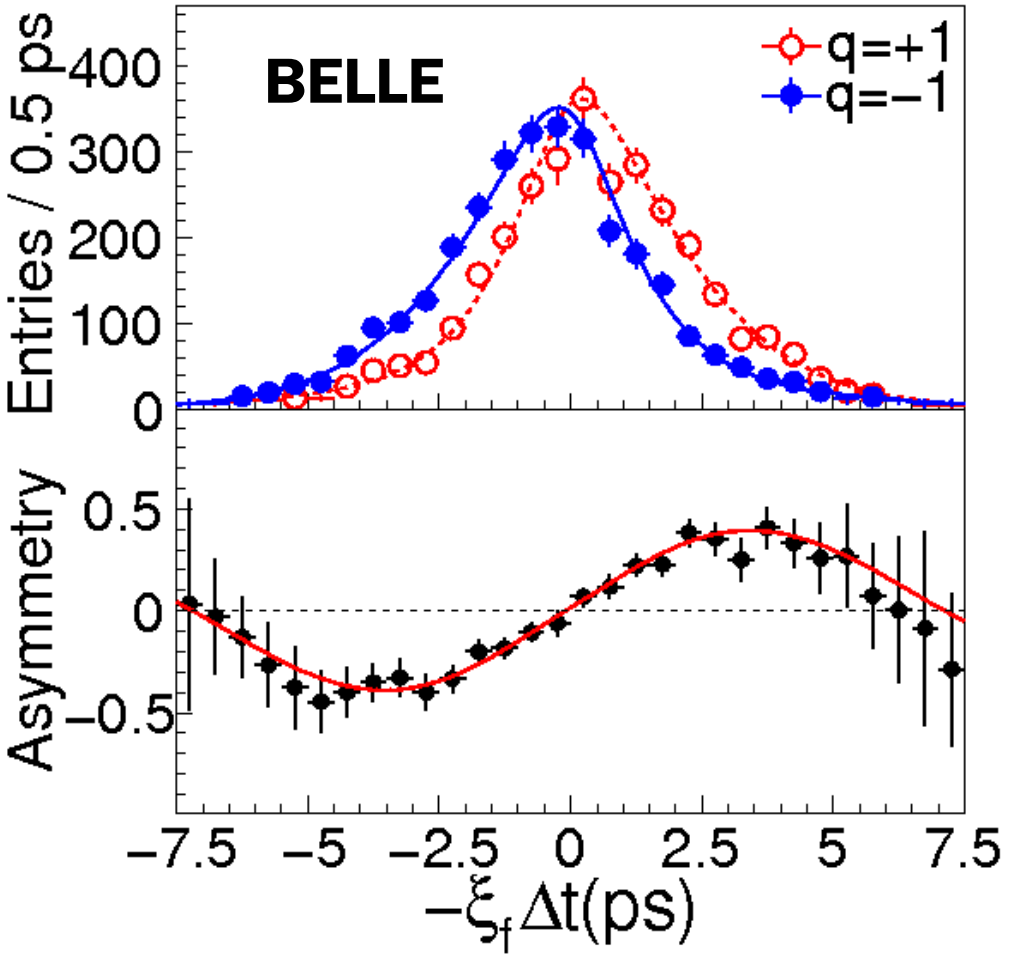
Results for the Golden Mode

$\sin(2\beta) = 0.691 \pm 0.029 \pm 0.014$



arXiv:0808.1903

$\sin(2\varphi_1) = 0.642 \pm 0.031 \pm 0.017$

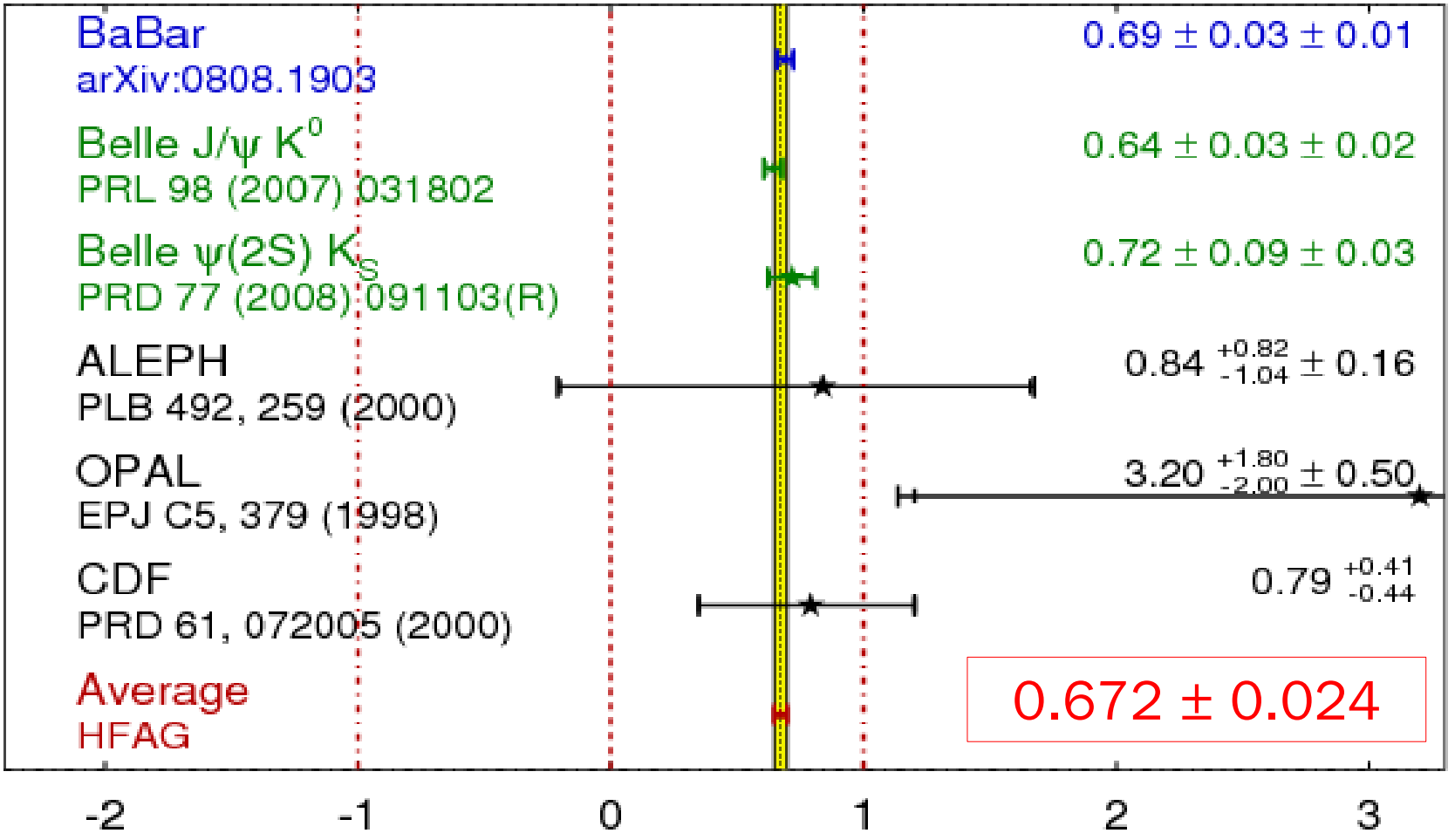


PRL 98 (2007) 031802

Compilation of Results

$$\sin(2\beta) \equiv \sin(2\phi_1)$$

HFAG
ICHEP 2008
PRELIMINARY

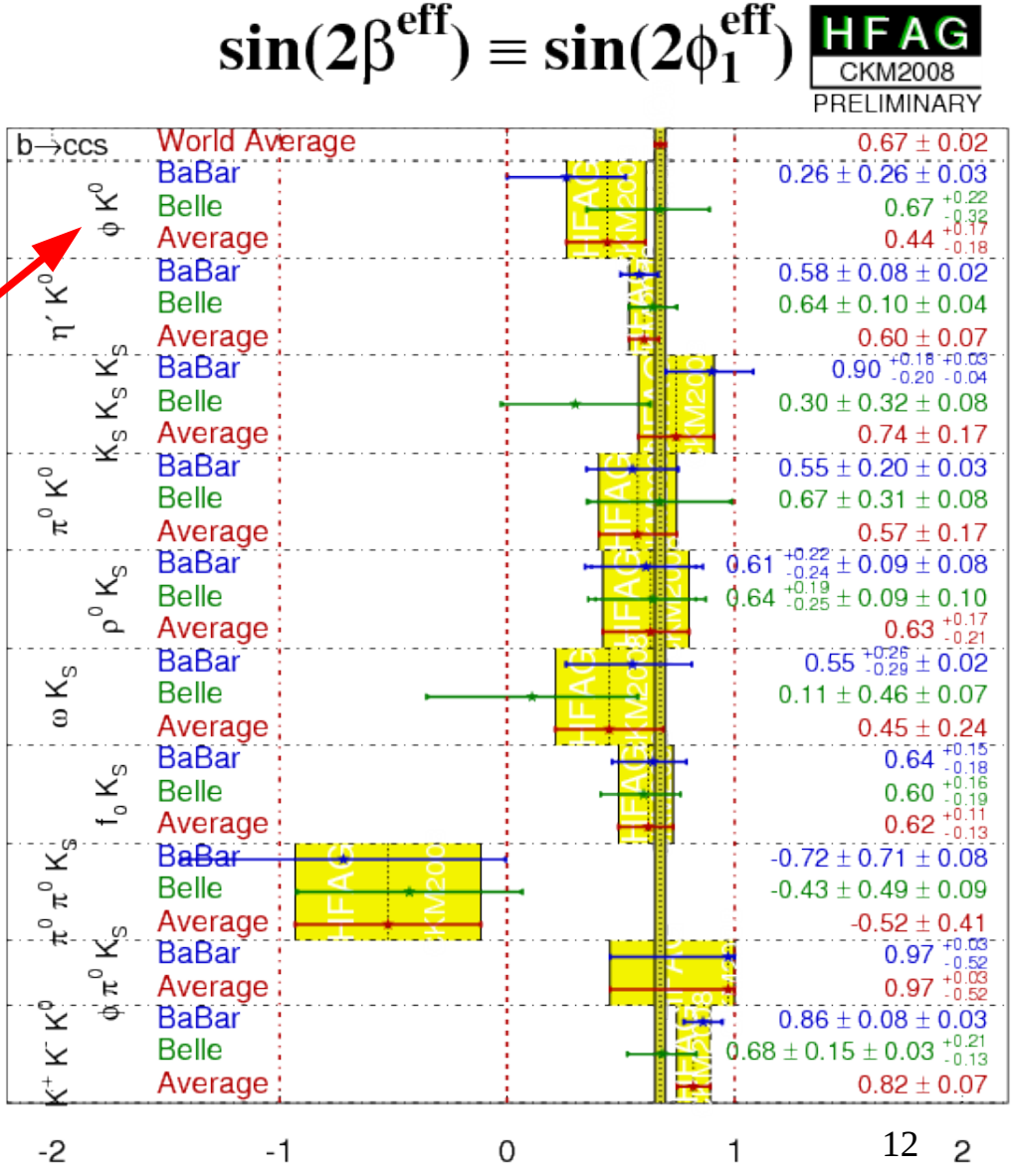


Measurement of sin(2β) Alternative Methods

- Decays mediated by several different quark-level transitions probe 2β
  - $b \to c\bar{c}s$ (eg. J/ψ K_S)
  - $b \to c\bar{c}d$ (eg. J/ψ π^0)
  - $b \to c\bar{u}d$ (eg. D_{CP} π^0)
  - $b \to q\bar{q}s$ (eg. φ K_S)
- Consistency of measurements tests the Standard Model
- Today's situation :

  no smoking gun

NB. Dalitz plot analyses for $\pi^+\pi^-K_S$ and $K^+K^-K_S$

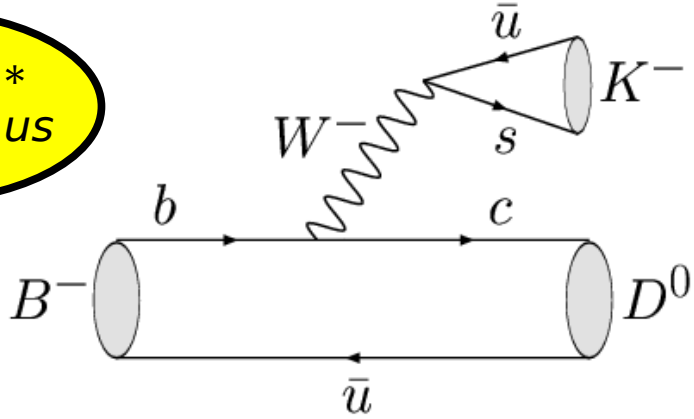


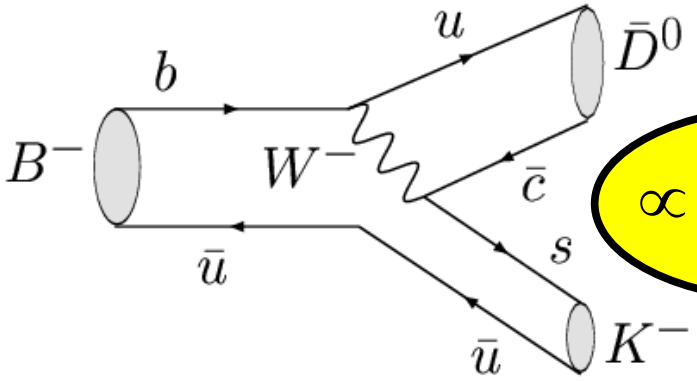
Measurement of γ

Gronau & Wyler, PLB 253 (1991) 483; Gronau & London, PLB 265 (1991) 172;
Atwood, Dunietz & Soni, PRL 78 (1997) 3257

- Exploit interference between

$\propto V_{cb}V_{us}^*$





$\propto V_{ub}V_{cs}^*$

- colour allowed
- final state contains D^0

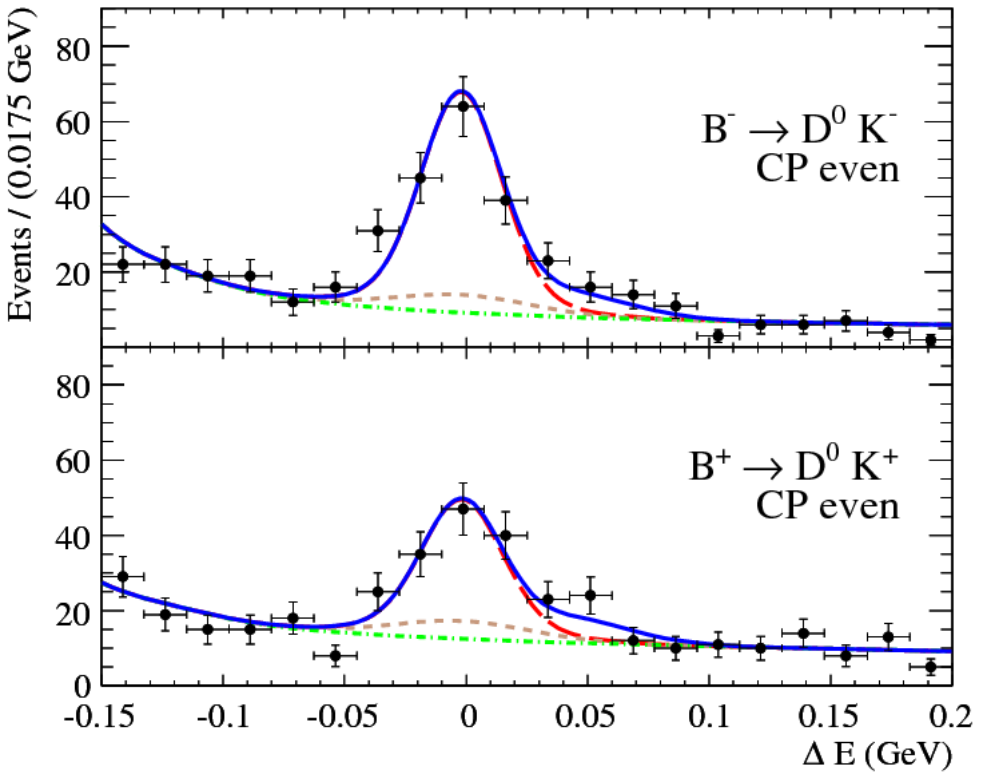
- colour suppressed
- final state contains $\overline{D}^0$

Relative magnitude of suppressed amplitude is r_B

Relative weak phase is $-\gamma$, relative strong phase is δ_B

$B \to D^{(*)}K^{(*)}$ with $D \to$ CP Eigenstates

BABAR PRD 77 (2008) 111102

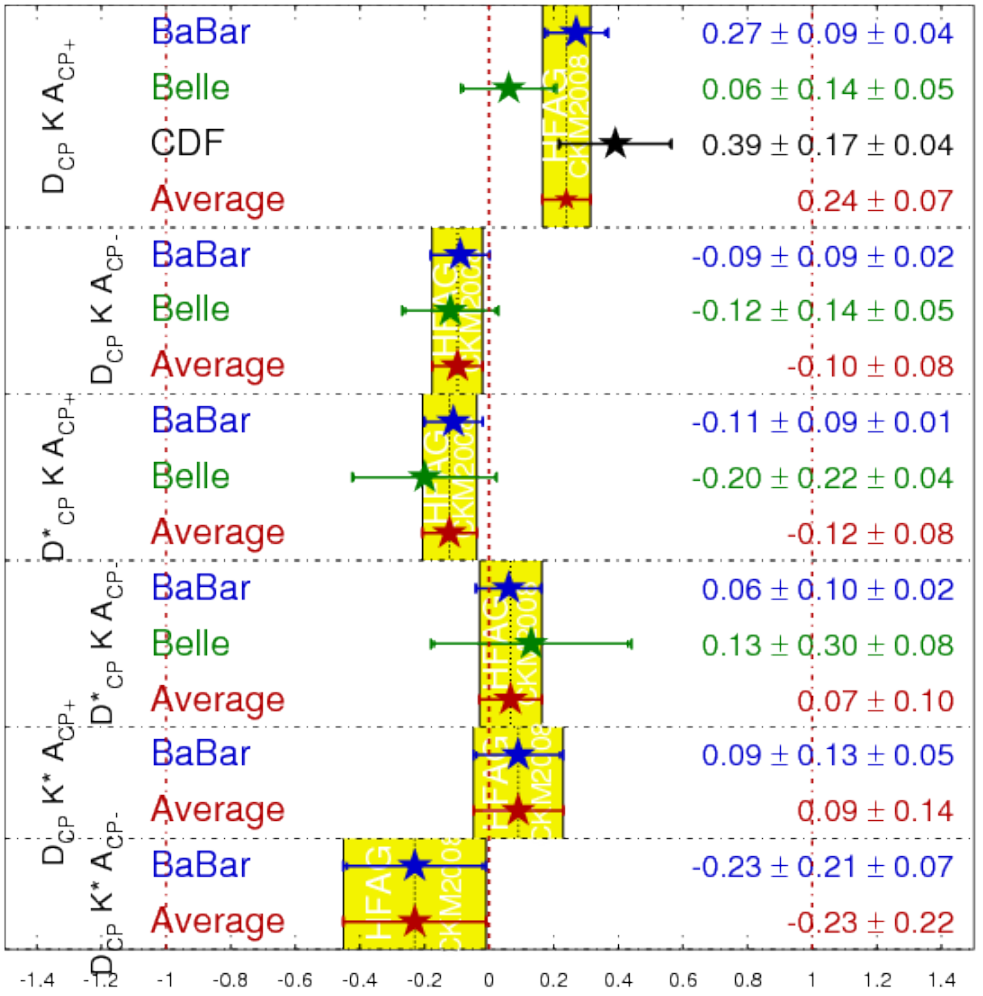


$A_{CP} = 0.27 \pm 0.09 \pm 0.04$

NB. Direct CP violation @ 2.8σ

A_{CP} Averages

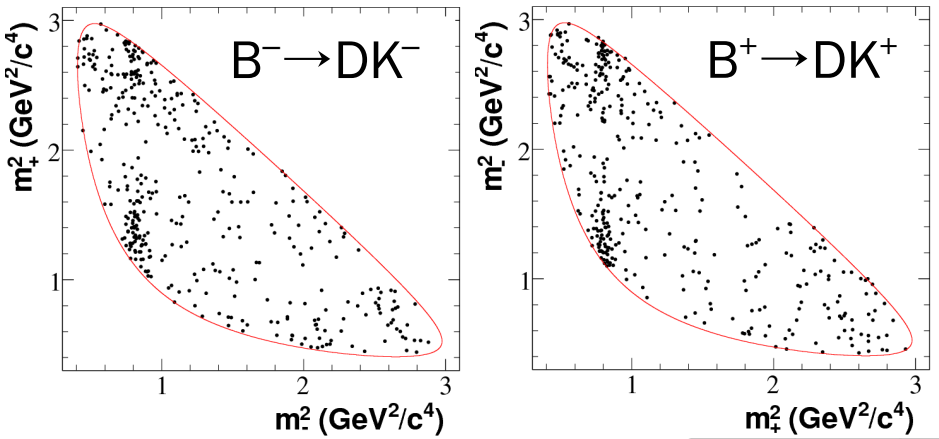
HFAG CKM2008 PRELIMINARY



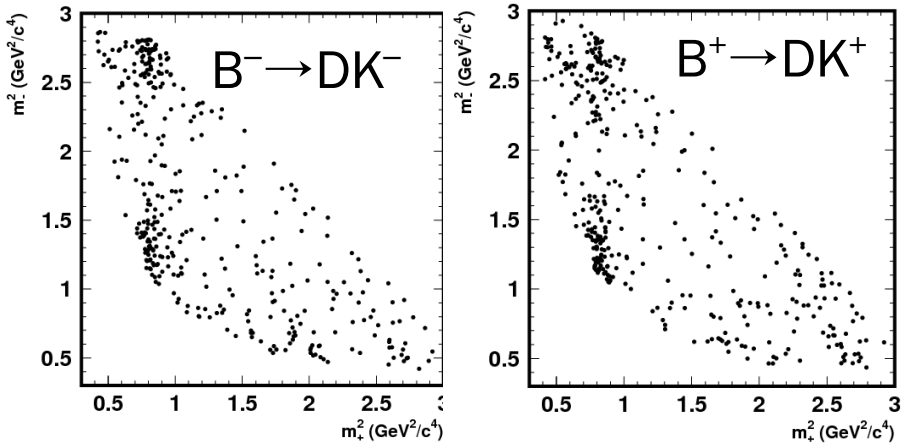
$B \to D^{(*)}K^{(*)}$ with $D \to K_S\pi^+\pi^-$ Dalitz Plot Analysis

Giri, Grossman, Soffer & Zupan, PRD 68 (2003) 054018 & Belle

BABAR PRD 78 (2008) 034023

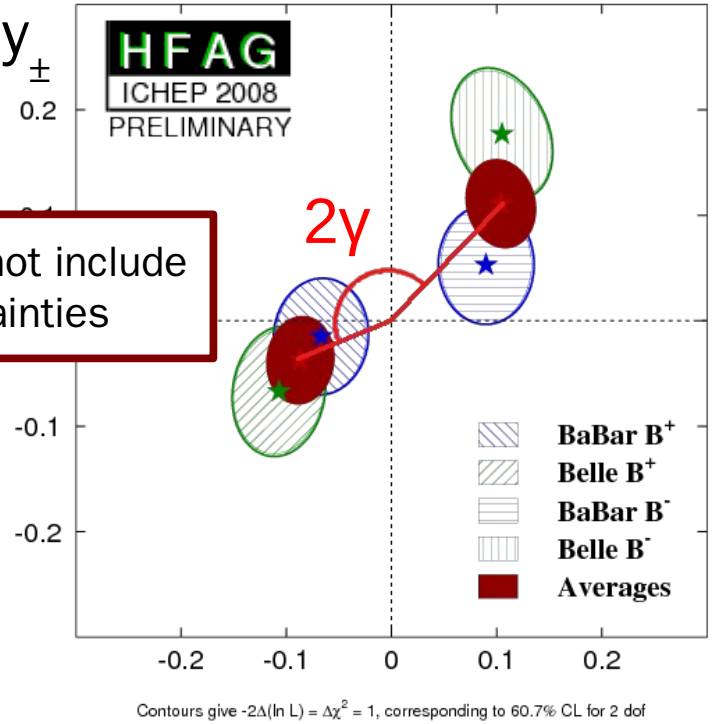


Belle arXiv:0803.3375



$\gamma = (76 \pm 22 \pm 5 \pm 5)°$

$\varphi_3 = (76\ ^{+12}_{-13} \pm 4 \pm 9)°$



NB. Contours do not include model uncertainties

Constraints on γ from combination of DK, D*K & DK* results using frequentist procedures

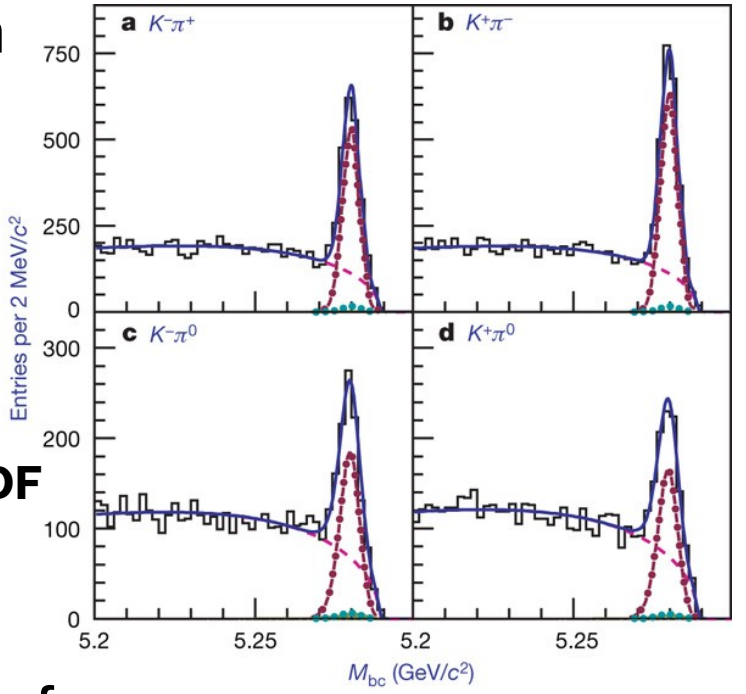
$$x_\pm = r_B \cos(\delta_B \pm \gamma)$$
$$y_\pm = r_B \sin(\delta_B \pm \gamma)$$

Measurement of γ Alternative Methods

- Direct CP violation in $B \to K\pi$ sensitive to γ
  - too many hadronic parameters ⇒ need theory input (or much better data on $B \to K_S\pi^0$)

NB. interesting deviation from naïve expectation

Belle Nature 452 (2008) 332



$$A_{CP}(K^-\pi^+) = (-9.8^{+1.2}_{-1.1})\% \quad A_{CP}(K^-\pi^0) = (5.0 \pm 2.5)\%$$
$$\Delta(A_{CP}) = (-14.8 \pm 2.8)\%$$

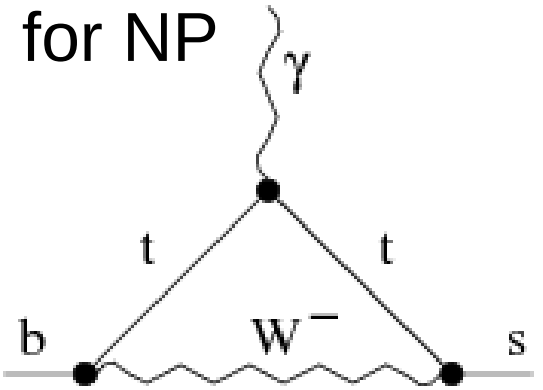
HFAG averages

BABAR PRD 76 (2007) 091102 & arXiv:0807.4226; also **CDF**

- Dalitz plot analyses of $B \to K\pi\pi$ provide extra information ⇒ can solve for γ

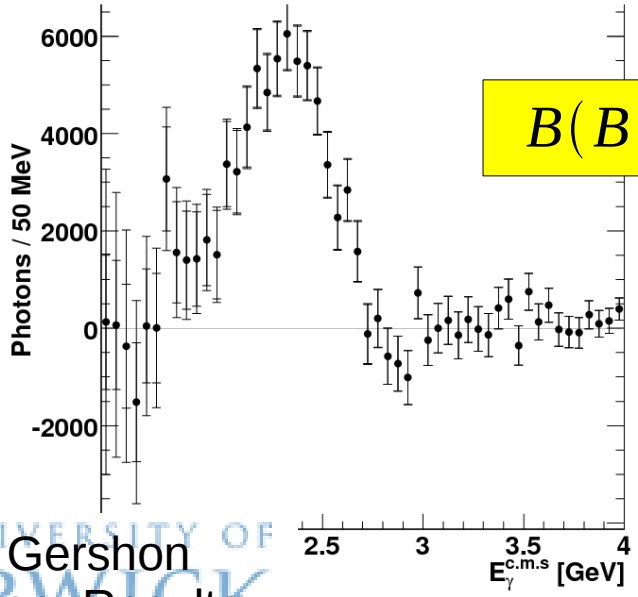
Rare Decays – $b \to s\gamma$

- $b \to s\gamma$ is prototype flavour-changing neutral current
  - rate & asymmetries highly constraining for NP
  - Recent NNLO calculations



Misiak et al. PRL 98 (2007) 022002; Becher & Neubert, PRL 98 (2007) 022003; Andersen & Gardi, JHEP 0701 (2007) 029

Belle arXiv:0804.1580



Fully inclusive rate measurement

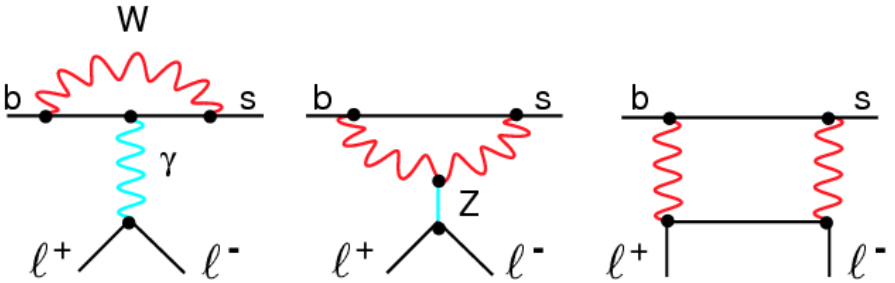
$$B(B \to X_s \gamma)_{E_\gamma > 1.8\ GeV} = (3.24 \pm 0.17 \pm 0.24 \pm 0.01) \times 10^{-4}$$

Consistent with SM expectation

Other measurements:

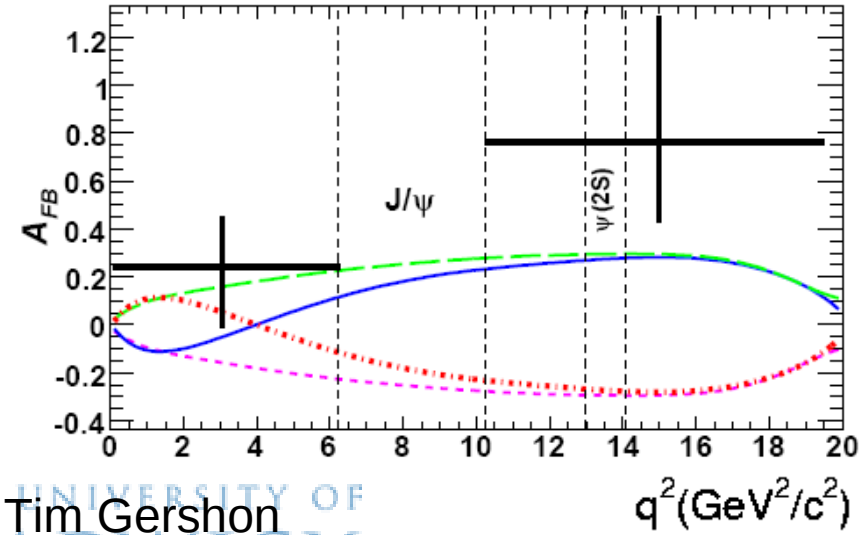
- **BABAR PRL 97 (2006) 171803**
- **BABAR PRD 72 (2005) 052004**

Rare Decays – $B \to K^* l^+ l^-$

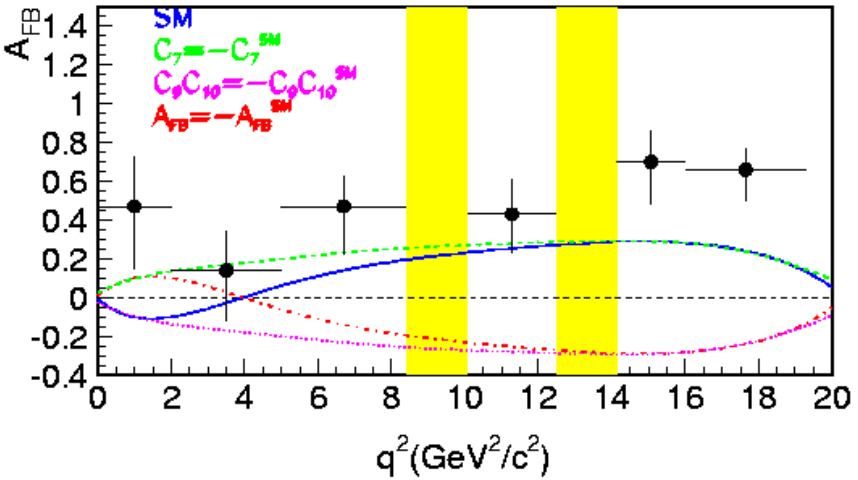


- Interference between contributing amplitudes
  - interesting distributions, eg. forward-backward asymmetry

BABAR arXiv:0804.4412



Belle ICHEP 2008

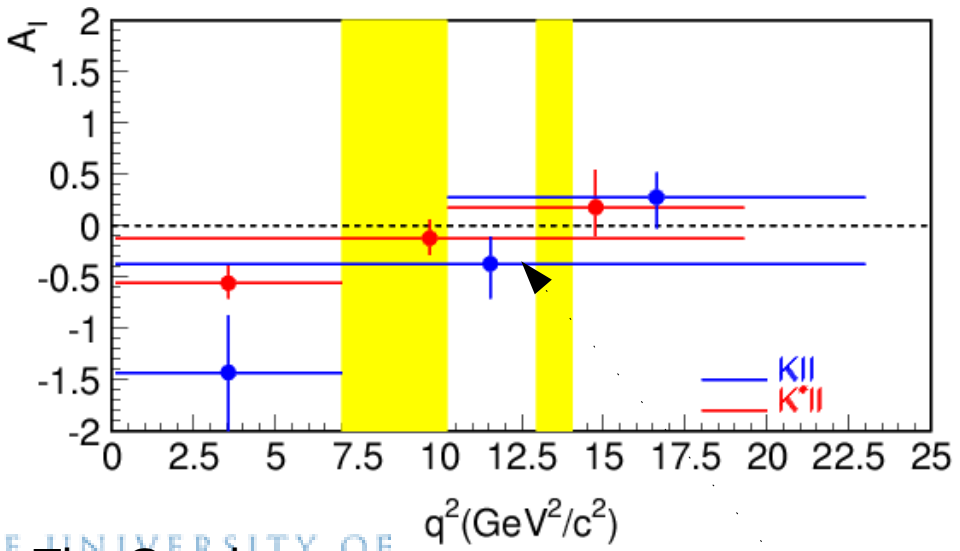


$B \to K^* l^+ l^-$ Isospin Asymmetry

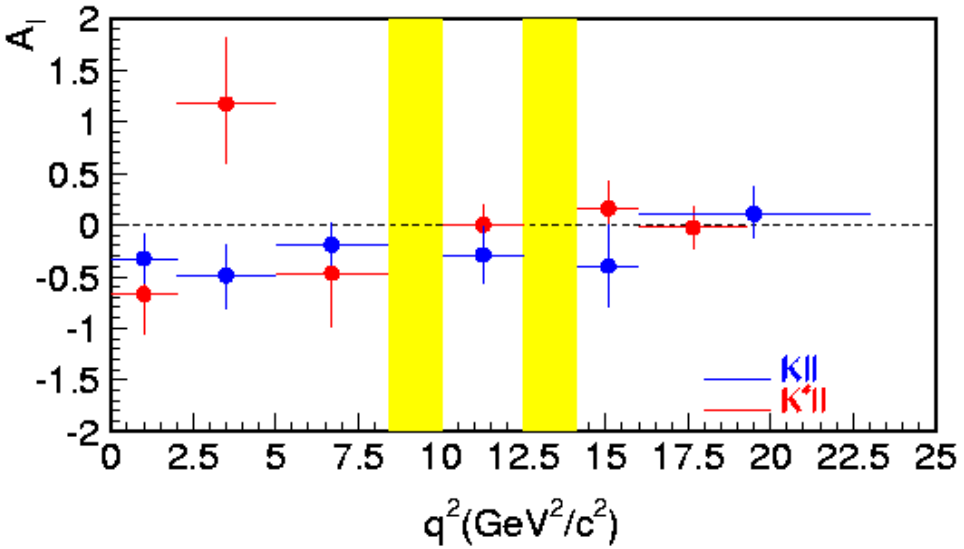
Feldmann & Matias, JHEP 0301 (2003) 074

- Another tantalizing possible hint ...
  - not expected to be significant in the SM
  - no effect seen in $B \to K^* \gamma$
    - (**BABAR arXiv:0808.1915; Belle PRD 69 (2004) 112001**)

BABAR arXiv:0807.4119



Belle ICHEP 2008

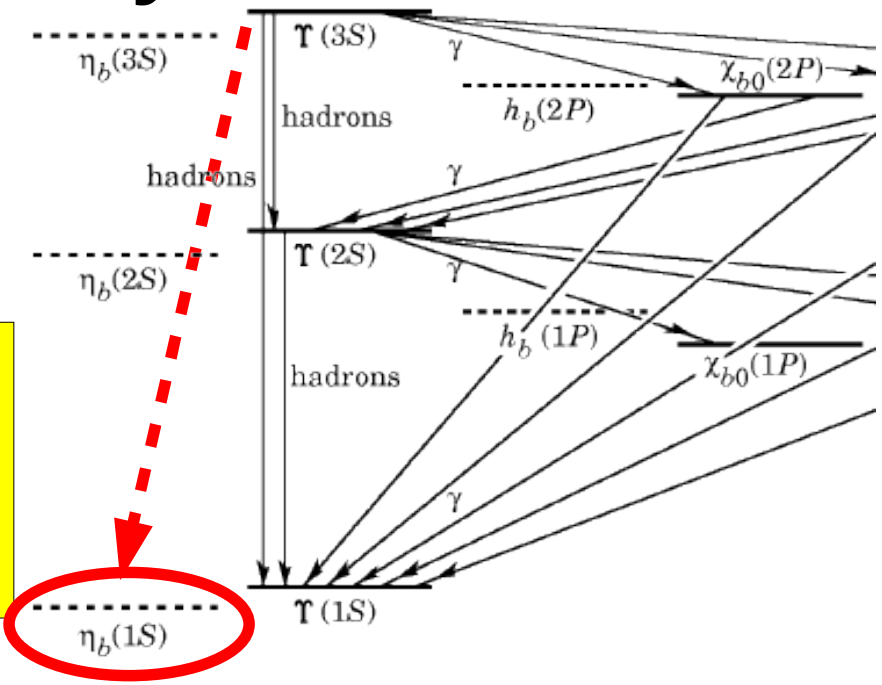


NB. Central points are average over whole q^2 range

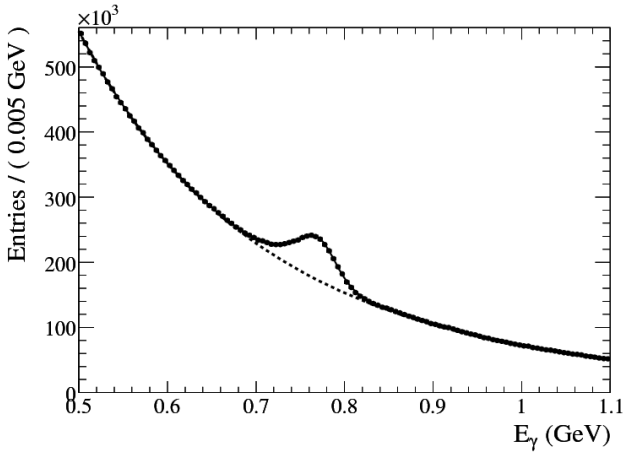
η_b Discovery

- Search for $\Upsilon(3S) \to \gamma\eta_b$
- Reconstruct only γ

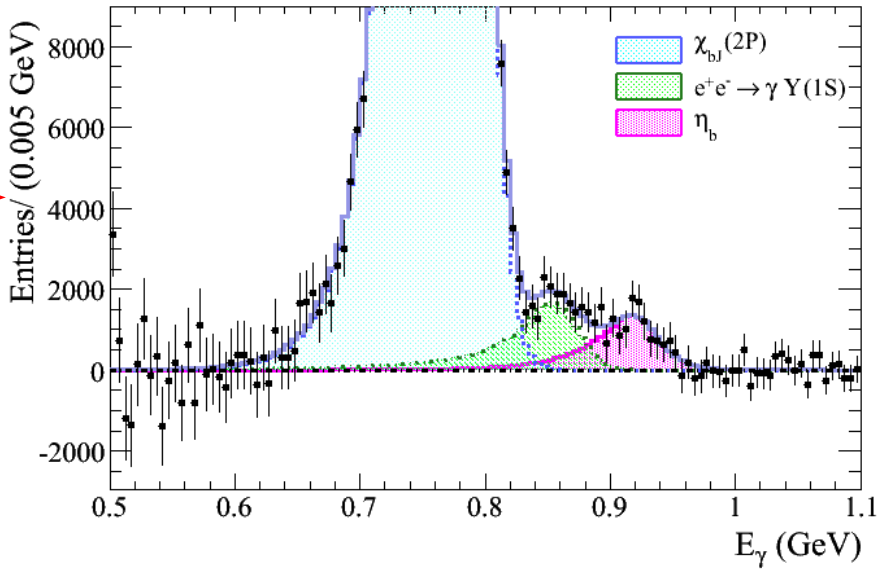
$$m(\eta_b(1S)) = (9388.9\,^{+3.1}_{-2.3} \pm 2.7)\,\mathrm{MeV}/c^2$$
$$m(\Upsilon(1S)) - m(\eta_b(1S)) = (71.4\,^{+2.3}_{-3.1} \pm 2.7)\,\mathrm{MeV}/c^2$$
$$B(\Upsilon(3S) \to \gamma\eta_b(1S)) = (4.8 \pm 0.5 \pm 1.2) \times 10^{-4}$$



BABAR PRL 101 (2008) 071801



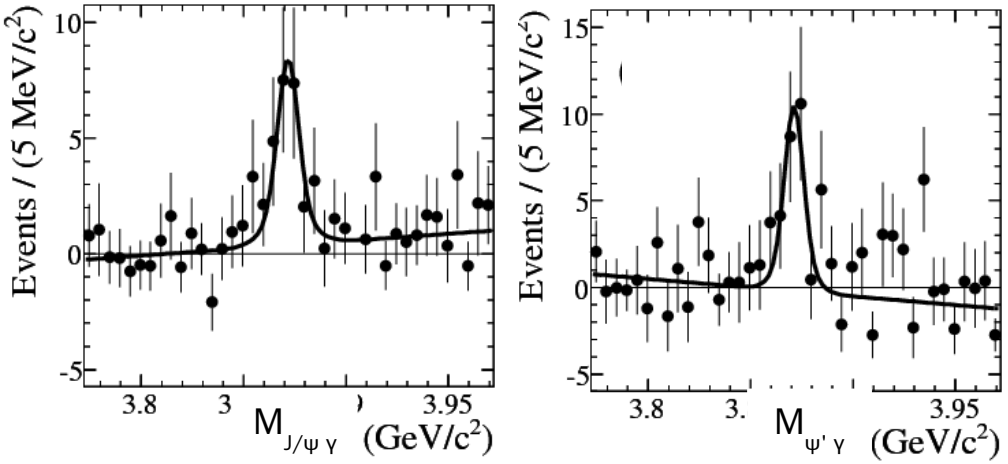
subtract smoothly varying background



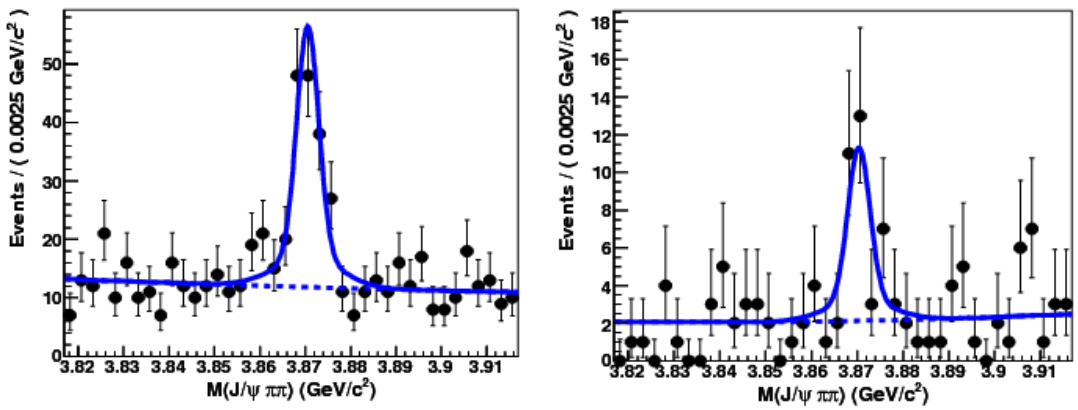
New & unconventional particles

- B factories have developed a remarkable sideline in discoveries of unexpected particles
- Example: X(3872) (likely $J^{PC} = 1^{++}$ – $D^0\bar{D}^{*0}$ molecule?)

BABAR arXiv: 0809.0042



Belle arXiv:0809.1224



$$B^+ \to X K^+ \qquad X \to J/\psi\,\gamma \qquad X \to \psi(2S)\,\gamma$$

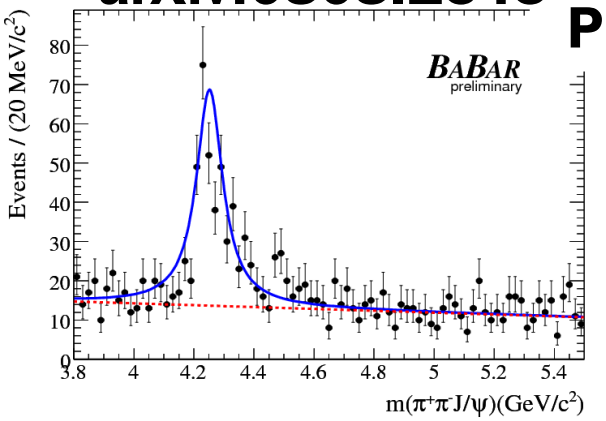
$$B^+ \to X K^+ \qquad B^0 \to X K_S \qquad X \to J/\psi\,\pi^+\pi^-$$

Also seen in DDπ⁰ & DDγ: **BABAR PRD 77 (2008) 011102** **Belle PRL 97 (2006) 162002**

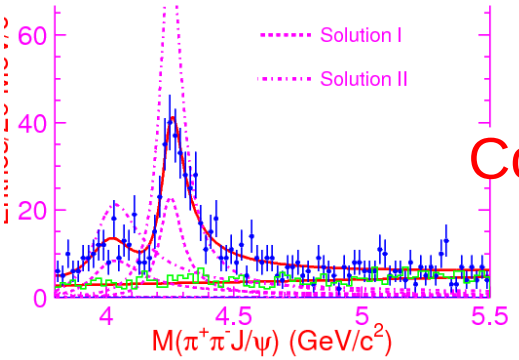
More new & unconventional particles

Y(4260) in J/ψππ ISR production

arXiv:0808.1543

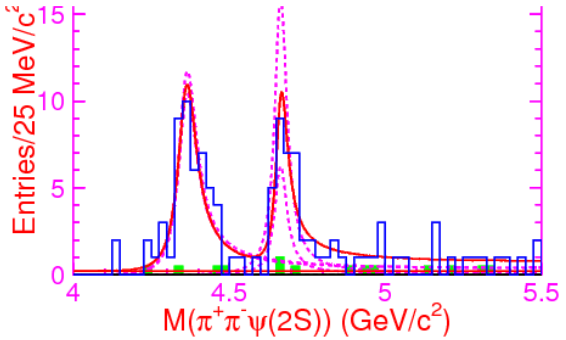


Belle
PRL 99 (2007) 182004



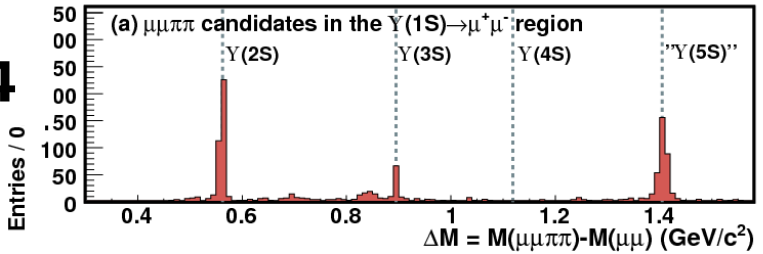
ψ'ππ ISR production

Belle PRL 99 (2007) 142002



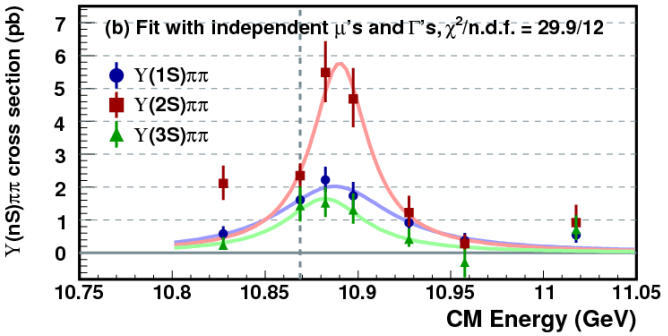
Excess of "Y(5S)" → Yππ

Belle PRL.100 (2008) 112001

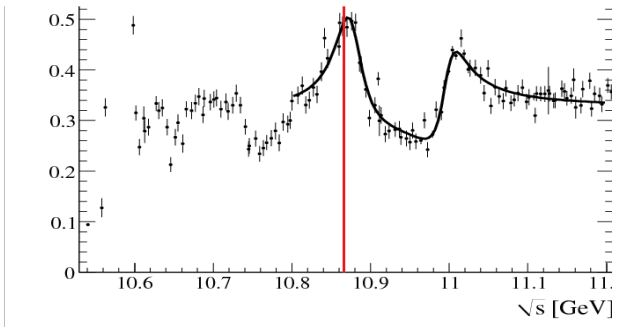


Compare lineshape to nominal Y(5S)

Belle arXiv:0808.2445



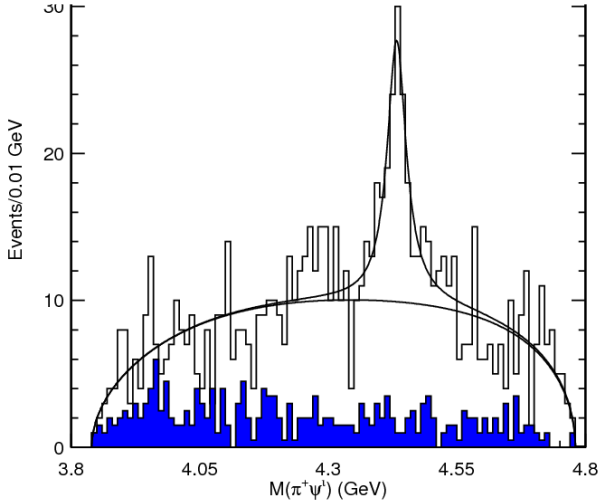
Compare R scan **BABAR arXiv:0809.4120**



Charged charmonium-like particles

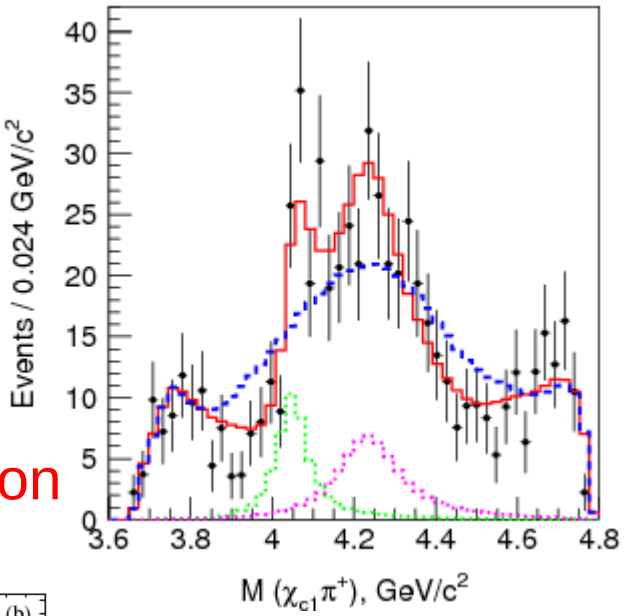
$B^0 \to Z(4430)^- K^+$, $Z(4430)^- \to \psi' \pi^-$

Belle PRL 100 (2008) 142001



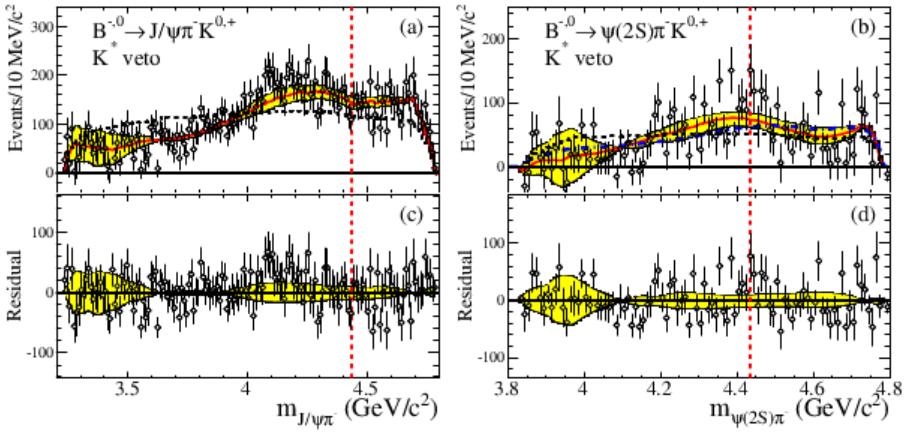
$B^0 \to Z^- K^+$, $Z^- \to \chi_{c1} \pi^-$

Belle arXiv:0806.4098



BABAR data consistent with (Kπ) reflection

BABAR-PUB-08/045

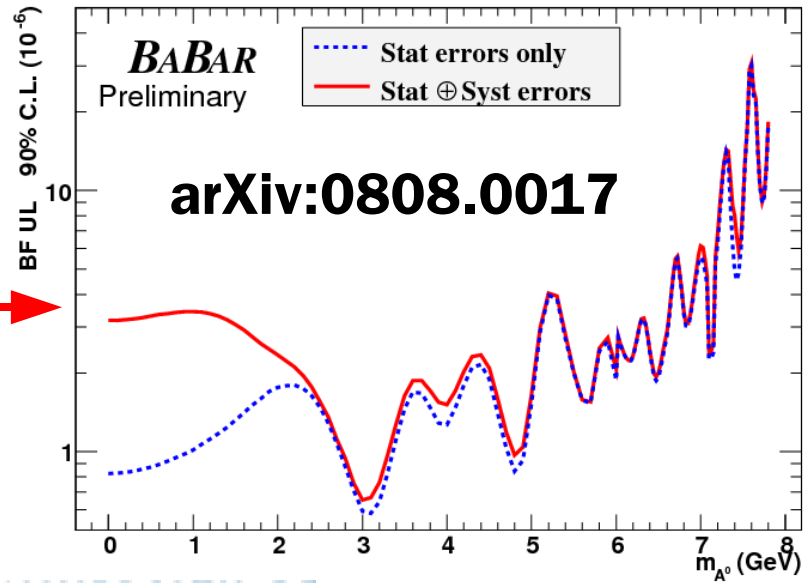


Searches for light Higgs & dark matter

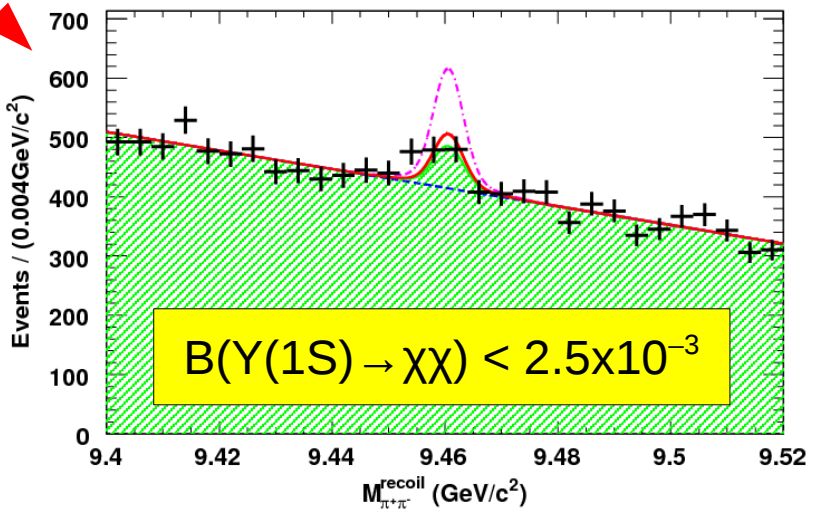
- Y(3S) data can be used to search for exotics
  - $Y(3S) \to \gamma A^0$, $A^0 \to$ invisible
    - A^0 is a light scalar (CP-odd Higgs in NMSSM)
  - $Y(3S) \to \pi^+\pi^- Y(1S)$, $Y(1S) \to$ invisible

Wilczek, PRL 39 (1977) 1304;
Dermisek, Gunion & McElrath PRD 76 (2007) 051105

McElrath PRD 72 (2005) 103508



Belle PRL 98 (2007) 132001



Also **CLEO arXiv:0807.1427**

Summary

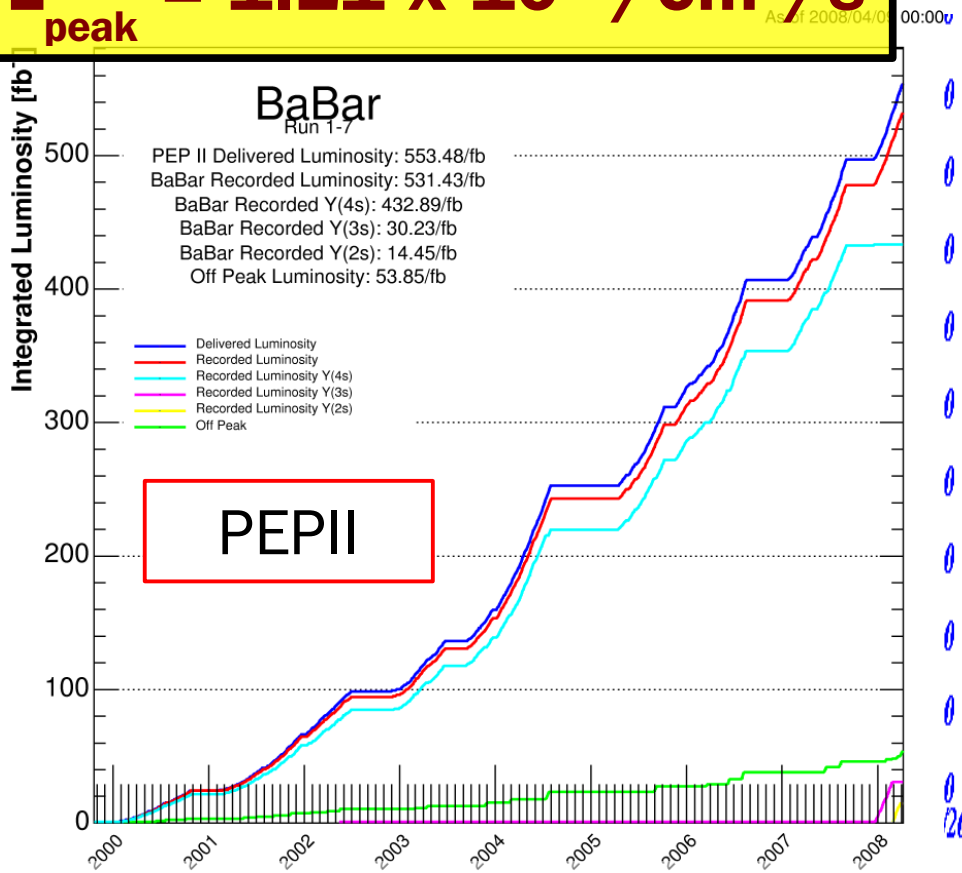
- B factories continuing to produce a wealth of results in a wide range of topics
- No smoking gun for new physics **BUT**
  - several interesting hints
  - strong constraints for model builders
  - powerful motivation for better measurements
    - LHCb & Super Flavour Factory
- Expect more (including more surprises) from the B factories as final data sets are analyzed

Some of the things I didn't have time to talk about

- Measurements of time-dependent CP violation in
  - $J/\psi\,\pi^0$, $D^{(*)+}D^{(*)-}$, $D\pi^0$, K_SK_S and more
- Measurements of the Unitarity Triangle angle α
- Measurement of γ from $B \to K\pi\pi$ Dalitz plots
- Measurements of $|V_{ub}|$ and $|V_{cb}|$
  - Inclusive and exclusive $b \to u l\nu$ and $b \to c l\nu$ processes
  - Alternative measurements using $B \to l\nu$ (evidence for $B \to \tau\nu$)
- Studies of photon polarization in $b \to s\gamma$
- Measurements of $b \to d\gamma$ dominated processes
- Searches for $b \to s\nu\bar{\nu}$
- Evidence for charm mixing
- Studies of (and discoveries of) charmed baryons
- Searches for lepton flavour violating tau decays
- Fundamental tests, eg. CPT, lepton universality
- Precise measurement of $|V_{us}|$ from tau decays
- Low energy spectroscopy: $e^+e^- \to \pi\pi$, KK, ρρ, $p\bar{p}$, ...

B factories – World Record Luminosities

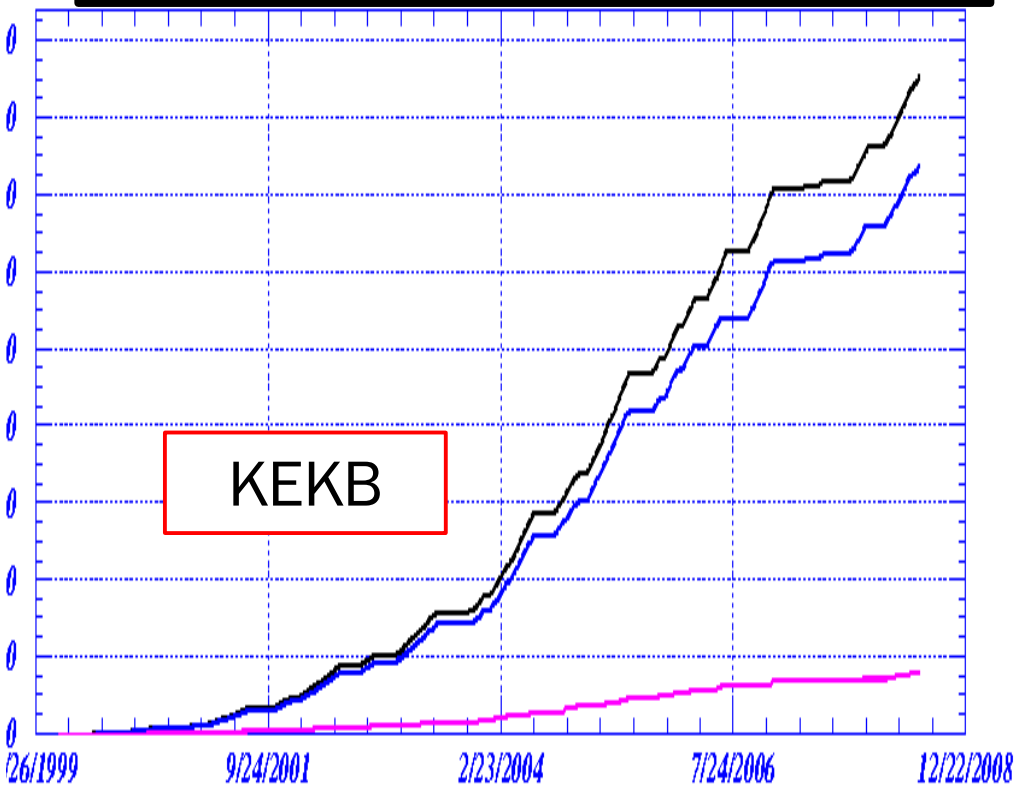
L_{peak} = 1.21 x $10^{34}/cm^2/s$



~ 433/fb on Y(4S)

~ 375 papers

L_{peak} = 1.71 x $10^{34}/cm^2/s$



~ 750/fb on Y(4S)

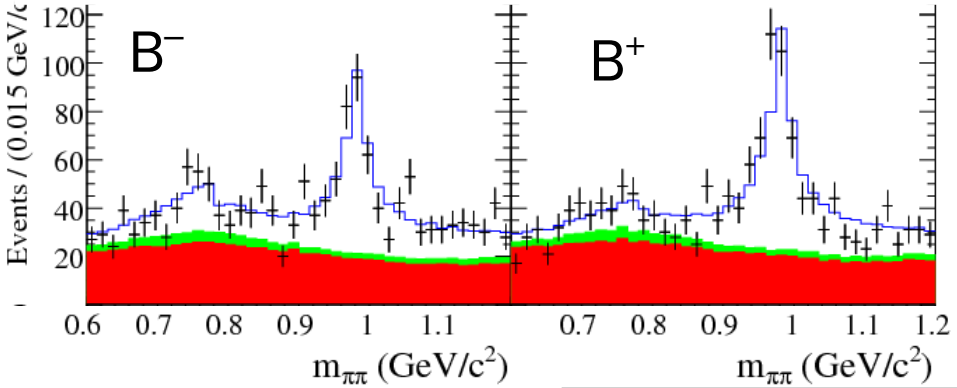
~ 275 papers

papers published or submtted for publication

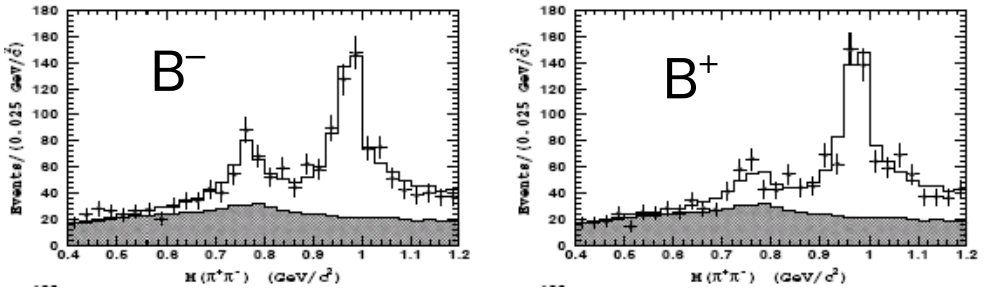
γ from B→Kππ Dalitz Plot Analyses

- Evidence of large direct CP violation in $B^{\pm}\to\rho^0 K^{\pm}$

BABAR PRD 78 (2008) 012004



Belle ICHEP 2008



$$HFAG \quad A_{CP}(\rho^0 K^+) = (42^{+8}_{-10})\%$$

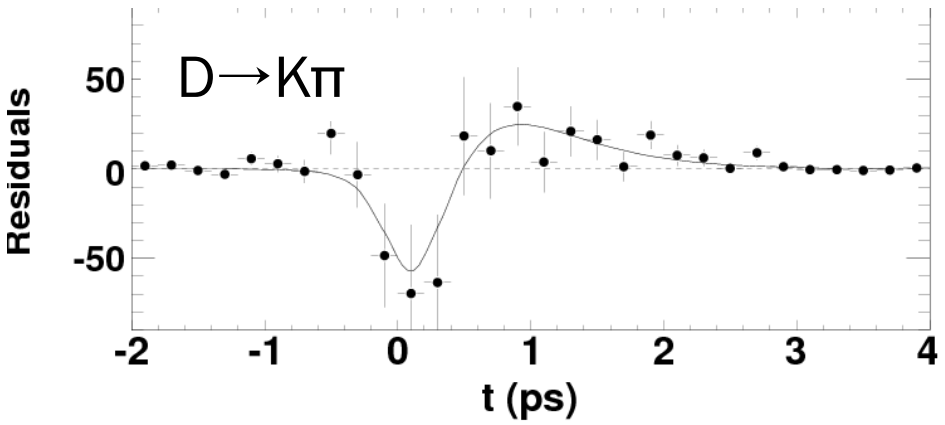
Ciuchini, Pierini & Silvestrini, PRD 74 (2006) 051301;
Gronau, Pirjol, Soni & Zupan, PRD 75 (2007) 014002

- Clean method to extract γ from
  - $B^0\to K_S\pi^+\pi^-$ (**BABAR arXiv:0708.2097& Belle ICHEP 2008**)
  - $B^0\to K^+\pi^-\pi^0$ (**BABAR PRD 78 (2008) 052005 & arXiv:0807.4567**)

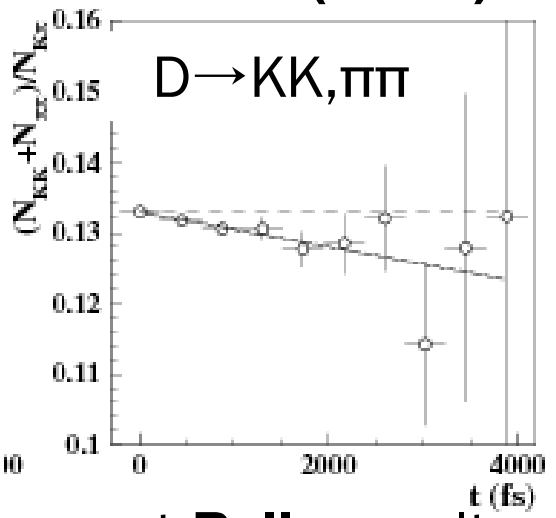
Charm Mixing

- Charm provides unique laboratory among up-type quarks
  - oscillations provide important test of Standard Model

BABAR PRL 98 (2007) 211802



Belle PRL 98 (2007) 211803



Other recent **BABAR** results

- D→KK,ππ **PRD 78 (2008) 011105**
- D→Kππ^0 **arXiv:0807.4544**

and more …

Other recent **Belle** results

- D→K_Sππ **PRL 99 (2007) 131803**
- D→K_SKK **arXiv:0808.0074**

and more …

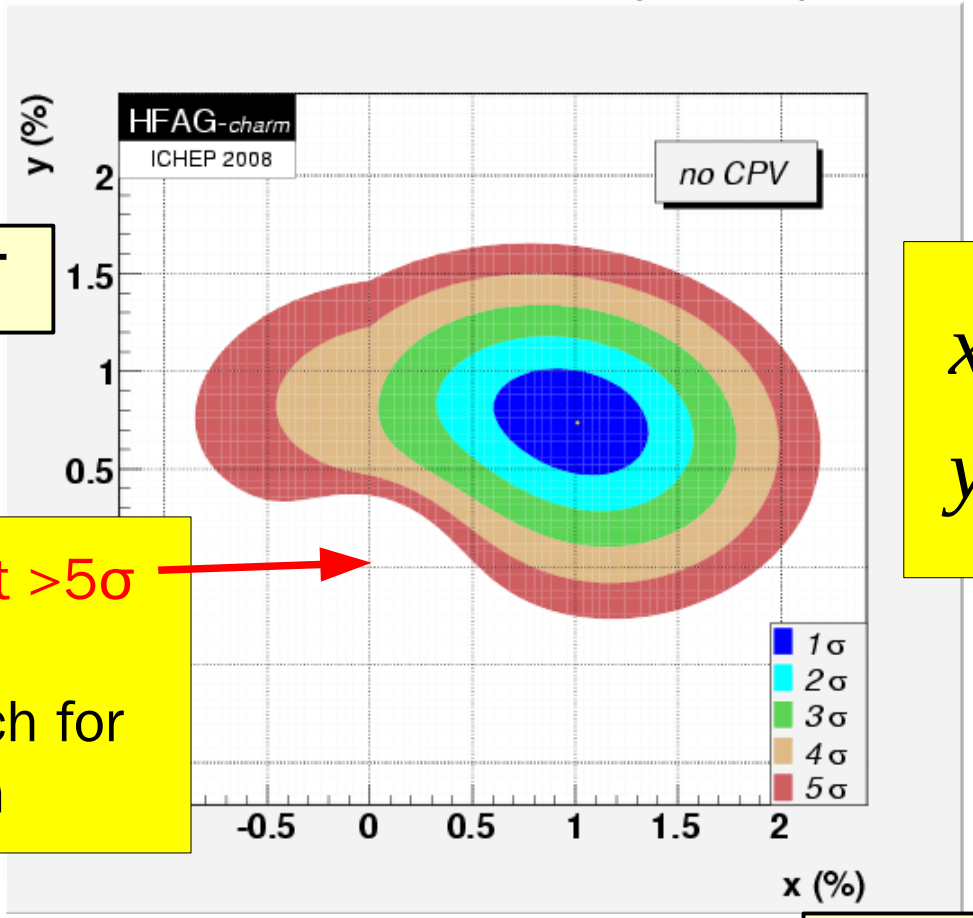
and **CDF**

Charm Mixing World Average

- HFAG world average includes results on

$D \to KK,\pi\pi$, $D \to K\pi$, $K\pi\pi^0$, $K\pi\pi\pi$, $D \to K_S\pi\pi$, K_SKK, $D \to Klv$ & $\Psi(3770) \to D\bar{D}$ (CLEOc)

$y = \Delta\Gamma/2\Gamma$



$$x = (1.01\,^{+0.23}_{-0.25})\%$$
$$y = (0.74\,^{+0.17}_{-0.18})\%$$

(0,0) excluded at >5σ

Next step: search for CP violation

$x = \Delta m/\Gamma$