BABAR Status & Physics Reach in Coming Years

Gautier Hamel de Monchenault
CEA-Saclay DAPNIA/SPP
on behalf of the BABAR Collaboration

CERN, 14 February 2006

Status of PEP-2 and BABAR

PEP-2 and BABAR at SLAC

Stanford
Linear
Accelerator
Center

PEP-2
Asymmetric
B Factory

Luminosity records

PEP-2 / *BABAR* at SLAC

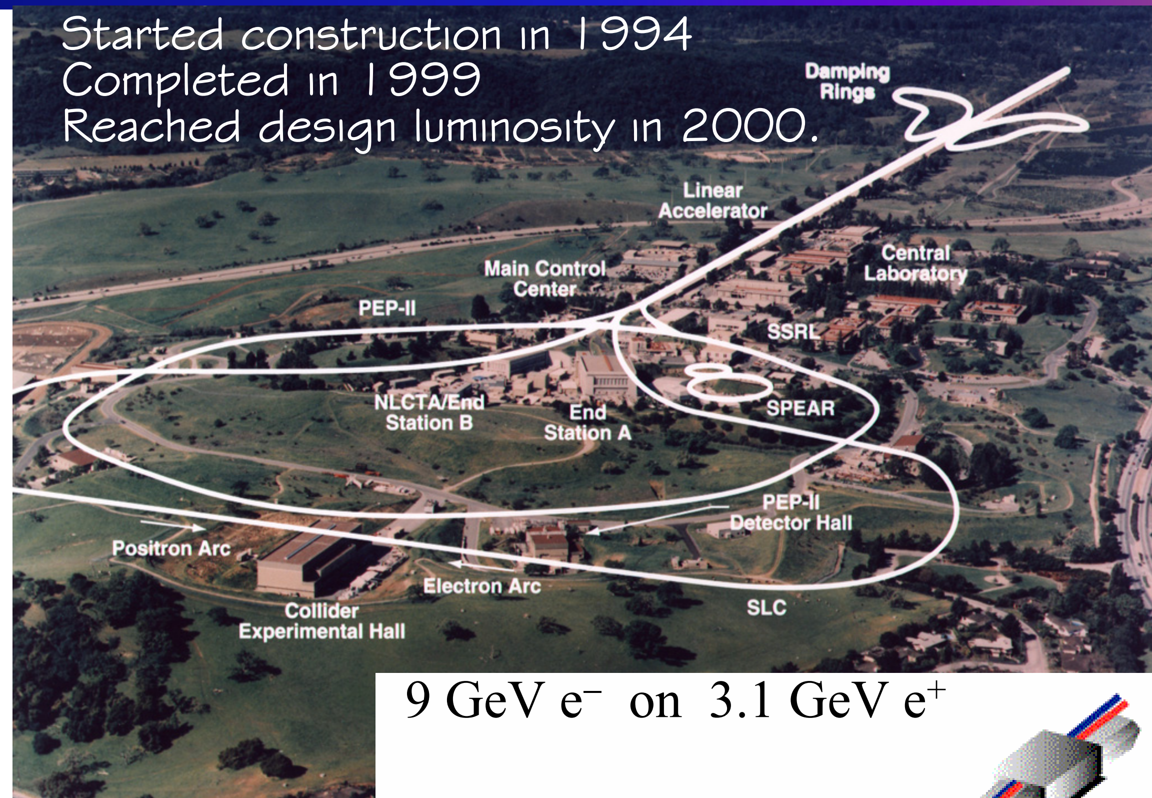
design peak:	$3\ 10^{33}\ \text{cm}^{-2}\text{s}^{-1}$
best peak:	$9.3\ 10^{33}\ \text{cm}^{-2}\text{s}^{-1}$
total recorded:	$\sim 319\ \text{fb}^{-1}$
best month:	$16\ \text{fb}^{-1}$

~230 million *BB* pairs
used for most analyses

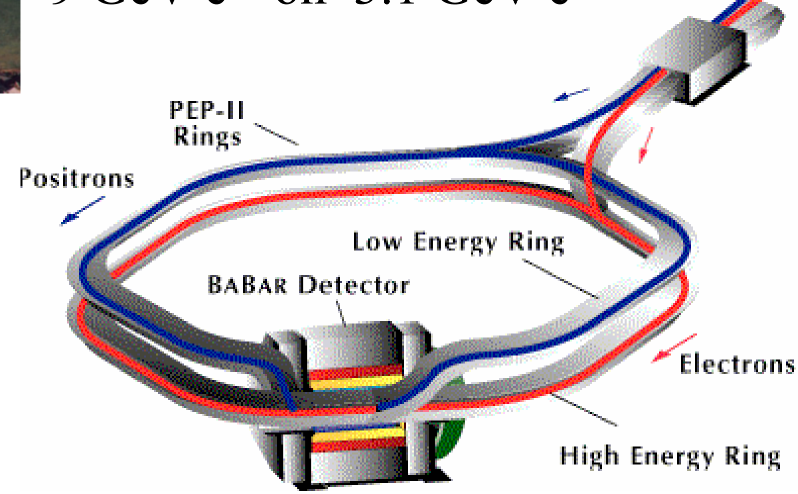
SLAC Accelerator Complex
shut down from October 2004 to April 2005
as a consequence of a severe electrical accident

PEP-2/BABAR resumed operation in April 2005
(additional ~76 fb^{-1} recorded since then)

Started construction in 1994
Completed in 1999
Reached design luminosity in 2000.

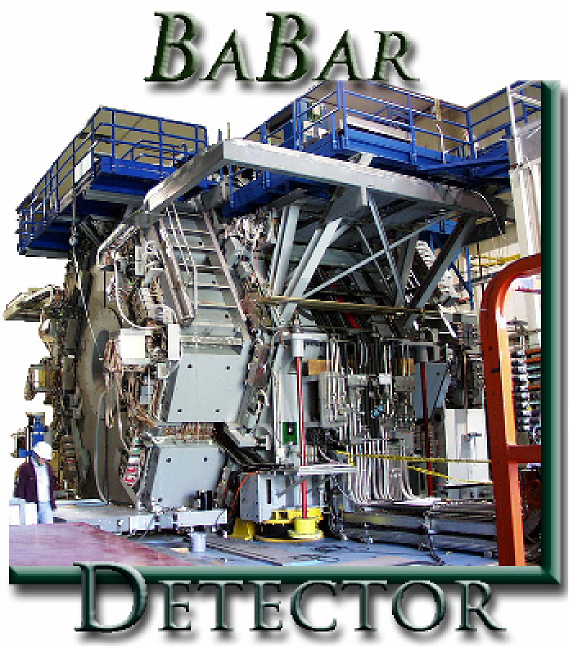


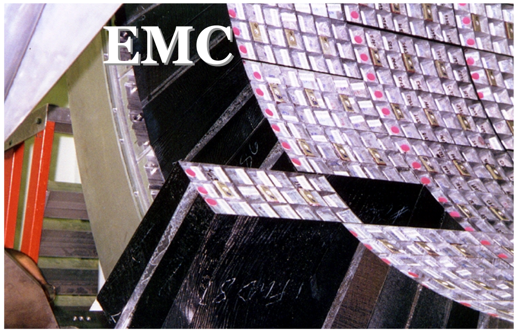
$9\ \text{GeV}\ e^-$ on $3.1\ \text{GeV}\ e^+$

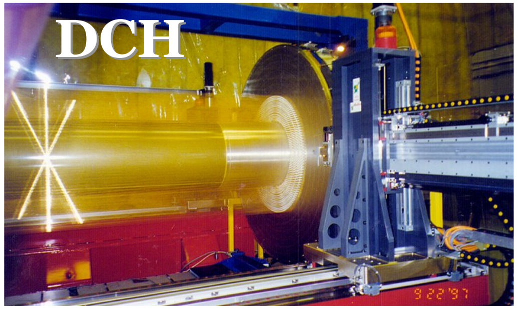


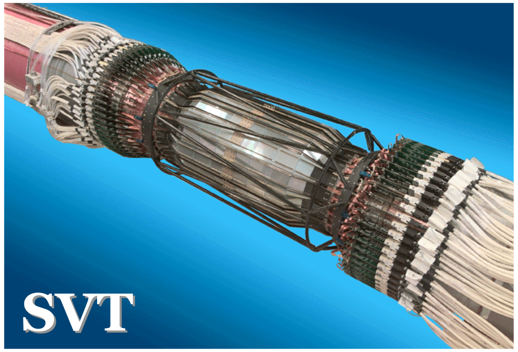
The BABAR Experiment

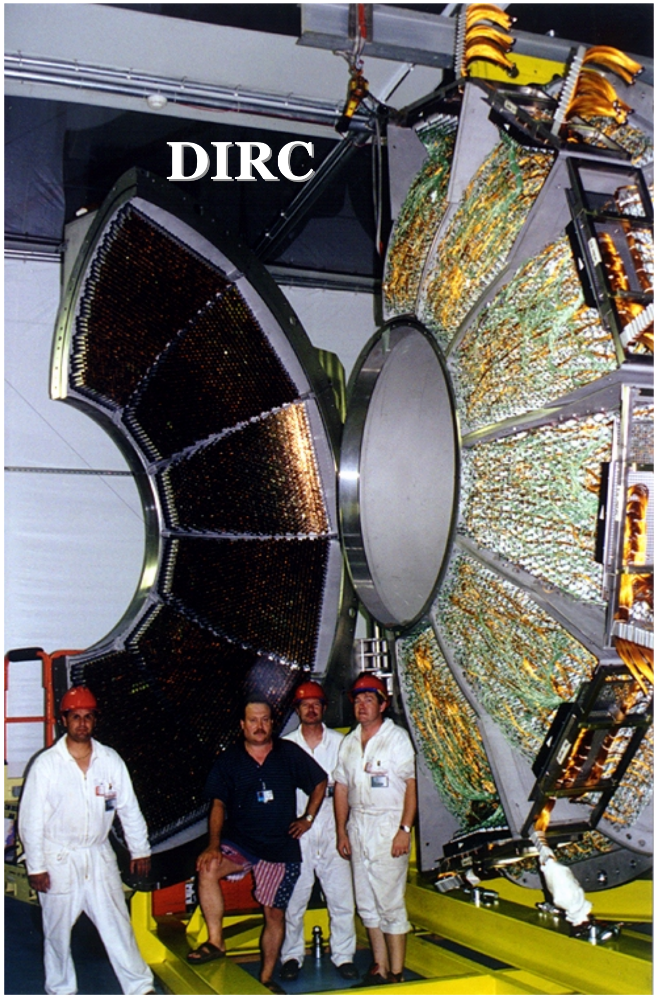
Stanford
Linear
Accelerator
Center





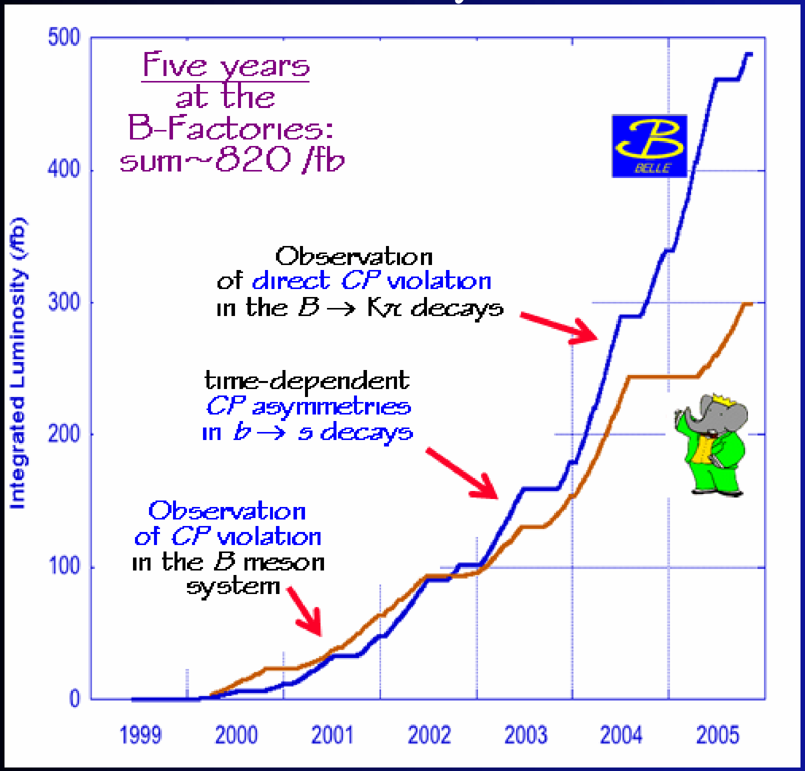




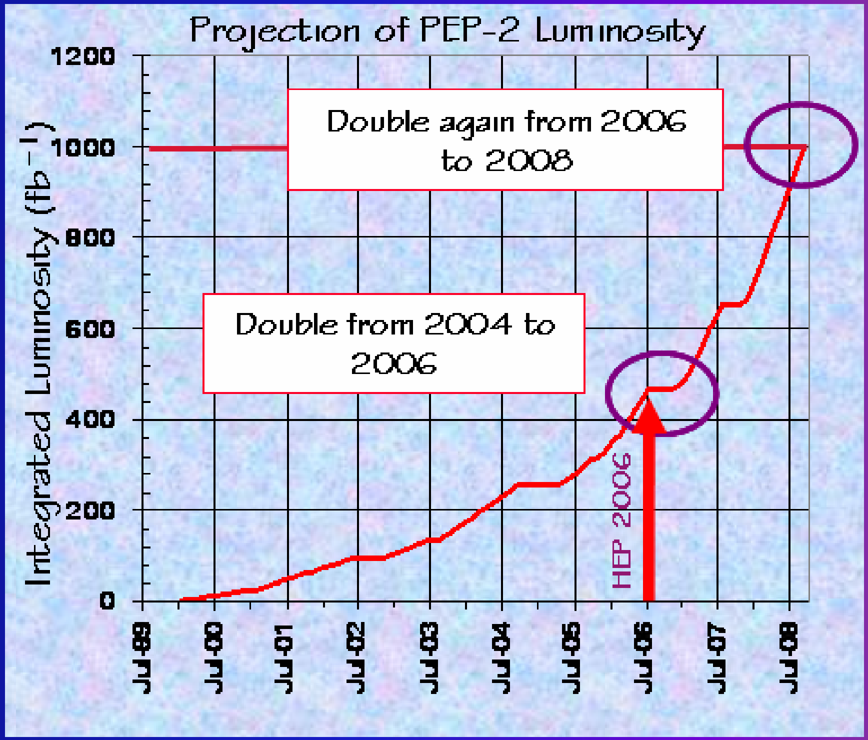


Projections to Summer 2008

Today



Toward 2008



- Summer 2006 : Added integrated luminosities of BABAR and Belle $\sim 1000\ fb^{-1} = 1\ ab^{-1}$ (1 inverse attobarn)
- PEP-2/BABAR are set to run between 2006 and 2008 with the goal of reaching a data set of order 1 ab^{-1}

Of order 1 ab^{-1} for BABAR by 2008

Flavor Physics & CP Violation

The Kobayashi-Maskawa Model

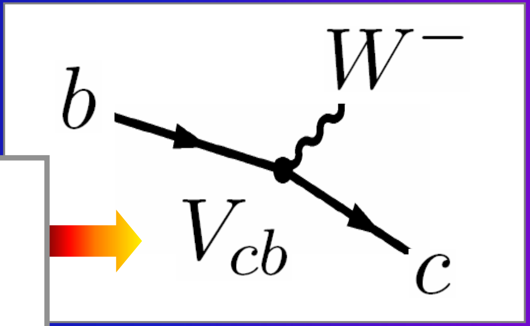
1972, M. Kobayashi & T. Maskawa :
introduction of CP violation in electroweak theory

Origin of CP violation :
the CKM matrix (« quark flavor mixing matrix »)

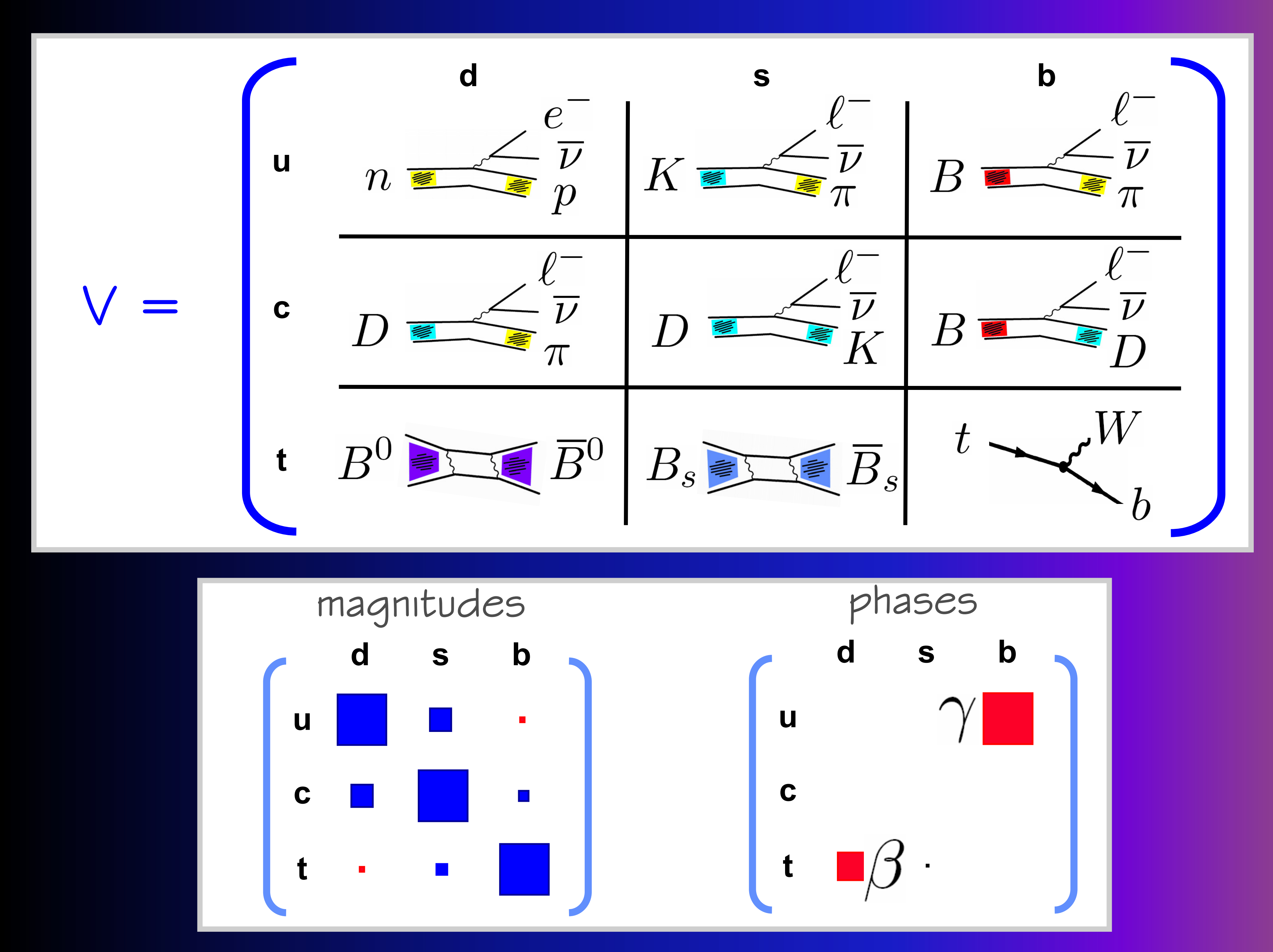
3 families → A single CP-violating parameter

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

transitions between quark-flavor and mass eigenstates



Elements of the CKM matrix:
« couplings » between
Down-type quarks
and Up-type quarks



V =
d
s
b
u
c
t
n
e⁻
ν̄
p
K
ℓ⁻
π
B
D
B⁰
B̄⁰
Bs
B̄s
W
b
magnitudes
phases
γ
β

The Unitarity Triangle

★ V is a complex unitary matrix:
determined by 4 real parameters

- sine of Cabibbo angle

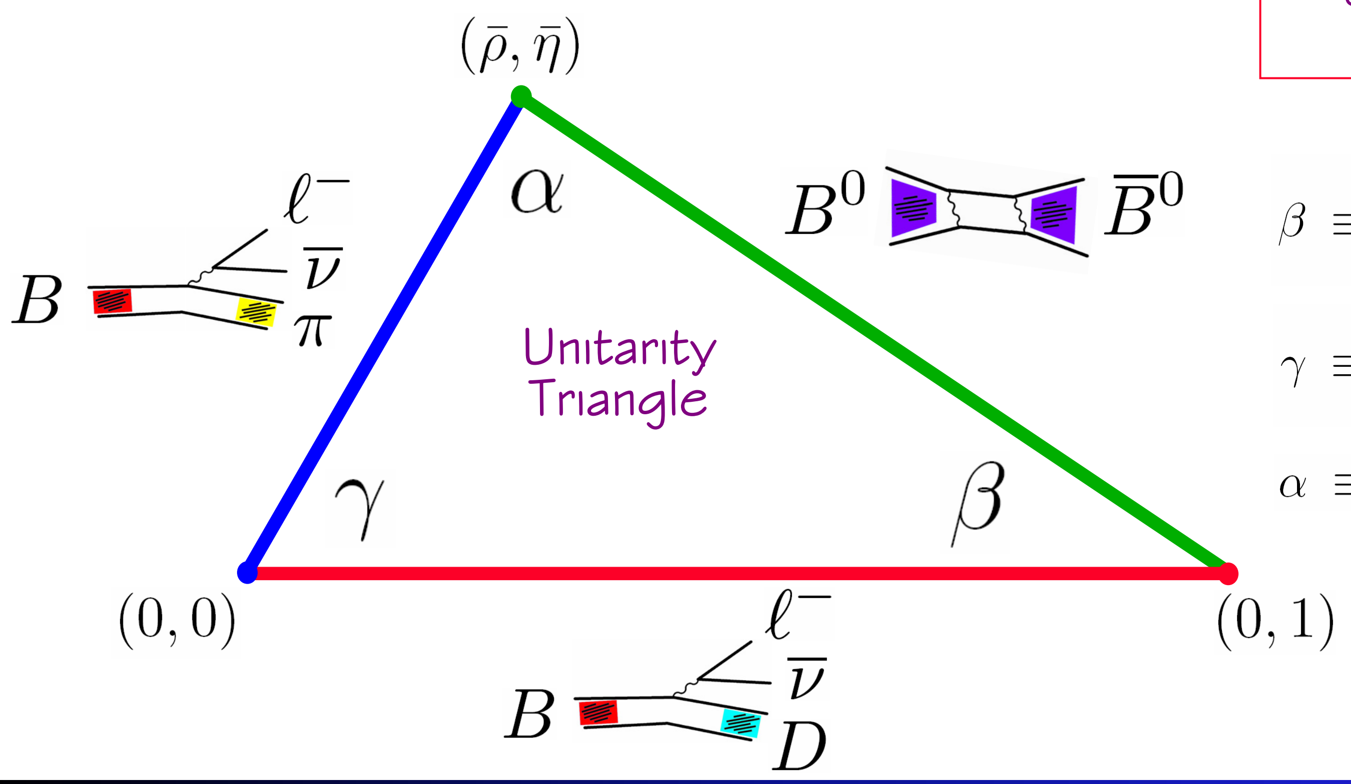
  $\lambda \sim 0.22$

- $b \rightarrow c$ transition (in units of λ^2)

  $A \sim 0.83$

- 2 coordinates of the apex of the Unitarity Triangle

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



$$\beta \equiv \arg\left[-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right] \sim 24^\circ$$

$$\gamma \equiv \arg\left[-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right] \sim 62^\circ$$

$$\alpha \equiv \pi - \beta - \gamma$$

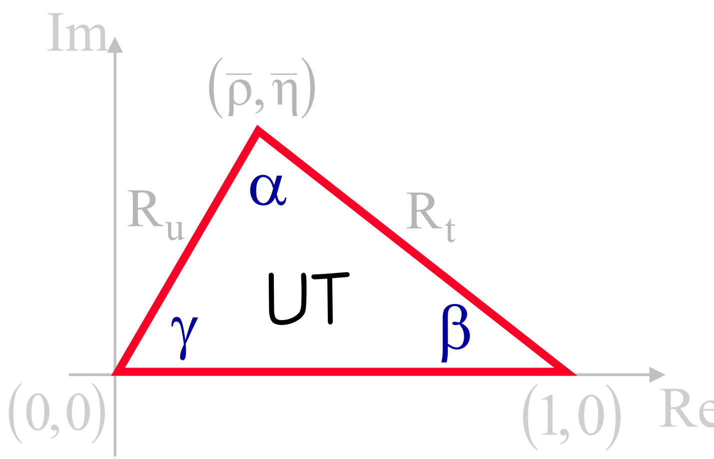
Ways to Look for New Physics

★ measure α

$B \to \pi^+\pi^-$
$B \to \rho^\pm\pi^\mp$
$B \to \rho^+\rho^-$

★ measure γ

$B \to D K^{(*)}$
$B \to D K^0_S$
$B \to K\pi$
$B \to D^*\pi$



★ improve UT side measurements

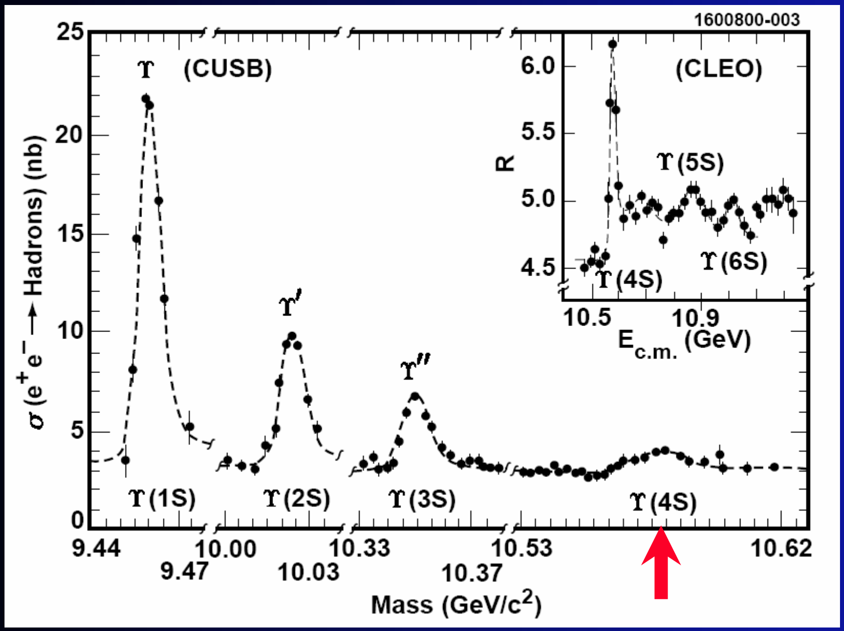
$B \to D^*\,\ell\nu$
$B \to \pi/\rho/\omega\,\ell\nu, \ldots$
$B^0 \leftrightarrow \overline{B}^0,\ \Delta m\,(\phi_M = -\beta)$
$B \to K^*\gamma + \rho/\omega\,\gamma$

★ measure $\sin 2\beta$ in decay modes sensitive to different short-distance physics

$B \to J/\psi\,K^0_S$	$b \to c\,\bar{c}\,s$
$B \to J/\psi\,\pi^0$ $B \to D^{*\pm}D^\mp$ $B \to D^{*+}D^{*-}$	$b \to c\,\bar{c}\,d$
$B \to \phi\,K^0_S$ $B \to K^0_S K^0_S K^0_S$	$b \to s\,\bar{s}\,s$
$B \to \eta'\,K^0_S$ $B \to f_0 K^0_S$ $B \to K K K^0_S$	
$B \to \pi^0 K^0_S$ $B \to \omega K^0_S$	$b \to q\bar{q}s$

Physics at the Υ(4S)

The Υ(4S) Region



The cleanest way
to produce B mesons

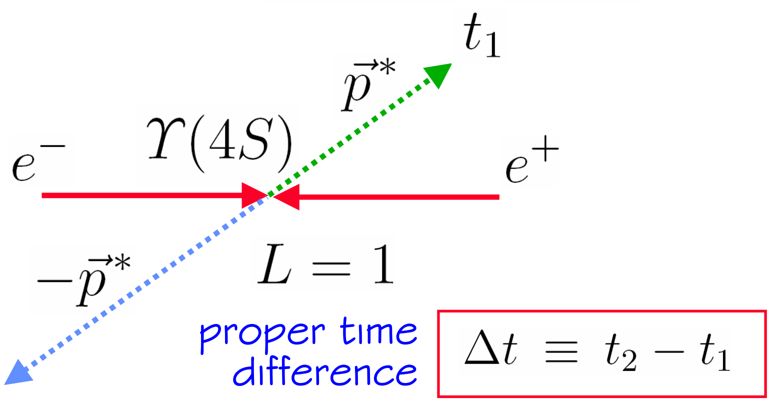
e^+e^- collisions around

$$\sqrt{s} = 10.58\,\mathrm{GeV}$$

production of $B\overline{B}$ pairs
with a cross section of ~1 nb
over a continuum of ~3 nb

$$50\%/50\%$$
$$B^+B^- \,\&\, B^0\overline{B}^0$$

$$e^+e^- \rightarrow \Upsilon(4S) \rightarrow B^0\overline{B}^0$$



proper time difference

$$\Delta t \equiv t_2 - t_1$$

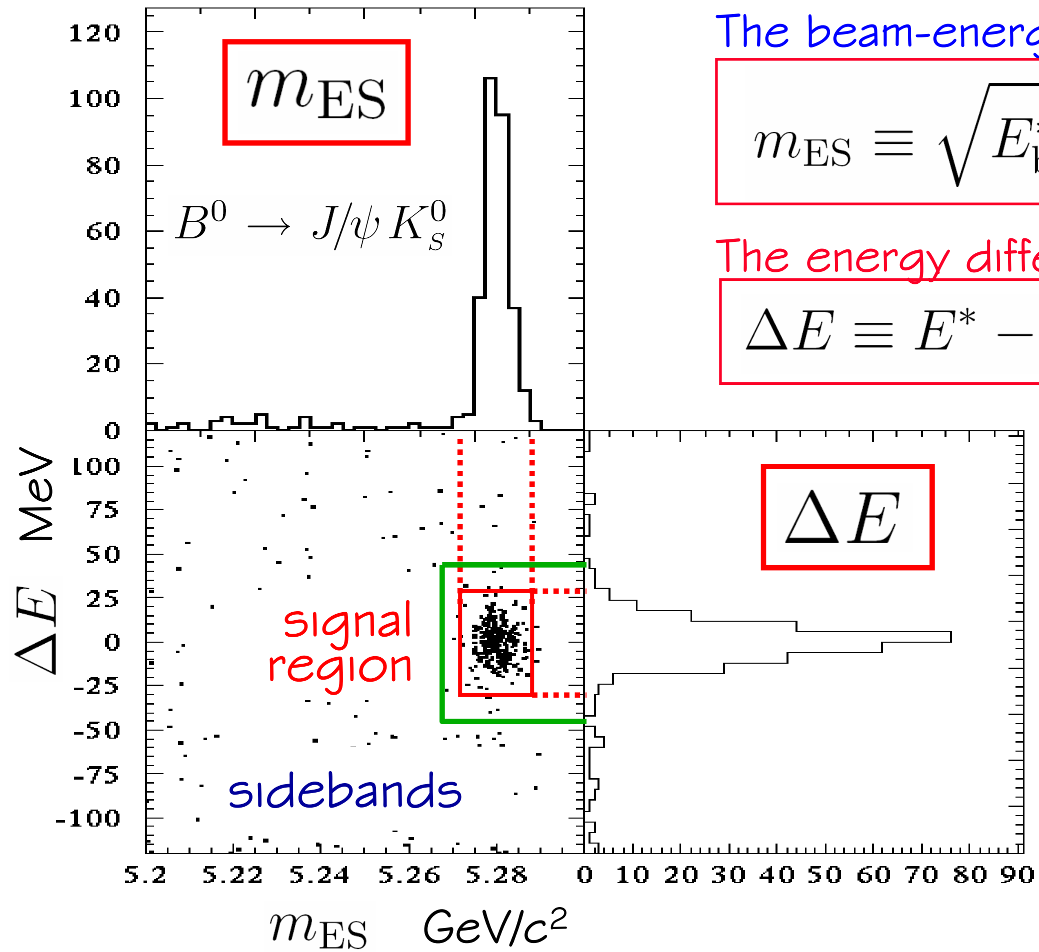
Quantum coherence

- *antisymmetric* wave function
- $\Delta t = 0$: one B^0 and one $\overline{B}^0$
  - ➡ flavor tagging
- Δt required for *CP* measurements
- measurement of Δt :
  - boost the CoM frame
  - ➡ asymmetric-energy beams

Kinematics at the Υ(4S)

Reconstruction of a B candidate
(from tracks and clusters in the event)

Lab frame $P = (E, \vec{p})$ **Boost** → CoM frame $P^* = (E^*, \vec{p}^*)$



The beam-energy substituted mass

$$m_{\rm ES} \equiv \sqrt{{E^*_{\rm beam}}^{2} - p^{*\,2}}$$

with

$$E^*_{\rm beam} = \sqrt{s}/2$$

(half-CoM energy)

The energy difference

$$\Delta E \equiv E^* - E^*_{\rm beam}$$

two largely *independent* analysis variables

$$\sigma_{m_{ES}} \approx 2.6\,{\rm MeV}/c^2$$

dominated by beam energy spread

$$\sigma_{\Delta E} \approx 10 \leftrightarrow 40\,{\rm MeV}$$

dominated by energy resolution

Time-Dependent Analyses

Differential Event Rates

- final state f

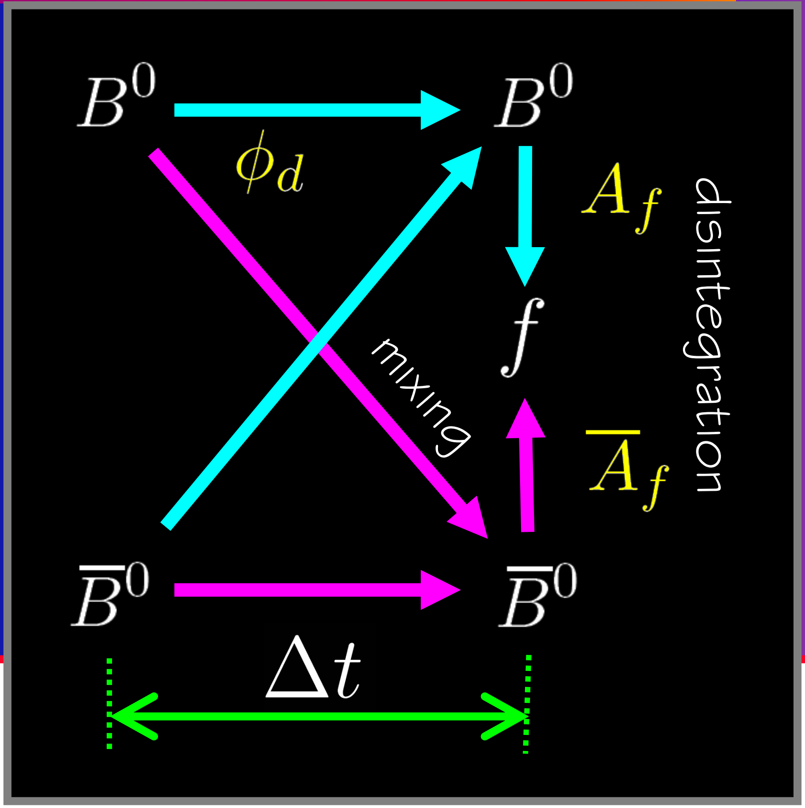
interference parameter (observable)

$$\lambda_f \equiv e^{-2i\phi_d}\frac{\overline{A}_f}{A_f}$$

$\phi_d \simeq \beta$ (usual phase convention)

- define C and S coefficients:

$$C_f \equiv \frac{1-|\lambda_f|^2}{1+|\lambda_f|^2} \quad \text{and} \quad S_f \equiv \frac{2\,\mathrm{Im}\lambda_f}{1+|\lambda_f|^2}$$



- differential event rate

$$\frac{d}{d\Delta t}\mathcal{N}\left(f, tag = B^0/\overline{B}^0\right) \propto \frac{1}{\Gamma}e^{-\Gamma|\Delta t|}\left\{1 \mp C_f \times \cos\left(\Delta m_d \Delta t\right) \pm S_f \times \sin\left(\Delta m_d \Delta t\right)\right\}$$

2 special cases

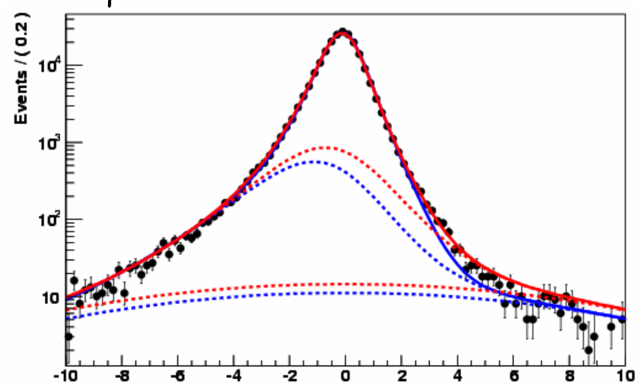
- f is a *CP eigenstate*: $|\lambda_f| \approx 1$ ➡ $C_f \approx 0$ and $S_f \neq 0$
- f is *flavor specific*: $|\lambda_f| \approx 0$ ➡ $C_f \approx 1$ and $S_f \approx 0$

Foundations of Time Measurements

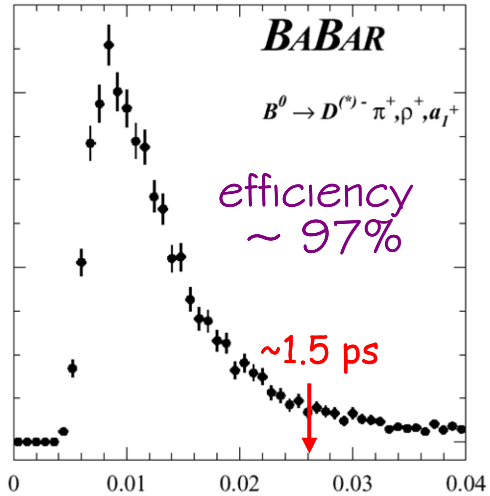
event-by-event vertex errors

Δt resolution function

shape from signal MC, parameters from data

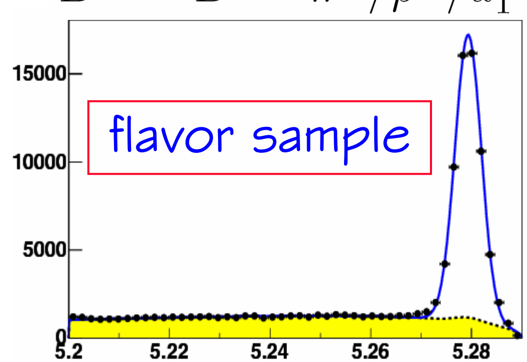


$(\Delta t_{meas} - \Delta t_{true})/\sigma(\Delta t)$



$\sigma(\Delta z)$ [cm]

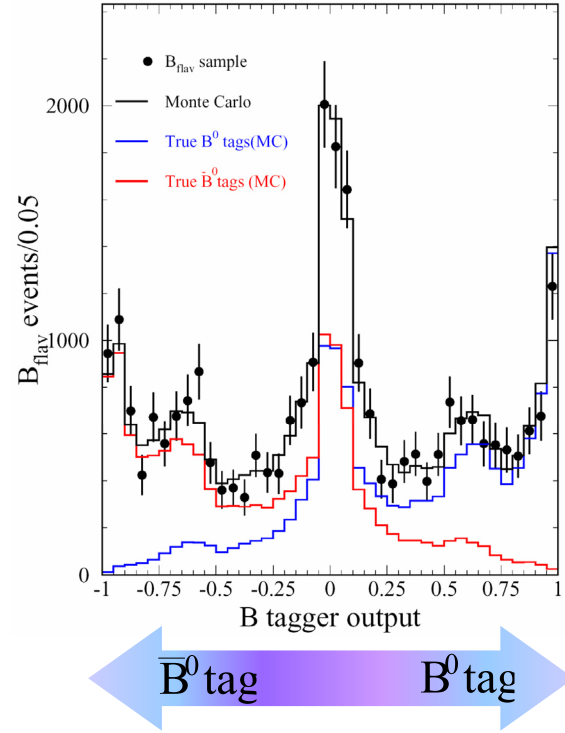
$B^0 \to D^{(*)-}\pi^+/\rho^+/a_1^+$



m_{ES} [GeV/c^2]

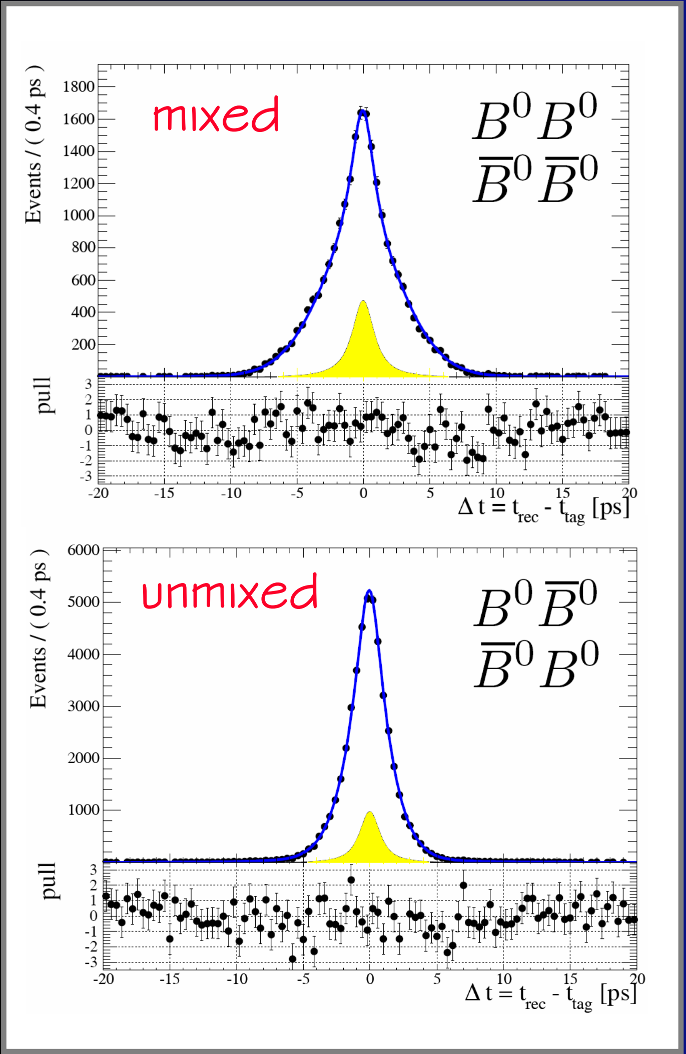
tagging

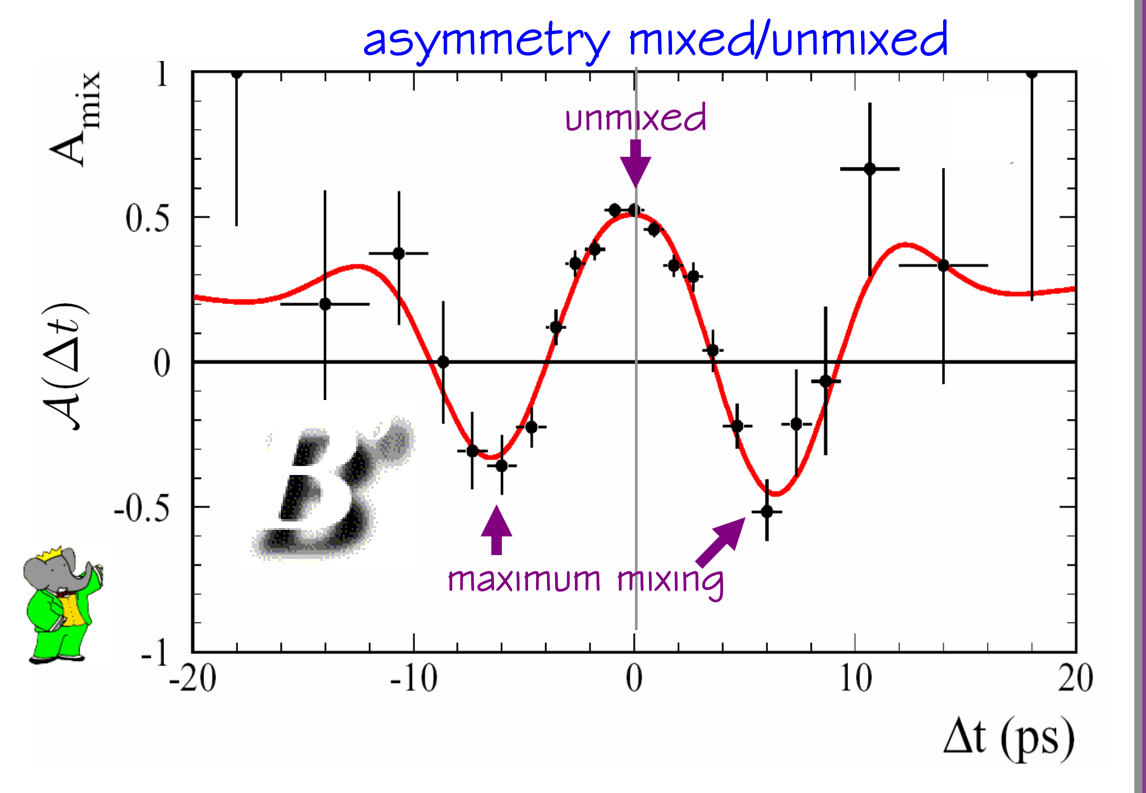
effective efficiency 30% measured on data



- Flavor control sample: 72 878 events
- *CP* sample for $\sin 2\beta$: 7 730 events

Flavor Oscillations

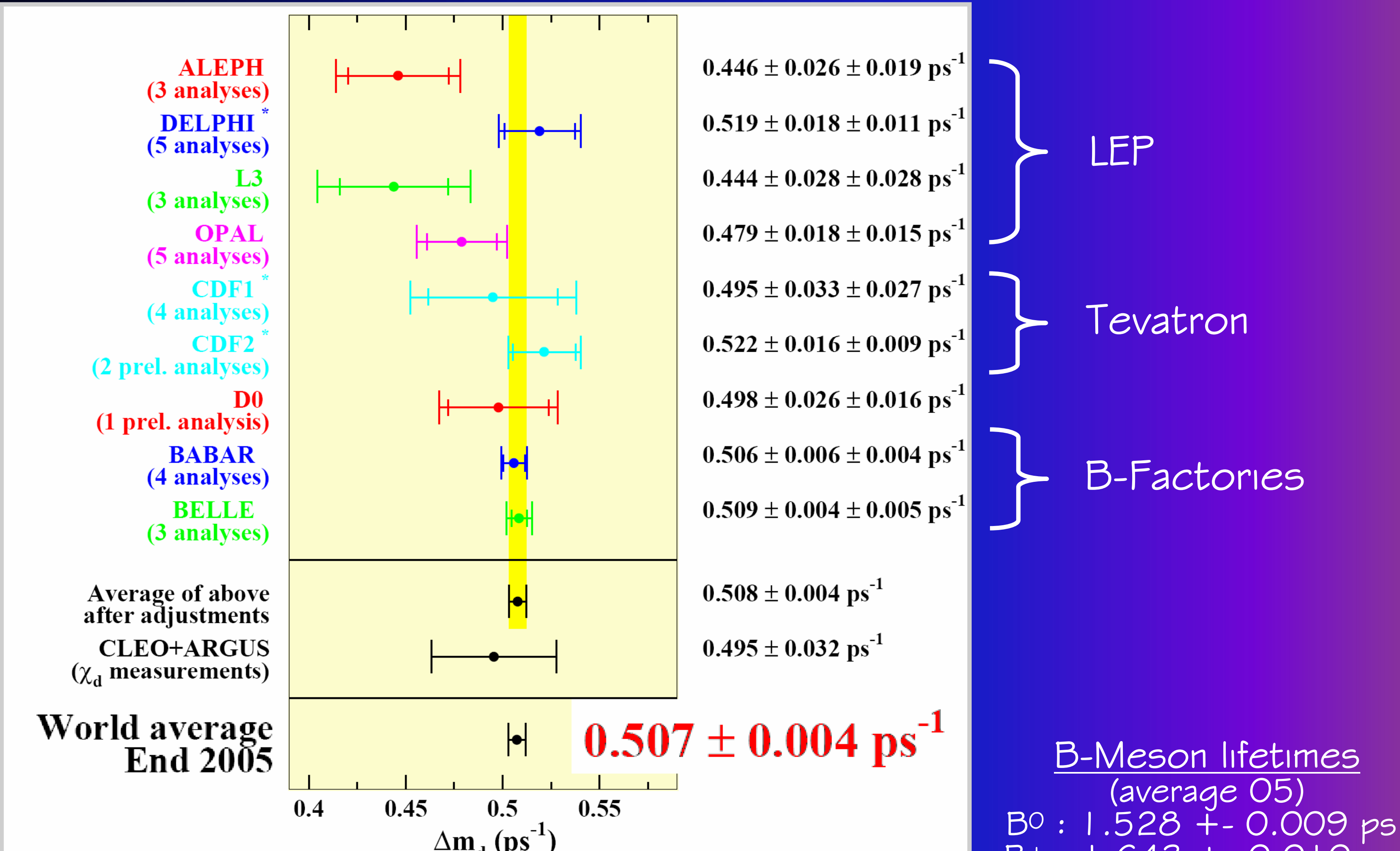




$$\mathcal{A}(\Delta t) \simeq \{(1-2\omega) \times \cos(\Delta m_d \Delta t)\} \otimes \mathcal{R}(\Delta t)$$

½ period ~ 6 ps
~ 4 B-meson lifetimes

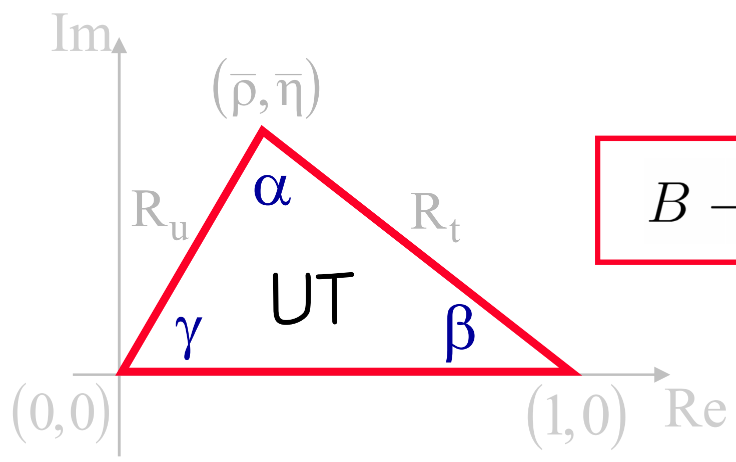
Mixing Measurements



B-meson lifetime and flavor-oscillation frequency
- TD techniques developed at LEP & Tevatron
- average dominated by B-factories measurements

B-Meson lifetimes
(average 05)
B^0 : 1.528 +- 0.009 ps
B^+ : 1.643 +- 0.010 ps
ratio : 1.076 +- 0.008

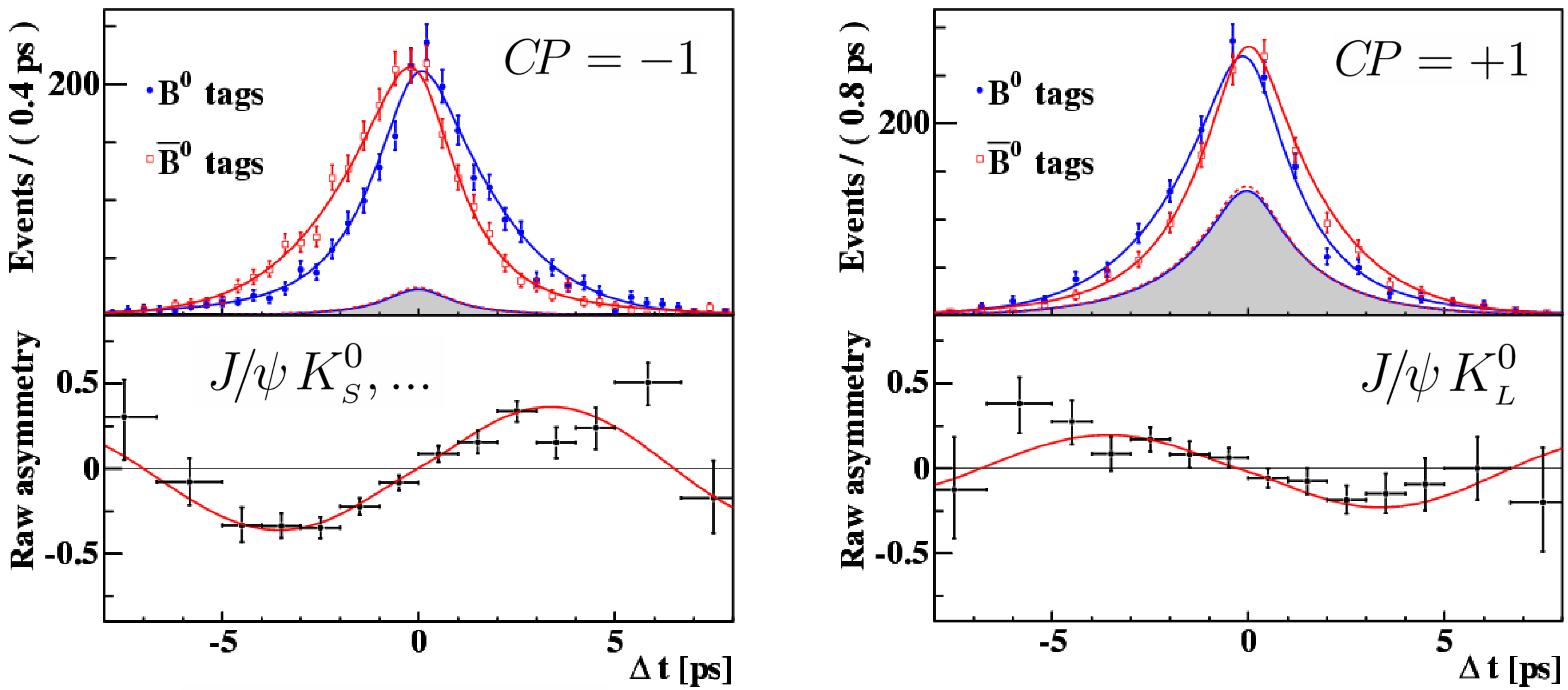
Measurement of β



$B \to J/\psi\ K_S^0$ and friends

A Precision Measurement

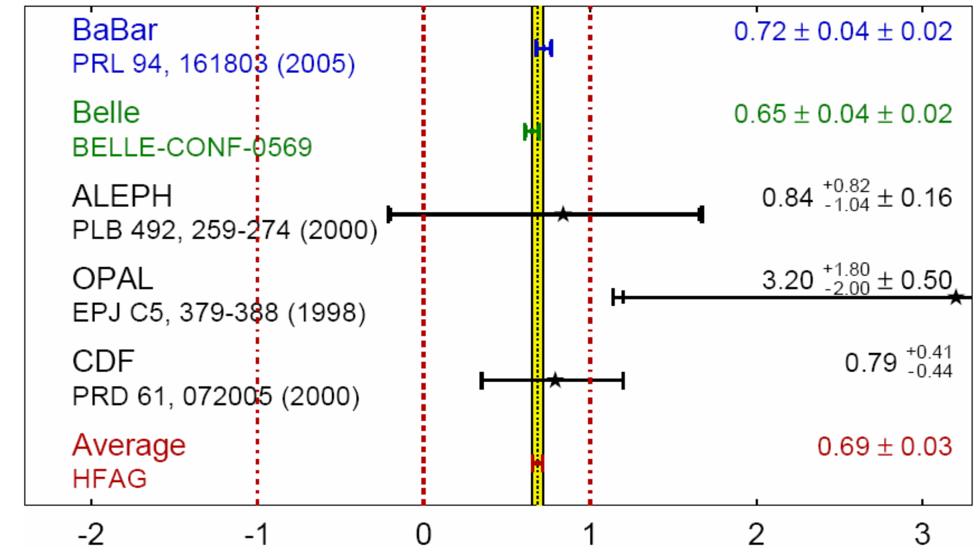
$$\mathcal{A}(\Delta t) \simeq \{(1-2\omega) \times \mathrm{Im}\,\lambda_{f_{CP}} \times \sin(\Delta m_d\, \Delta t)\} \otimes \mathcal{R}(\Delta t)$$



$$\lambda_{J/\psi\, K^0_S} = -\, e^{-2i\,\beta} \qquad \lambda_{J/\psi\, K^0_L} = +\, e^{-2i\,\beta}$$

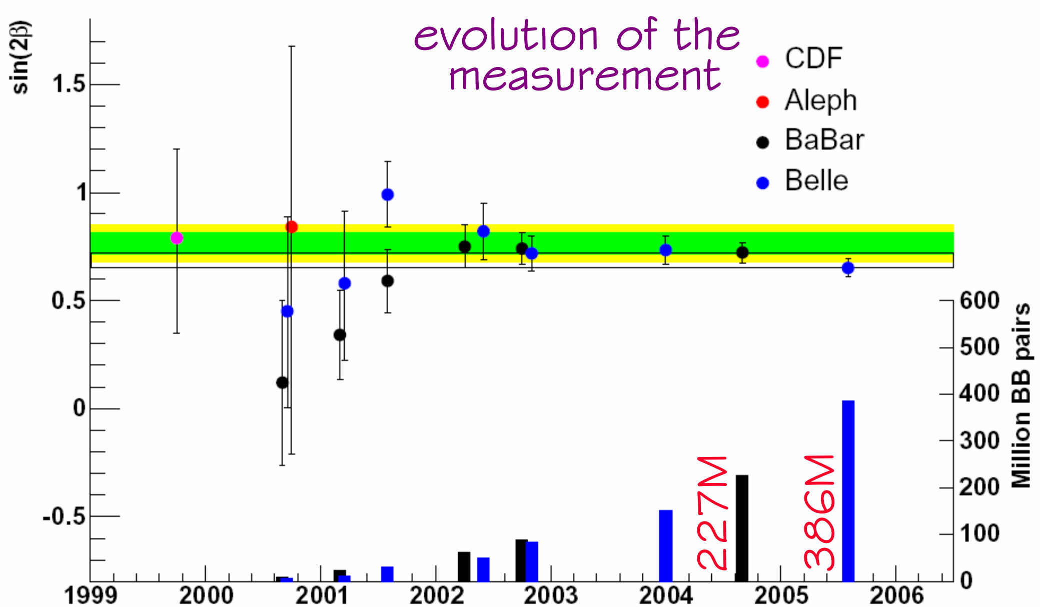
BABAR $\quad \sin 2\beta = 0.722 \pm 0.040\,(\mathrm{stat}) \pm 0.023\,(\mathrm{syst})$

PRL 94, 161803 (2005), (hep-ex/0408127)

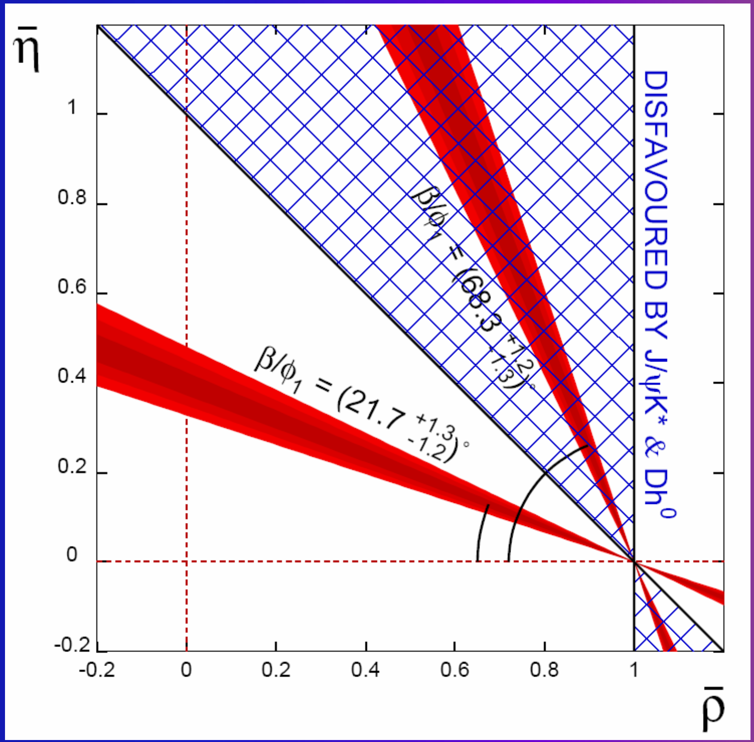


$$\text{BABAR} \quad \sin 2\beta = 0.722 \pm 0.040\,(\text{stat}) \pm 0.023\,(\text{syst})$$

$$\text{Belle} \quad \sin 2\beta = 0.652 \pm 0.039\,(\text{stat}) \pm 0.020\,(\text{syst})$$



latest



"non-SM solution" disfavored:

★ $B \to J/\psi\, K^*$

→ sensitive to cos2β

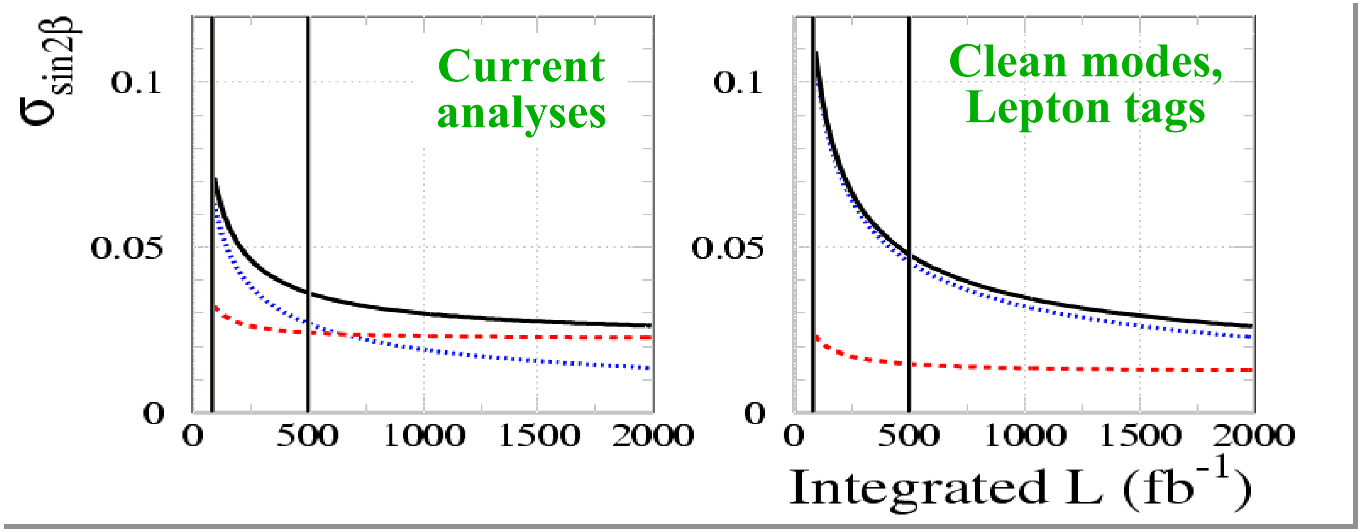
(BABAR 04: angular analysis + study of S/P-wave interference)

★ $B \to D[\to K_S^0 \pi^+ \pi^-]\pi^0$

→ direct extraction of 2β

(Belle 05: β ∈ [-30°,62°] @ 95% C.L.)

sin2β at High Luminosity

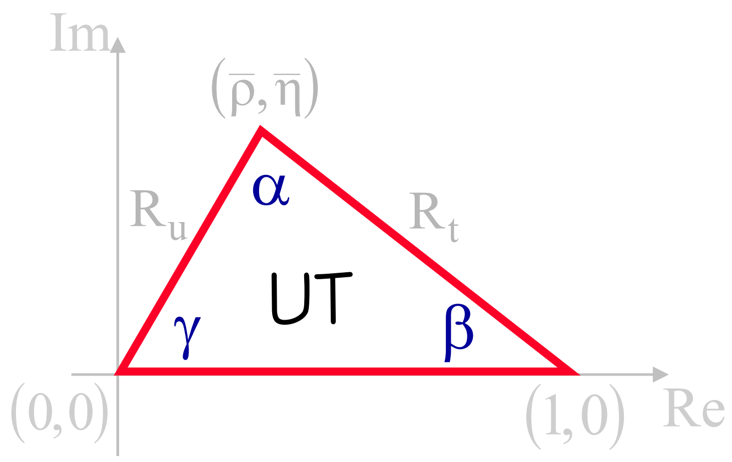


	Current analyses			Clean modes, Lepton tags		
Integrated L (fb^{-1})	**81**	**500**	**2000**	**81**	**500**	**2000**
Statistical error	**0.067**	**0.028**	**0.013**	**0.113**	**0.047**	**0.022**
Systematic error	**0.034**	**0.024**	**0.022**	**0.025**	**0.015**	**0.012**
Total error	0.075	0.037	0.026	0.116	0.049	0.025

today

Measurements of Angle α

$$B \to \pi^+\pi^-$$
$$B \to \rho^\pm\pi^\mp$$
$$B \to \rho^+\rho^-$$



Charmless 2-Body

- ★ B → ππ : historically (perhaps *ultimately* ?) the best way to measure sin2 α
- ★ if Tree amplitudes dominate

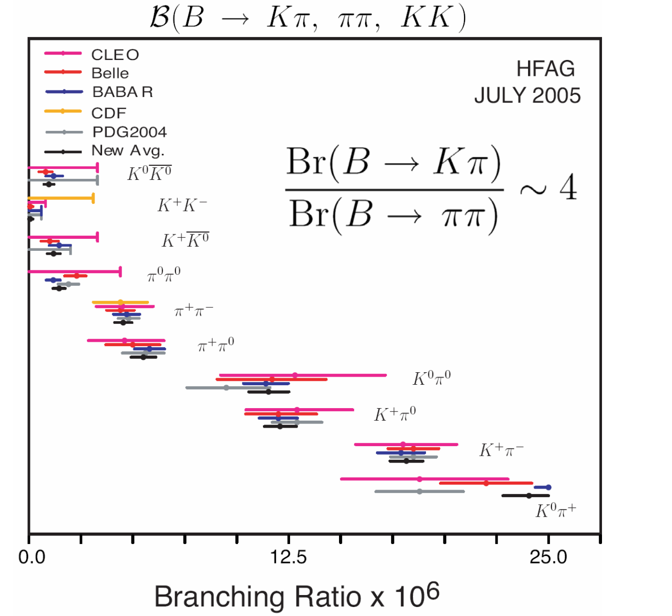
$$\lambda^{\text{tree}}_{\pi^+\pi^-} = +e^{-2i(\beta+\gamma)} = e^{2i\alpha}$$

$$\Rightarrow \quad S^{\text{tree}}_{\pi^+\pi^-} = \sin 2\alpha$$

- ★ if Gluonic Penguin amplitude contributes

⇒ need to estimate $\Delta\alpha \equiv \alpha_{\text{eff}} - \alpha$

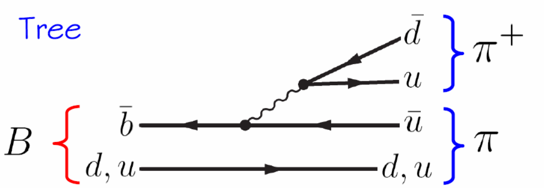
e.g. isospin analysis (Gronau-London)



$$\frac{\text{Br}(B \to K\pi)}{\text{Br}(B \to \pi\pi)} \sim 4$$

B → ππ

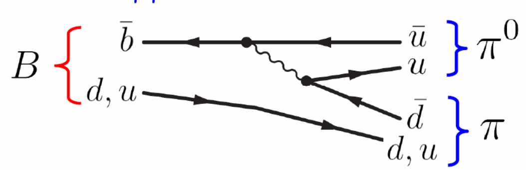
⇒ Tree



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

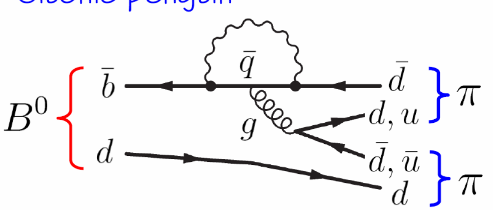
$V_{ud}V^*_{ub}$

⇒ Color-suppressed tree



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

⇒ Gluonic penguin

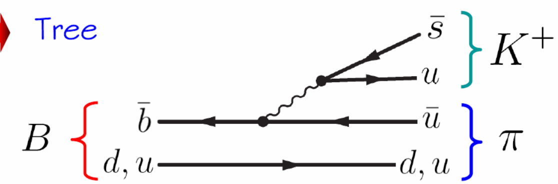


$V_{qd}V^*_{qb}$
$q = u, c, t$

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

B → Kπ

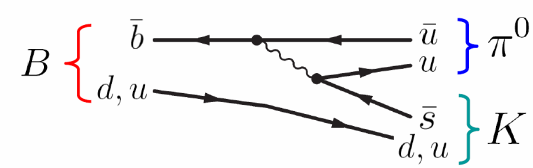
⇒ Tree



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

$V_{us}V^*_{ub}$

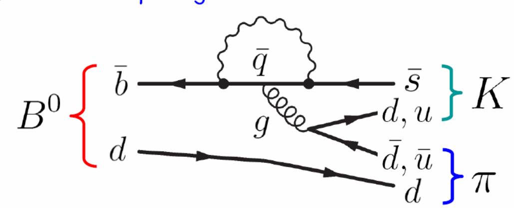
⇒ Color-suppressed tree



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

⇒ Gluonic penguin

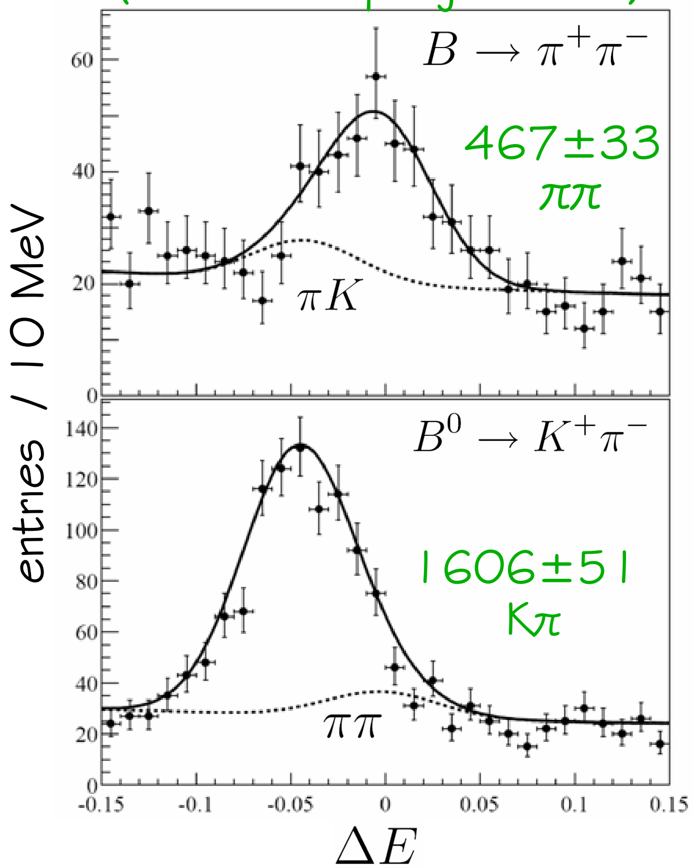
$V_{qs}V^*_{qb}$
$q = u, c, t$



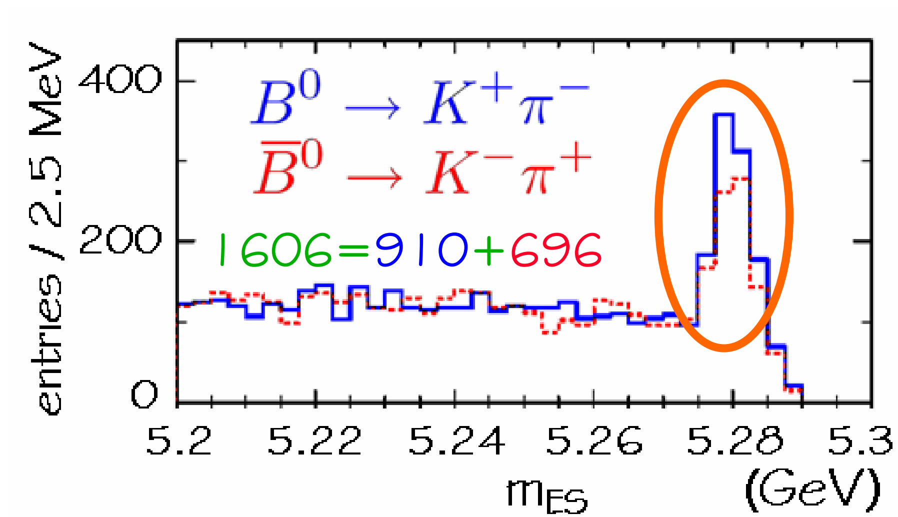
$B^0 \to K^+\pi^-$
$B^0 \to K^0\pi^0$
$B^+ \to K^+\pi^0$
$B^+ \to K^0\pi^+$

Penguins at Work

(likelihood projections)



Observation of Direct *CP* Violation



$$\mathcal{A}_{K\pi} = -0.133 \pm 0.030 \pm 0.009$$

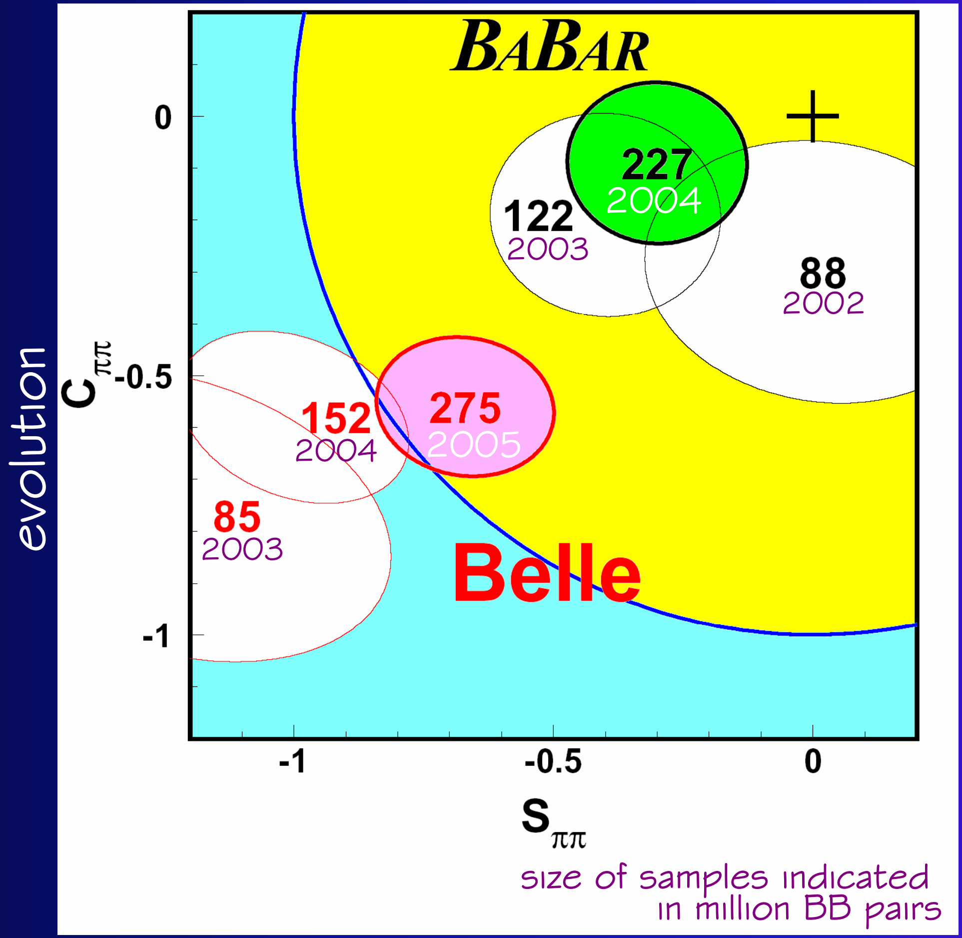
(a 4.2 sigma effect)

Spectacular manifestation of <u>tree-penguin interference</u>

One can not ignore penguin amplitudes in $B \to \pi\pi$ … $|P/T| \sim 30\%$

$C_{\pi^+\pi^-} \neq 0$ and $S_{\pi^+\pi^-} = \sqrt{1 - C^2_{\pi^+\pi^-}}\ \sin 2\alpha_{\rm eff}$

CP results in $\pi\pi$

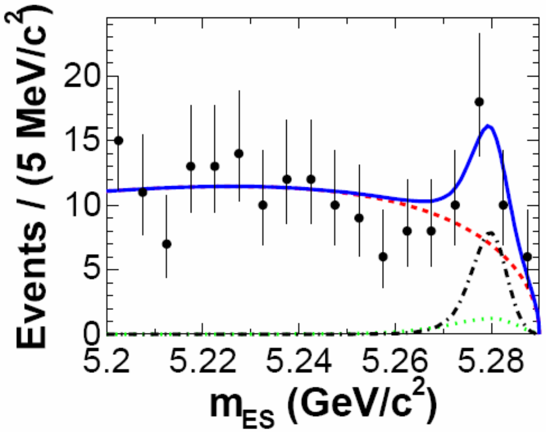


- ★ Belle and BABAR in marginal agreement (2.3σ)
- ★ Belle observes significant direct CP violation in this mode while BABAR result is consistent with no CP violation

Worst Case Scenario for α ?

★ Observation of $B \to \pi^0\pi^0$

(5 sigma significance)



★ $\pi^0\pi^0$ rate

- much too large to obtain a useful Grossman-Quinn limit

$$|\Delta\alpha| < 35^o\ (90\%\ \mathrm{C.L})$$

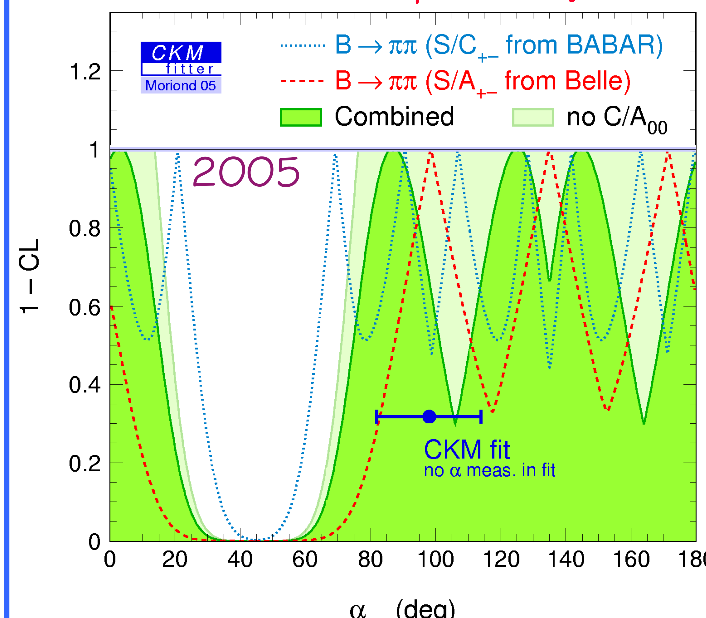
- much too small for a precise direct-*CP* measurement …

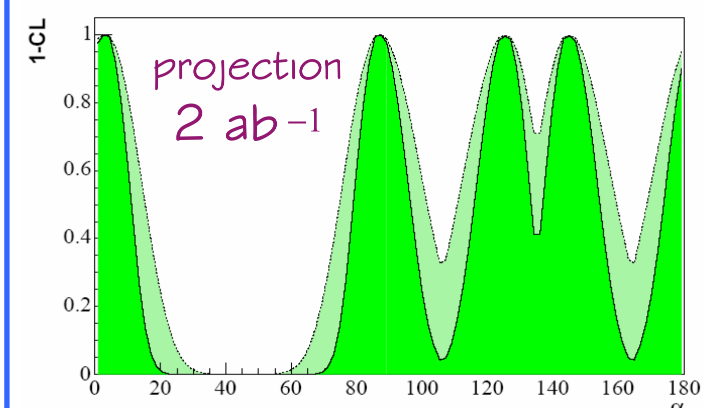
New hope for α : combination of $B \to \rho^+\rho^-$ and $B \to \rho\pi$ modes!

★ Issues to be resolved with more data

- direct *CP* Violation in $\pi^+\pi^-$?
- $\pi^0\pi^0$: factor ~2 discrepancy with Belle ?

poor constraints on angle α from full isospin analysis



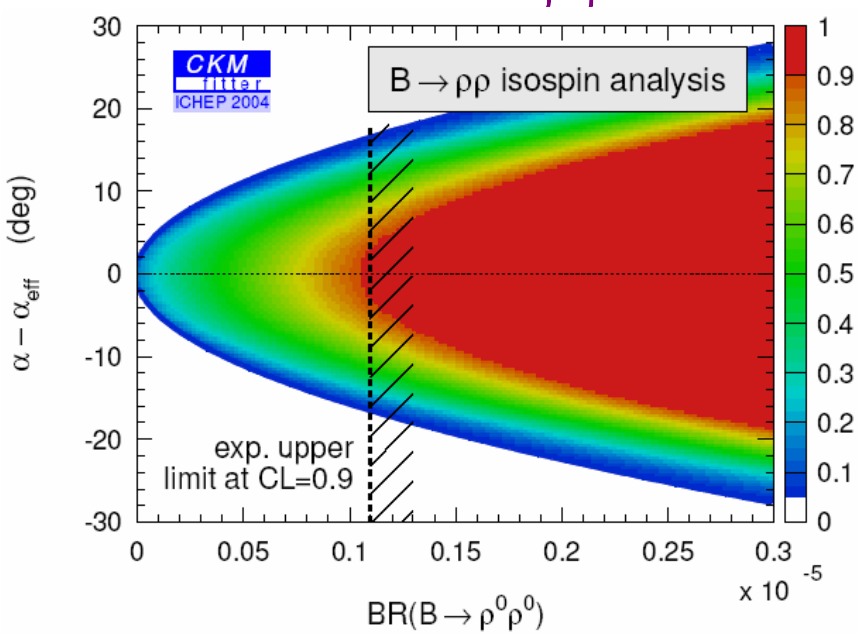


Why is ρρ so Promising for α ?

- the final state is a mixture of CP-even and CP-odd
  in principle this complicates the isospin analysis
- BUT the data show that CP-even (longitudinal polarization) dominates
- small rate of $B \to \rho^0\rho^0$ indicates much smaller penguin "pollution"

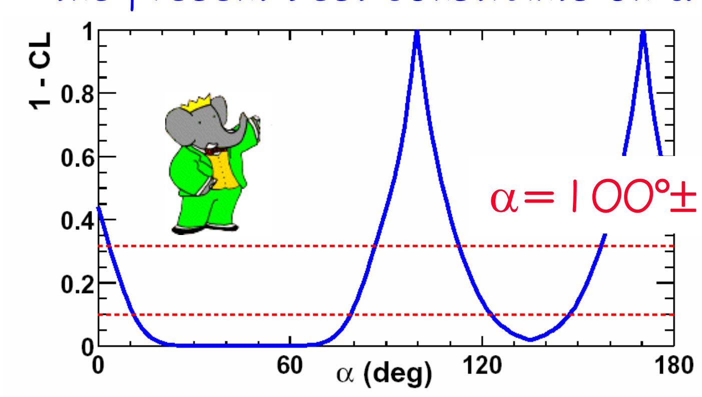
→ while $\pi^0\pi^0$ is of order 30% of $\pi^+\pi^-$
$\rho^0\rho^0$ is smaller than 4% of $\rho^+\rho^-$ (at 90%CL)

BABAR, PRL 94, 131801 (2005)



Br($B \to \rho^0\rho^0$) < 1.1×10^{-6} (90% CL)

with reasonable theoretical assumptions this mode provides the present best constraints on **α**



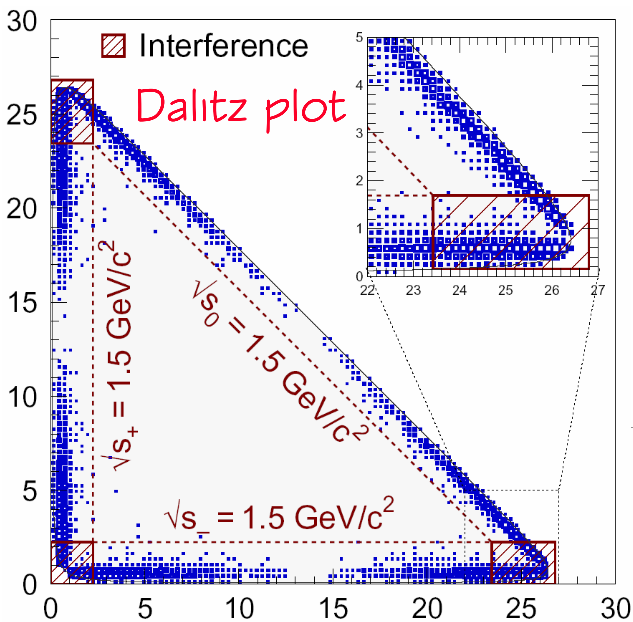
α=100°±13°

79°< α <123° @ 90% CL

PRL 95, 041805 (2005)

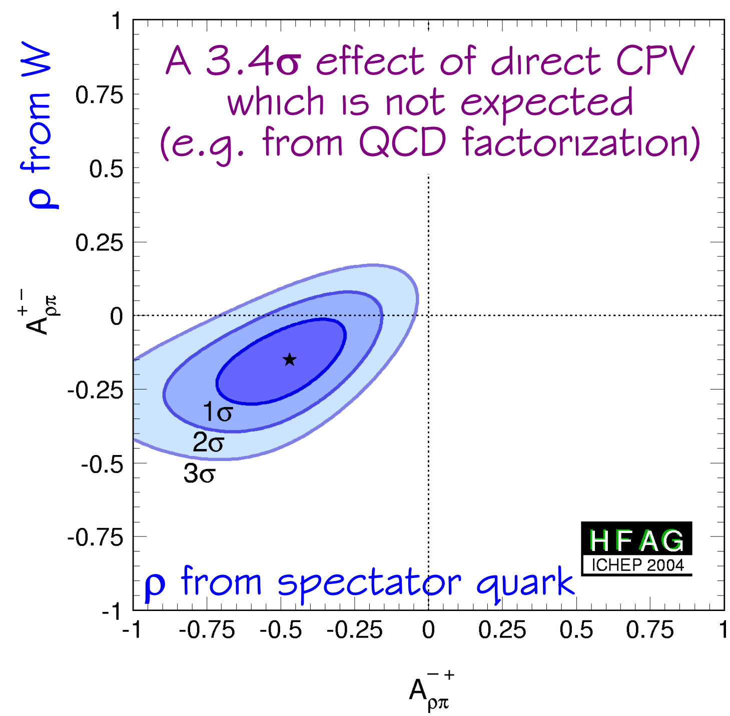
The $B \to 3\pi$ Analysis

★ The three-pion final state is dominated by the transitions through a ρ meson

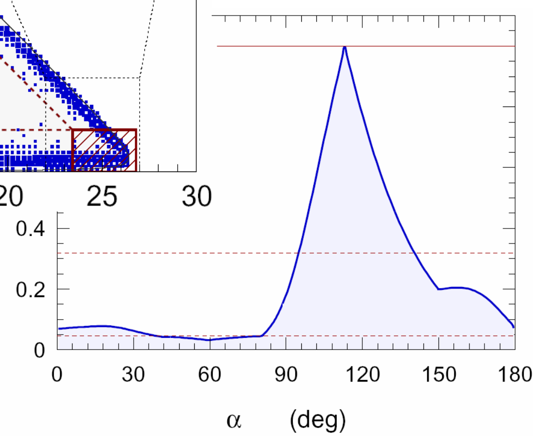


interfering contributions from $\rho^+\pi^-$, $\pi^+\rho^-$ (and $\rho^0\pi^0$)

➡ full time-dependent Dalitz analysis (Snyder-Quinn method)



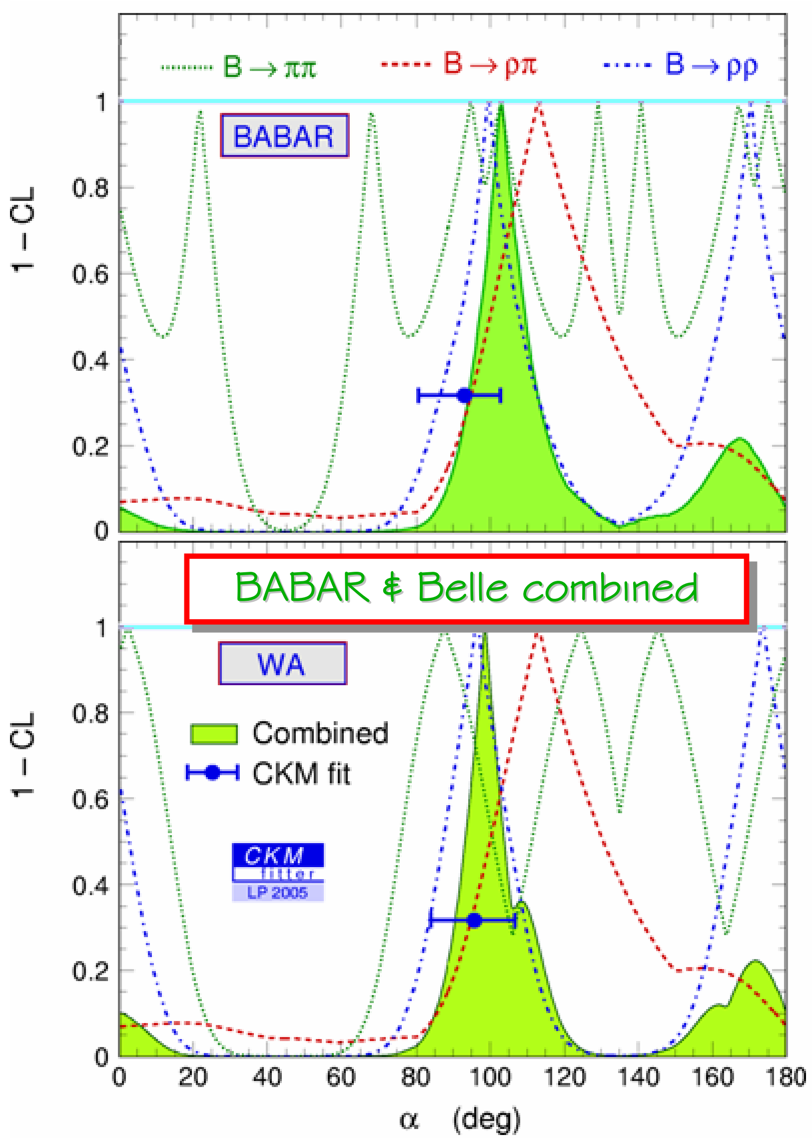
BW phase variations break degeneracy in solutions



Already interesting constraints on angle α and an evidence for direct CPV

$\alpha = (113^{+27}_{-17} \pm 6)^\circ$

The α Program is just Starting!



Constraints from $\pi\pi$, $\rho\pi$ and $\rho\rho$

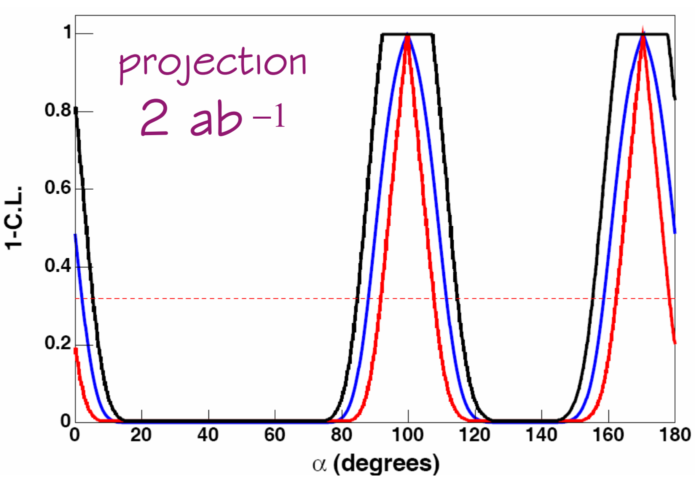
$$\alpha = \left(100\,^{+\,9}_{-10}\right)^{\circ}$$

CKM Constraints

$$\alpha = (\,98 \pm 16\,)^{\circ}$$

With more statistics:

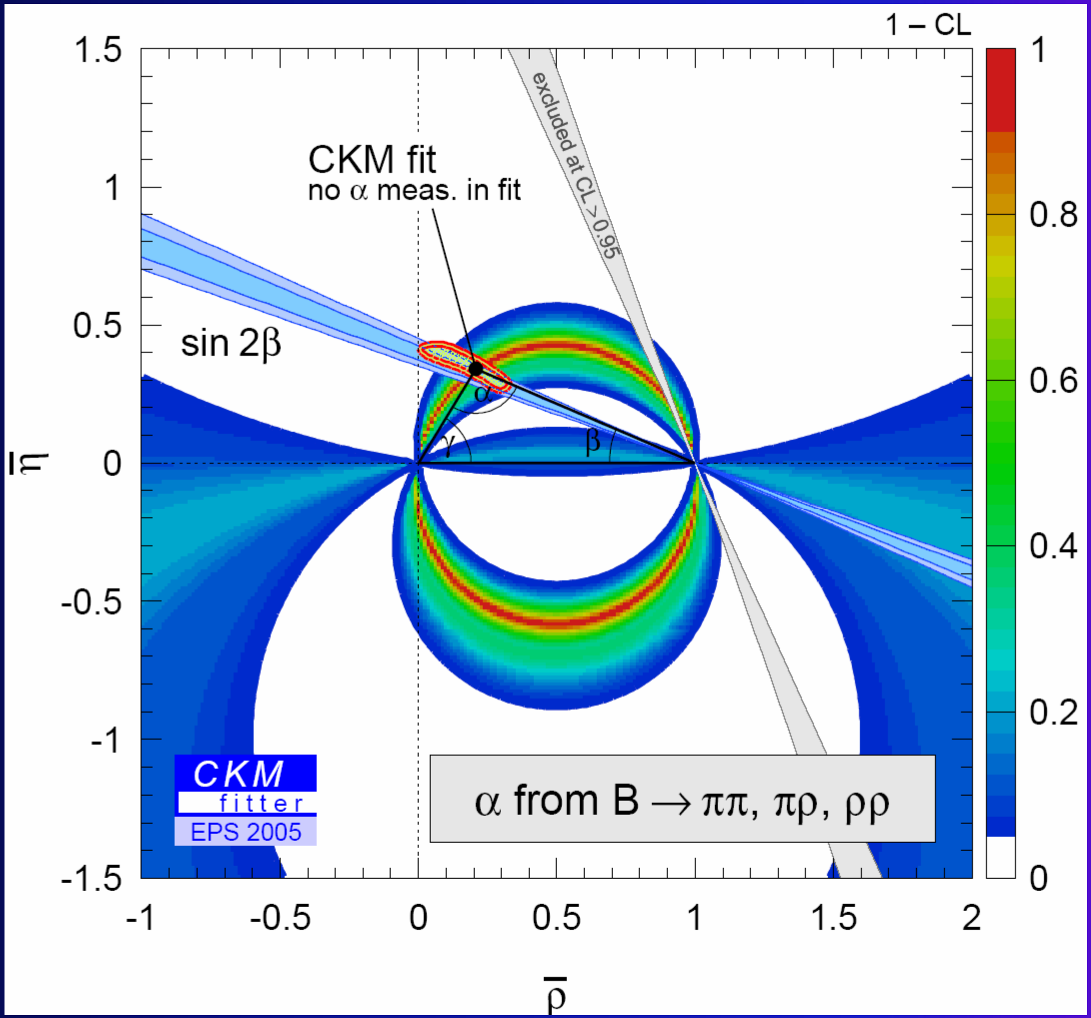
- observe $B \to \rho^0\rho^0$
- improve S and C in $B \to \rho\rho$
- confirm that "mirror solution" in $B \to \rho\rho$ is disfavored by Dalitz analysis in $B \to \rho\pi$
- investigate direct CPV effect in $B \to \rho\pi$



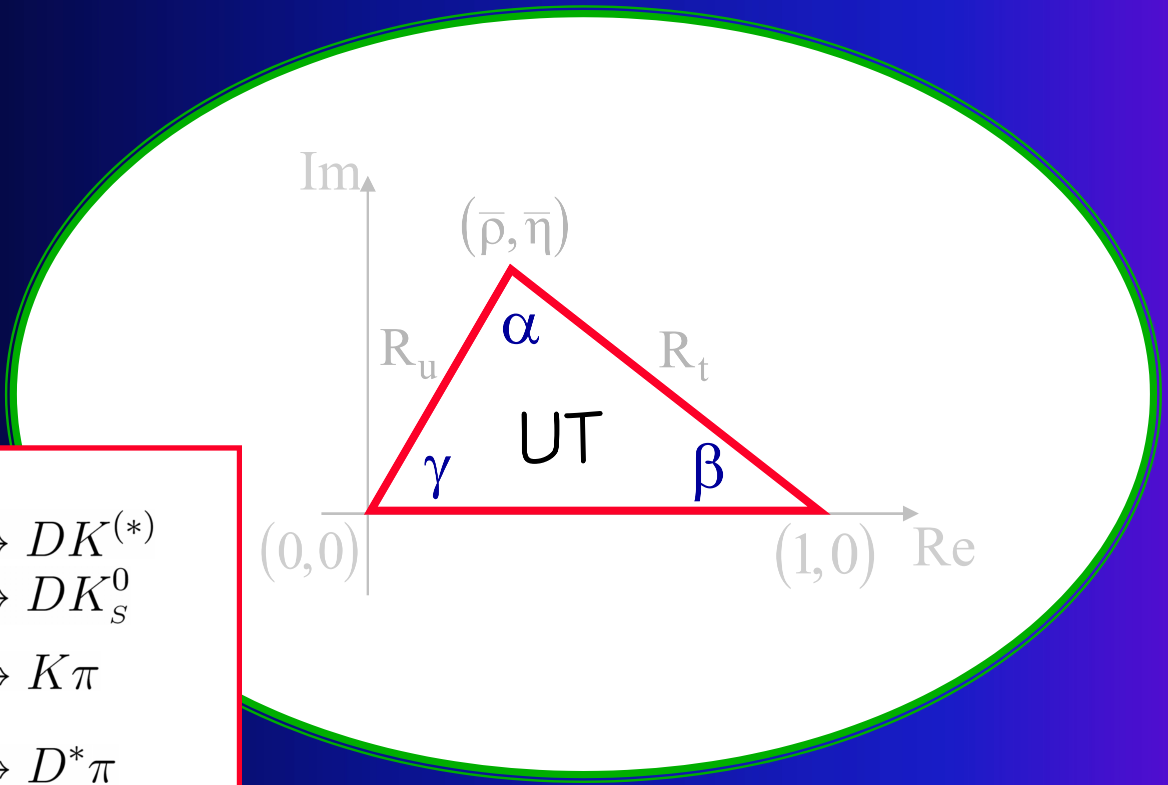
3 scenarios for $\rho^0\rho^0$

- central
- $+1\sigma$
- -1σ

Constraints on α in the (ρ, η) Plane



Measurements of Angle γ



$B \to DK^{(*)}$
$B \to DK_s^0$

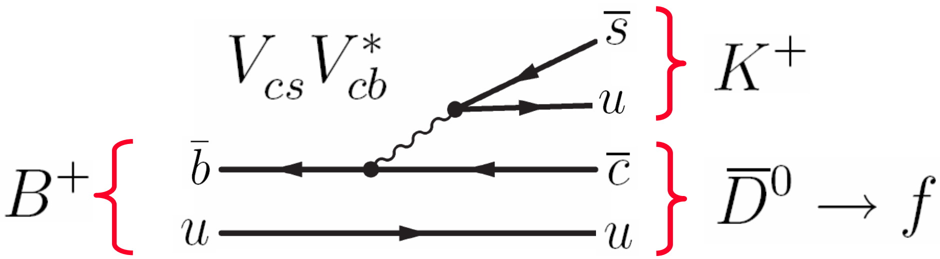
$B \to K\pi$

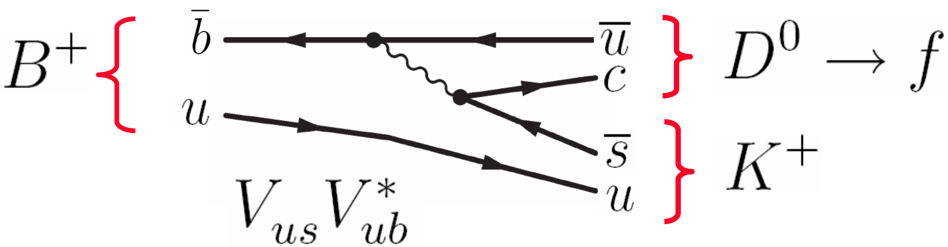
$B \to D^*\pi$

Methods to Measure Angle γ

Basic Idea

use *interference* between tree decays
Cabibbo-suppressed $(b \to c)$ $B^+ \to$ anti-$D^0 K^+$ and
CKM- and color-suppressed $(b \to u)$ $B^+ \to D^0 K^+$,
where the D^0 and the anti-D^0 decay to a common final state





only tree diagrams:
no issue with
new physics in loops

$$r_B \equiv A(b \to u)/A(b \to c)$$
$$\approx 0.39 f_c \sim 0.1 - 0.3$$

color factor

interference parameter

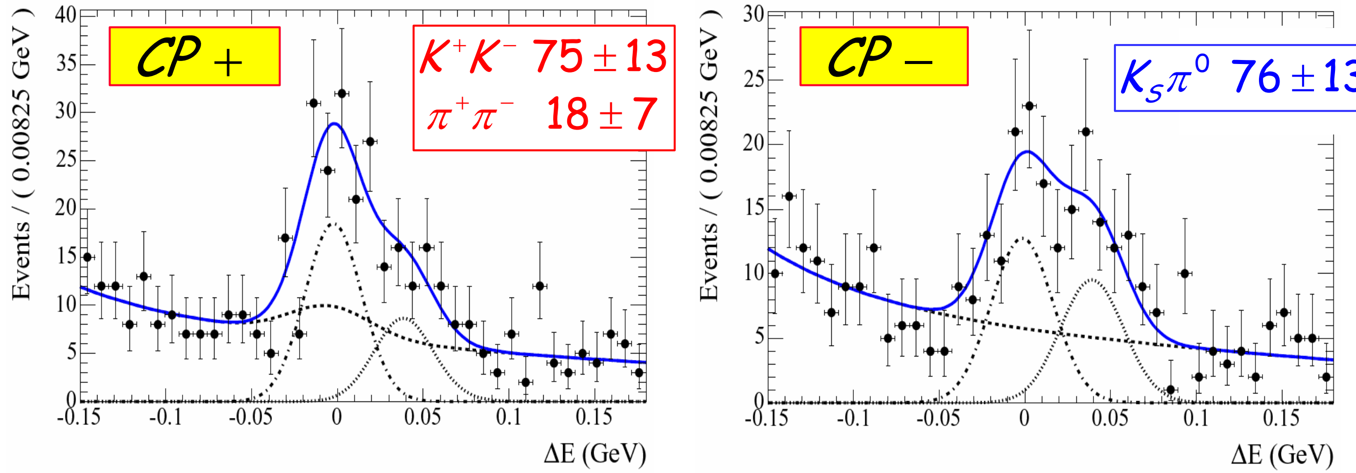
$$R = r_B \frac{A(D^0 \to f)}{A(\overline{D}^0 \to f)}$$

- GWL (Gronau-Wyler-London) — f is a CP eigensate
- ADS (Atwood-Dunietz-Soni) — $\overline{D}^0 \to f$ is doubly-Cabibbo suppressed
- GGSZ (Giri-Grossman-Soffer-Zupan) — $D^0(\overline{D}^0) \to K_S^0 \pi^+ \pi^-$ (interference in Dalitz plot)

GWL & ADS, First Analyses

★ Gronau-Wyler-London (GWL) Method $B \to D_{CP} K$

- small interference
- sensitivity to γ
- no sensitivity to r_B



★ Atwood-Dunietz-Soni (ADS) Method

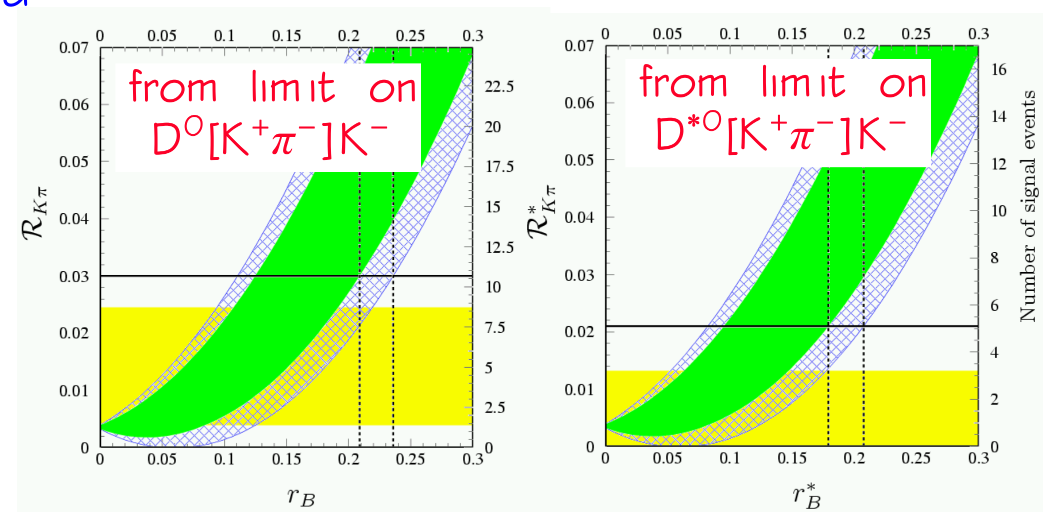
- larger interference
- unknown D relative strong phase
- sensitivity to r_B

$$R_{K\pi}^{(*)} = \frac{Br(D^{(*)0}[K^+\pi^-]K^- + c.c.)}{Br(D^{(*)0}[K^-\pi^+]K^- + c.c.)} \sim r_B^{(*)2}$$

➡ no observation yet – set limits

$r_B^2 < 0.23$ (90% C.L)

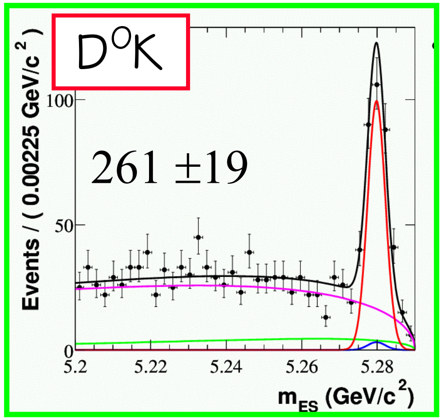
$r_B^{*2} < 0.21$ (90% C.L)



Analysis of $B^- \to D^{(*)0}[\to K^0_S\pi^+\pi^-]K^-$

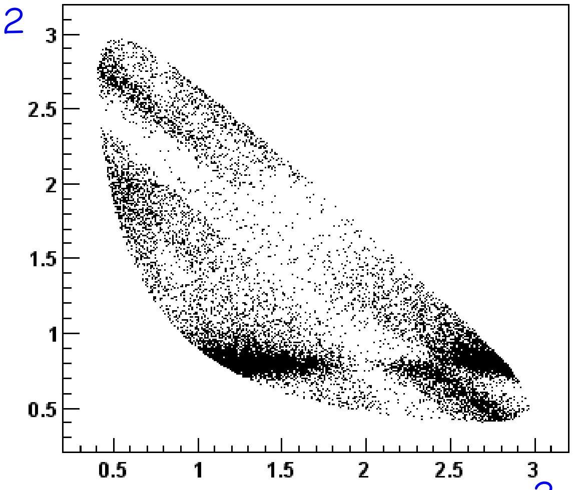
★ Giri-Grossman-Soffer-Zupan (GGSZ) method

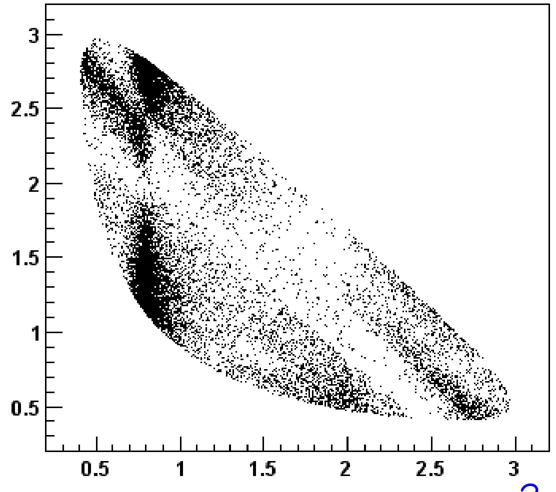
- exploit interference pattern in Dalitz plot
- in principle sensitivity to both γ and r_B
- a two-fold ambiguity remains in the extraction of γ



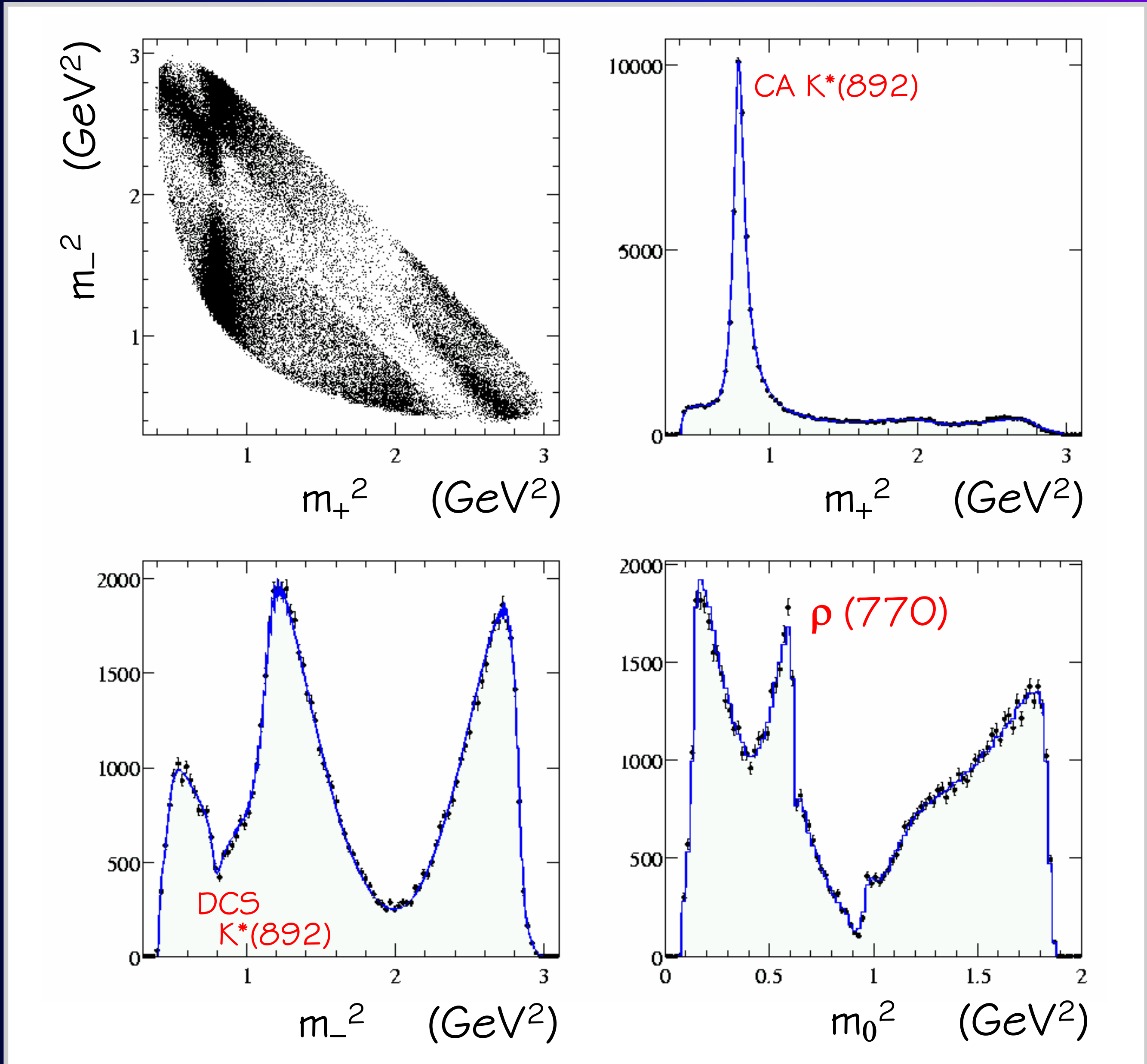
➡ *schematic* view of the interference

$$|A_\mp|^2 = \left| \text{[Dalitz plot]} + r_B\, e^{i(\gamma\pm\delta)} \text{[Dalitz plot]} \right|^2$$

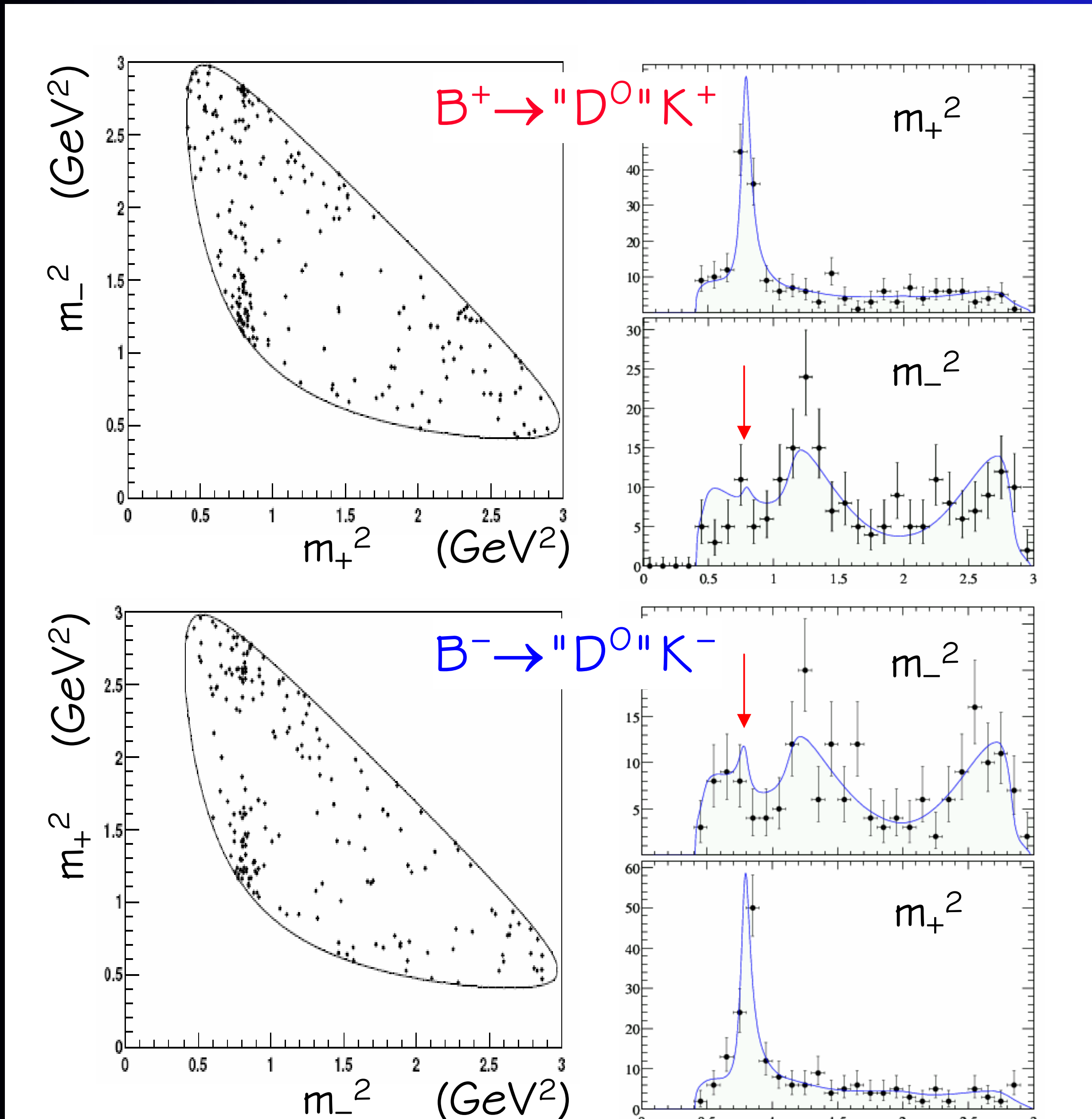




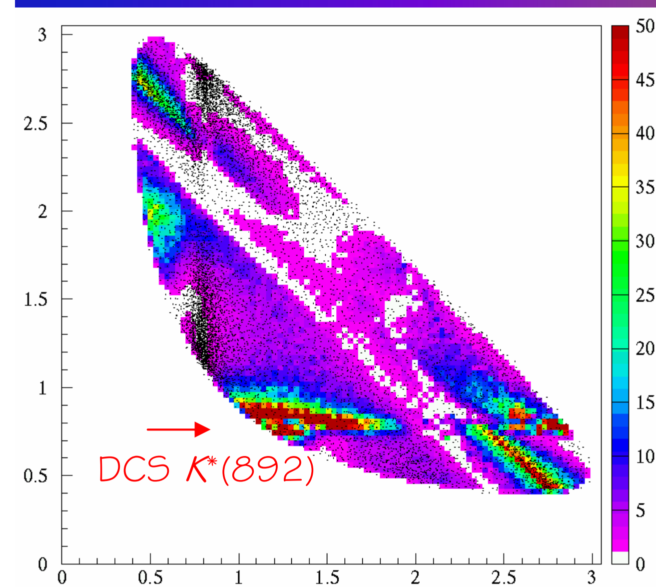
Dalitz Amplitudes from the D Sample



Dalitz Plots and Projections



sensitivity on γ across the Dalitz Plot

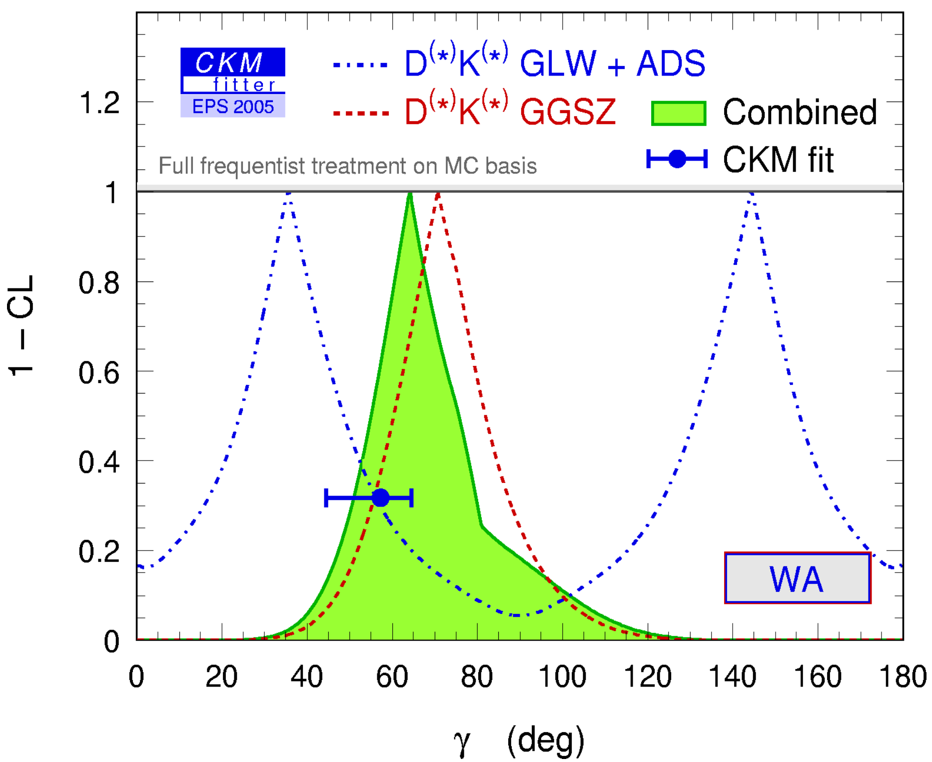


Large statistics is needed for this method!

γ from B → DK (all methods)

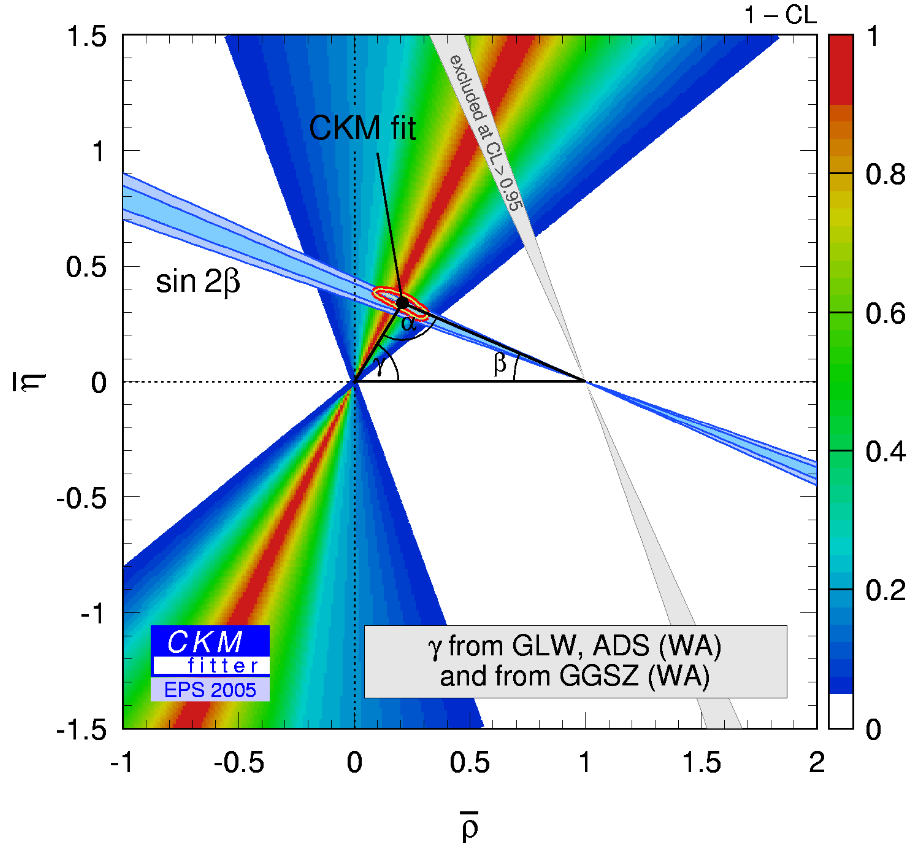
Direct constraints from all modes

$$\gamma = \left(63\,^{+15}_{-12}\right)^\circ$$



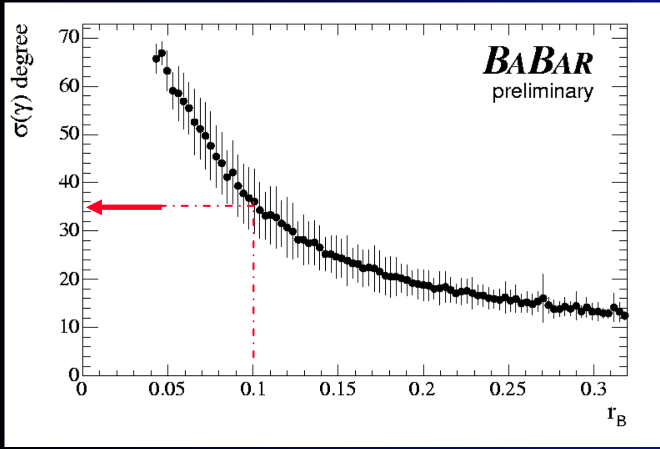
Indirect CKM constraints

$$\gamma = \left(57\,^{+7}_{-13}\right)^\circ$$

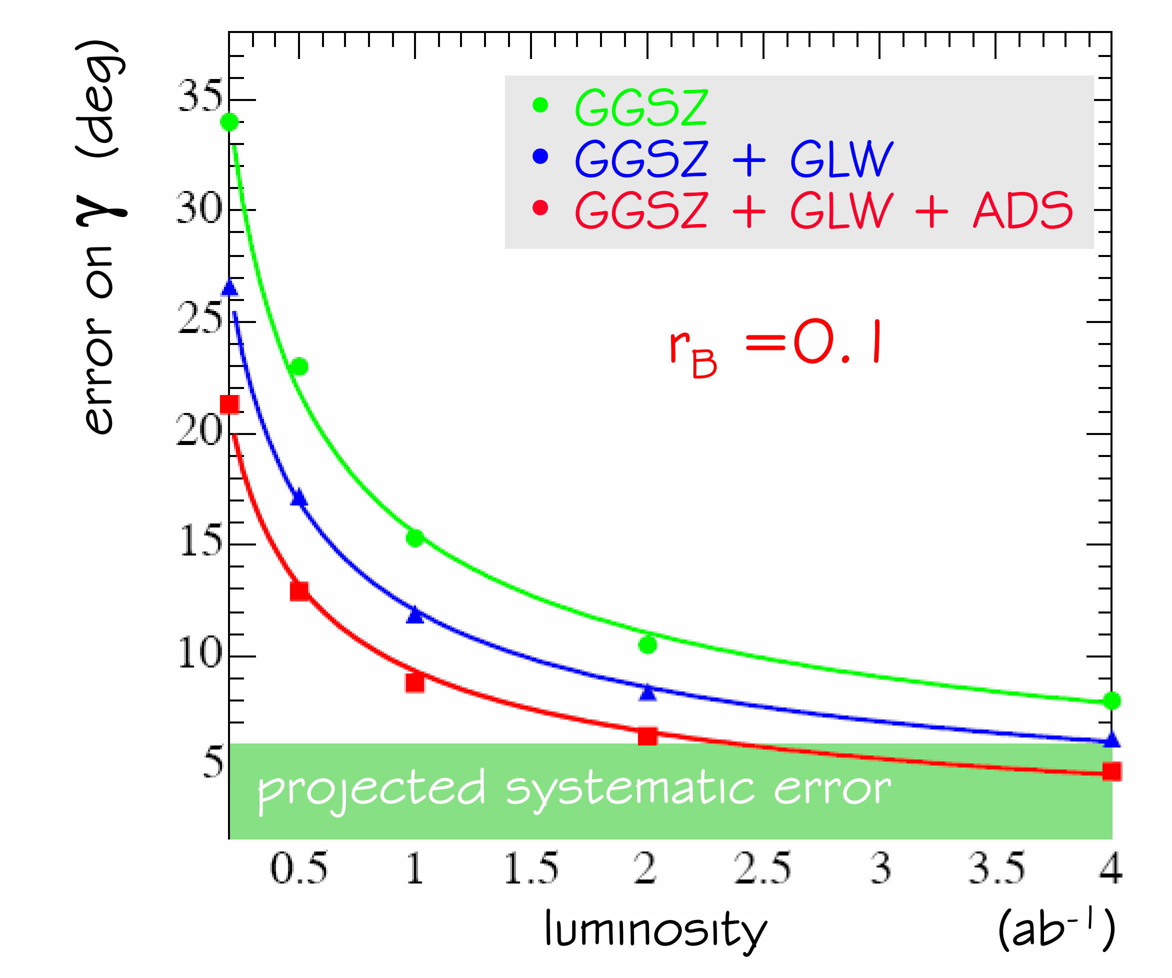


Prospects on γ

importance of the value of r_B on the error on gamma, illustrated here for the GGSZ method in BABAR:



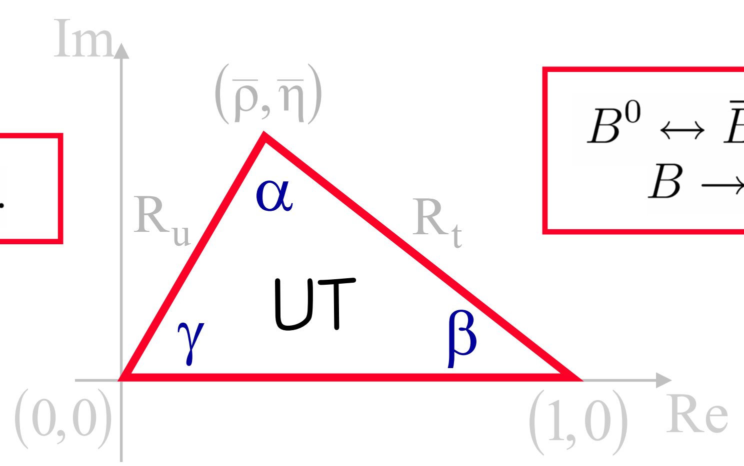
error as a function of r_B



error as a function of integrated luminosity for r_B=0.1

Measurements of UT Sides

$B \to \pi/\rho/\omega\, \ell\nu, \ldots$



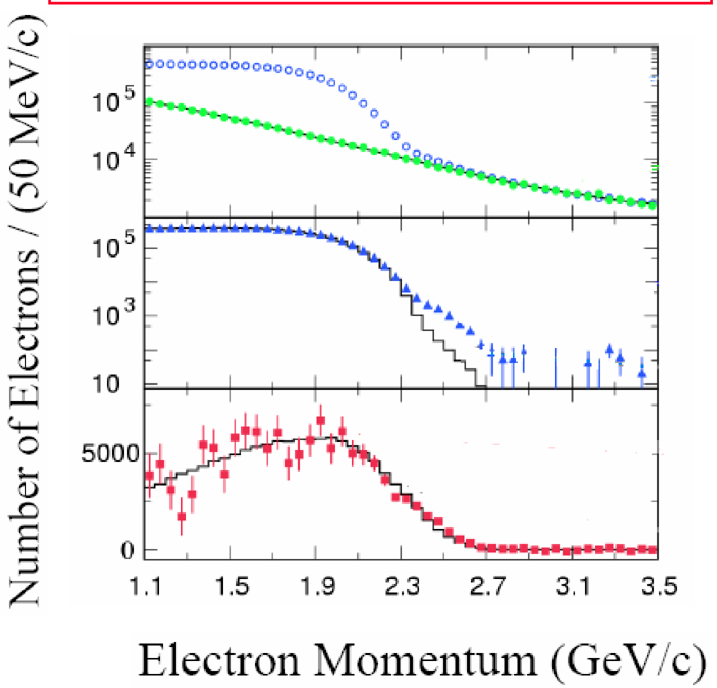
$B^0 \leftrightarrow \overline{B}^0,\ \Delta m\,(\phi_M = -\beta)$
$B \to K^*\gamma + \rho/\omega\,\gamma$

$B \to D^*\,\ell\nu$

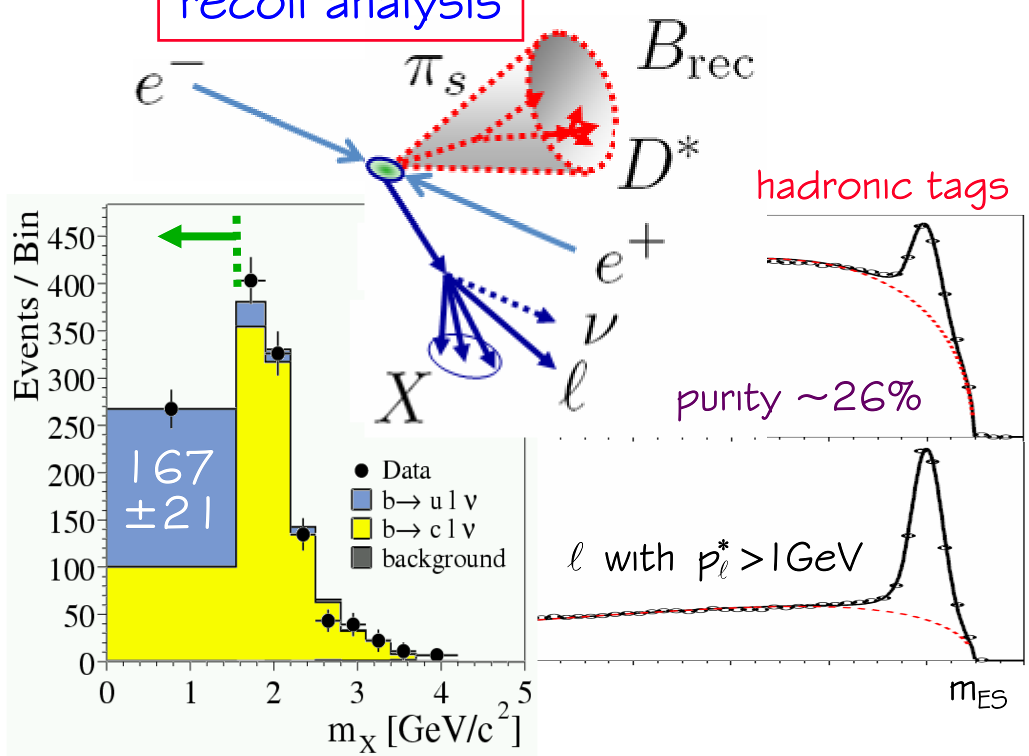
Measurement of V_{ub}

- V_{ub} : a key CKM constraint (only Trees, no NP)
- dependence on theory predictions for kinematical extrapolations
- inclusive : extract m_b and QCD parameters from $B \to Xc\, l\, \nu$ and $B \to Xs\, \gamma$ spectra (error on $m_b \sim 4.5\%$)

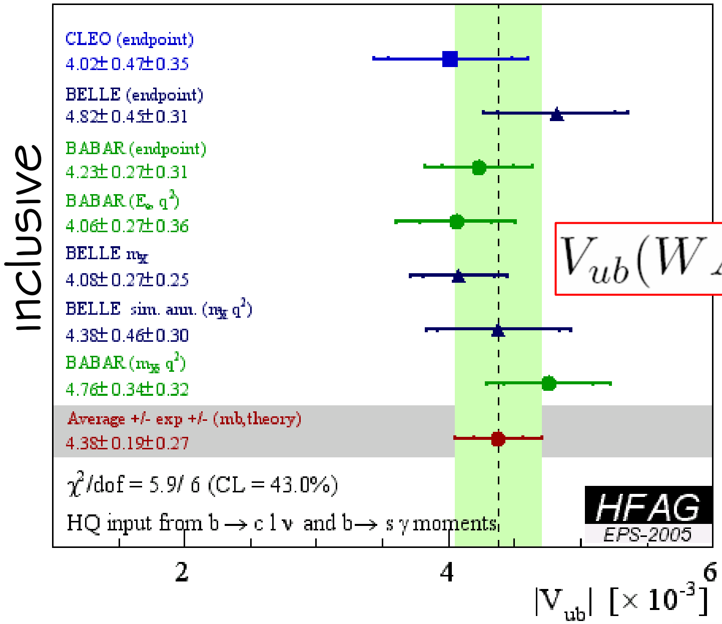
lepton spectrum end-point



recoil analysis



Vub Results & Prospects



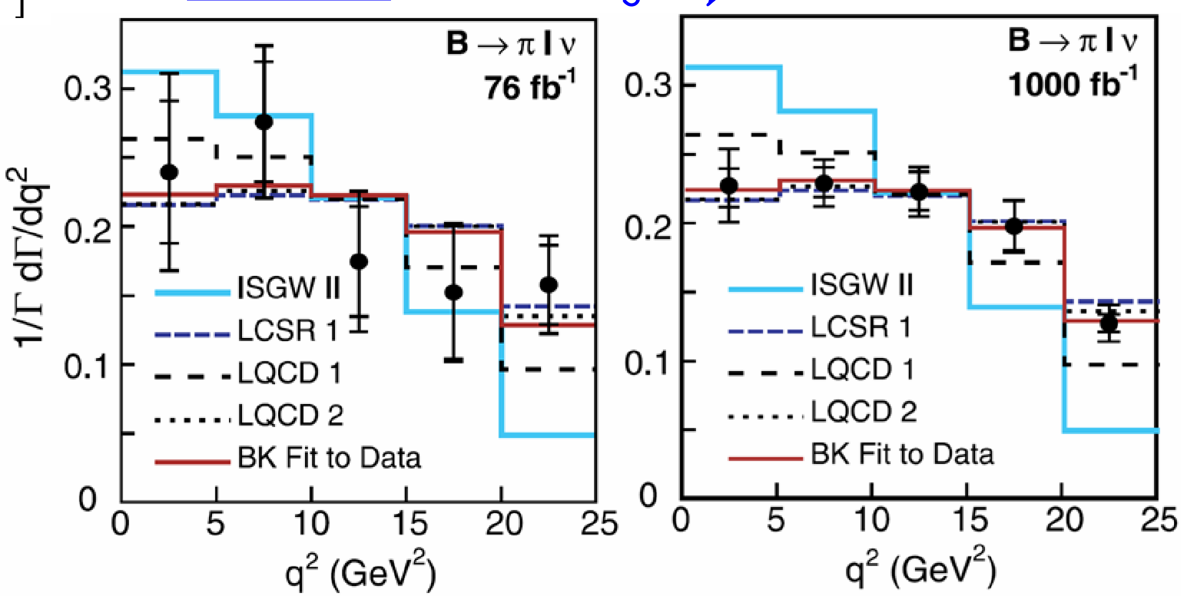
Inclusive

most methods with uncertainties around 10%

$$V_{ub}(WA) = (4.38 \pm 0.19(\text{exp}) \pm 0.27(m_b, \text{theory})) \times 10^{-3}$$

with mode data, uncertainty on inclusive V_{ub} can be pushed down to ~6%

Exclusive: $\pi l \nu$ at high q^2 + lattice QCD

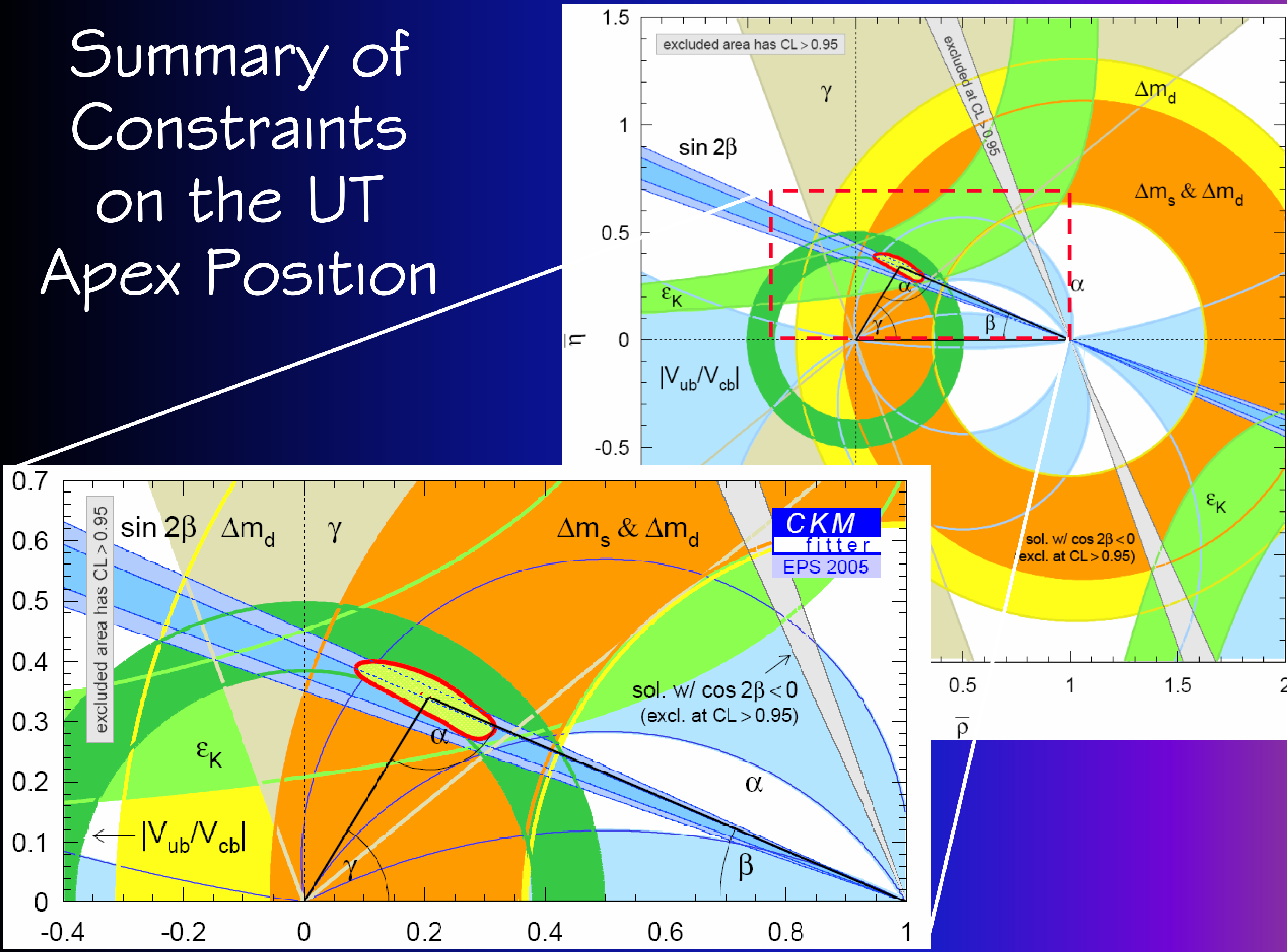


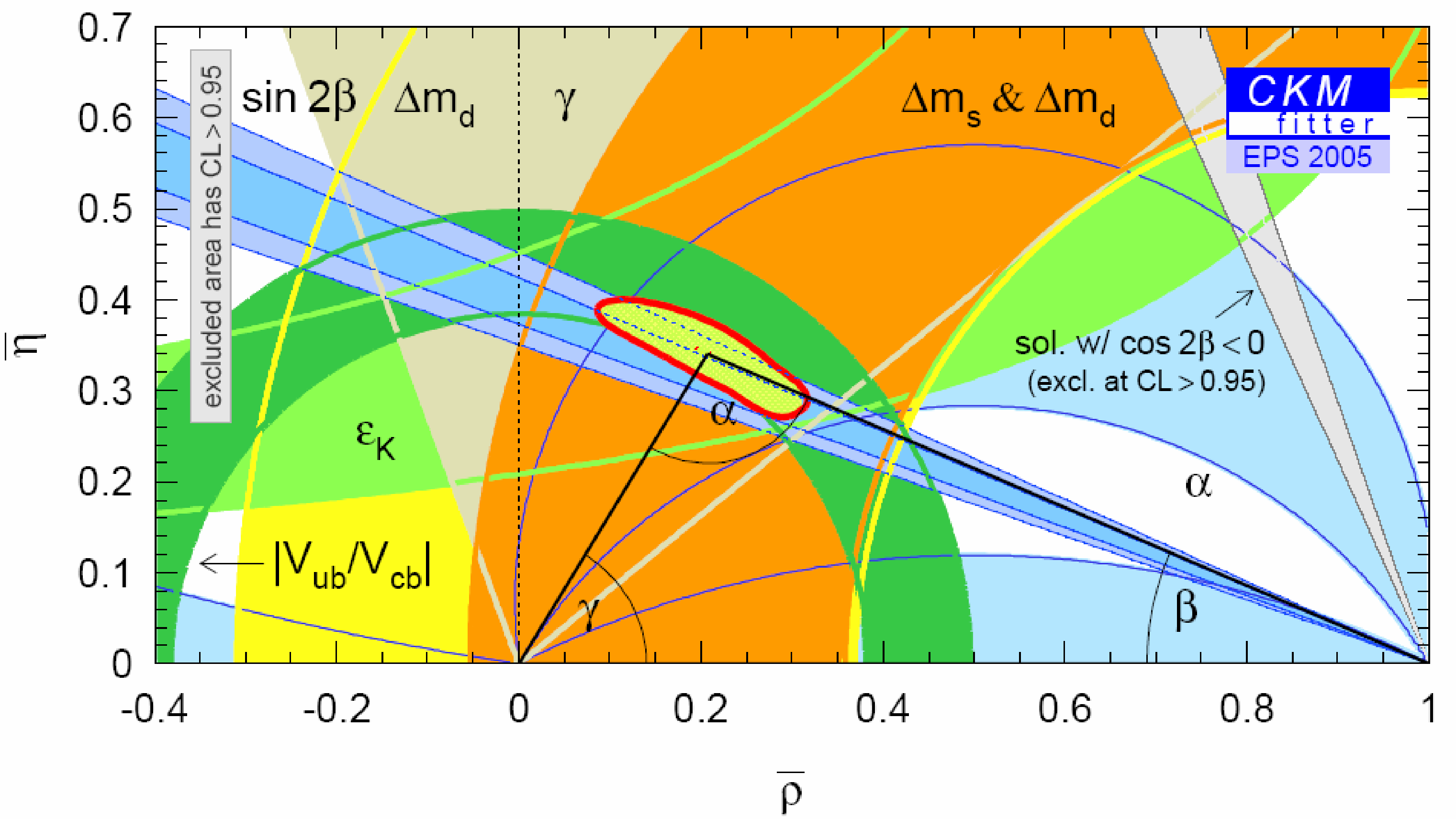
Exclusive

- still limited by statistics
- expect errors from $\pi l \nu$ on the lattice down to below ~8% by end of decade

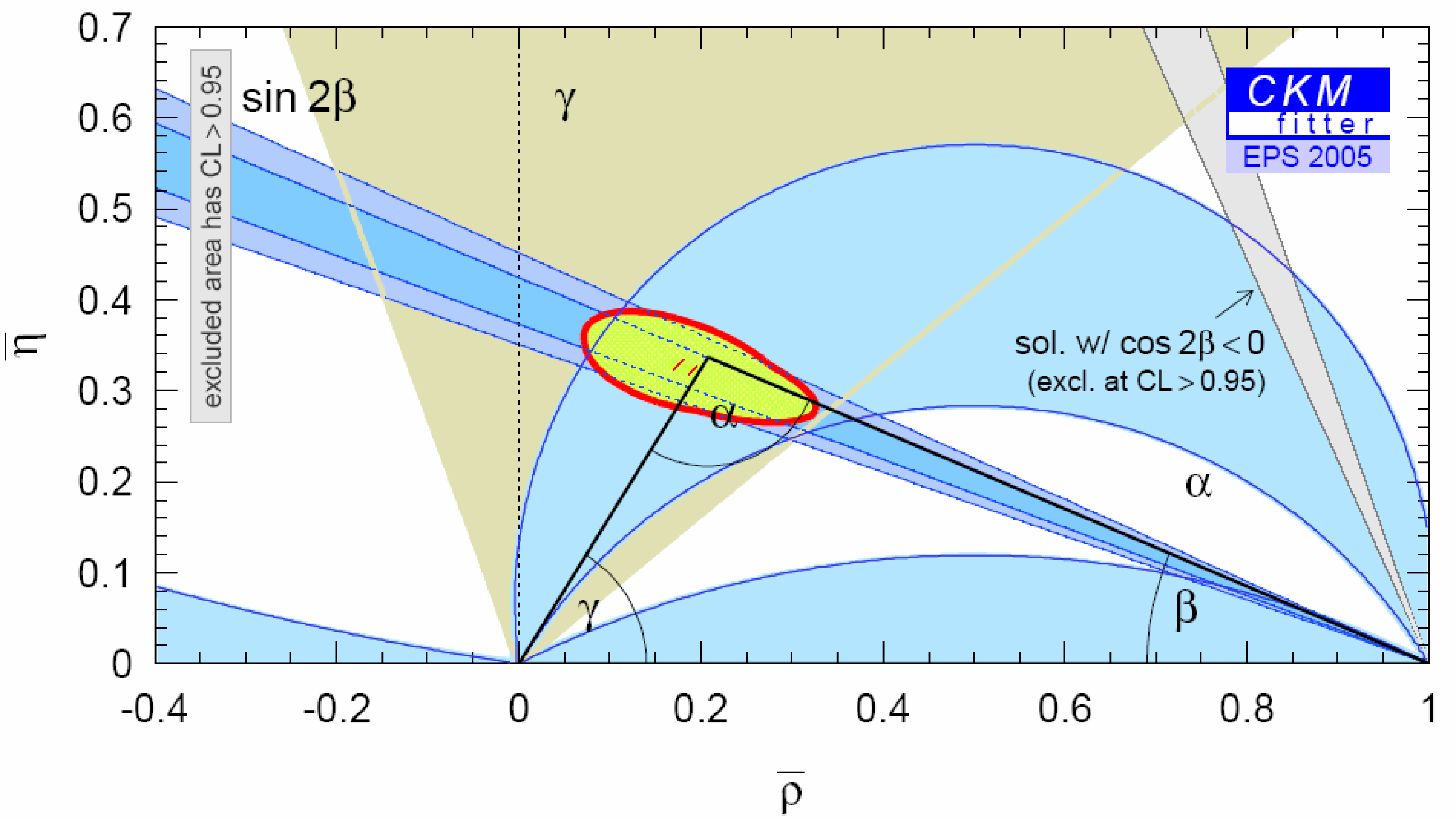
Goal for 2008:
precision of ~5% on V_{ub}

Summary of Constraints on the UT Apex Position



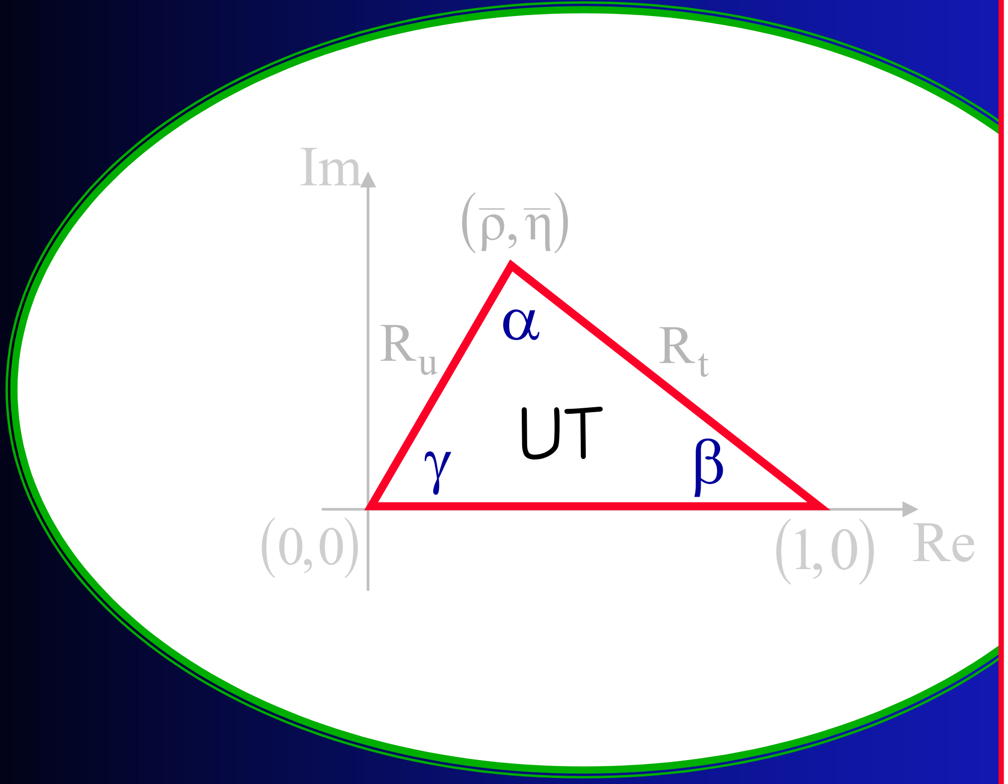


All measurements



Angle measurements only

Measurements of sin2β in Decay Modes Sensitive to Different Short-Distance Physics

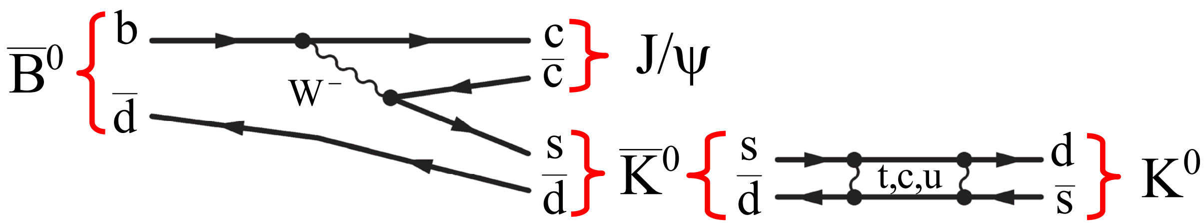


$B \to J/\psi\, K^0_S$	$b \to c\bar{c}s$
$B \to J/\psi\, \pi^0$ $B \to D^{*\pm} D^{\mp}$ $B \to D^{*+} D^{*-}$	$b \to c\bar{c}d$
$B \to \phi K^0_S$ $B \to K^0_S K^0_S K^0_S$	$b \to s\bar{s}s$
$B \to \eta' K^0_S$ $B \to f_0 K^0_S$ $B \to K K K^0_S$	
$B \to \pi^0 K^0_S$ $B \to \omega K^0_S$	$b \to q\overline{q}s$

CP Violation in “s-Penguin” Modes

★ $b \longrightarrow c\,\bar{c}\,s$

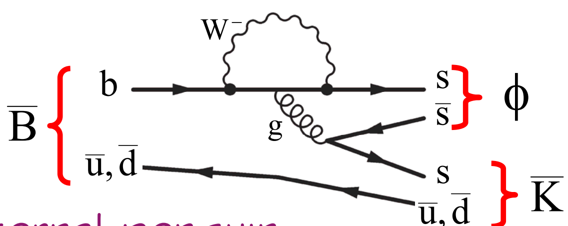
Reference mode: Tree dominance



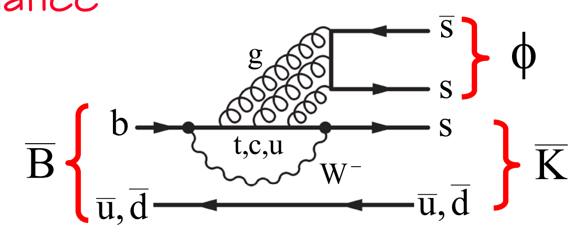
$$\lambda_{J/\psi K^0_S} = -\left(\frac{q}{p}\right)\left(\frac{V_{cb}V_{cs}{}^*}{V^*_{cb}V_{cs}}\right)\left(\frac{q}{p}\right)_K = -\,e^{-2i\beta}$$

★ $b \longrightarrow s\,\bar{s}\,s$

Penguin dominance



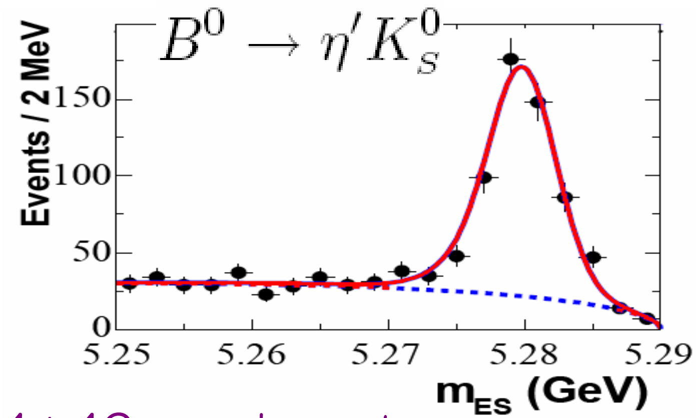
internal penguin



flavor-singlet penguin

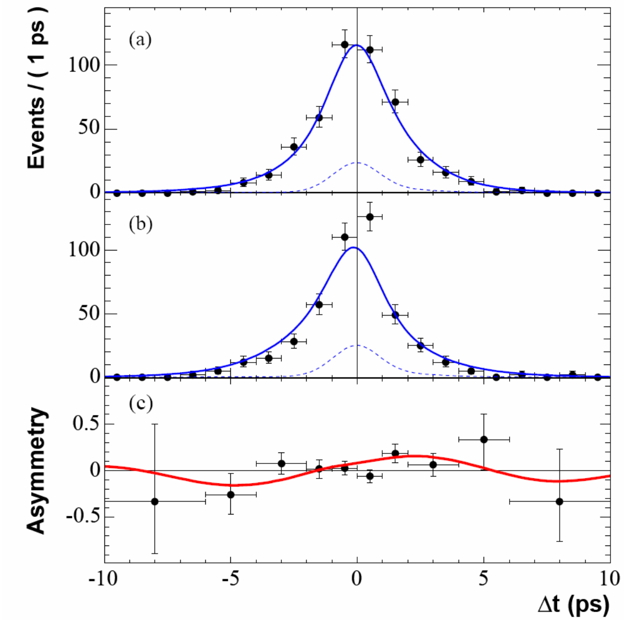
$$\lambda_{\phi K^0_S} = -\left(\frac{q}{p}\right)\left(\frac{V_{tb}V_{ts}{}^*}{V^*_{tb}V_{ts}}\right)\left(\frac{q}{p}\right)_K \approx -\,e^{-2i\beta}$$

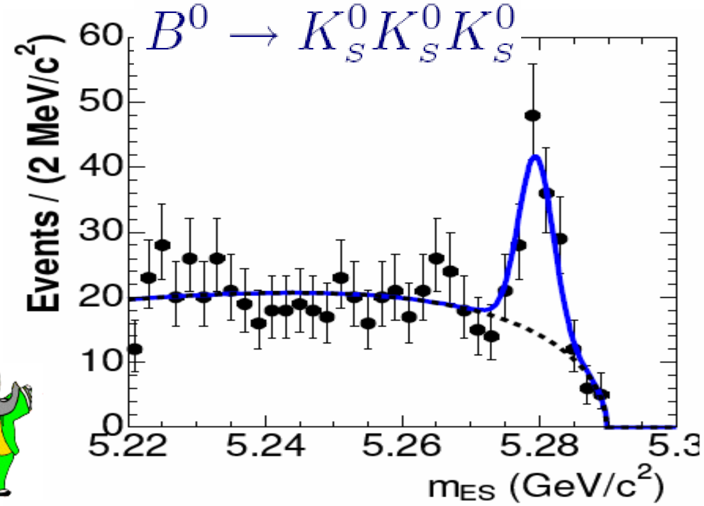
T-D Analyses in η'Ks and KsKsKs

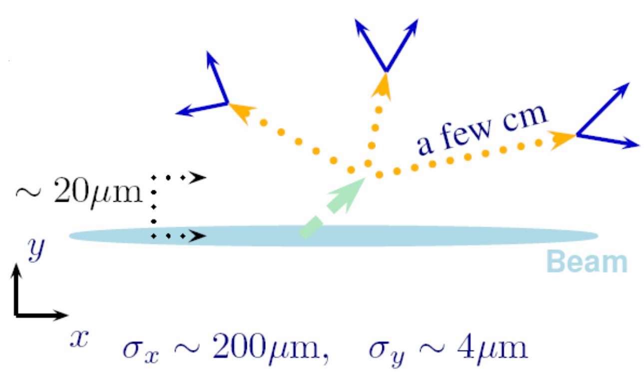


804±40 signal events

$$\sin 2\beta(B^0 \to \eta' K^0_S) = 0.30 \pm 0.14 \pm 0.02$$





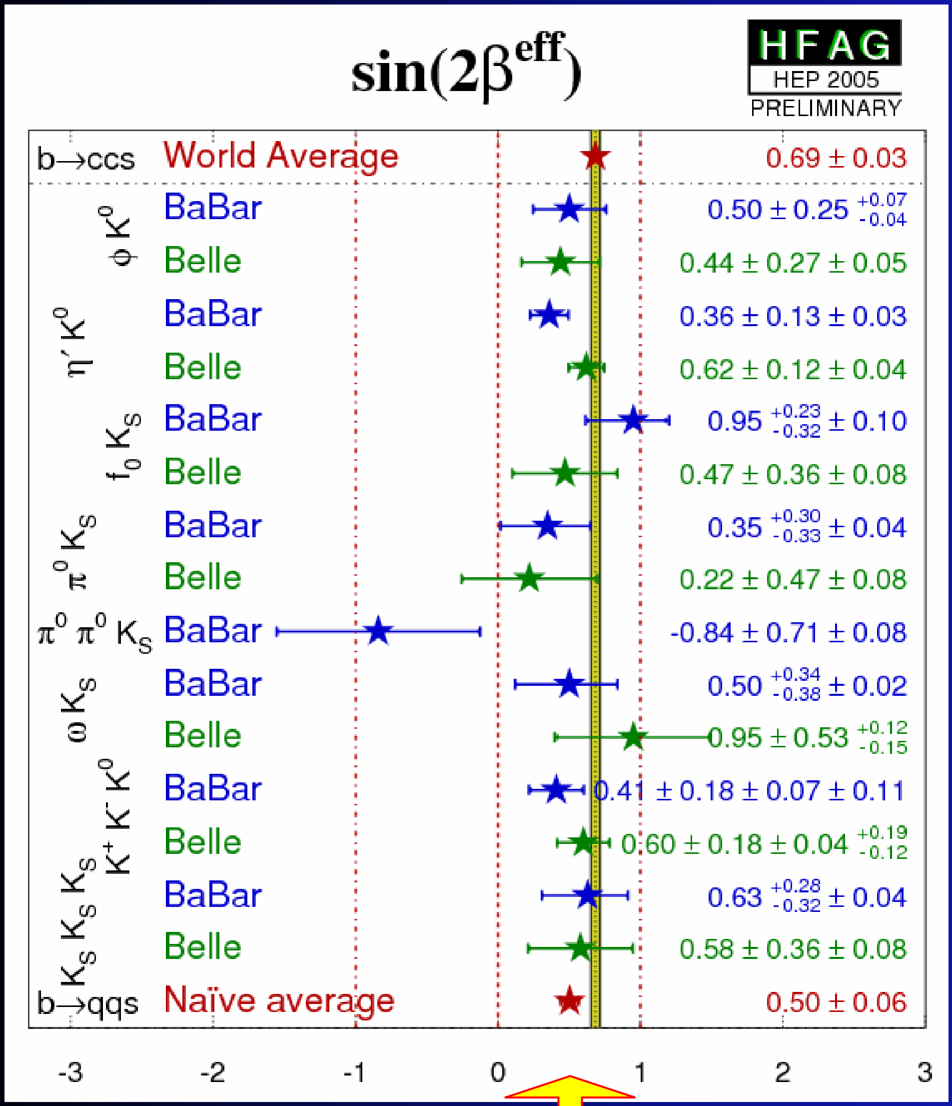


take advantage of the small beam size in the transverse plane

88±10 signal events

$$\sin 2\beta(B^0 \to K^0_S K^0_S K^0_S) = 0.63^{+0.26}_{-0.32} \pm 0.04$$

Compilation of s-Penguin Results



~2.4σ from s-penguin to sin2β

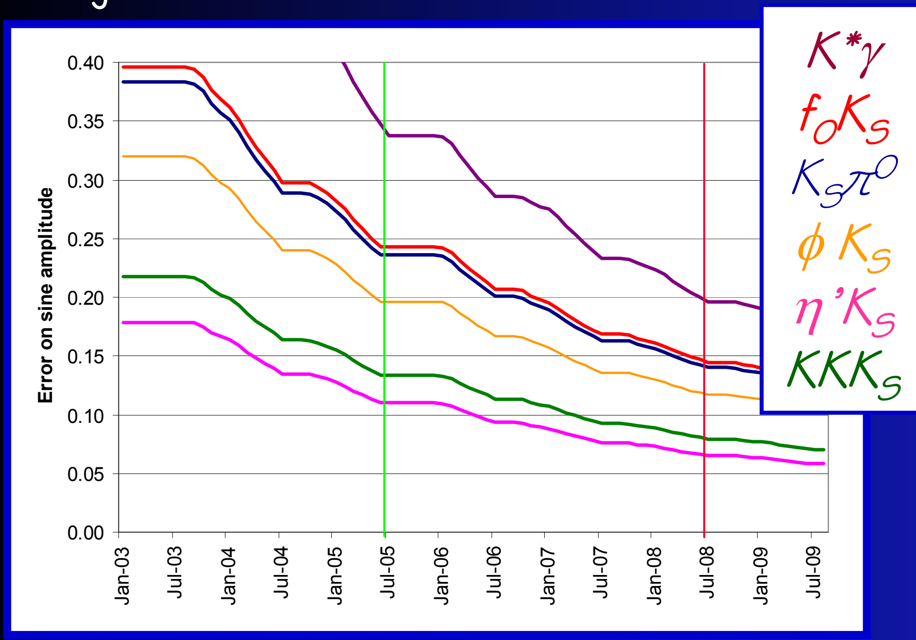
Naïve average of "s-Penguin" S coefficients 2.4σ away from reference value of sin2β (cc)

(significance of deviation decreased due to recent updated value of sin2β by Belle)

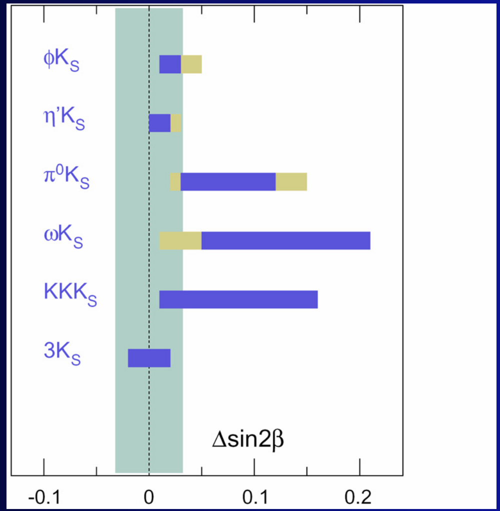
New physics may affect different modes in different ways:
→ use the pattern of deviations to go beyond the naïve average

Deviations from Standard Model

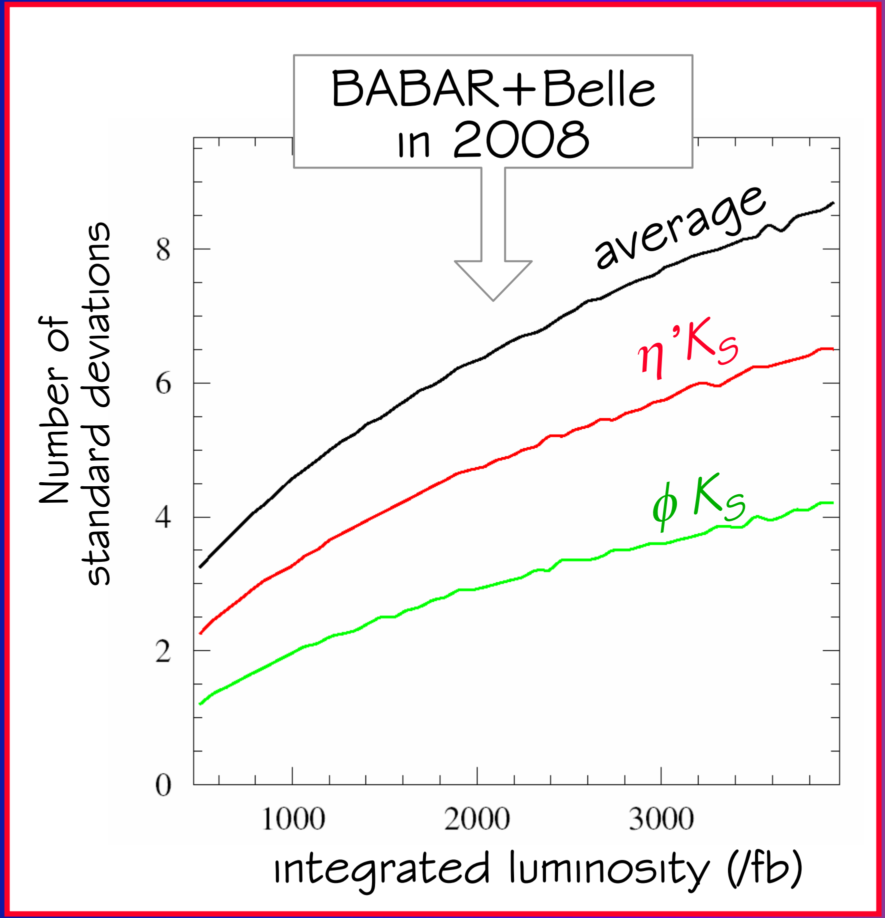
Projected errors as a function of time



Theory errors



Significance of deviation from Standard Model expectation as a function of luminosity (assuming fluctuations around present central values)



Discriminating Among NP Models

Exploit the pattern of deviations ΔS in the various modes to discriminate among different models

Buchalla, Hiller, Nir, Raz (hep-ph/0503151)

Wilson coefficients:

$$C_i(m_W) = C_i^{\rm SM}(m_W) + \varepsilon_i e^{i\theta_i}$$

Three NP models, six scenarios:

- NP only in the Z^0-penguin coupling

  ★ $(\varepsilon_z, \theta_z) = (0.02, 0.85)$ ★ $(\varepsilon_z, \theta_z) = (0.02, 1.79)$

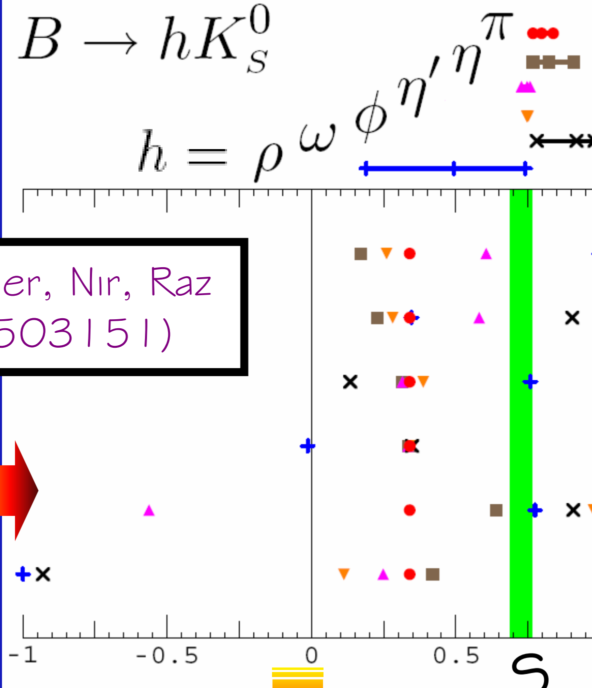
- NP in Kaluza-Klein gluon excitations

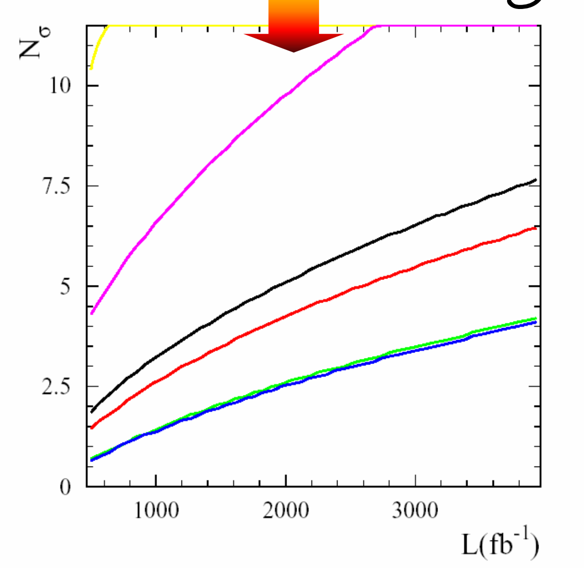
  ★ $(\varepsilon_k, \theta_k) = (0.02, 0.812)$ ★ $(\varepsilon_k, \theta_k) = (0.02, 2.52)$

- NP in chromo-magnetic operator

  ★ $(\varepsilon_g, \theta_g) = (1, 3.27)$ ★ $(\varepsilon_g, \theta_g) = (1, 5.64)$

Full analysis:
for each model
constraints in the plane of the
two NP parameters (modulus and phase)





Selected Measurements Sensitive to New Physics

New Physics Issues

★ KM mechanism: one single source of CP violation

New sources of flavor or CP violation
can induce large deviations
from SM predictions

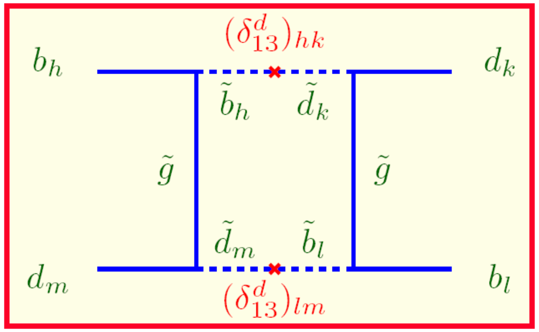
For instance, in MSSM
- 124 independent parameters
- 44 are CP violating

★ Where can one expect deviations?

➡ Flavor Mixing

large deviations in Bd system are unlikely
but SUSY can affect mixing in the Bs system

distinguish measurements involving
flavor mixing or not

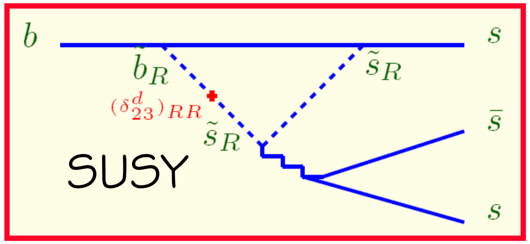


➡ Flavor Changing Neutral Currents

helicity-changing $b \to s\gamma$

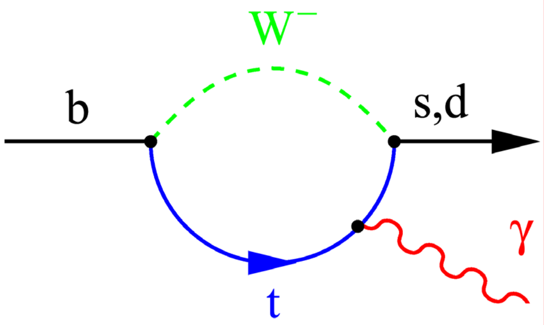
helicity-conserving $b \to s\,\bar{s}\,s$

gluonic "penguin" diagrams with
intermediate squarks and gluinos



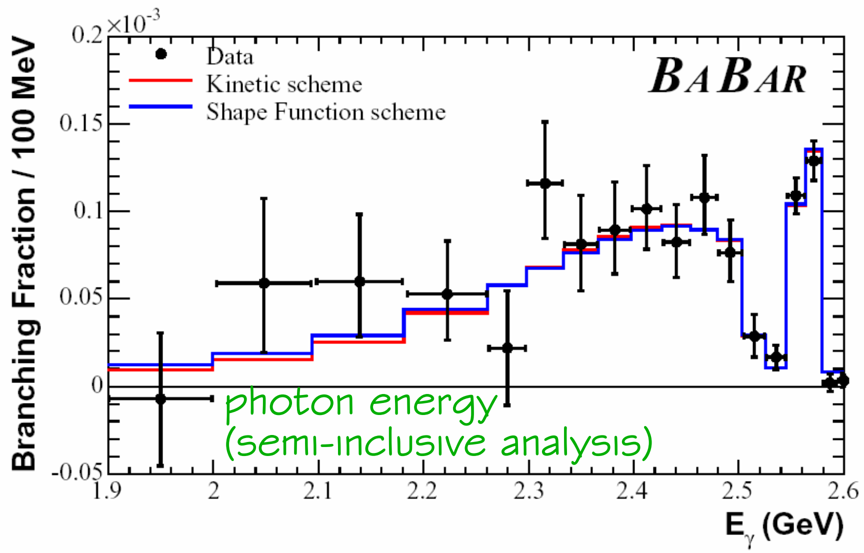
➡ Very rare decays (e.g. leptonic)

FCNC: $b \to s\gamma$



★ The transition $b \to s\gamma$ has been heavily studied by CLEO then by BABAR and Belle in a variety of ways

- fully inclusive
- exclusive ($B \to K^*\gamma$)
- semi-inclusive

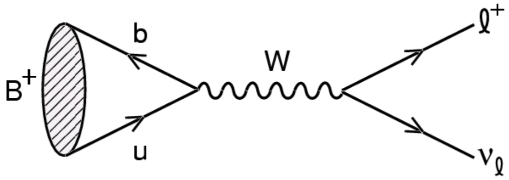


So far all measurements are consistent with SM predictions (typical errors: 10%)

expect improvements towards 5% error by 2008

★ this mainly constrains "LR" mass insertions

Leptonic *B* decays



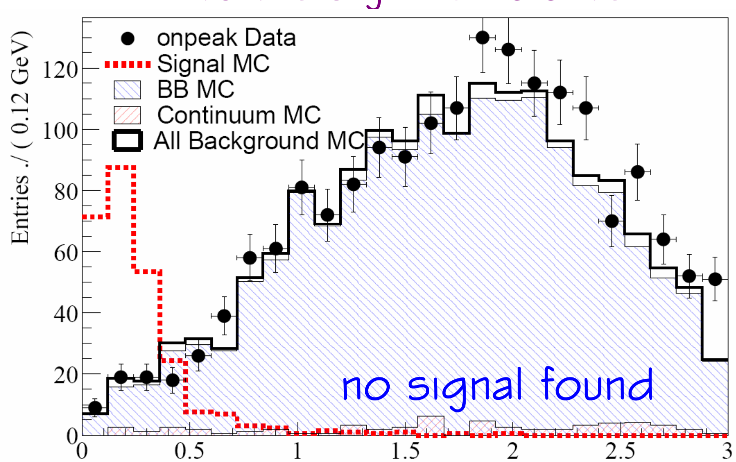
$$Br\left(B \to \ell\, \nu\right) = \frac{G_F^2 \left|V_{ub}\right|^2}{8\pi} f_B^2 \cdot \tau_B \cdot m_B \cdot m_\ell^2 \cdot \left[1 - \frac{m_\ell^2}{m_B^2}\right]^2$$

(decay constant from LQCD)

- Recoil technique (semileptonic and hadronic)
- Look for 1 and 3 prong tau decays

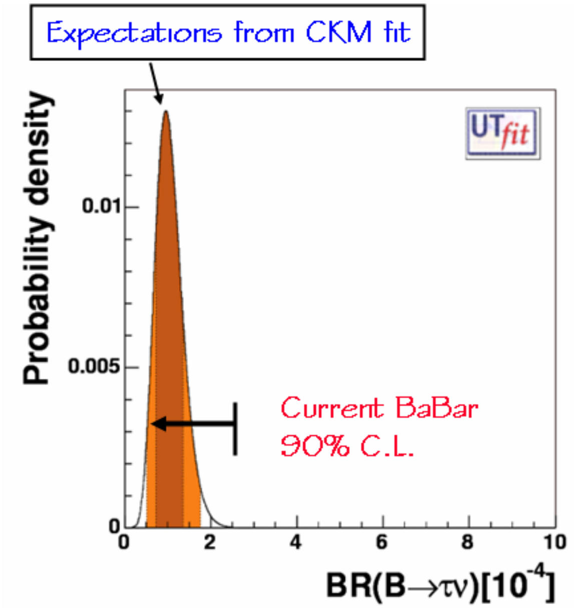
$$Br\left(B^+ \to \tau^+ \nu_\tau\right) < 2.6 \times 10^{-4} \ @ 90\% CL$$

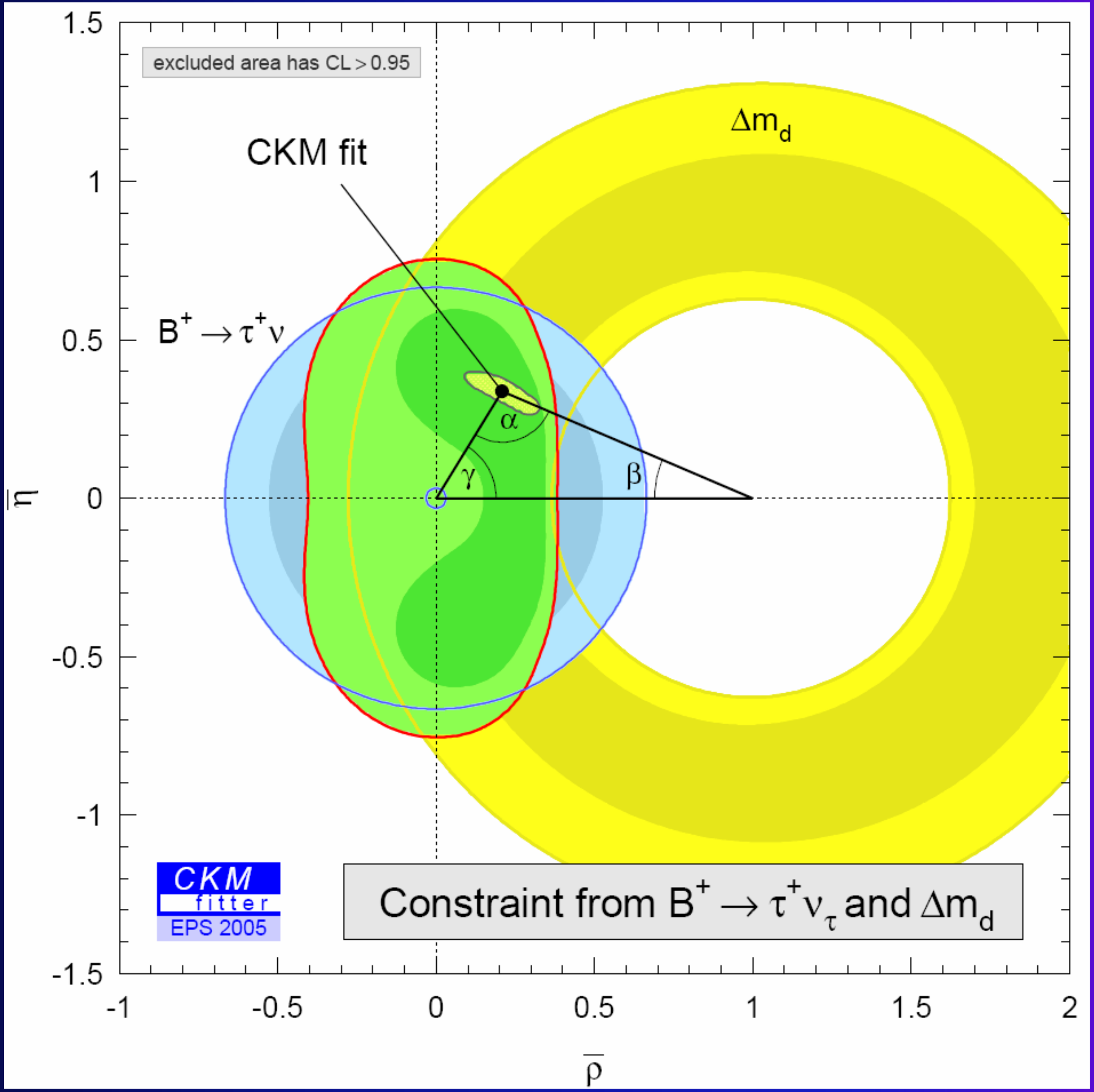
plot the energy in addition to the signal candidate



Extra Energy (GeV)

limit reaching a factor of ~2 of SM expectation :
soon a constraining measurement

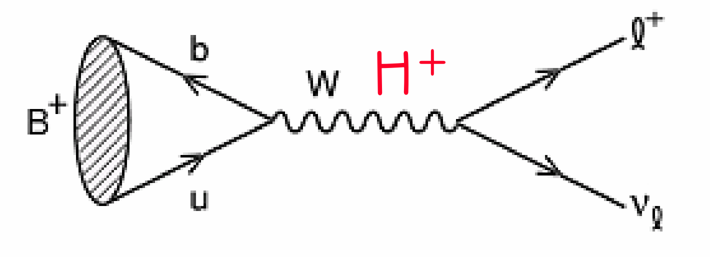


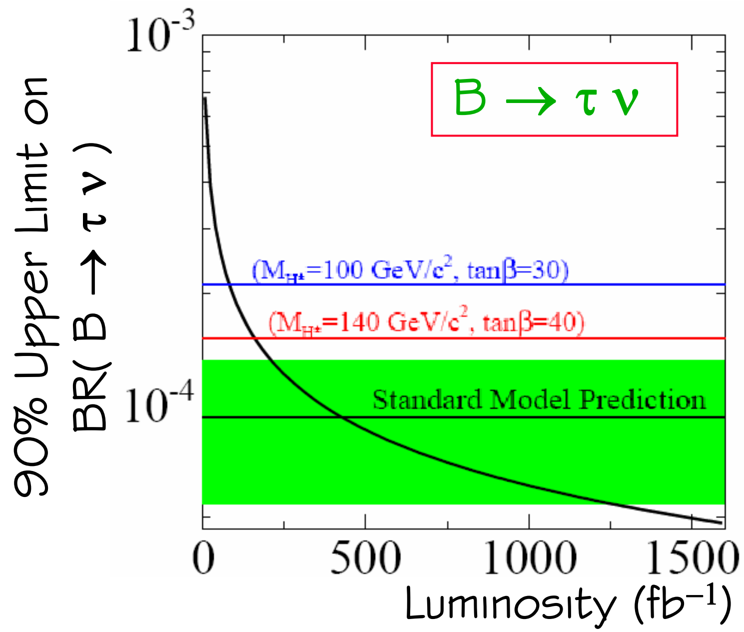

excluded area has CL > 0.95
Δm_d
CKM fit
B⁺ → τ⁺ν
α
γ
β
CKM fitter
EPS 2005
Constraint from B⁺ → τ⁺ν_τ and Δm_d
1.5
1
0.5
0
-0.5
-1
-1.5
-1
-0.5
0
0.5
1
1.5
2
ρ̄
η̄

$B \to \tau \nu$: Sensitivity to NP Models

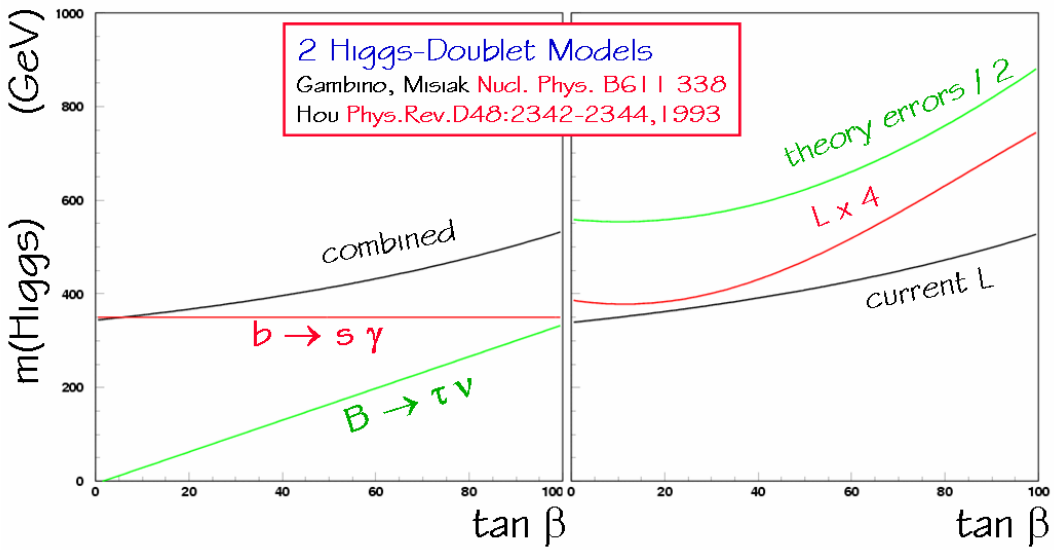
Two examples of constraints on the parameter space for specific NP models

★ Limits on $m(H^+)$ in the MSSM from $Br(B \to \tau \nu)$





★ Limits on the $m(H^+)$-$\tan\beta$ plane in 2HDM (of type II) from $Br(B \to \tau \nu)$ and $Br(b \to s \gamma)$



Conclusions

B-Factories will perform important SM measurements some of which cannot be improved elsewhere

Four major CKM measurements will improve by 2008

- $\sin 2\beta$ -- with expected error of order ±0.025
- angle α -- with charmless two-, three- and four-body decays
- angle γ -- with DK modes, to better than 9°, depending on r_B
- $|V_{ub}|$ -- with m_b and QCD parameters extracted from the data and progress on exclusive measurements

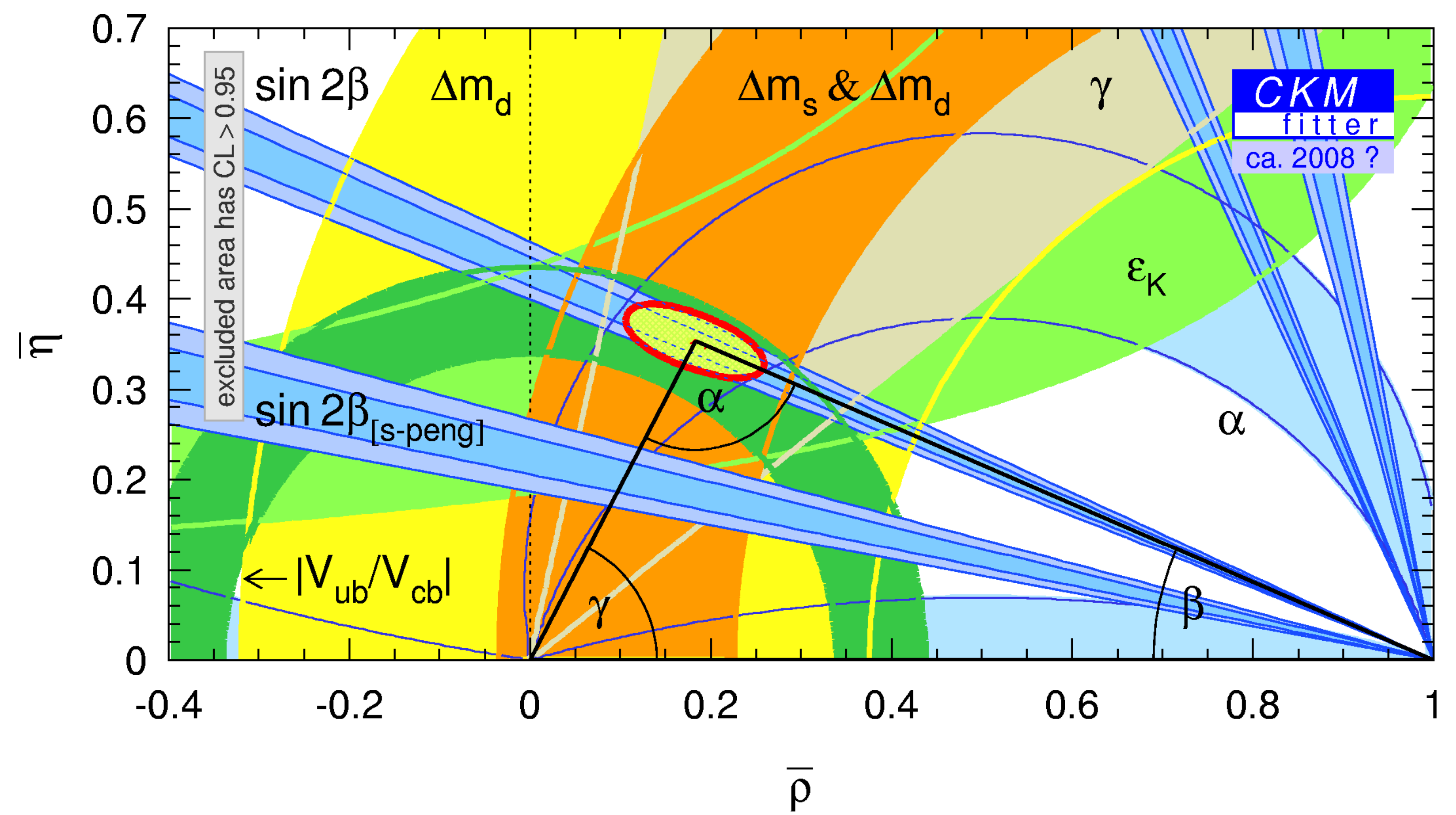
Overconstraining the Unitarity Triangle strongly bounds New Physics

The flavor sector is a key ingredient to NP model building

B-Factory physics goes beyond CKM metrology!

- sensitivity to New Physics through radiative corrections, e.g. $b \to sg$ (complementary to direct observation of NP particles at the LHC)
- sensitivity to very rare *B*, *D*, D_s and τ decays

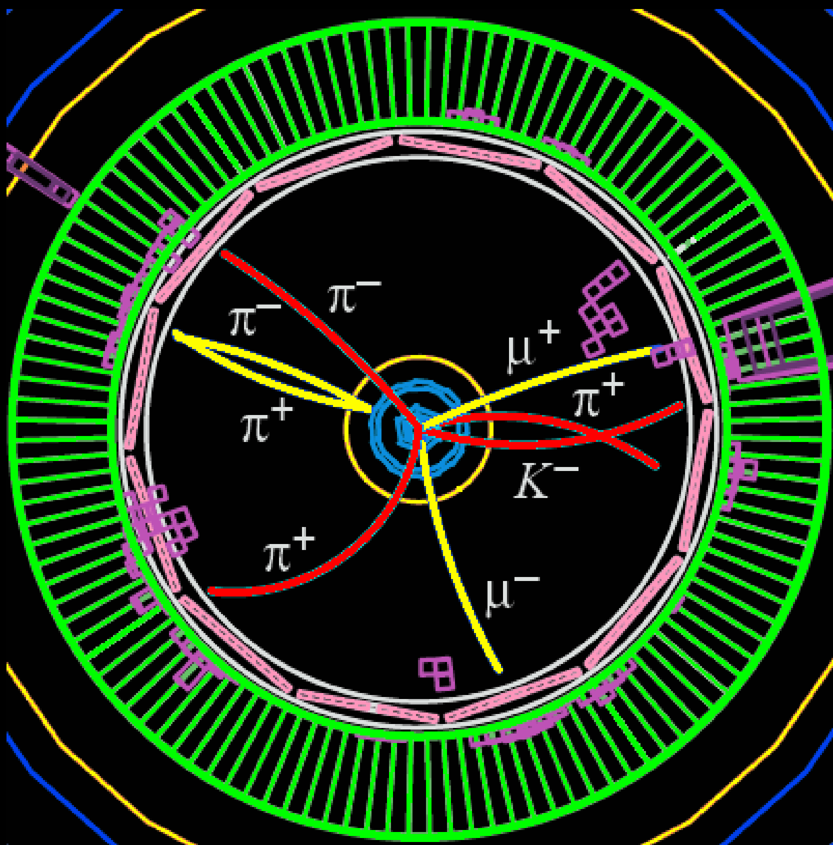
Possible Situation in 2008?

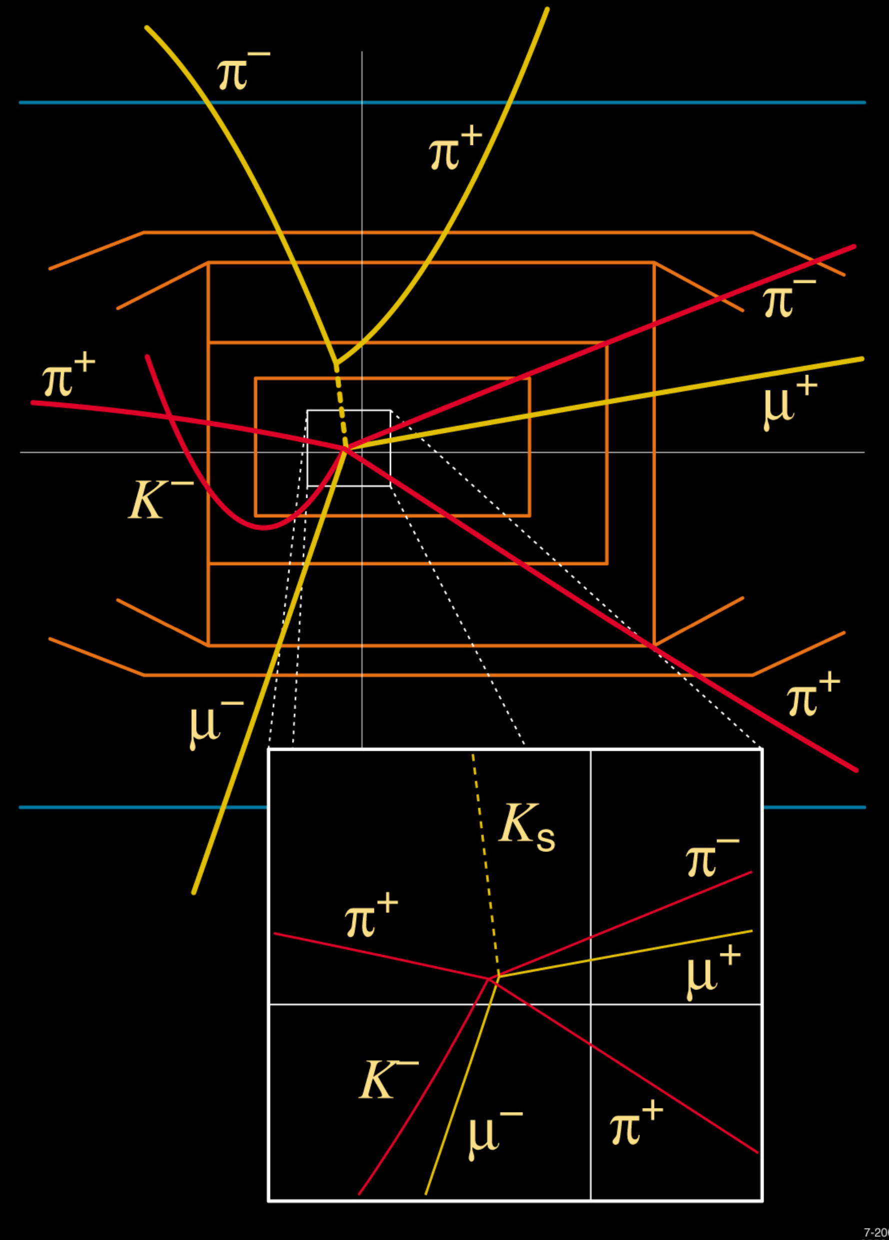


$\sigma(V_{ub}) = 7\%$

$\sigma(\Delta m_s) = 5\%$

$\sigma(\sin 2\beta) = 0.019 \quad \sigma(\alpha) = 6^\circ \quad \sigma(\gamma) = 10^\circ$





BABAR Status & Physics Reach

Gautier Hamel de Monchenault
CEA-Saclay DAPNIA/SPP
on behalf of the BABAR Collaboration

CERN, 14 February 2006