What Would We Like To Measure at B Factories?

Tim Gershon
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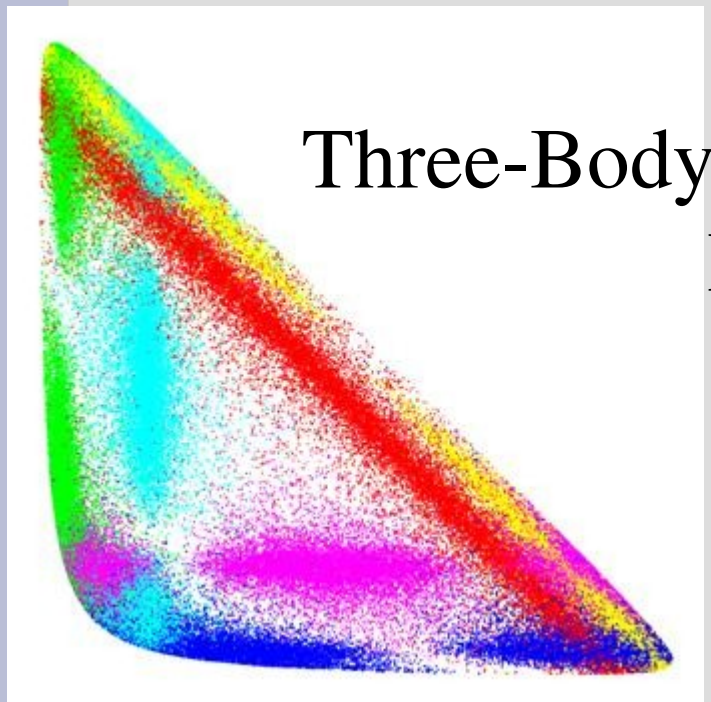


Three-Body Charmless B Decays Workshop
Paris, February 2006

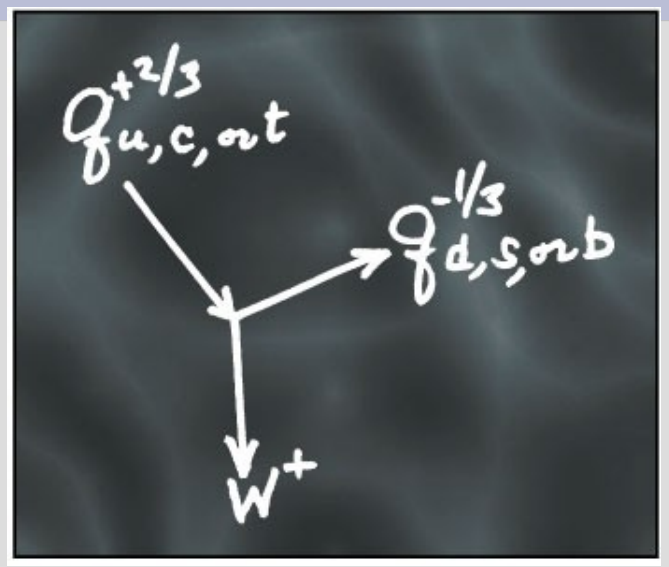
What Would We Like To Measure at B Factories?

(personal, and incomplete opinions)

- The old answer
- The current status
- New answers
- Three-Body Charmless B Decays

The CKM Matrix

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

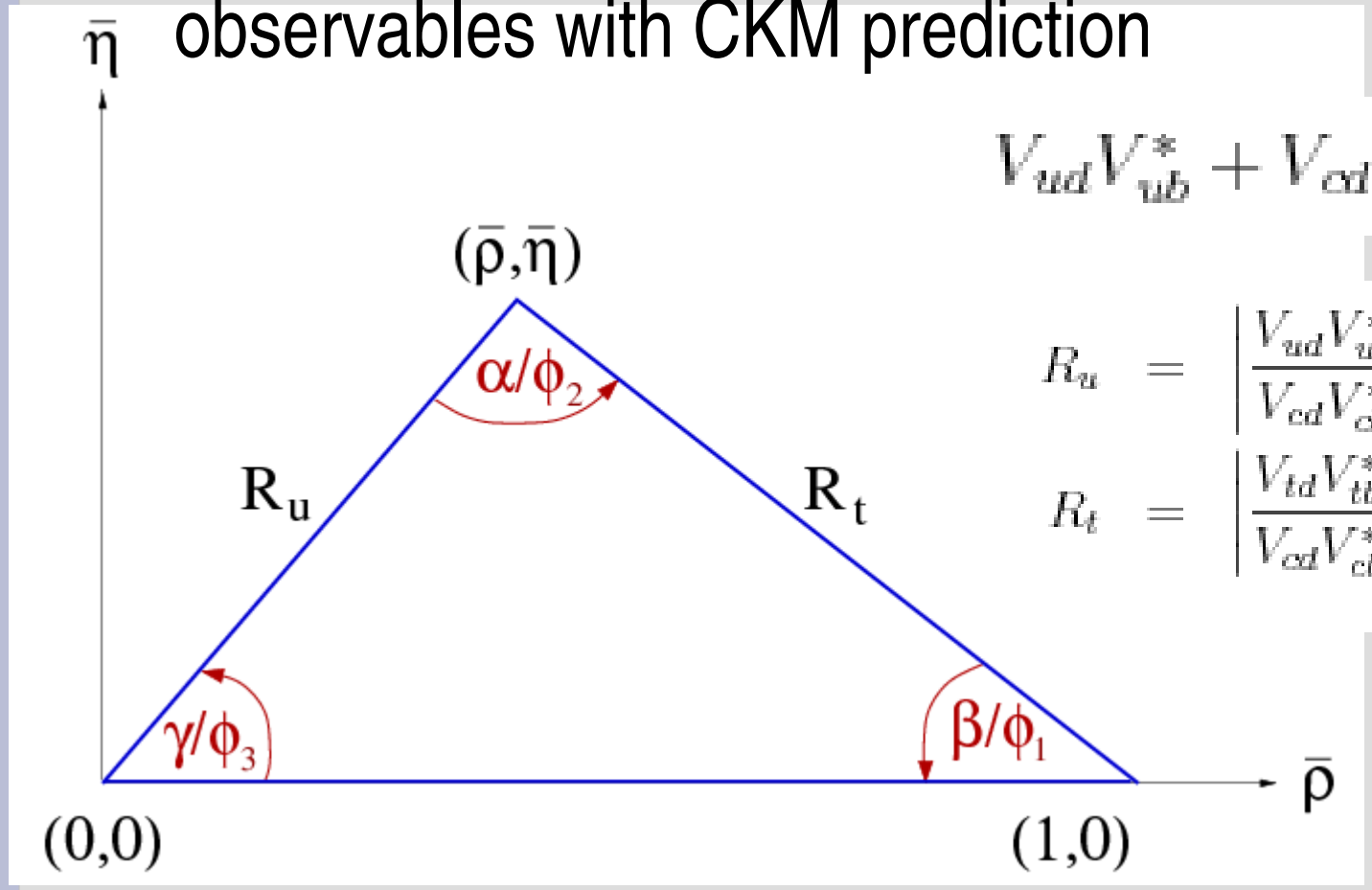


There are (exactly) three families of quarks

3x3 unitary mixing matrix => one phase

The Unitarity Triangle

- Convenient method to illustrate (dis-)agreement of observables with CKM prediction



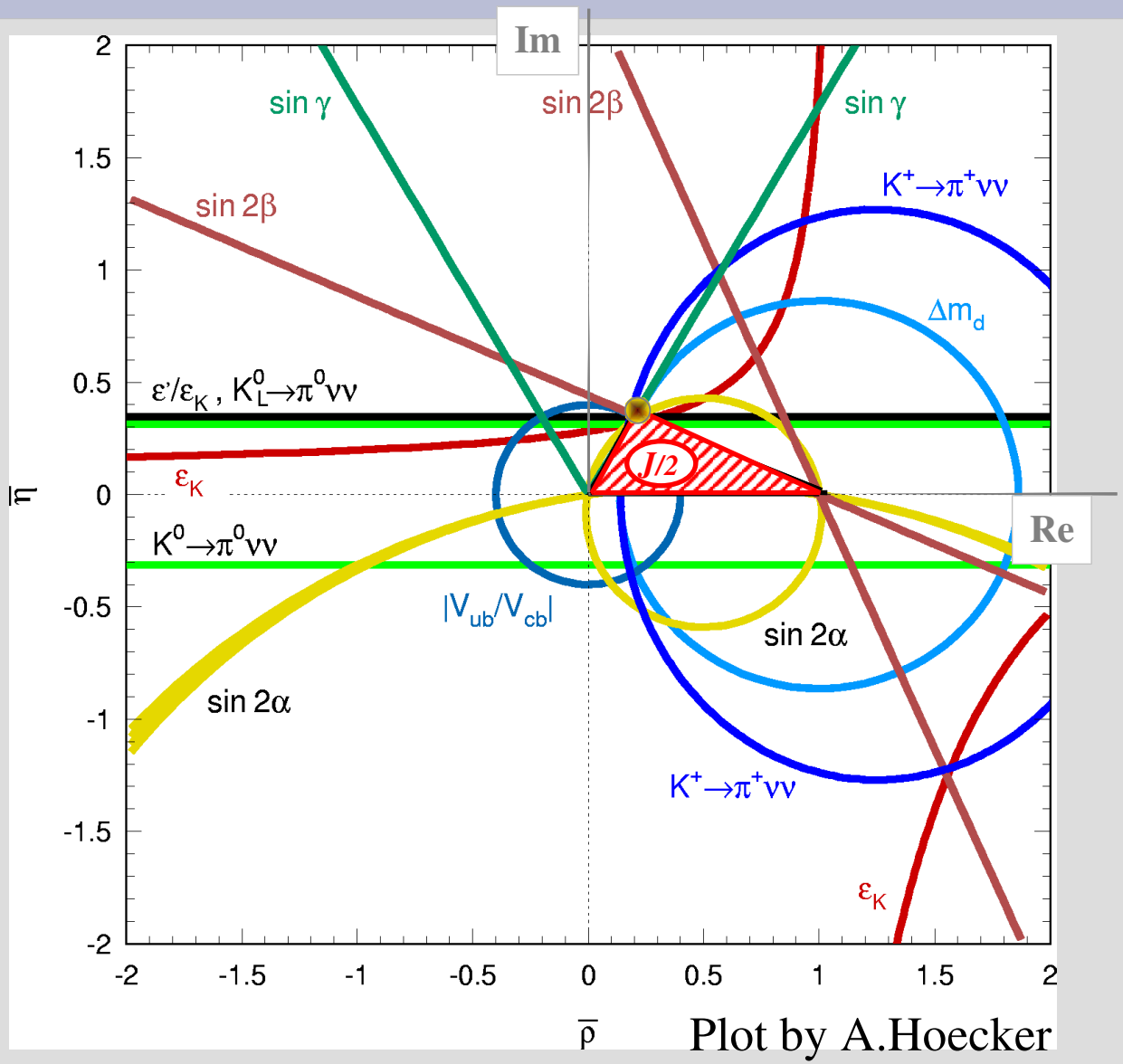
$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0,$$

$$R_u = \left|\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right| = \sqrt{\bar{\rho}^2+\bar{\eta}^2},$$

$$R_t = \left|\frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*}\right| = \sqrt{(1-\bar{\rho})^2+\bar{\eta}^2}.$$

Predictive Nature of KM Mechanism

All measurements must agree

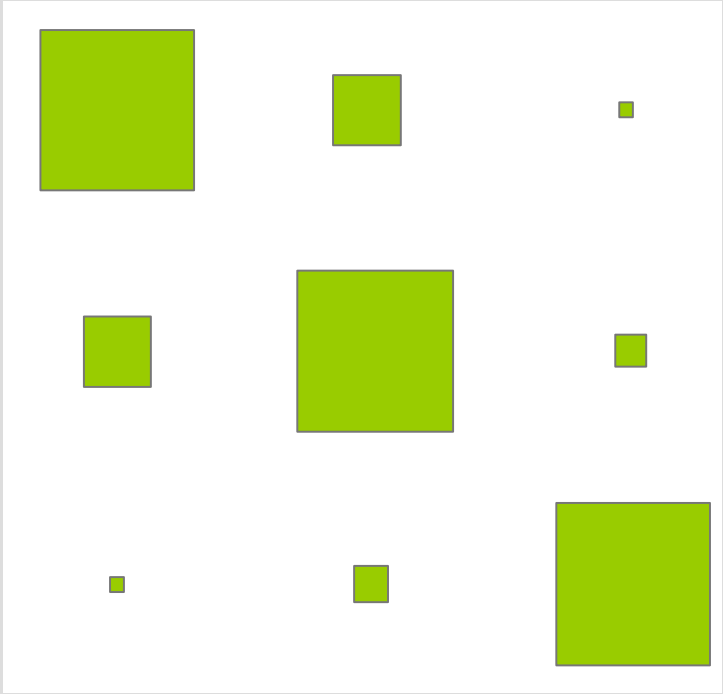


Plot by A.Hoecker

The Wolfenstein Parametrization

Hierarchy in quark mixing

$$V = \begin{pmatrix} 1 - \frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1 - \frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1 - \rho - i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}\left(\lambda^4\right)$$



Note also: hierarchy in quark masses

The Strong Interaction

- We *never* directly observe quarks
  - always bound in hadrons
- Unavoidable hadronic uncertainties
  - reduced by studying ratios (asymmetries)
- Essential to understand strong interaction effects
  - interesting of themselves
  - can help (*eg.* to reduce ambiguities)

- Note: virtual quarks are not bound in hadrons

What Would We Like To Measure at B Factories?

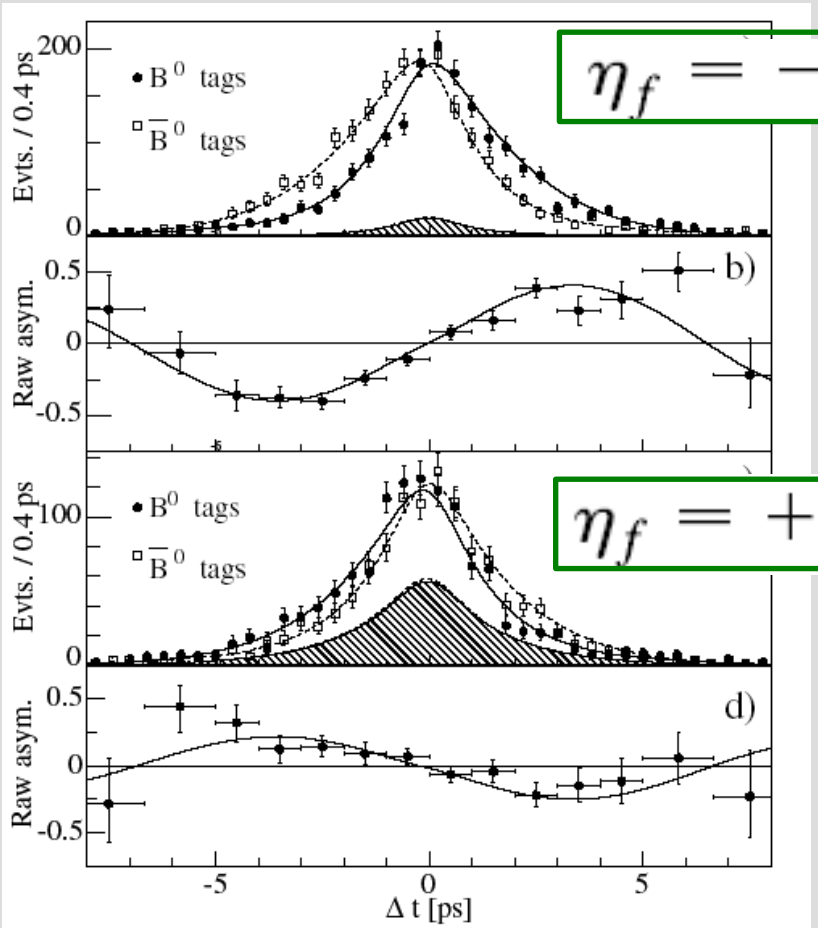
(pre B-factory answer)

- **Does CP violation exist in the B system?**
  - How about direct CP violation?
- Are there large CP violation effects?
  - How about large direct CP violation?
- **Is everything consistent with the KM mechanism?**

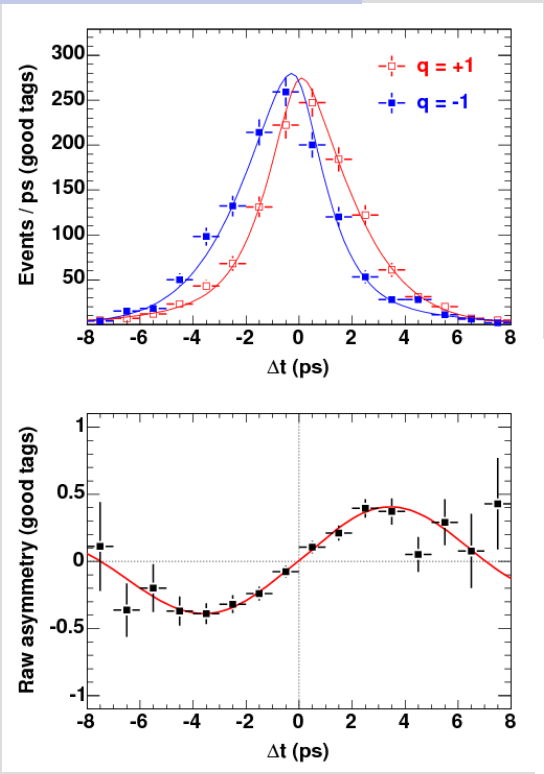
Does CP violation exist in the B system?

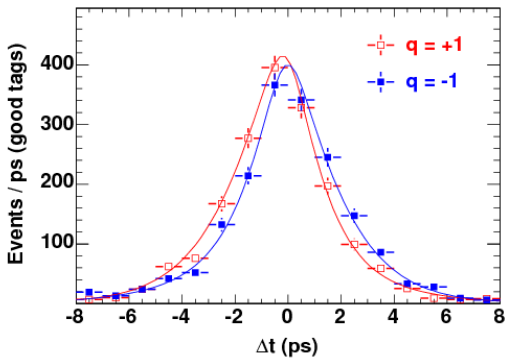
$$B^0 \to J/\psi K^0$$

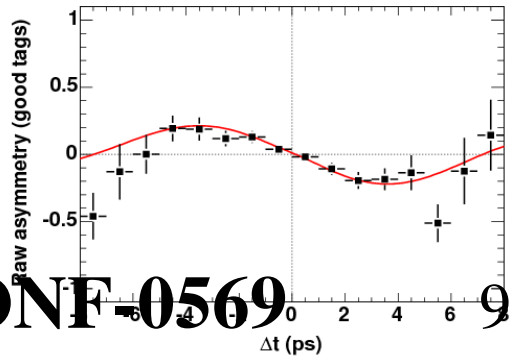
BABAR



PRL **94,** 161803 (2005)

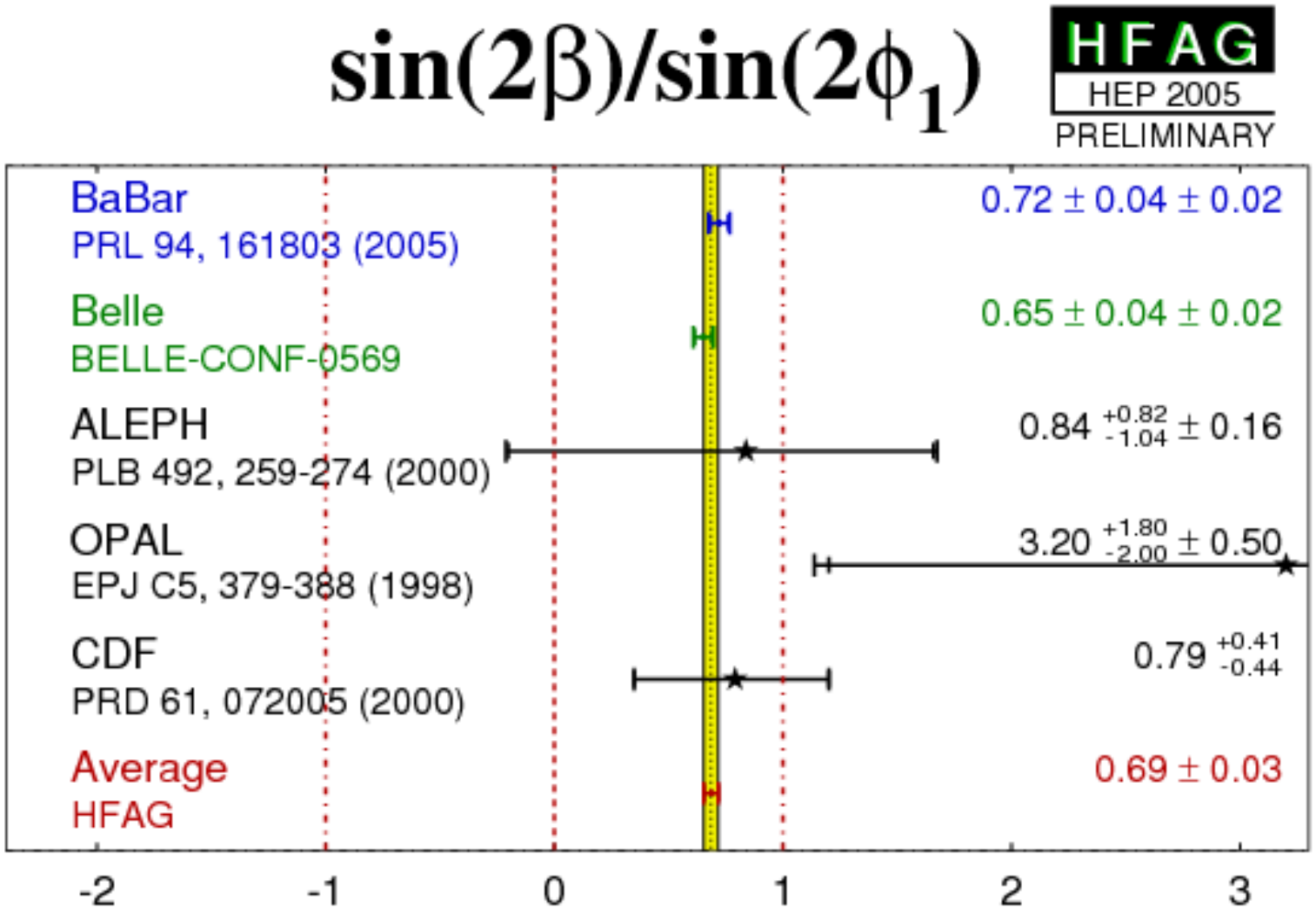






BELLE-CONF-0569

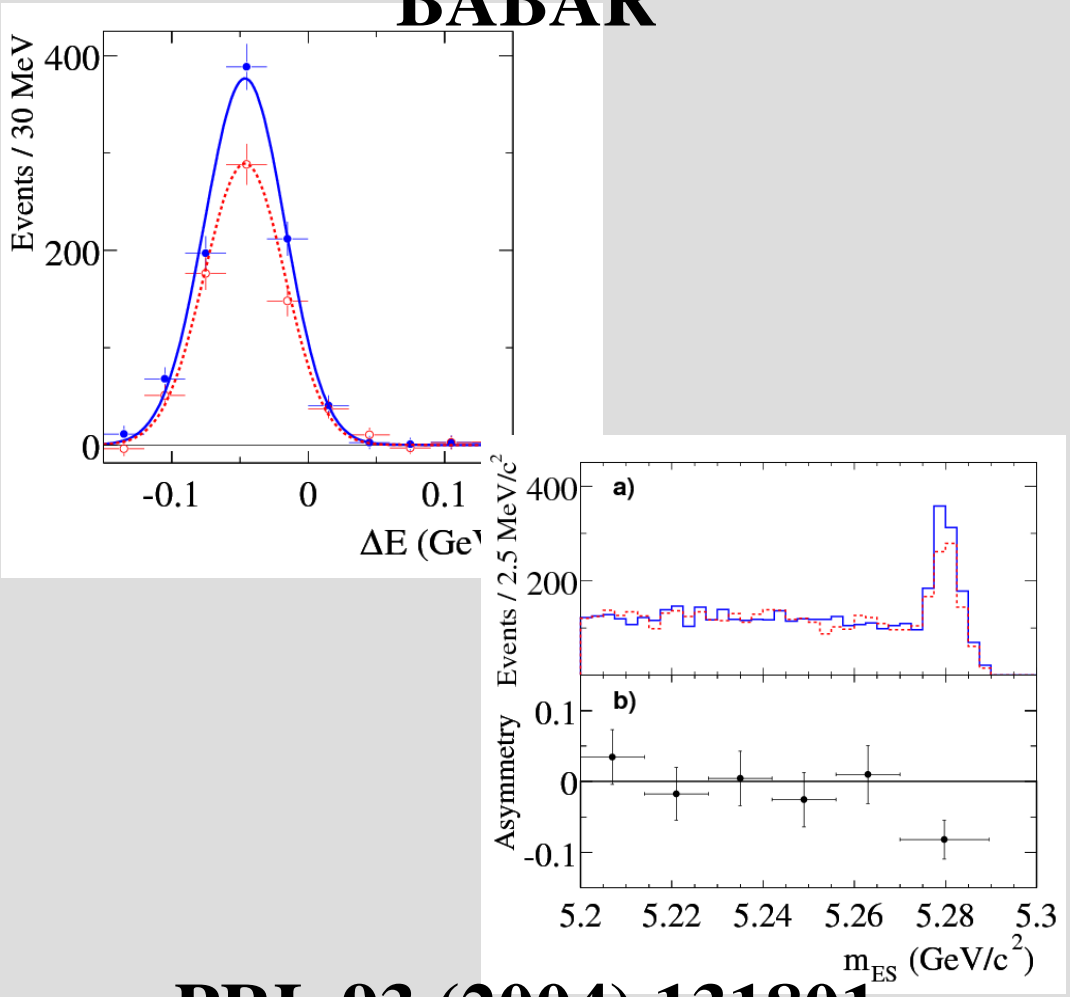
Does CP violation exist in the B system?



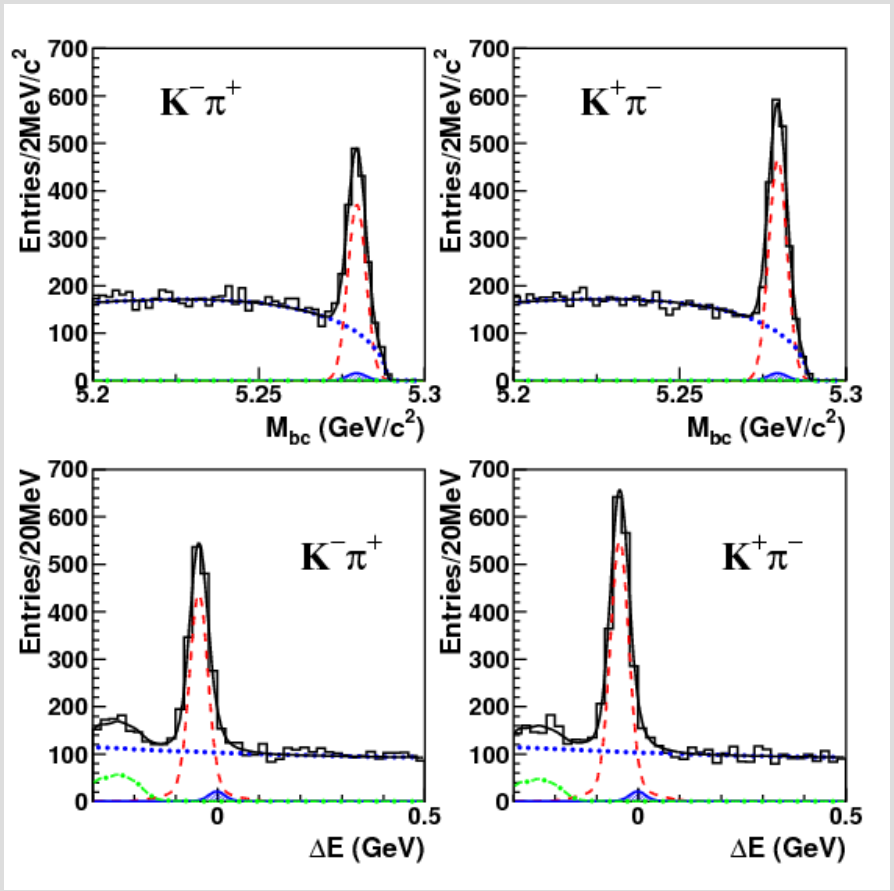
How about direct CP violation?

$$B^0 \to K^+\pi^-$$

BABAR



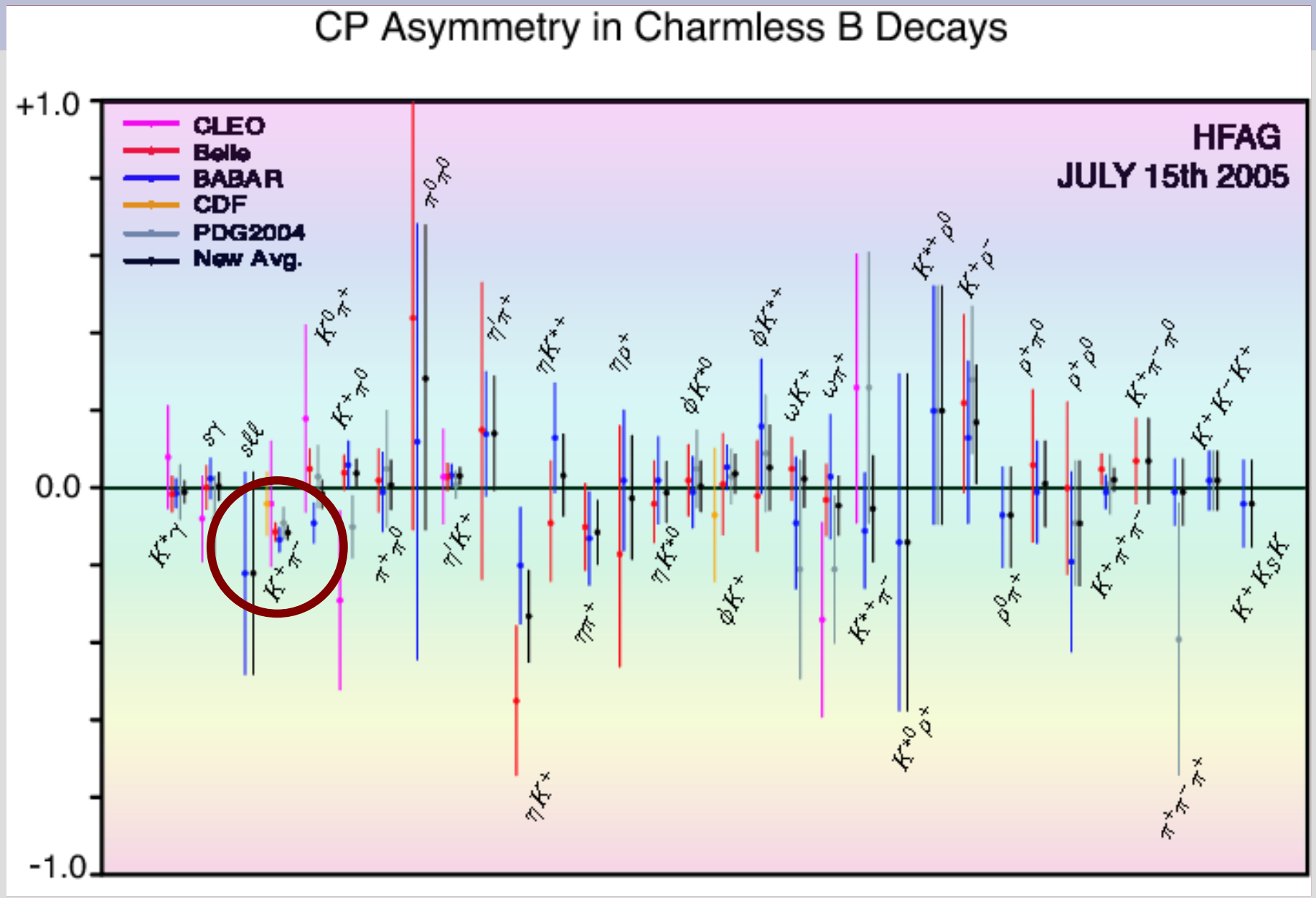
BELLE



PRL 93 (2004) 131801

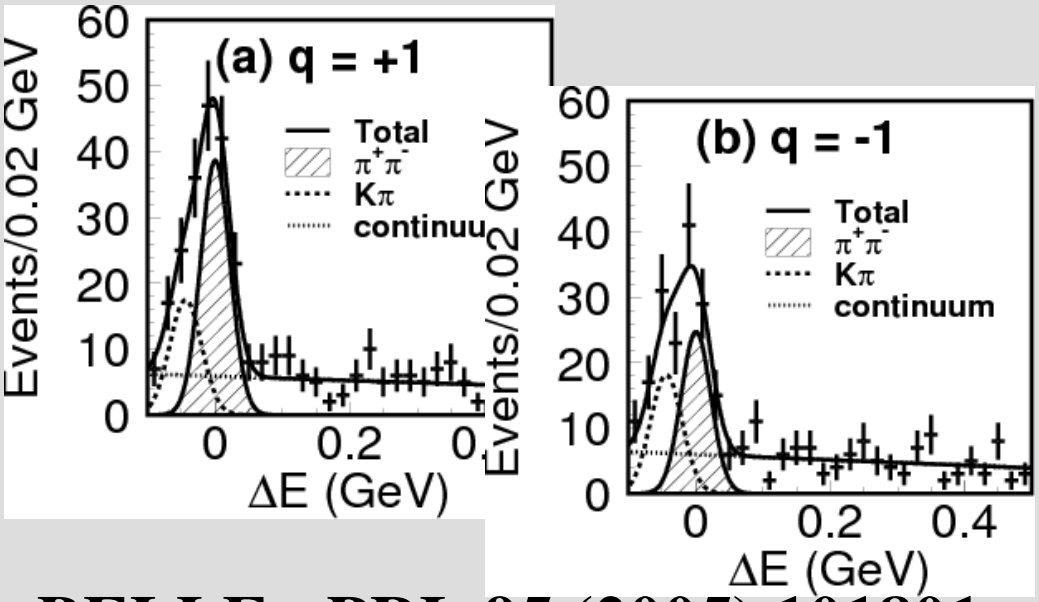
BELLE-CONF-0523

How about direct CP violation?



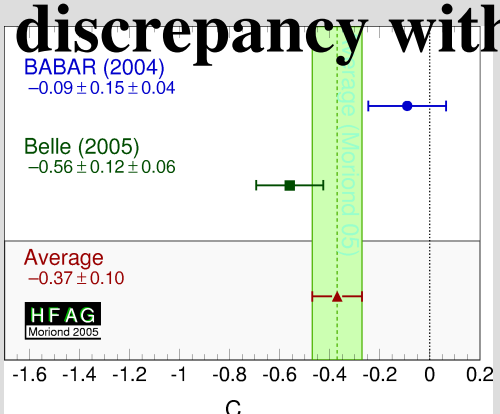
How about large (direct) CP violation?

$$B \to \pi^+\pi^-$$

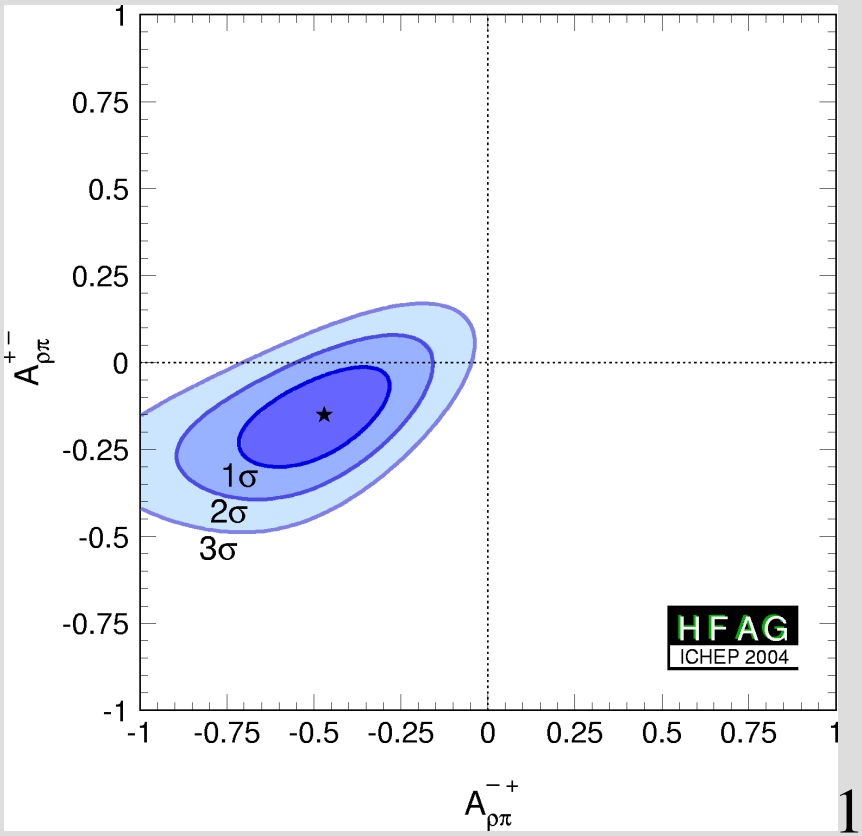


BELLE - PRL 95 (2005) 101801

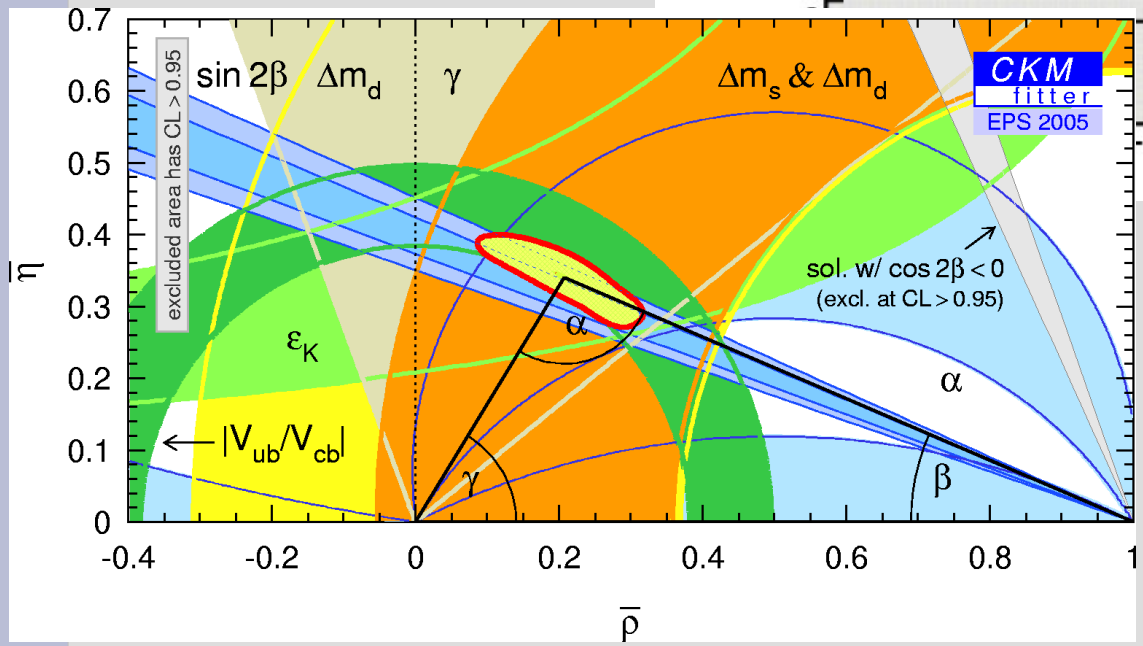
(Small discrepancy with BABAR)

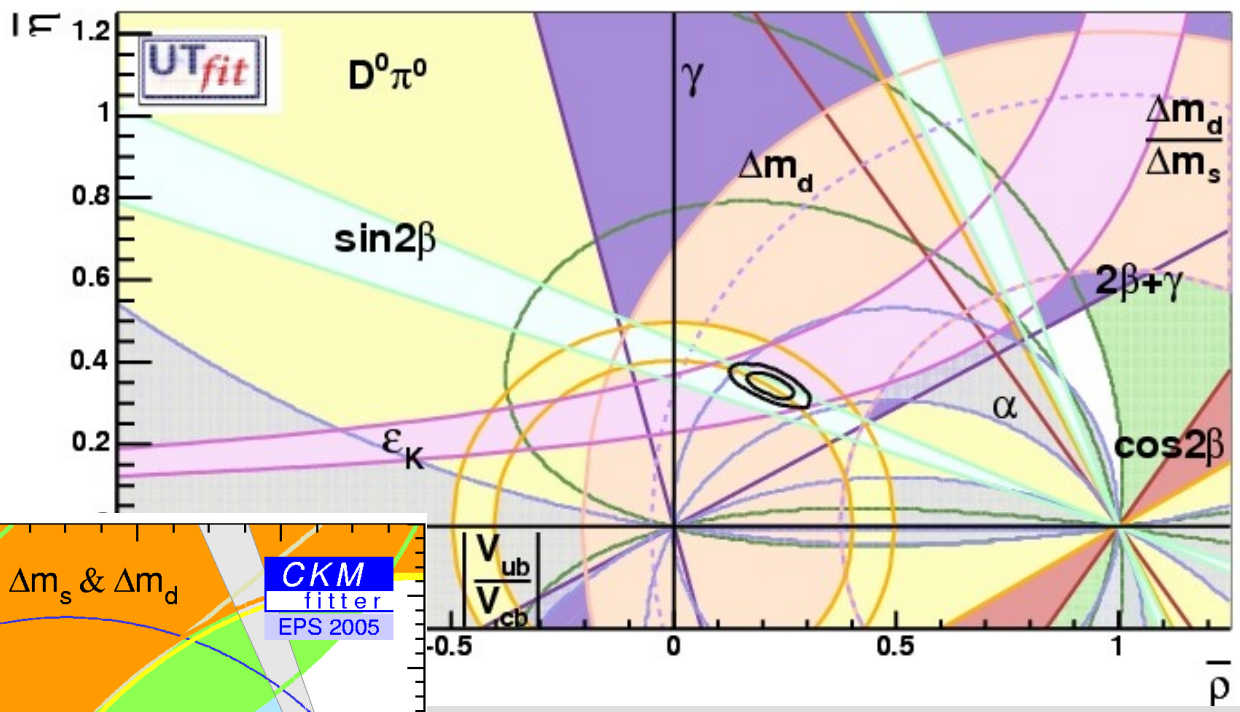


$$B^0 \to \rho^{\pm}\pi^{\mp}$$



Is Everything Consistent With The KM Mechanism?





What Would We Like To Measure at B Factories?

(pre B-factory answer)

- **Does CP violation exist in the B system?** ★
  - How about direct CP violation? ★
- Are there large CP violation effects? ★
  - How about large direct CP violation? ★
- **Is everything consistent with the KM mechanism?**

more or less, so far ...

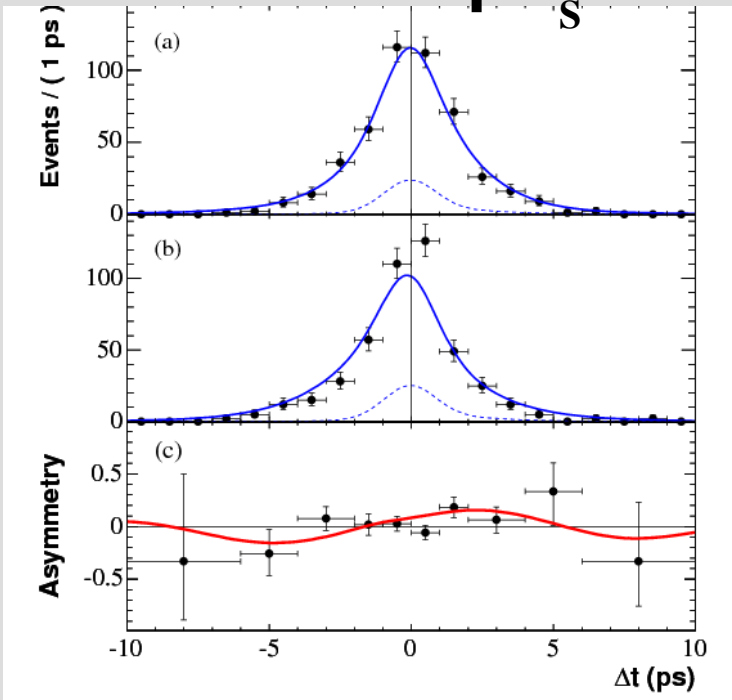
Is Everything Consistent With The KM Mechanism?

More or less, so far, but ...

- Slight tension between V_{ub} and sin(2β)
- Kπ (& ππ) puzzle
- Polarization puzzle ($B \rightarrow VV$)
- Discrepancies in hadronic $b \rightarrow s$ TDCPV

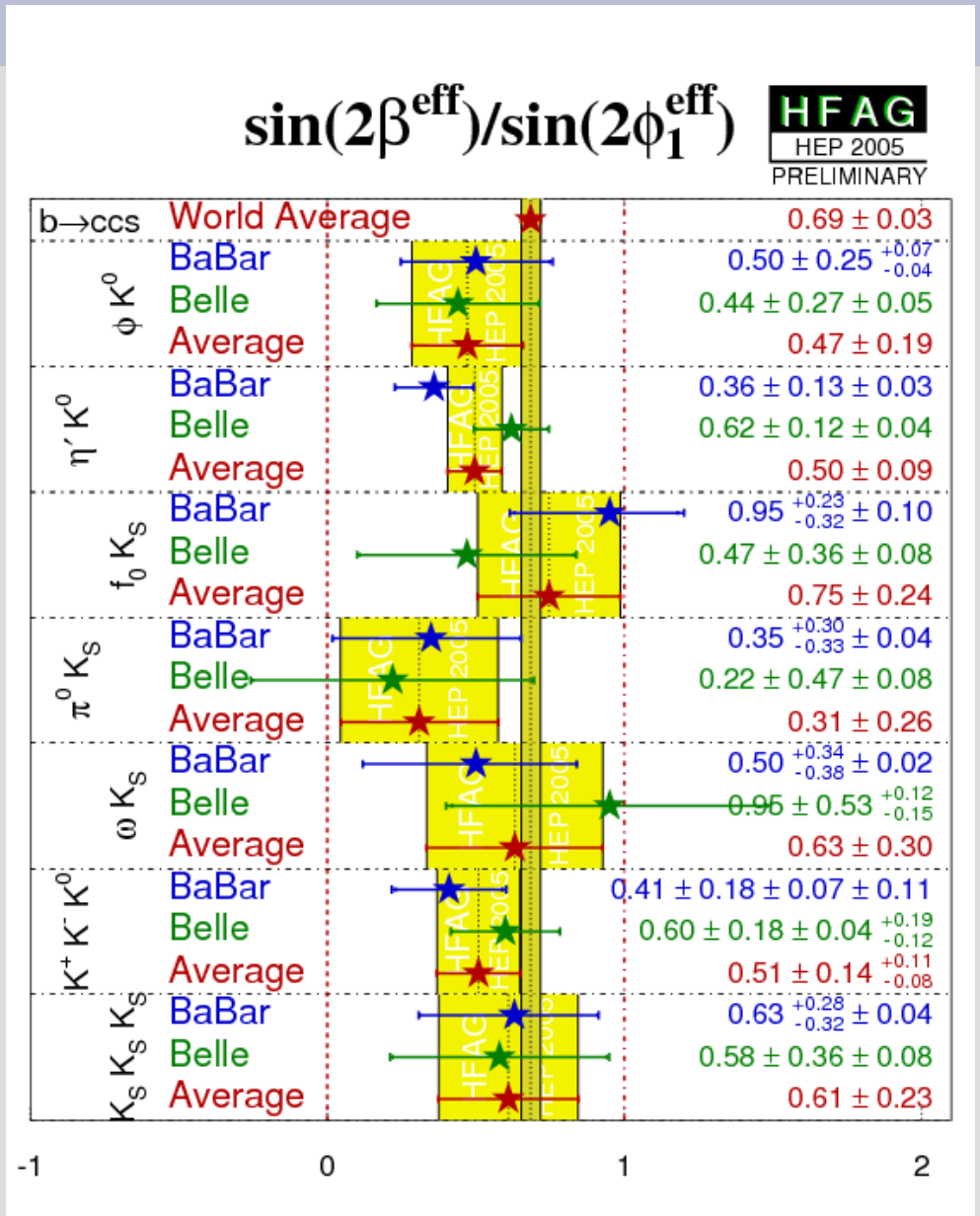
Discrepancies in hadronic b→s TDCPV

BABAR - $B^0 \to \eta' K_S$

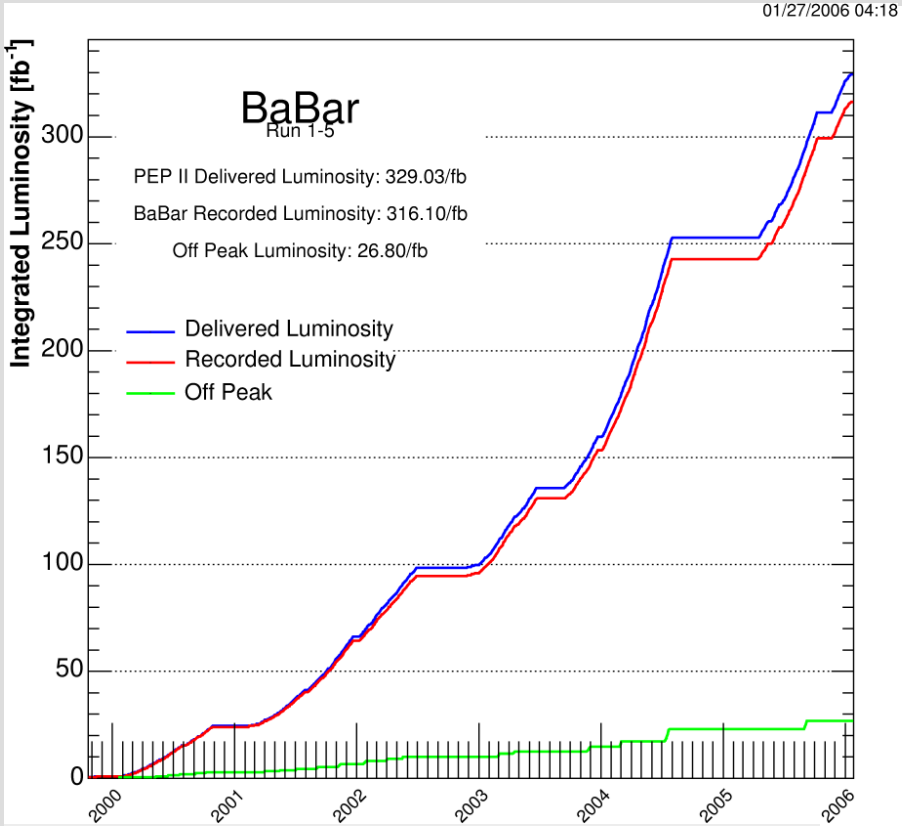


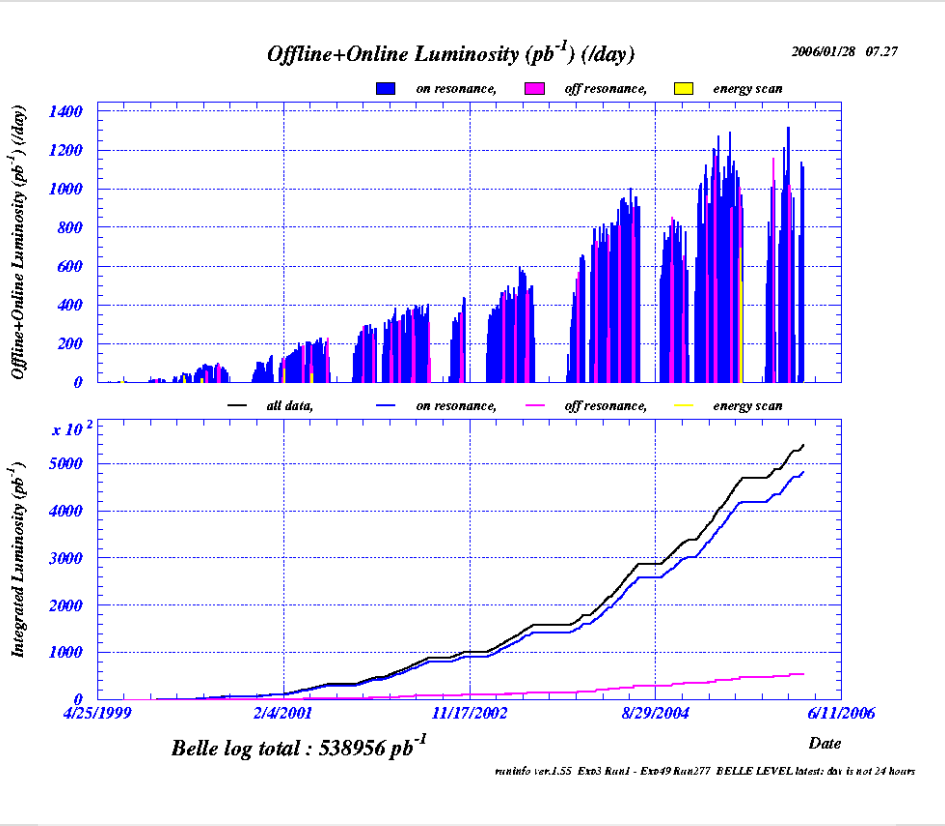
PRL 94 (2005) 191802

Improved & additional measurements essential



The Current Status

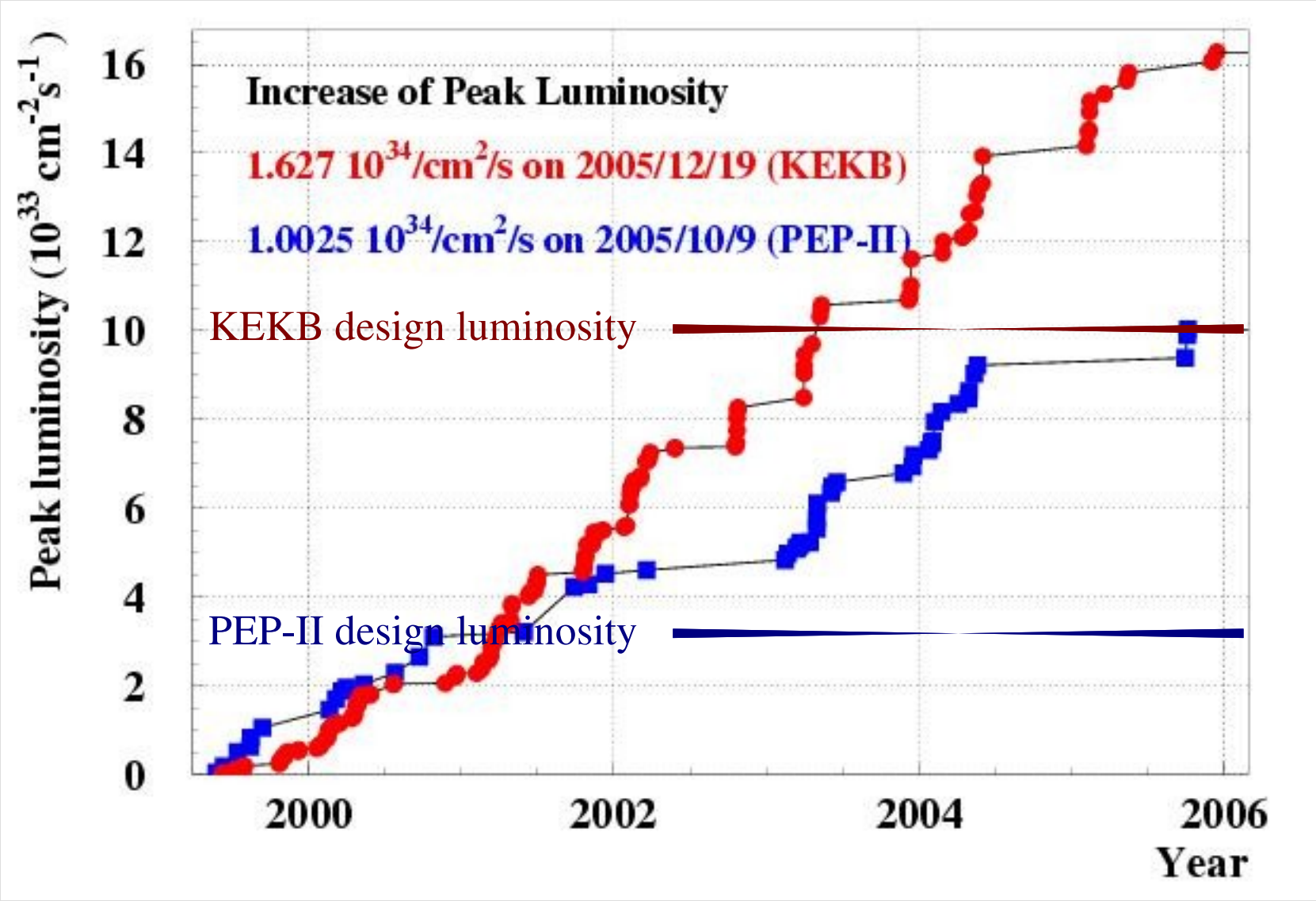




~ 290/fb on Y(4S)

~ 490/fb on Y(4S)

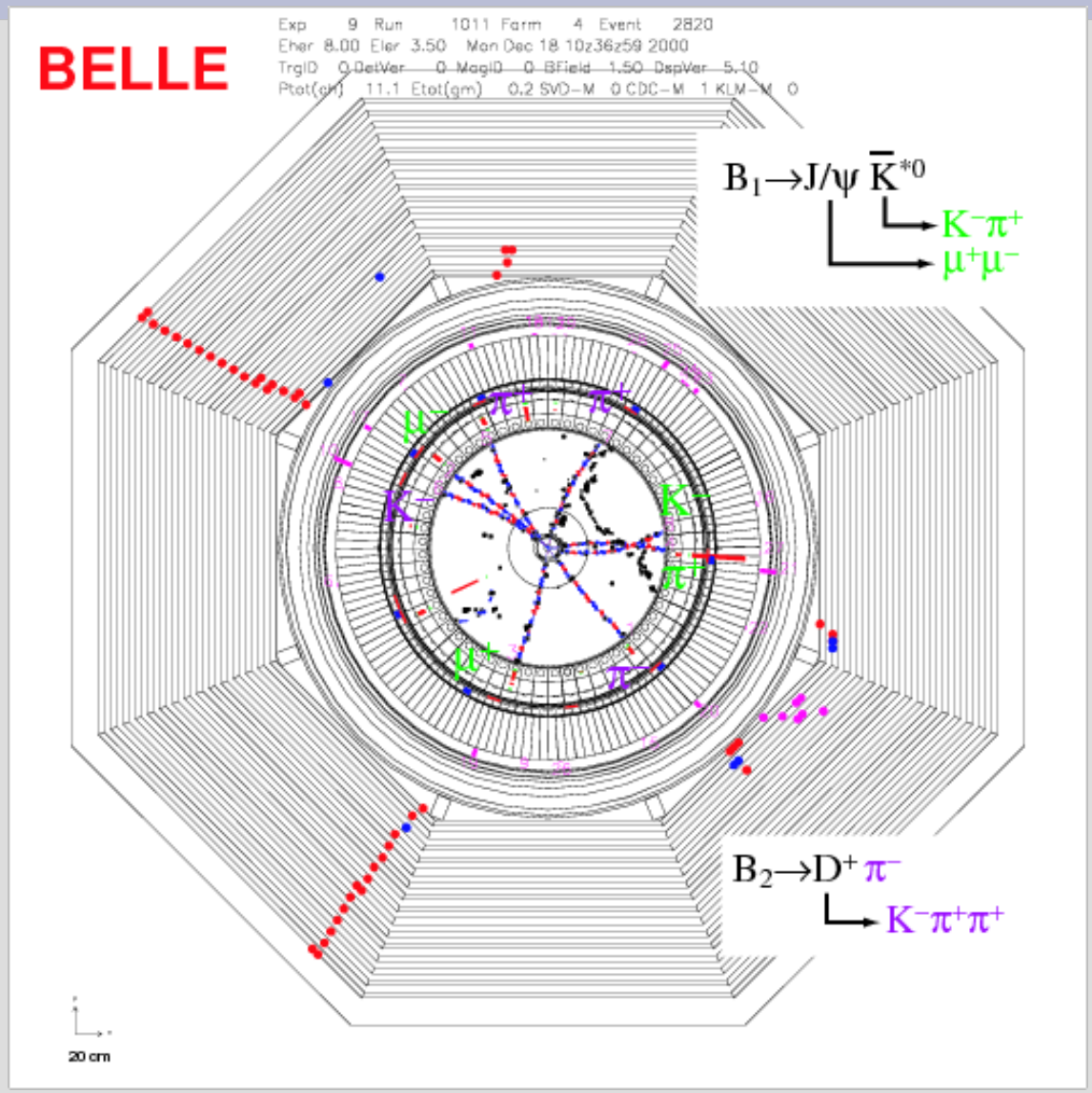
Record Luminosities



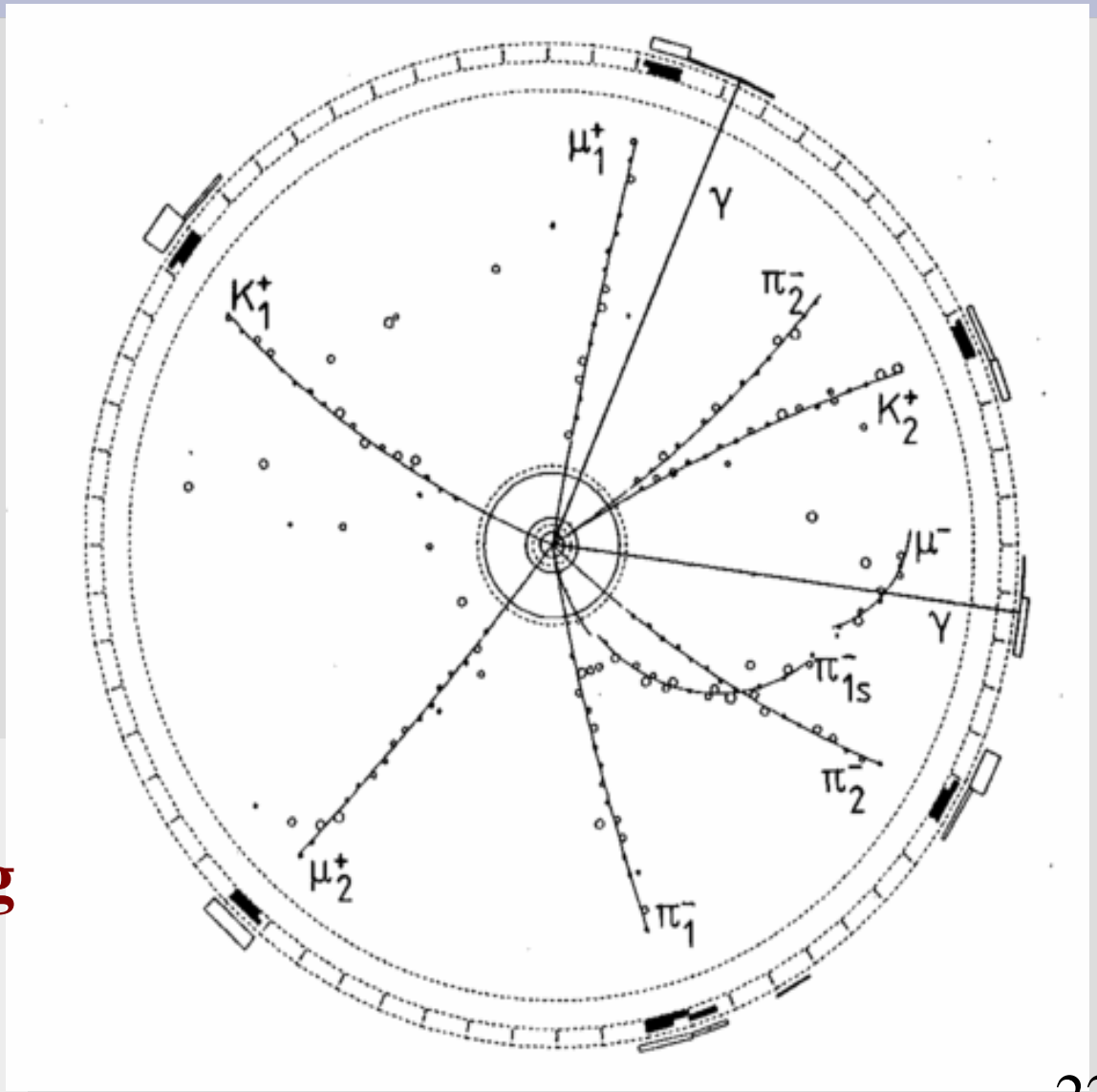
Features of $e^+e^- \rightarrow \Upsilon(4S)$ B Factories

- High luminosity
  - can search for rare decay modes
- Clean environment
  - can reconstruct almost any decay, even with neutrinos
- Well understood backgrounds
  - mainly QED; fragmentation in $e^+e^- \rightarrow q\bar{q}$ can be studied
- Asymmetric energies
  - can make time-dependent measurements
- Coherent production of BB pairs
  - can tag flavour with high efficiency

BB event reconstruction



BB event reconstruction



ARGUS experiment
Observation of BB mixing
103/pb
PLB 192 (1987) 245

What Would We Like To Measure at B Factories?

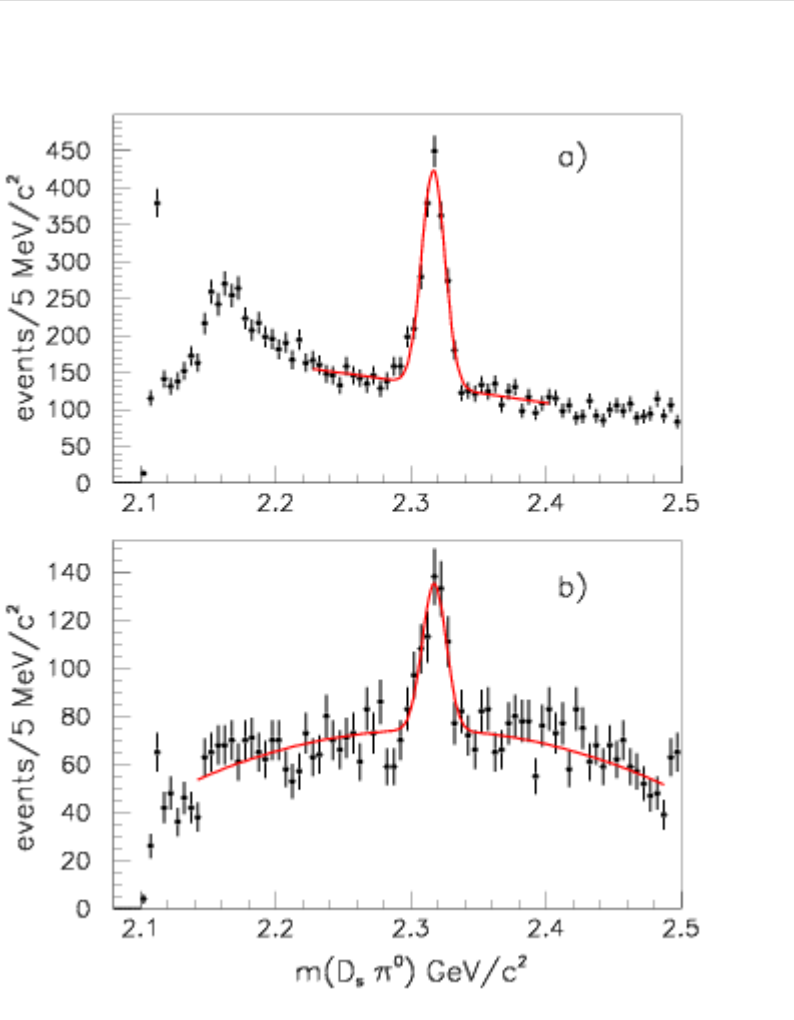
The key features of the B factories, make these (arguably) the best machines to search for new physics, for the next few years.

$\therefore$ We should fully exploit this potential

The Rebirth of "Old Physics"

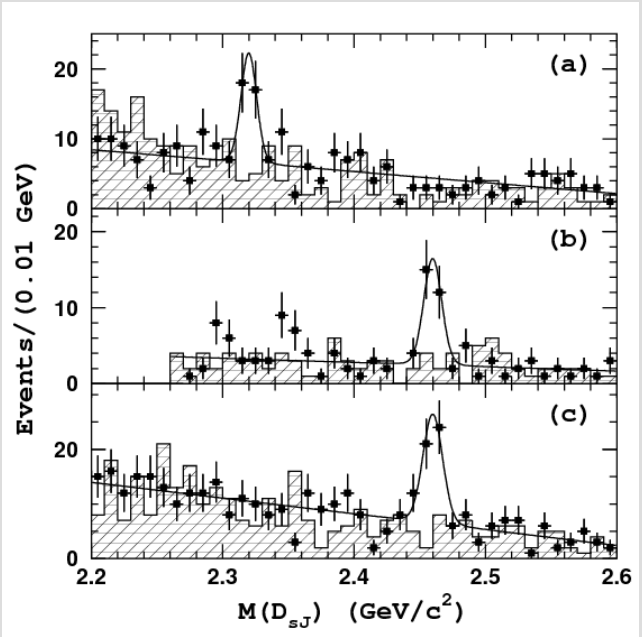
- Most cited B factory publications (>150 cites, from SPIRES):
- BELLE
  - OBSERVATION OF LARGE CP VIOLATION IN THE NEUTRAL B MESON SYSTEM (340)
  - A MEASUREMENT OF THE BRANCHING FRACTION FOR THE INCLUSIVE B ---> X(S) GAMMA DECAYS WITH BELLE (244)
  - AN IMPROVED MEASUREMENT OF MIXING INDUCED CP VIOLATION IN THE NEUTRAL B MESON SYSTEM (216)
  - OBSERVATION OF A NARROW CHARMONIUM - LIKE STATE IN EXCLUSIVE B+- ---> K+- PI+ PI- J / PSI DECAYS (171)
- BABAR
  - OBSERVATION OF CP VIOLATION IN THE B0 MESON SYSTEM (329)
  - MEASUREMENT OF THE CP VIOLATING ASYMMETRY AMPLITUDE SIN 2BETA (320)
  - OBSERVATION OF A NARROW MESON DECAYING TO D+(S) PI0 AT A MASS OF 2.32-GEV/C**2 (271)
  - MEASUREMENTS OF BRANCHING FRACTIONS AND CP VIOLATING ASYMMETRIES IN B0 ---> PI+ PI-, K+ PI-, K+ K- DECAYS (192)

OBSERVATION OF A NARROW MESON DECAYING TO D+(S) PI0



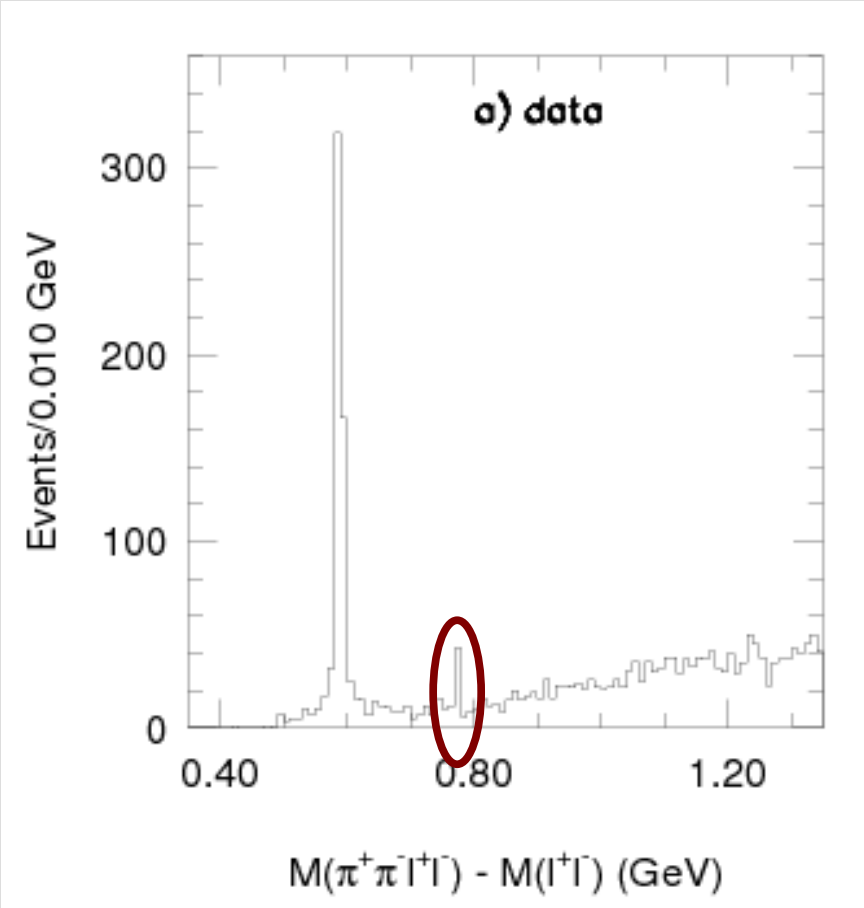
PRL 90 (2003) 242001

Quickly confirmed by Belle (& CLEO):



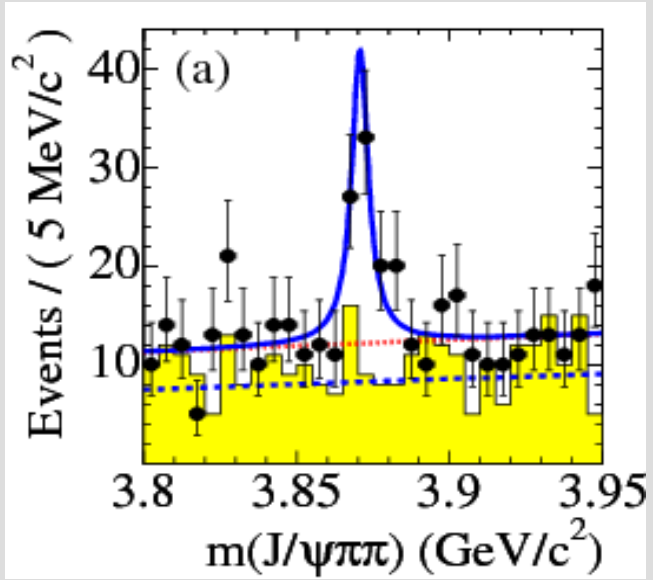
PRL 91 (2003) 262002

OBSERVATION OF A NARROW CHARMONIUM–LIKE STATE



PRL 91 (2003) 262001

Quickly confirmed by Babar (& CDF &D0):



PRD 73 (2006) 011101

Spectroscopy

- Many important results
- Discovery of $\sim$1 new particle/year
  - all newly observed particles need confirmation
- Huge impact on understanding of charm and (especially) charmonium
- How about lower energies?
  - Various unresolved/controversial issues
    - scalar mesons
    - glueballs

Low Energy Spectroscopy

- Various possibilities for studies
  - $B \rightarrow (\eta,\eta',\varphi)\pi^+\pi^-$ K (and others)
  - $B \rightarrow \pi\pi K$, KKK

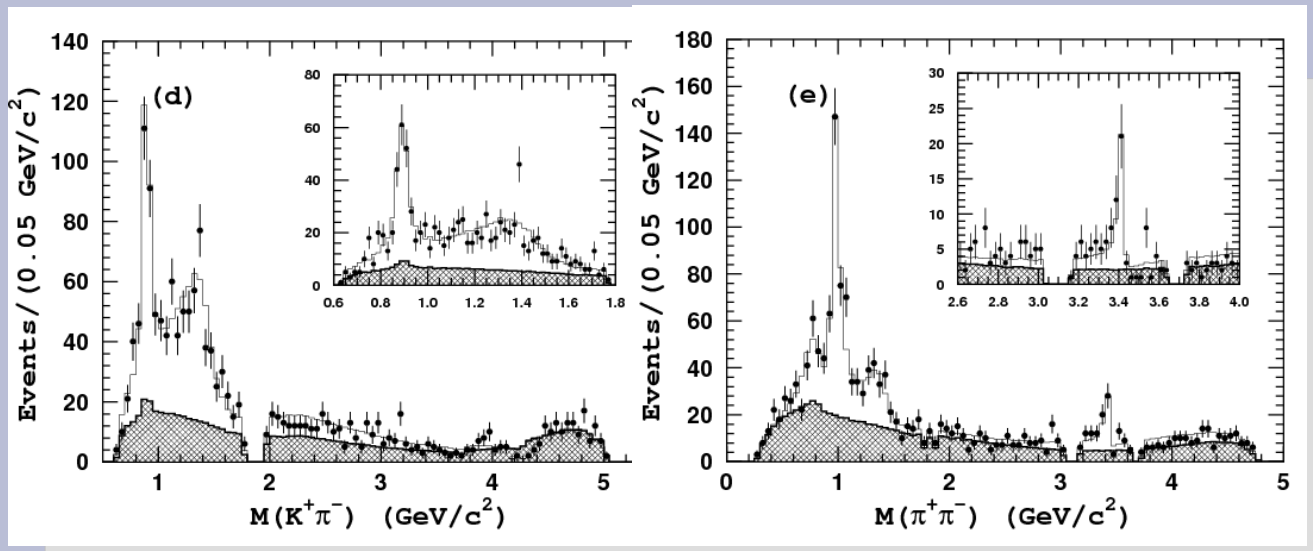
3 body charmless B decays

also D decays, but not in this talk

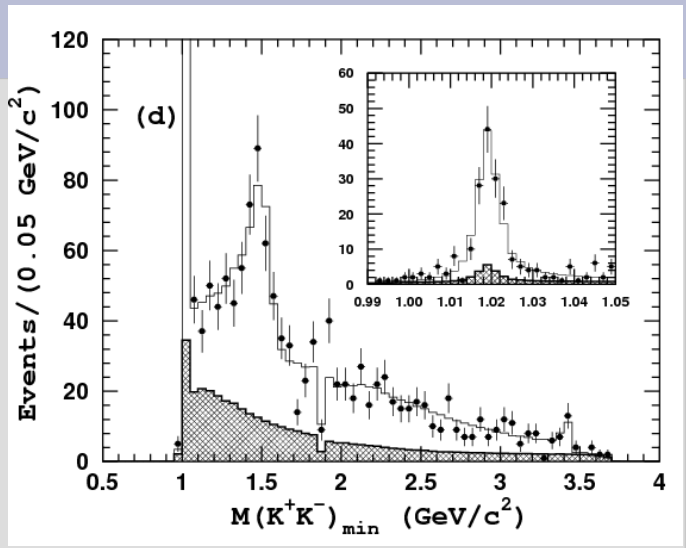
- Some progress already in this direction
  - Study of three-body charmless B decays
    - Belle; PRD 65 (2002) 092005; 65 cites
  - Study of B meson decays to three-body charmless hadronic final states
    - Belle; PRD 69 (2004) 012001; 47 cites
  - Dalitz analysis of the three-body charmless decays $B^+ \rightarrow K^+\pi^+\pi^-$ and $B^+ \rightarrow K^+K^+K^-$
    - Belle; PRD 71 (2005) 092003; 23 cites
  - Amplitude Analysis of the Decay $B^{+-} \rightarrow \pi^{+-}\pi^{+-}\pi^{-+}$
    - Babar; PRD 72 (2005) 052002; 3 cites
  - Dalitz-plot analysis of the decays $B^{+-} \rightarrow K^{+-}\pi^{+-}\pi^{-+}$
    - Babar; PRD 72 (2005) 072003; 8 cites

Belle; PRD 71 (2005) 092003

$B^+ \to K^+\pi^+\pi^-$

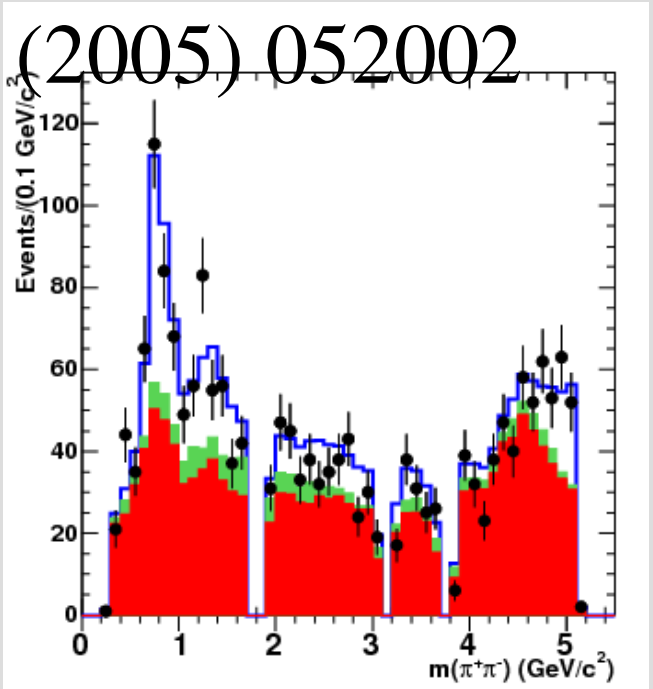


$B^+ \to K^+K^+K^-$



Babar; PRD 72 (2005) 052002

$B^+ \to \pi^+\pi^+\pi^-$

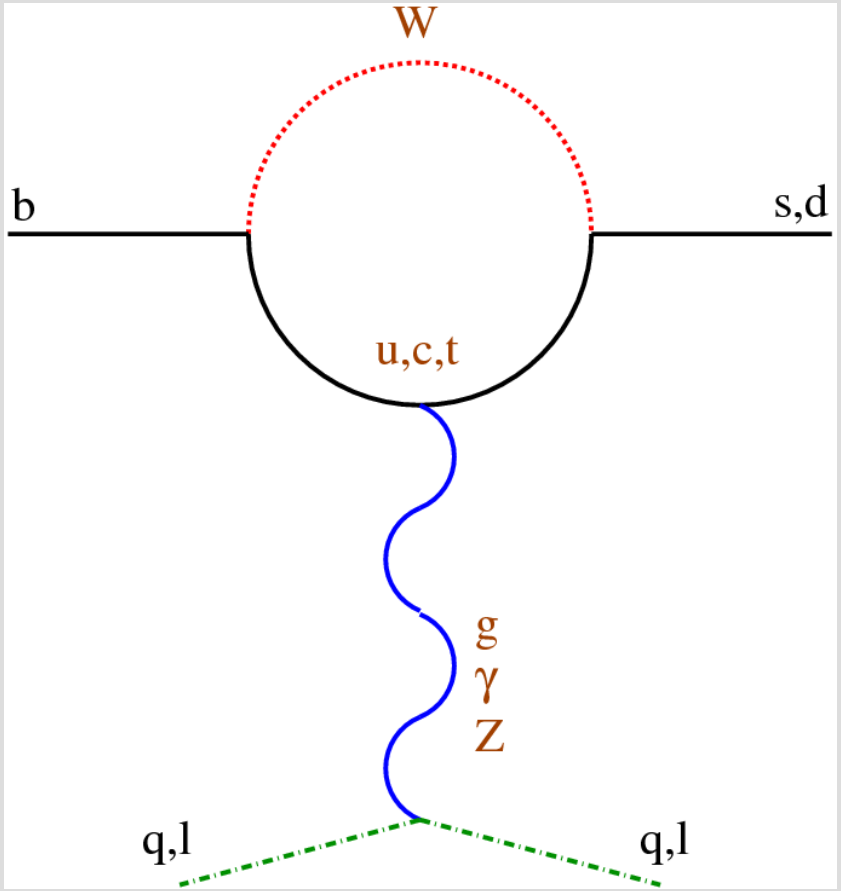


Three Body Charmless B Decays

- The study of 3b0c B decays raises old, unresolved questions related to hadronic effects
- New experimental information raises prospect to address (some parts of) these questions
- Essential to deal with hadronic effects to maximize sensitivity to possible new physics effects

Search for New Physics at B Factories

- Loops ⇒ high energy scales
- New particles effect SM predictions for observables
  - rates (large uncertainties)
  - phases
  - polarizations
  - asymmetries
- Charmless (rare) B decays an important testing ground



Charmless Hadronic B Decays

- Generally, at least two Standard Model contributions
  - penguin
  - tree
    - relative weak phase of γ (for $b \to sqq$ transitions)
- Difficult to disentangle
  - *eg.* $A_{CP}(K\pi) \propto \sin(\gamma)$, but hard to extract γ
- Need additional experimental observables
- Theory input also invaluable

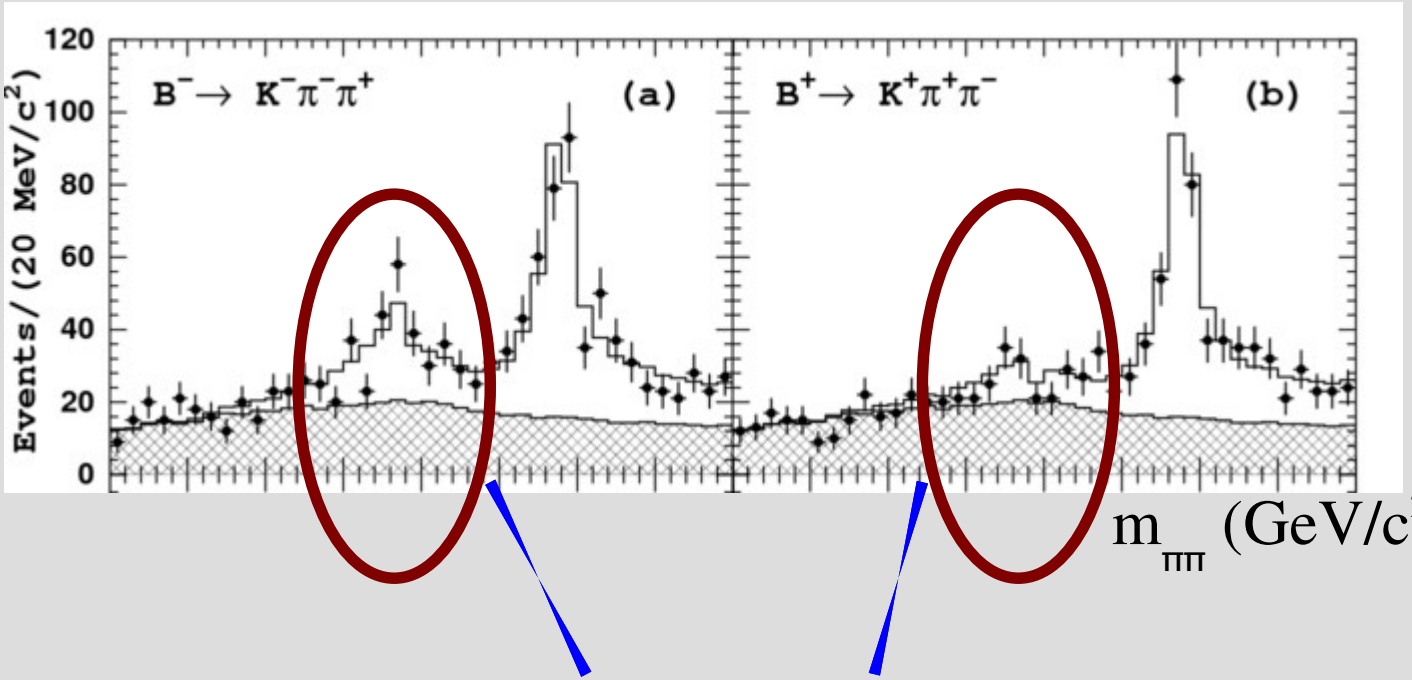
Additional Observables

- Amplitude analysis of 3 body decays ("Dalitz analysis") allows measurement of the total phase and magnitude of each contributing quasi-two-body resonance
  - both phase and magnitude measured relative to something
- Contrast situation for 2 body decays, where only magnitude is observed

  - additional sensitivity to (*eg.*) direct CP violation
  - possibility to disentangle penguin and tree contributions

Direct CP Violation in 3 Body B Decay

Belle, hep-ex/0512066 (submitted to PRL)



Clear asymmetry in the ρ region

$A_{CP}(\rho K^+) = (30 \pm 11 \pm 2\ ^{+11}_{-4})\%$ 3.9σ significance

first evidence for CP in any charged particle!

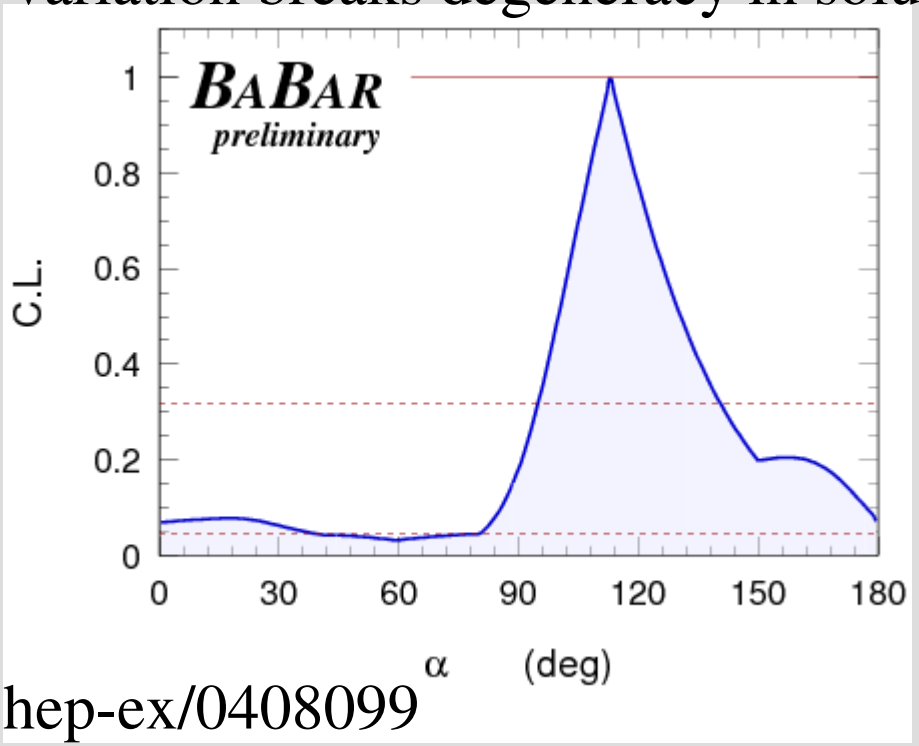
Measurement of α from $B \to \pi^+\pi^-\pi^0$

$B \to \pi^+\pi^-$: measure $S_{\pi\pi}$ & $C_{\pi\pi}$

- not enough information to extract α, |P/T| & $\delta_{P\text{-}T}$

$B \to \pi^+\pi^-\pi^0$: interfering contributions from $\rho^+\pi^-$, $\pi^+\rho^-$ (& $\rho^0\pi^0$)

- sensitivity to phases allows all parameters to be extracted
- BW phase variation breaks degeneracy in solutions



hep-ex/0408099

Methods to Search for NP in 3b0c B Decays

- Extract:
  - α from $B \to \pi^+\pi^-\pi^0$
  - γ from $B \to K\pi\pi$, KKK
  - β_{eff} from $B \to K_S\pi^+\pi^-$, $K_S\pi^0\pi^0$, $K_SK^+K^-$, $K_SK_SK_S$
    - Q2B contributions from $K_S\rho^0$, K_Sf_0, $K^*\pi^0$, etc.
    - $K_S\pi^0\pi^0$, $K_SK_SK_S$ are CP eigenstates
      - DP analysis not essential, but gives additional information

Are measured values consistent with expectation/CKM fits?

Methods to Search for NP in 3b0c B Decays

- Can we do more?
  - extract parameters like |P/T|, δ_{P-T} for each Q2B term
  - compare these to theory SM prediction
    - alternatively, can be used as input for theoretical models
  - compare with parameters measured in different final state
    - can we handle $K_S f_0 \rightarrow K_s K^+K^-$ vs. $K_S f_0 \rightarrow K_s \pi^+\pi^-$?
    - how about $\pi^+(K^+\pi^-)_{S\ wave}$ vs. $\pi^+(K^0\pi^0)_{S\ wave}$?
  - compare with parameters measured in different processes and at different experiments
- Answer is yes, but how much more?
  - open question for this workshop

Pre-Final comments

- Three body charmless B decay analyses are difficult
  - numerous complicated aspects to the physics
  - technically challenging
- Be prepared to be patient, and careful
  - high standards of internal quality control essential
- 3b0c B decay program will continue for the B factory lifetime
  - Nonetheless, timely publication of results essential
- If 3b0c starts looking too easy, you can move to 4b0c

What Would We Like To Measure at B Factories?

- Study Dalitz plot structure in all possible charmless three body B decays
  - including many not mentioned in this talk
  - relate results between different modes, if possible
- Search for CP violation as generically as possible
  - direct CP in flavour specific modes
  - time-dependent CP violation
- Maximize understanding of hadronic interactions
- Search for new physics