Measurements of the Unitarity Triangle at BaBar

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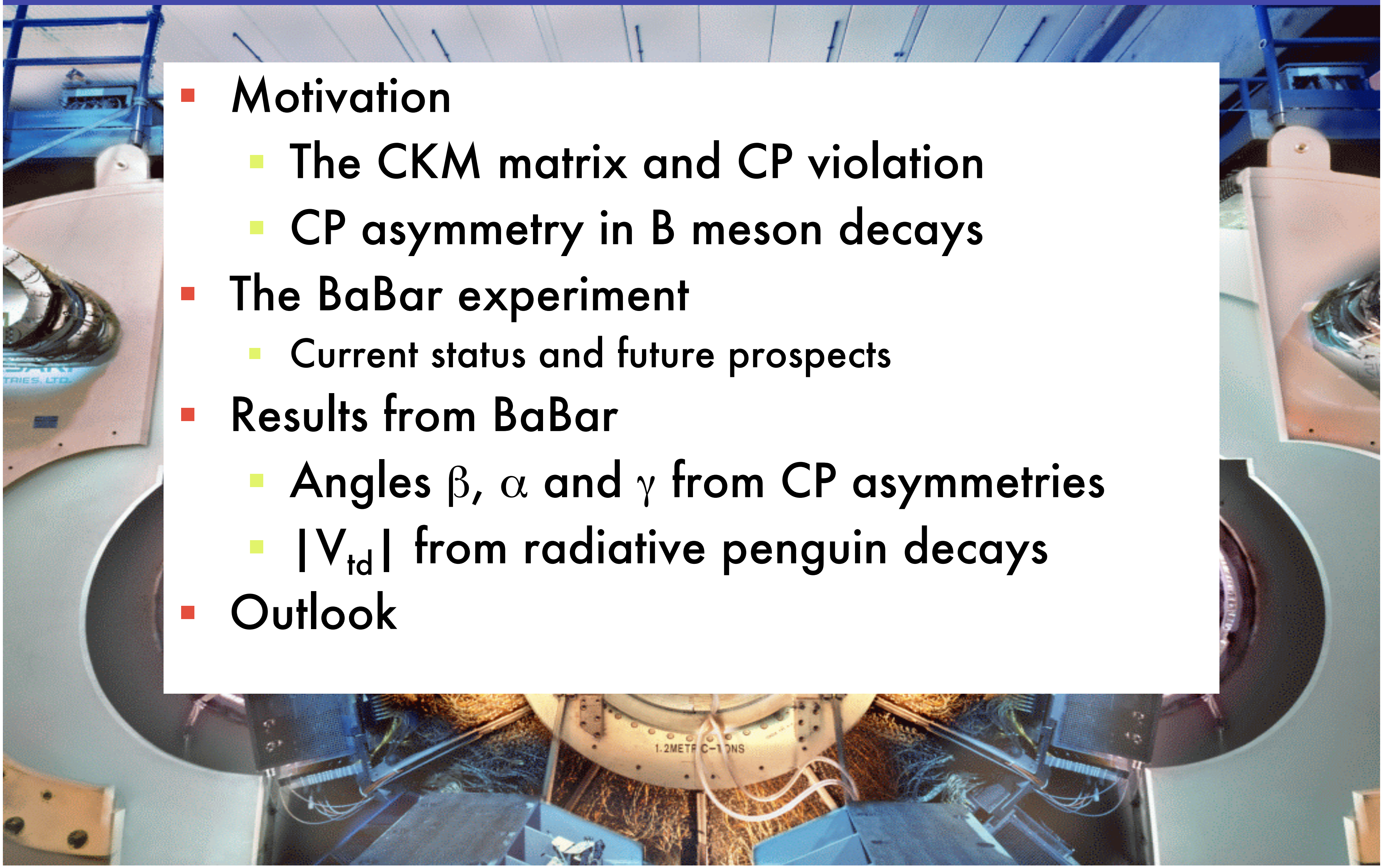
Klystron Gallery of the 2-mile long PEP-II accelerator

SLAC Research Yard

BaBar Detector

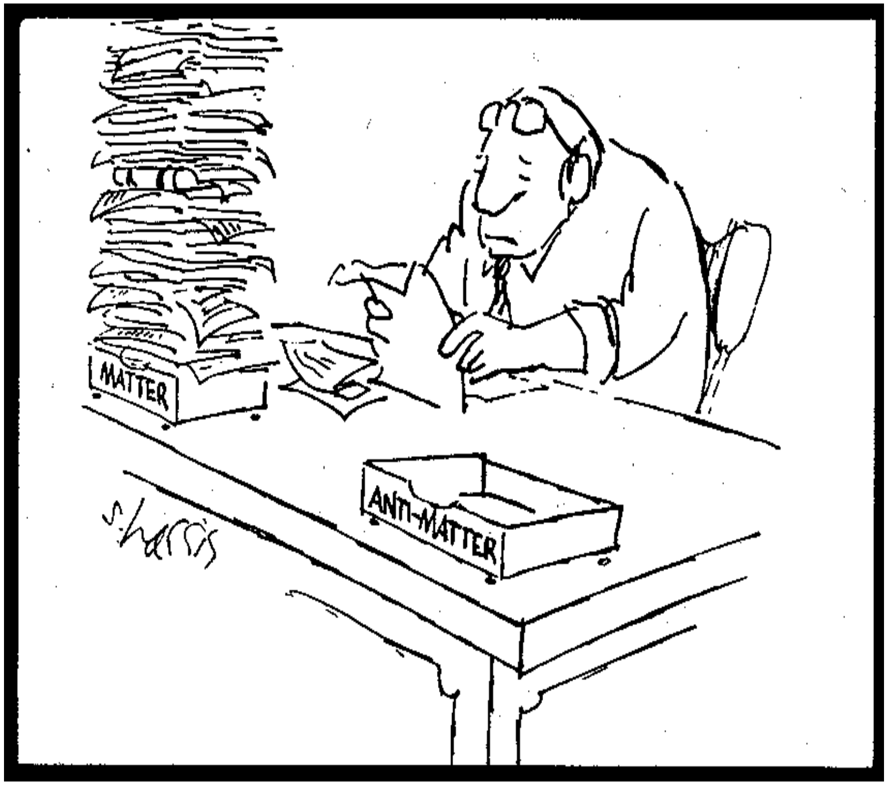
Seminar at Sheffield University - November 22nd 2006

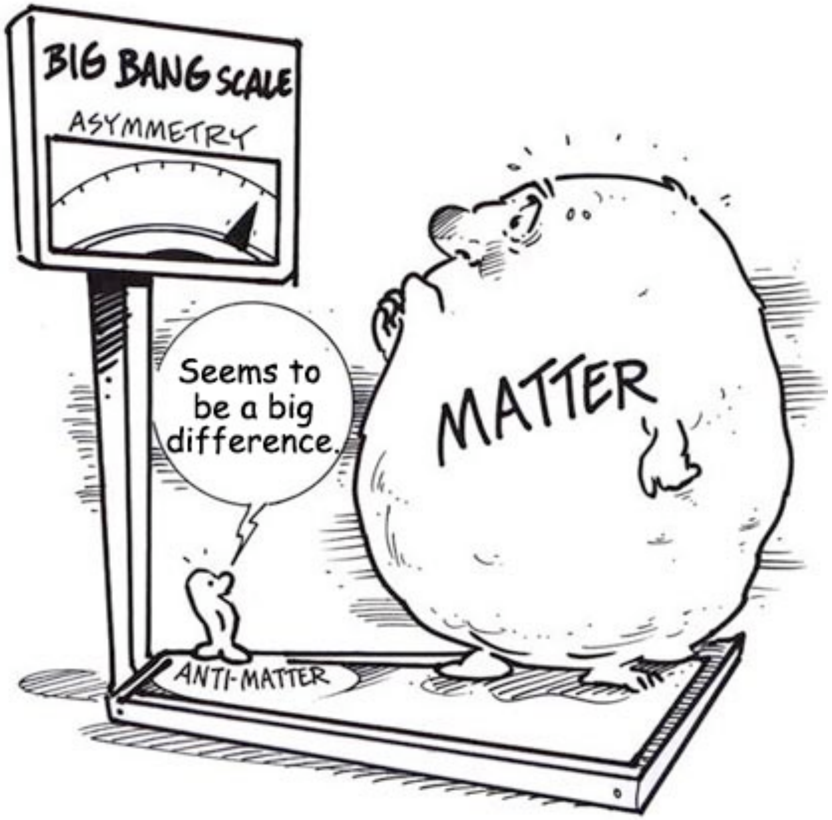
Outline



- Motivation
  - The CKM matrix and CP violation
  - CP asymmetry in B meson decays
- The BaBar experiment
  - Current status and future prospects
- Results from BaBar
  - Angles β, α and γ from CP asymmetries
  - $|V_{td}|$ from radiative penguin decays
- Outlook

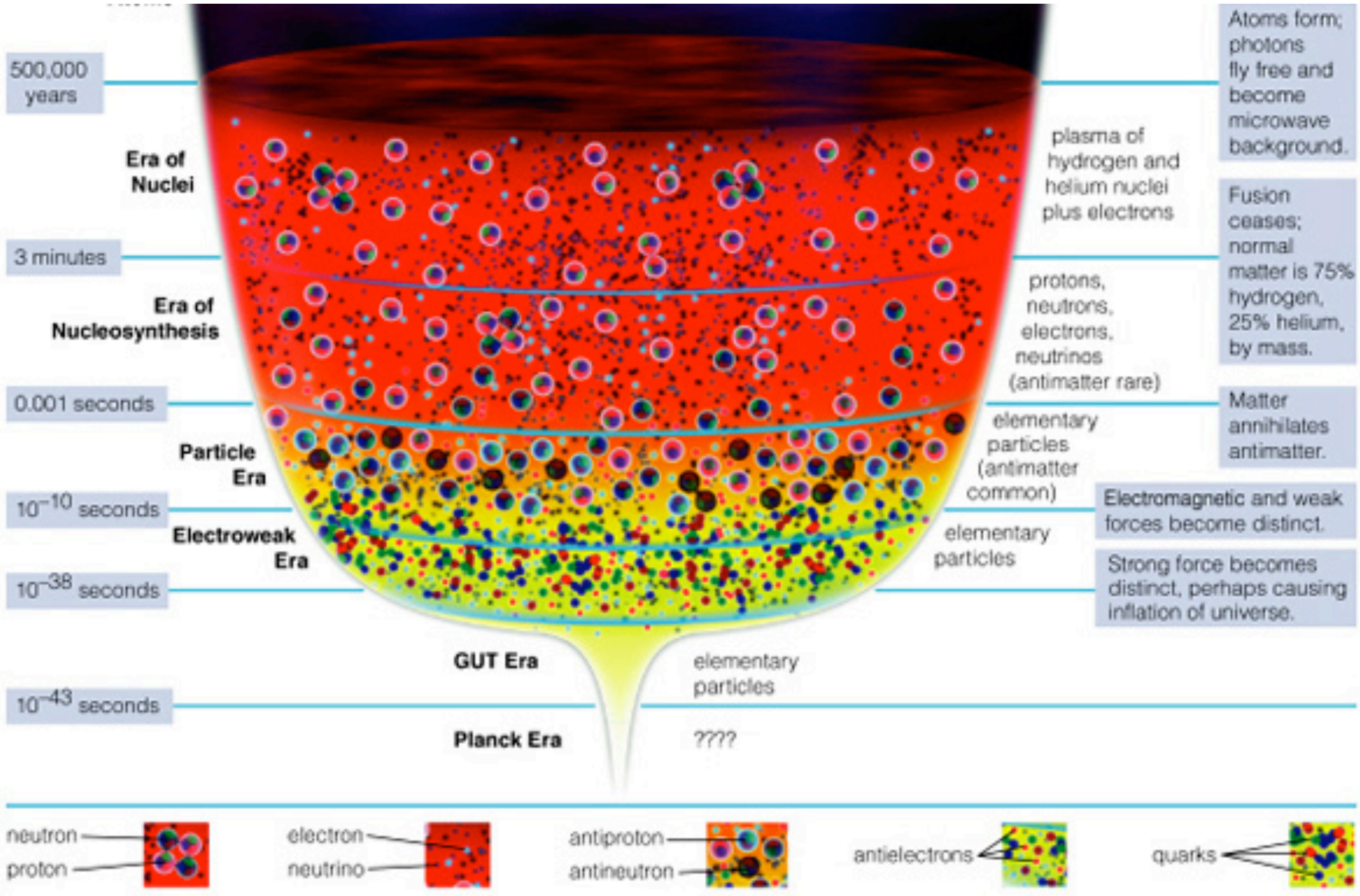
Why is the universe matter dominated ?





This wasn't always true .....

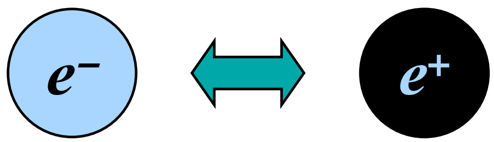
How the universe has evolved



- As the universe expanded and cooled, symmetry breaking occurred, leading to a matter-antimatter asymmetry.

Matter and anti-matter

- Dirac predicted existence of anti-matter in 1928
  - Positron (= anti-electron) discovered in 1932



- Our Universe contains (almost) only matter

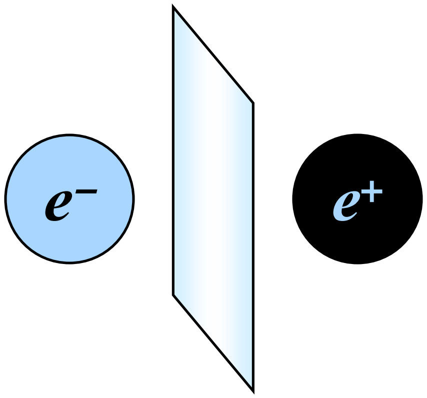
> I do not believe in the hole theory, since I would like to have the asymmetry between positive and negative electricity in the laws of nature (it does not satisfy me to shift the empirically established asymmetry to one of the initial state)
>
> Pauli, 1933 letter to Heisenberg

- Translation: Pauli would like the laws of physics to be different for particles and anti-particles

CP symmetry

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), Garwin, Lederman, Weinrich (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)



1. Violation of C and CP
2. Baryon number violation e.g. proton decay
3. Departure from thermal equilibrium

CP Violation

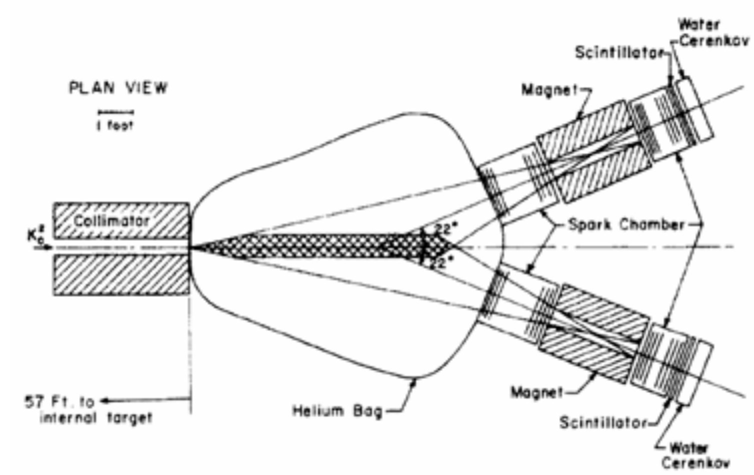
Christenson *et al.* (1964)

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

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

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

Final states have different *CP* eigenvalues



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

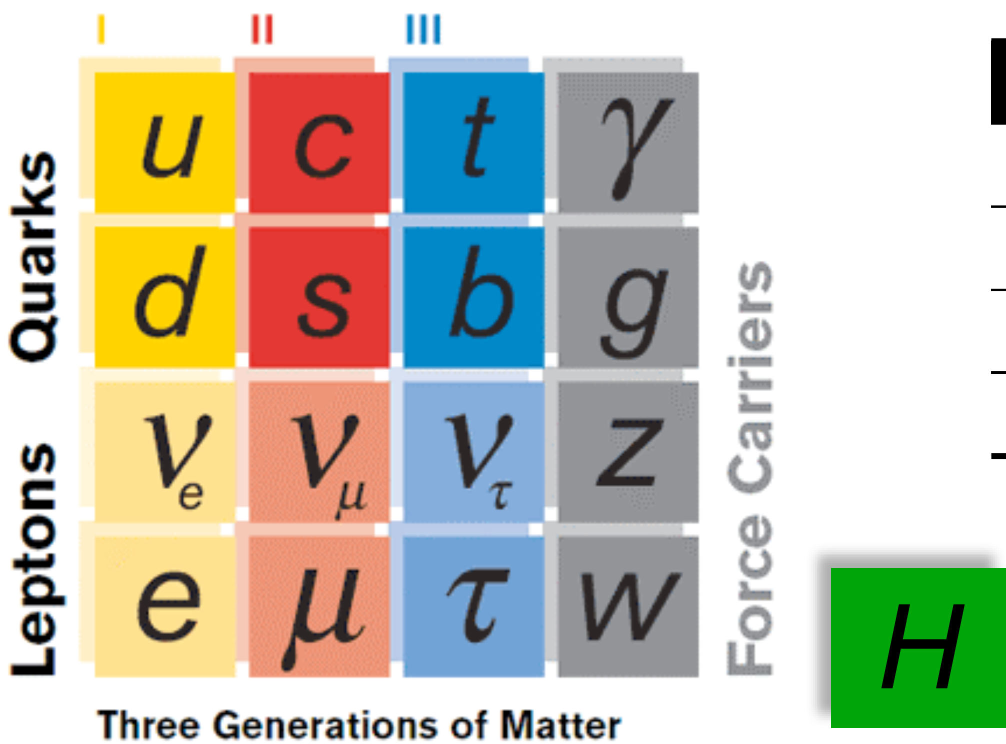
➔ Laws of physics apply differently to matter and antimatter

- 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 Standard Model

- The theory of fundamental particles and how they interact,



	strong	E&M	weak
u	Yes	Yes	Yes
d	Yes	Yes	Yes
e^-	No	Yes	Yes
ν_e	No	No	Yes

- Why 3 sets (= generations) of particles?
  - How do they differ? How do they interact with each other?

Weak interactions : quarks

- 3 quark generations.
- Differ only by masses.

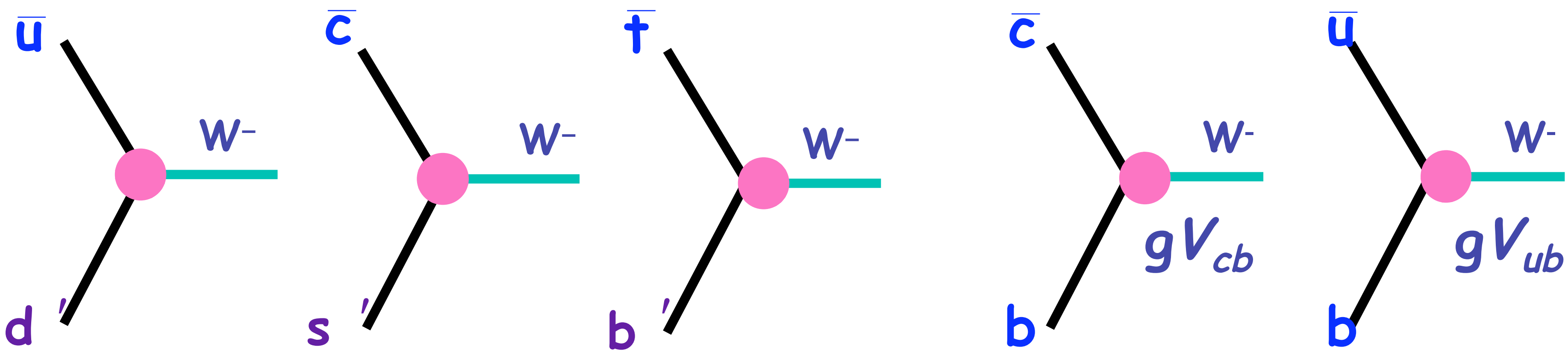
$Q = +2/3$, $Q = -1/3$

$$\begin{pmatrix} u' \\ d \end{pmatrix}_L \quad \begin{pmatrix} c' \\ s \end{pmatrix}_L \quad \begin{pmatrix} t' \\ b \end{pmatrix}_L$$

$m_t > m_c > m_u$

$m_b > m_s > m_d$

Doublets Coupling to W Boson

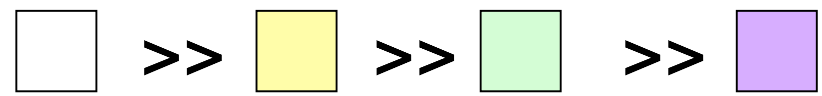


Quarks ‘couple’ within the same generation Can also ‘couple’ between generations

The Cabibbo-Kobayashi-Maskawa (CKM) Matrix

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

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



- This is 'easier to see' when using the Wolfenstein parameterisation. A, λ, ρ and η are the Wolfenstein parameters. [PRL. 51, 1945 (1983)]
  - Think in 'orders of λ'

$$V_{CKM} = \begin{pmatrix} 1-\frac{1}{2}\lambda^2-\frac{1}{8}\lambda^4 & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda\left[1+A^2\lambda^4\left(\rho+i\eta-\frac{1}{2}\right)\right] & 1-\frac{1}{2}\lambda^2-\frac{1}{8}\lambda^4(1+4A^2) & A\lambda^2 \\ A\lambda^3\left[(1-\rho-i\eta)\left(1-\frac{1}{2}\lambda^2\right)\right] & -A\lambda^2\left[1+\lambda^2\left(\rho+i\eta-\frac{1}{2}\right)\right] & 1-\frac{1}{2}A^2\lambda^4 \end{pmatrix} + \mathcal{O}(\lambda^6).$$

- Understanding CP Violation in the Standard Model requires accurate measurements of ρ and η.

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

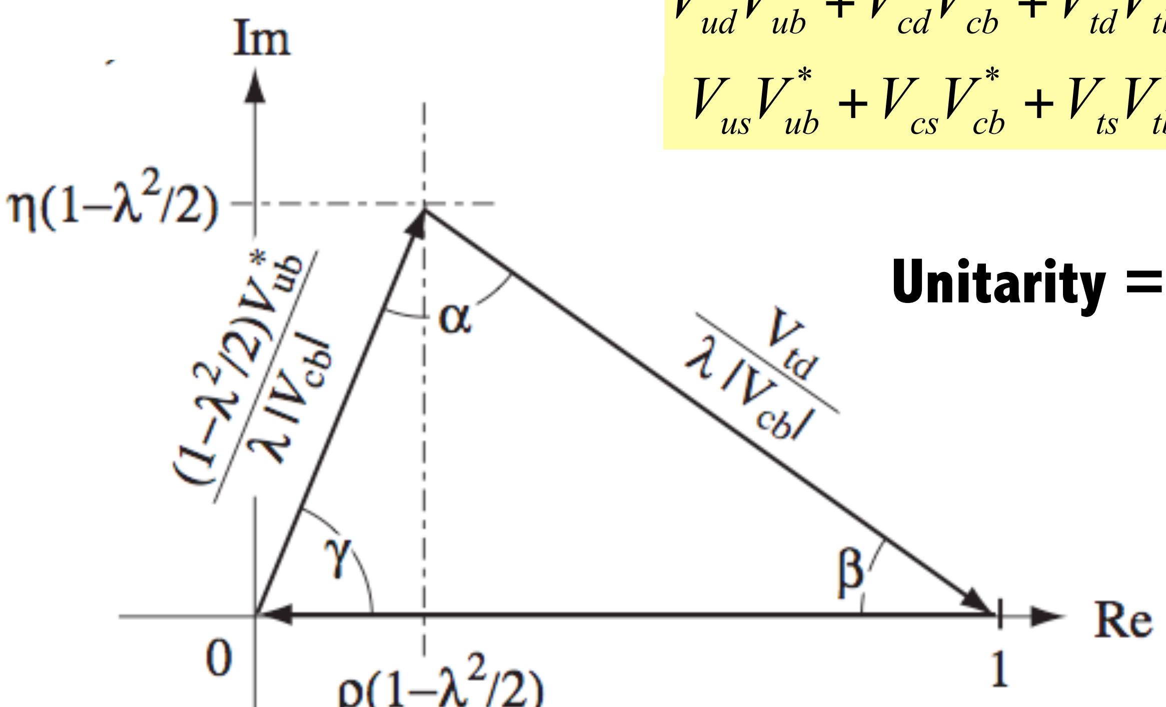
  - Precision studies of the CKM matrix may uncover them

The Unitarity Triangle

- $V^\dagger V = 1$ gives us

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

This one has the 3 terms in the same order of magnitude



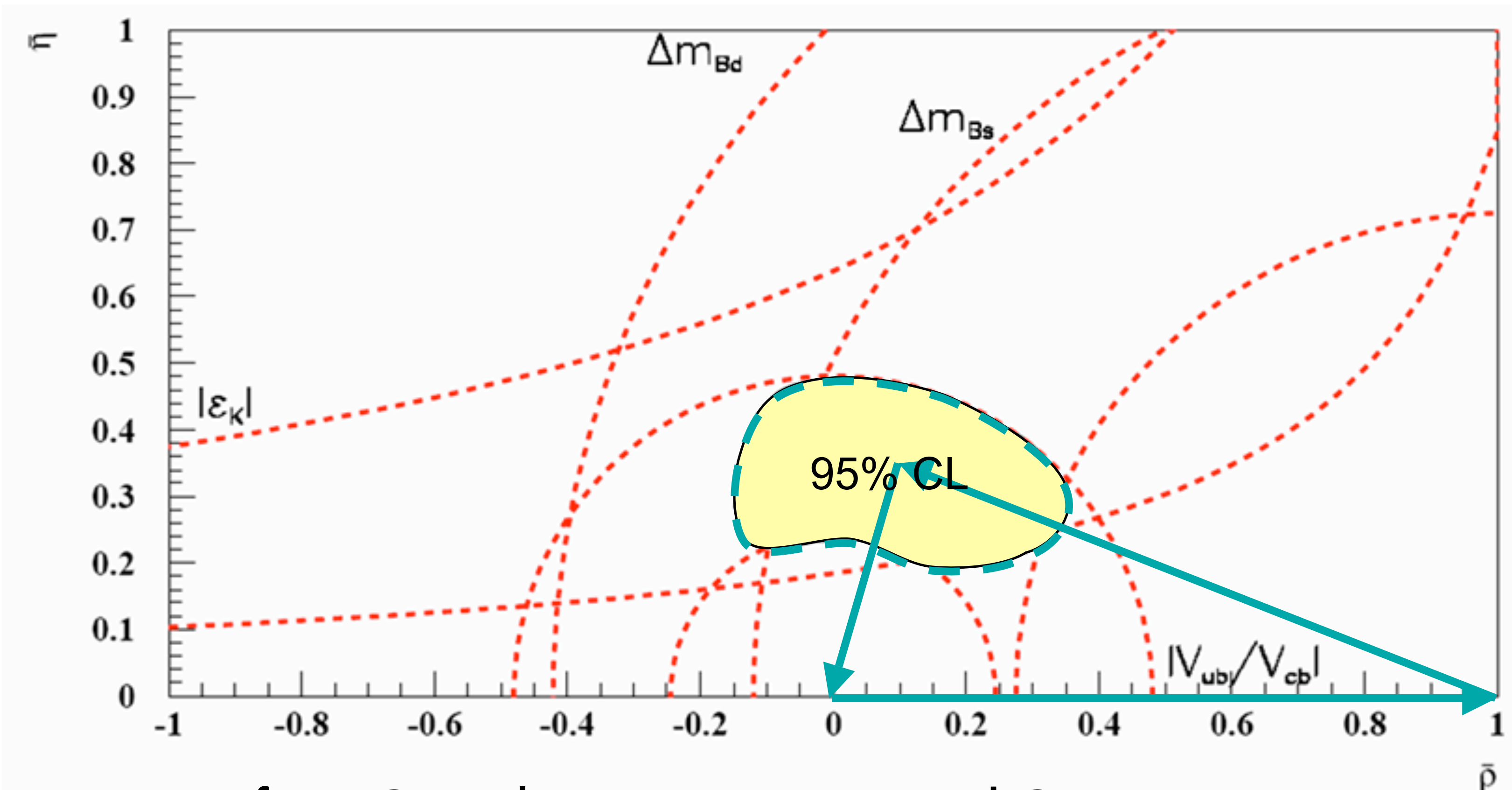
Unitarity = "Preserves probability"

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

- 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 ....

What did we know about the UT?

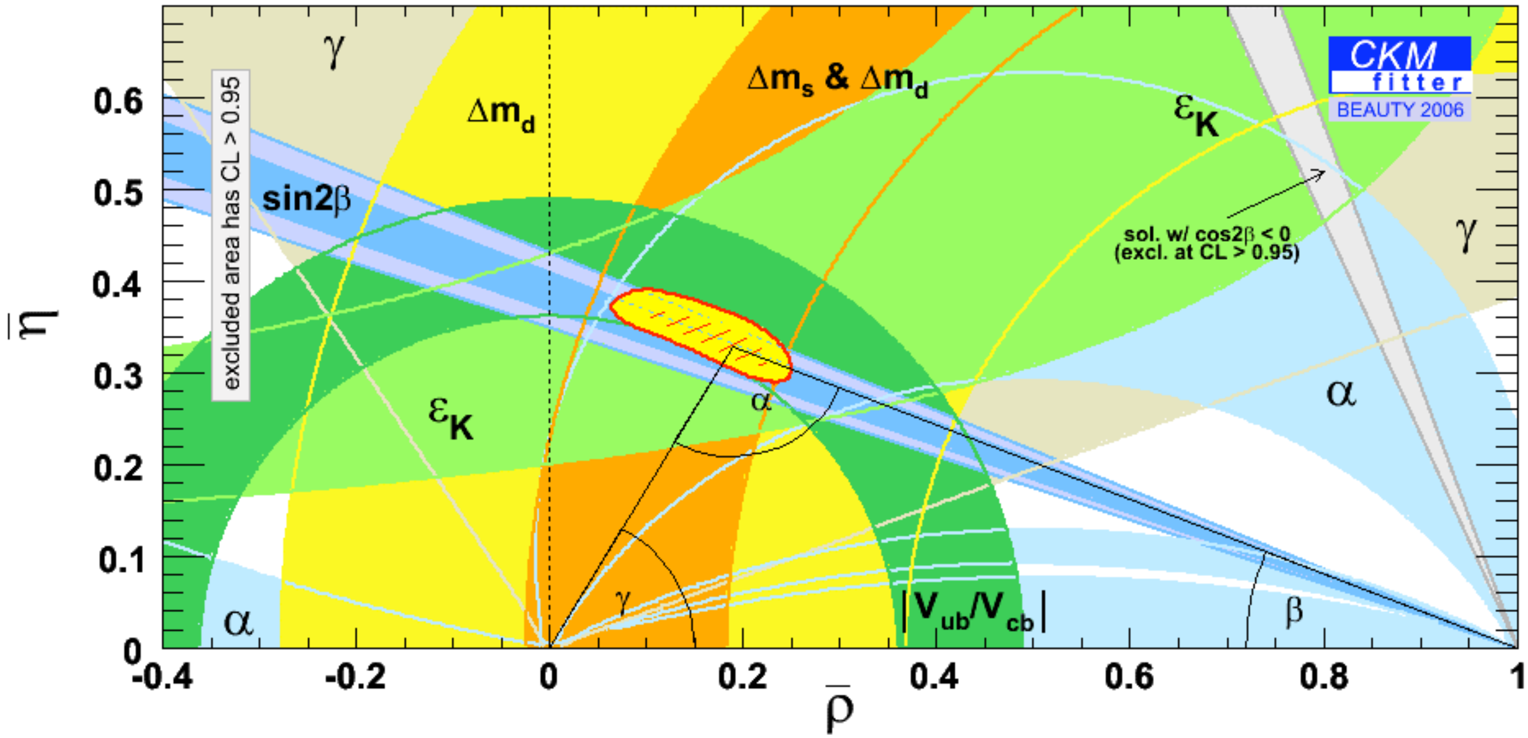
- How the UT looked in the last century (1998)



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

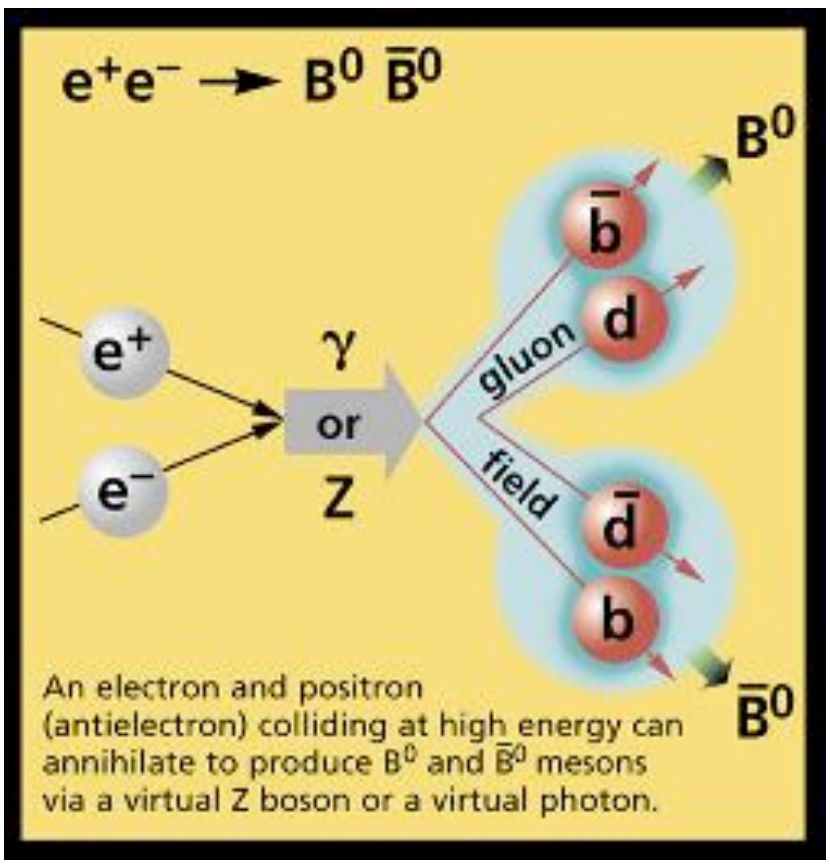
What do we know about the UT?

- How the UT looks now (2006)

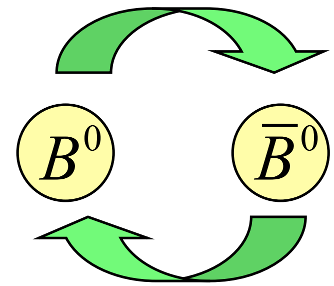


Anatomy of the B^0 system

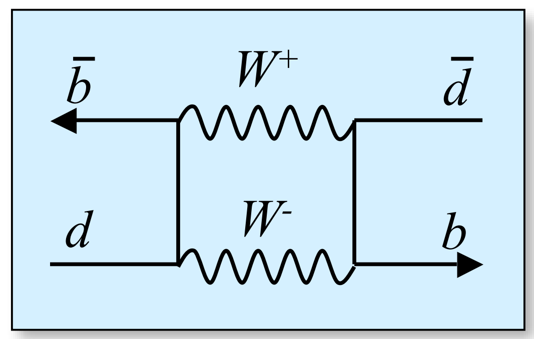
- The B^0 meson is a bound state of b and d quarks
- Production mechanism　　　　　Mixing



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



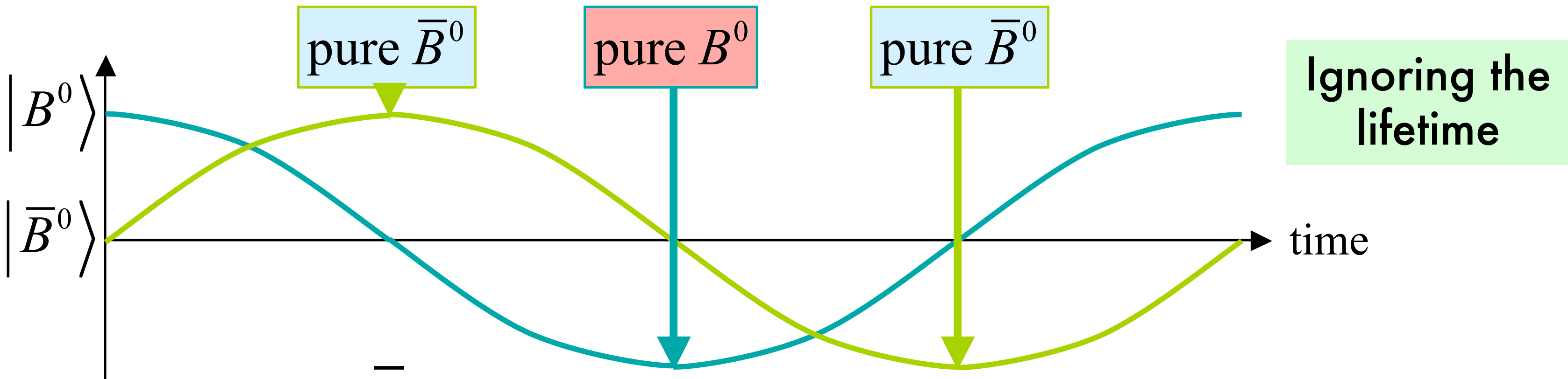
$\bar{B}^0 = (b\bar{d})$



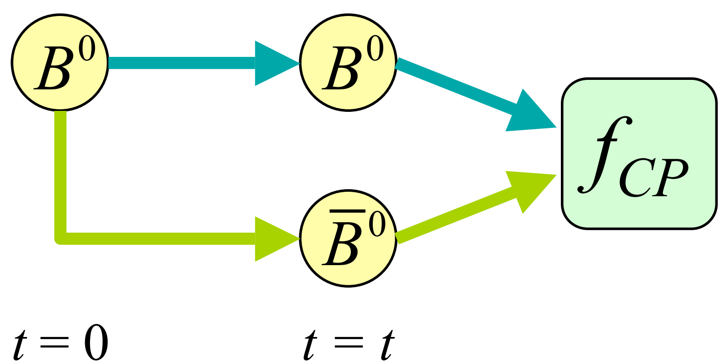
⇒ B^0 decays as a quantum interferometer

Time-dependent Interference

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



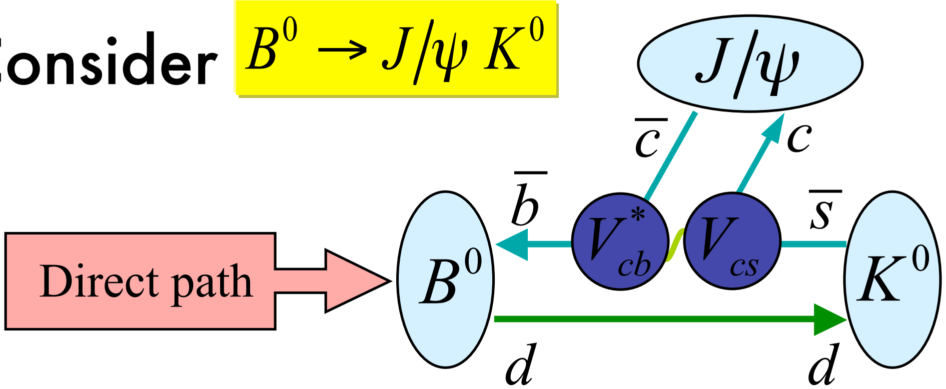
- Suppose B^0 and $\overline{B}^0$ can decay into a same final state f_{CP}



- Two paths can interfere
- Decay probability depends on:
  - the decay time t
  - the relative complex phase between the two paths

The Golden Mode

- Consider $B^0 \to J/\psi\, K^0$



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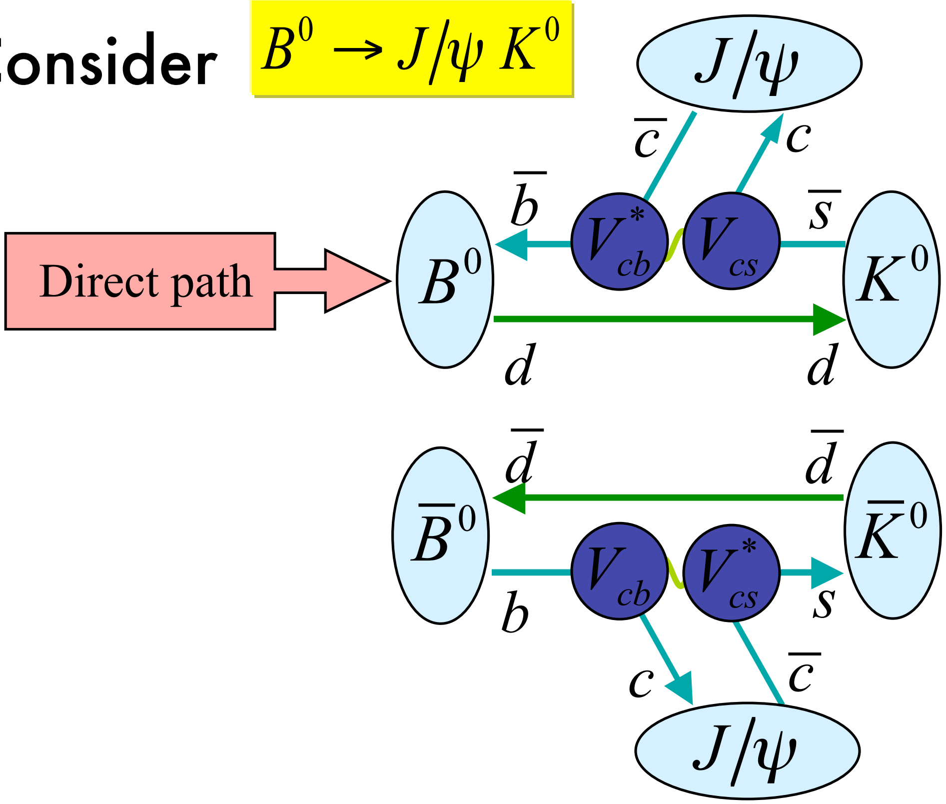

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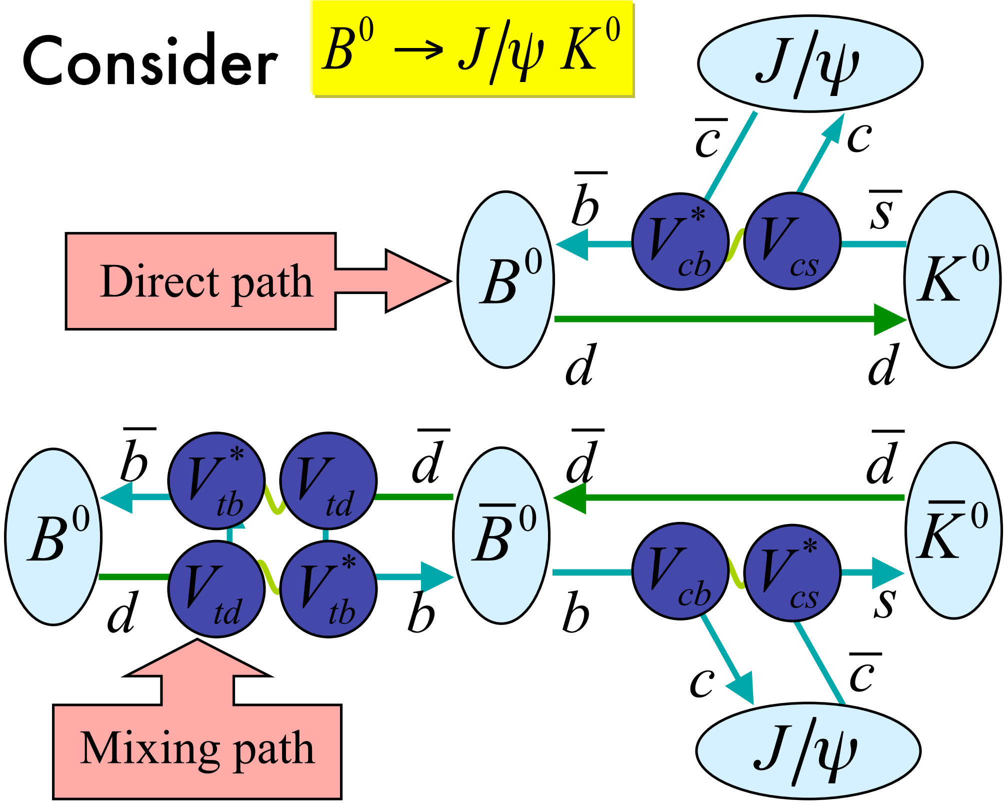

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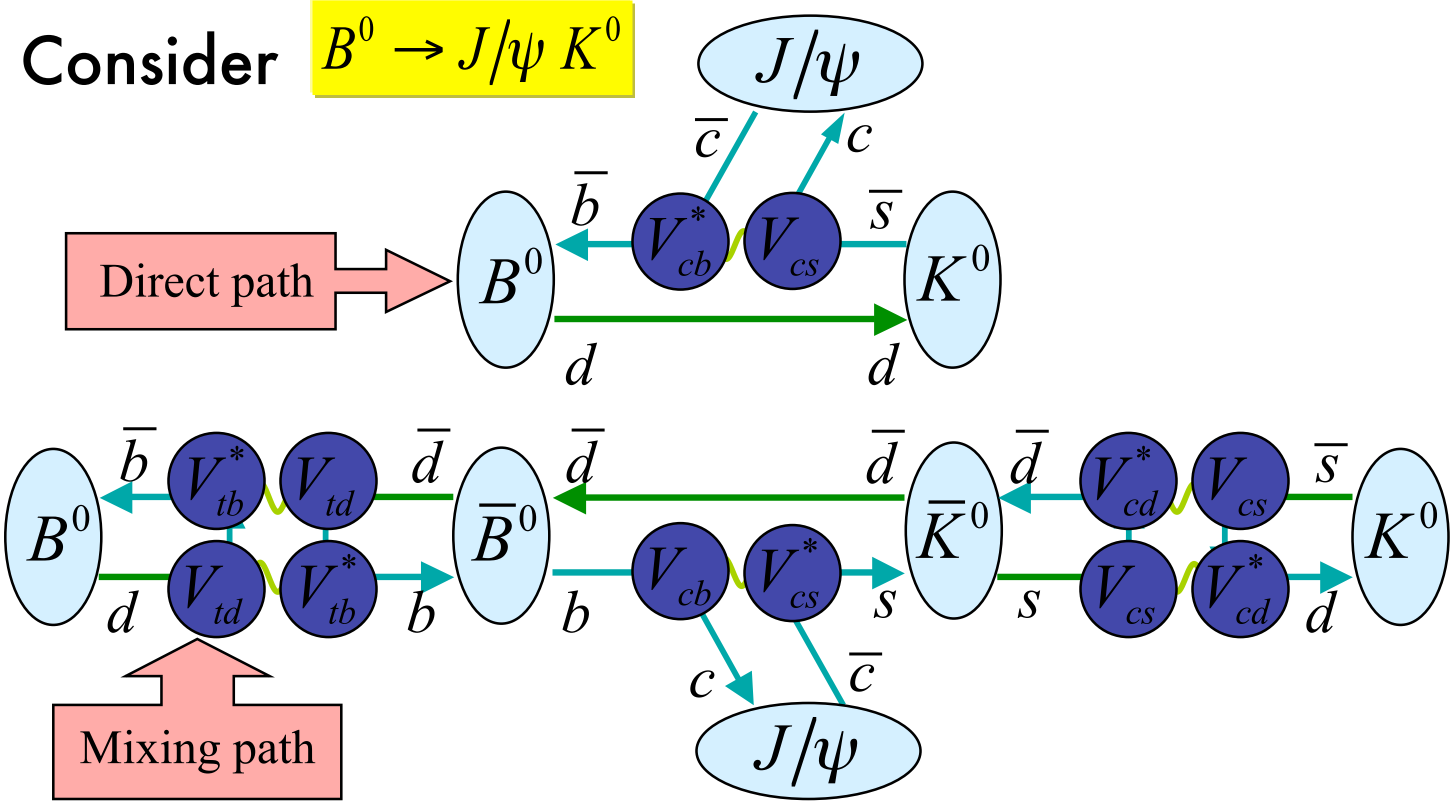

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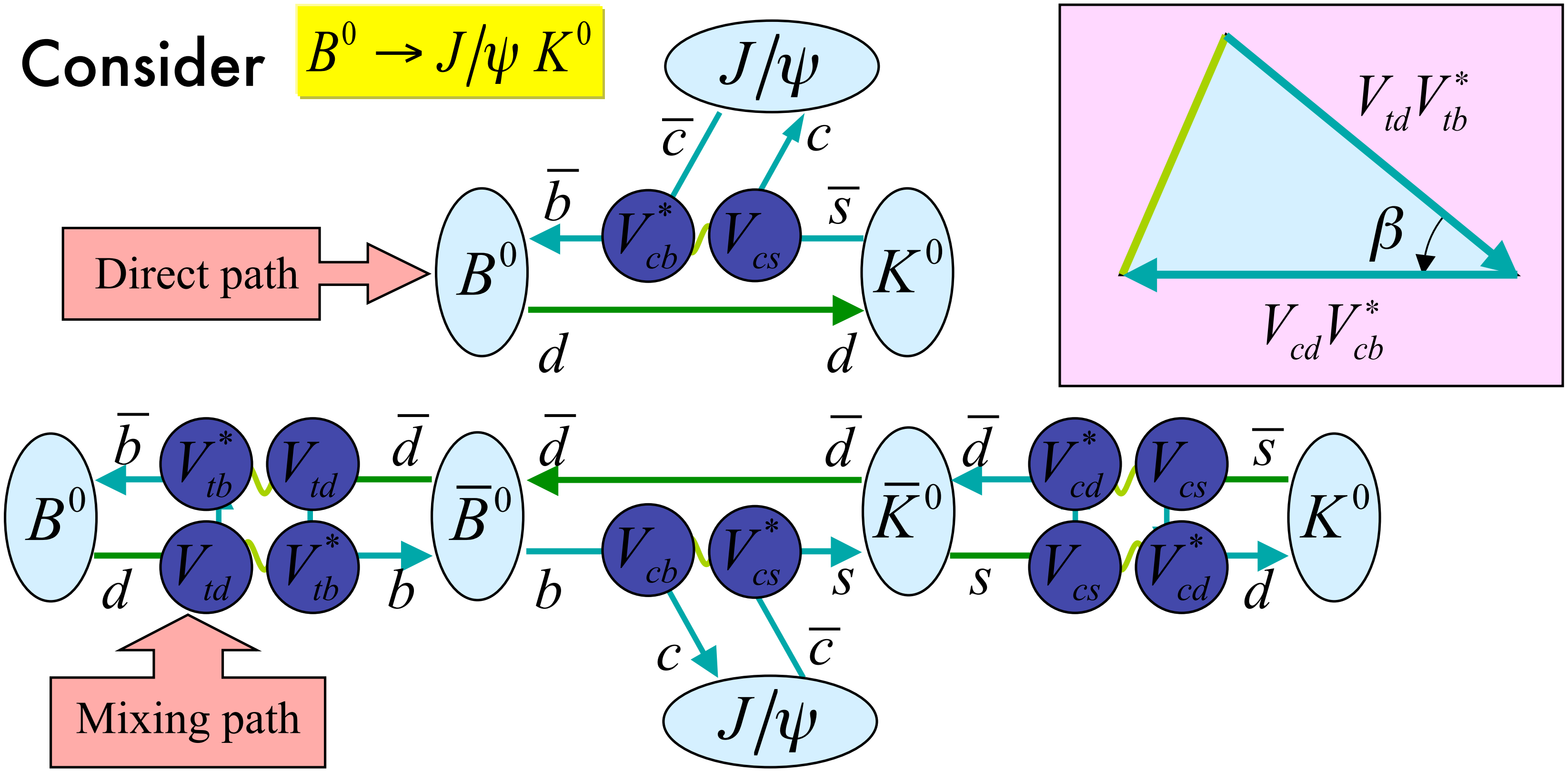

- Phase difference is

$$\arg(V_{cs}V_{cb}^*) - \arg(V_{td}^2 V_{tb}^{*2} V_{cb} V_{cs}^* V_{cs}^2 V_{cd}^{*2}) = 2\left[\arg(V_{cd}V_{cb}^*) - \arg(V_{td}V_{tb}^*)\right] = -2\beta$$

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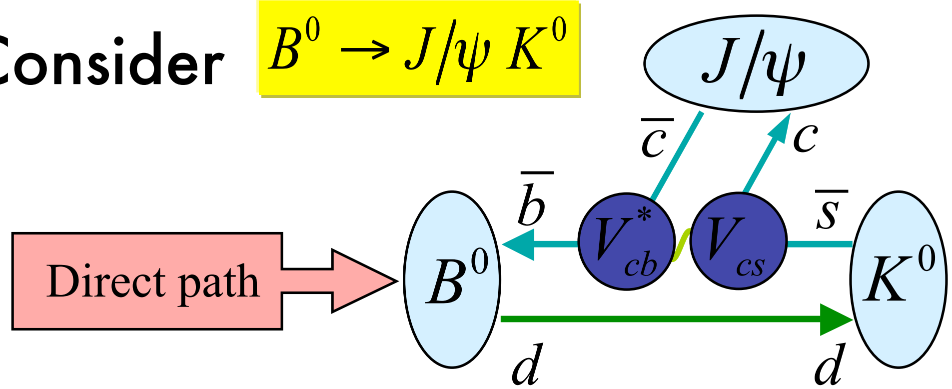

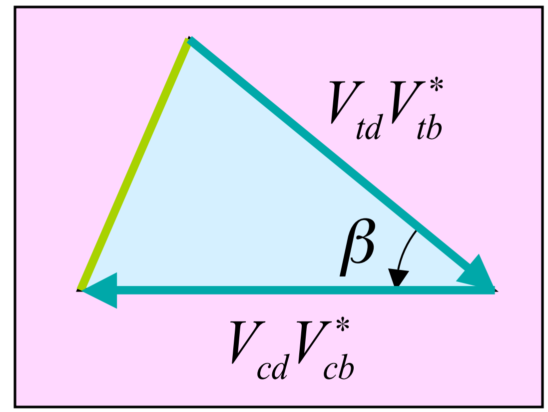

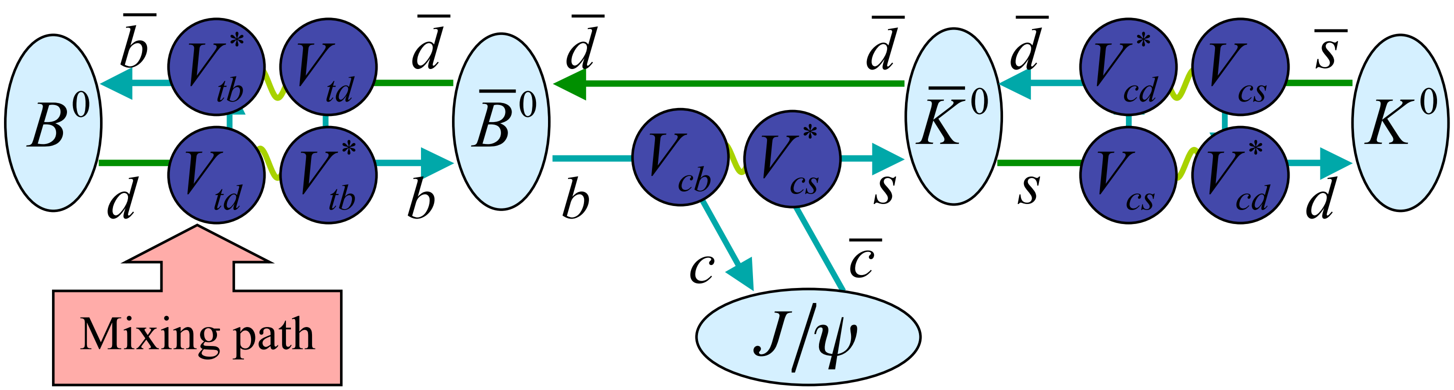

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Time-dependent *CP* Asymmetry

- Quantum interference between the direct and mixed paths makes $B^0(t) \to J/\psi\, K^0$ and $\overline{B}^0(t) \to J/\psi\, K^0$ different
- Define time-dependent *CP* asymmetry:

$$A_{CP}(t) = \frac{N(\overline{B}^0(t) \to J/\psi\, K_S^0) - N(B^0(t) \to J/\psi\, K_S^0)}{N(\overline{B}^0(t) \to J/\psi\, K_S^0) + N(B^0(t) \to J/\psi\, K_S^0)} = \sin(2\beta)\sin(\Delta m t)$$

  - We can measure the angle β of the UT
- What do we have to do to measure $A_{CP}(t)$?
  - Step 1: Produce and detect $B^0 \to f_{CP}$ events
  - Step 2: Separate $\overline{B}^0$ from B^0
  - Step 3: Measure the decay time *t*

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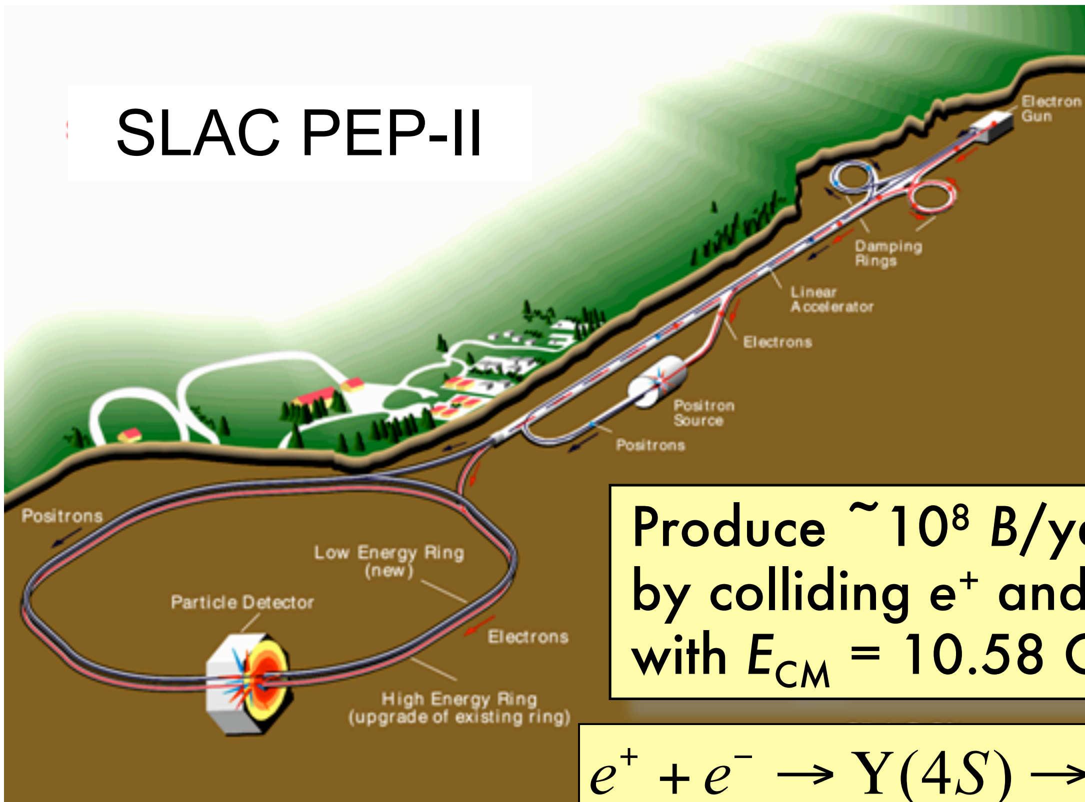
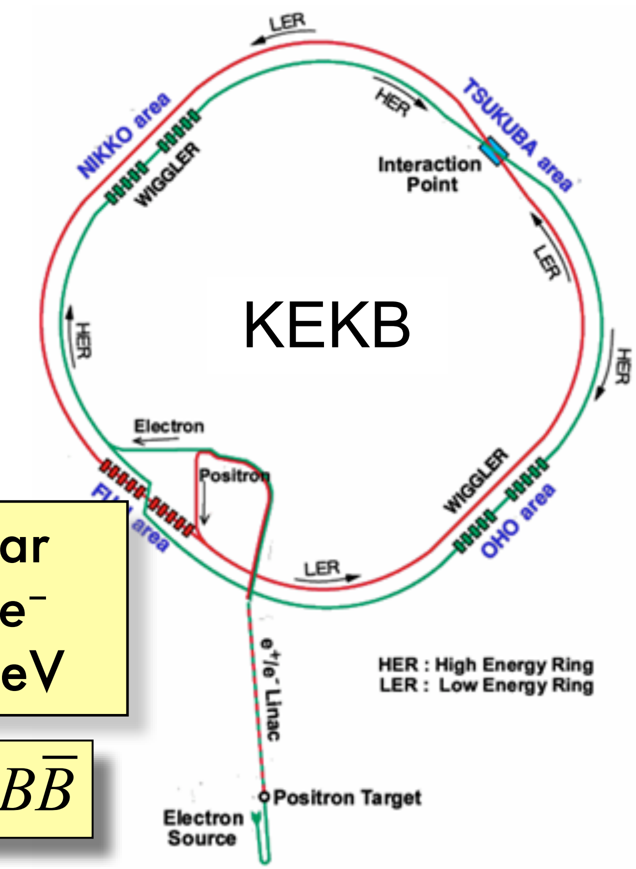
Solution: Asymmetric *B* Factory

B Factories

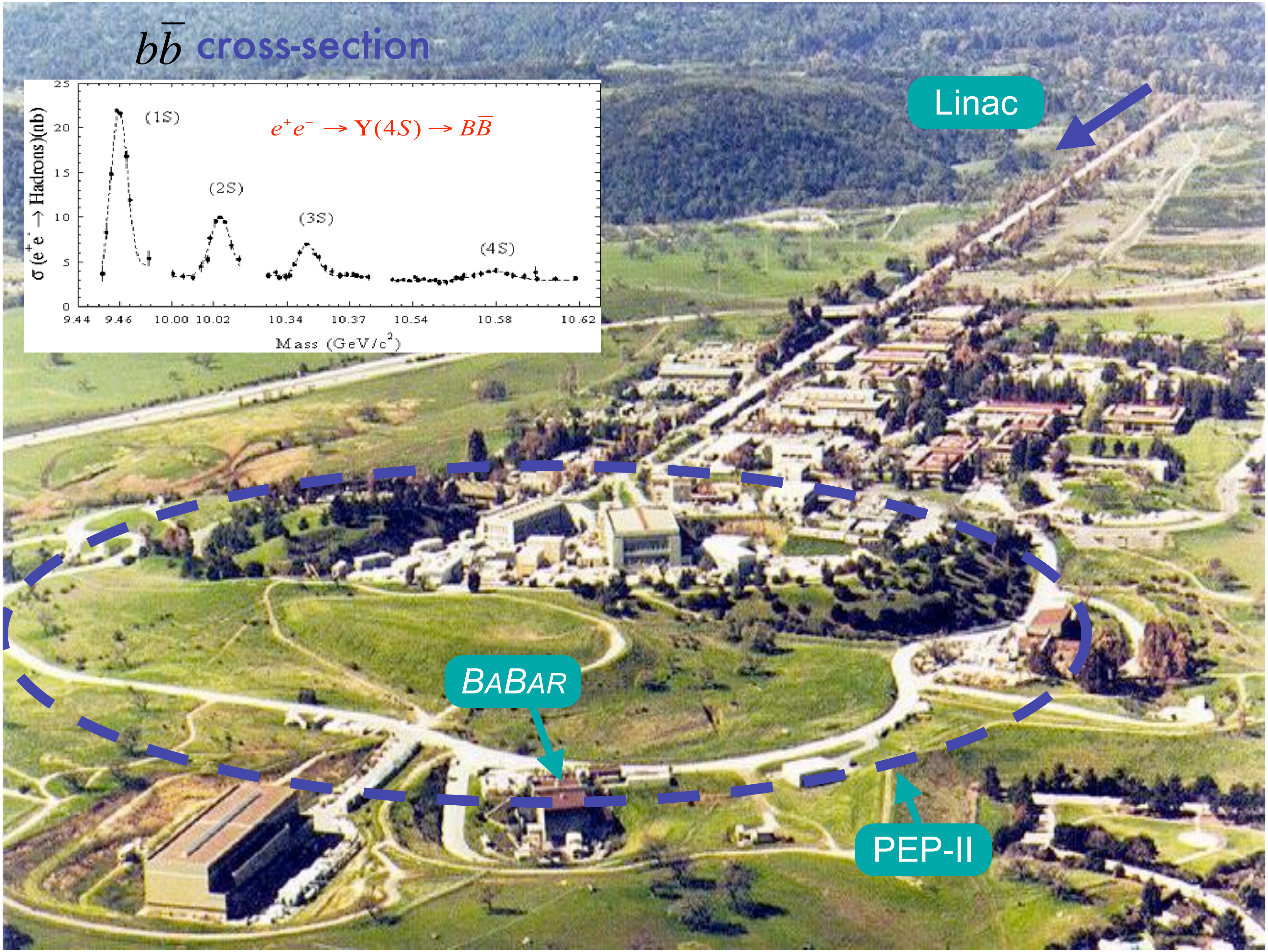
- Designed specifically for precision measurements of the *CP* violating phases in the CKM matrix





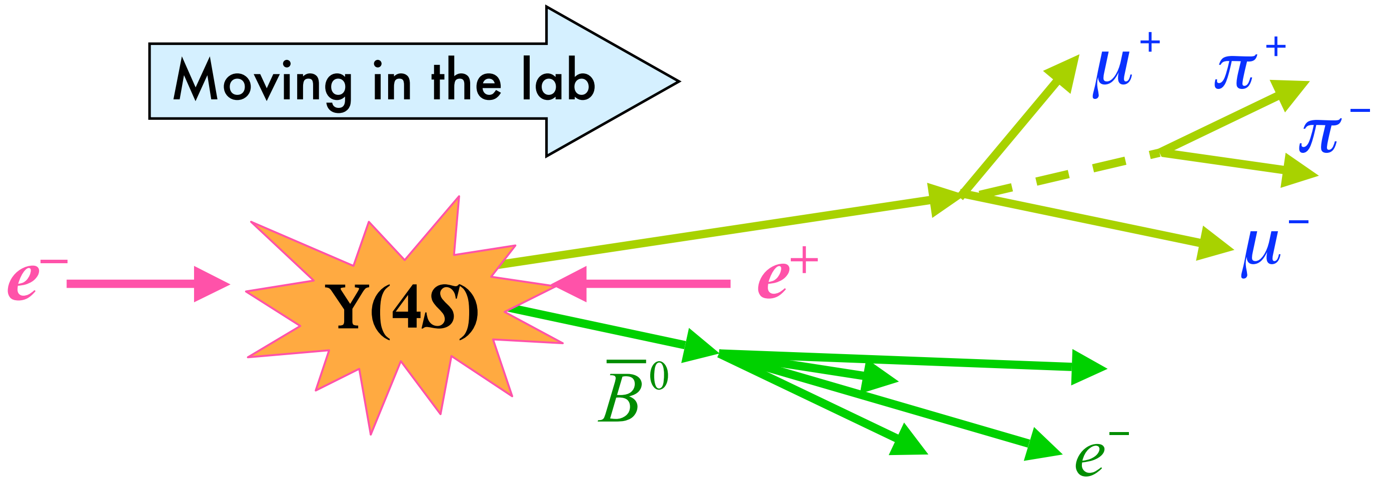
Produce ~10^8 *B*/year by colliding e^+ and e^- with E_{CM} = 10.58 GeV

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


$b\bar{b}$ cross-section
$e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B}$
(1S)
(2S)
(3S)
(4S)
$\sigma(e^+e^- \rightarrow \text{Hadrons})(\text{nb})$
Mass (GeV/c^2)
0
5
10
15
20
25
9.44
9.46
10.00
10.02
10.34
10.37
10.54
10.58
10.62
Linac
BABAR
PEP-II

Asymmetric energy *B* Factory

- Collide e^+ and e^- with energy(e^+) ≠ energy (e^-)
  - PEP-II: 9 GeV e^- vs. 3.1 GeV e^+ → $\beta\gamma = 0.56$



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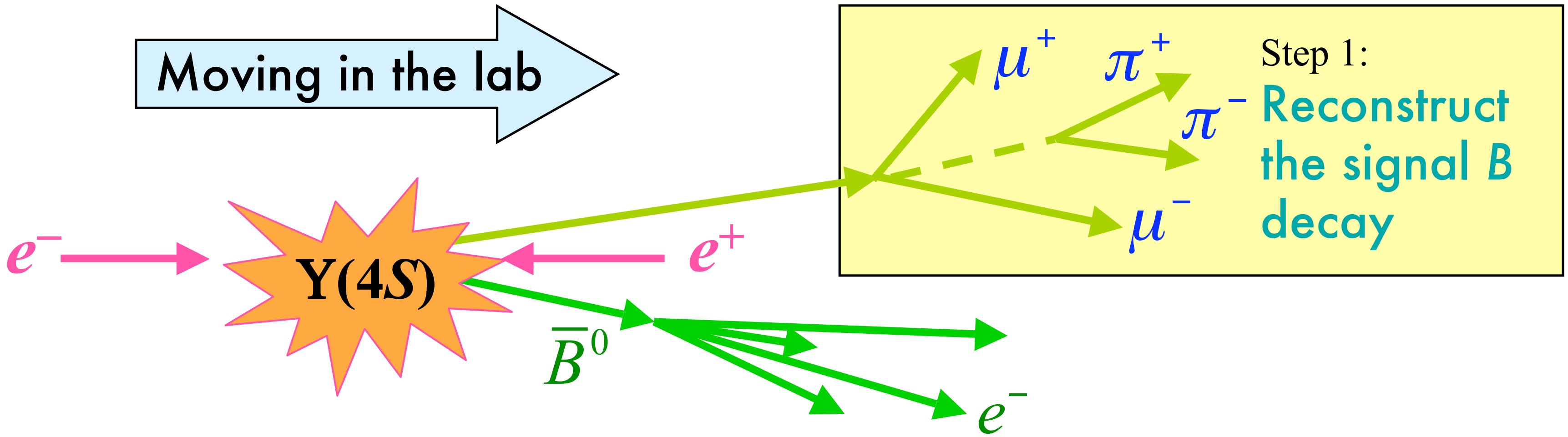

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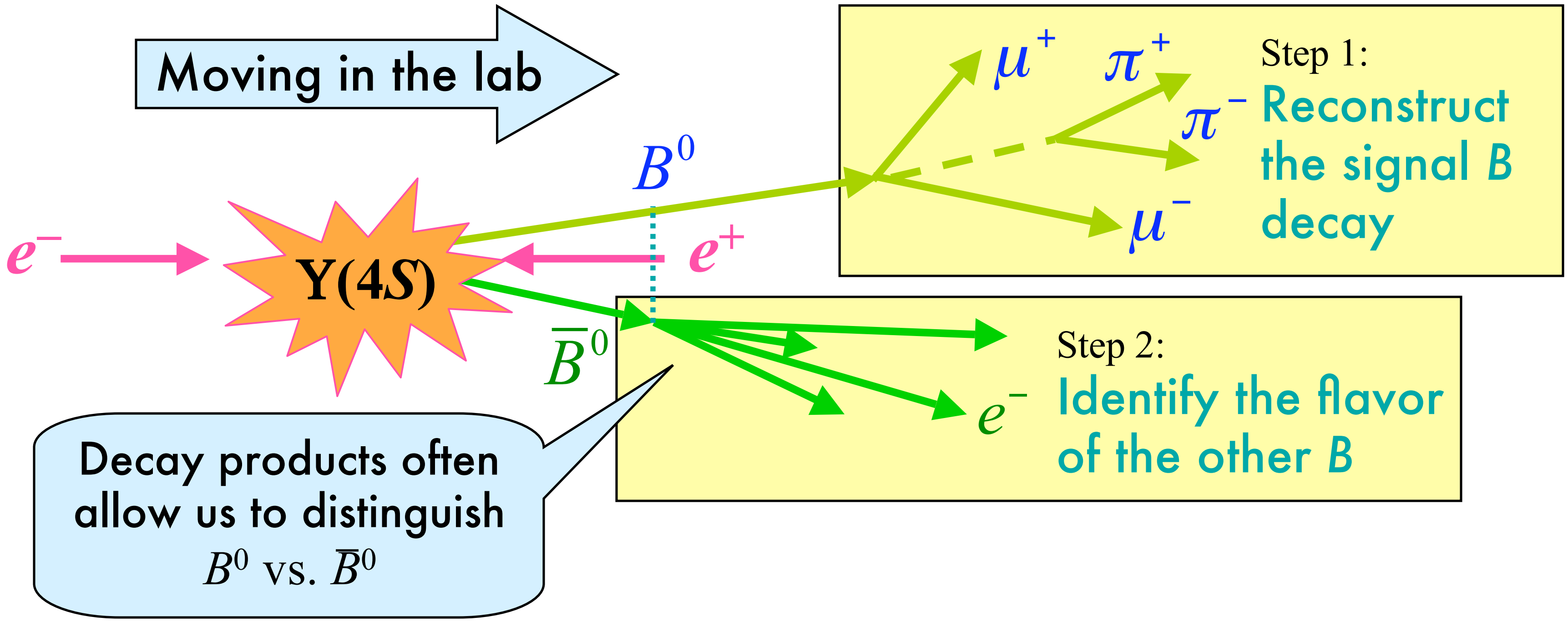

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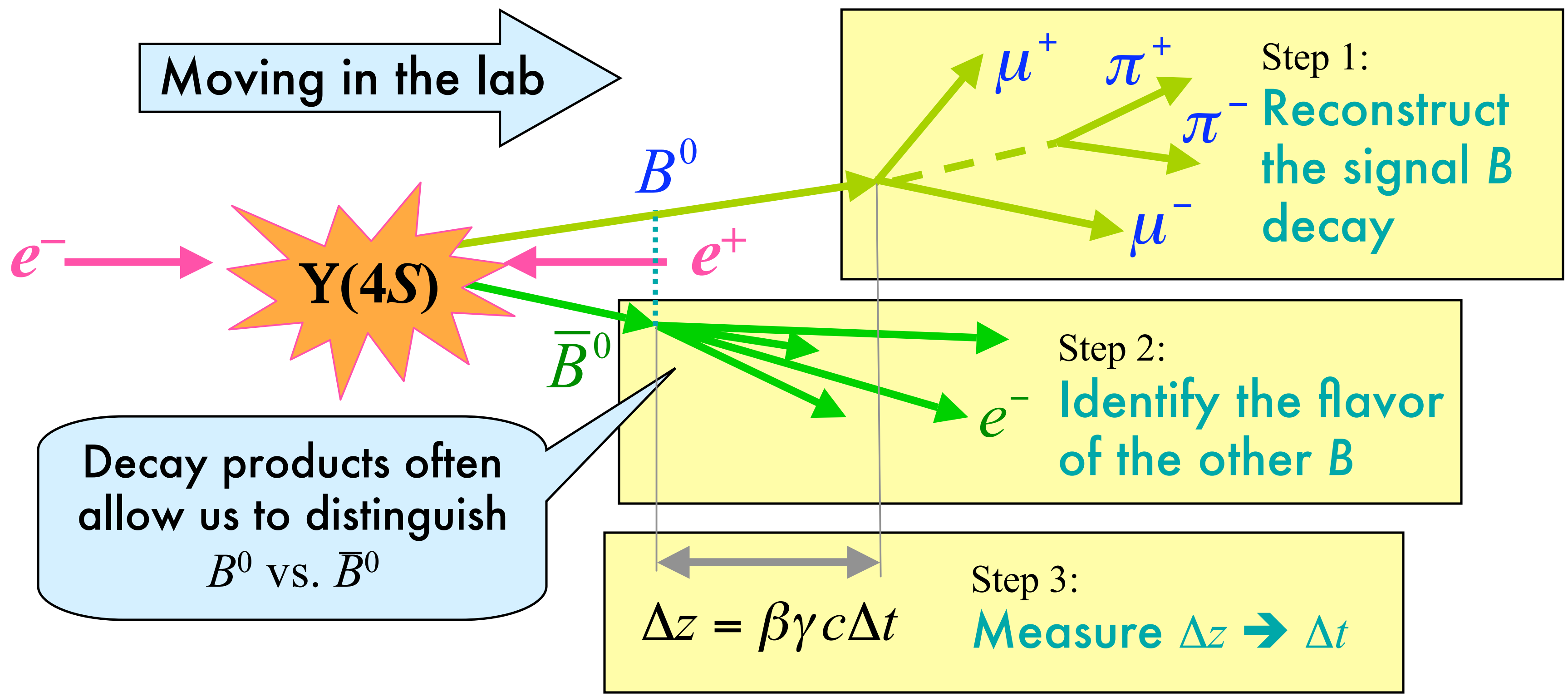
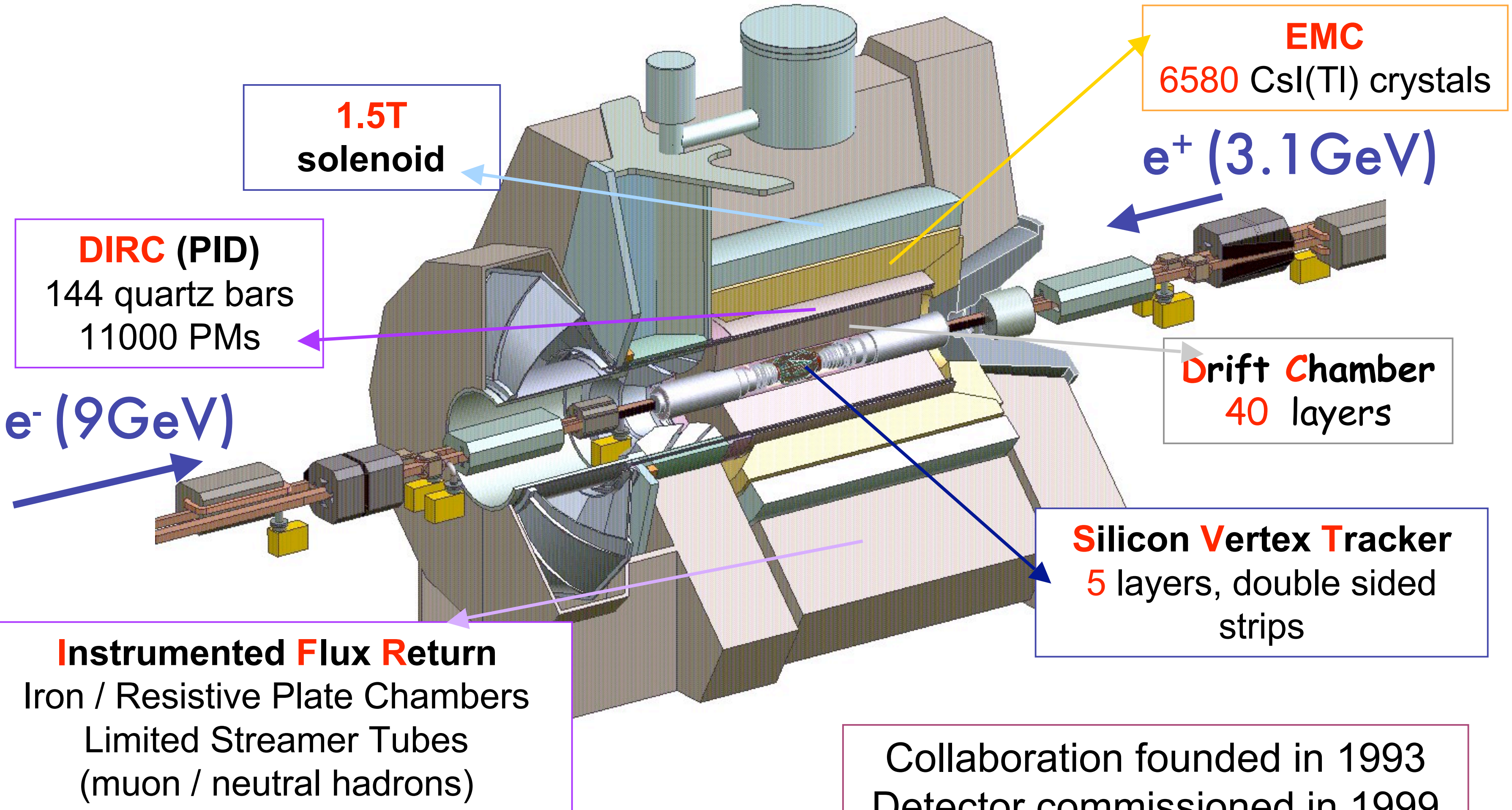


The BaBar Detector

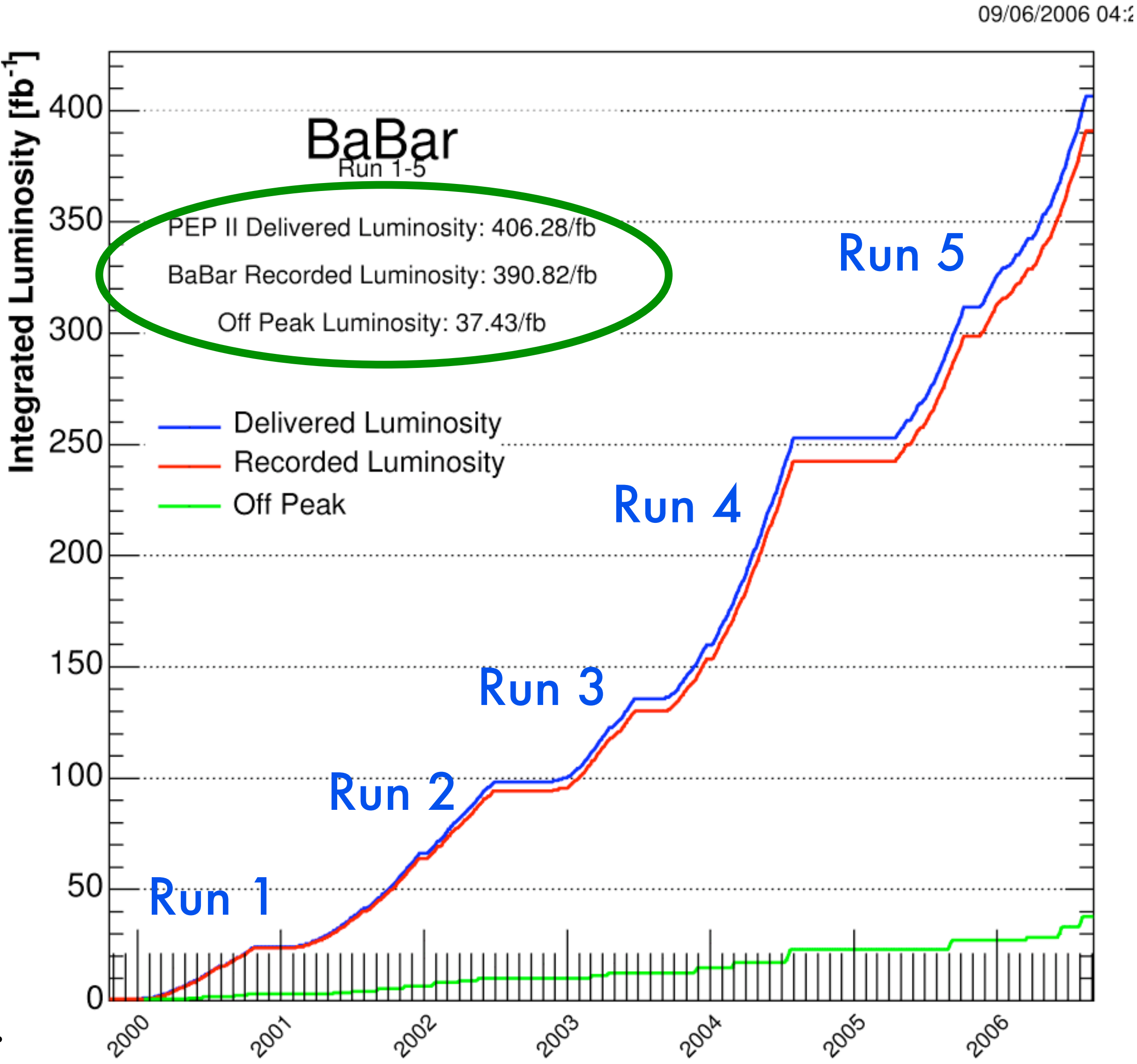


Collaboration founded in 1993
Detector commissioned in 1999
Data-taking scheduled until 2008

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

- The BaBar Collaboration
- 623 Physicists from 11countries, 80 institutions.



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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35% (I+, I-)

30% (β_y^*, Bunch length)

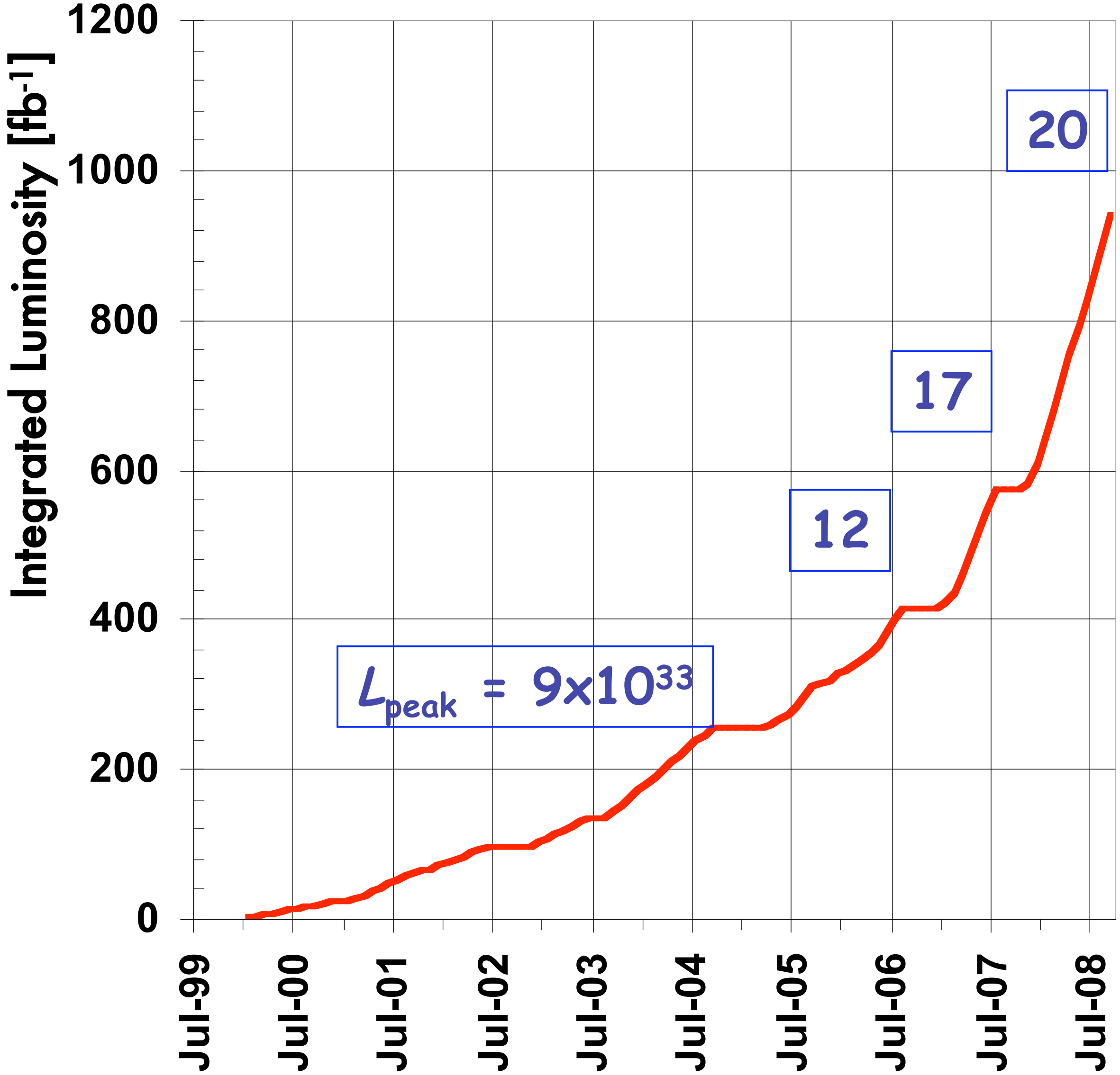
5% (ξ_y)

Factor 70%

$$\text{Luminosity} \propto \frac{\xi_y \cdot I}{\beta_y^*}$$

ξ is the beam-beam parameter

Projected data sample growth



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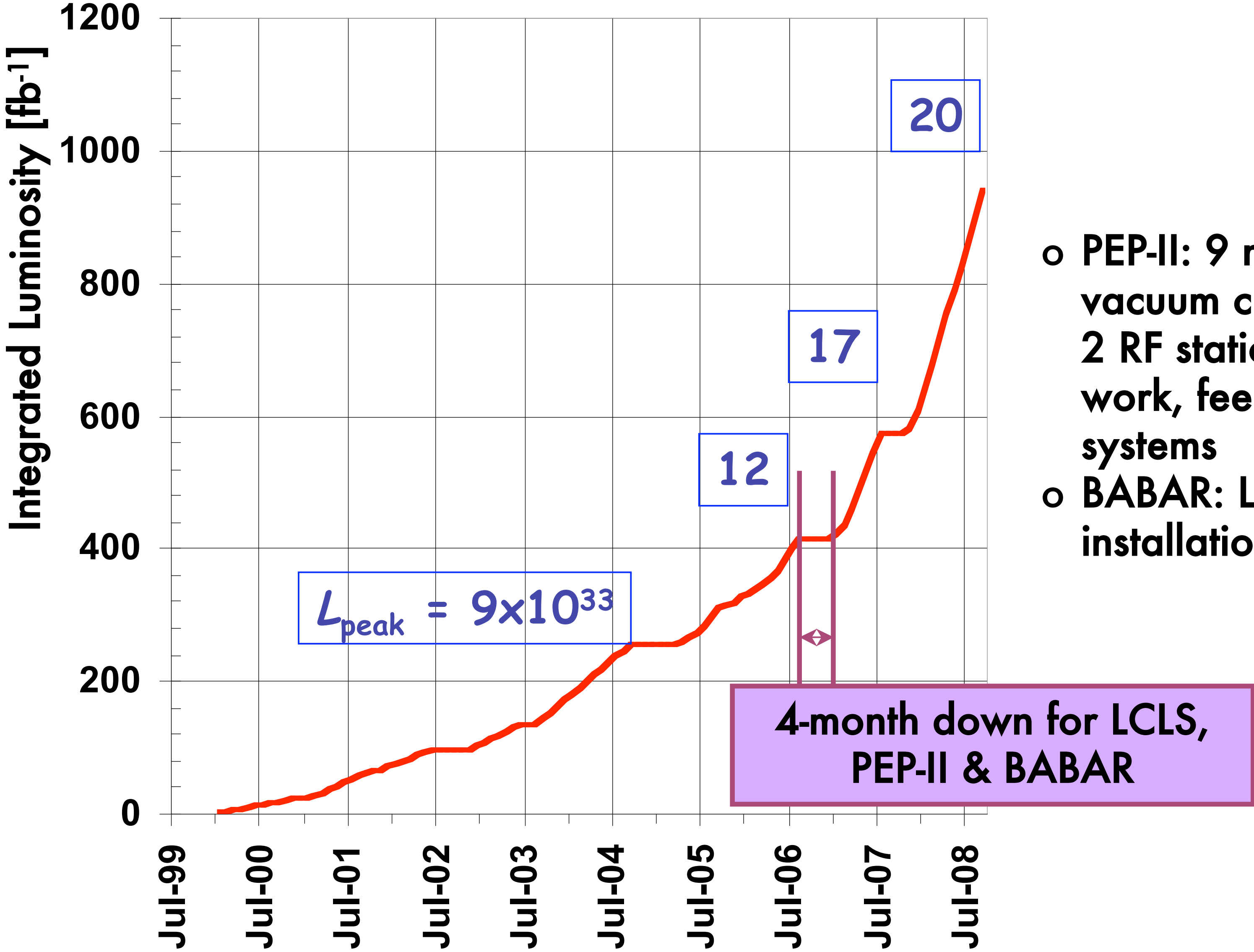
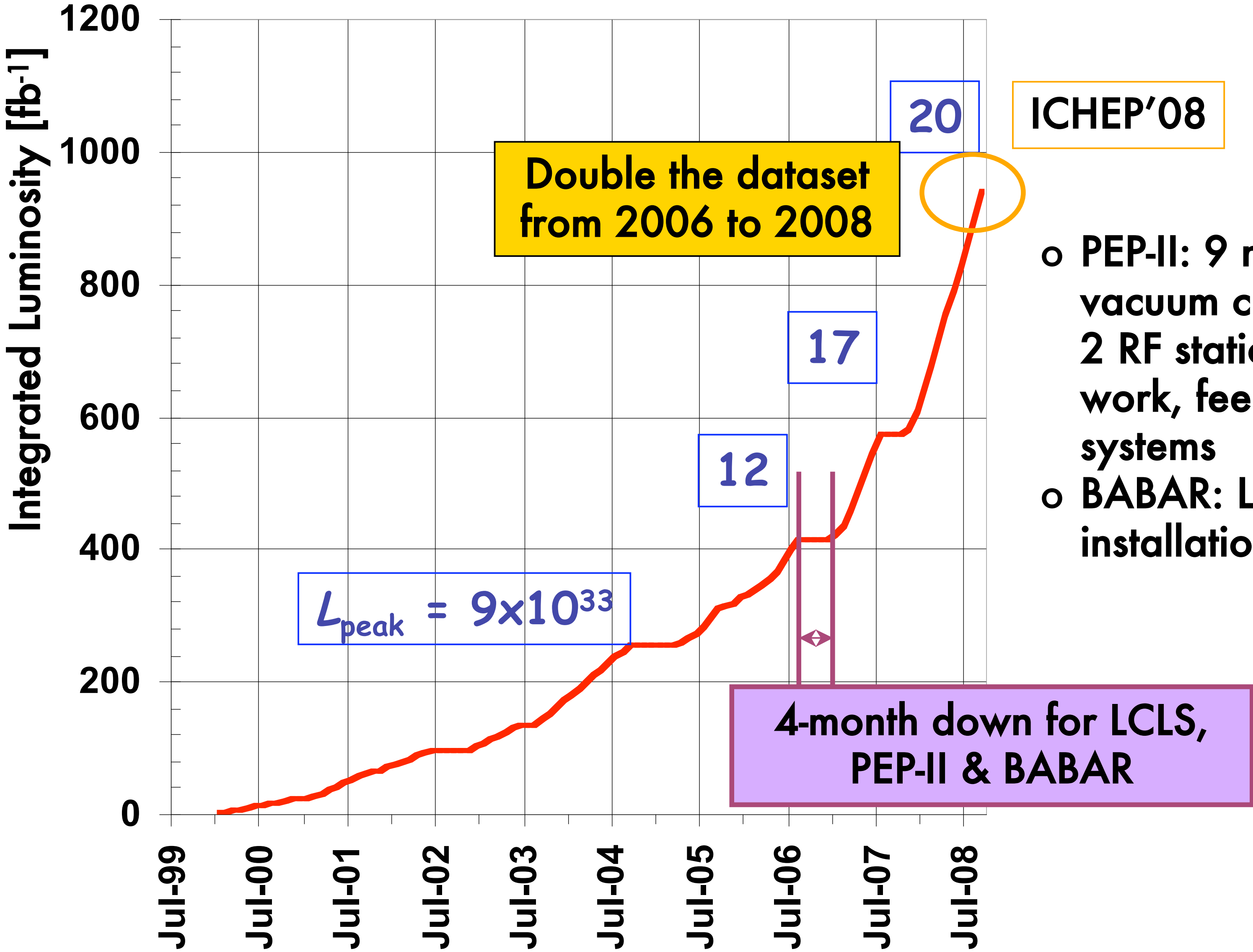


- PEP-II: 9 new vacuum chambers, 2 RF stations, BPM work, feedback systems
- BABAR: LST installation

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.

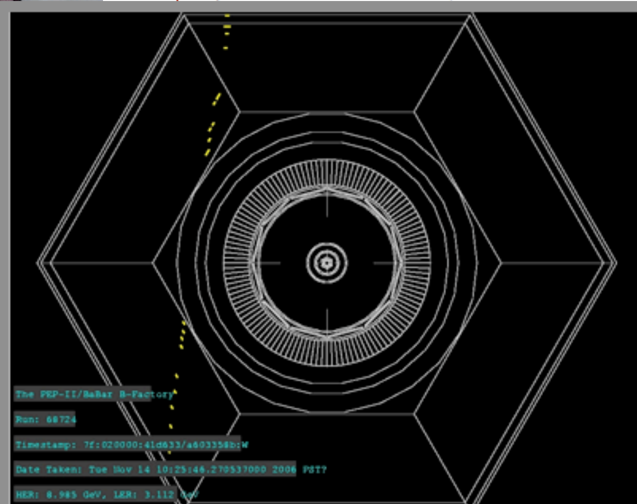
At the end of the summer, crews opened the "doors" that seal the front end of the detector, exposing its belly. In a delicate operation, the collaboration has been putting new muon detectors in four of the six sides of the 3-story-tall hexagon that makes up the overall detector's outer layer. With the 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.

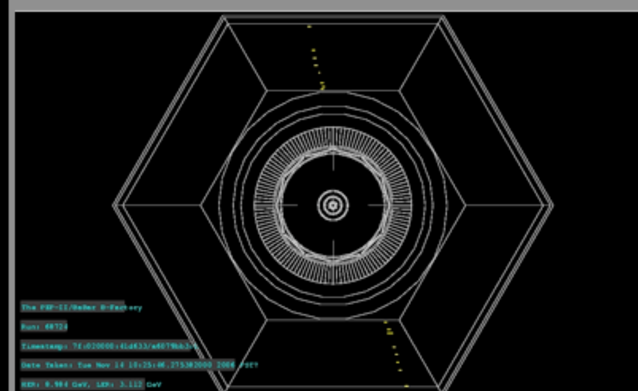
The performance of the original muon detectors, called Resistive Plate Chambers, declined unexpectedly and steadily soon after BaBar turned on in 1999. By 2002 it had become clear they could not be saved.

"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.

Analysis methods

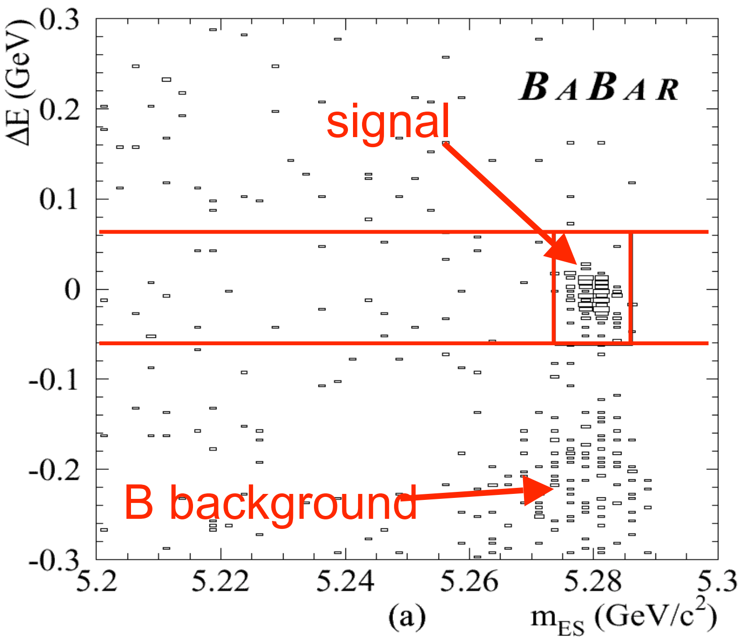
(Selecting signal)

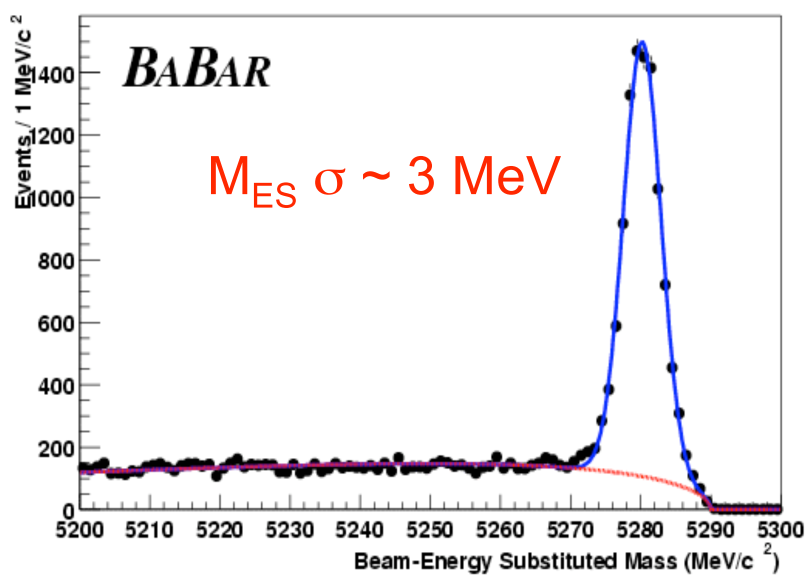
- The beam energy is very well known at an e^+e^- collider like PEP-II
  - We use an effective mass (m_{ES}) and an energy difference (ΔE) to select events

$\sigma(\Delta E) \approx$ 15-80 MeV (mode dependent)

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

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



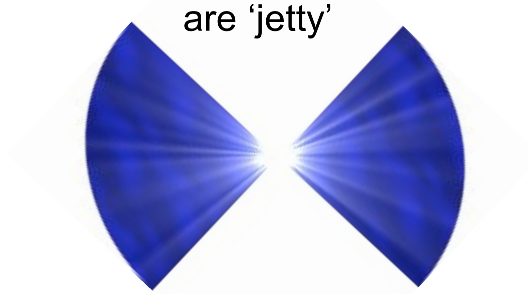


Analysis methods
(Continuum Supression)

- We can use the 'shape' (topology) of an event to distinguish between $\Upsilon(4S) \to B\bar{B}$ and continuum events: $e^+e^- \to q\bar{q}, (q = u,d,c,s)$

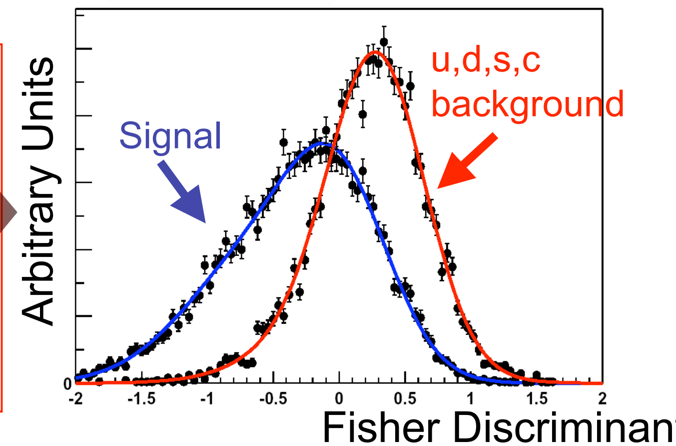
B events tend to be spherical

continuum (ee→qq) events are 'jetty'



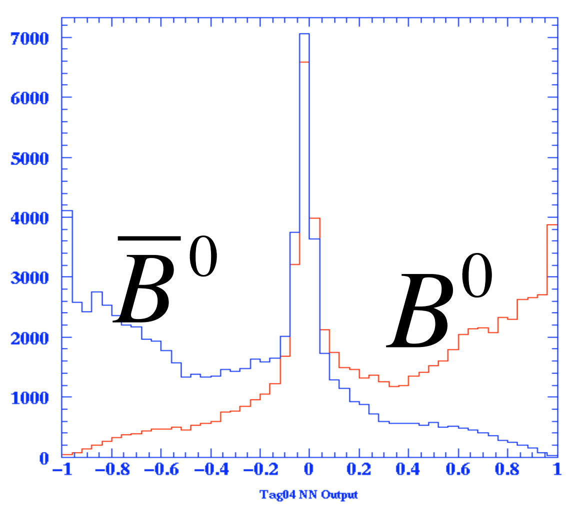
Analyses typically combine several event shapes in a single discriminating variable: either Fisher/NN or likelihood ratio.

This allows for some discrimination between B and continuum events

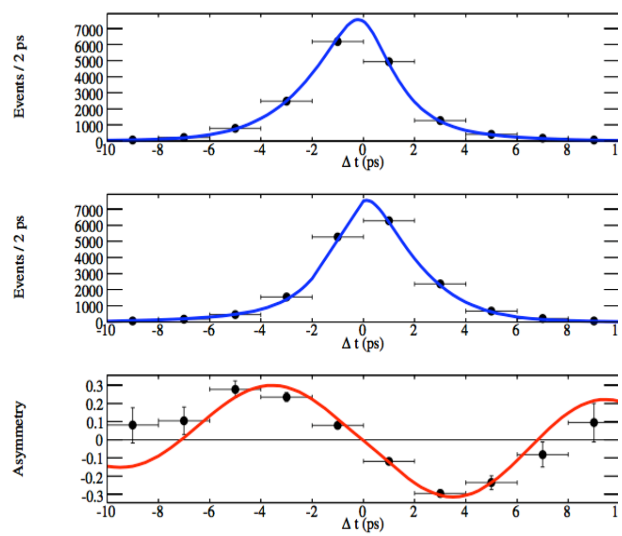


B-Flavor Tagging

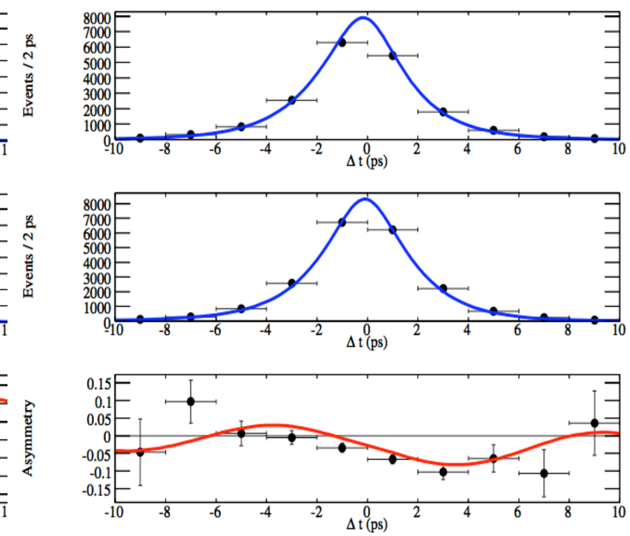
- How 'B-like' is the event ? Did we reconstruct a B^0 or $\overline{B}^0$?
- Use the purity of the final state (lepton, kaons, pions) to calculate the 'flavor tag' (take a value between -1 and 1)
  - Indicator of our confidence that an event is a B^0 or a $\overline{B}^0$.



Flavor Tag

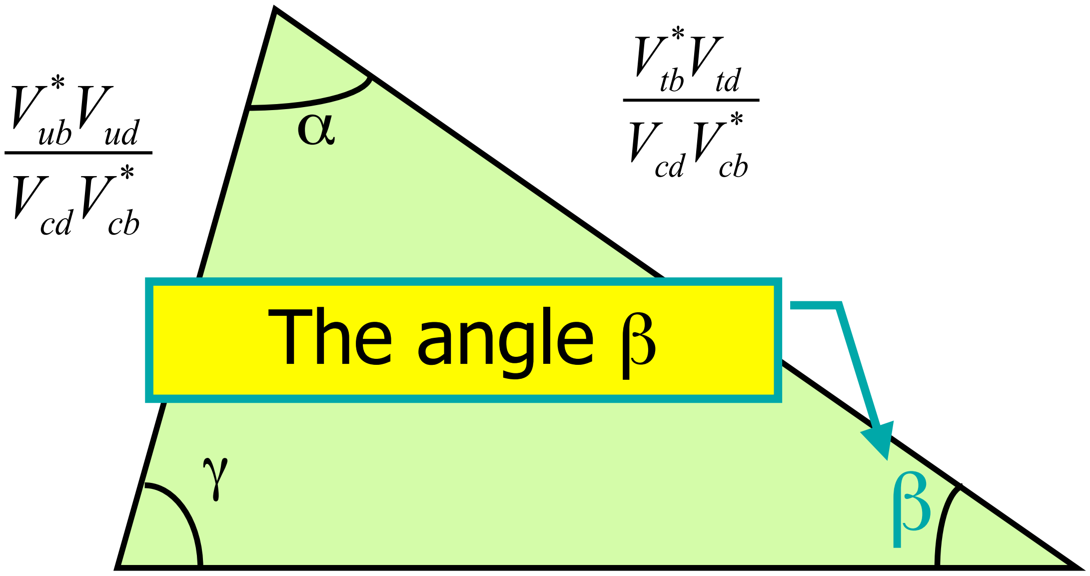


Lepton tagged events
(Highest purity)

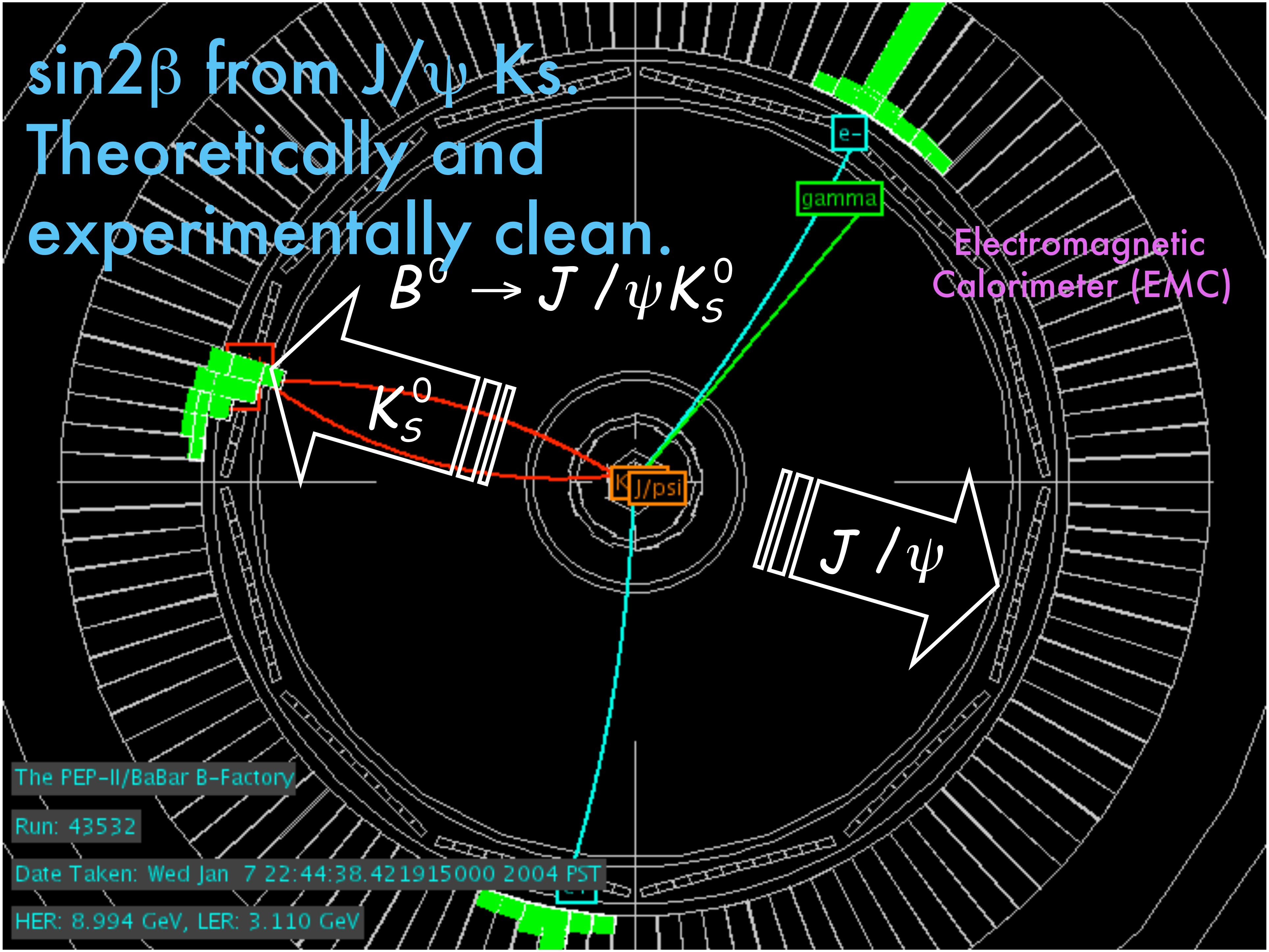


'Other' tagged events
(Lowest purity)

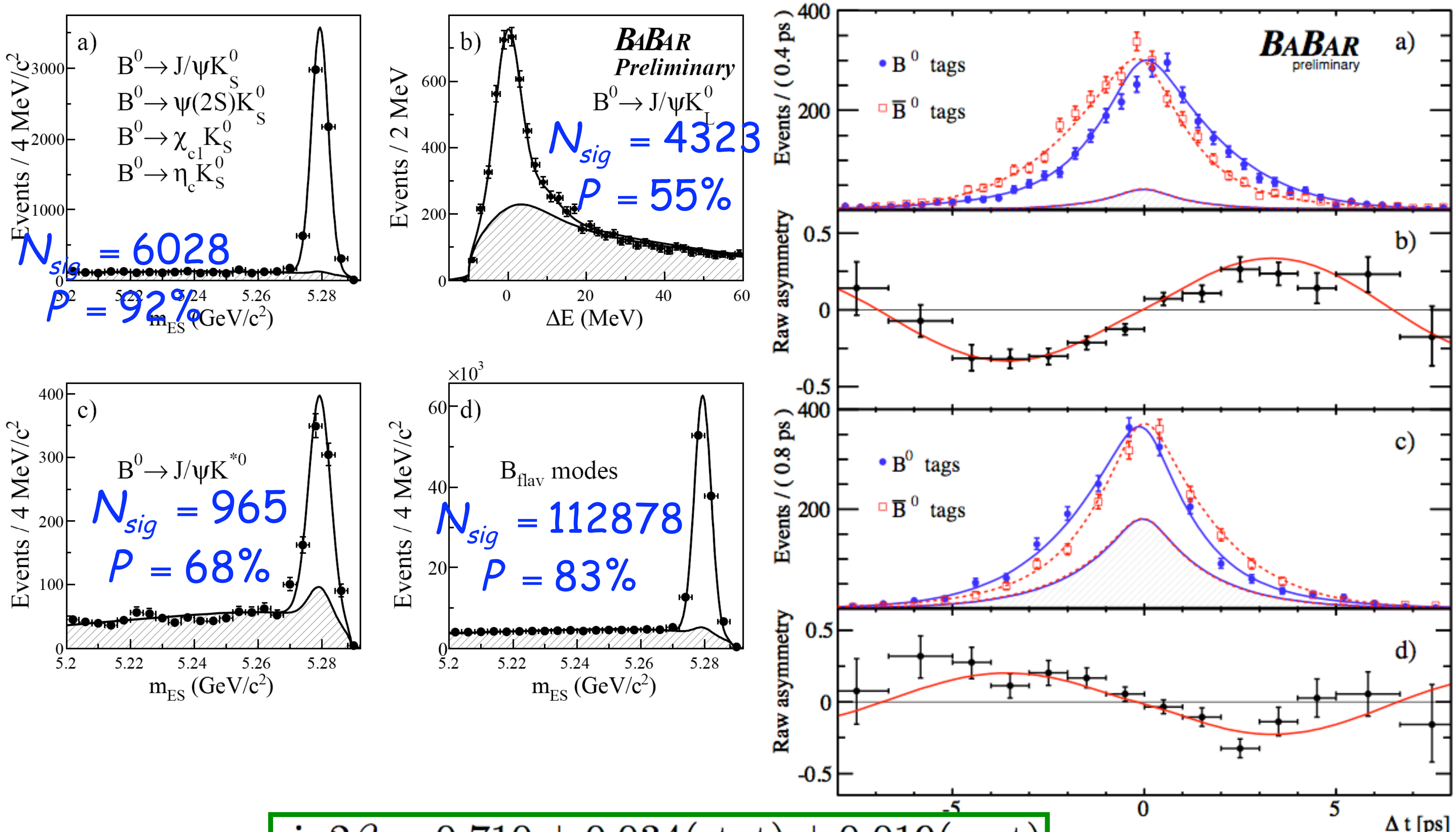
Measuring the angle β



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

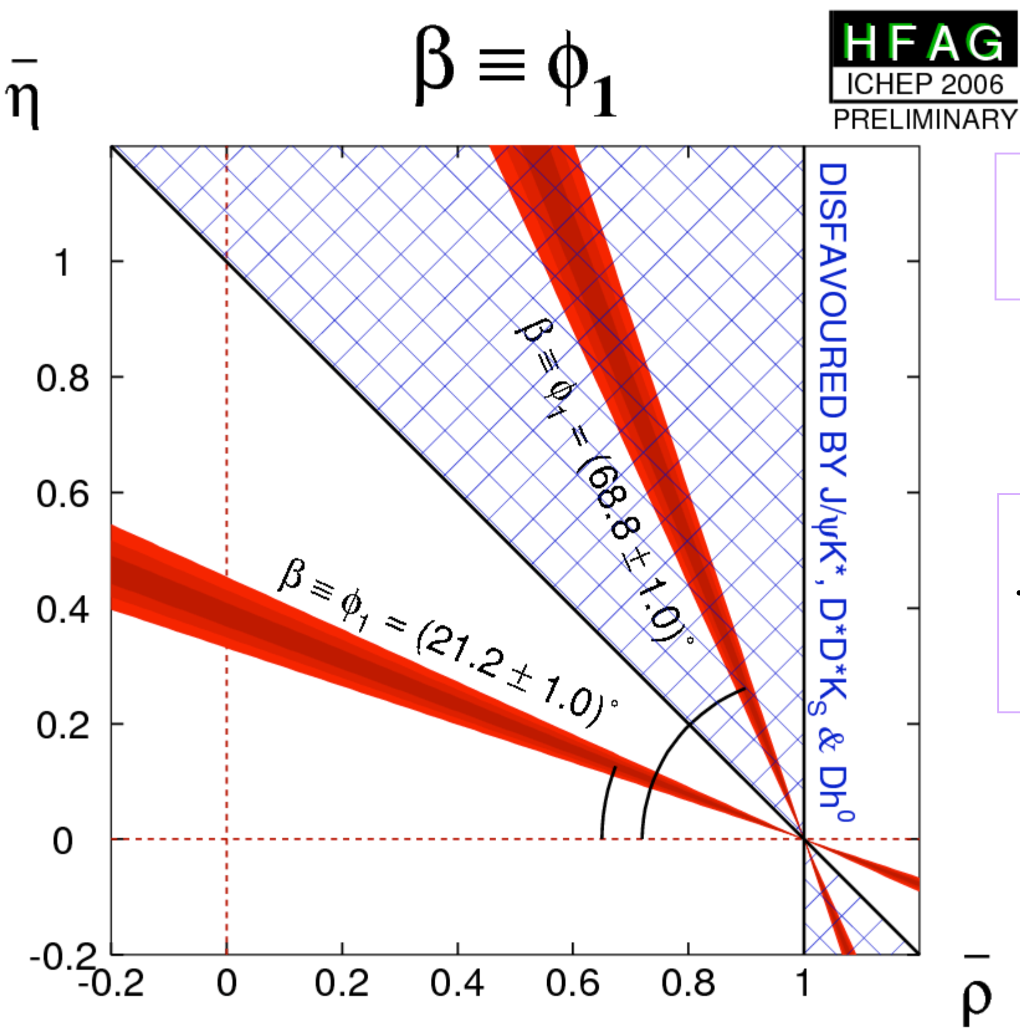


BaBar charmonium sample



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

Removing the 4-fold ambiguity for β



$B^0 \to D^{*+}D^{*-}K_S^0$ time-dependent Dalitz analysis

$\cos 2\beta > 0$ at 94% CL

PR D74 (2006) 091101

$B^0 \to Dh^0$ ($h^0 = \pi^0, \eta, \eta', \omega$) with time-dependent Dalitz analysis of $D^0 \to K_S^0 \pi^+ \pi^-$

$\cos 2\beta > 0$ at 98.3% CL

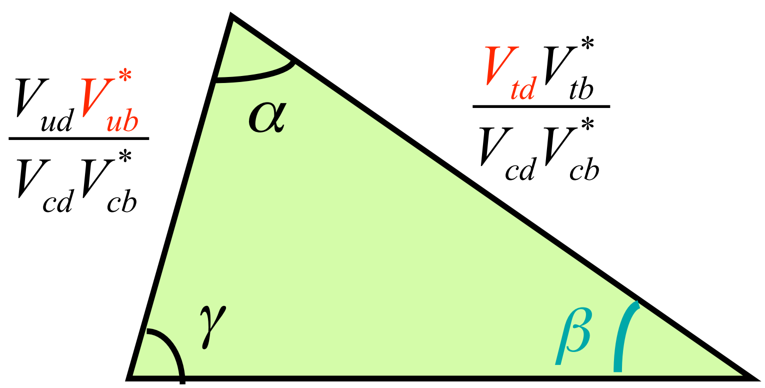
PRL 97 (2006) 081801

$\cos 2\beta > 0$ at 87% CL

BABAR CONF-06/017

CKM precision tests

- The measurement of sin2β agrees with what we knew before the B-factories began.
  - The CKM mechanism is responsible for the bulk of the CP violation in the quark sector
  - But is this *all*?
- We look for small deviation from the CKM-only hypothesis by using this precise measurement of angle β as the reference

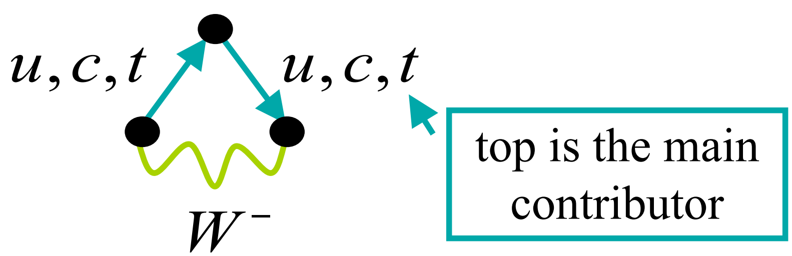


Next steps

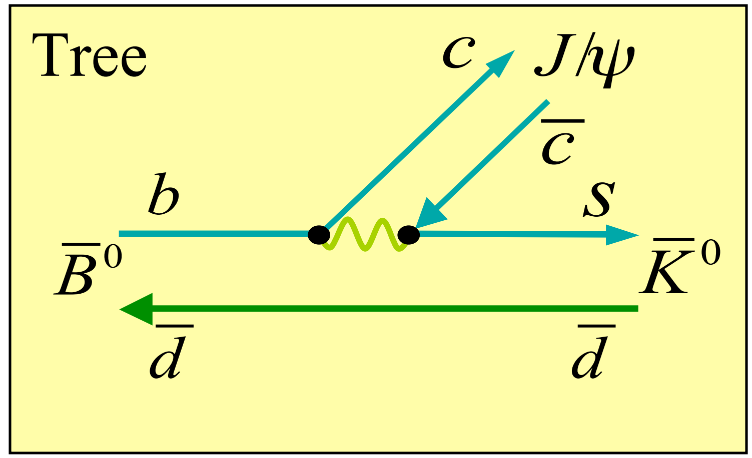
- Measure β with different methods that have different sensitivity to New Physics
- Measure the other angles
- Measure the sides

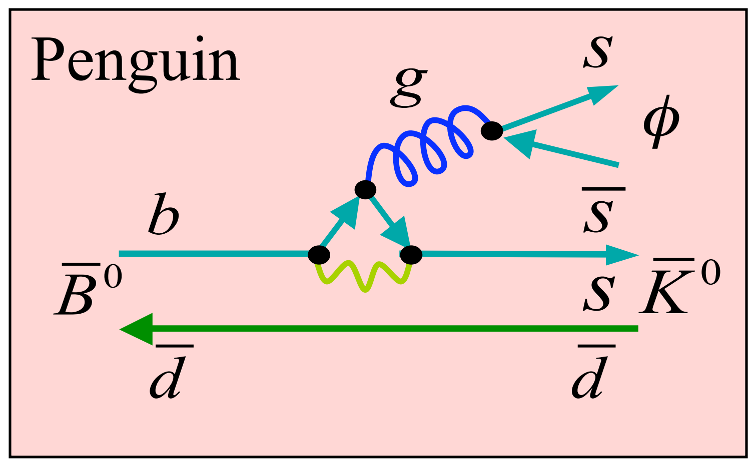
Angle β from penguin decays

- 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
  - The main diagram has a loop



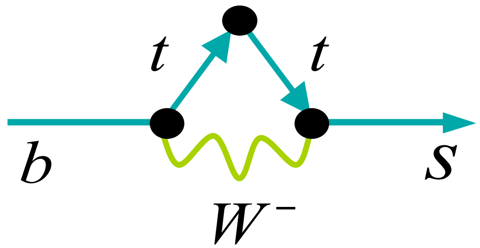
  - The phase from the CKM matrix is identical to the Golden Mode
- We can measure angle β in e.g. $B^0 \to \phi + K_S$ and $B^0 \to \eta' K_S$

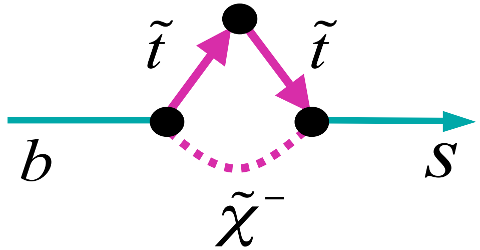




New Physics in the loop

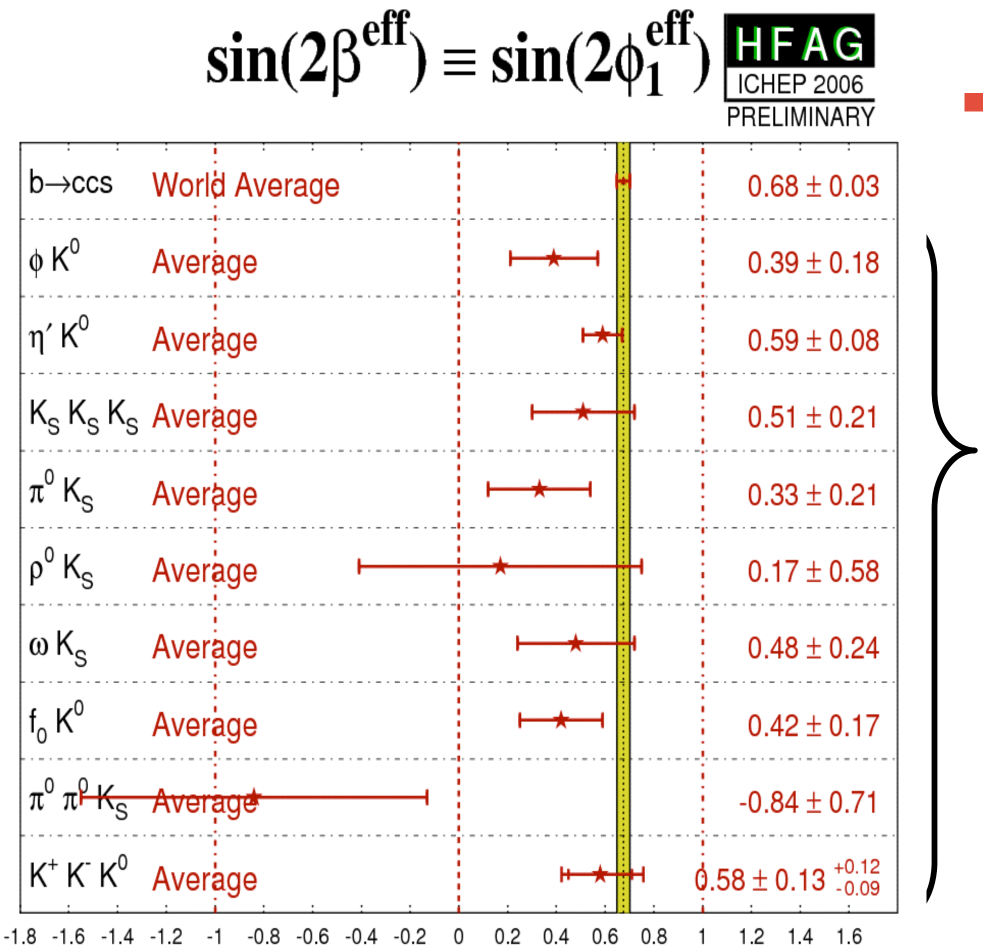
- The loop is entirely virtual
  - W and t are much heavier than b
  - It could be made of heavier particles unknown to us
- Most New Physics scenarios predict multiple new particles in 100-1000 GeV
  - Lightest ones close to m_{top} = 174 GeV
  - Their effect on the loop can be as big as the SM loop
  - Their complex phases are generally different





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

Hints of New Physics ?



- Measured *CP* asymmetries show the trend

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

Penguin decays

  - Naive average of penguins gives $\sin2\beta = 0.50 \pm 0.06$
  - Marginal consistency from the Golden Mode (2.6σ deviation)

- New physics will affect different modes in different ways.
- 1 ab^{-1} data samples may give us the answer.

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?"

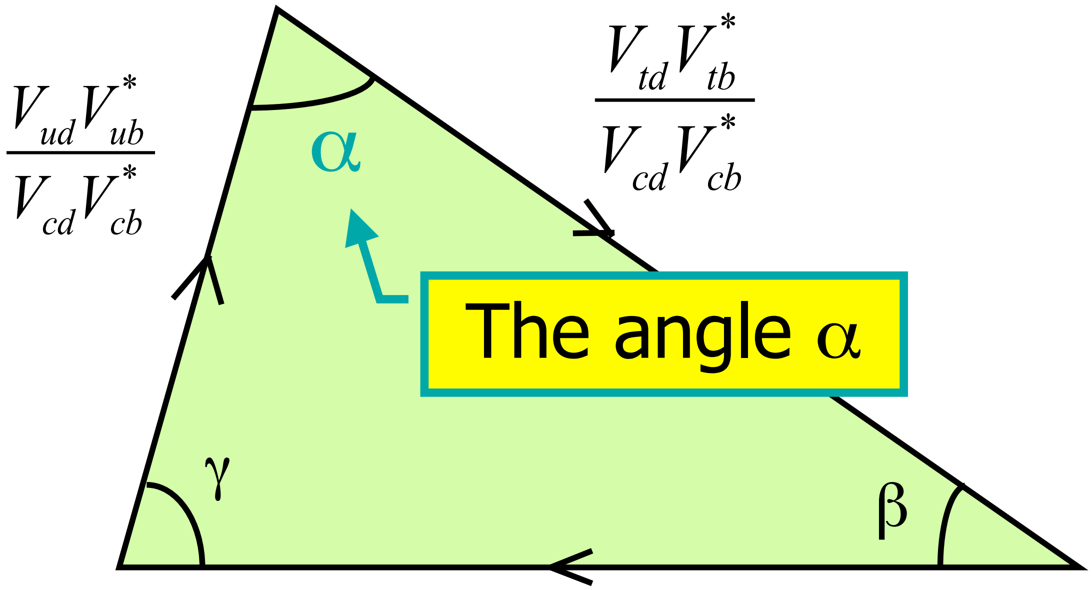
http://today.slac.stanford.edu/feature/cp-violation-092806.asp

384 M BB pairs

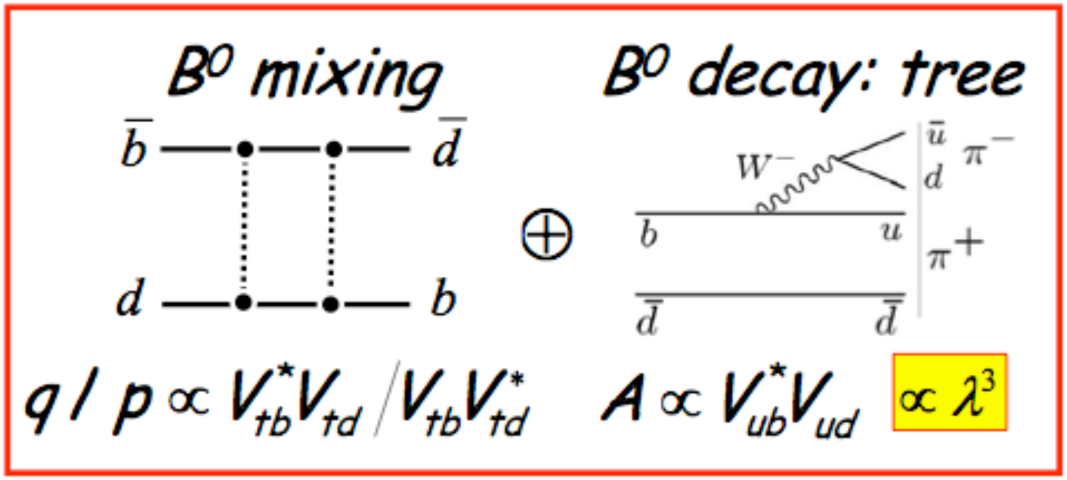
- S = 0.581 +/- 0.10 +/- 0.03
  - Mixing induced CP violation with 5.5σ significance.
- C = -0.16 +/- 0.07 +/- 0.03
  - 2.1σ from zero.

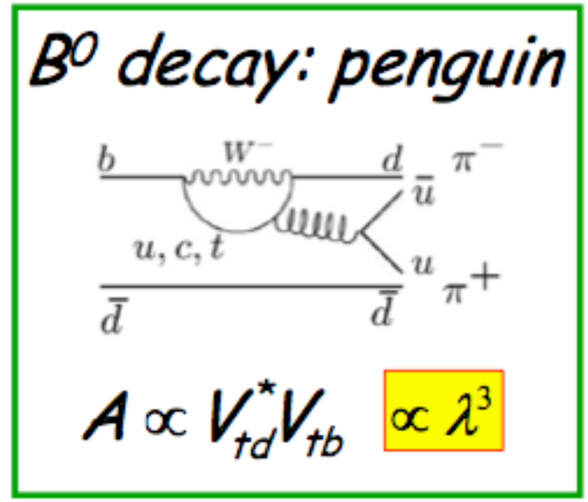
(Submitted to PRL)

Measuring the angle α



More trees and penguins …





- Interference of B mixing and a b → u tree decay
  - e.g. $B \to \rho\rho,\ B \to \rho\pi,\ B \to \pi\pi, B \to a_1\rho, B \to a_1\pi$
- Analogous to J/ψ Ks, if there are no penguin contributions,

  S = sin2α and C = 0
- In reality, there are penguin contributions, and so we measure an ‘effective’ α, where C can be non-zero and

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

- The most promising mode is that in which the penguin contribution is smallest.

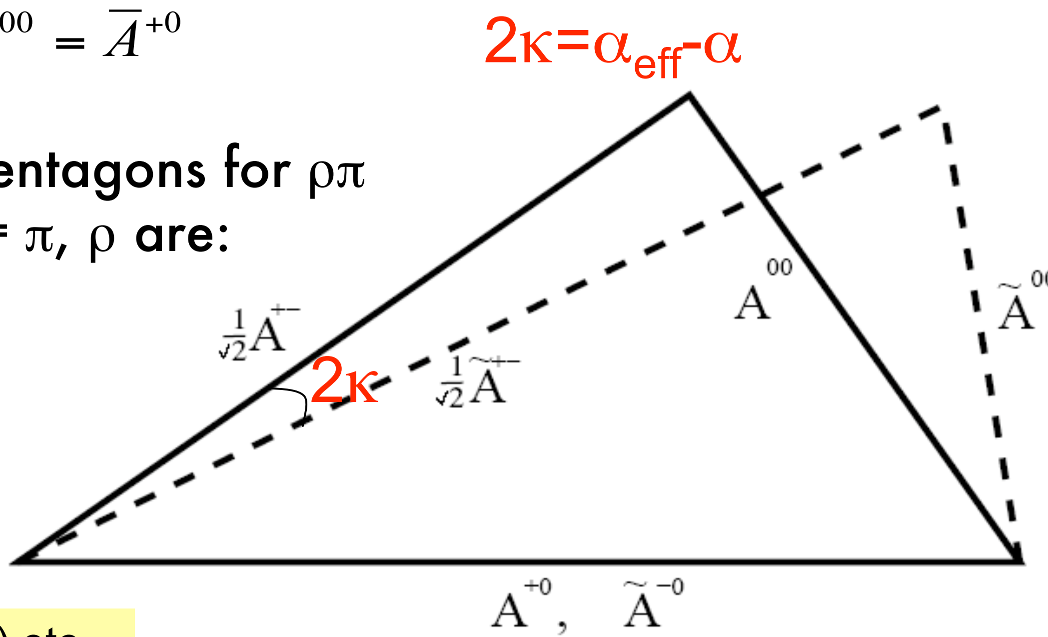
Isospin analysis : B →ρρ, ρπ, ππ

- Different B →ρρ, ρπ, ππ 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.

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

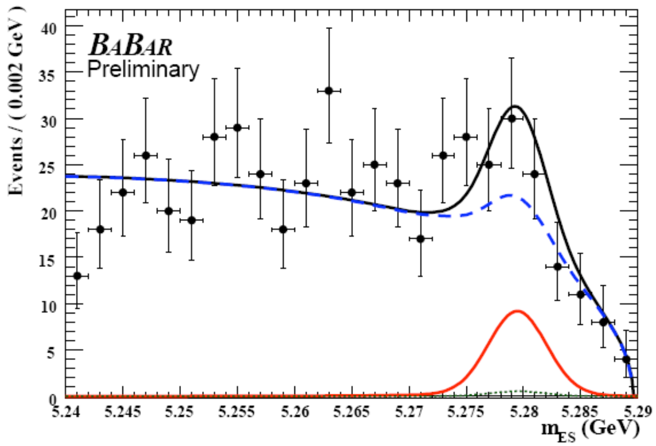
$$\frac{1}{\sqrt{2}} \bar{A}^{+-} + \bar{A}^{00} = \bar{A}^{+0}$$

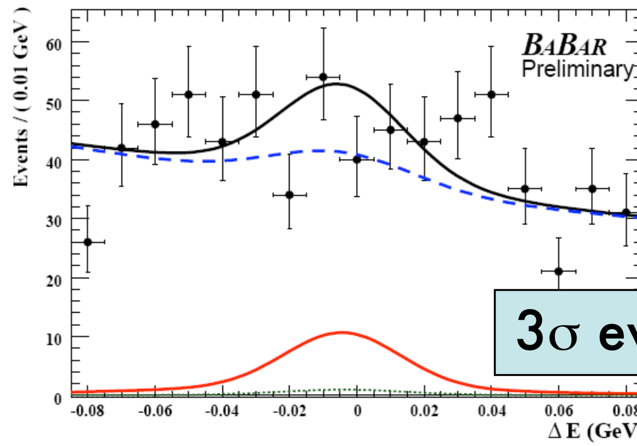
  - Triangles for ππ, ρρ and pentagons for ρπ
- Inputs to measuring α from h = π, ρ are:
  - $B^0 \to h^+h^-$ + C.C
  - $B^0 \to h^0h^0$ + C.C
  - $B^+ \to h^+h^0$ + C.C
  - S_{h+h-} = $\sqrt{1-C^2}\sin(2\alpha+2\kappa)$



ππ: Gronau & London PRL**65**, 3381 (1990) etc.
ρπ Snyder-Quinn: PRD**48**, 2139 (1993) etc.

Measuring α with $B \to \rho\rho$ decays (1)





347 M BB pairs

3σ evidence for $\rho^0\rho^0$.

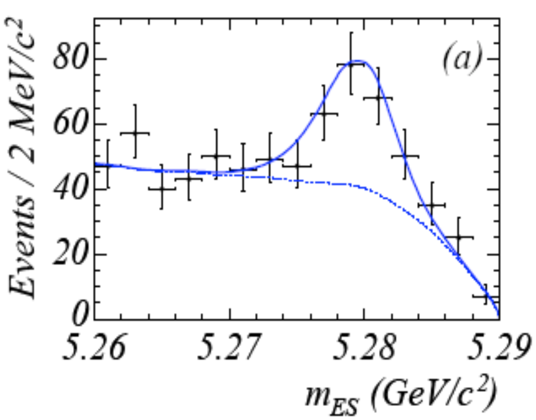
$$\mathcal{B}(B^0 \to \rho^0\rho^0) = [1.16^{+0.37}_{-0.36}\ (\text{stat.}) \pm 0.27\ (\text{syst.})] \times 10^{-6}$$

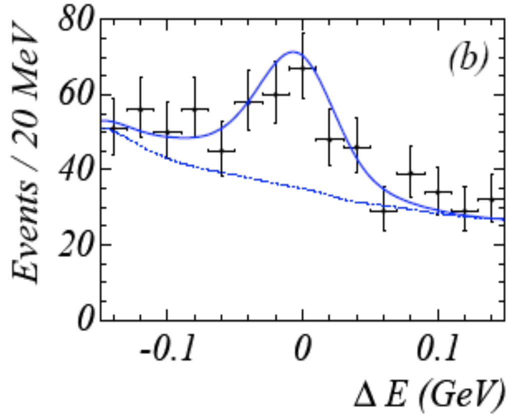
$$f_L = 0.86^{+0.11}_{-0.13}\ (\text{stat.}) \pm 0.05\ (\text{syst.})$$

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

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

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





232 M BB pairs

390±49 events

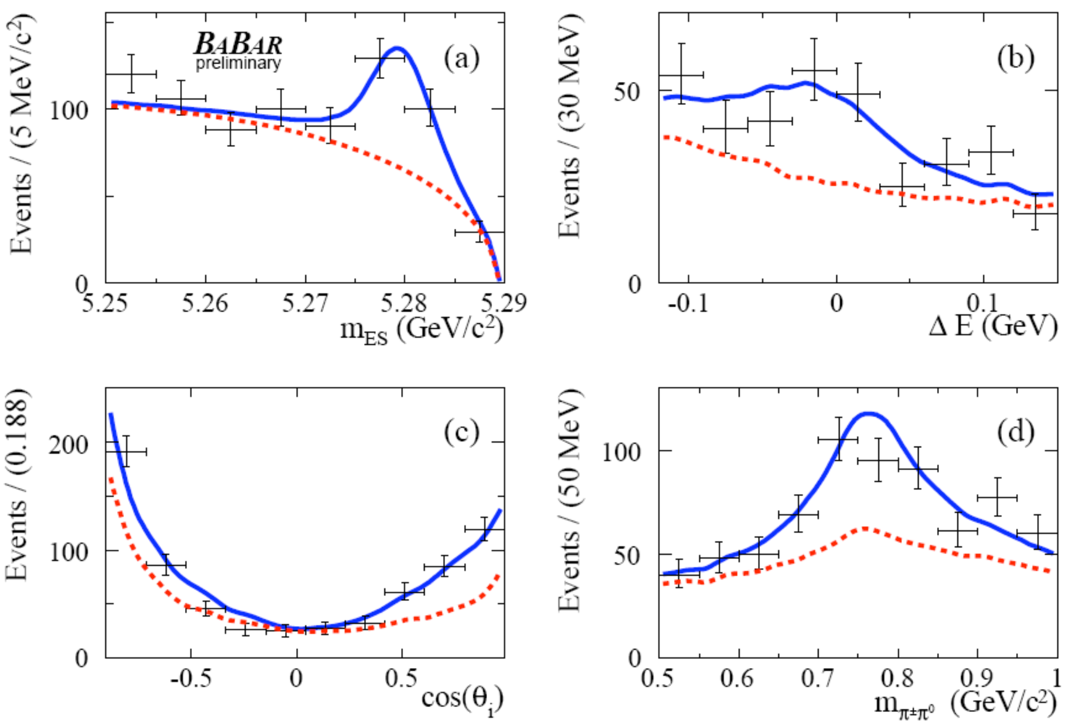
$$\mathcal{B} = (16.8 \pm 2.2 \pm 2.3) \times 10^{-6}$$

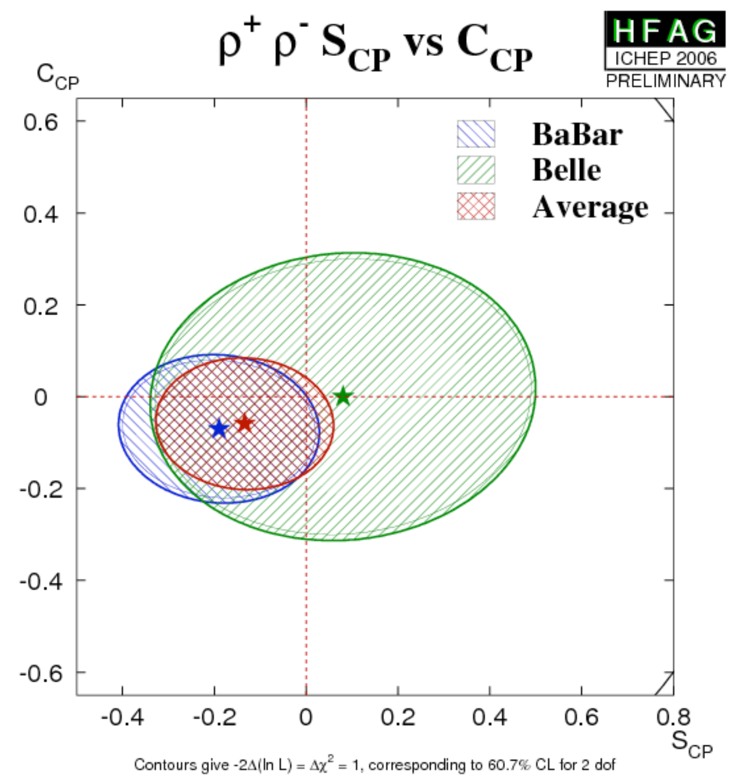
$$f_L = 0.905 \pm 0.042^{+0.023}_{-0.027}$$

Measuring α with B→ρρ decays (2)

347 M BB pairs

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

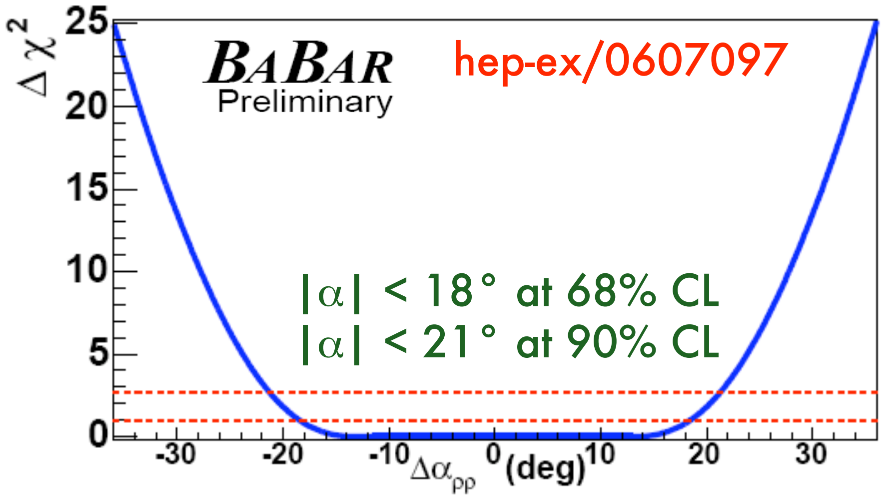




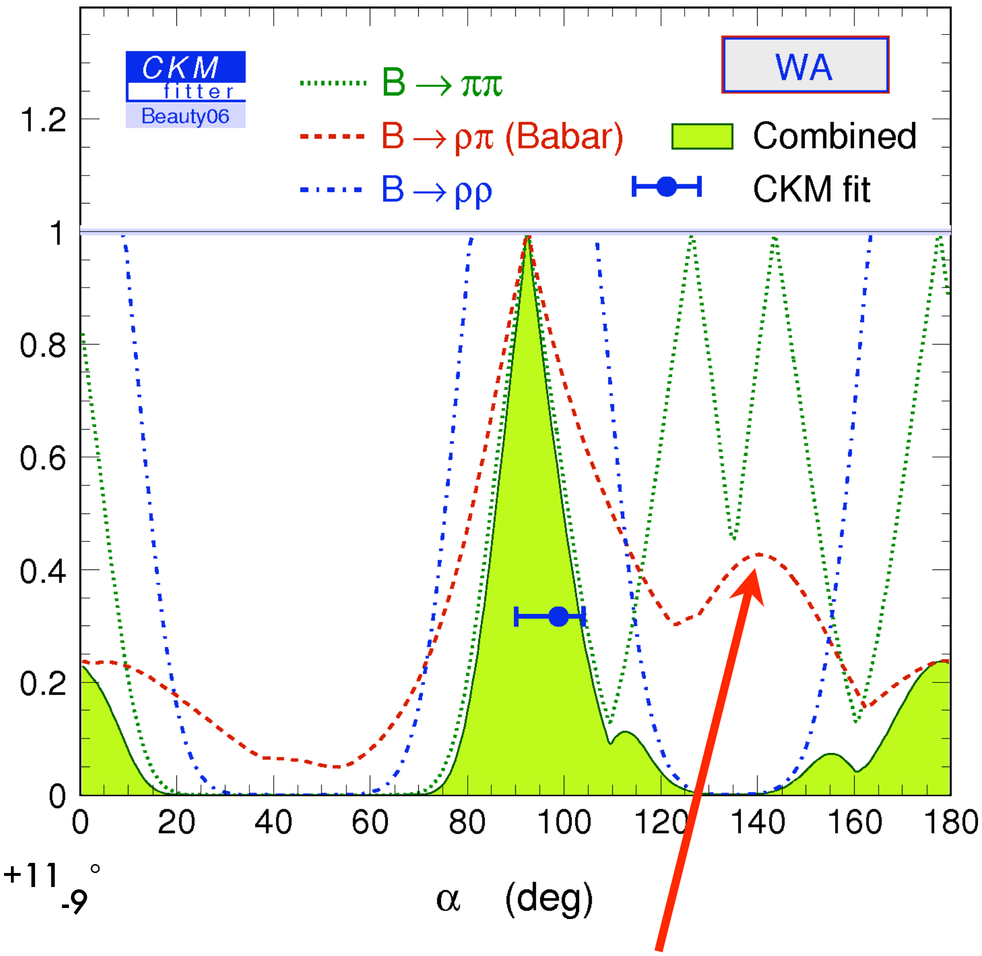
Note that the WA is dominated by the BaBar measurement.

Combined constraints on α

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

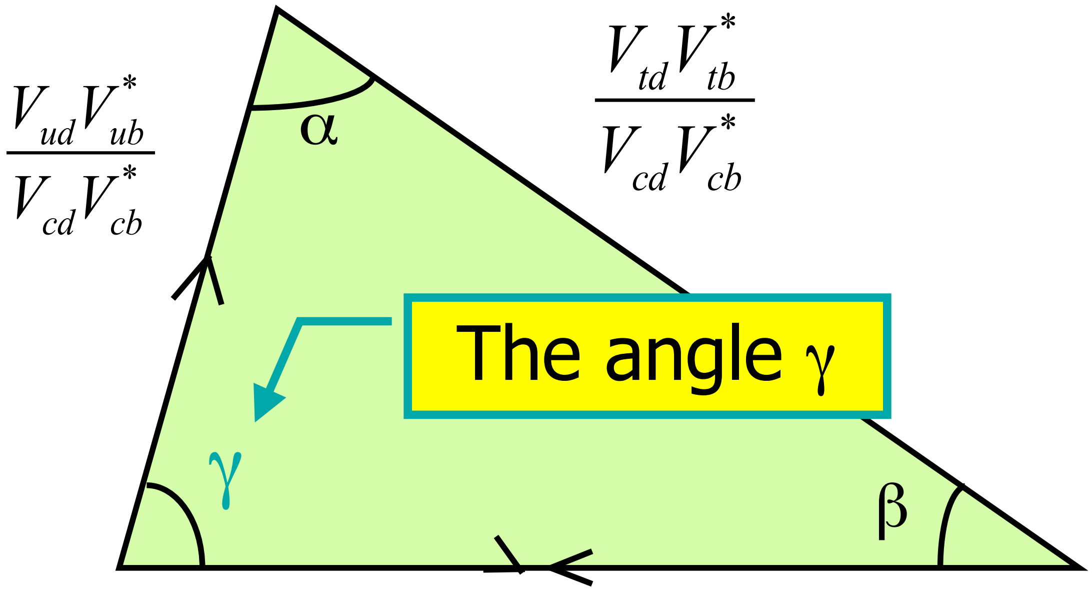


- Weaker constraints come from the ρπ and ππ decays.
- CKM Fitter (direct constraint) : $\alpha = 93^{+11}_{-9}{}^\circ$

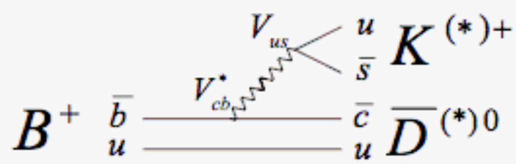


ρπ suppresses the non-SM solution

Measuring the angle γ

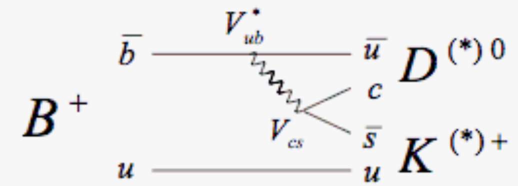


The angle γ



b→c color-favored

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



b→u color-suppressed

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

$\lambda \approx 0.22$

- No 'golden channel for γ.
- Combine measurements from several theoretically clean modes e.g. $B^+ \to D^{(*)}K^{(*)}$.

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

- 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

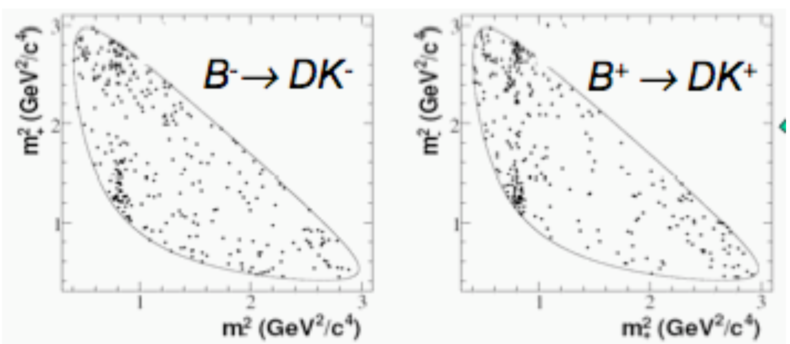
The angle γ

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

Different observables
"Dalitz"
"ADS"
"GLW"

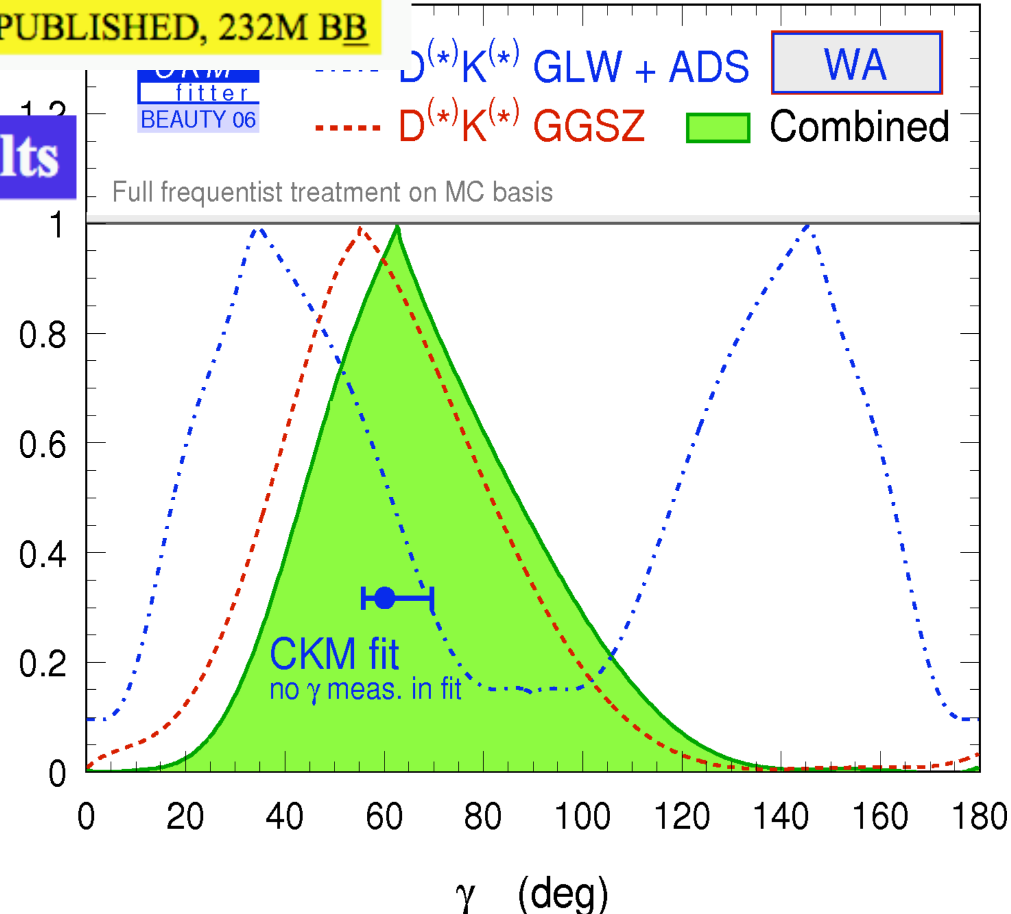
γ from $B \to D^{(*)0}K$, $D^0 \to K_S\pi\pi$: results

347 $\times 10^6$ $B\bar{B}$ pairs
BABAR-CONF-06/038



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

Stat, Syst, Dalitz

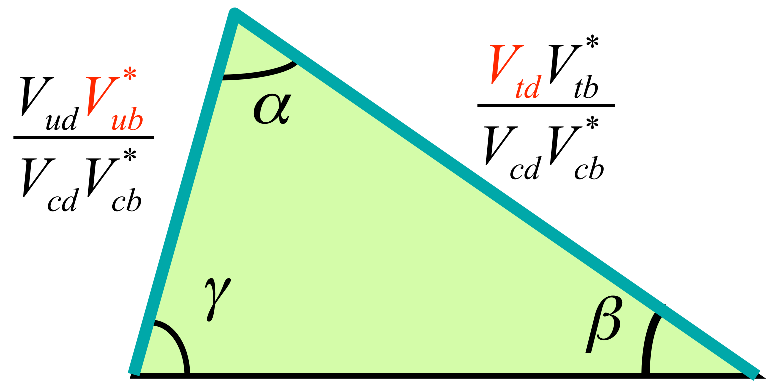


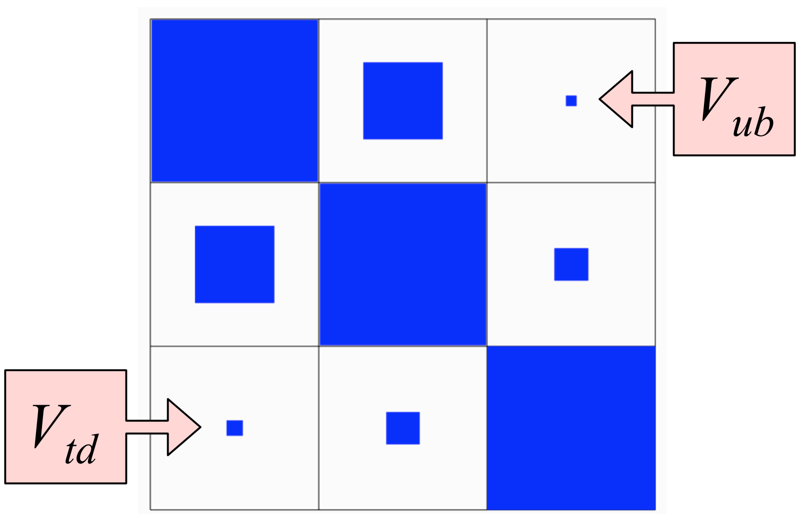
γ[combined] = 62^{+38}_{-24} deg.

See Giovanni Marchiori's BaBar ICHEP talk :
http://ichep06.jinr.ru/reports/279_8s4_11p54_marchiori_web.pdf

Measuring the sides

- To measure the lengths of the two sides, we must measure $|V_{ub}| \approx 0.004$ and $|V_{td}| \approx 0.008$
  - The smallest elements – not easy!

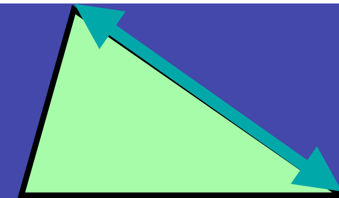




- Main difficulty: Controlling theoretical errors due to hadronic physics
  - Collaboration between theory and experiment plays key role

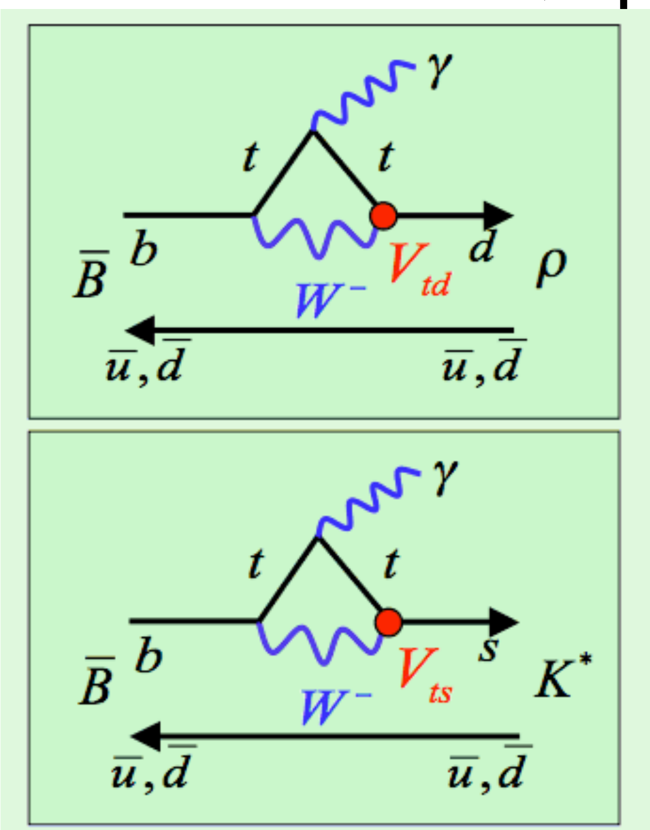
BaBar results for Vub :
See http://ichep06.jinr.ru/reports/188_10s3_10p05_dubitzky(2).pdf

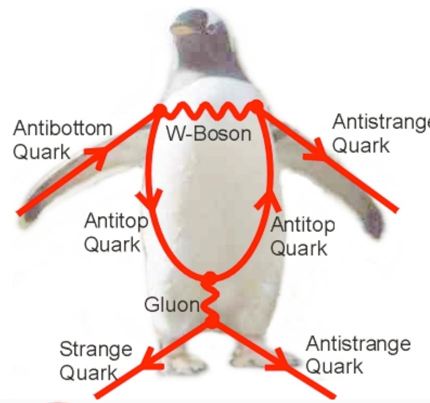
$|V_{td}|$ – the right side



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

- Can't just measure the $t \to d$ decay rates
  - Top quarks are hard to make $$\Gamma(t \to d)/\Gamma(t \to b) = V_{td}^2 / V_{tb}^2 < 10^{-4}$$
- Look at radiative penguin processes





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

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/0105302

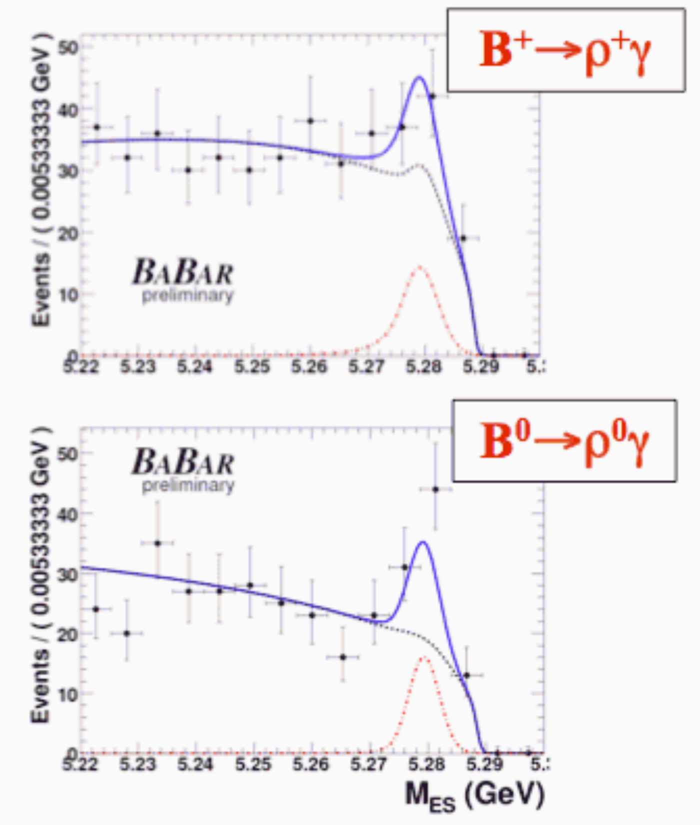
Extraction of $|V_{td}/V_{ts}|$ with $B \to \rho(\omega)\gamma$ decays

- Determine $|V_{td}/V_{ts}|$ from $B^0 \to \rho(\omega)\gamma$

Reconstructed decays:

- $B \to \rho^+\gamma$, $\rho^+ \to \pi^+\pi^0$
- $B \to \rho^0\gamma$, $\rho^0 \to \pi^+\pi^-$
- $B \to \omega\gamma$, $\omega \to \pi^+\pi^-\pi^0$

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



316 /fb

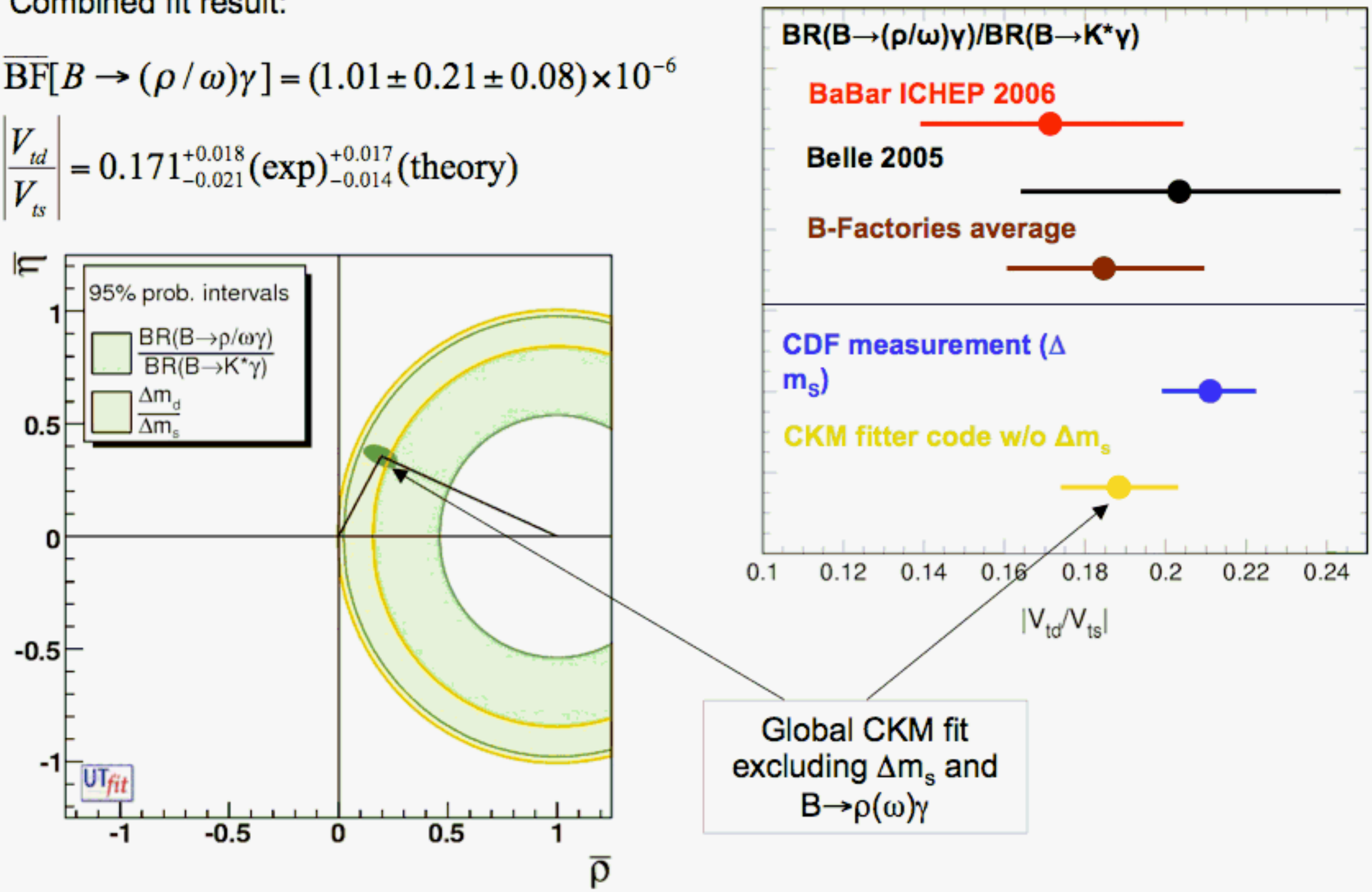
Mode	n_{sig}	Significance	$\epsilon(\%)$	$\mathcal{B}(10^{-6})$
$B^+ \to \rho^+\gamma$	$42.4^{+14.1}_{-12.6}$	4.1σ	11.6	$1.06^{+0.35}_{-0.31} \pm 0.09$
$B^0 \to \rho^0\gamma$	$38.7^{+10.6}_{-9.8}$	5.2σ	14.5	$0.77^{+0.21}_{-0.19} \pm 0.07$
$B^0 \to \omega\gamma$	$11.0^{+6.7}_{-5.6}$	2.3σ	8.1	$0.39^{+0.24}_{-0.20}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

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

Combined fit result:

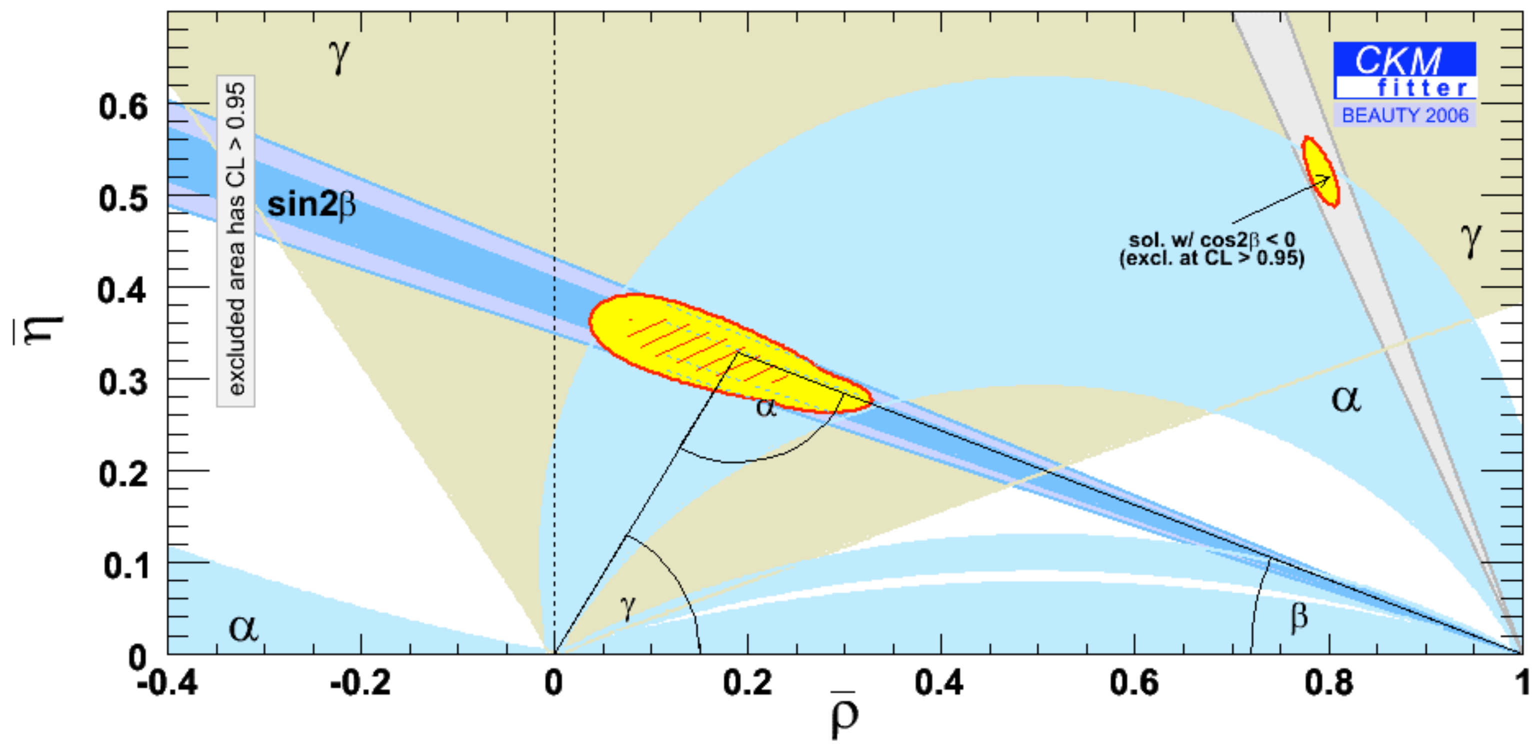
$$\overline{\mathrm{BF}}[B \to (\rho/\omega)\gamma] = (1.01 \pm 0.21 \pm 0.08) \times 10^{-6}$$

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



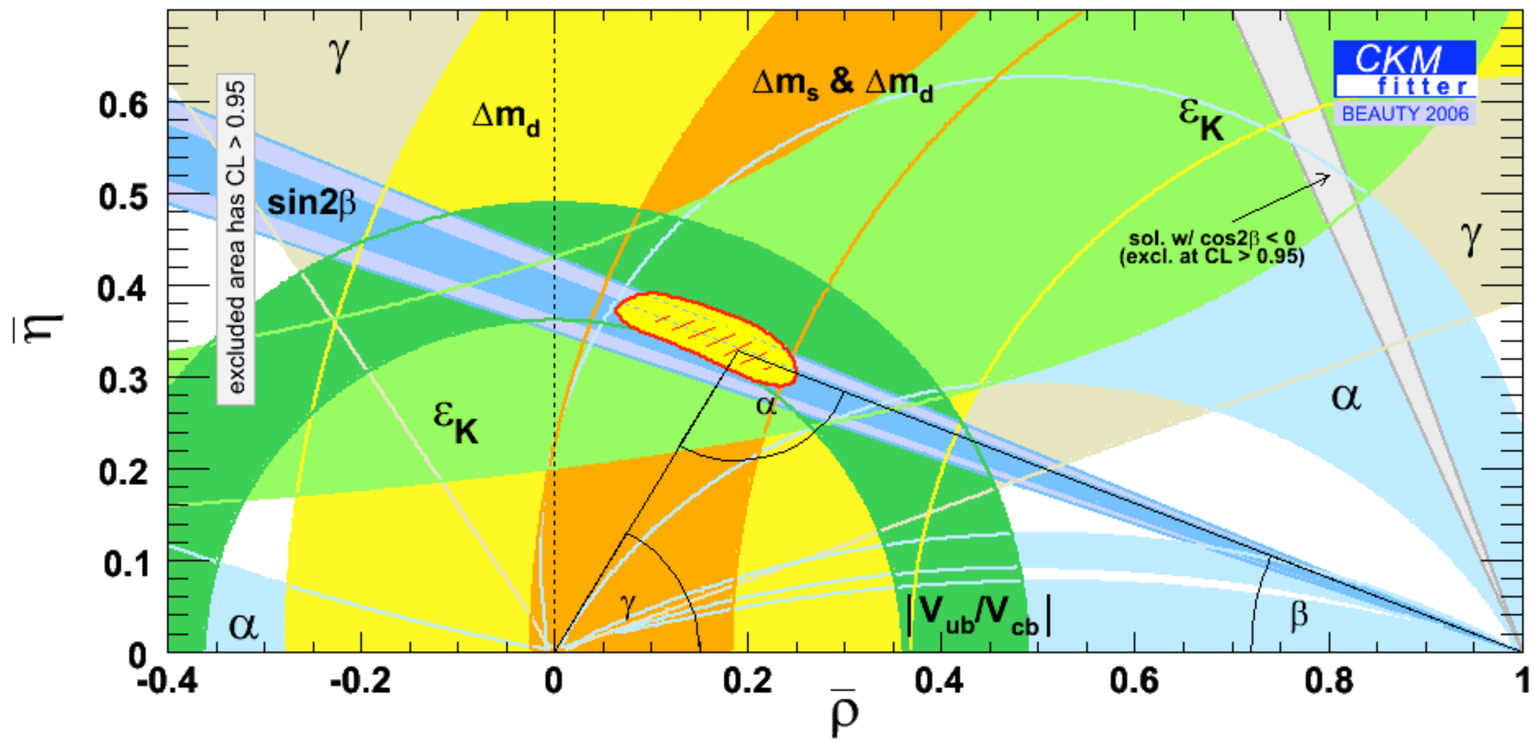
The UT today

Angles from *CP* asymmetries



The UT today

All constraints

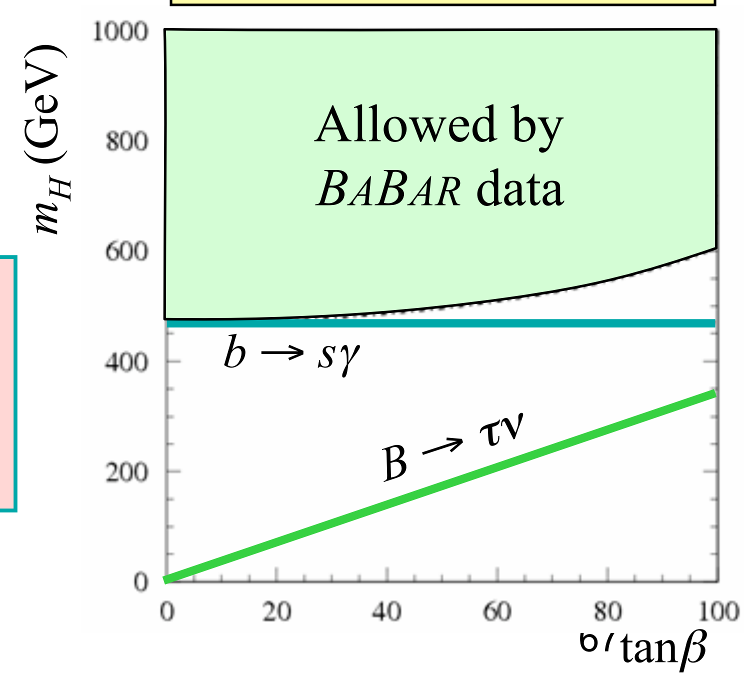


Constraining New Physics

- New Physics at ~TeV scale should affect low-energy physics such as B physics
  - Effects may be subtle, but we have precision
  - Even absence of significant effects helps to identify NP
- In addition to the UT, we explore:
  - rare *B* decays into $X_s\gamma$, $X_s\lambda^+\lambda^-$, $\tau\nu$
  - D^0 mixing and rare *D* decays
  - lepton-number violating decays

Precision measurements at the *B* Factories place strong constraints on the nature of New Physics

Two Higgs doublet model



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)

Outlook

- The *B* Factories will pursue increasingly precise measurements of the UT and other observables over the next two years.
- Data-taking at BaBar resumes in January 2007
  - By the end of BaBar's lifetime, aim to:
    - Reach nearly 7 x design luminosity (10 x design integrated luminosity per day)
    - Accumulate 1 ab^{-1} of data
- Not necessarily the end of *B*-physics at an e+e- collider

A Super-B factory to compliment LHC physics program

e.g. see http://arxiv.org/abs/hep-ex/0611031


More
Slides?!
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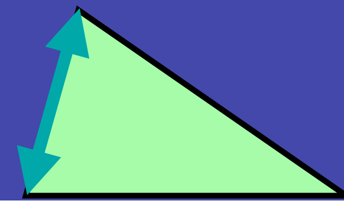
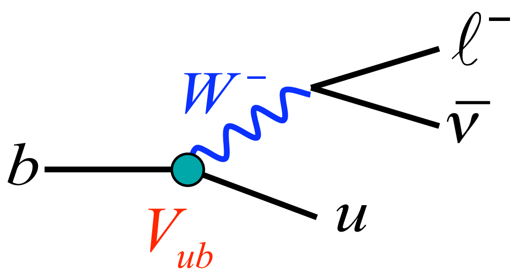
$|V_{ub}|$ – the left side

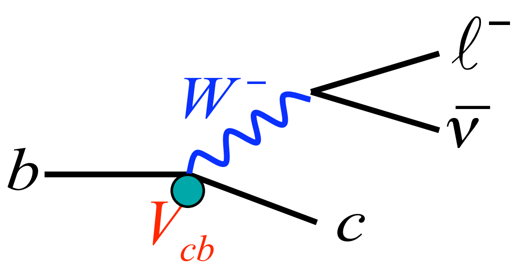


- $|V_{ub}|$ determines the rate of the $b \rightarrow u$ transition
  - Measure the rate of $b \rightarrow u\lambda\nu$ decay (λ = e or μ)



$$\Gamma(b \rightarrow u\ell\bar{\nu}) = \frac{G_F^2}{192\pi^2}|V_{ub}|^2 m_b^5$$

  - The problem: $b \rightarrow c\lambda\nu$ decay is much faster

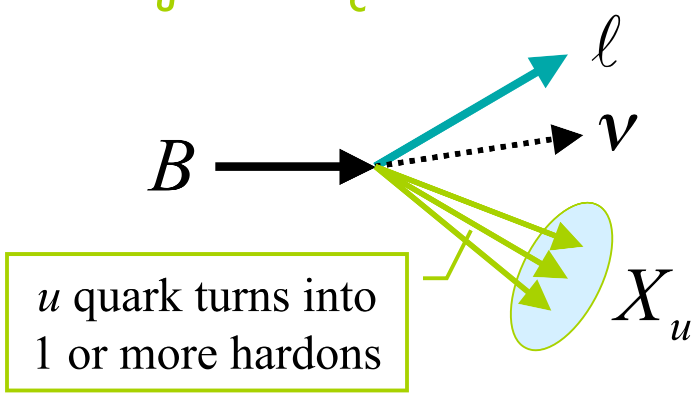


$$\frac{\Gamma(b \rightarrow u\ell\bar{\nu})}{\Gamma(b \rightarrow c\ell\bar{\nu})} \approx \frac{|V_{ub}|^2}{|V_{cb}|^2} \approx \frac{1}{50}$$

  - Can we overcome a 50× larger background?

Detecting $b \to u\ell\nu$

- Use $m_u \ll m_c$ → difference in kinematics

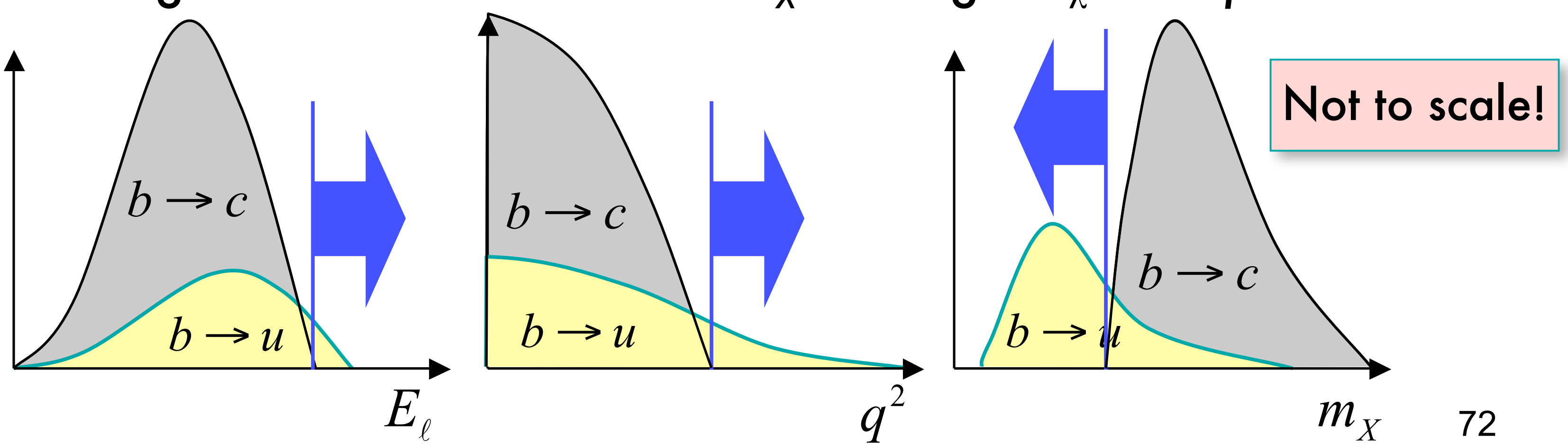


E_λ = lepton energy

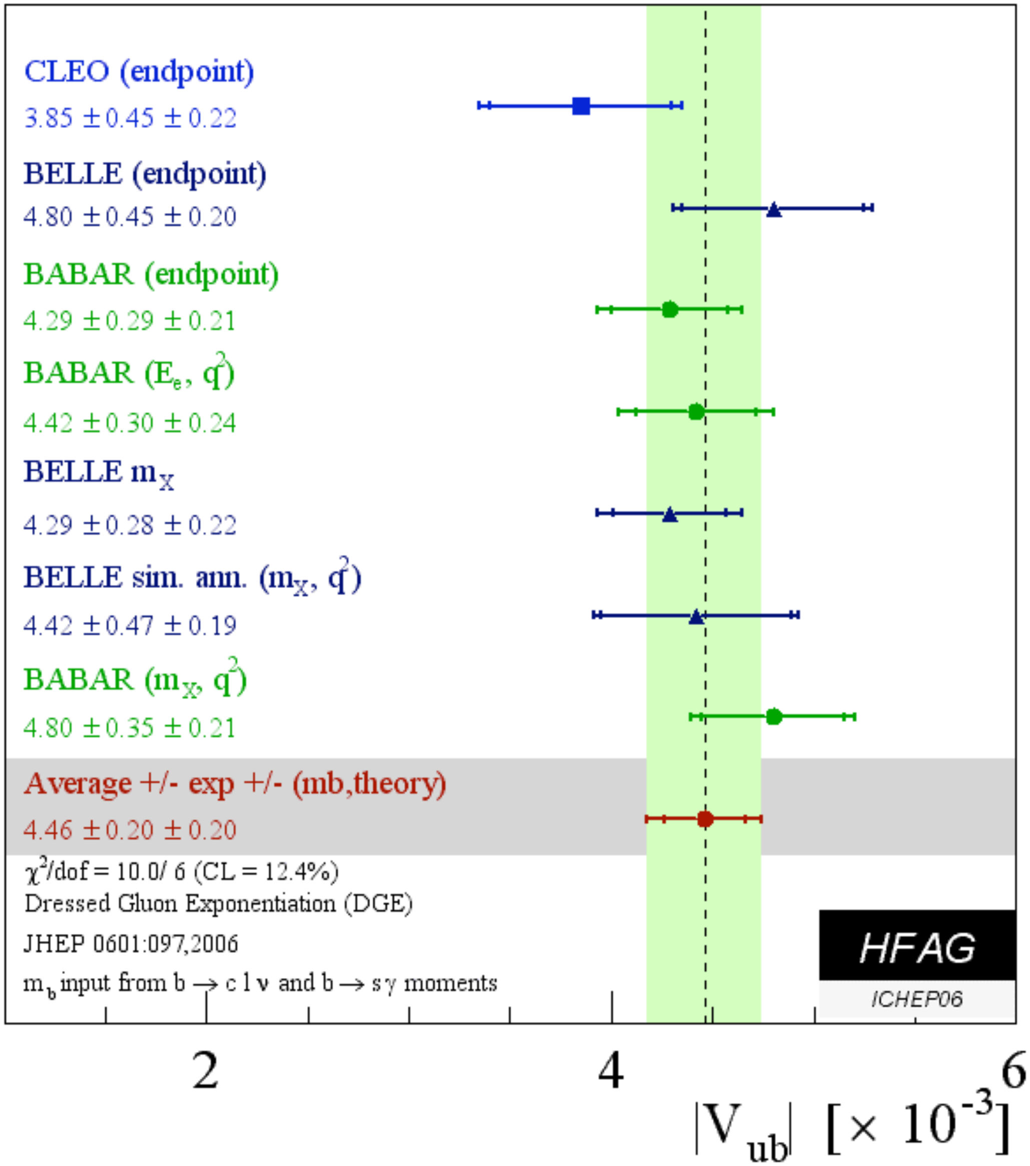
q^2 = lepton-neutrino mass squared

m_X = hadron system mass

- Signal events have smaller m_X → Larger E_λ and q^2

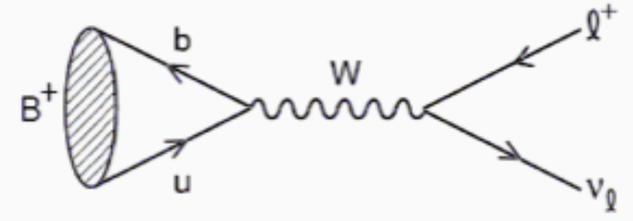


Status of $|V_{ub}|$



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

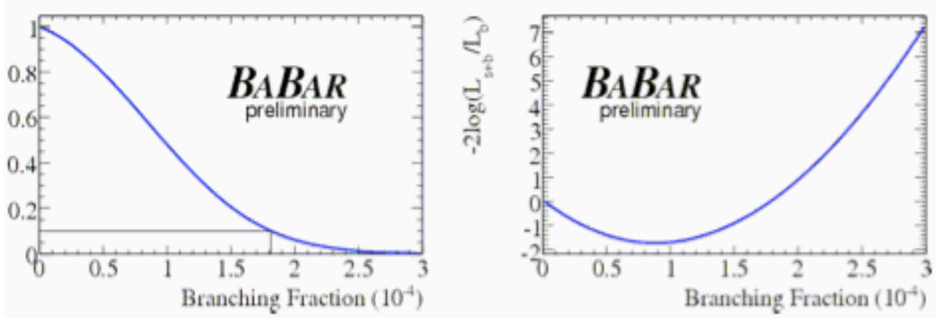
$BR(B^+ \to e^+\nu) < 7.9\times10^{-6}$ at the 90% C.L.
$BR(B^+ \to \mu^+\nu) < 6.2\times10^{-6}$ at the 90% C.L.

324 M BB

PRELIMINARY

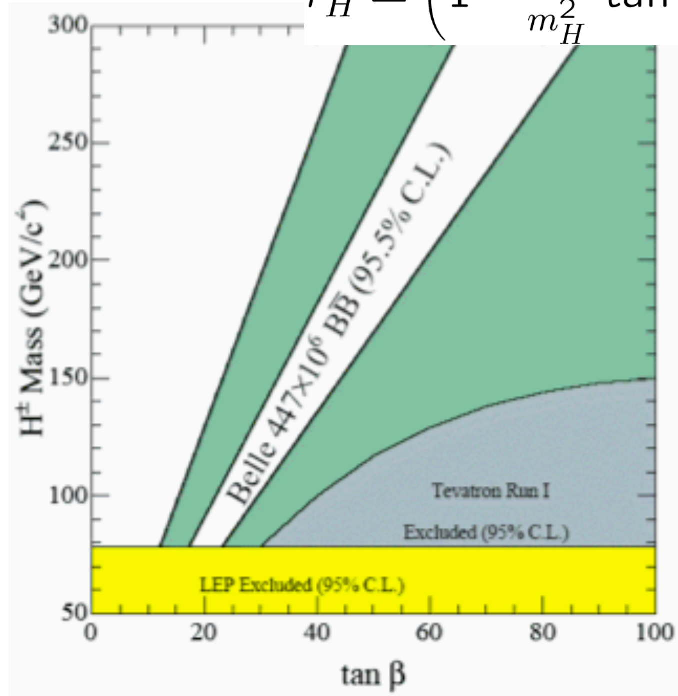
$BR(B^+ \to \tau^+\nu) < 1.8\times10^{-4}$ at the 90% CL

$BR(B^+ \to \tau^+\nu) = (0.88^{+0.68}_{-0.67}(stat.) \pm 0.11(syst.))\times10^{-4}$



$f_B|V_{ub}| = \left|7.0^{+2.3}_{-3.6}(stat.)^{+0.4}_{-0.5}(syst.)\right|\times10^{-4}$ 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

- Use SU(3) to relate $B^0 \to \rho(\omega)\gamma$ to $B^0 \to K^*\gamma$
- **Reconstructed decays:**
  - $B \to \rho^+\gamma$, $\rho^+ \to \pi^+\pi^0$
  - $B \to \rho^0\gamma$, $\rho^0 \to \pi^+\pi^-$
  - $B \to \omega\gamma$, $\omega \to \pi^+\pi^-\pi^0$

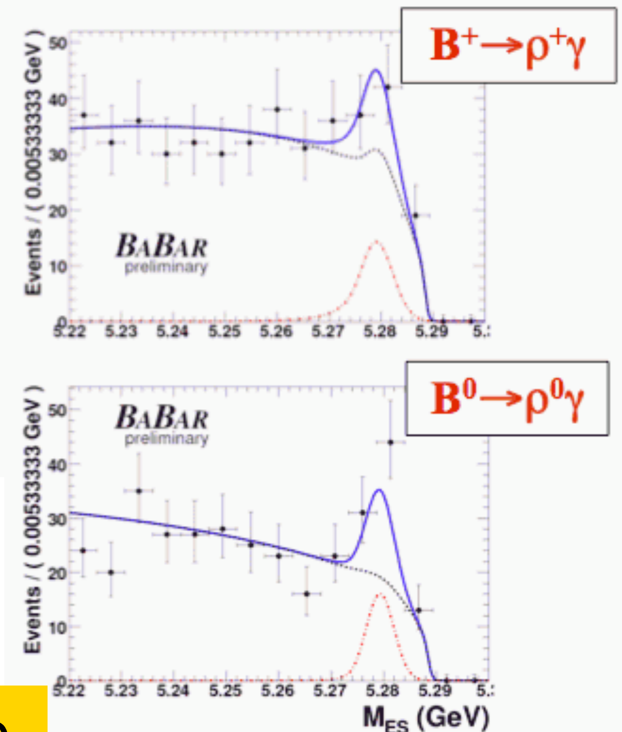
$$\frac{\overline{BF}(B \to (\rho/\omega)\gamma)}{BF(B \to K^*\gamma)} = \left|\frac{V_{td}}{V_{ts}}\right|^2 \left(\frac{1-m_\rho^2/M_B^2}{1-m_{K^*}^2/M_B^2}\right)^3 \zeta^2[1+\Delta R]$$

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

- Determine |Vtd/Vts| 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 $B^+ \to \rho^+\gamma$



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316 /fb

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

Combined fit result:

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

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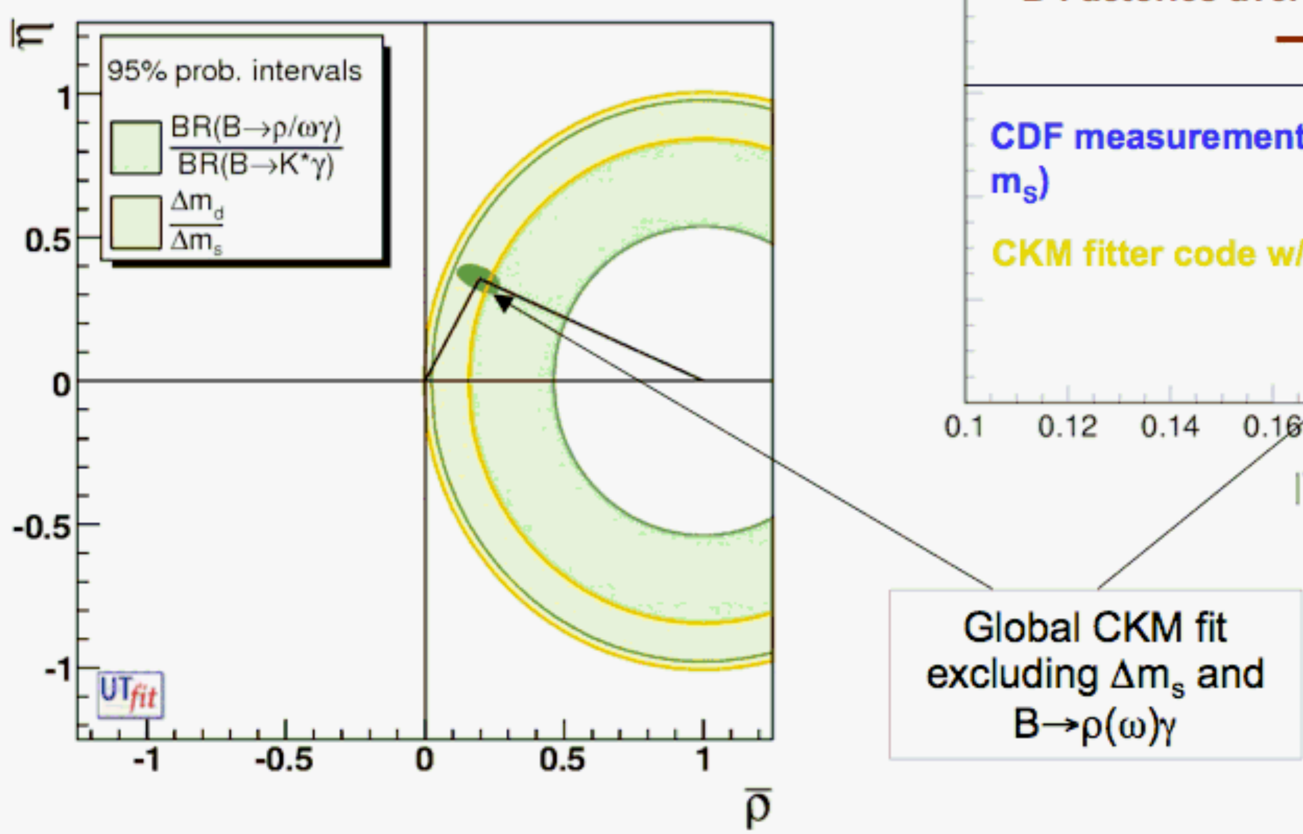
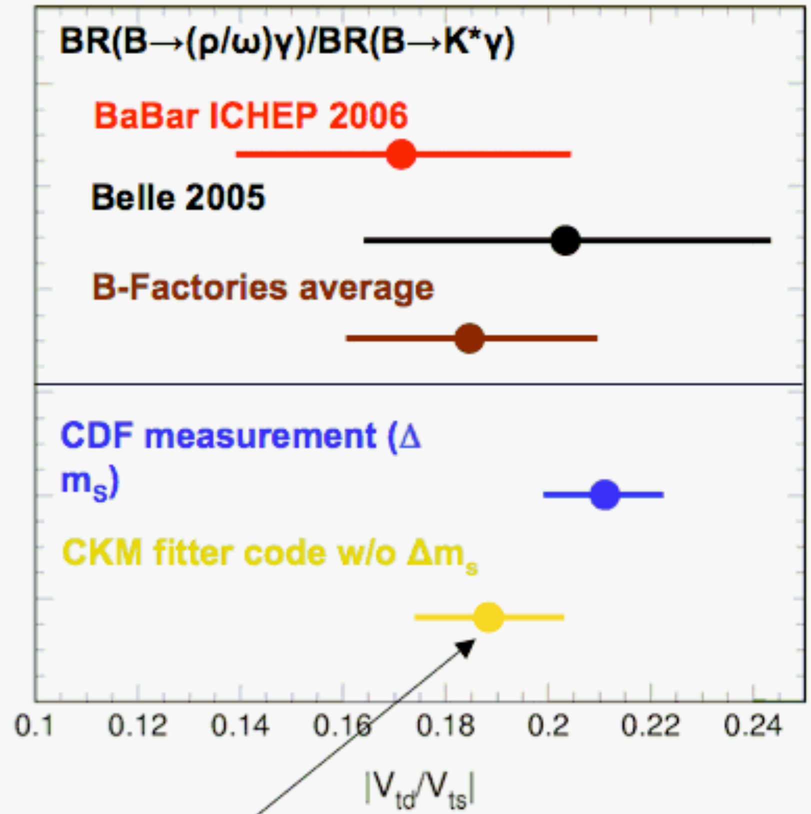
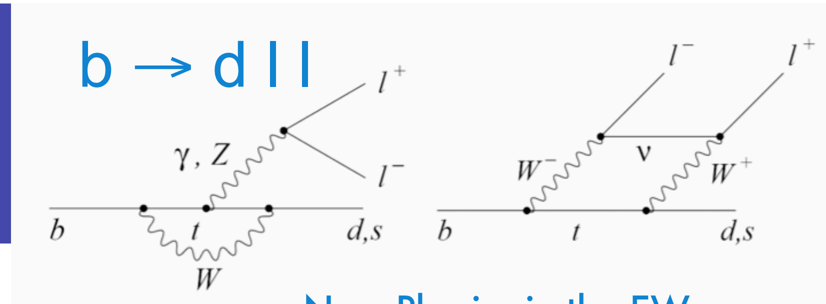




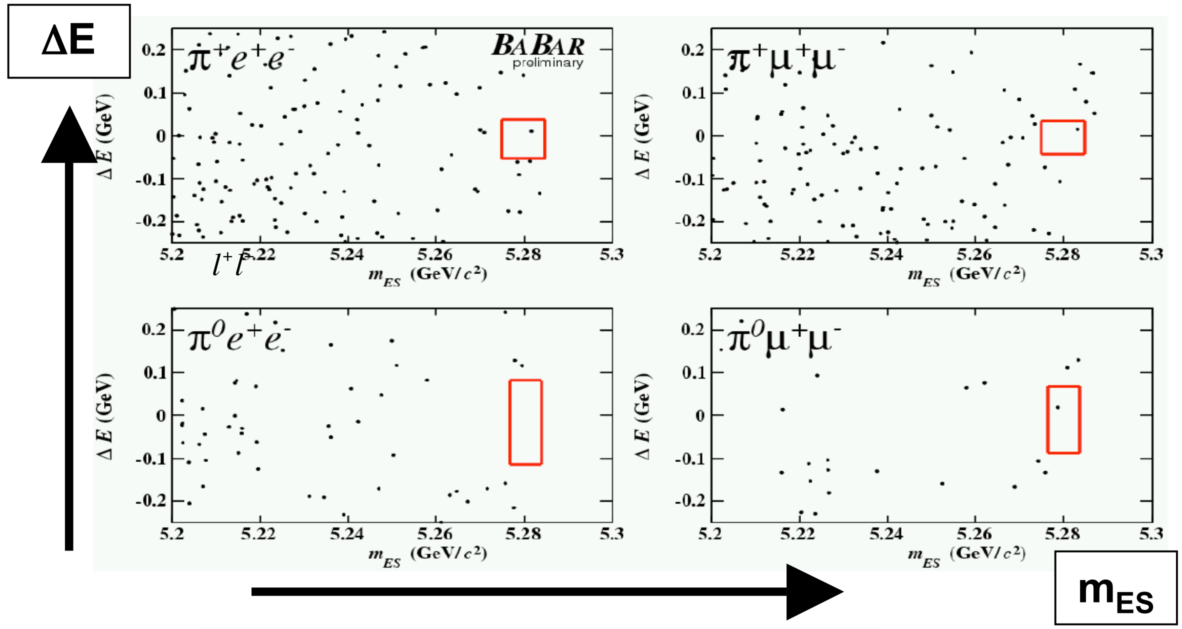
Search for B $\rightarrow \pi\ l^+l^-$



New Physics in the EW penguin and box diagrams ?

- Reconstruct $B \to \pi \ell^+ \ell^-$ $(\pi = \pi^+ \text{or } \pi^0)$ 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})
$B^+ \to \pi^+ e^+ e^-$	1.72
$B^0 \to \pi^0 e^+ e^-$	1.29
$B^+ \to \pi^+ \mu^+ \mu^-$	2.47
$B^0 \to \pi^0 \mu^+ \mu^-$	4.56
$B^+ \to \pi^+ e^+ \mu^-$	1.72
$B^0 \to \pi^0 e^+ \mu^-$	1.50

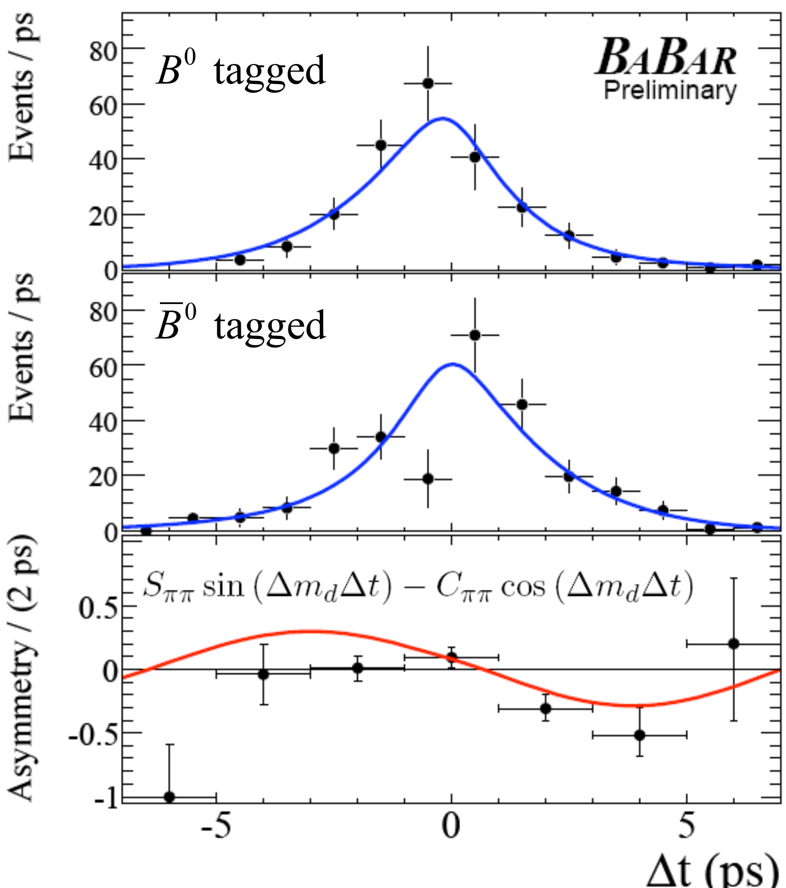


- Standard Model prediction: $\mathrm{BF}[B \to \pi l^+ l^-] = 3 \times 10^{-8}$
- Find: $\mathcal{B}(B^+ \to \pi^+\ell^+\ell^-) = 2 \times \frac{\tau_{B^+}}{\tau_{B^0}} \mathcal{B}(B^0 \to \pi^0\ell^+\ell^-) < 7.9 \times 10^{-8}$
- Standard Model limit is just around the corner .... ?

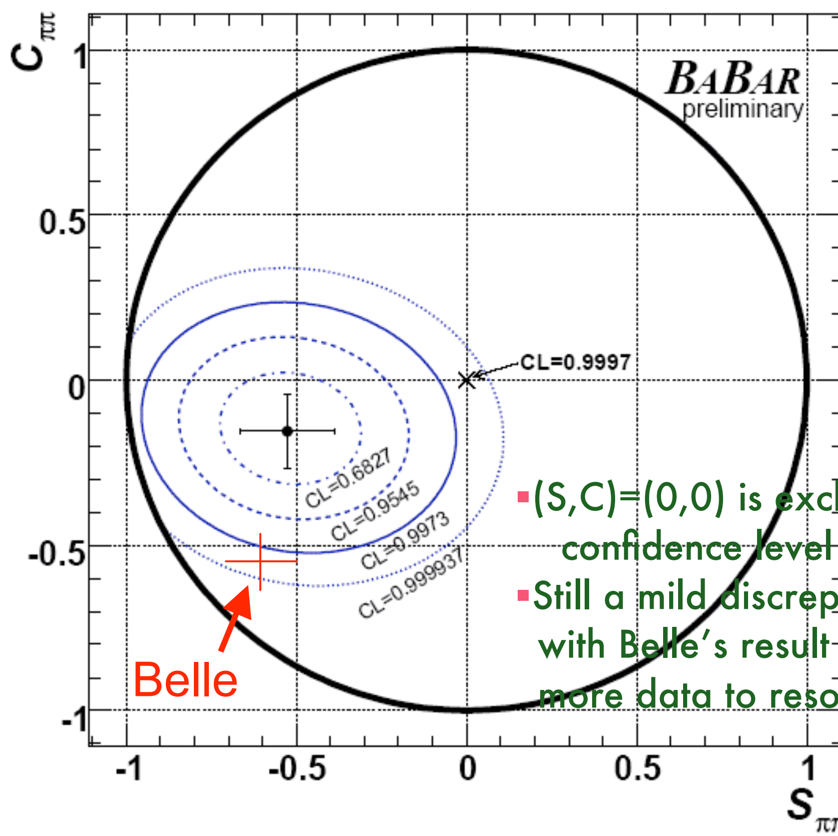
$B^0 \to \pi^+\pi^-$: Evidence for direct CP violation

- 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)

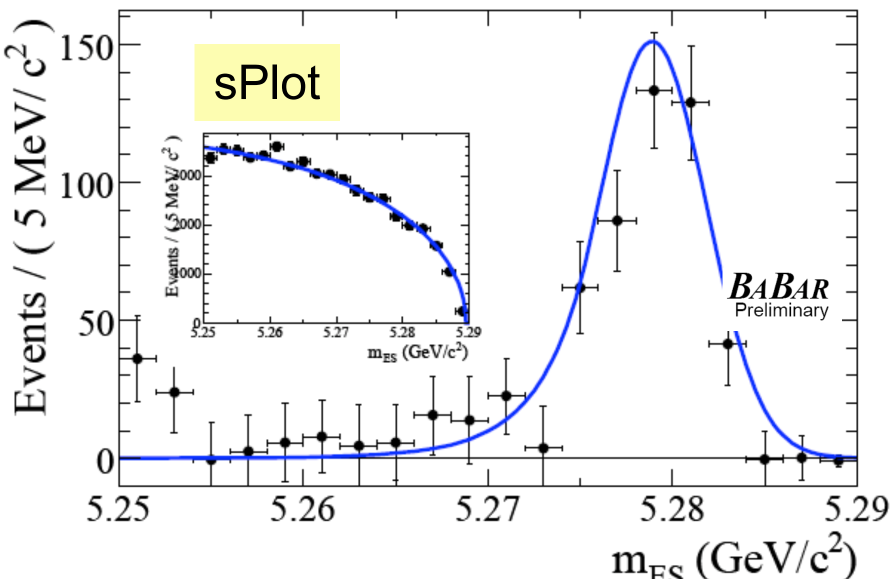


- (S,C)=(0,0) is excluded at a confidence level of 0.9997.
- Still a mild discrepancy with Belle's result ⇒ need more data to resolve this.

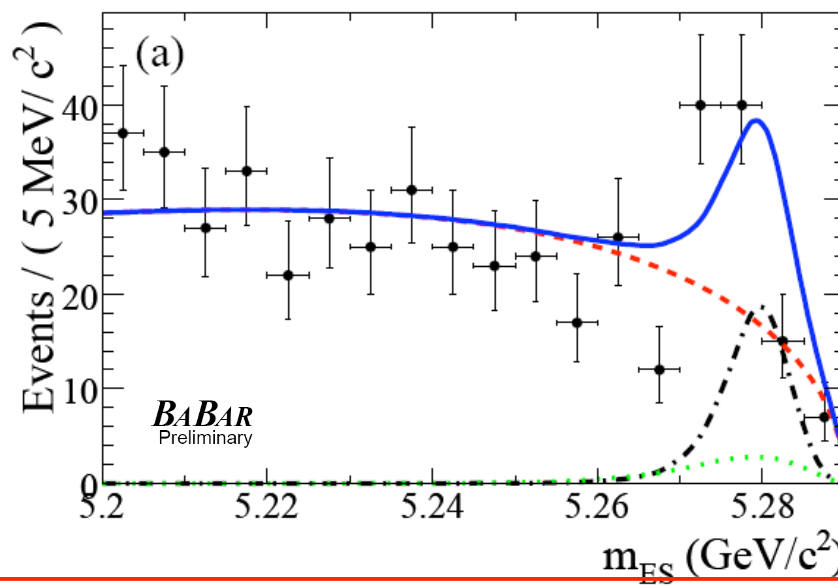
The other sides of the ππ triangle

- 347 M BB pairs.

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



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



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

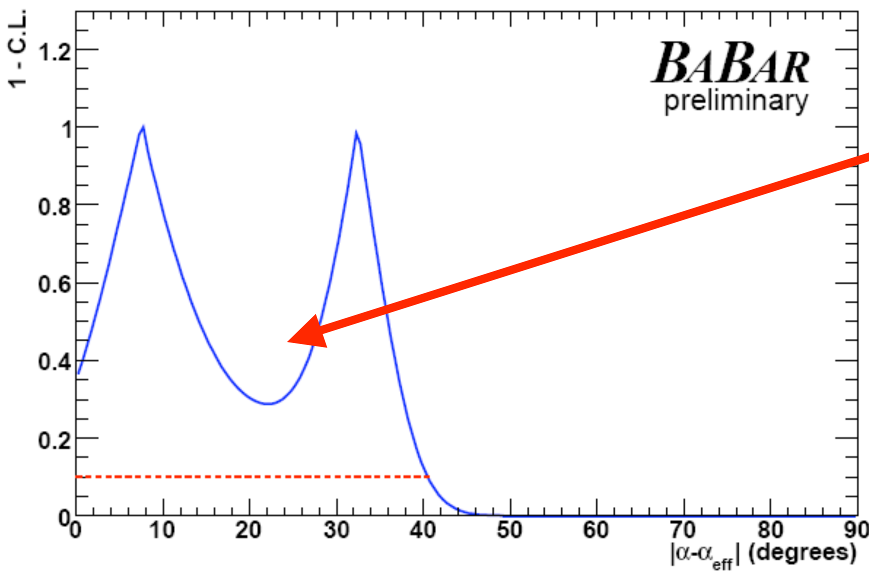
572±53 events

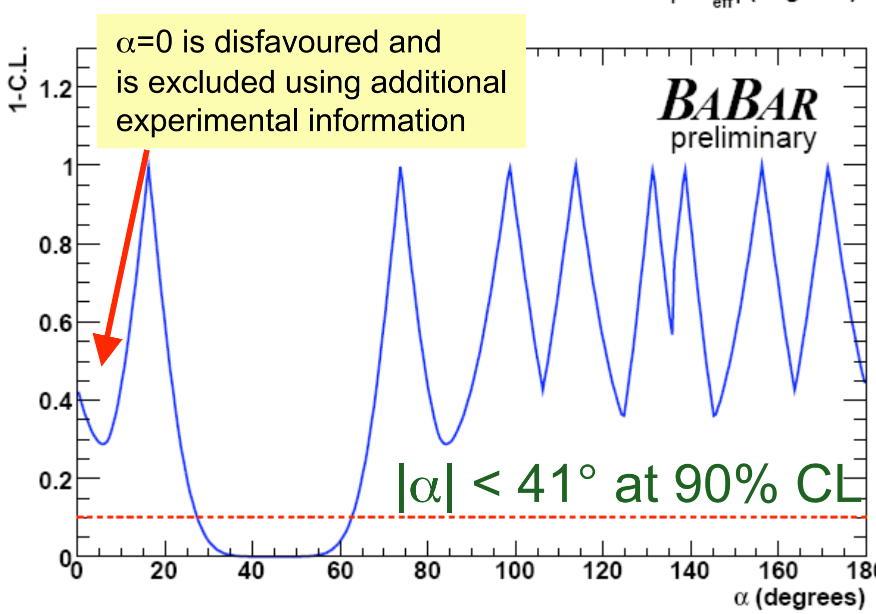
$$\mathcal{B}(B^{0} \to \pi^{0}\pi^{0}) = (1.48 \pm 0.26 \pm 0.12) \times 10^{-6}$$
$$C_{\pi^0\pi^0} = -0.33 \pm 0.36 \pm 0.08$$

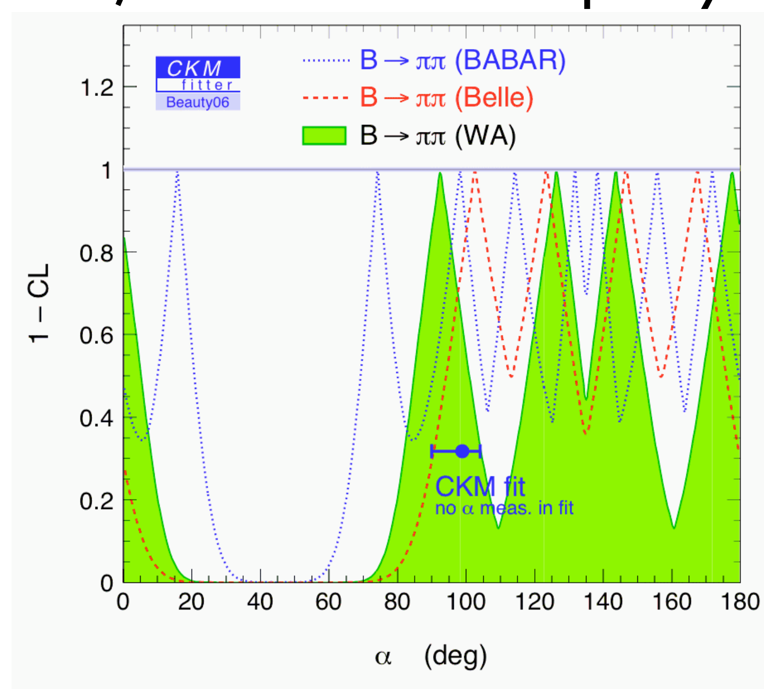
140±25 events

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.

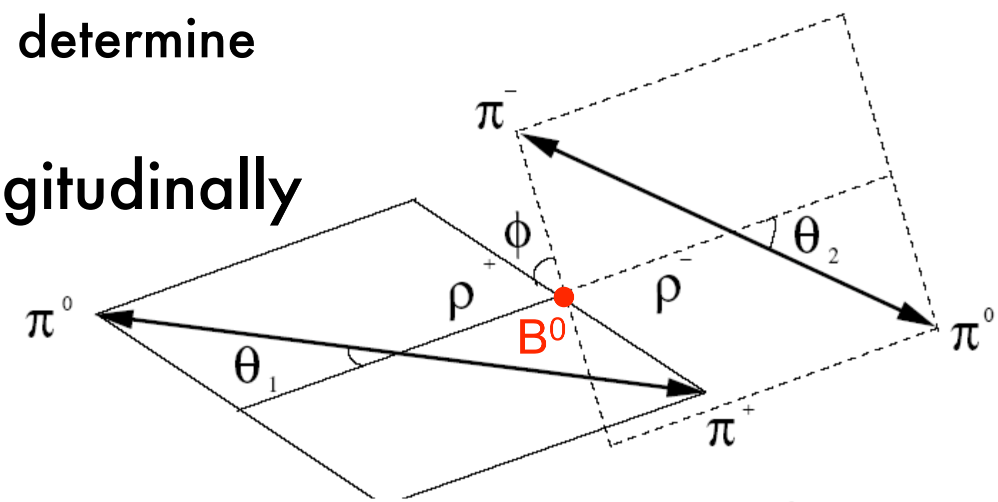






Measuring α with $B \rightarrow \rho\rho$ decays

- 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!



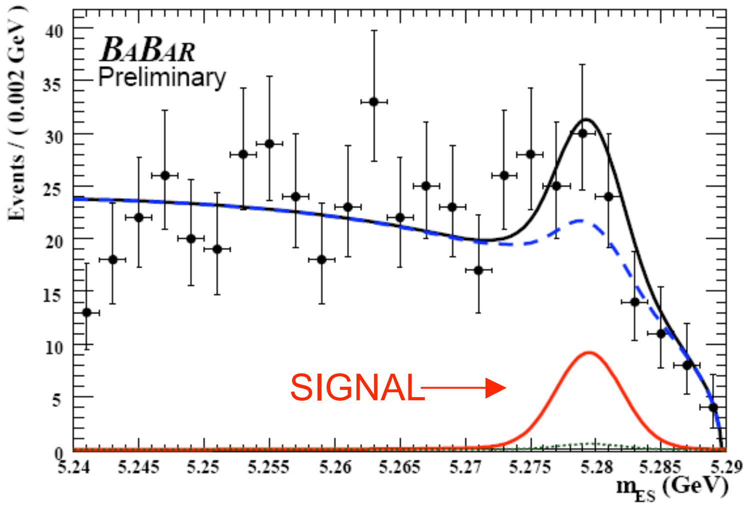
$$\frac{d^2\Gamma}{\Gamma d\cos\theta_1 d\cos\theta_2} = \frac{9}{4}\left(f_L \cos^2\theta_1 \cos^2\theta_2 + \frac{1}{4}(1-f_L)\sin^2\theta_1 \sin^2\theta_2\right)$$

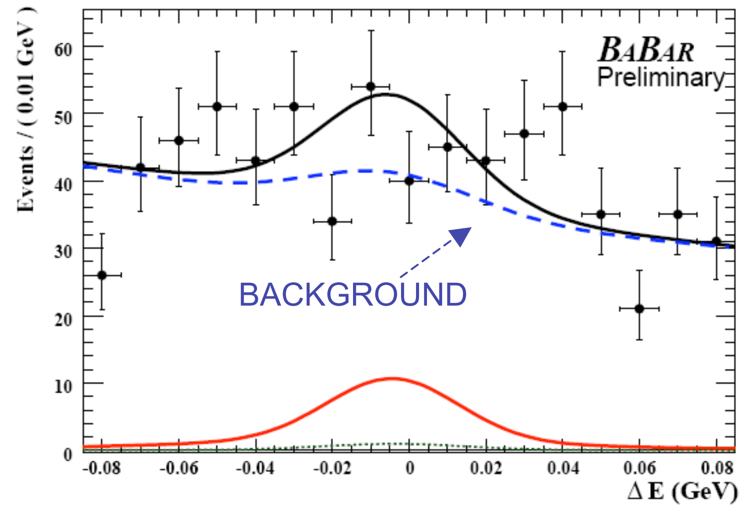
Longitudinal (CP even)

Transverse (Mixed CP state)

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

- Updated measurement using 347 M BB pairs.





Previous result UL < 1.1×10^{-6} (central value was 0.54×10^{-6})

$$\mathcal{B}(B^0 \to \rho^0\rho^0) = [1.16^{+0.37}_{-0.36}\ (\text{stat.}) \pm 0.27\ (\text{syst.})]\times10^{-6}$$

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

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

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

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

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

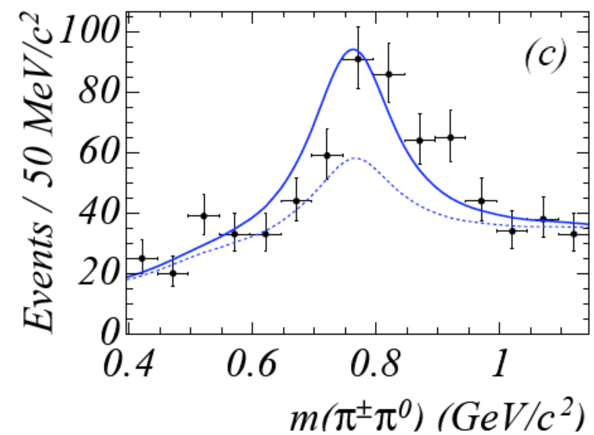
Another side of the ρρ triangle : $\rho^+\rho^0$

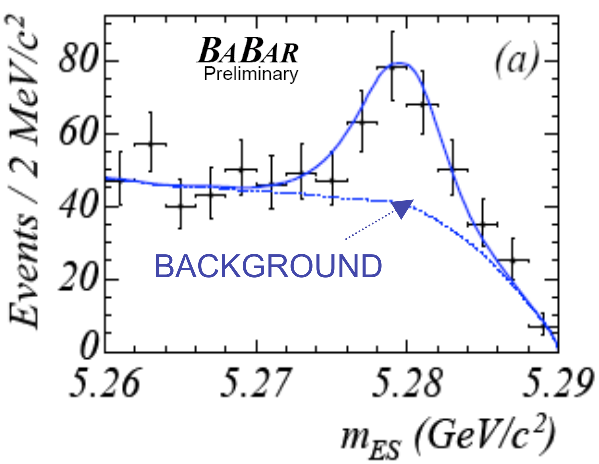
- Updated measurement using 232 M BB pairs.
- Simultaneous fit for $B^+ \to \rho^+ f_0(980)$.
- Smaller branching fraction measured (than on Run1+2 data)
  - Leads to a weaker constraint on penguin pollution
  - Fit:

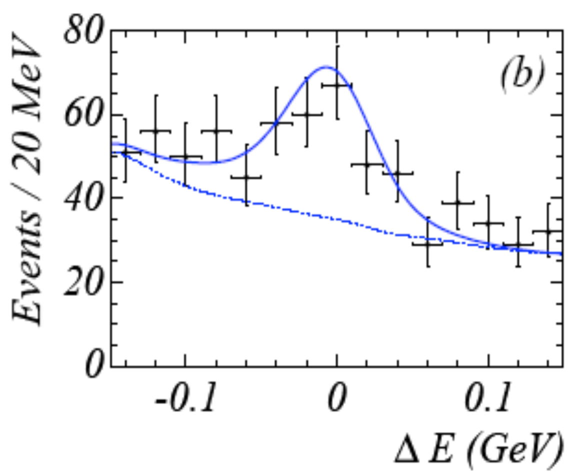
390±49 events

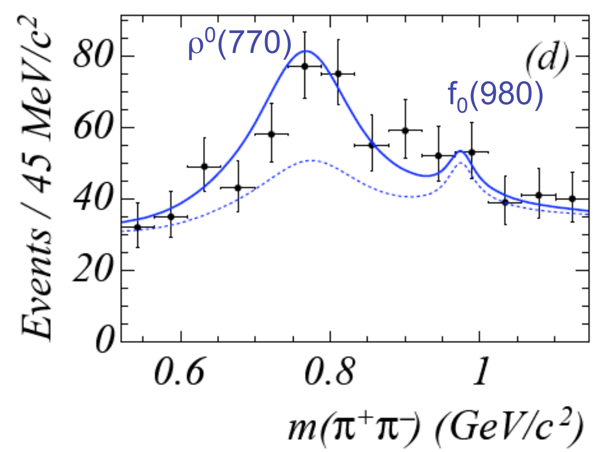
$$\mathcal{B} = (16.8 \pm 2.2 \pm 2.3) \times 10^{-6}$$

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



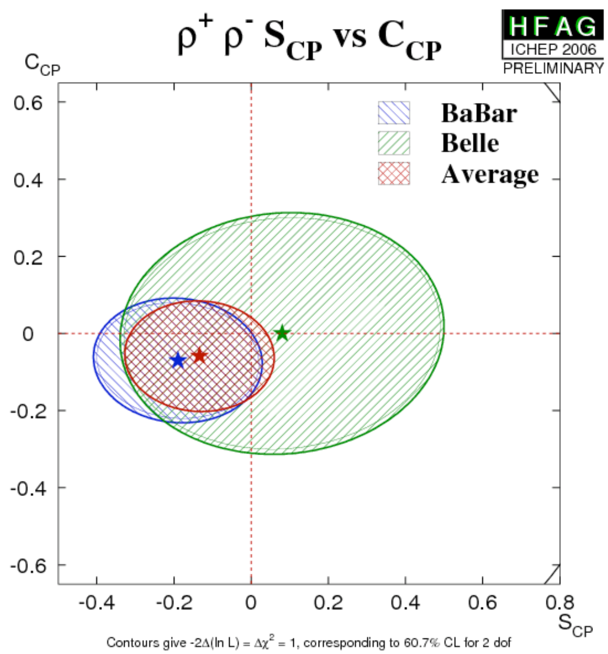


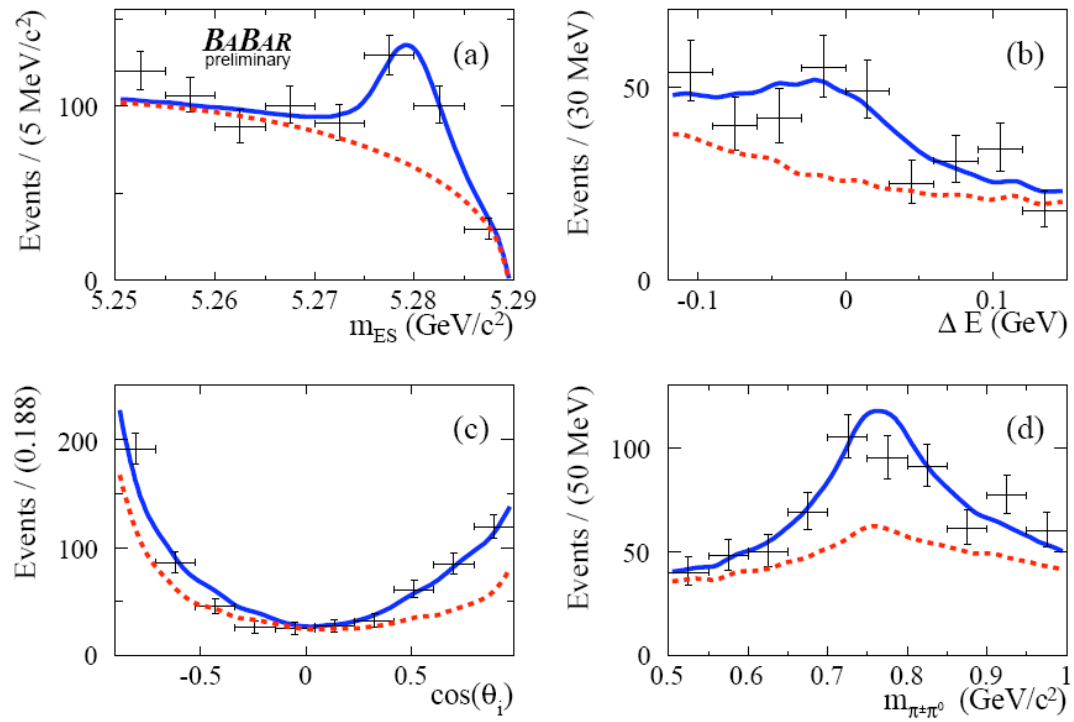




$B^0 \rightarrow \rho^+\rho^-$

- 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.

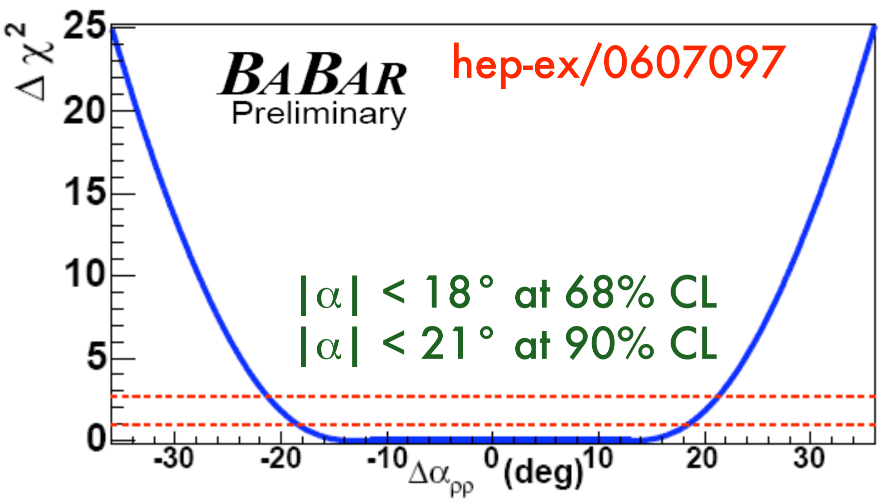




$$
\begin{aligned}
\mathcal{B}(B^0 \rightarrow \rho^+\rho^-) &= (23.5 \pm 2.2(\mathrm{stat}) \pm 4.1(\mathrm{syst}))\times 10^{-6}, \\
f_L &= 0.977 \pm 0.024(\mathrm{stat})^{+0.015}_{-0.013}(\mathrm{syst}), \\
S_{\mathrm{long}} &= -0.19 \pm 0.21(\mathrm{stat})^{+0.05}_{-0.07}(\mathrm{syst}), \\
C_{\mathrm{long}}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

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

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



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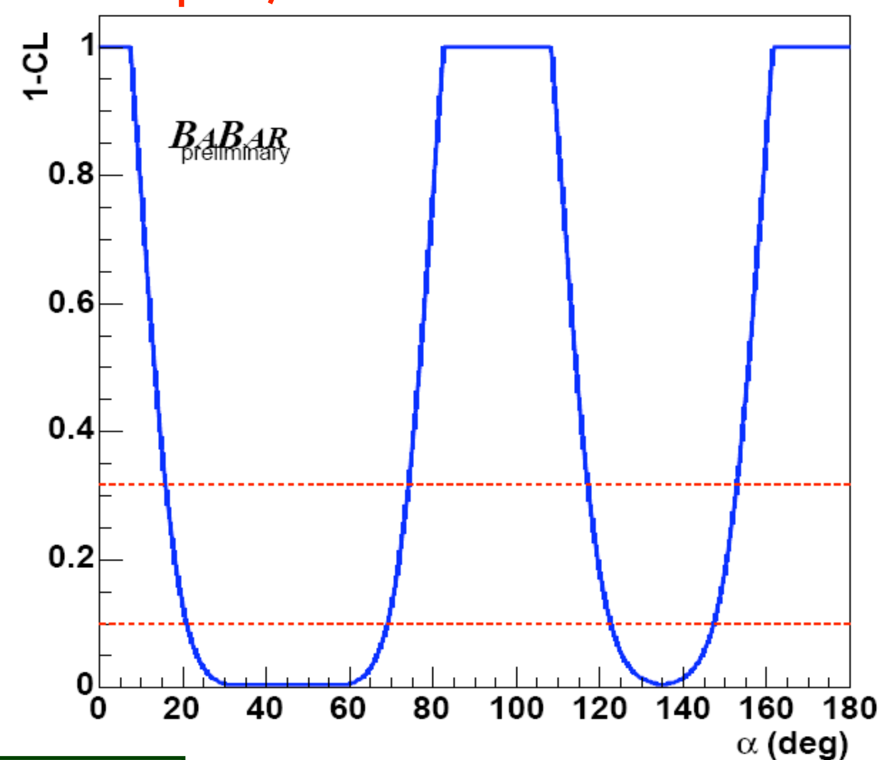


- Combination of:
  - Evidence for $\rho^0\rho^0$
  - Lower branching fraction for $\rho^+\rho^0$

  results in a weakened constraint on α.

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

$B^0 \rightarrow \rho^+\rho^-$: Progress since ICHEP ...

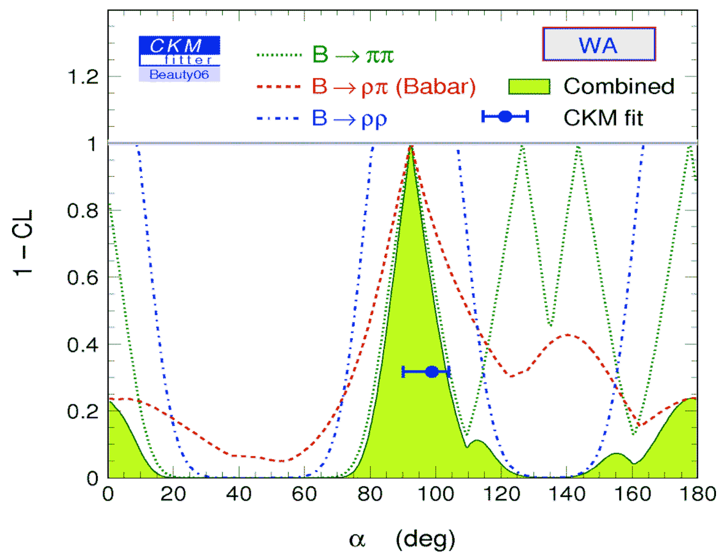
Conservative uncertainty on mis-reconstructed signal fraction which can be reduced.

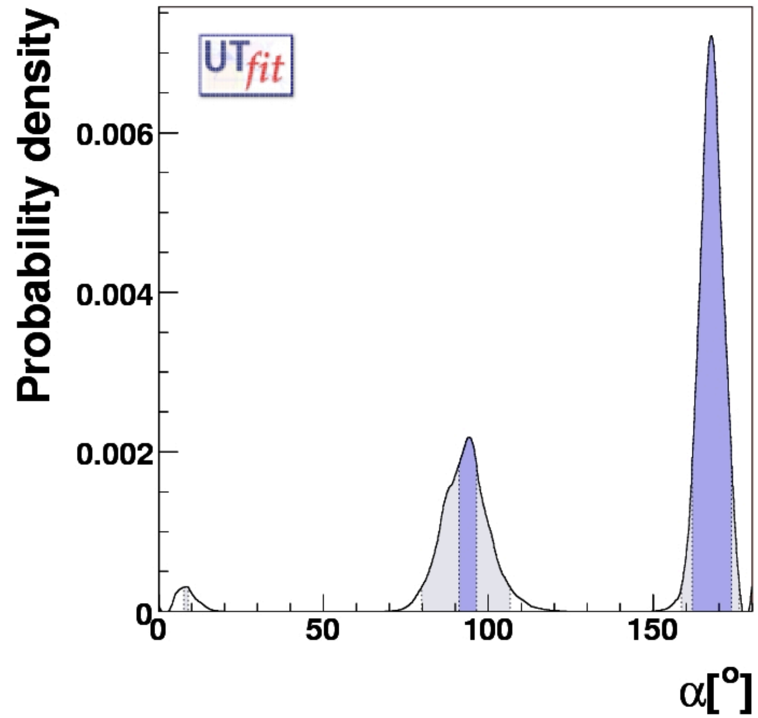
Table 4: Summary of additive systematic uncertainty contributions.

Contribution	$\sigma(N_{signal})$	$\sigma(f_L)$	$\sigma(S_{\rm long})$	$\sigma(C_{\rm long})$
PDF parameterisation	$^{+16.7}_{-30.2}$	$^{+0.0082}_{-0.0064}$	$^{+0.0149}_{-0.0425}$	$^{+0.0300}_{-0.0306}$
SCF fraction	84.0	$^{+0.0007}_{-0.0011}$	$^{+0.00235}_{-0.00355}$	$^{+0.0070}_{-0.00683}$
m_{ES} and ΔE width	22.9	0.005	0.011	0.012
B background normalisation	$^{+16.0}_{-17.2}$	$^{+0.0033}_{-0.0038}$	$^{+0.0096}_{-0.0115}$	$^{+0.0024}_{-0.0015}$
floating B backgrounds	33.6	0.004	0.033	0.006
CPV in B background	$^{+3.3}_{-2.0}$	$^{+0.0006}_{-0.0016}$	$^{+0.0059}_{-0.0214}$	$^{+0.0118}_{-0.0115}$
τ	$^{+0.1}_{-0.4}$	$^{+0.0000}_{-0.0002}$	$^{+0.0002}_{-0.0008}$	0.0007
Δm	$^{+0.0}_{-0.2}$	$^{+0.0000}_{-0.0002}$	$^{+0.0014}_{-0.0020}$	$^{+0.0018}_{-0.0012}$
tagging and dilution	$^{+2.6}_{-8.1}$	$^{+0.0029}_{-0.0021}$	$^{+0.0016}_{-0.0053}$	$^{+0.0068}_{-0.0054}$
transverse polarisation CPV	$^{+0.0}_{-8.3}$	$^{+0.0057}_{-0.0000}$	$^{+0.0125}_{-0.0152}$	$^{+0.0095}_{-0.0110}$
WT SCF CPV	$^{+0.2}_{-1.1}$	$^{+0.0000}_{-0.0003}$	$^{+0.0051}_{-0.0065}$	$^{+0.0116}_{-0.0113}$
DCSD decays	–	–	0.012	0.037
Interference	14.8	0.0036	0.023	0.022
Fit Bias	28	0.007	0.002	0.022
SVT Alignment	–	–	0.0100	0.0055
Total	$^{+97}_{-101}$	$^{+0.015}_{-0.013}$	$^{+0.05}_{-0.07}$	± 0.06

- Before ICHEP ...
  - Improvements in modelling correlations and backgrounds resulted in a reduced systematic uncertainty on S and C.
  - Improved upper limit for $B^0 \rightarrow a_1^+\rho^-$ also helped to reduce systematic uncertainty.
- Now ...
  - Updated to the full Run 1-5 dataset.
  - Can half the SCF systematic error by correcting the branching fraction central value.
  - Update the interference systematic error using latest W.A.
  - Writing a PRD ...

Combining results : CKM Fitter and UTFit

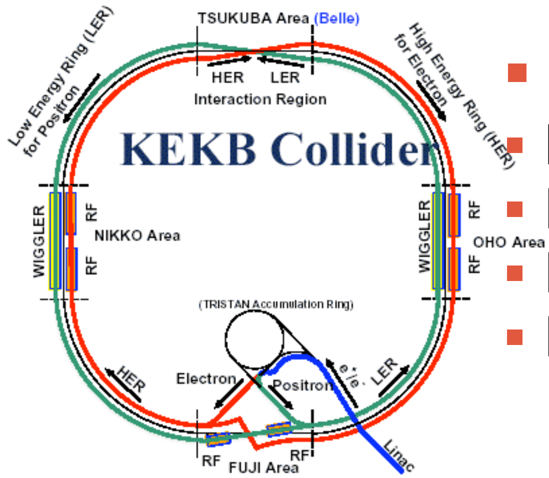




- The constraint on α is dependent on the statistical treatment used.
- This is a reflection of the fact that we need more data to perform a precision measurement of α.
- Excluded regions are common to both methods.
- CKM Fitter (direct constraint) : $\alpha = 93^{+11}_{-9}{}^{\circ}$
- UT Fit (direct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

I haven't mentioned anything about ρπ. See talks by e.g. Sasha Telnov (ICHEP'06), Fabrizio Bianchi (Beauty'06) or Christos Touramanis (HQL'06).

We have competition …
(Belle at KEK-B, Japan)



- Belle Experiment at the KEK-B accelerator, Japan.
- Data-taking since 1999.
- KEK-B Asymmetric collider : 3.5 GeV e^+, 8.0 GeV e^-
- Belle detector is very similar to BaBar.
- Peak luminosity of 16.27 x 10^{34} $cm^{-2}s^{-1}$