It's not just about B mesons

Measurements of the unitarity triangle angles, and selected other results from BaBar

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Klystron Gallery of the 2-mile long PEP-II accelerator

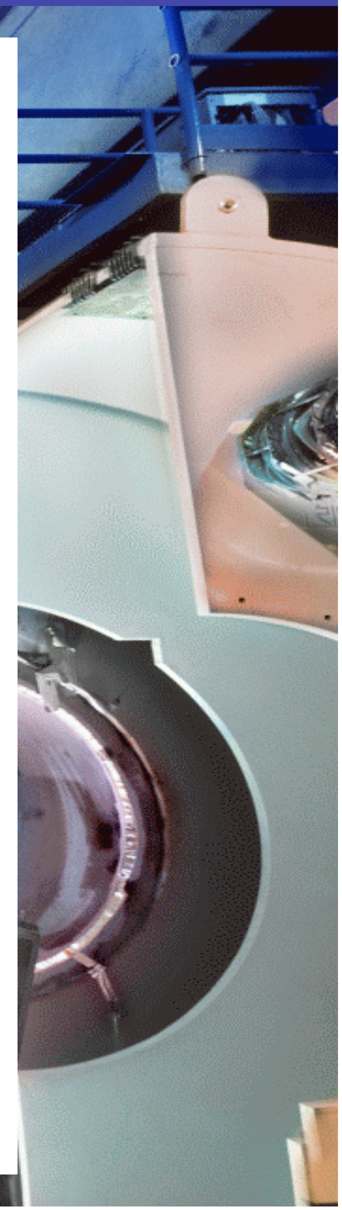
SLAC Research Yard

BaBar Detector

Seminar at Edinburgh University - November 23rd 2006

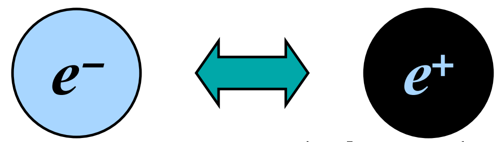
Overview

- Motivation / Introduction
  - The CKM matrix and CP violation
- The BaBar experiment
- Recent results from BaBar
  - Angles β, α and γ
  - Others (as time permits)
    - FCNC in D decays
    - Y(4260)
    - Tau decays
    - $|V_{td}|$ from radiative penguin decays
    - Electroweak penguin decays
    - …
- Outlook



CP symmetry

- Dirac predicted existence of anti-matter in 1928
  - Positron discovered in 1932



- Our Universe contains (almost) only matter

C	charge conjugation	particle ↔ anti-particle
P	parity	$x \to -x,\ y \to -y,\ z \to -z$

- C and *P* symmetries are broken in weak interactions
  - Lee, Yang (1956), Wu et al. (1957),
- Combined *CP* symmetry seemed to be good
  - Anti-Universe can exist as long as it is a mirror image of our Universe
- To create a matter-dominant Universe
  - CP symmetry must be broken
    - This is one of the three necessary conditions Sakharov (1967)

CP Violation

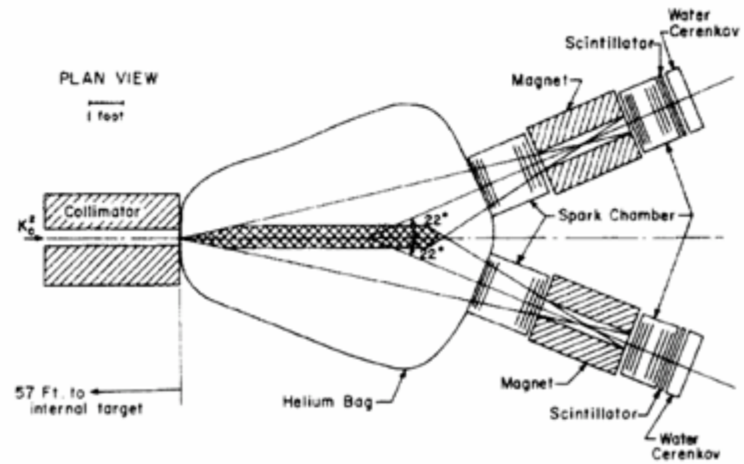
Christenson *et al.* (1964)

- *CP* violation observed in K_L decays
  - K_L decays into either 2 or 3 pions

$$K_L \to (3\pi)^0 = 33\% \quad CP = -1$$

$$K_L \to (2\pi)^0 = 0.3\% \quad CP = +1$$

Final states have different *CP* eigenvalues



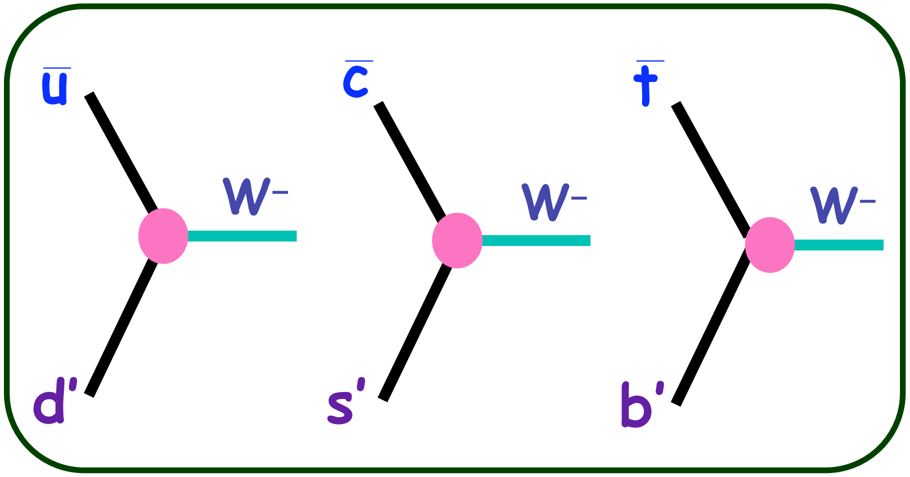
  - Couldn't happen if *CP* was a good symmetry of Nature

➔ Laws of physics apply differently to matter and antimatter

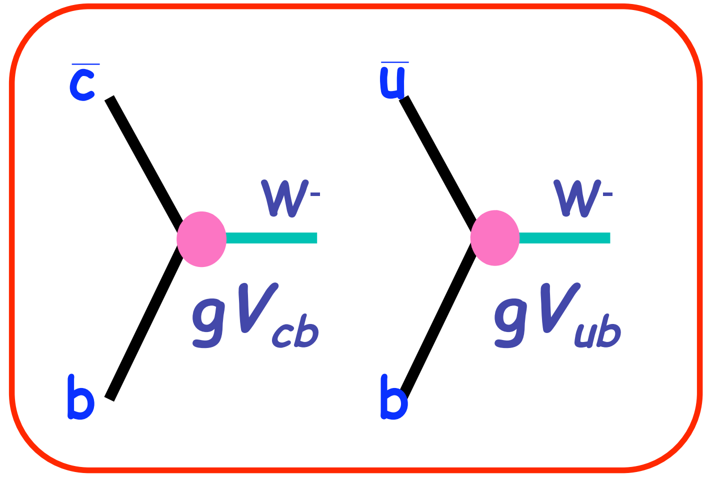
- The complex phase in the CKM matrix causes *CP* violation
  - It is the only source of *CP* violation in the Standard Model

Is there anything else?

The Cabibbo-Kobayashi-Maskawa (CKM) Matrix



Quarks 'couple' within the same generation

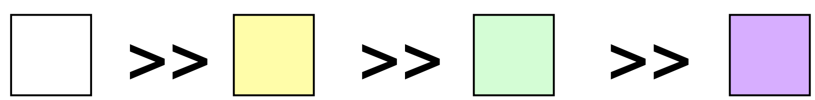


Also 'couple' between generations

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

CKM matrix

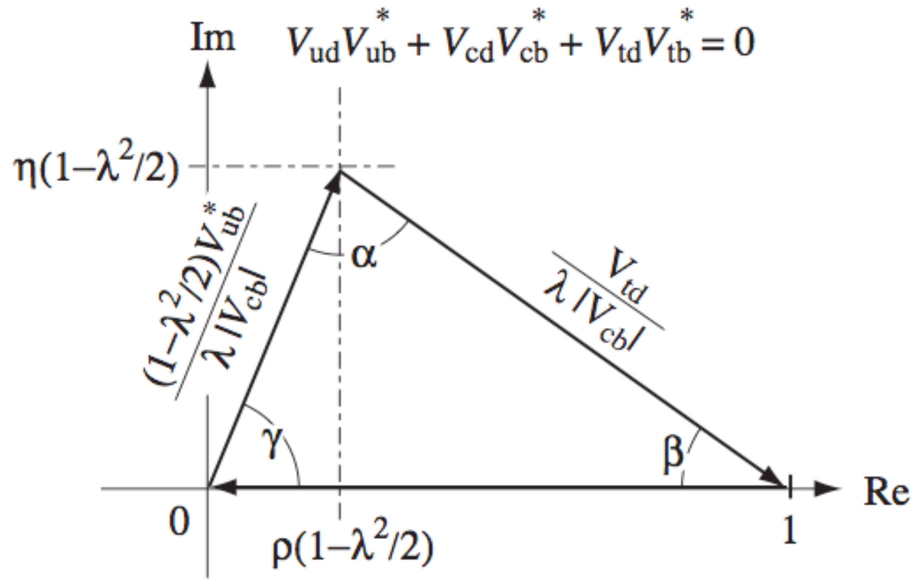
- V_{ij} is the coupling of i^{th} and j^{th} quarks
- Hierachy



The Unitarity Triangle (UT)

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

- $V_{CKM}^{\dagger} V_{CKM} = 1$ gives us



$$\alpha \equiv \arg\left(-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right), \quad \beta \equiv \arg\left(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right), \quad \gamma \equiv \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$$

- So, in theory, we can measure α, β and γ; and the sides of the triangle.
- If the triangle doesn't close, then our picture is incomplete ....

CP violation and New Physics

Are there additional (non-CKM) sources of *CP* violation?

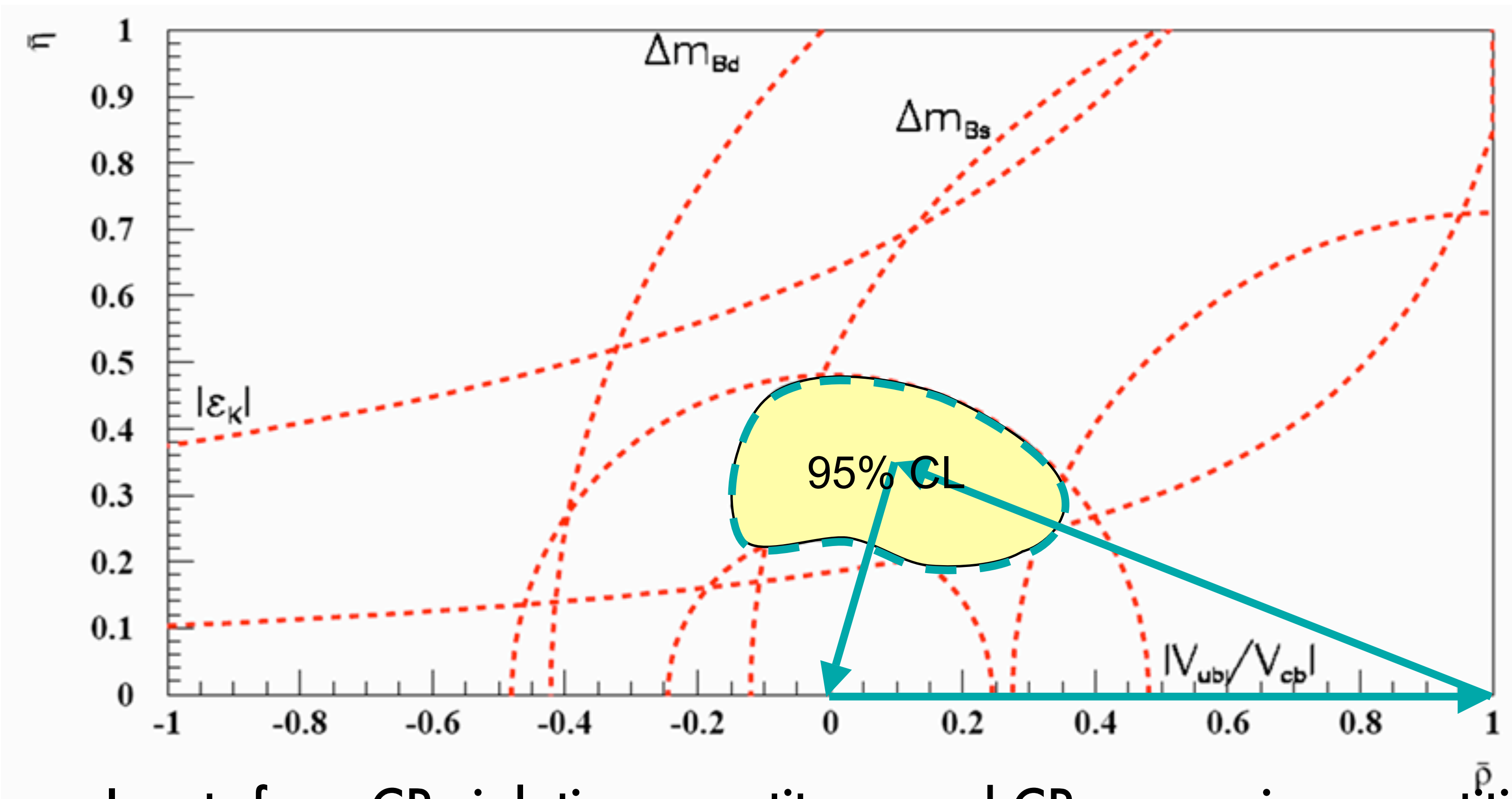
- The CKM mechanism fails to explain the *amount* of matter-antimatter imbalance in the Universe
  - … by several orders of magnitude
- New Physics beyond the SM is expected at 1-10 TeV scale
  - e.g. to keep the Higgs mass < 1 TeV/c^2
  - Almost all theories of New Physics introduce new sources of *CP* violation (e.g. 43 of them in supersymmetry)

New sources of *CP* violation almost certainly exist

- Precision studies of the CKM matrix may uncover them

What did we know about the UT?

- How the UT looked before the B factories

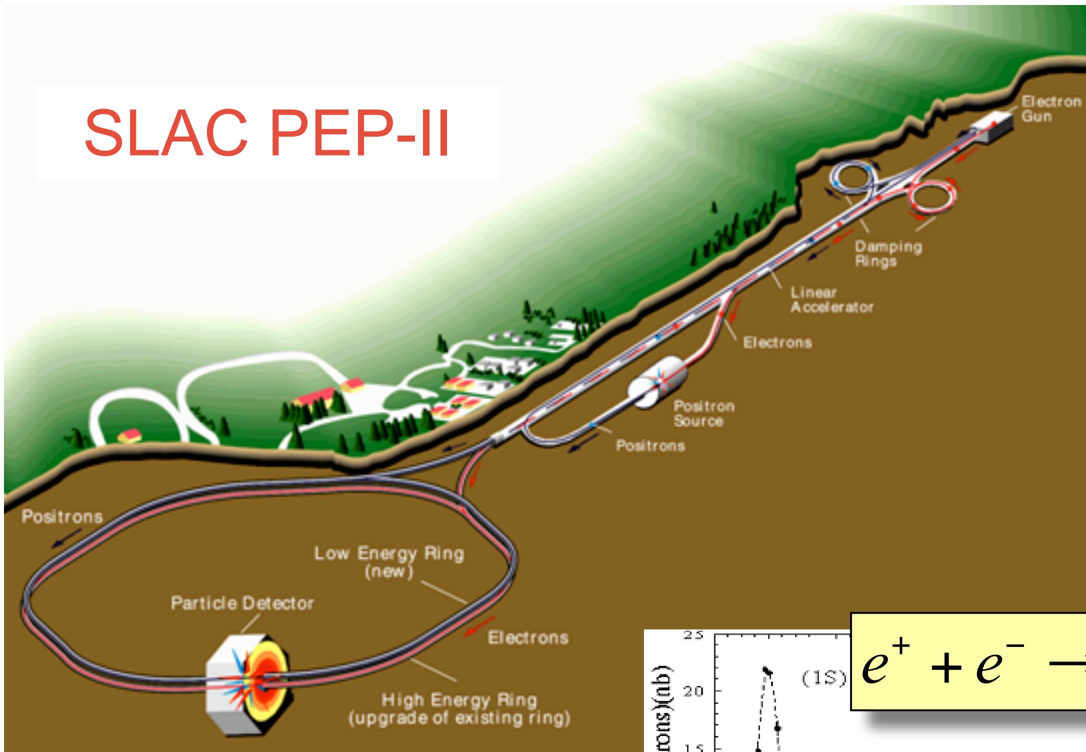


  - Inputs from CP violating quantity ε_K and CP conserving quantities Δm_{Bd} , Δm_{Bs} and $|V_{ub}/V_{cb}|$

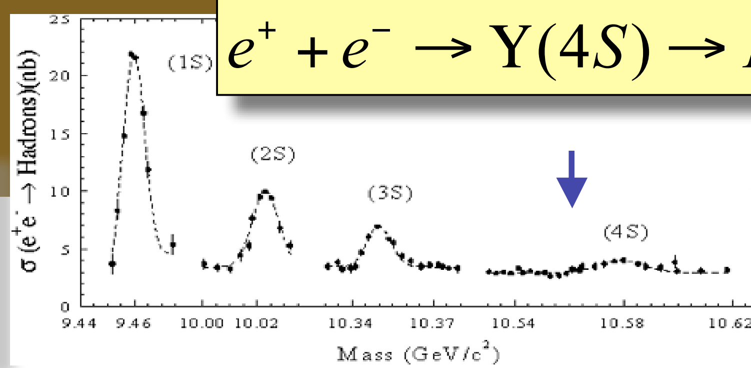
B Factories

- Designed specifically for precision measurements of the *CP* violating phases in the CKM matrix

SLAC PEP-II

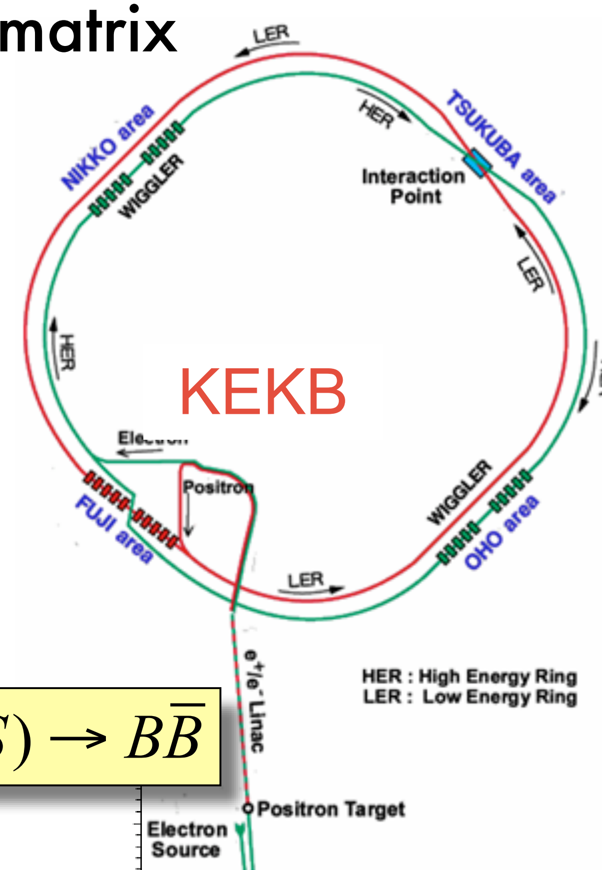


Produce ~10^8 *B*/year by colliding e^+ and e^- with E_{CM} = 10.58 GeV



$$e^+ + e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B}$$

KEKB



1.5T **solenoid**

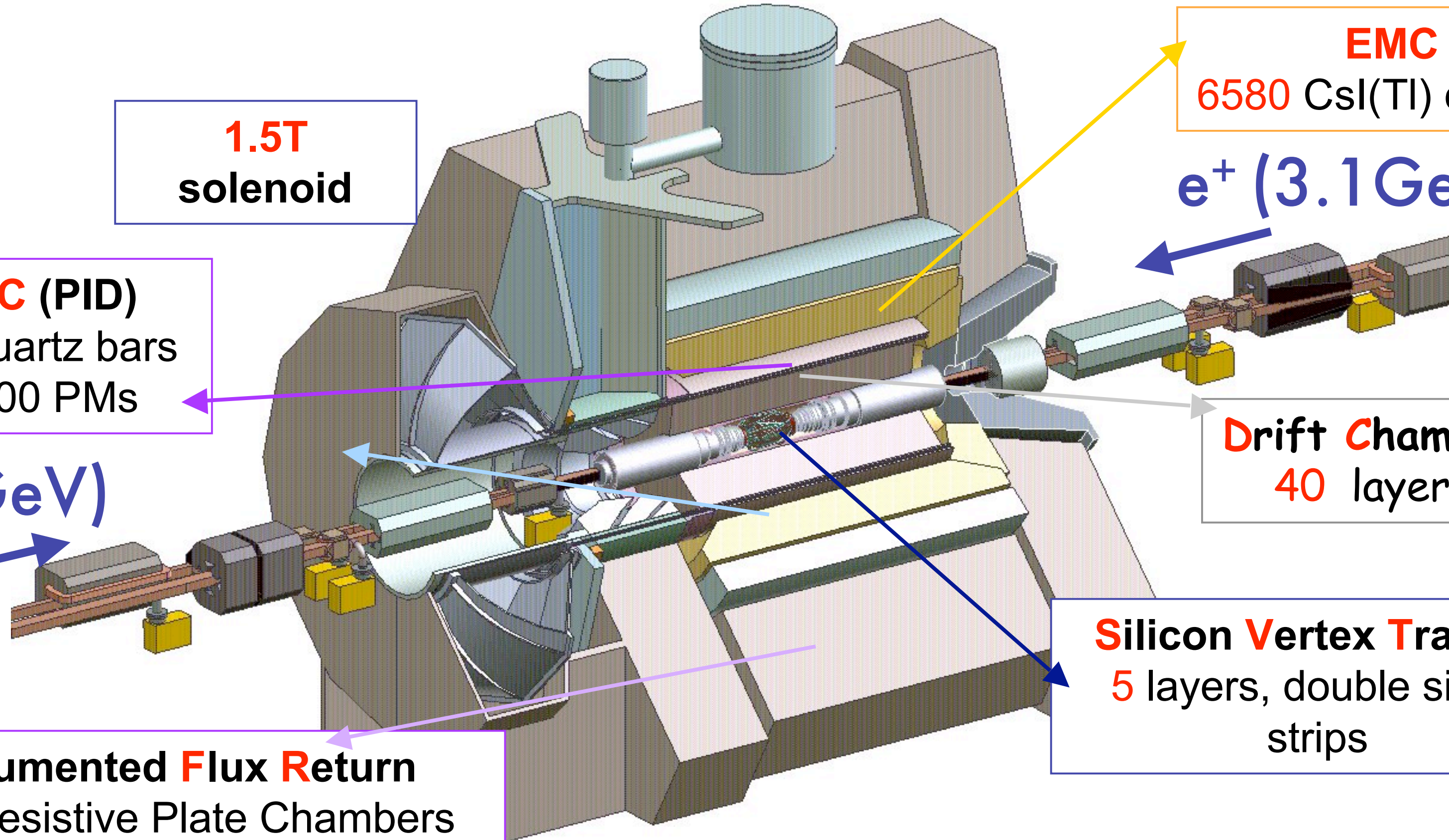
EMC 6580 CsI(Tl) crystals

e^+ (3.1GeV)

DIRC **(PID)**
144 quartz bars
11000 PMs

Drift Chamber
40 layers

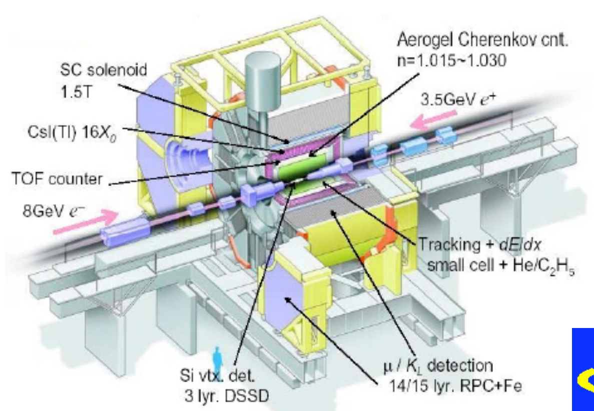
e^- (9GeV)



Silicon Vertex Tracker
5 layers, double sided strips

Instrumented Flux Return
Iron / Resistive Plate Chambers
Limited Streamer Tubes
(muon / neutral hadrons)

Collaboration founded in 1993
Detector commissioned in 1999
Data-taking scheduled until 2008

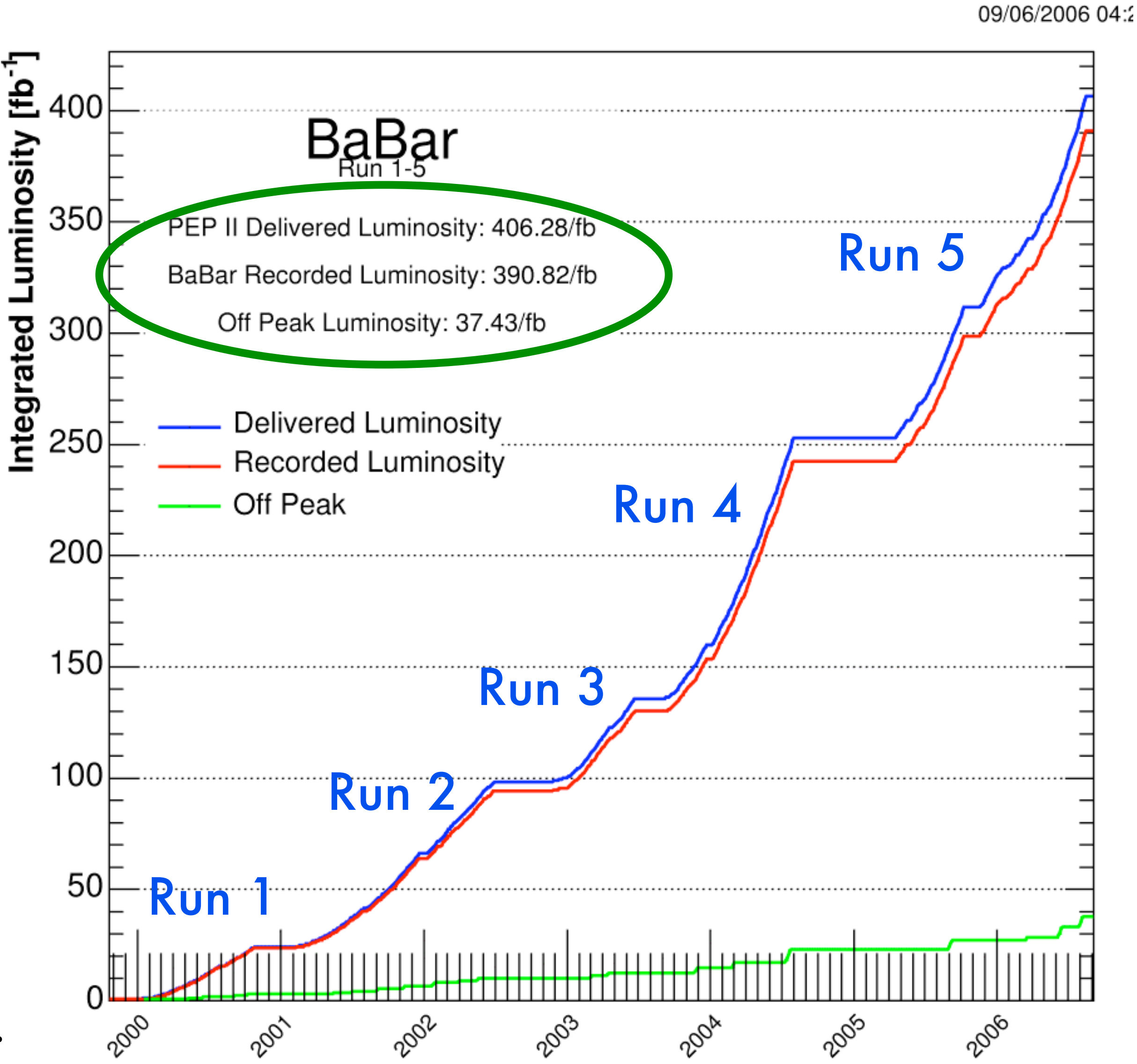


- Belle : 8 GeV electrons, 3.5 GeV positrons
- BaBar : 9 GeV electrons, 3.1 GeV positrons

Integrated data sample to date

- Most recent period of data-taking was Run 5
  - Ended August 16th
- Currently in shutdown
  - Muon system upgrade
- Run 6 scheduled to start in January '07
- End of data-taking in Summer '08

- 623 Physicists from 11countries, 80 institutions.



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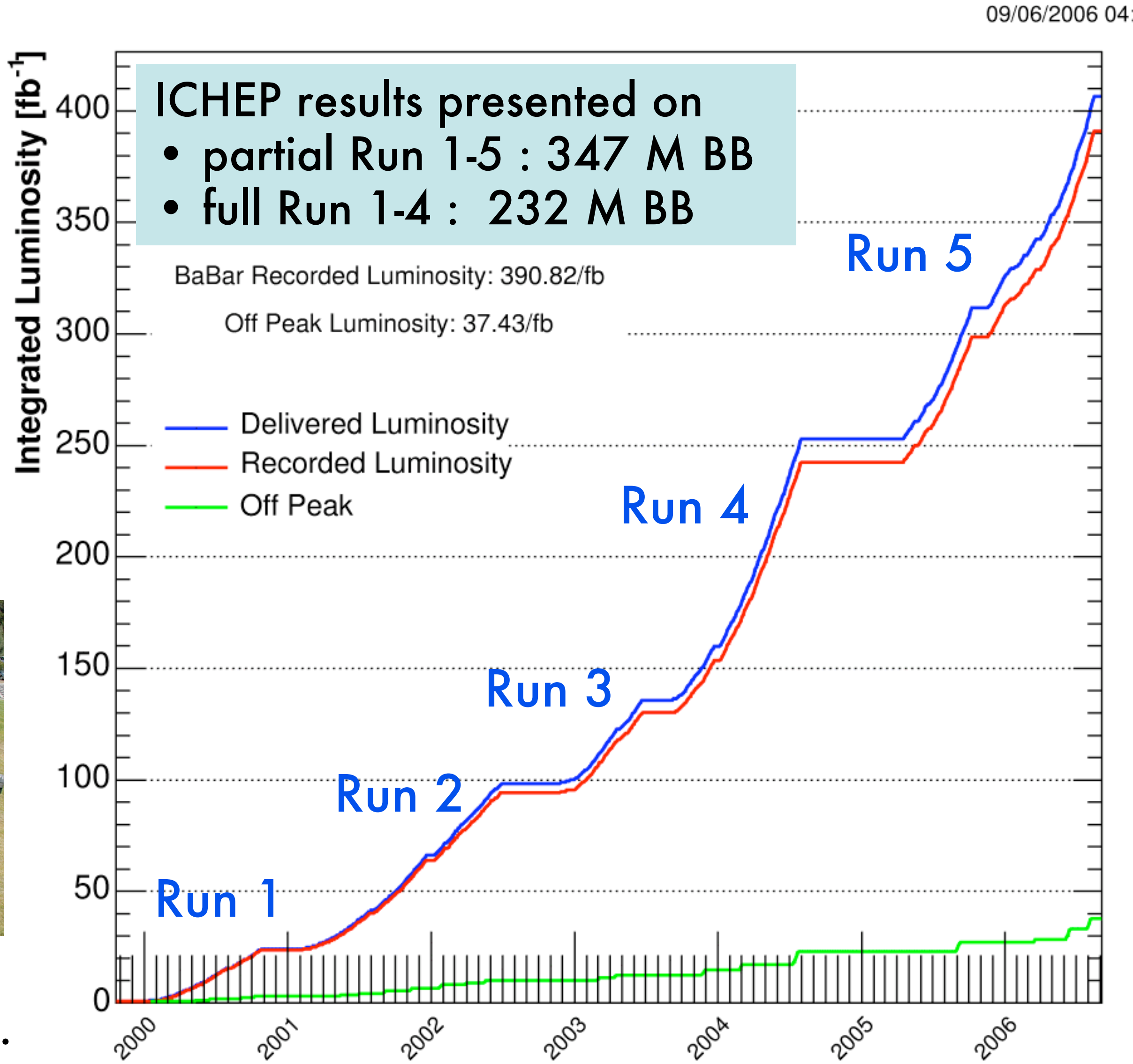
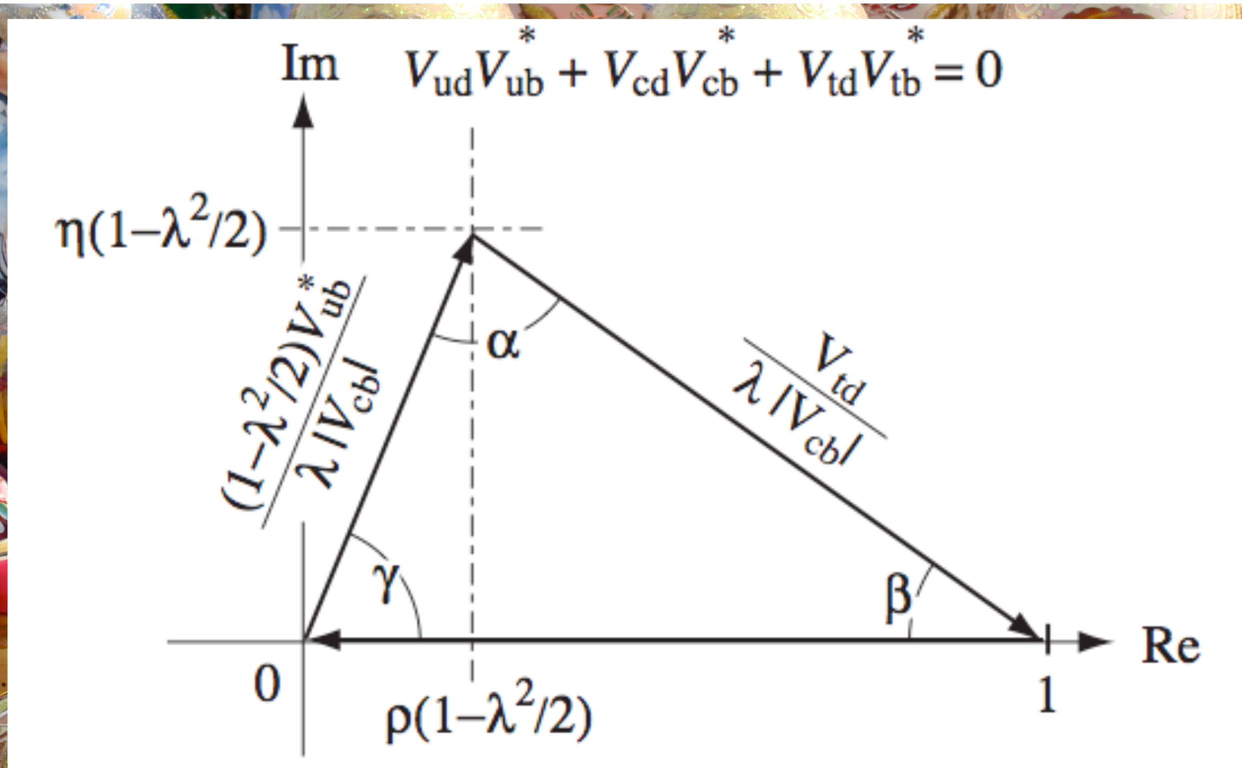
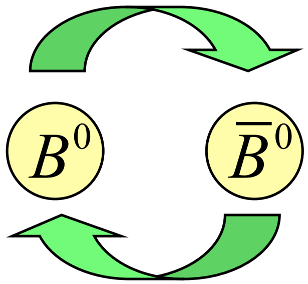


B Factory CKM Measurements

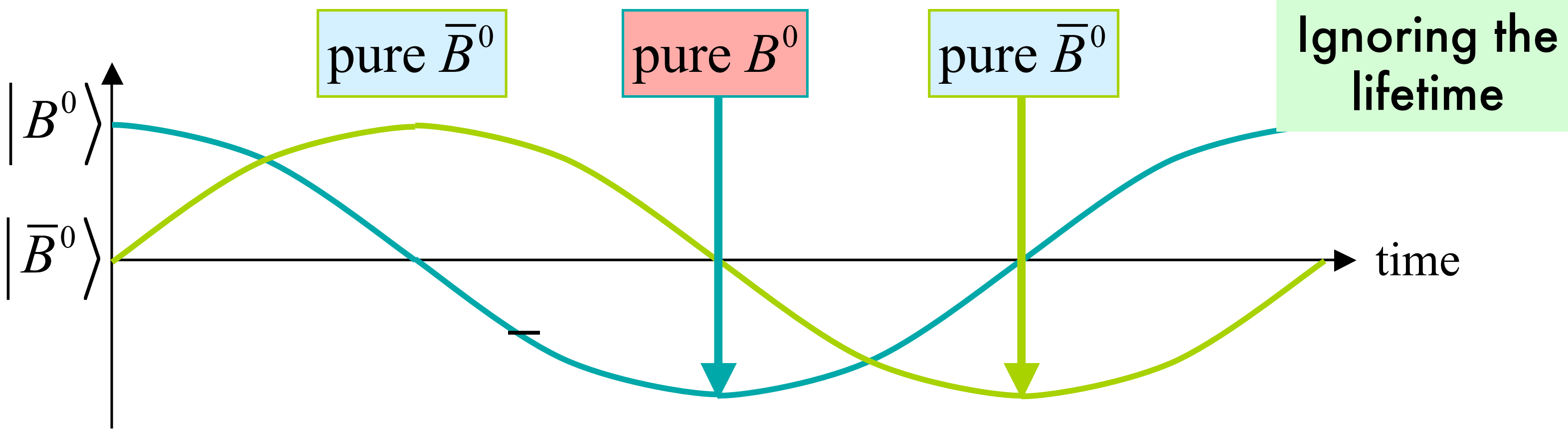
Measurements of the angles and sides of the Unitarity Triangle



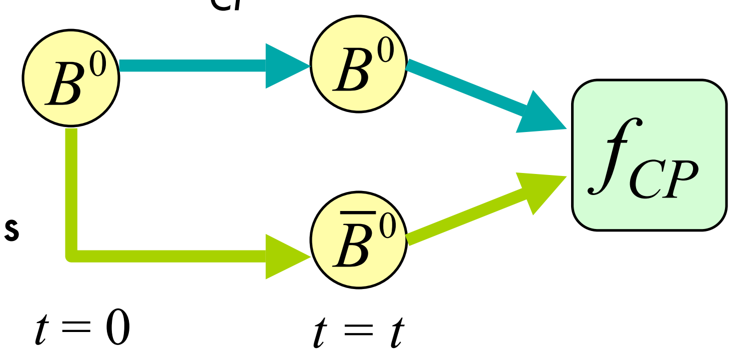
B^0 mixing and decay

$B^0 = (\bar{b}d)$  $\overline{B}^0 = (b\bar{d})$

- Starting from a pure $|B^0\rangle$ state, the wave function evolves as



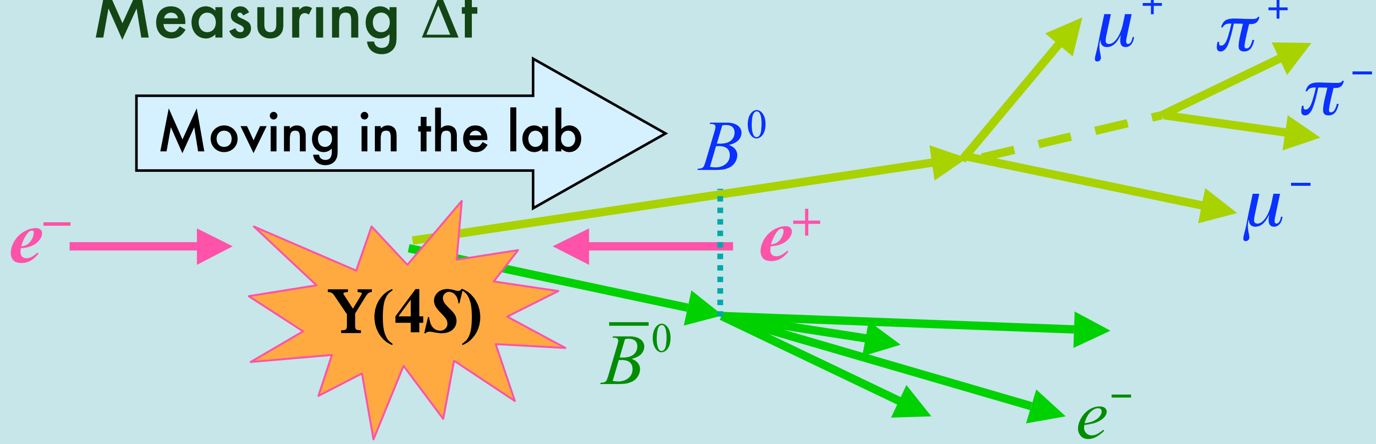
- Suppose B^0 and B^0 can decay into a same final state f_{CP}
  - Two paths can interfere
  - Decay probability depends on:
    - the decay time t
    - the relative complex phase between the two paths



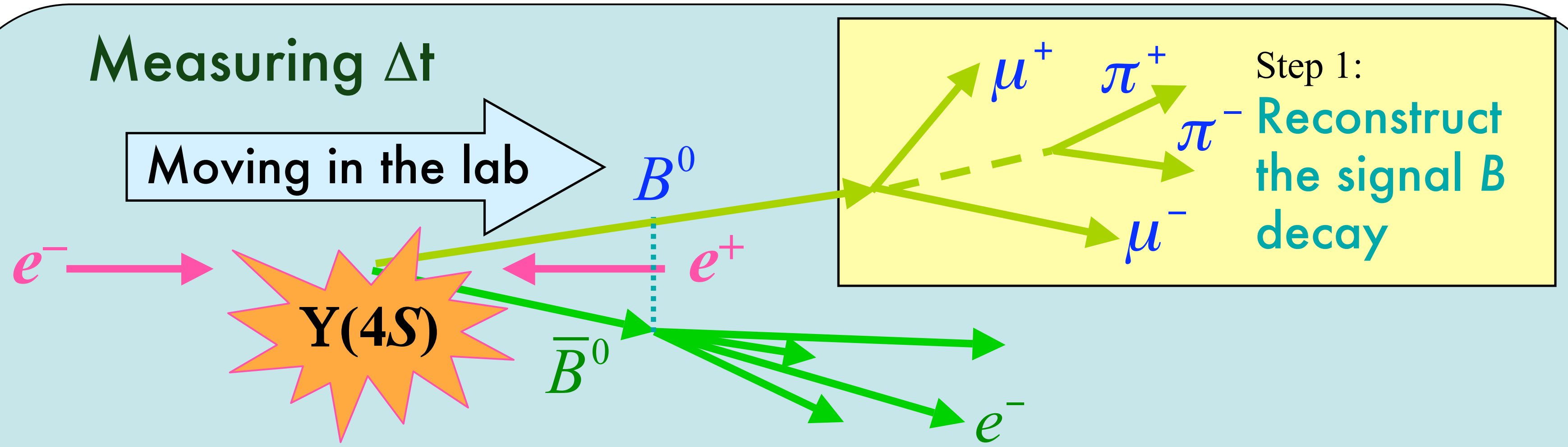
- Time-dependent asymmetry A_{CP}

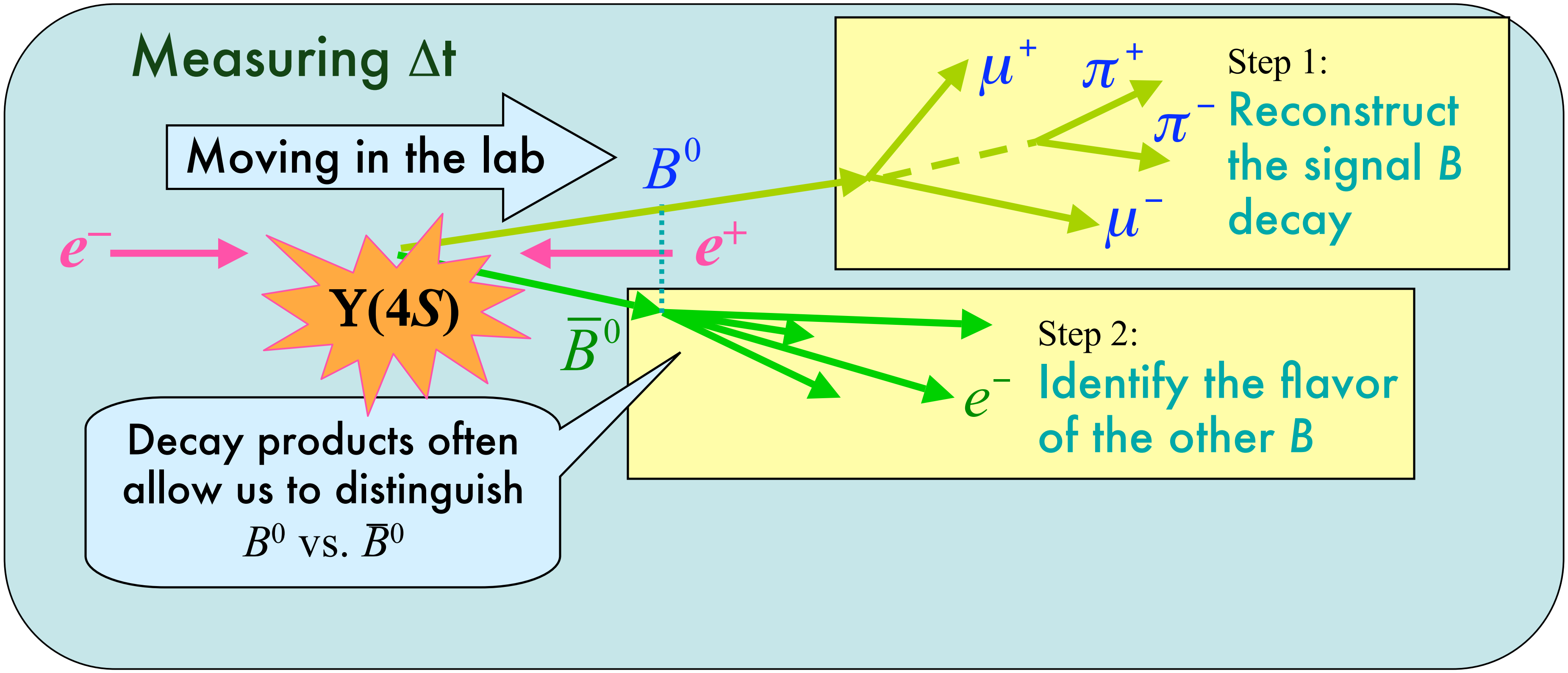
$$A_{CP}(t) = \frac{N(\overline{B}^0(t) \to f_{CP}) - N(B^0(t) \to f_{CP})}{N(\overline{B}^0(t) \to f_{CP}) + N(B^0(t) \to f_{CP})} = S\sin(\Delta m \Delta t) - C\cos(\Delta m \Delta t)$$

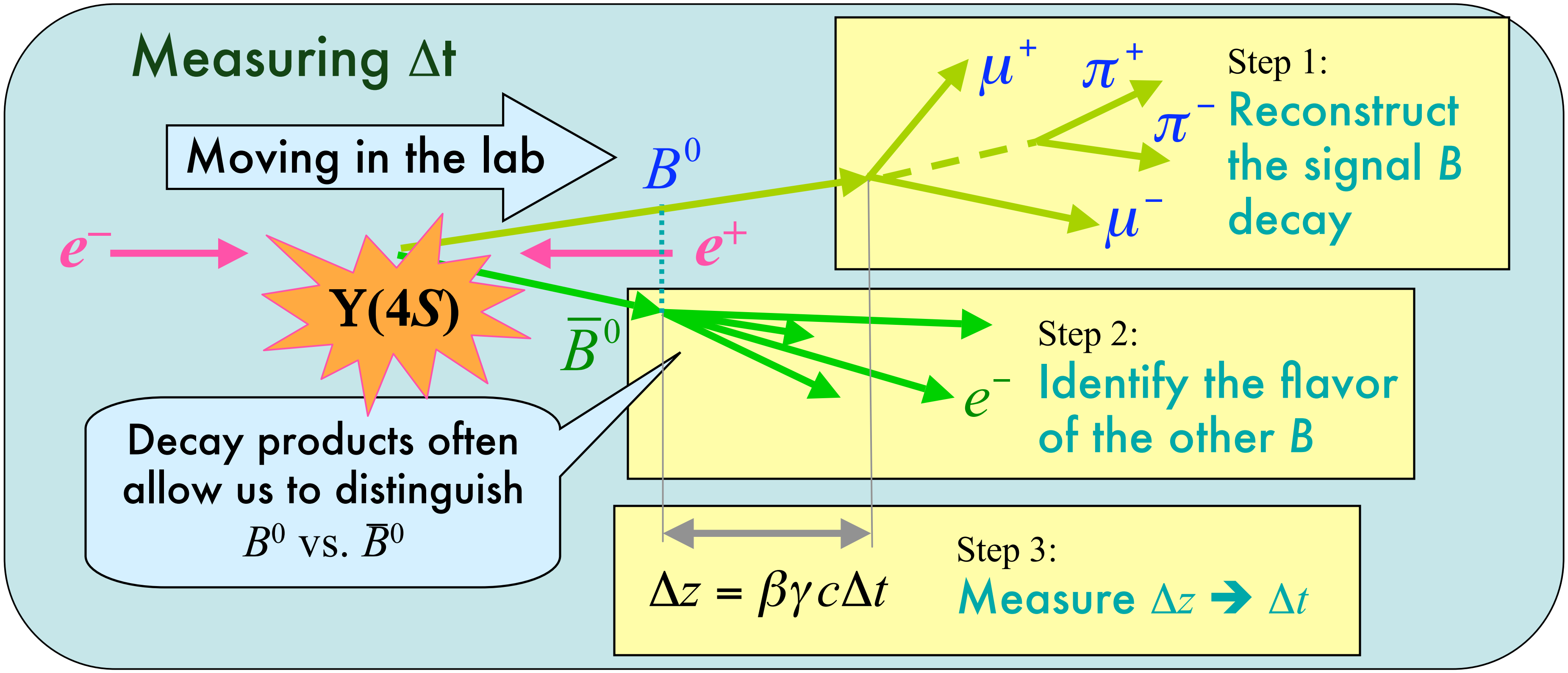
Measuring Δt



Measuring Δt




Measuring Δt
Moving in the lab
B^0
e^-
e^+
Υ(4S)
$\overline{B}^0$
μ^+
π^+
π^-
μ^-
Step 1:
Reconstruct the signal B decay
e^-
Step 2:
Identify the flavor of the other B
Decay products often allow us to distinguish B^0 vs. $\overline{B}^0$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π^-
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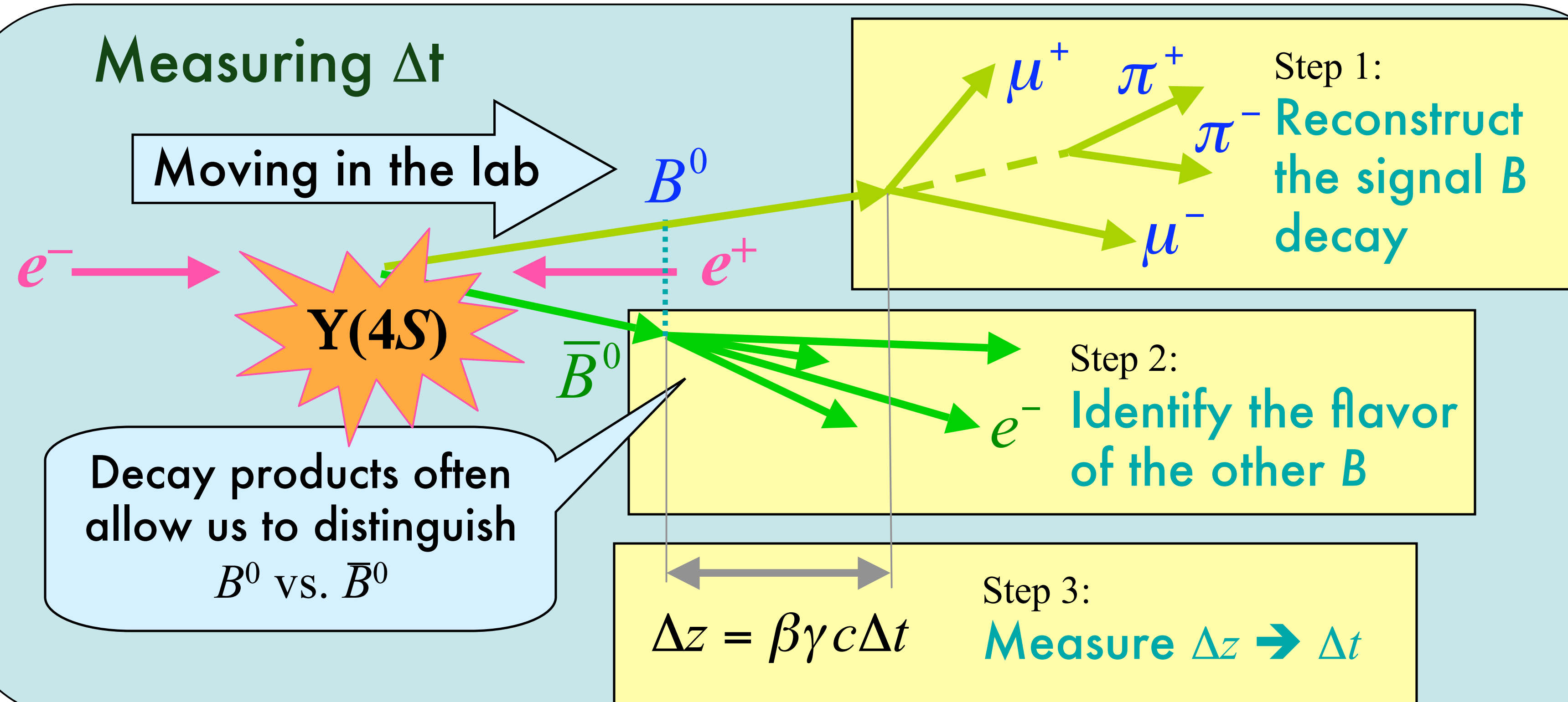
Step 1:
Reconstruct the signal B decay
e^-
Step 2:
Identify the flavor of the other B
Decay products often allow us to distinguish B^0 vs. $\overline{B}^0$
$\Delta z = \beta\gamma c\Delta t$
Step 3:
Measure $\Delta z \rightarrow \Delta t$

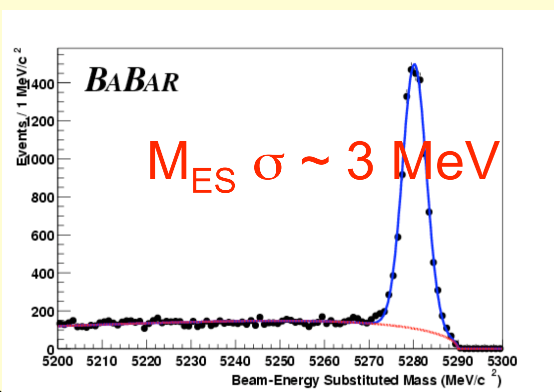
Measuring Δt

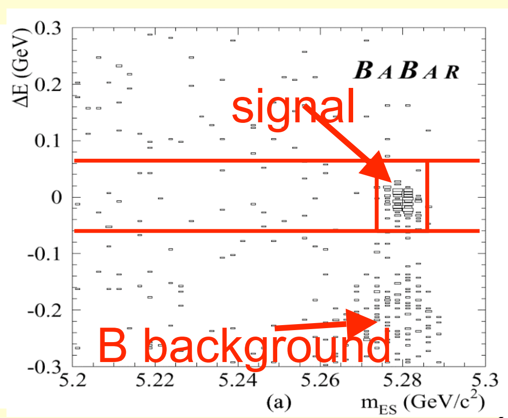


Typical analysis variables

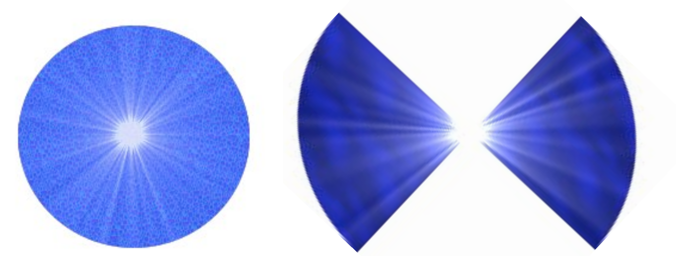
$$m_{ES} = \sqrt{(E^*_{beam})^2 - P_B^2}$$

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





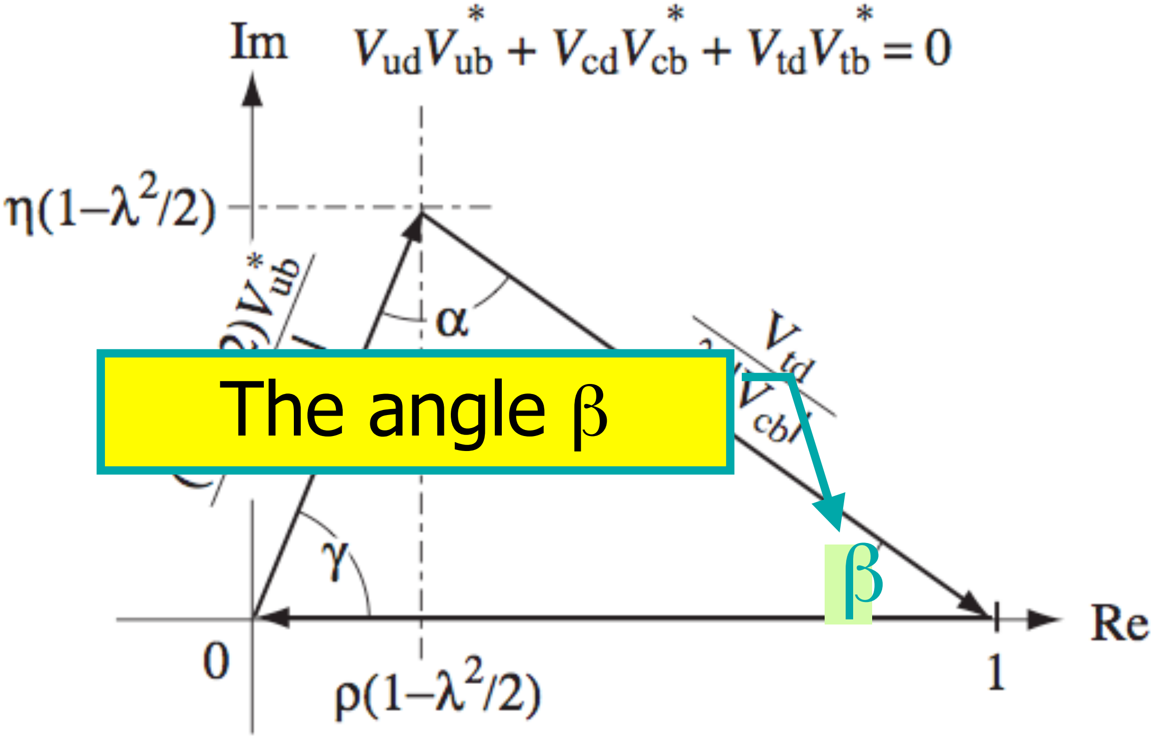
Continuum suppression



B events tend to be spherical
Continuum (ee to qq) events are 'jetty'

UT angles measurements

The angle β



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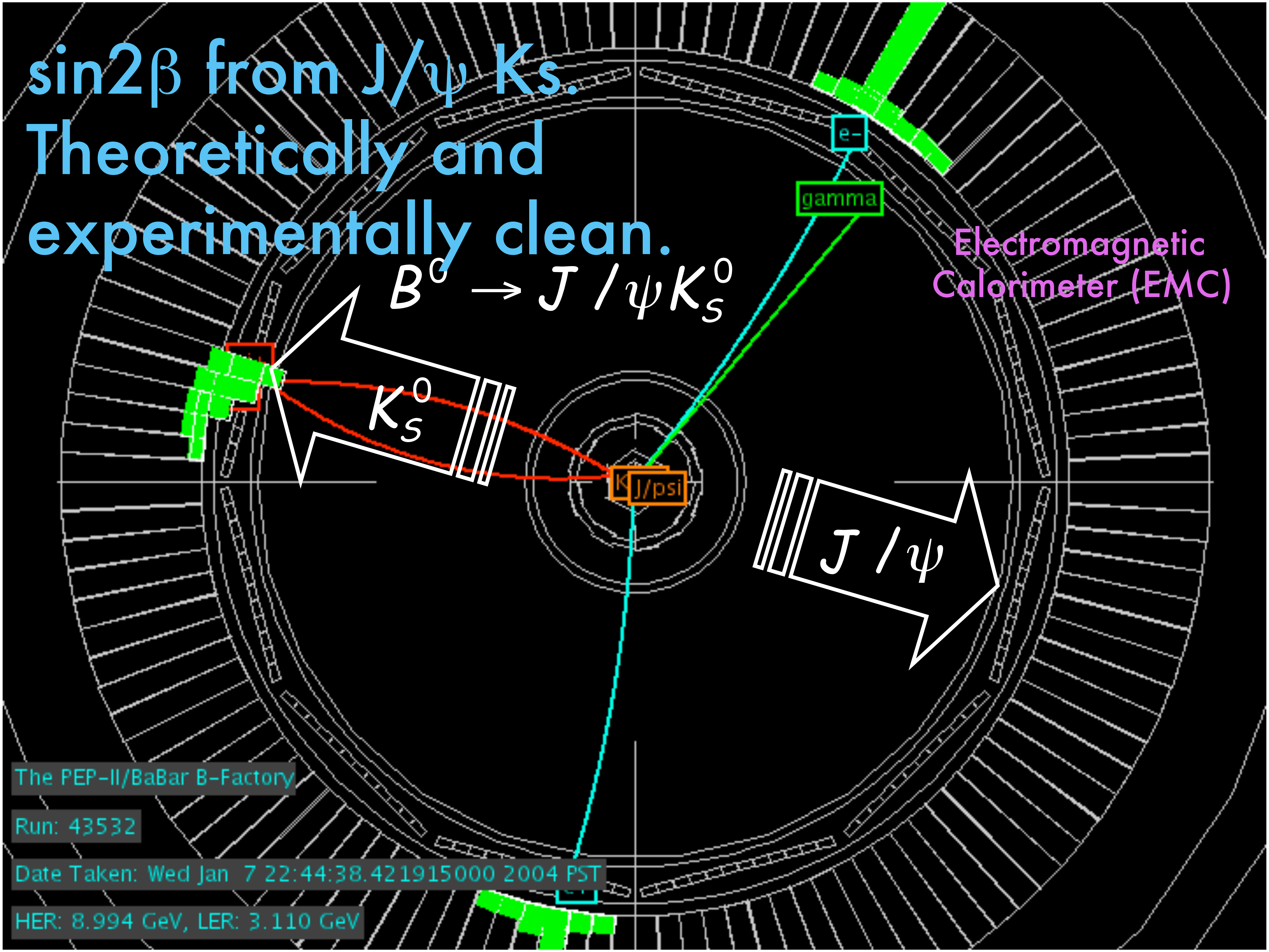
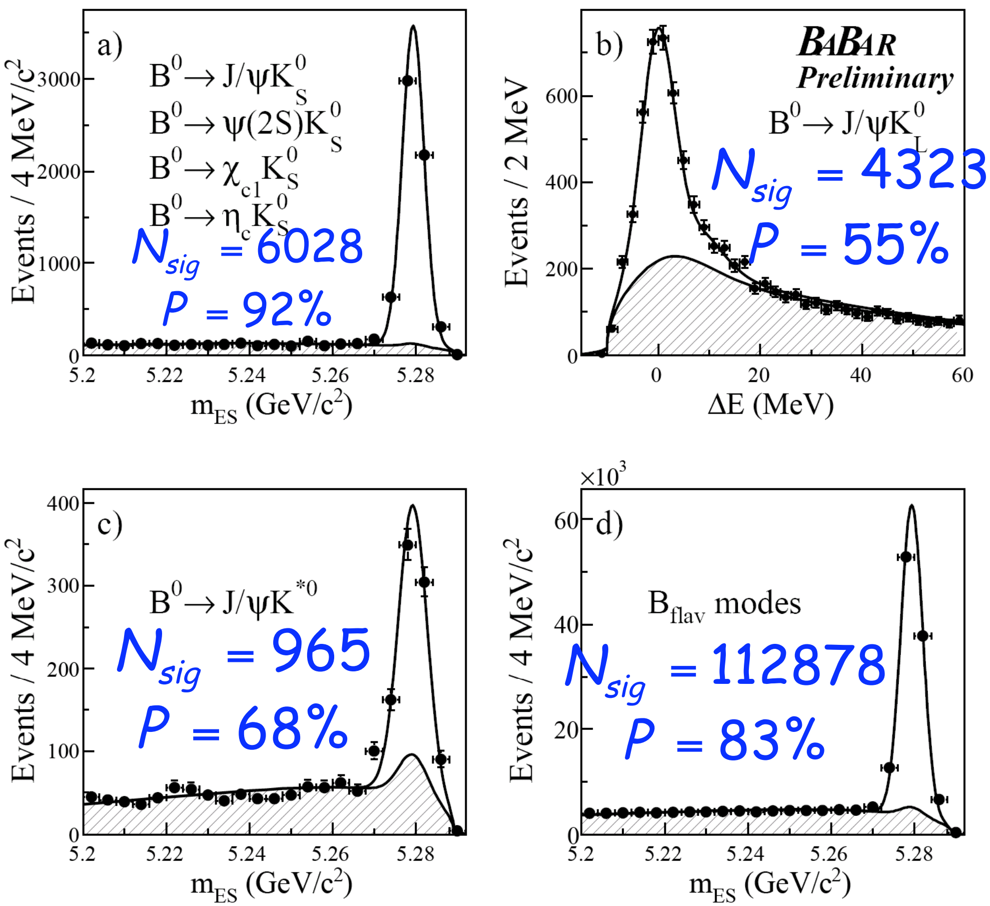
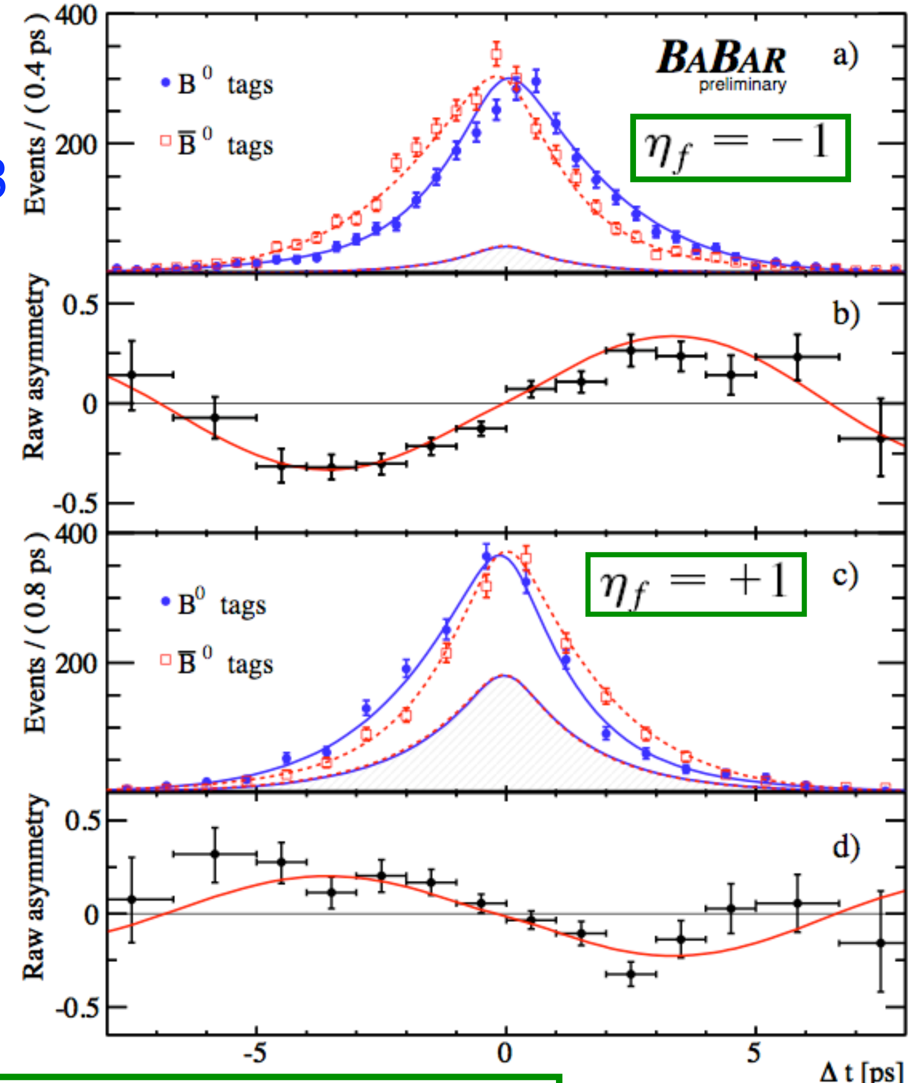
sin2β from J/ψ Ks. Theoretically and experimentally clean.



BaBar charmonium sample





311 M BB pairs

hep-ex/0607107

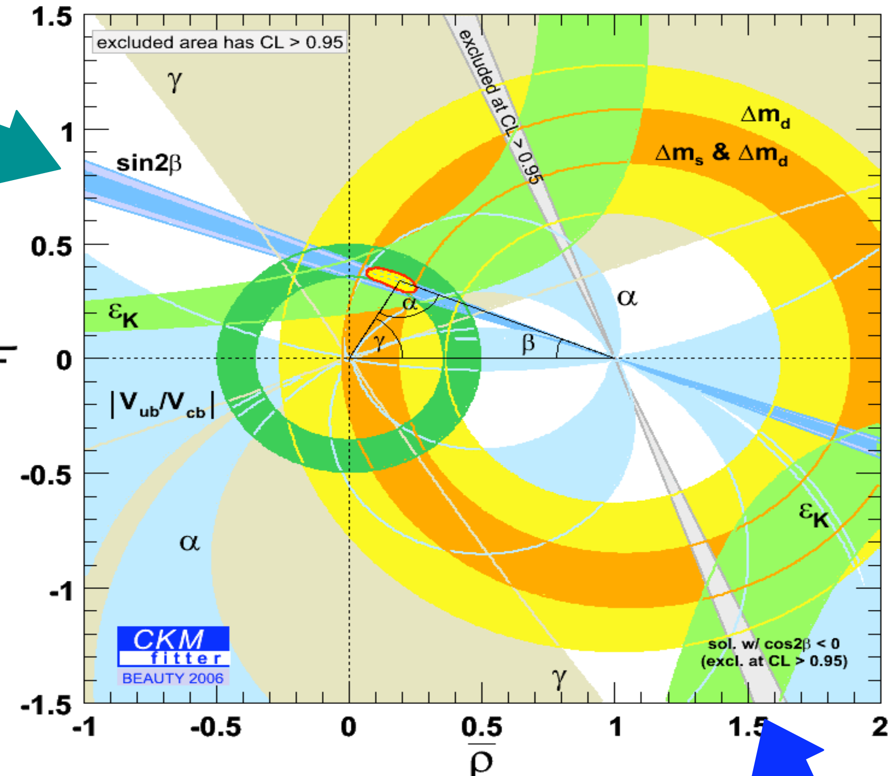
$$\sin 2\beta = 0.710 \pm 0.034(\text{stat}) \pm 0.019(\text{syst})$$

4-fold ambiguity in the $\bar{\rho}$-$\bar{\eta}$ plane

- Measuring sin(2β) from $b \rightarrow c\bar{c}s$ decay modes leaves a 4-fold ambiguity on β as shown in the $\bar{\rho}$-$\bar{\eta}$ plane:

cos2β > 0

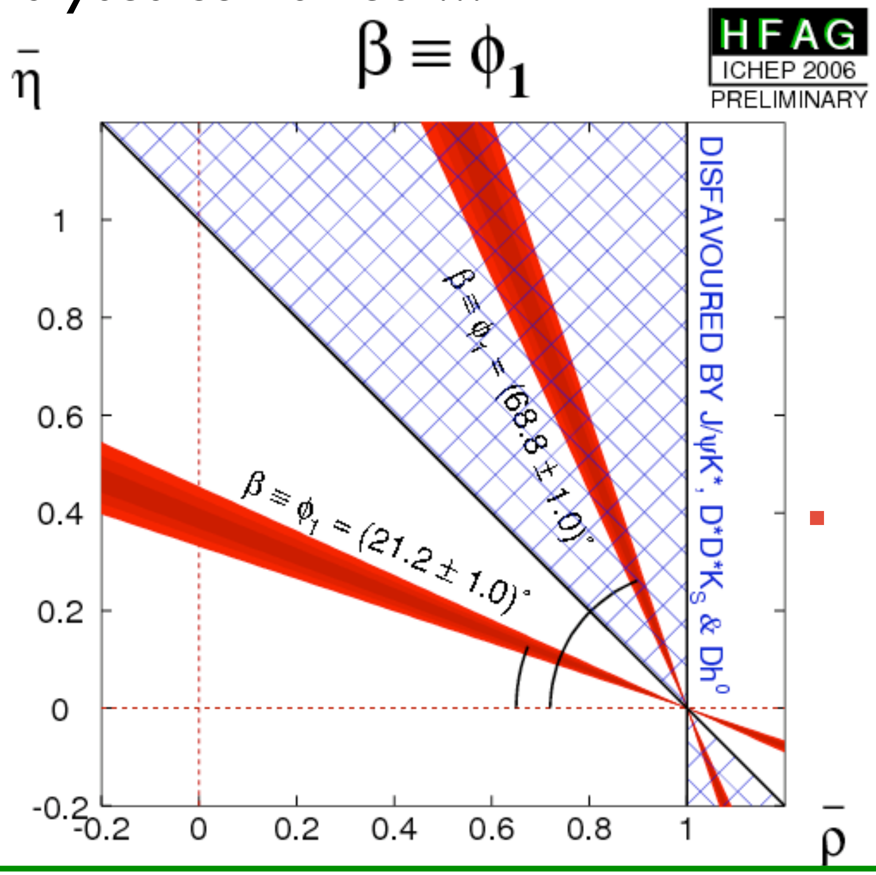
- Resolve by measuring the sign of cos(2β).
- Use strong phase information e.g. Dalitz mode to distinguish between different interference effects in cos2β > 0 and cos2β < 0.



cos2β < 0

Impact of cos2β measurements

- BaBar (see right) + Belle $B^0 \to D^{(*)0}h^0$ and $B^0 \to J/\psi K^*$ analyses combined …



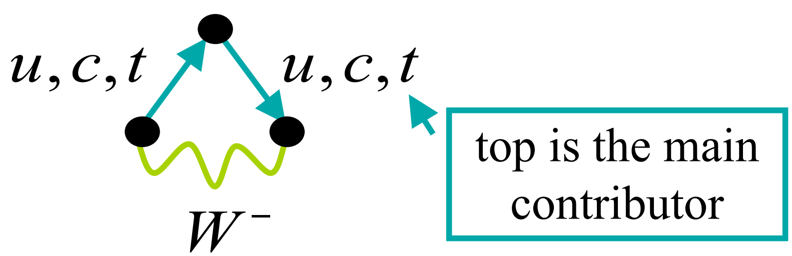
Inputs from BaBar …

- $B^0 \to D^{(*)0}h^0$
  - Time-dependent Dalitz analysis of $D^0 \to K_S\pi^+\pi^-$
  - 311 M BB pairs
  - Model independent
  - Varying strong phase of the Dalitz plot resolves the $(\beta, \pi/2 - \beta)$ ambiguity.
  - Prefers $\beta = 22°$ to $\beta = 68°$ at 87% CL
    - hep-ex/0607105
- Time dependent analysis of $B^0 \to D^{*+}D^{*-}K_S$ (232 M BB pairs)
  - Model dependent -
  - $\cos(2\beta) > 0$ at 94% CL
    - hep-ex/0608016

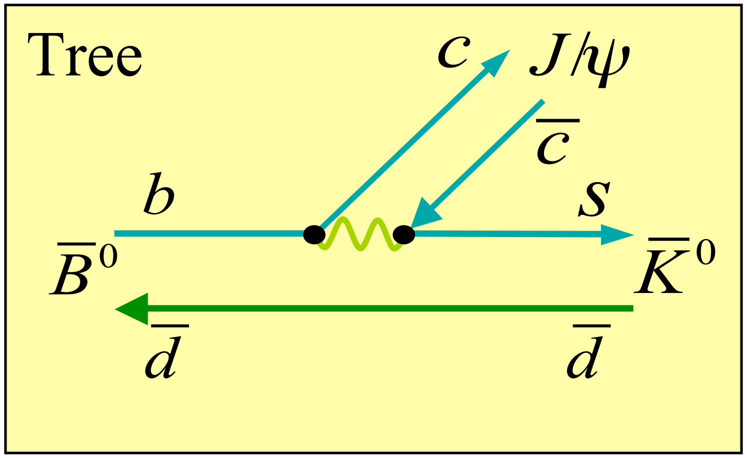
⟹ Standard Model solution of $\beta = (21.1 \pm 1.0)°$ is strongly favoured.

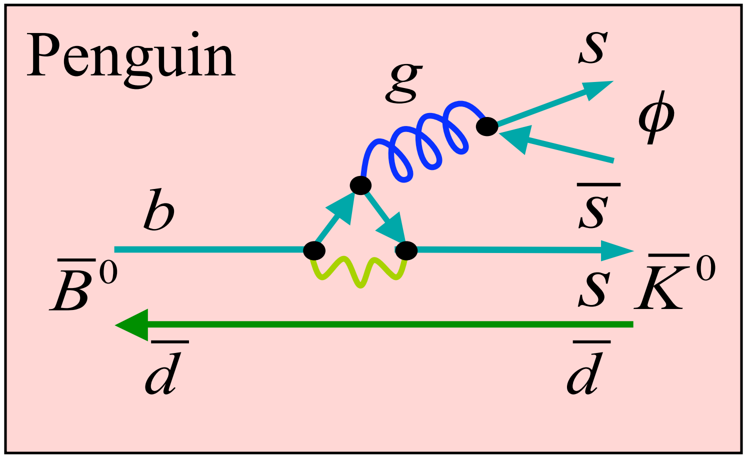
Angle β from penguin decays

- The Golden mode is $b \to c\bar{c}s$
- Consider a different decay e.g., $b \to s\bar{s}s$
  - *b* cannot decay directly to *s*
  - Main diagram has a loop



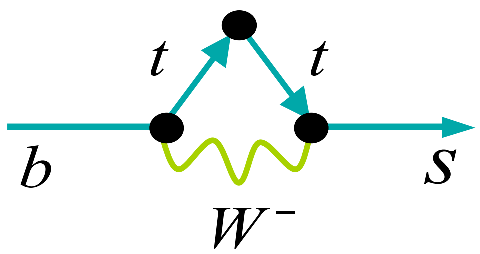
  - Phase from the CKM matrix is identical to the Golden Mode
- Can measure angle β in e.g. $B^0 \to \phi K_S$ and $B^0 \to \eta' K_S$

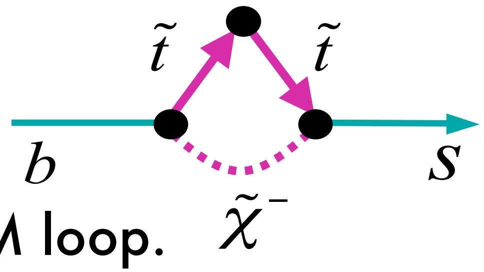




New Physics in the loop ?

- The loop is entirely virtual
  - Could be made of unknown heavier particles
- Most New Physics scenarios predict multiple new particles in 100-1000 GeV
  - Lightest ones close to m_{top} = 174 GeV
  - Their effect on the loop can be as big as the SM loop.



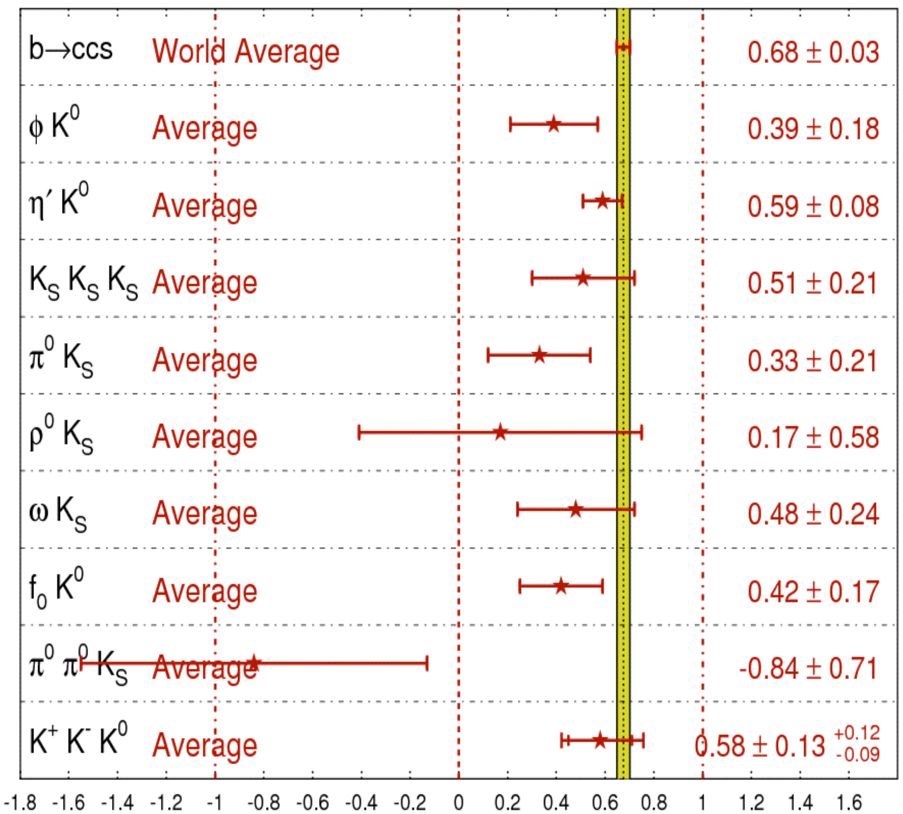


∴Comparing penguins with trees is a sensitive probe for New Physics

Hints of New Physics ?

$$\sin(2\beta^{\text{eff}}) \equiv \sin(2\phi_1^{\text{eff}})$$

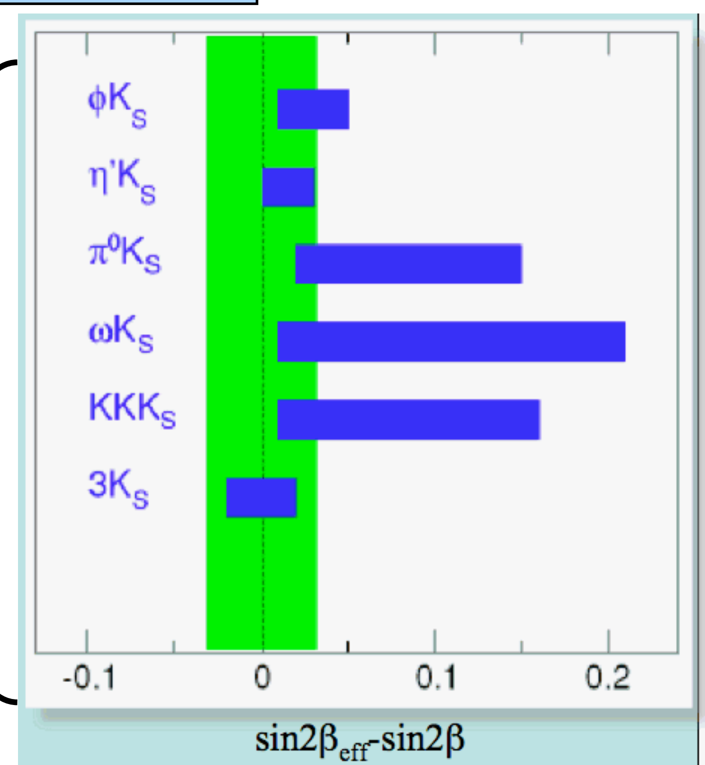
HFAG
ICHEP 2006
PRELIMINARY



- Measured *CP* asymmetries show the trend
  - Belle + BaBar combined

$$\sin 2\beta(\text{penguin}) < \sin 2\beta(\text{tree})$$

Penguin decays



- New physics is predicted to affect different modes in different ways
- Need more data ….

Observation of CP violation in η'K

New Form of CP Violation Discovered

Finding something expected has brought researchers at SLAC one step closer to discovering the unexpected.

The BaBar collaboration has discovered that CP violation—an asymmetry between the behavior of matter and antimatter—exists even in a very rare class of particle decays. This result offers the most sensitive avenue yet for exploring matter-antimatter asymmetries, with implications for the future understanding of physics beyond the Standard Model.

"BaBar has proven to be a fantastic instrument for exploring the origins of matter-antimatter asymmetries, allowing us to probe with exquisite precision very rare processes related to how the early universe came to be matter dominated," said BaBar Spokesperson David MacFarlane.

The Standard Model theory provides a beautifully consistent picture of the building blocks of the subatomic world around us and the forces between them. Yet we now know it only describes 5 percent of the total mass of universe and leaves many fundamental questions in particle physics and cosmology unanswered. The very rare particle decays studied by the BaBar collaboration could offer the first hints of a breakdown of the Standard Model. By reaching the threshold where asymmetries in such decays can be seen, the BaBar collaboration has opened the door to finding new physics.

"Demonstrating a significant level of CP violation in these rare modes is a watershed for BaBar," said Professor Fernando Palombo of the INFN (the Italian Nuclear Physics Institute) and the Department of Physics of the University of Milan. "It also allows us to pose the next question: does the size of the asymmetry match expectations from the Standard Model?"

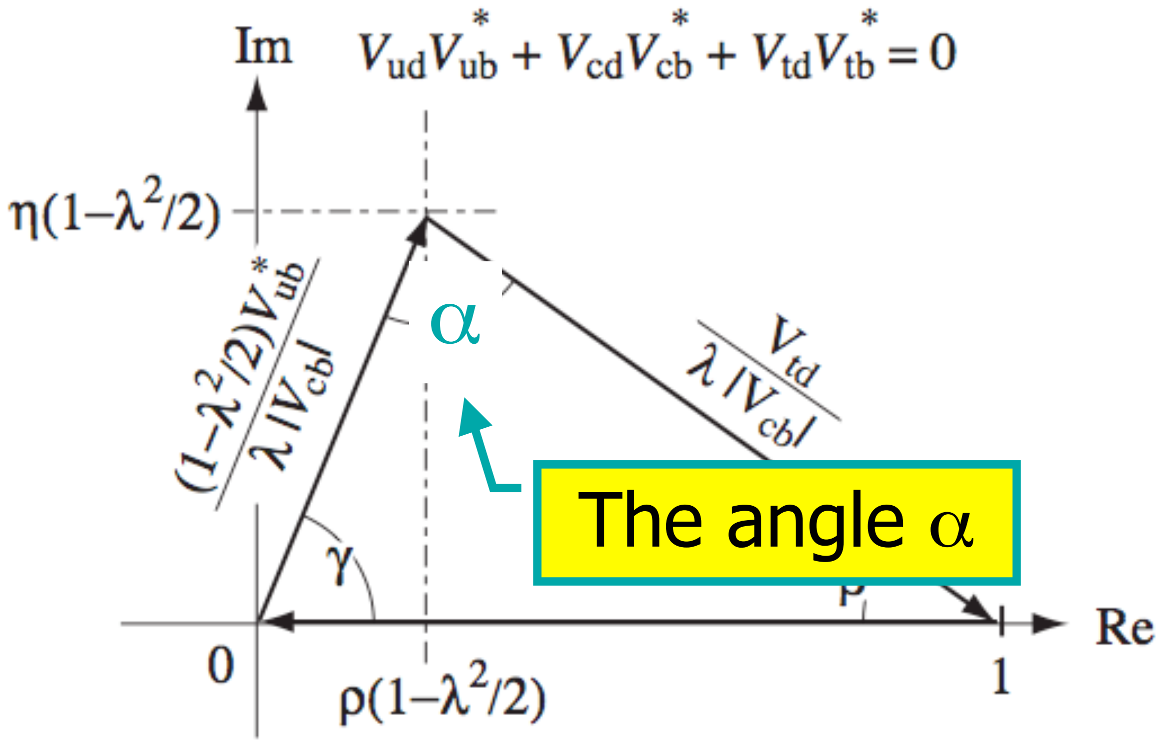
http://today.slac.stanford.edu/feature/cp-violation-092806.asp

- S = 0.581 +/- 0.10 +/- 0.03
  - Mixing induced CP violation with 5.5σ significance.
- C = -0.16 +/- 0.07 +/- 0.03
  - 2.1σ from zero.

384 M BB pairs

(Submitted to PRL)

The angle α



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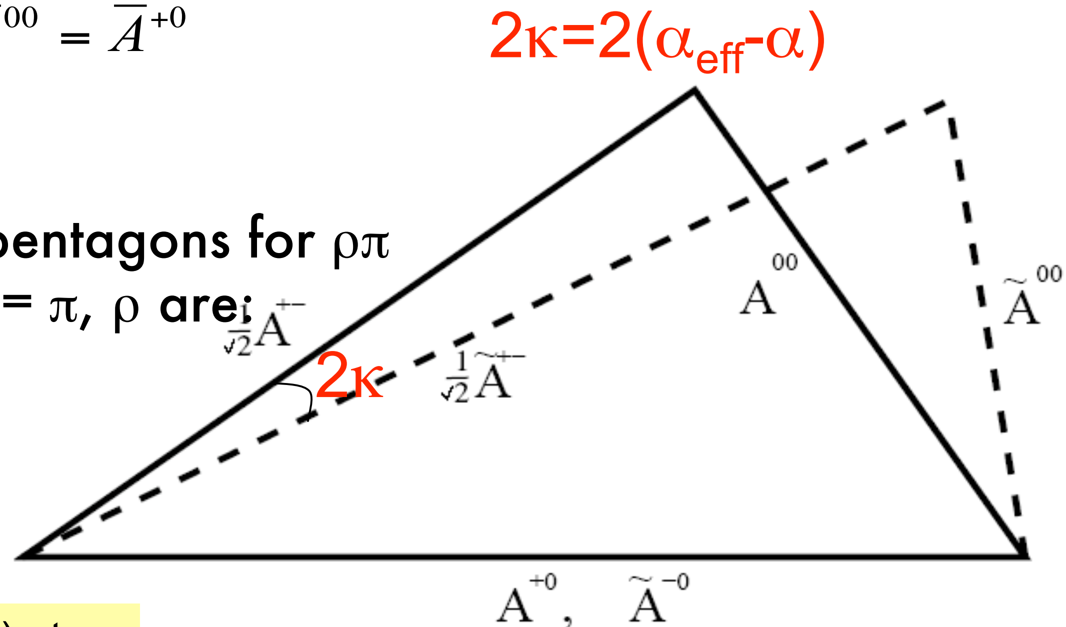
Isospin analysis : B $\rightarrow \rho\rho$, $\rho\pi$, $\pi\pi$

- Different B $\rightarrow \rho\rho$, $\rho\pi$, $\pi\pi$ final states can be related to each other through isospin amplitudes [SU(2) isospin symmetry].
- Amplitude relations can be used to constrain the penguin shift in the time-dependent measurements of these decays.

$$\frac{1}{\sqrt{2}} A^{+-} + A^{00} = A^{+0}$$

$$\frac{1}{\sqrt{2}} \overline{A}^{+-} + \overline{A}^{00} = \overline{A}^{+0}$$



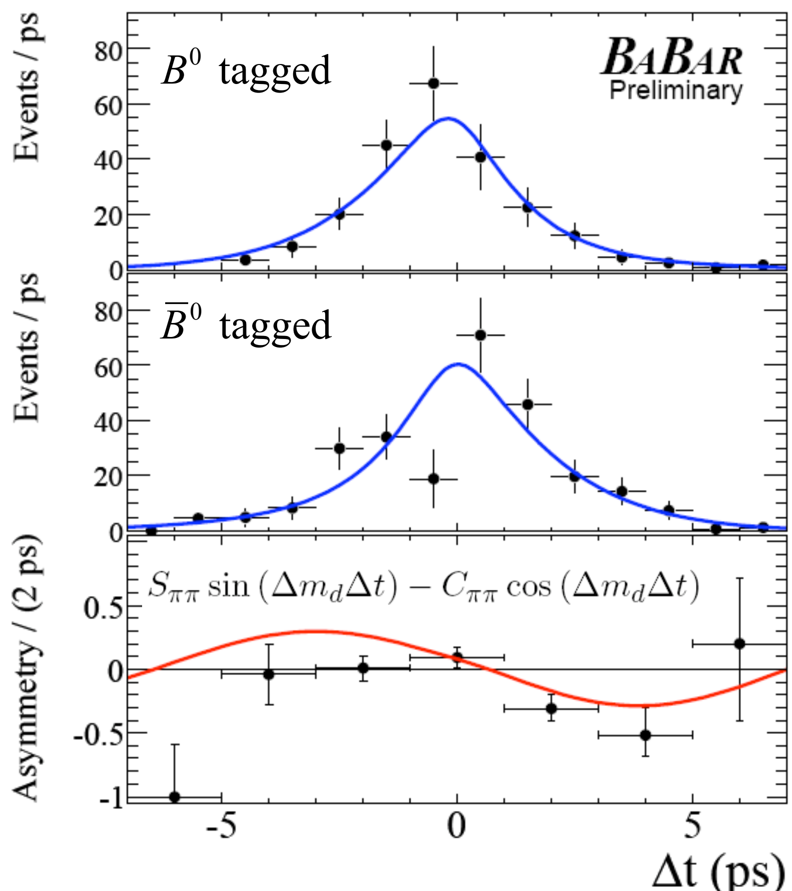
  - Triangles for $\pi\pi$, $\rho\rho$ and pentagons for $\rho\pi$
- Inputs to measuring α from $h = \pi, \rho$ are:
  - $B^0 \rightarrow h^+h^-$ + C.C
  - $B^0 \rightarrow h^0h^0$ + C.C
  - $B^+ \rightarrow h^+h^0$ + C.C
  - $S_{h+h-} = \sqrt{1 - C^2}\,\sin(2\alpha + 2\kappa)$

$\pi\pi$: Gronau & London PRL**65**, 3381 (1990) etc.
$\rho\pi$ Snyder-Quinn: PRD**48**, 2139 (1993) etc.

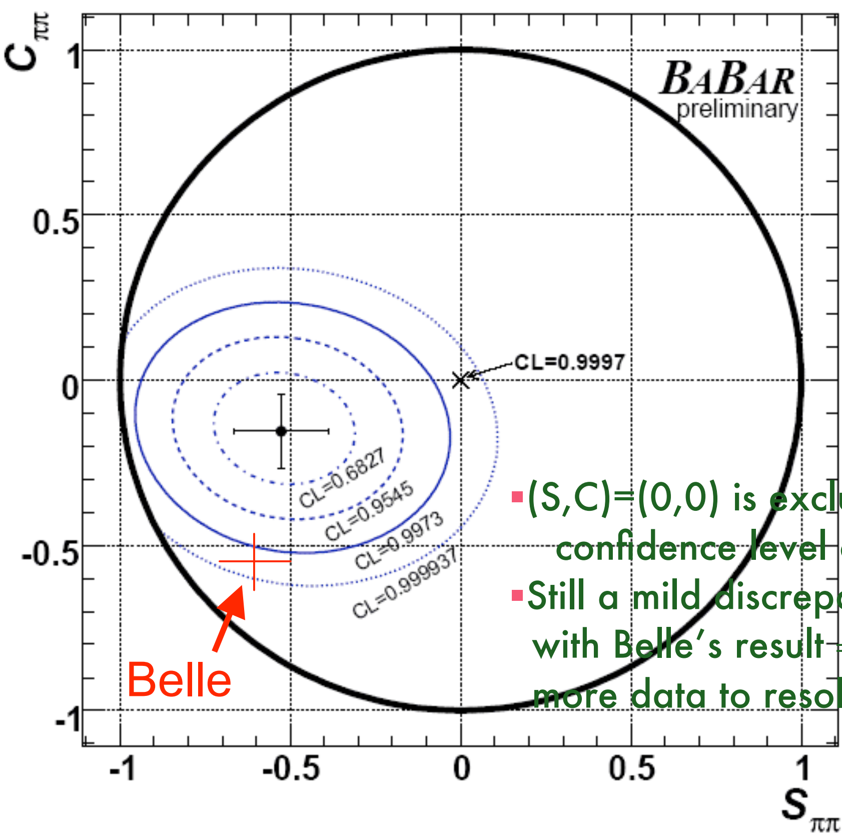
$B^0 \to \pi^+\pi^-$: Evidence for direct CP violation

- Updated measurement using 347 M BB pairs (675 ± 42 signal events)
- BaBar data shows evidence for CP violation at 3.6σ using the S and C measurement in $B \to \pi^+\pi^-$.

$$S_{\pi\pi} = -0.53 \pm 0.14 \pm 0.02$$
$$C_{\pi\pi} = -0.16 \pm 0.11 \pm 0.03$$



Belle (hep-ex/060803), 535 M BB pairs (1464 ± 65 signal events).
Direct CP violation (5.5 σ) and mixing-induced CP violation (5.6 σ)

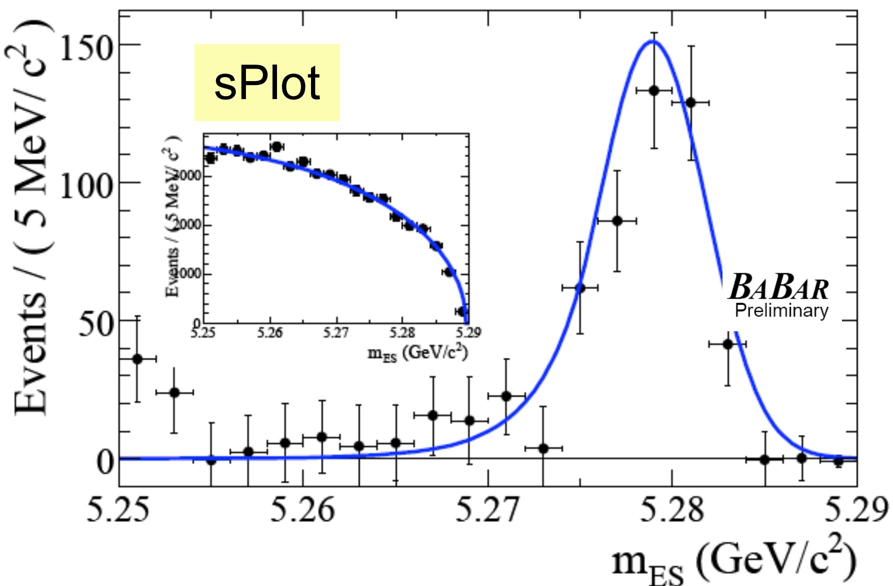


- (S,C)=(0,0) is excluded at a confidence level of 0.9997.
- Still a mild discrepancy with Belle's result ⇒ need more data to resolve this.

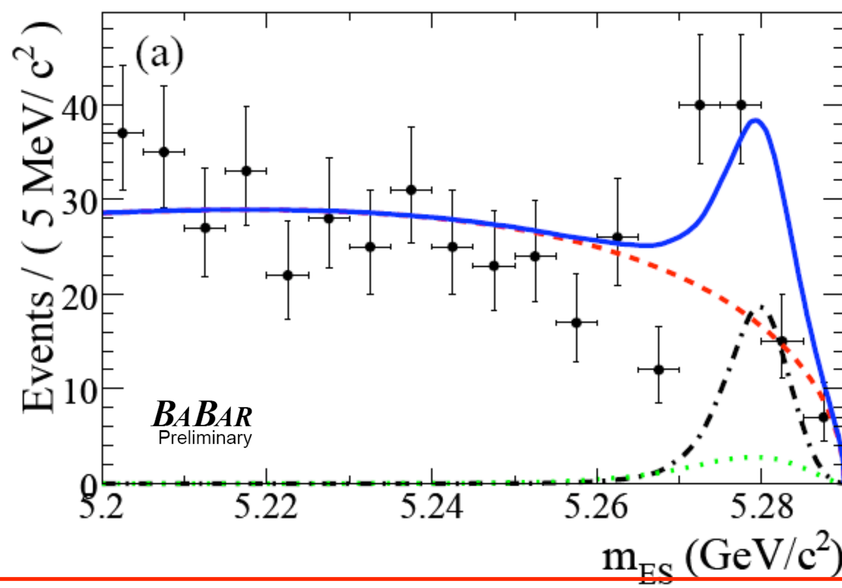
The other sides of the ππ triangle

- 347 M BB pairs.

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



$B^0 \to \pi^0\pi^0$



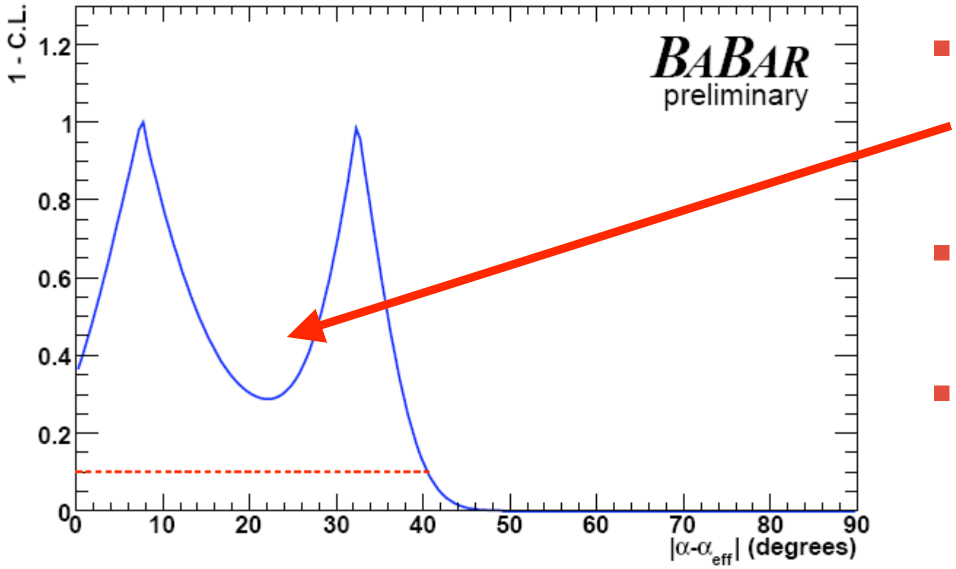
$$\mathcal{B}(B^\pm \to \pi^\pm\pi^0) = (5.12 \pm 0.47 \pm 0.29) \times 10^{-6}$$
$$\mathcal{A}_{\pi\pi^0} = -0.019 \pm 0.088 \pm 0.014$$

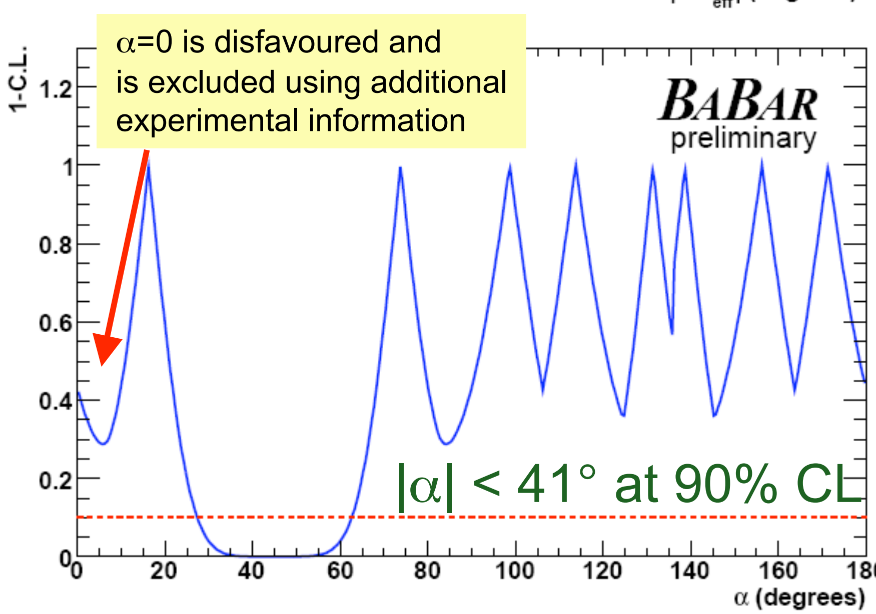
572±53 events

$$\mathcal{B}(B^0 \to \pi^0\pi^0) = (1.48 \pm 0.26 \pm 0.12) \times 10^{-6}$$
$$C_{\pi^0\pi^0} = -0.33 \pm 0.36 \pm 0.08$$

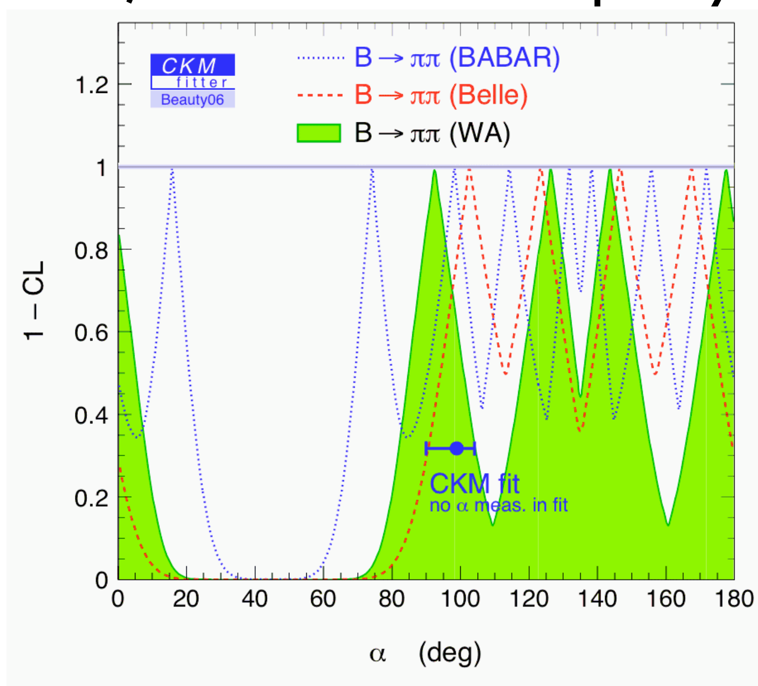
140±25 events

B→ππ isospin analysis



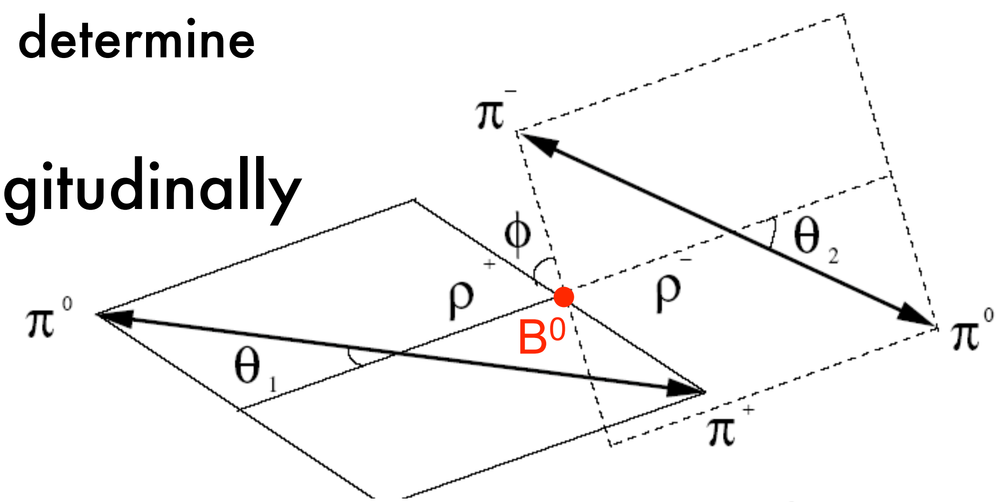


- The measurement of C^{00} is starting to distinguish between possible solutions for $\delta\alpha$.
- Need more data before the dip starts to become significant.
- More data should resolve the Belle/BaBar 2.3σ discrepancy.



Measuring α with $B \rightarrow \rho\rho$ decays

- Theory more complicated and experimentally more challenging than $\pi\pi$.
  - But the data tells us that penguins are better constrained than $\pi\pi$.
- $B \rightarrow VV$ decay;
  - Need angular analysis to determine CP content.
- $\rho^+\rho^-$ is almost 100% longitudinally polarized
  - Simplifies analysis a lot!

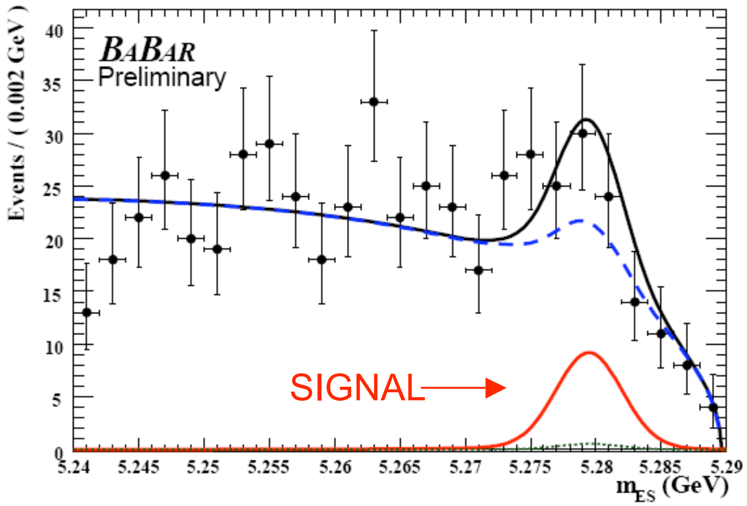


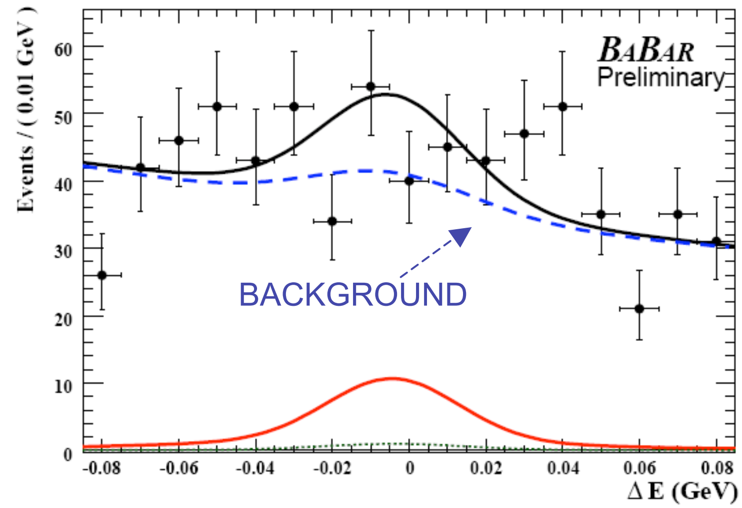
$$\frac{d^2\Gamma}{\Gamma d\cos\theta_1 d\cos\theta_2} = \frac{9}{4}\left(f_L \cos^2\theta_1 \cos^2\theta_2 + \frac{1}{4}(1-f_L)\sin^2\theta_1 \sin^2\theta_2\right)$$

Longitudinal (CP even) — Transverse (Mixed CP state)

One sides of the ρρ triangle : $\rho^0\rho^0$

- Updated measurement using 347 M BB pairs.





Previous result UL < $1.1\text{x}10^{-6}$ (central value was $0.54\text{x}10^{-6}$)

$$\mathcal{B}(B^0 \to \rho^0\rho^0) = [1.16^{+0.37}_{-0.36}\ (\text{stat.}) \pm 0.27\ (\text{syst.})]\text{x}10^{-6}$$

$$f_L = 0.86^{+0.11}_{-0.13}\ (\text{stat.}) \pm 0.05\ (\text{syst.})$$

$$N(\rho^0\rho^0) = 98^{+32}_{-31} \pm 22$$

$$N(\rho^0 f^0) = 12^{+18}_{-17} \pm 13$$

$$N(f^0 f^0) = -5^{+7}_{-6} \pm 12$$

- 3σ evidence for $\rho^0\rho^0$ with systematic errors.
  - Leads to a weaker constraint on penguin pollution.

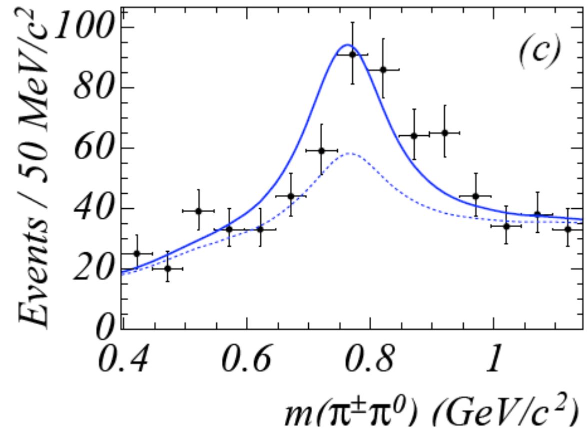
Another side of the ρρ triangle : $\rho^+\rho^0$

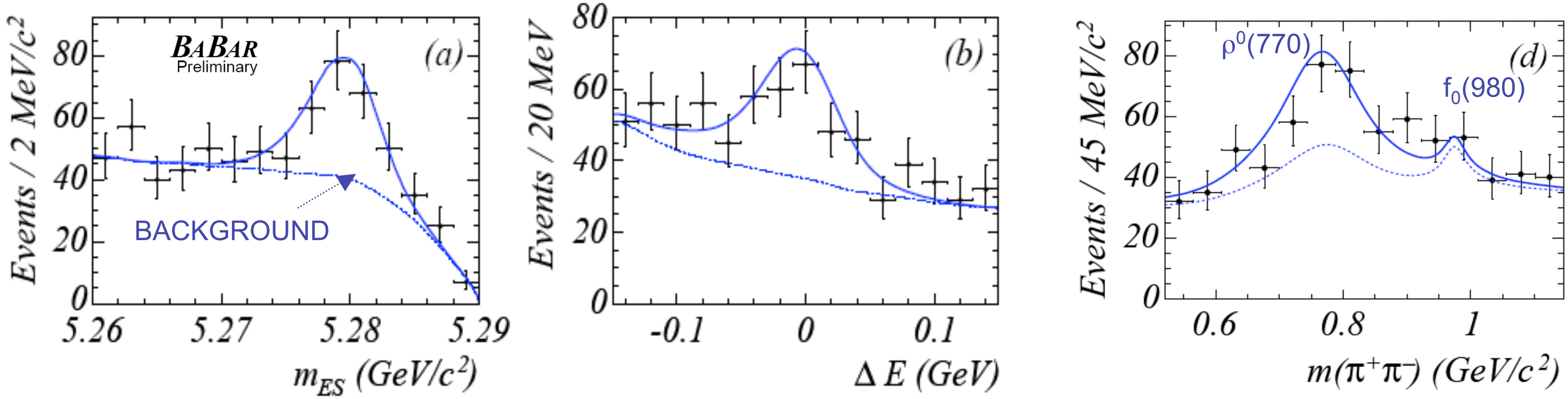
- Updated measurement using 232 M BB pairs.
- Simultaneous fit for $B^+ \to \rho^+ f_0(980)$.
- Smaller branching fraction measured (than on Run1+2 data)
  - Leads to a weaker constraint on penguin pollution
  - Fit:

390±49 events

$$\mathcal{B} = (16.8 \pm 2.2 \pm 2.3) \times 10^{-6}$$

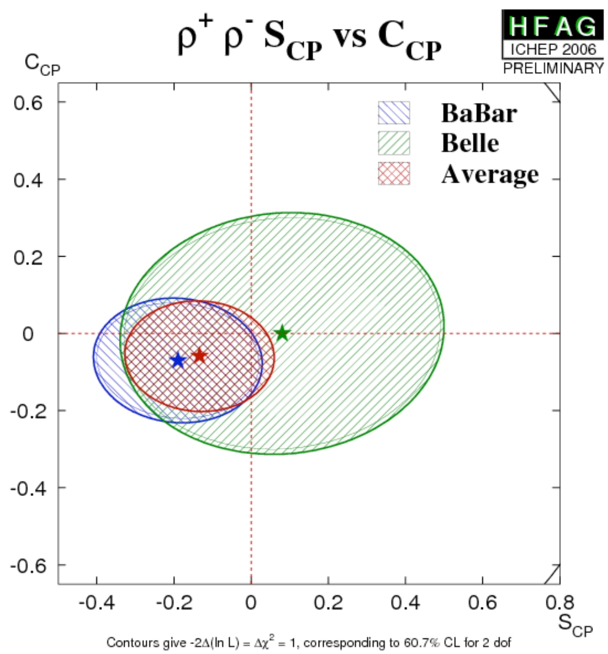
$$f_L = 0.905 \pm 0.042^{+0.023}_{-0.027}$$

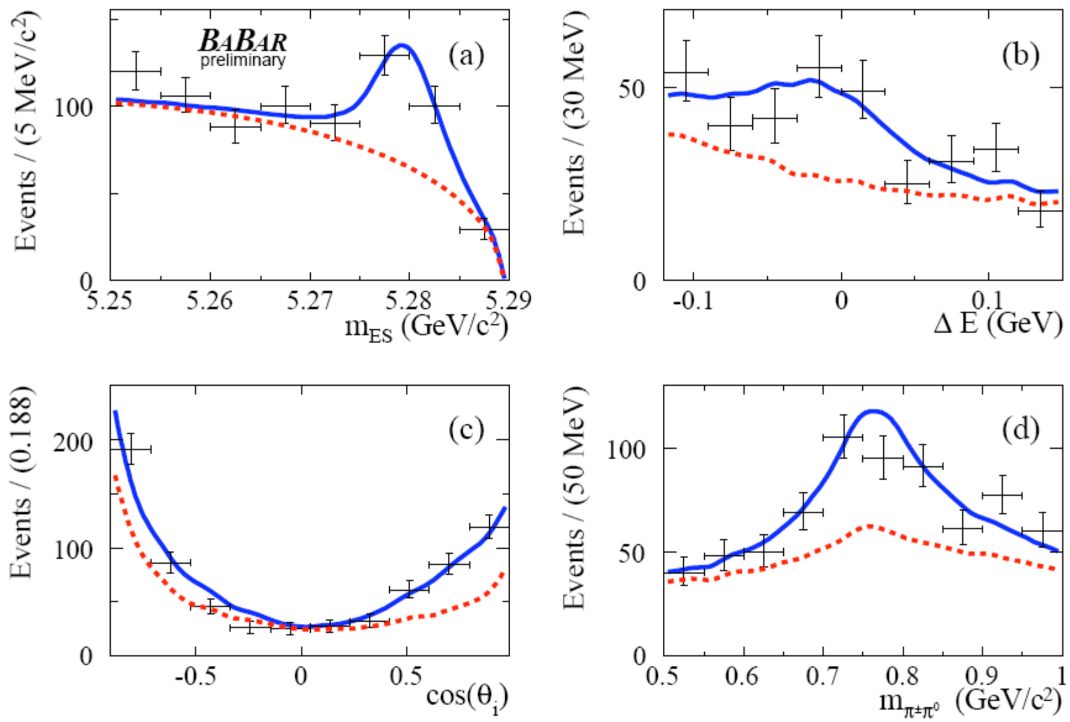




$B^0 \to \rho^+\rho^-$

- 347 M BB pairs.
- Reduce systematic uncertainty by improving treatment of correlations.
- Use only the tagged events for all results.
    - Reduce syst. error on BF and fL.

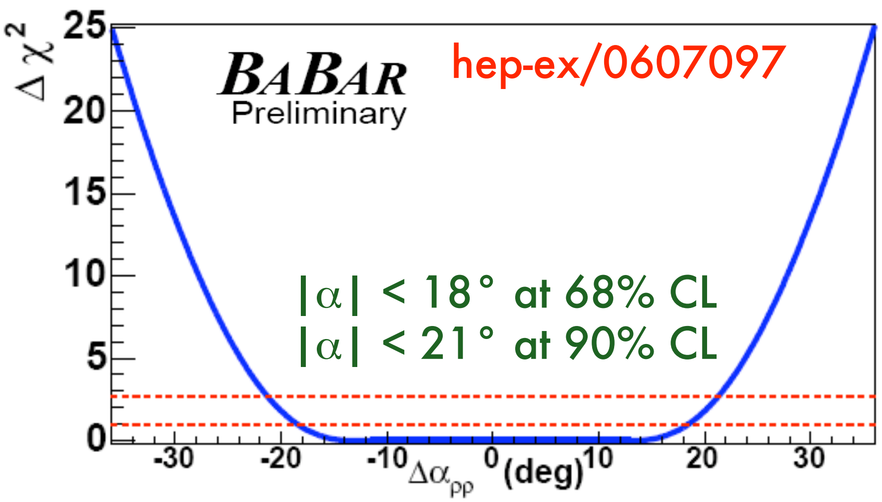




$$\mathcal{B}(B^0 \to \rho^+\rho^-) = (23.5 \pm 2.2(\text{stat}) \pm 4.1(\text{syst}))\times 10^{-6},$$
$$f_L = 0.977 \pm 0.024(\text{stat})^{+0.015}_{-0.013}(\text{syst}),$$
$$S_{\text{long}} = -0.19 \pm 0.21(\text{stat})^{+0.05}_{-0.07}(\text{syst}),$$
$$C_{\text{long}} = -0.07 \pm 0.15(\text{stat}) \pm 0.06(\text{syst}).$$

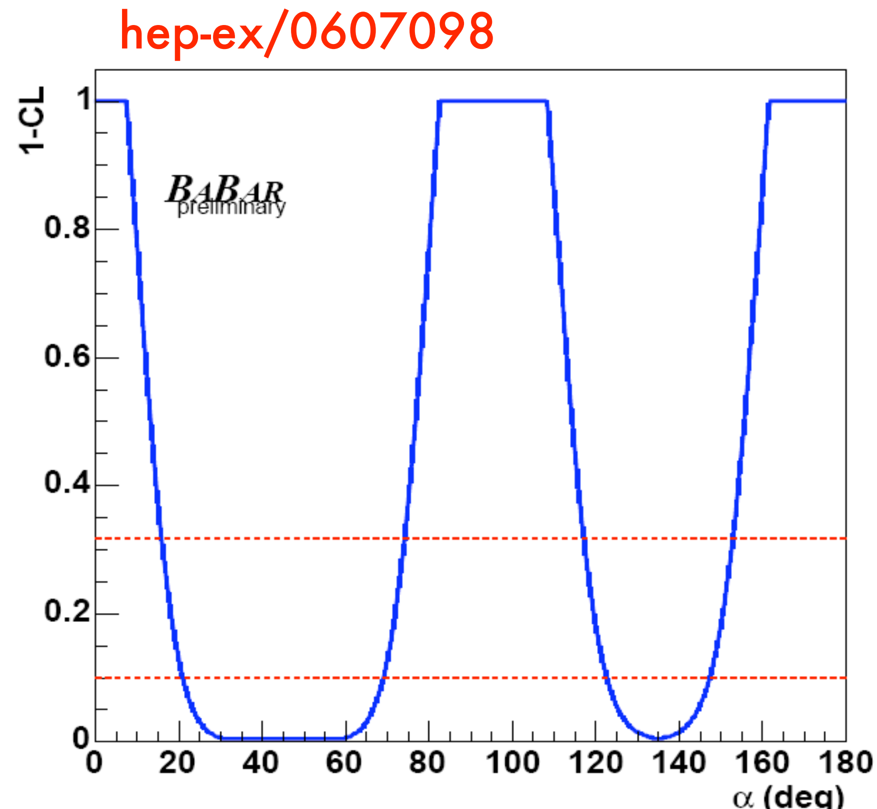
Updated constraint on α from $B \rightarrow \rho\rho$

- Penguin pollution is constrained to be <18° (68% CL).



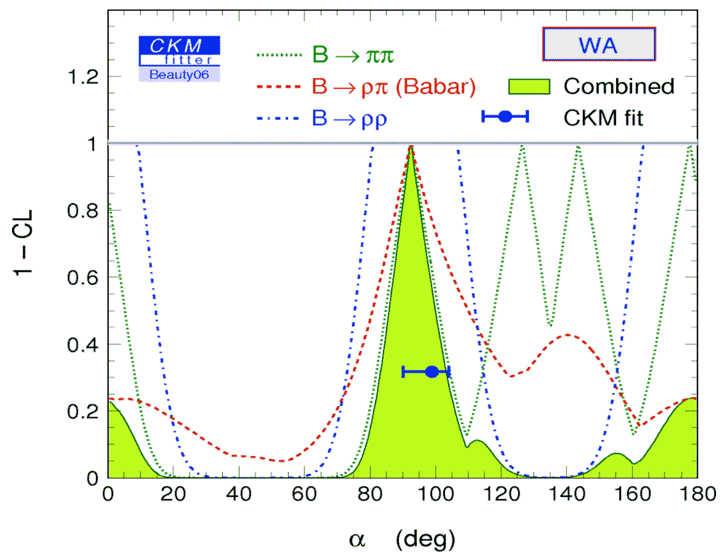
- Combination of:
  - Evidence for $\rho^0\rho^0$
  - Lower branching fraction for $\rho^+\rho^0$

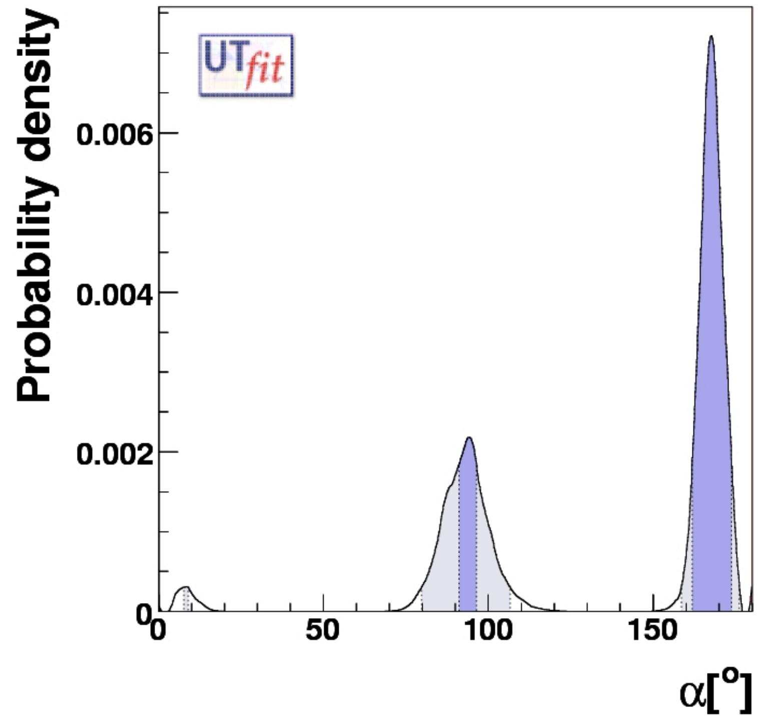
results in a weakened constraint on α.



$$\alpha_{\text{eff}} = (95.5^{+6.9}_{-6.2})^\circ$$
$$\alpha = [74, 117]^\circ \text{ at } 68\% \text{ CL}$$

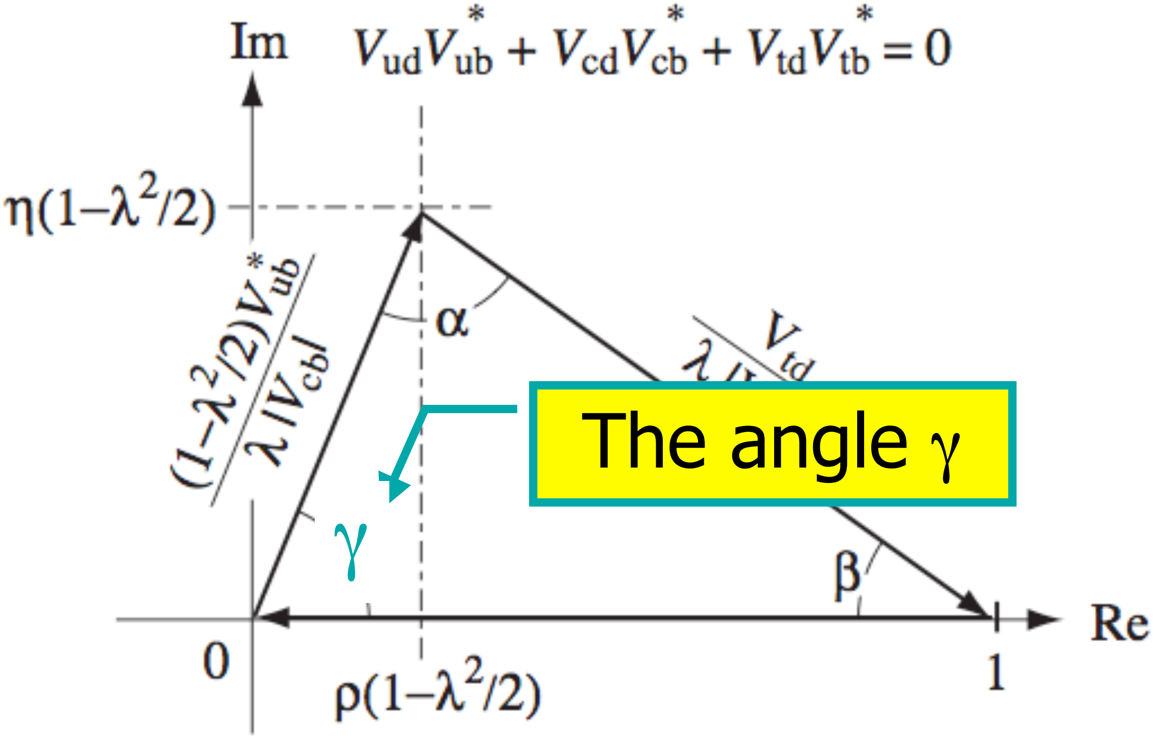
Combining results : CKM Fitter and UTFit





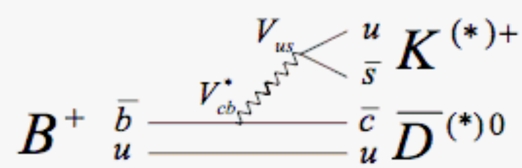
- The constraint on α is dependent on the statistical treatment used.
- This is a reflection of the fact that we need more data to perform a precision measurement of α.
- Excluded regions are common to both methods.
- CKM Fitter (direct constraint) : $\alpha = 93^{+11}_{-9}{}^{\circ}$
- UT Fit (direct constraint) : $\alpha = 92^{+7}_{-7}{}^{\circ}$

The angle γ



$$\alpha \equiv \arg\left(-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right), \quad \beta \equiv \arg\left(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right), \quad \gamma \equiv \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$$

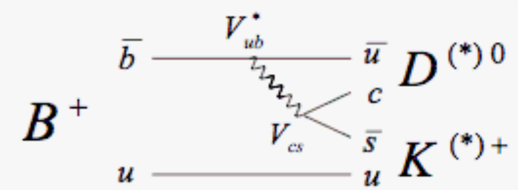
The angle γ



b→c color-favored

$A(B^+ \to \bar{D}^0 K^+) \propto V^*_{cb} V_{us} \propto \lambda^3$

$\lambda \approx 0.22$



b→u color-suppressed

$A(B^+ \to D^0 K^+) \propto V^*_{ub} V_{cs} \propto \lambda^3 \, r_B e^{i\delta_B} e^{i\gamma}$

$$r_B = \frac{|A(B^+ \to D^0 K^+)|}{|A(B^+ \to \bar{D}^0 K^+)|} \sim 0.1 - 0.3$$

- No 'golden channel for γ.
- Combine measurements from several theoretically clean modes e.g. $B^+ \to D^{(*)}K^{(*)}$.
- Measure γ with direct CP violation from interference when D^0 and $\bar{D}^0$ decay to the same final state f
  - 3 methods:

Gronau-London-Wyler (GLW):
f = CP eigenstate

Atwood-Dunietz-Soni (ADS):
f = doubly Cabibbo suppressed decay

Limits on r_B, more statistics needed to really constrain γ

Giri-Grossman-Soffer-Zupan (GGSZ):
f = 3-body final state (Dalitz)

} Most promising

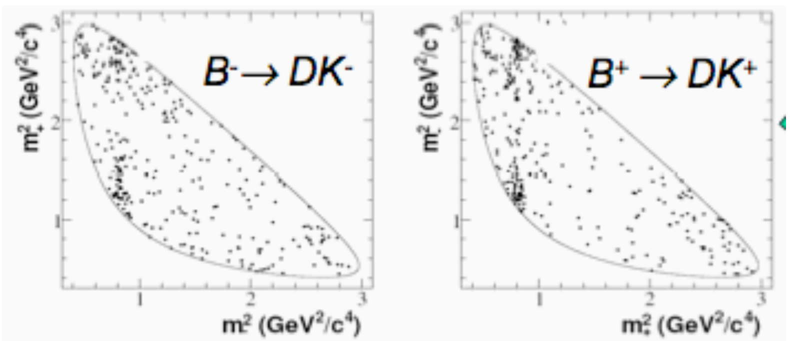
The angle γ

- γ from $B \rightarrow D^{(*)0}K$, $D^0 \rightarrow K_S\pi\pi$ — UPDATED, 347M $B\bar{B}$
- γ from $B \rightarrow D^0K^*$, $D^0 \rightarrow K_S\pi\pi$ — OLD, 227M $B\bar{B}$
- Additional constraints & combined γ result from
  - $B^- \rightarrow D^0K$, $D^0 \rightarrow K^+\pi^-\pi^0$ — NEW, 227M $B\bar{B}$
  - $B^- \rightarrow D^{(*)0}K^{(*)-}$, $D^0 \rightarrow K^+\pi^-$ — PUBLISHED, 232M $B\bar{B}$
  - $B^- \rightarrow D^{(*)0}_{CP}K^{(*)-}$ — UPDATED & PUBLISHED, 232M $B\bar{B}$

Different observables
"Dalitz"
"ADS"
"GLW"

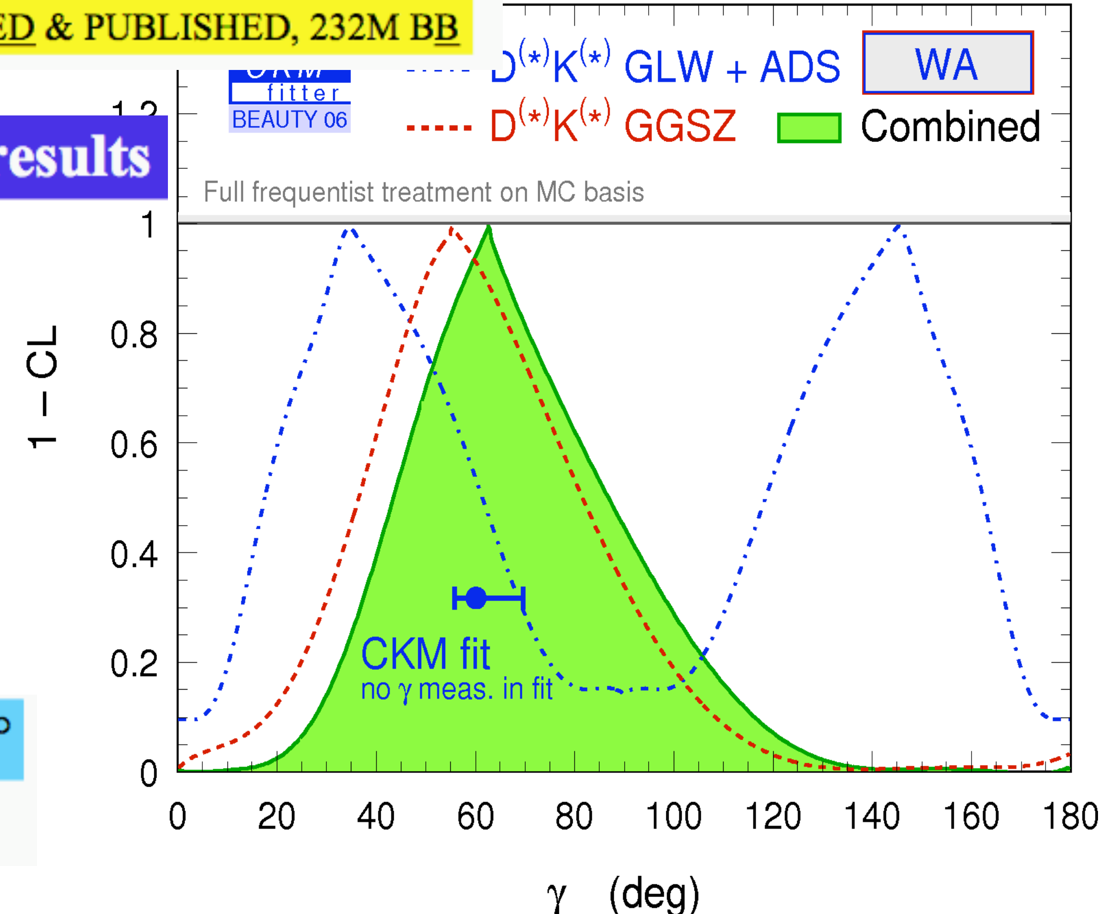
γ from $B \rightarrow D^{(*)0}K$, $D^0 \rightarrow K_S\pi\pi$: results

347 *10[6] $B\bar{B}$ pairs
BABAR-CONF-06/038



$$\gamma \bmod 180° = (92 \pm 41 \pm 11 \pm 12)°$$

Stat Syst Dalitz



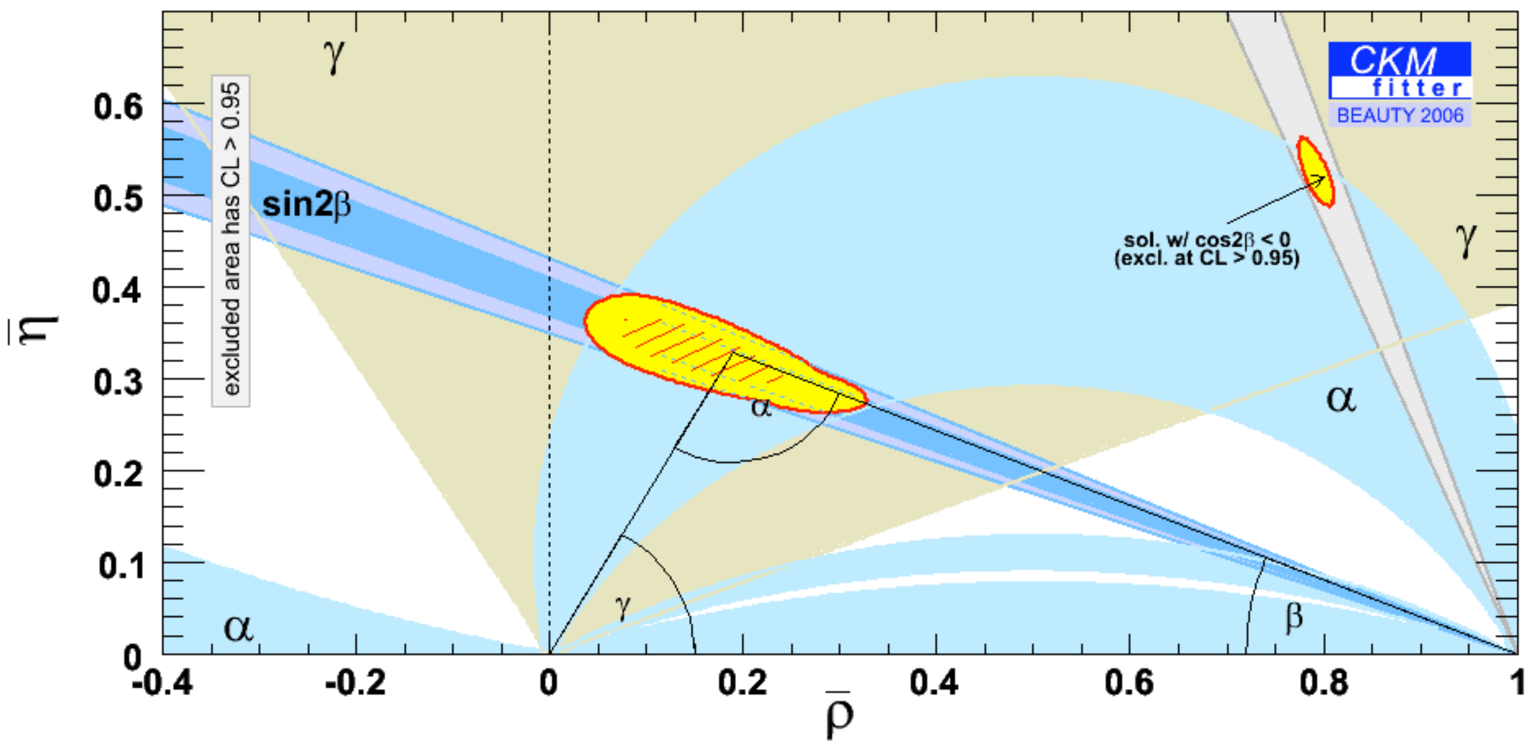
γ[combined] $= 62\ ^{+38}_{-24}$ deg.

See Giovanni Marchiori's BaBar ICHEP talk :

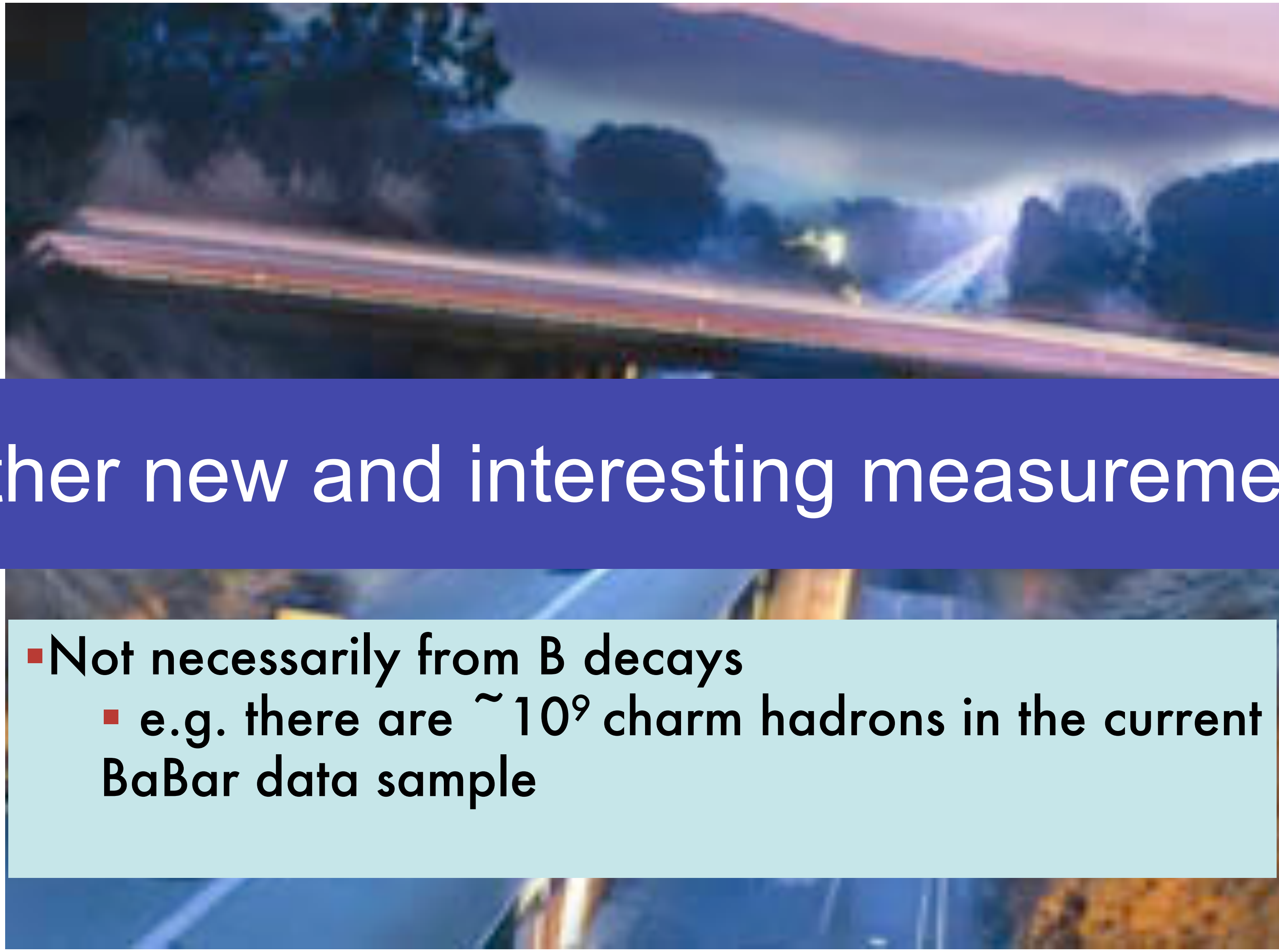
http://ichep06.jinr.ru/reports/279_8s4_11p54_marchiori_web.pdf

The UT today

Angles from *CP* asymmetries



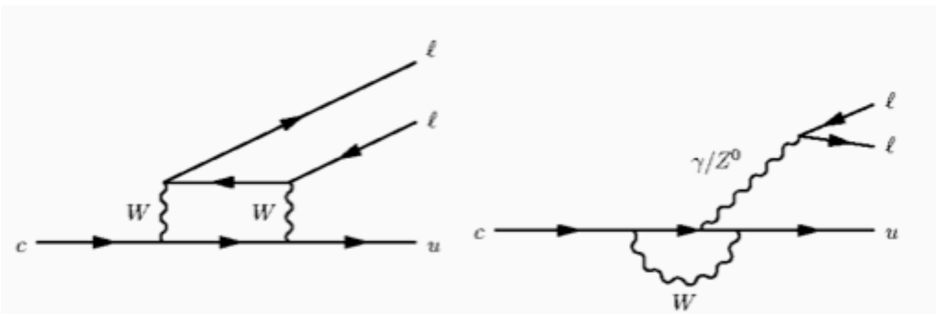
Other new and interesting measurements



Other new and interesting measurements

- Not necessarily from B decays
  - e.g. there are ~10^9 charm hadrons in the current BaBar data sample

Flavor Changing Neutral Currents in D decays



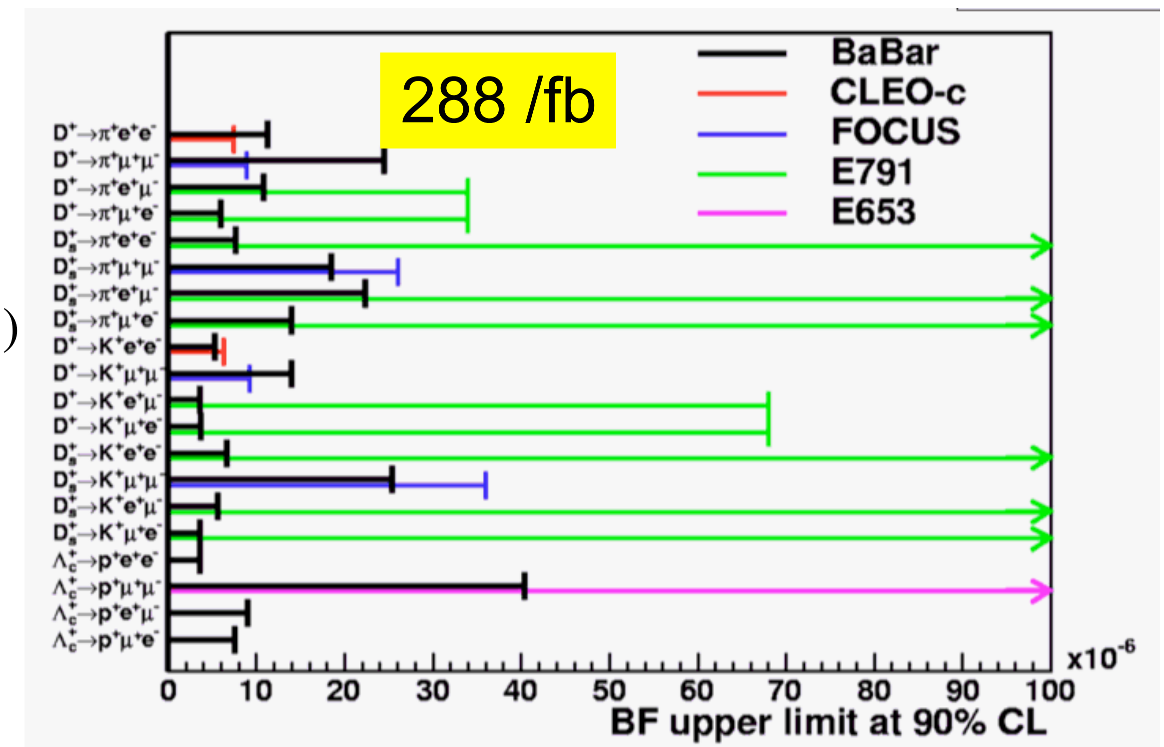
- Standard Model expectation

$$B(X_c \to X_u l^+ l^-) = O(10^{-8})$$

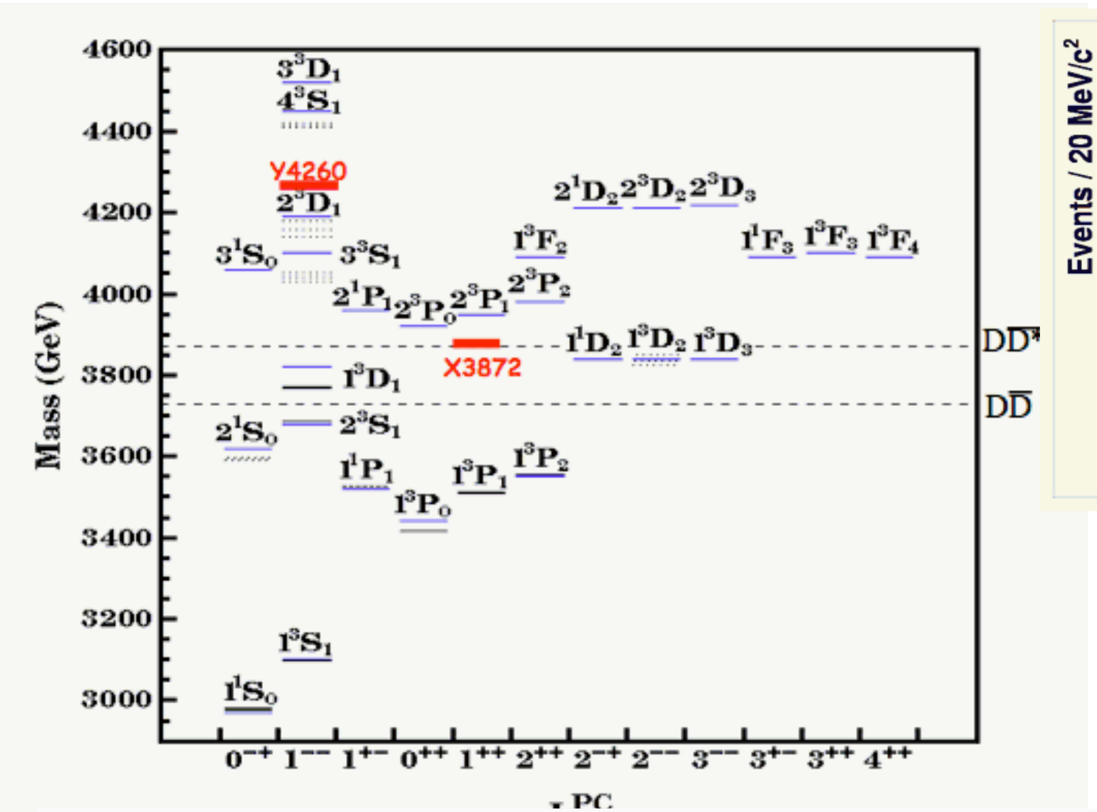
- New physics e.g. R-parity violating SUSY may enhance the rate:

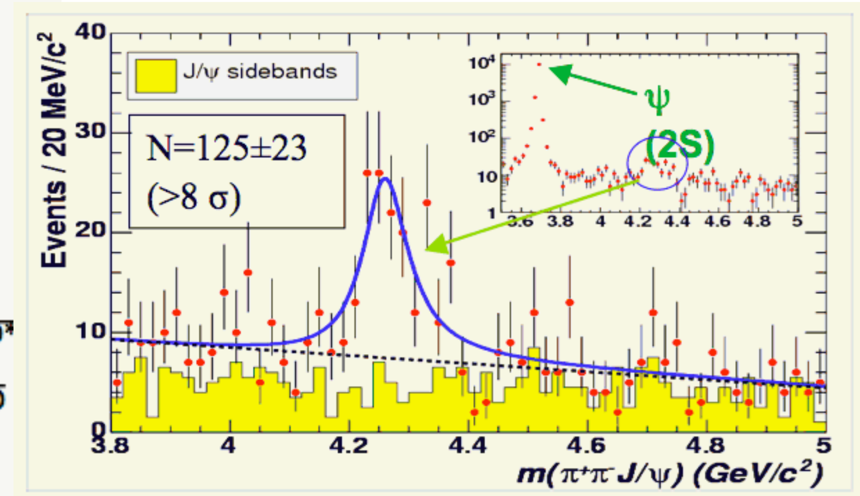
$$B(X_c \to X_u l^+ l^-) \leq O(10^{-5})$$

- BaBar measures all of the $X_C \to X_u l^+ l^-$ modes
- Upper limits $\sim O(10^{-5} - 10^{-6})$
  - Many limits better than from other experiments
  - hep-ex/0607051



Y(4260)





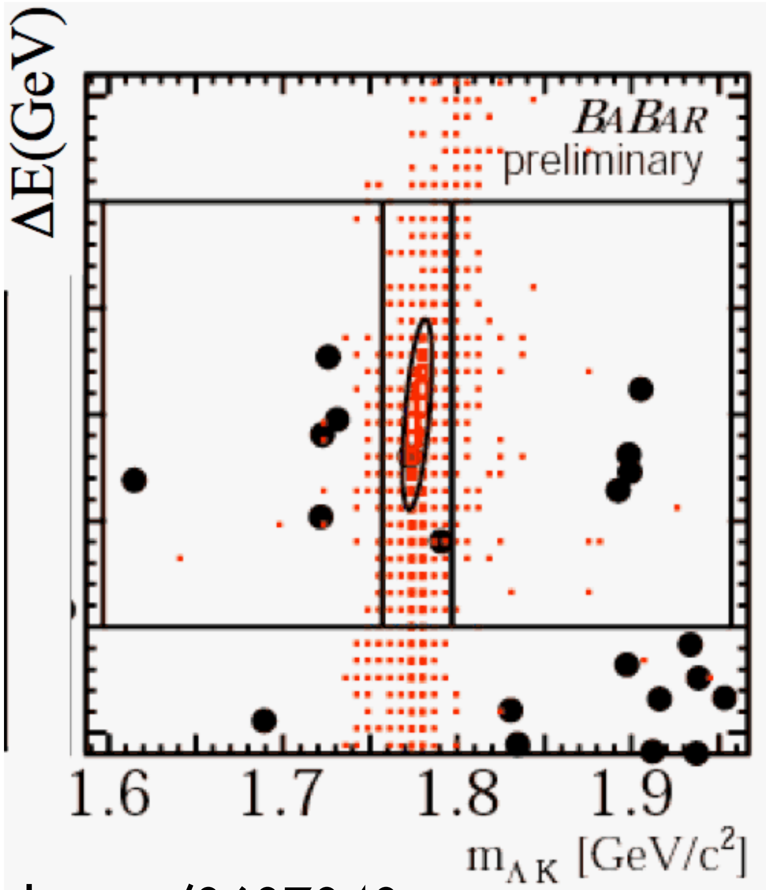
- Searches for decay modes other than Y(4260) →J/ψππ

Channel (X)	DD	pp	J/ψη	J/ψπ⁰	χc1γ	χc2γ	J/ψγγ
B(Y→X)/ B(Y→ π⁺π⁻ J/ψ)	<7.6	<0.13	< 1.4	< 0.6	< 3.6	< 2.6	<1.2

Difficult to interpret the Y(4260) as a conventional charmonium state

Searches for baryon and lepton number violation in τ decays

- Search for both B-L conserved and violating processes
- B-L conservation : allowed in the SM
- B-L violation : baryogenesis may require a Δ(B-L) = 2 component

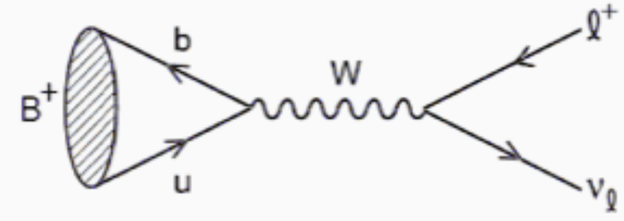


Channel	B-L	Background	N	@90% CL
$\tau^- \to \bar{\Lambda}\pi^-$	C	0.42±0.42	0	<5.94 10^{-8}
$\tau^- \to \Lambda\pi^-$	V	0.56±0.56	0	<5.76 10^{-8}
$\tau^- \to \bar{\Lambda}K^-$	C	0.26±0.26	0	<7.19 10^{-8}
$\tau^- \to \Lambda K^-$	V	0.12±0.12	1	<14.6 10^{-8}

hep-ex/0607040

Leptonic B decays

$B^+ \to (e^+, \mu^+, \tau^+)\nu$



$$\mathcal{B}(B^+ \to l^+ \nu_l) = \frac{G_F^2 m_B m_l^2}{8\pi}\left(1 - \frac{m_l^2}{m_B^2}\right) f_B^2 |V_{ub}|^2 \tau_B$$

- Standard Model (SM) branching fractions:
  e: $O(10^{-12})$ μ: $O(10^{-7})$ τ: $O(10^{-4})$

229 M BB

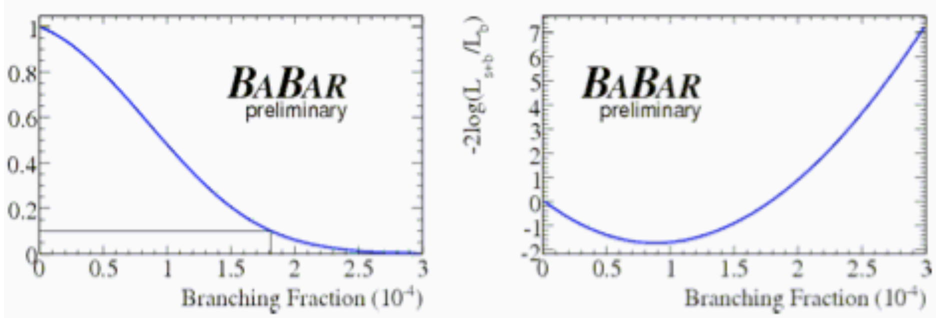
$$BR(B^+ \to e^+ \nu) < 7.9 \times 10^{-6} \text{ at the 90\% C.L.}$$
$$BR(B^+ \to \mu^+ \nu) < 6.2 \times 10^{-6} \text{ at the 90\% C.L.}$$

324 M BB

PRELIMINARY

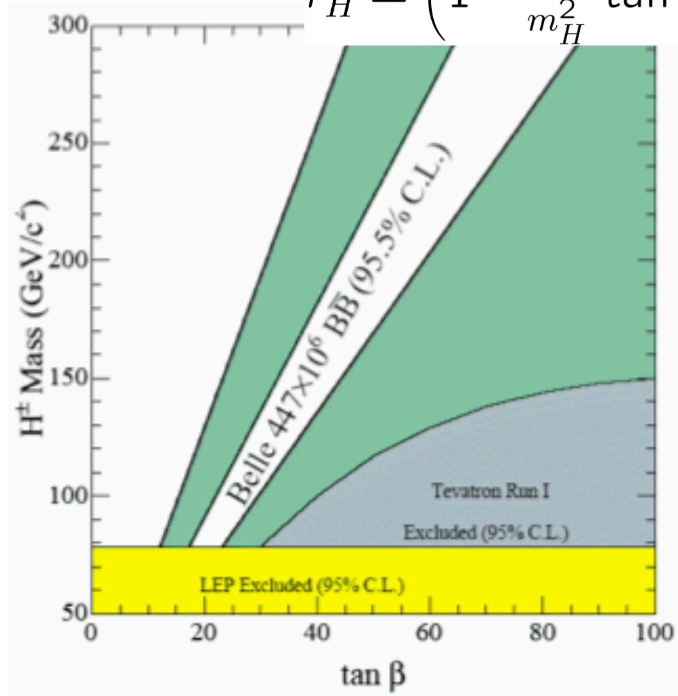
$$BR(B^+ \to \tau^+ \nu) < 1.8 \times 10^{-4} \text{ at the 90\% CL}$$

$$BR(B^+ \to \tau^+ \nu) = (0.88^{+0.68}_{-0.67}(stat.) \pm 0.11(syst.)) \times 10^{-4}$$



$$f_B |V_{ub}| = \left|7.0^{+2.3}_{-3.6}(stat.)^{+0.4}_{-0.5}(syst.)\right| \times 10^{-4} \text{ GeV}$$

- τ mode: current sensitivity at SM level
  - W (suppressed by V_{ub}) can be replaced by e.g. charged Higgs to enhance/suppress branching fraction by factor $r_H = \left(1 - \frac{m_B^2}{m_H^2}\tan^2\beta\right)^2$



e.g. 2 Higgs Doublet Model
W.S. Hou, PRD **48**, 2342 (1993).

Extraction of $|V_{td}/V_{ts}|$ with $B \to \rho(\omega)\gamma$ decays

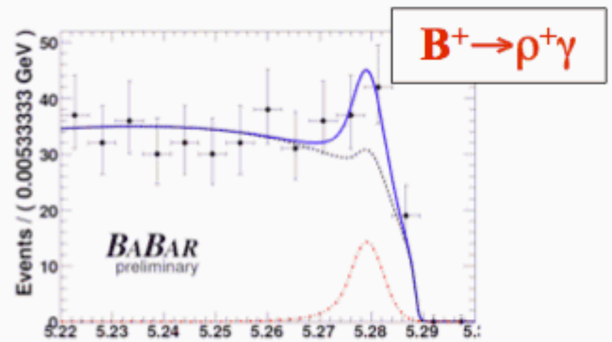
$$\frac{\overline{BF}(B \to (\rho/\omega)\gamma)}{BF(B \to K^*\gamma)} = \left|\frac{V_{td}}{V_{ts}}\right|^2 \left(\frac{1-m_\rho^2/M_B^2}{1-m_{K^*}^2/M_B^2}\right)^3 \zeta^2[1+\Delta R]$$

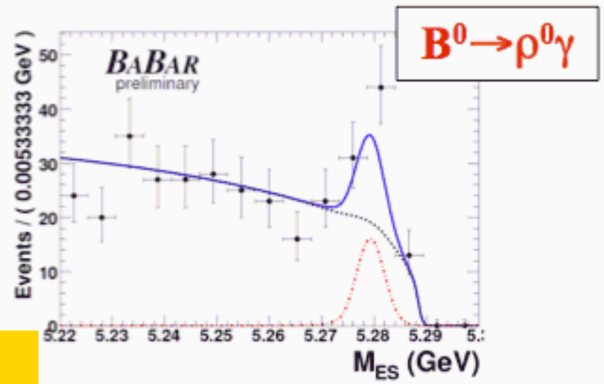
SU(3) breaking corrections:

Form factor ratio $1/\zeta = 1.17 \pm 0.09$ *hep-ph/0603232*	Annihilation amplitude corrections $\Delta R = 0.1 \pm 0.1$

A.Ali, A.Parhomenko hep-ph

- Use SU(3) to relate $B^0 \to \rho(\omega)\gamma$ to $B^0 \to K^*\gamma$
- **Reconstructed decays:**
  - $B \to \rho^+\gamma$, $\rho^+ \to \pi^+\pi^0$
  - $B \to \rho^0\gamma$, $\rho^0 \to \pi^+\pi^-$
  - $B \to \omega\gamma$, $\omega \to \pi^+\pi^-\pi^0$
- Determine $|V_{td}/V_{ts}|$ from $B^0 \to \rho(\omega)\gamma$
- Belle : Observed $\rho\gamma$ in 2005
  - $\Rightarrow$ First direct measurement of $|V_{td}/V_{ts}|$
- BaBar : Confirmed Belle $\rho^0(\omega)\gamma$
  - First evidence for $B^+ \to \rho^+\gamma$





Mode	n_{sig}	Significance	$\epsilon(\%)$	$\mathcal{B}(10^{-6})$
$B^+ \to \rho^+\gamma$	$42.4^{+14.1}_{-12.6}$	4.1σ	11.6	$1.06^{+0.35}_{-0.31} \pm 0.09$
$B^0 \to \rho^0\gamma$	$38.7^{+10.6}_{-9.8}$	5.2σ	14.5	$0.77^{+0.21}_{-0.19} \pm 0.07$
$B^0 \to \omega\gamma$	$11.0^{+6.7}_{-5.6}$	2.3σ	8.1	$0.39^{+0.24}_{-0.20} \pm 0.03$

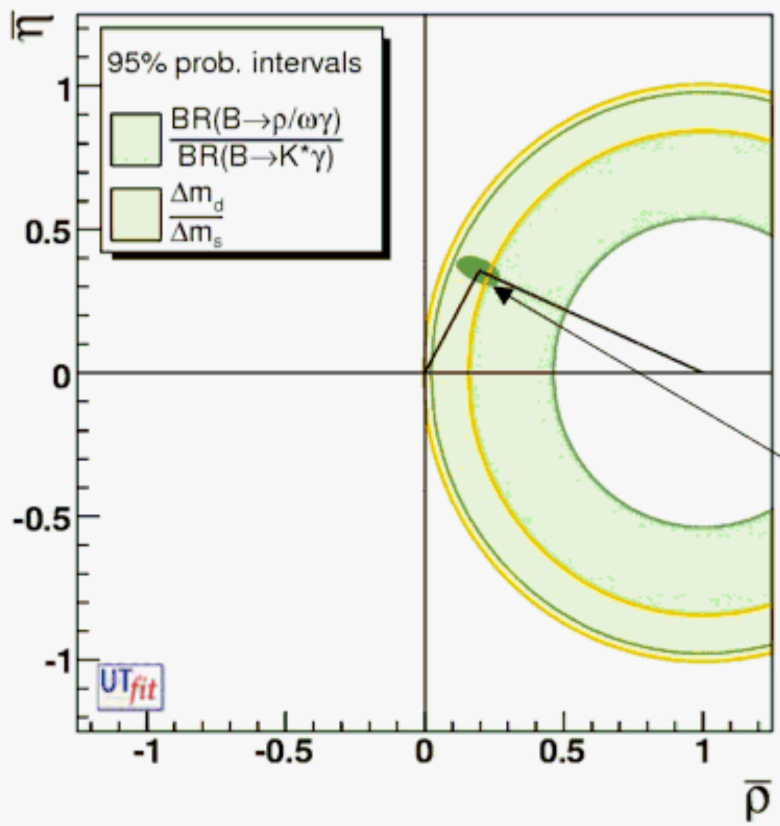
316 /fb

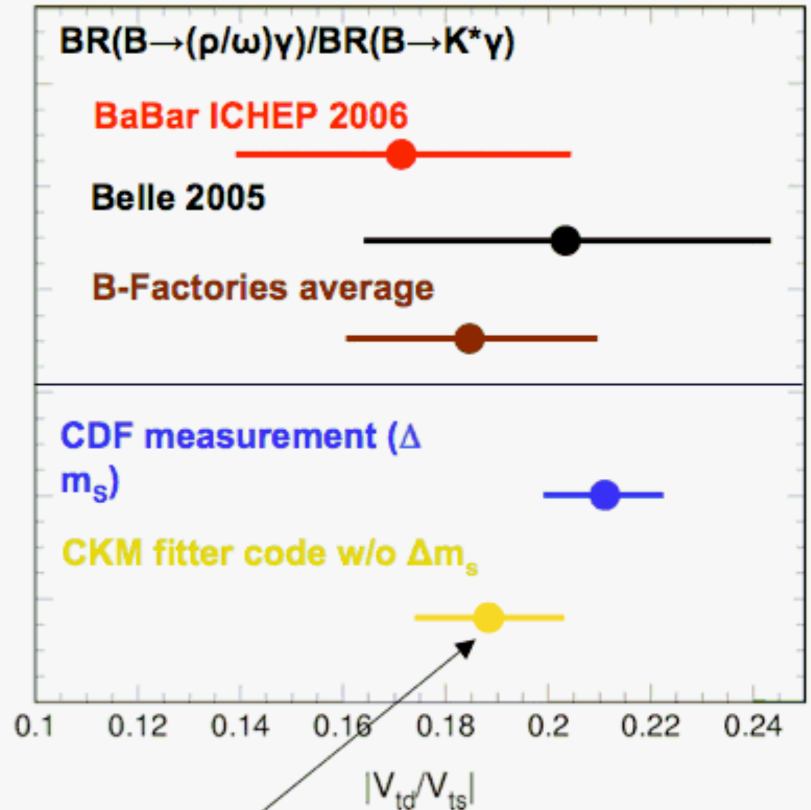
Extraction of $|V_{td}/V_{ts}|$ with $B \to \rho(\omega)\gamma$ decays

Combined fit result:

$$\overline{\mathrm{BF}}[B \to (\rho/\omega)\gamma] = (1.01 \pm 0.21 \pm 0.08) \times 10^{-6}$$

$$\left|\frac{V_{td}}{V_{ts}}\right| = 0.171^{+0.018}_{-0.021}(\mathrm{exp})^{+0.017}_{-0.014}(\mathrm{theory})$$

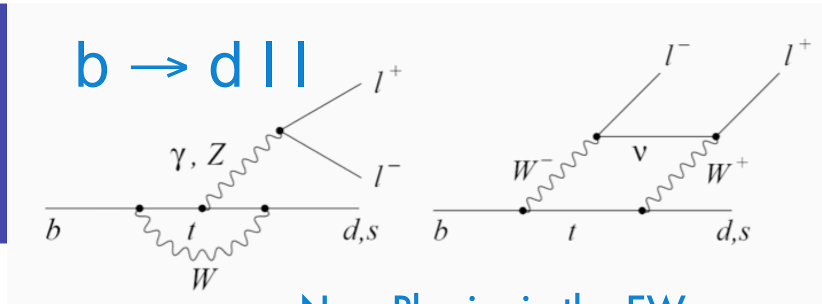




Global CKM fit excluding Δm_s and $B \to \rho(\omega)\gamma$

Search for B $\rightarrow \pi\, l^+ l^-$

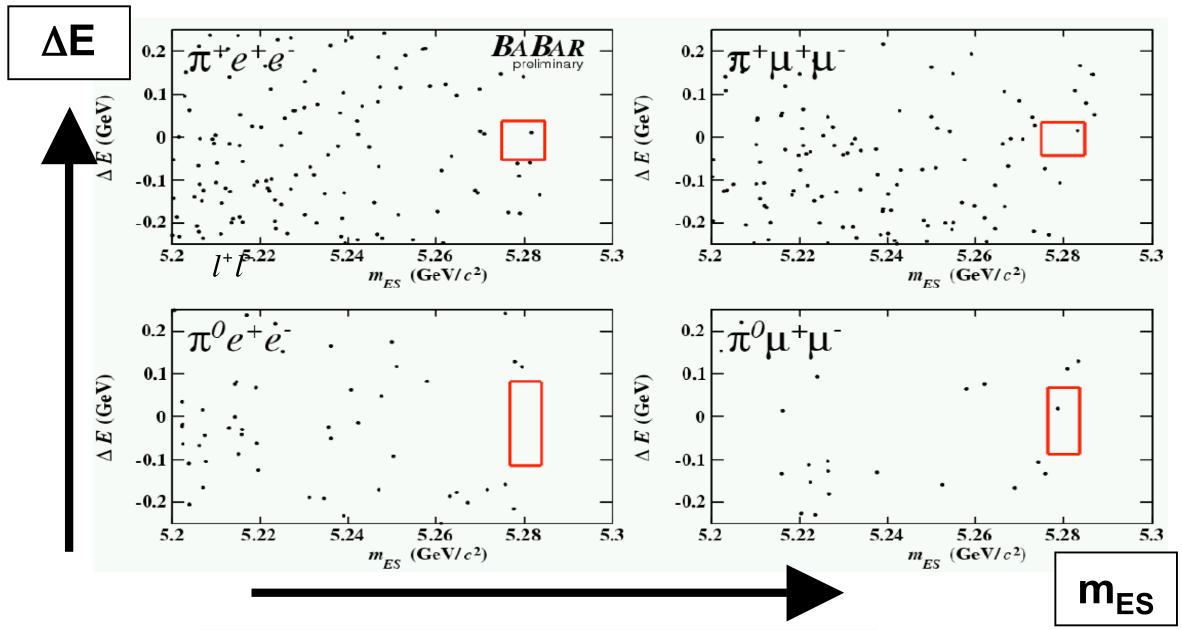
(also an electroweak penguin)



New Physics in the EW penguin and box diagrams ?

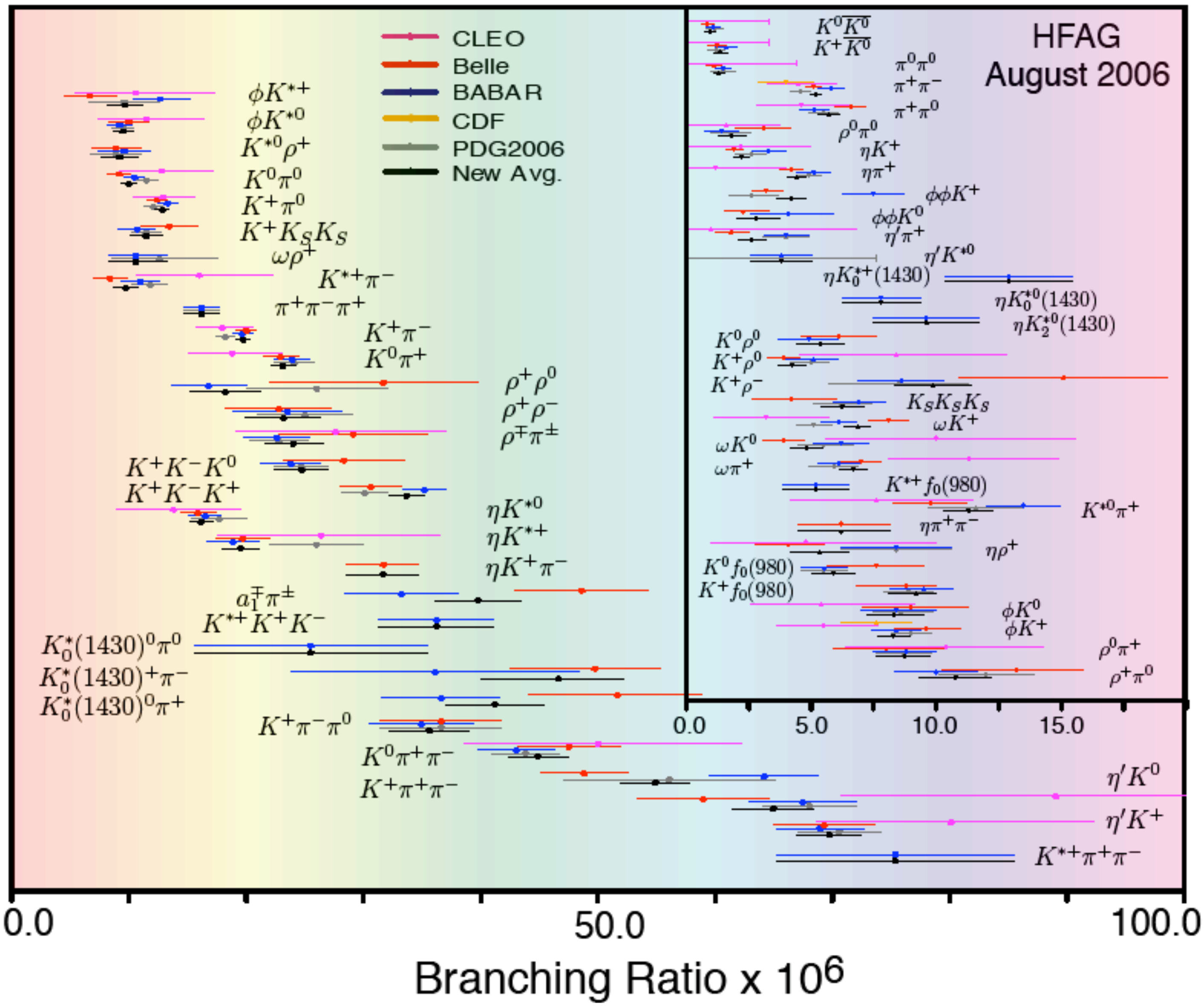
- Reconstruct $B \rightarrow \pi \ell^+ \ell^- \;\; (\pi = \pi^+ \text{or } \pi^0)$ and perform cut-and-count analysis in m_{ES} and ΔE
- Last measurement by Mark-II experiment (1990).
- ICHEP'06 preliminary
  - 232 M BB pairs

Mode	BF UL 90% C.L. (10^{-7})
$B^+ \rightarrow \pi^+ e^+ e^-$	1.72
$B^0 \rightarrow \pi^0 e^+ e^-$	1.29
$B^+ \rightarrow \pi^+ \mu^+ \mu^-$	2.47
$B^0 \rightarrow \pi^0 \mu^+ \mu^-$	4.56
$B^+ \rightarrow \pi^+ e^+ \mu^-$	1.72
$B^0 \rightarrow \pi^0 e^+ \mu^-$	1.50



- Standard Model prediction: $\mathrm{BF}[B \rightarrow \pi l^+ l^-] = 3 \times 10^{-8}$
- Find: $\mathcal{B}(B^+ \rightarrow \pi^+ \ell^+ \ell^-) = 2 \times \frac{\tau_{B^+}}{\tau_{B^0}} \mathcal{B}(B^0 \rightarrow \pi^0 \ell^+ \ell^-) < 7.9 \times 10^{-8}$
- Standard Model limit is just around the corner .... ?

Many rare B decays …



Preparing for Run 6

(Starting January 2007)

PEP-II luminosity records

Last update:
August 18, 2006

Peak Luminosity

12.069×10^{33} $cm^{-2} sec^{-1}$ **August 16, 2006**

1722 bunches 2900 mA LER 1875 mA HER

Integration records of delivered luminosity

Best shift (8 hrs, 0:00, 08:00, 16:00)	339.0 pb^{-1}	**Aug 16, 2006**
Best 3 shifts in a row	910.7 pb^{-1}	**Jul 2-3, 2006**
Best day	849.6 pb^{-1}	**Aug 14, 2006**
Best 7 days (0:00 to 24:00)	5.385 fb^{-1}	**Jul 27-Aug 3, 2006**
Best week (Sun 0:00 to Sat 24:00)	5.111 fb^{-1}	**Jul 30-Aug 5, 2006**
Peak HER current	1900 mA	**Aug 15, 2006**
Peak LER current	2995 mA	**Oct 10, 2005**
Best 30 days	19.315 fb^{-1}	**Jul 19 – Aug 17, 2006**
Best month	17.036 fb^{-1}	**July 2004**

Total delivered 410 fb^{-1}

PEP-II parameters and design goals

Parameter	Units	Design	Aug 2006	2007-08 goal
I+	mA	2140	2900	4000
I-	mA	750	1875	2200
Number of bunches		1658	1722	1732
β_y^*	mm	15-20	11	8-8.5
Bunch length	mm	15	11-12	8.5-9
ξ_y		0.03	0.044-0.065	0.054-0.07
Luminosity	$x10^{33}$	3.0	12.1	20
Int lumi / day	pb^{-1}	130	910.7	1300

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Luminosity	$\times 10^{33}$	3.0	12.1	20
Int lumi / day	pb^{-1}	130	910.7	1300

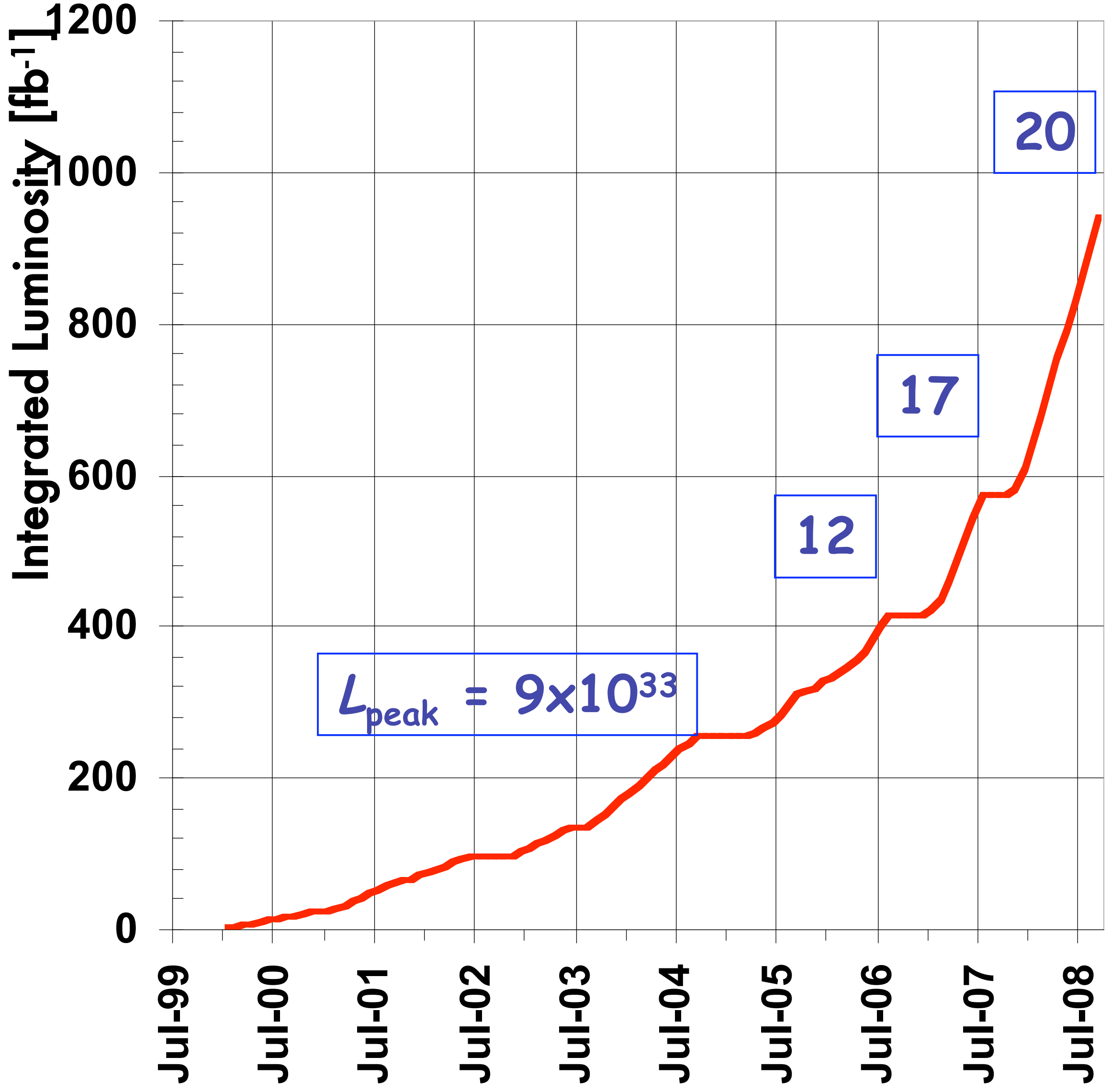
35%

30%

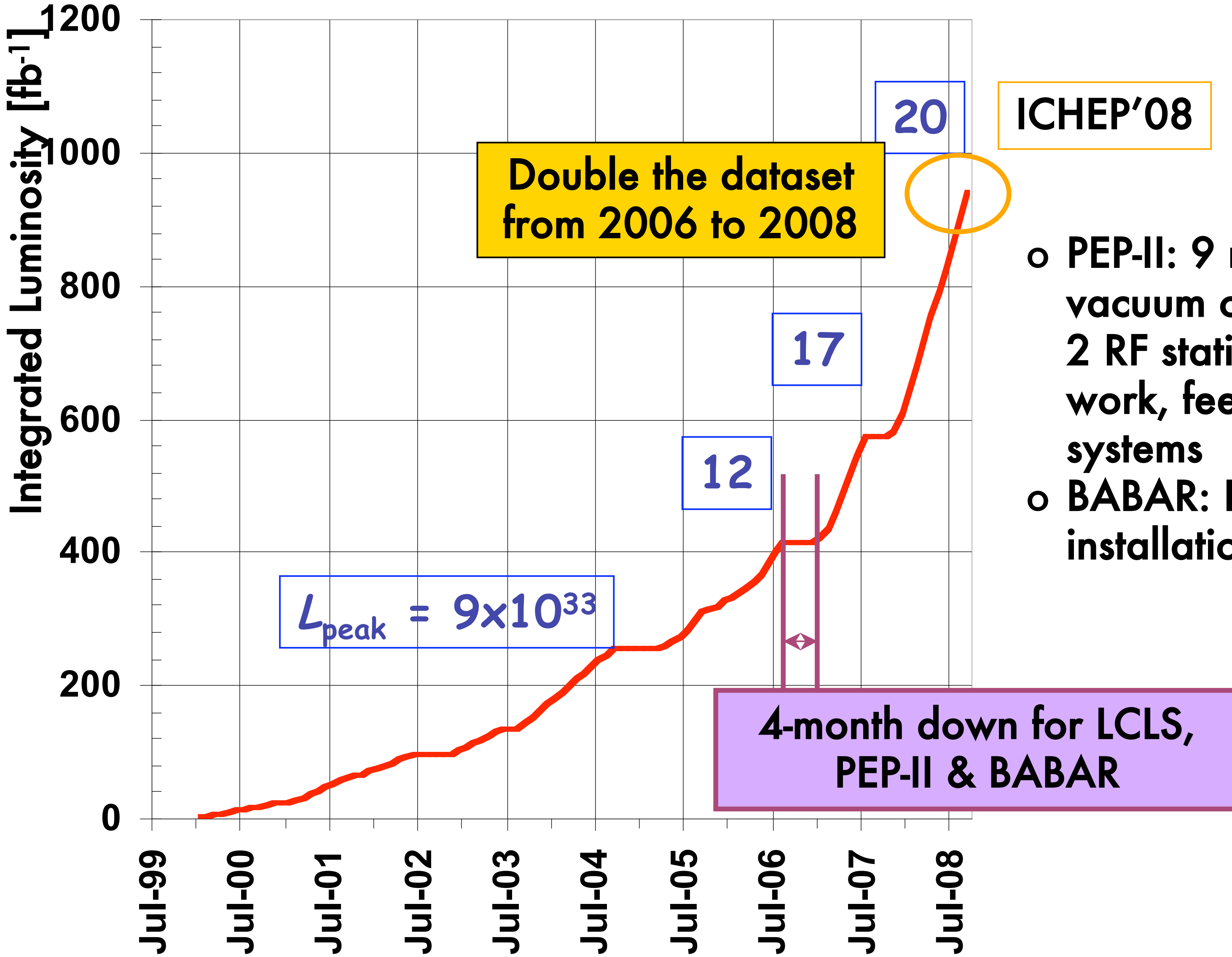
5%

Factor 70%

Projected data sample growth



Projected data sample growth



- PEP-II: 9 new vacuum chambers, 2 RF stations, BPM work, feedback systems
- BABAR: LST installation

http://today.slac.stanford.edu/feature/babar-replume.asp

BaBar Re-feathers its Nest

Like a bird in molt, the BaBar detector is temporarily vulnerable while it acquires better plumage.

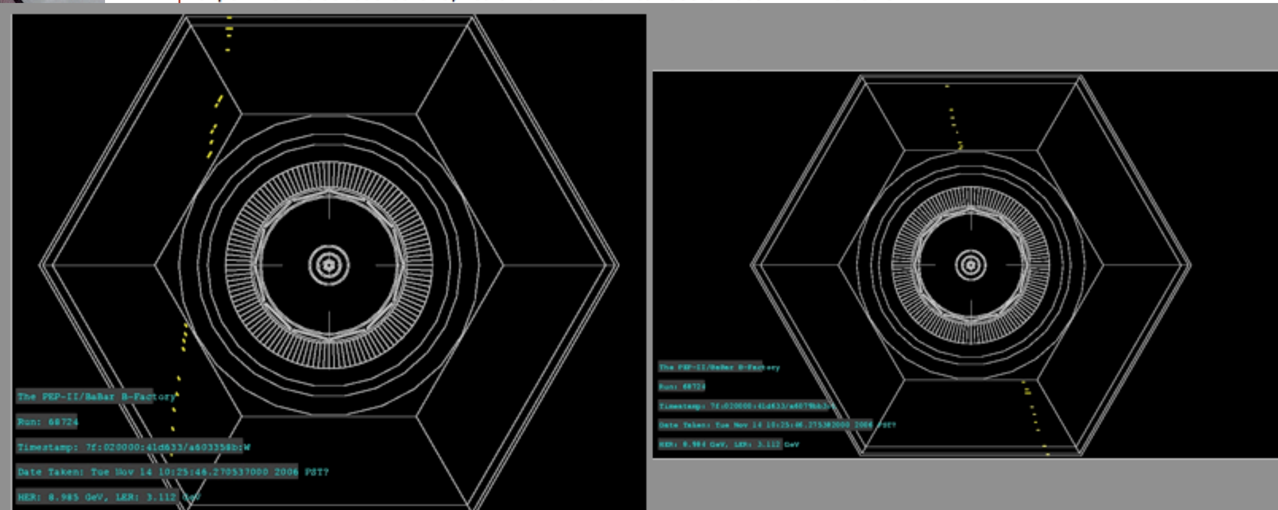
At the end of the summer, crews opened the "doors" that seal the front end of the detector, exposing its belly. In a delicate operation, the collaboration has been putting new muon detectors in four of the six sides of the 3-story-tall hexagon that makes up the overall detector's outer layer. With the final sextant successfully installed on Monday, BaBar now sports a vastly improved system for identifying muons and reconstructing rare but important decays.

"This is the most invasive change to BaBar in its history. The detector was not designed to be taken apart. It's tricky," said LST commissioner Mark Convery.

The performance of the original muon detectors, called Resistive Plate Chambers, declined unexpectedly and steadily soon after BaBar turned on in 1999. By 2002 it had become clear they could not be saved.

"We had no choice but to replace them, even though the project would require an enormous effort by BaBar and SLAC engineering and technical staff under severe time pressure," reported Stewart Smith of Princeton University, BaBar's spokesperson at the time the decision was made.

"A lot of the physics we're going after at this point requires identifying muons. The detectors were losing one percent efficiency a month. Without replacing the muon system, there would be no efficiency left before the experiment's scheduled end," said BaBar Technical Coordinator Bill Wisniewski.

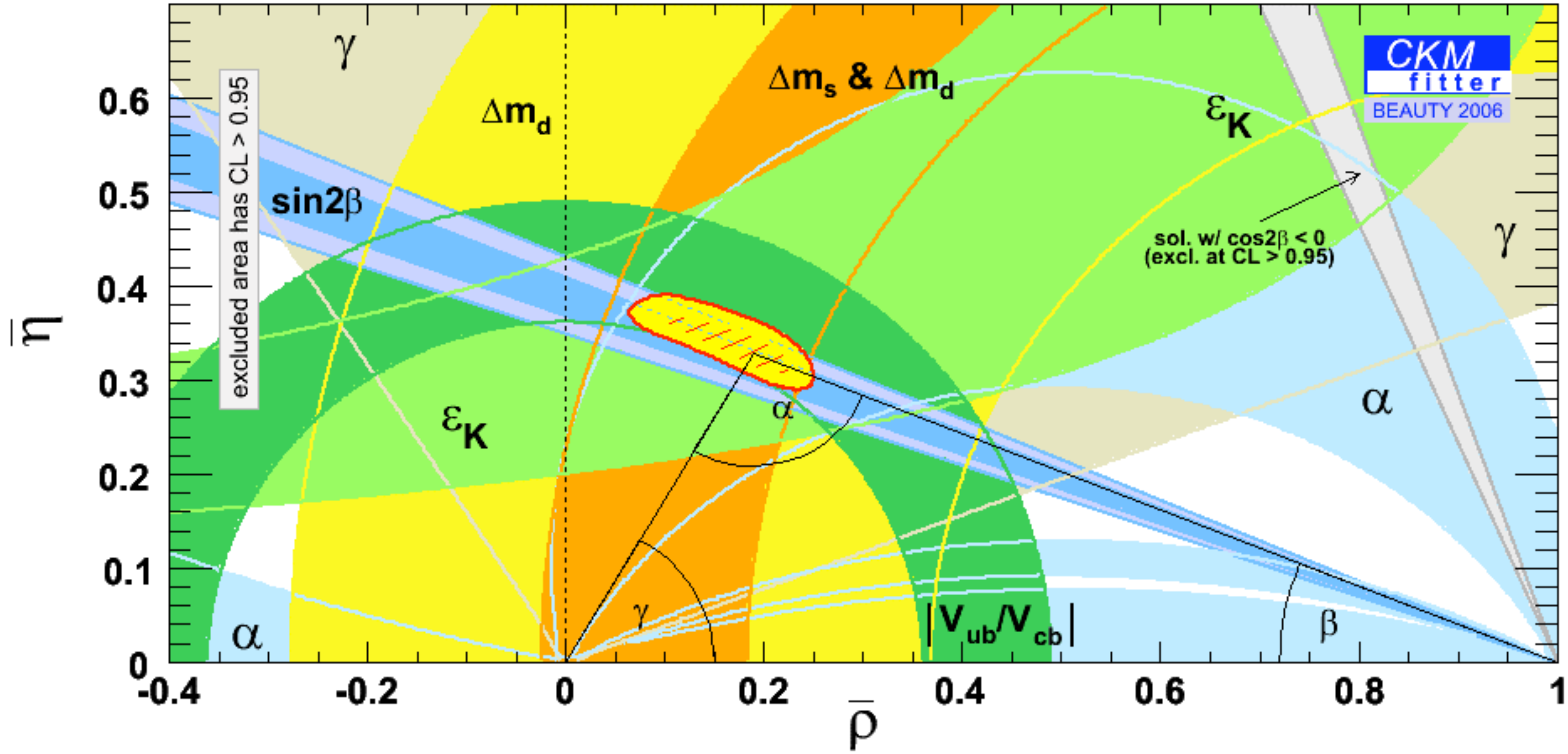


Muon crossing sextant 2, 3, 4
Run #68724 taken on 14-Nov-2006

Muon crossing sextant 2, 5 (installed on 2004)
Run #68724 taken on 14-Nov-2006

- Upgrade to the BaBar muon system completed last week.

Summary



CKM fitter
BEAUTY 2006
γ
Δm_d
Δm_s & Δm_d
ε_K
sin2β
excluded area has CL > 0.95
sol. w/ cos2β < 0
(excl. at CL > 0.95)
γ
α
ε_K
α
γ
α
|V_ub/V_cb|
β
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
η̄
ρ̄

Summary

- The *B* Factories continue to perform increasingly precise measurements of the UT and other observables
  - ...and will continue to do so for the next few years ....
- Data-taking at BaBar resumes in January 2007
  - By the end of the experiment's lifetime, aim to
    - Reach nearly 7 x design luminosity
    - Record 10 x design of integrated luminosity per day
    - Accumulate 1 ab^{-1} of data

For more results see

BaBar at ICHEP'06

- http://www-public.slac.stanford.edu/babar/ICHEP06_talks.htm

BaBar Talks at ICHEP 2006

The BaBar Collaboration presented its 114 new results in 24 parallel session talks and two plenary talks.

Plenary sessions

Measuring Vub: measurements related to gamma and semileptonic B decays (R. Kowlewski)

Rare B and Tau decays and the search for New Physics (R. Barlow)

Heavy Quark Session

1. Hot Topics in Heavy Quark Physics (U. Mallik)
2. Study of B decays to Open Charm final states with the BaBar experiment (G. Calderini)
3. Study of the decays of Charm mesons with the BaBar experiment (M. Bondioli)
4. Study of two-body Charmless B decays with the BaBar experiment (M. Bona)
5. Study of multi-body Charmless B decays with the BaBar experiment (T. Latham)
6. Shape function from radiative B decays with the BaBar experiment (M. Convery)
7. b-->c lnu decays and measurement of Vcb with the BaBar experiment (R. Dubitzky)
8. b-->u lnu decays and measurement of Vub with the BaBar experiment (R. Dubitzky)

CKM physics Session

1. Measurements of Charmless hadronic Branching Fractions (E. Di Marco)
2. Measurements of the CP angle alpha with the BaBar experiment (A. Telnov)
3. Measurements of the CP angle gamma with the BaBar experiment (G. Marchiori)
4. Study of exclusive radiative and electroweak penguin B decays with the BaBar experiment (D. Kowalsky)
5. Search for mixing and CP violation in D decays with the BaBar experiment (M. Wilson)
6. easurements of the CP angle beta in Charmless B decays (A. Lazzaro)
7. Measurements of CP violation in B-->Charm decays (K. George)
8. Search for leptonic B decays with the BaBar experiment (S. Sekula)

Spectroscopy session

1. Quarkonium spectroscopy with the BaBar experiment (X. Lou)
2. Study of recently observed mesonic Charm states with the BaBar experiment and possible observation of new states (D. Del Re)
3. Observation of new baryonic Charm states and search for pentaquarks with the BaBar experiment (P. Kim)
4. Study of Charmed Baryons with the BaBar experiment (B. Petersen)

Soft QCD session

1. Measurement of form factors with the BaBar experiment (S. Li)
2. Tests of QCD in final states with Charm and Charmonium hadrons at the B-Factories (C. Patrignani)

Beyond the Standard Model Session

1. Search for Physics Beyond Standard Model with BaBar and Belle Detectors (G. Hamel de Monchenault)

Hard QCD session

1. Initial state radiation (ISR) study at BaBar and the application to R measurement and hadron spectroscopy (E. Solodov)


More
Slides?!
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