  

CLEO's impact:
A view from the Inside & the Outside

On the occasion of celebration of David Cassel's contributions to science & teaching.

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University of Maryland
March 12, 2011

CLEO Physics Impact is breathtaking: 500+ papers

- Bottomonium spectroscopy
  - Most of the current knowledge is due to CLEO, CUSB and ARGUS results; (recent results on hyperfine splitting & transitions from the BaBar).
- Discovery and pioneering studies of B flavored mesons- and much of the techniques involved:
  - CLEO results prepared the ground for the study of CP violation, and played a major role in validating the CKM picture
- Charm hadron production & decays
  - Charmed hadron spectroscopy, precision measurement of decay Br of D+, D0, Ds, properties, Ds and D+ decay constants (test of LQCD), strong phases of the decay final states (key to precision measurement of γ)
- Charmonium spectroscopy
  - Confirmation of singlet states, measurement of hyperfine splitting, precision measurement of Br… study of charmonium-like states (so-called X,Y,Z)
- Tau decays

- Continuum e+e- annihiliation at the 10 GeV region, ISR & 2-photon physics

- The CLEO-II detector concept; Major of aspects followed at the B factories and to continue at the SuperB experiments.

My talk is organized, from a narrow perspective, around a set of pathbreaking CLEO contributions that significantly influenced:

- The development of the CKM picture
- Flavor physics as a probe of new physics
- The work that followed at the B factories
- The basis for the next phase: precision Flavor Physics

10^{11}--

Precision flavor physics: Flavor structure of New Physics through precision measurements of CKM [O(1%) level], FCNC processes & Lepton Flavor Violation- a complementary program to the direct searches at LHC.

10^{10}--

CKM celebrated by Nobel Prize(2008) & The Flavor puzzle

10^{9}--

The 1/ab phase: D0 mixng, CPV in pure penguin processes, Leptonic $B\to\tau\nu$; Bs mixing at Tevatron & , limit on tau LFV< 10^{-7}; Hints of tension (~2σ) with SM: CKM fit, $K\pi$ puzzle, ϕs, polarization effects, ..

10^{8}--

Precision $\sin 2\beta$; α & γ measured; CKM over-constrained and established as the primary source of observed CPV effects. Observation of direct CPV in $B\to K\pi$.

#B's

2001- CPV in B decays observed. Sin2β consistent with SM

10^{7}--

1999- B Factories start operation.

1993-2000 CLEO observed loop level processes in B decays: $b\to s\gamma$; constraints on charged higgs mass & SUSY models; CLEO observed B->$K\pi$ –1st evidence for gluonic penguins in B decays; evidence for $B\to\pi\pi$

10^{6}--

B factory projects launched.

10^{5}--

1987-B^0 mixing(UA1/ARGUS/CLEO)[m(top)> 50 GeV]; V_{ub} measured(CLEO/ARGUS); With large mixing & non-zero V_{ub}, CKM in the game as a source of CPV

10^{4}--

1981- CLEO observed $\Upsilon(4S)$, Evidence for weakly decaying b-flavored meson

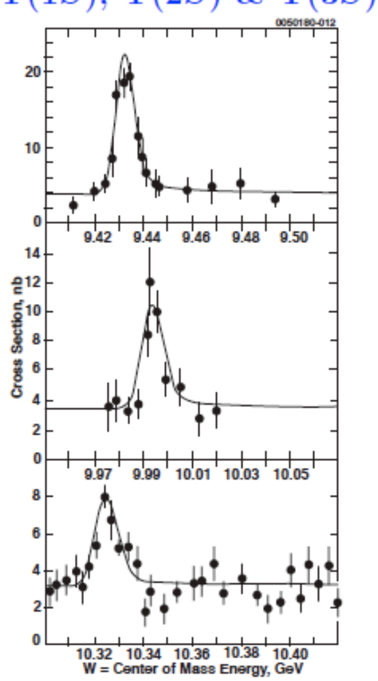
CLEO-c:
Precision
D^+,D^0, D^s
f_D
Strong
phases

CLEO-II:
$|V_{ub}|$
$|V_{cb}|$
B->$s\gamma$-
charmless
decays

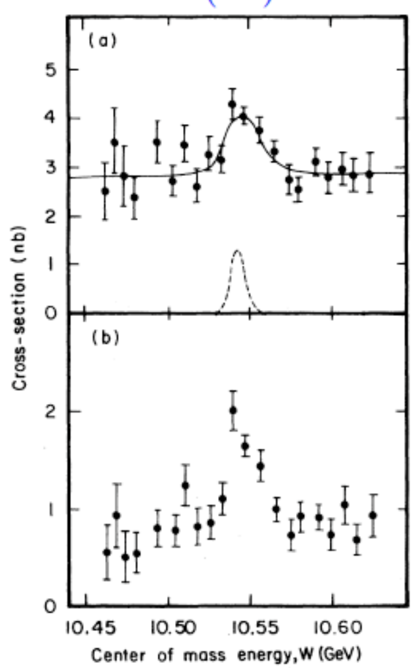
1981 –(Start of my Inside story)

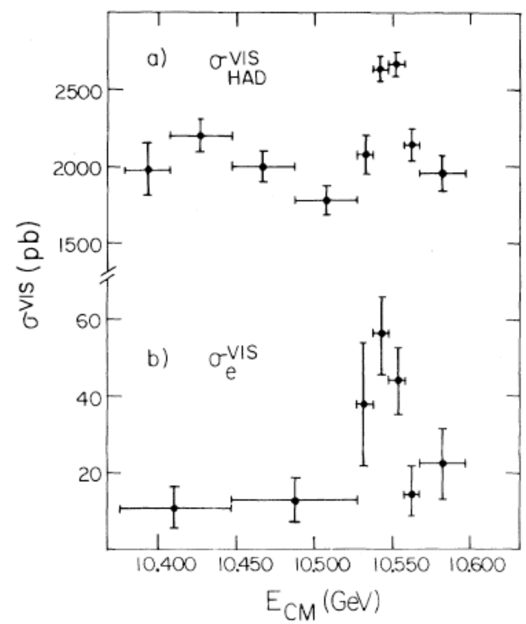
- •Existence of the narrow Υ resonances established at FNAL, DORIS and CESR
- •CLEO had observed Υ(4S) – 22 MeV above the $B\bar{B}$ threshed. PRL 45, 219 (1981)
- •CLEO observed enhanced e & μ rates at the 4S- PRL 46, 84(1981)
  - •Evidence for weakly decaying B meson: B(B→Xeν)=$13 \pm 3 \pm 3\%$

$\Upsilon(1S)$, $\Upsilon(2S)$ & $\Upsilon(3S)$



$\Upsilon(4S)$





CLNS 51/505
CLEO 81/05
JULY 1981

CLEO

CORNELL HARVARD ROCHESTER RUTGERS SYRACUSE VANDE

WHAT CAN WE HOPE TO LEARN FROM B MESON DECAY?

Proceedings of a
CLEO Collaboration Workshop

Fig. 1. What We Do and Don't Know About Particle Physics

e_R, μ_R, τ_R, u_R, d_R, etc.	gluon
$\begin{pmatrix} e \\ \nu_e \end{pmatrix}_L$ $\begin{pmatrix} \mu \\ \nu_\mu \end{pmatrix}_L$ $\begin{pmatrix} \tau \\ \nu_\tau \end{pmatrix}_L$	γ
	$W^\pm$, Z^o
$\begin{pmatrix} u \\ d \end{pmatrix}_L$ $\begin{pmatrix} c \\ s \end{pmatrix}_L$ b	Higgs

CP is violated in

- - - - - - - - - - - - - - - - - - -

√√ Is there a t quark?

How are the lepto

√ How are the quark

X Are leptons and q

X Is QCD the correc

√ Is SU(2) × U(1) t…

√ Where are the Higgs Particles?

√ What is the nature of CP violatio

the

reas

Fig. 3. A Program to Understand B Decay

1. Search for exotic B decays.

   If found, explore details;

   -otherwise-

2. Search for flavor changing neutral currents.

   If found, measure $(b \to dZ^o)/(b \to sZ^o)$;

   -otherwise-

3. Measure semileptonic decay branching ratio.

4. Measure ratio $(b \to uW^-)/(b \to cW^-)$.

5. Measure $e\nu:\mu\nu:\tau\nu$ ratio in semileptonic decay.

- - - - - - - - - -

Non-b-Decay Features of B Decay

6. Look for lifetime difference between $B^\pm$ and B^o.

7. Look for B^o-$\bar{B}^o$ mixing.

[8. CP violation?]

The last item on my list is the nature of CP violation. This violation observed so far only in K^O decays, must show up in some other place. Our theoretical advice is that the size of the effects expected in B decay is very small, unobservably small. John Hagelin will tell us about that this afternoon, and also tell us about the experimentally more promising subject of $B^O\bar{B}^O$ mixing.

A paper that did not make it to the yellow book

And Carter & Sanda (1980)

NOTES ON THE OBSERVABILITY OF *CP* VIOLATIONS IN B DECAYS

I.I. BIGI
Institut für Theor. Physik der RWTH Aachen, D-5100 Aachen, FR Germany

A.I. SANDA[1]
Rockefeller University, New York 10021, USA

Received 16 June 1981

We describe a general method of exposing *CP* violations in on-shell transitions of B mesons. Such *CP* asymmetries can reach values of the order of up to 10% within the Kobayashi–Maskawa model for plausible values of the model parameters. Our discussion focuses on those (mainly non-leptonic) decay modes which carry the promise of exhibiting clean and relatively large *CP* asymmetries at the expense of a reduction in counting rates. Accordingly we address the complexities encountered when performing *CP* tests with a high statistics B meson factory like the Z^0 (and a toponium) resonance.

Indirect CPV due to the interference of decay and mixing amplitudes

$$B_d^0, \bar{B}_d^0 \to \psi K_S + X,\ D\bar{D}[F^+F^-]K_S + X\,,$$

The required elements of a program for CPV study:

- Large $B^0 \Leftrightarrow \bar{B}^0$ mixing
- Long B lifetime [i.e. suppressed $|V_{cb}|$]
- And non-zero $b \rightarrow u$
  - All CP violating effects are proportional to $\mathrm{Im}[V_{us}V_{cd}V_{cs}^{*}V_{ub}^{*}] = c_{12}c_{23}c_{13}^{2}s_{12}s_{23}s_{13}\sin\delta$

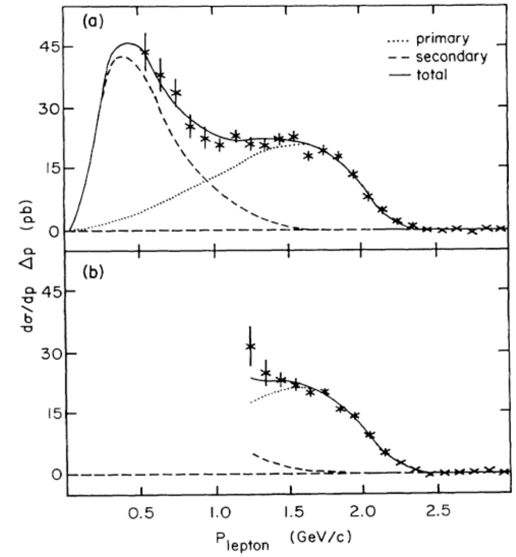
Early Period- CLEO I

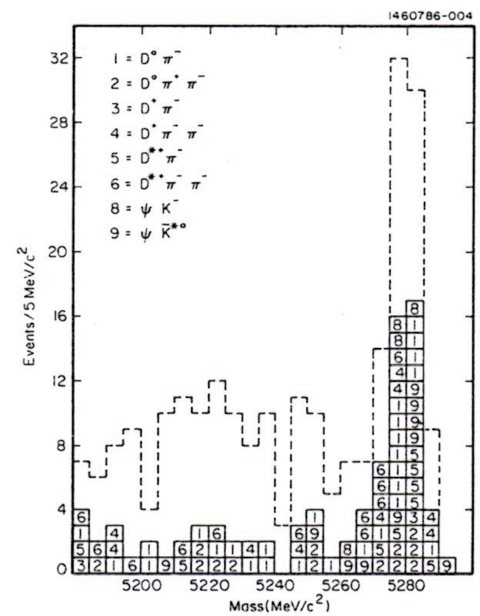
- Ruled out exotic behavior of b
  - No evidence for B→Xl+l+, B->Xbaryon
- Established b→c dominance
  - |Vub|/V|cb|<0.10 (Altarelli model)

$$B(B \rightarrow Xl\nu) = 0.110 \pm 0.003 \pm 0.005 \pm 0.005$$

  - With measured B lifetime at PEP:
    |Vcb|~0.04
- Measured the dominant inclusive & exclusive B→DX decays:
  - Consistent with b->c dominance
    - Initially, found an apparent Charm deficit, caused by incorrect Mark-III D branching ratios
  - Measured B->ΨX & B→J/Ψ K_S

PRL 59, 407(1987)





Early Period- CLEO I

- Important Charm Physics studies
- Discovered the "F" meson (Otherwise known as D_s)
  - Measured the correct Mass

  1970 +/- 5 +/- 5 MeV

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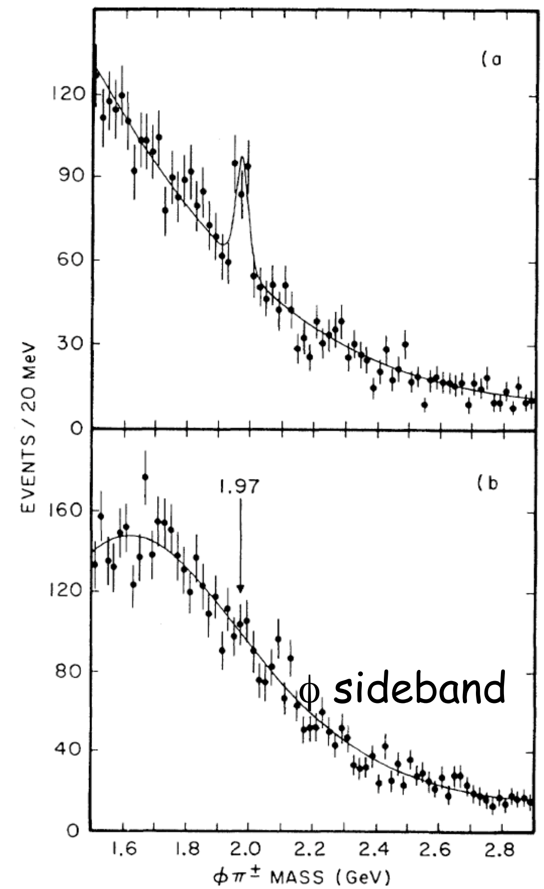
- Studied charm decays relevant to the "hot" issue of D^+ and D^0 lifetime ratio
  - $D^0 \rightarrow \phi K_s$

- Initiated a comprehensive program of Charm Baryon spectroscopy

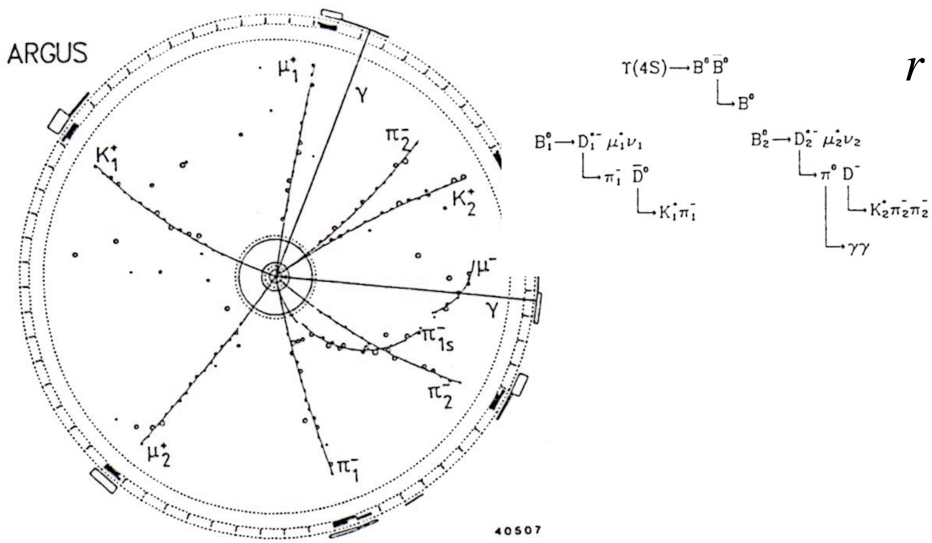


The CLEO-I.V (DR2)
The B^0 Mixing

Status in 1987

- Evidence for B (B_d & B_s) mixing seen in UA1 data

- Observed by ARGUS(88)



$$r = \frac{B(B \to \bar{B} \to \bar{X})}{B(B \to X)} = 0.21 \pm 0.08$$

- Confirmed by CLEO (88)[212/pb]

$$r = 0.18 \pm 0.05 \pm 0.06$$

$$\Delta m/\Gamma = 0.66 \pm 0.13 \pm 0.13$$

  - DR2 with dE/dx measurements was the key to CLEO's measurement

	unlike sign			like sign		
Dilepton types	e^+e^-	$\mu^+\mu^-$	μ^+e^-	$e^\pm e^\pm$	$\mu^\pm\mu^\pm$	$\mu^\pm e^\pm$
on $\Upsilon(4)$	186	66	223	28	6	39
on the continuum	4	2	0	1	1	0
Calculated Background						
$\Upsilon(4S)$ Fakes	9.4	6.3	17.2	3.8	2.2	6.7
	±2.7	±2.1	±5.2	±1.1	±0.7	±2.0
Cascade	2.0	0.5	1.9	11.6	2.8	11.4
	±0.8	±0.2	±0.8	±3.2	±0.8	±3.2
ψ	0.7	0.3	1.0	0.7	0.3	1.0
	±0.3	±0.2	±0.5	±0.3	±0.2	±0.5
Total Background						
$\Upsilon(4S)$	12.1	7.1	20.1	16.1	5.3	19.1
	±2.8	±2.1	±5.3	±3.4	±1.1	±3.8
Net Signal	167.0	57.	207.	11.9	0.7	19.9
Statis. error	±15.	±9.	±16.	±5.3	±2.5	±6.2
System. error				±3.6	±1.6	±3.8

•Large B mixing required/implied large m(top); mt>50 GeV:

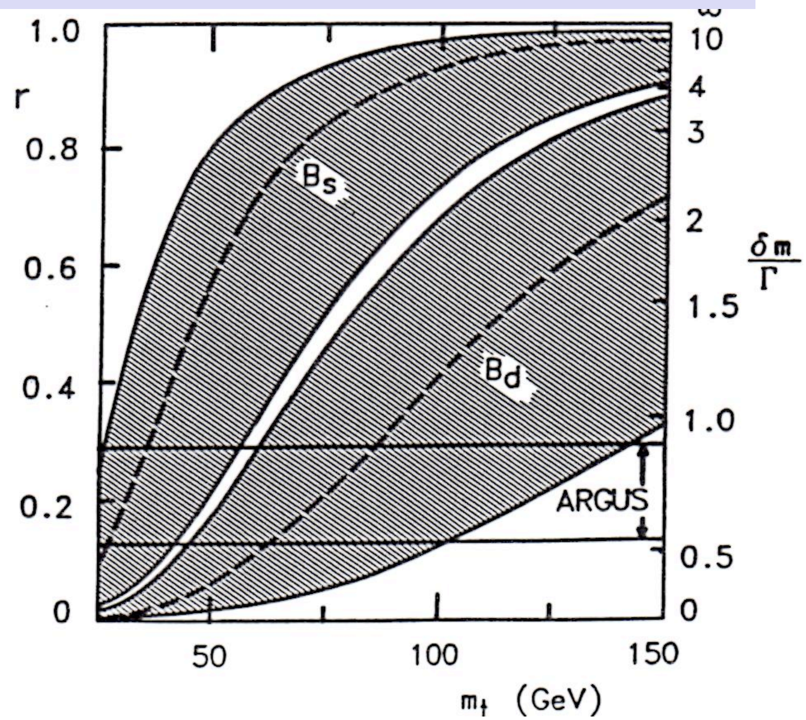
- •Relief for theorists who needed large m(t) to accommodate kaon CPV in SM
- • Not a good news for PEP & PETRA programs.

•Brought the b quark closer to acceptance in the SM weak isospin doublet structure.

- •Final acceptance came with TRISTAN's & LEP's measurements of forward-backward asymmetries

•Another major step toward the CPV program

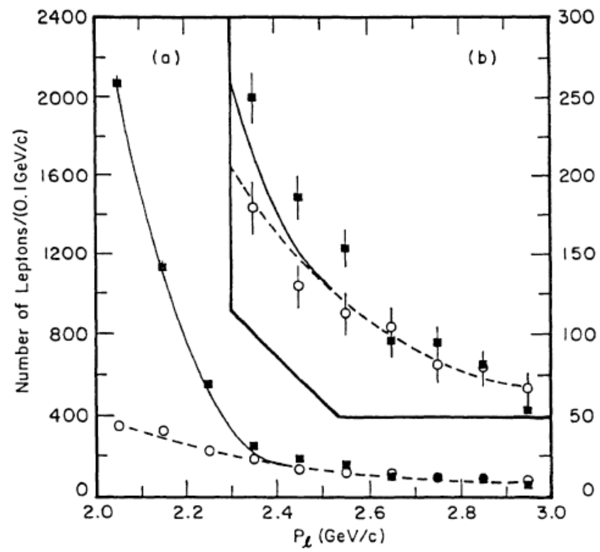
From Schmidt-Parzefall LP88



The CLEO-I.V (DR2)
The non-zero b->u

- Observation of b->non-charm decays
- First evidence of b->u by CLEO (PRL 64, 16(1990) & quickly followed by ARGUS

Another DR2 achievement:
Both the improved momentum resolution and dE/dx were crucial factors for this measurement.



$$\Delta B_{ub}(2.2,2.6) = (3.3 \pm 0.8 \pm 0.8) \times 10^{-4}.$$

•Together with long B lifetime and large B^0 mixing, now all elements of CPV program were in place.

•Extracting $|V_{ub}|$ involved very large theoretical uncertainties.

TABLE III. $d(p)$ calculated from various theoretical models of $b \to u l \nu$ decay, the corresponding values of $|V_{ub}/V_{cb}|^2$, and weighted averages of the two momentum intervals.

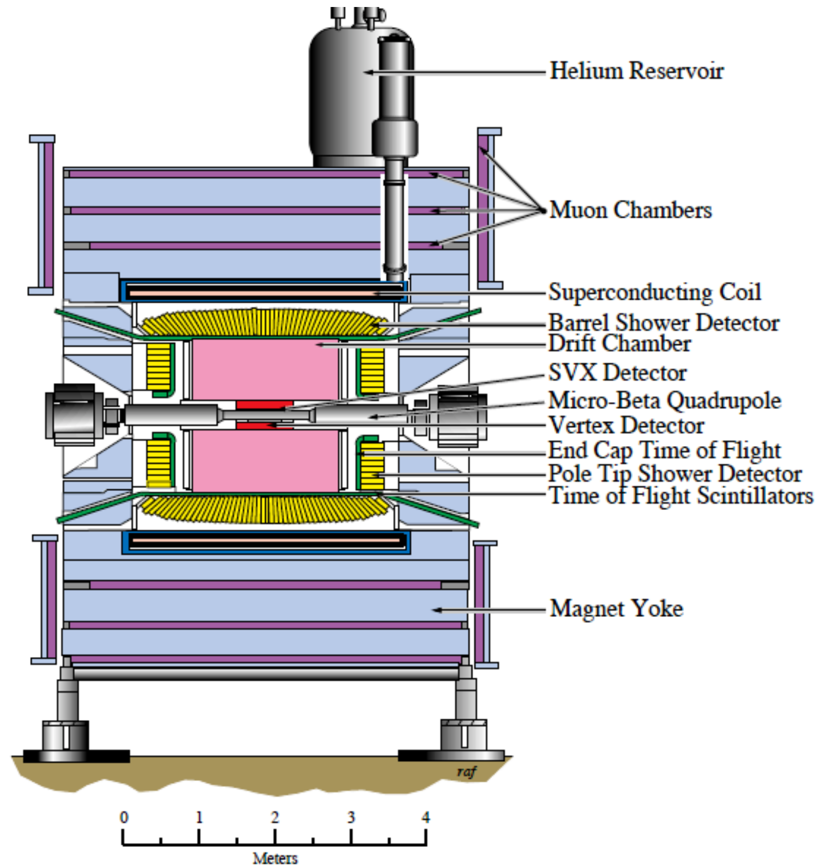
Model	2.2–2.4 GeV/c $d(p)$	2.2–2.4 GeV/c $10^2|V_{ub}/V_{cb}|^2$	2.4–2.6 GeV/c $d(p)$	2.4–2.6 GeV/c $10^2|V_{ub}/V_{cb}|^2$	Average $10^2|V_{ub}/V_{cb}|^2$
ISGW	0.12	1.3 ± 0.8	0.05	3.6 ± 1.0	2.2 ± 0.6
ACCMM	0.29	0.5 ± 0.3	0.13	1.4 ± 0.4	0.8 ± 0.2
WSB	0.20	0.8 ± 0.5	0.10	1.8 ± 0.5	1.3 ± 0.4
KS	0.27	0.6 ± 0.4	0.16	1.1 ± 0.3	0.9 ± 0.2
RDB			0.12	1.5 ± 0.4	

A New Detector for B Decays: CLEO-II

The principal goals:

- Efficient detection of both charged & neutral hadrons, as well as e & mu

- The solution:
  - Tracking, Calorimetery and PID all inside the magnet.
  - CSI(Tl)- with PIN diodes as light sensor- emerged as the optimal choice.
    - Much Less hygroscopic than the standard choice- NaI(Tl)- & light output best matched to photodiode response.
  - DR2: Small cell Drift chamber simultaneous readout of ionization charge & drift time info.
  - The instrumented magnet yoke with LST sensors (in proportional mode) as hadron absorber for muon ID



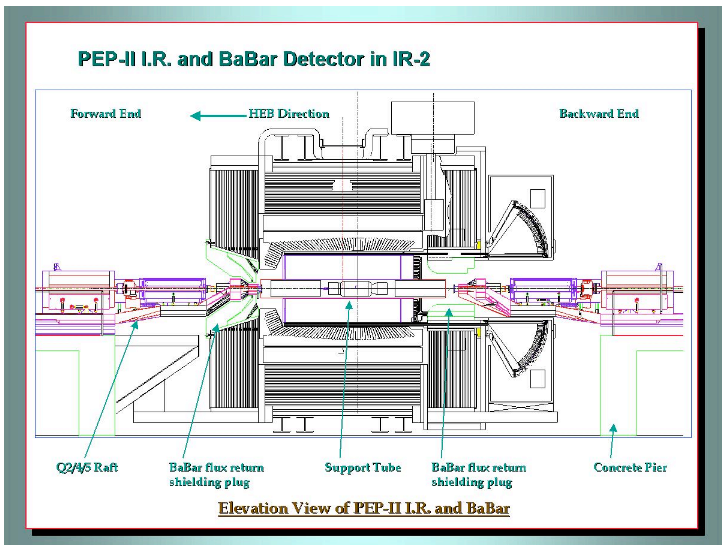
The CLEO II concept at the B factories

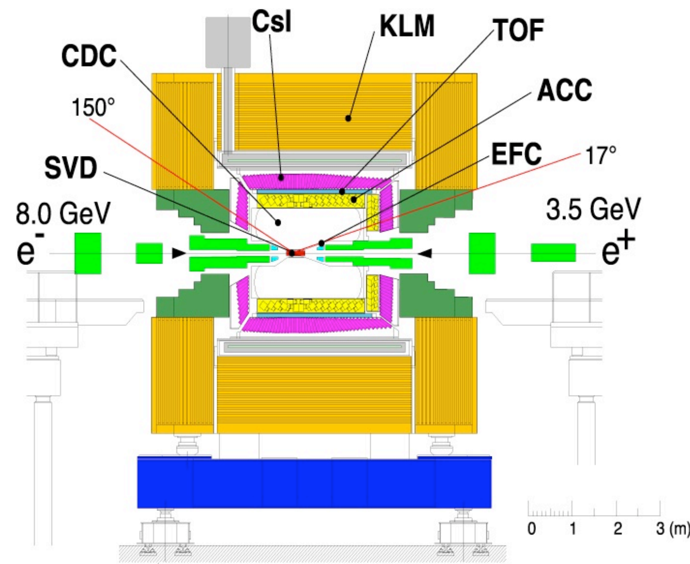
•Much of the CLEO-II concept was applied to the design of BaBar and Belle:

- EM calorimeter: CSI(Tl) with Photodiode readout-
- BaBarians benefited greatly from the experience of DR2 on both what-to-do and what-not-to-do.

•But they faced additional challenges & higher rate issues to deal with:

- Precise vertexing near IP & tracking critical for CPV measurements
- PID in much wider momentum range (up to 4 GeV)





CSI(Tl) Calorimeters performed remarkably well throughout the life of BaBar and Belle and are now destined for Super B factories at 100 times the intensity! A great testimony to the wisdom & beauty of the CLEO-II concept

CLEO-II concept at the Super B factories

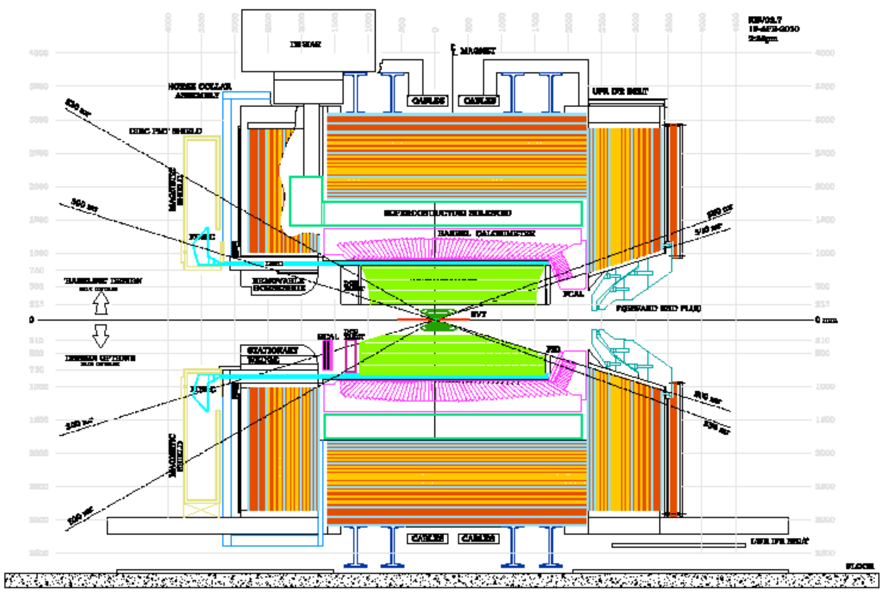
• The CLEO II concept, augmented with BaBar-like PID concept, lives yet another life in the next generation of flavor physics experiments:

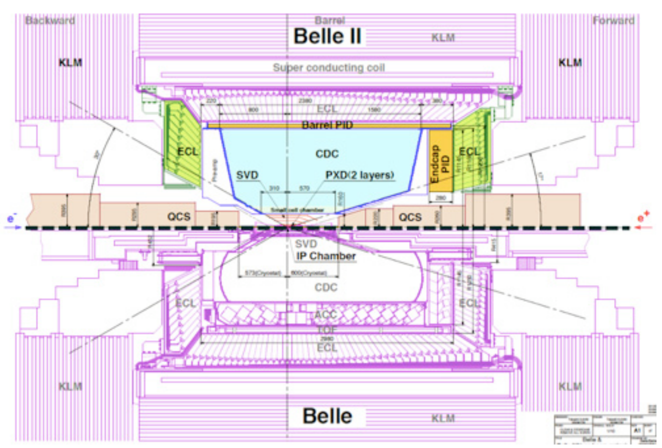
•Both Super B experiments have determined that the existing barrel CsI(Tl) calorimeters are the right solutions and will survive the rate at the Super B machines. Other solutions needed for endcaps.

•PID: Cherenkov light in quartz:

•Italy: BaBar's DIRC with new focusing camera with Multi-anode PMT's

•Japan:Time-of-Propagation with MCP PMT





An Outside View from the B factories

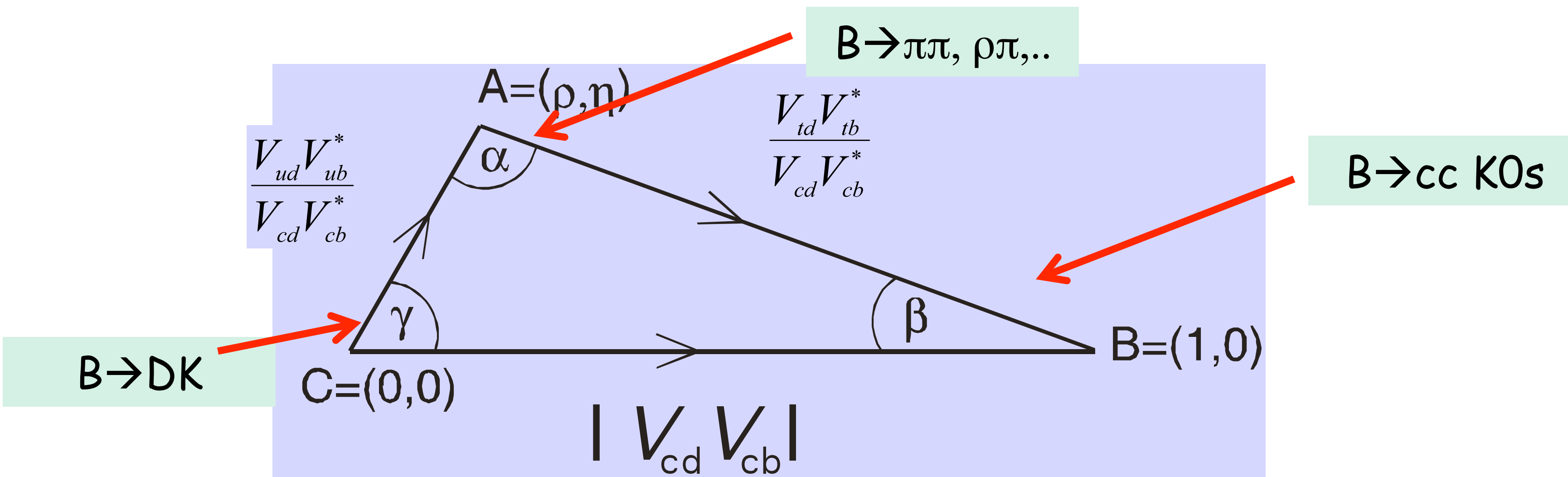
The CPV program at the B factories

The program in a nutshell:

•Observe the breaking of CP symmetry in B decays

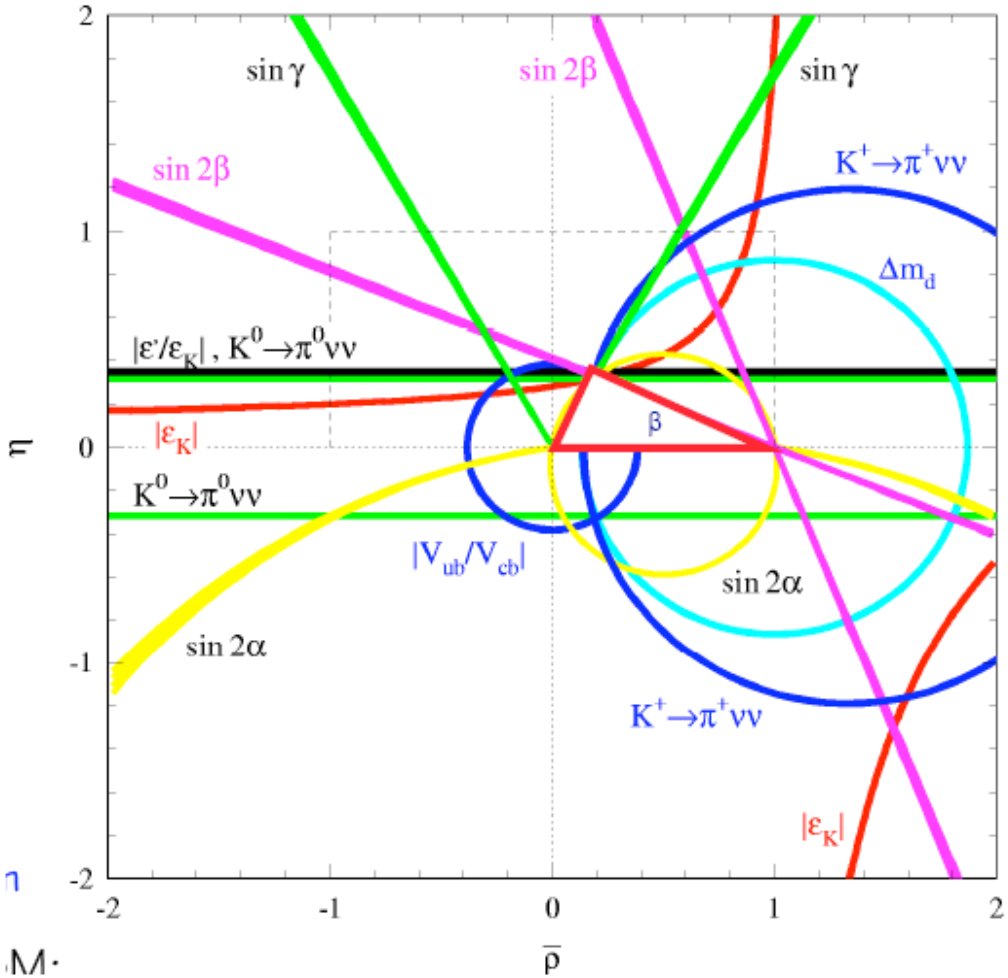
•Test the CKM picture – the Unitarity test.

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

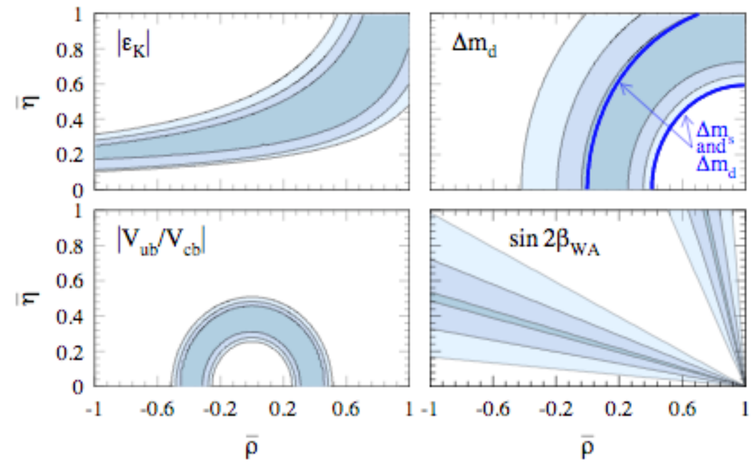


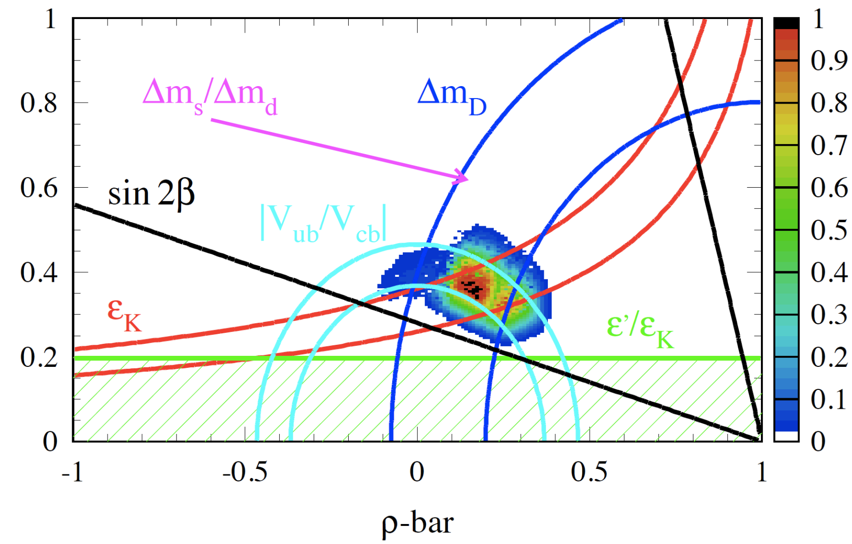
- Unitarity Tests : Measure the sides and angles→ Overconstrain the triangle
  - check: $\alpha + \gamma + \beta = 180$
  - Check the consistency of CP violating and CP conserving measurements

CKM Observables



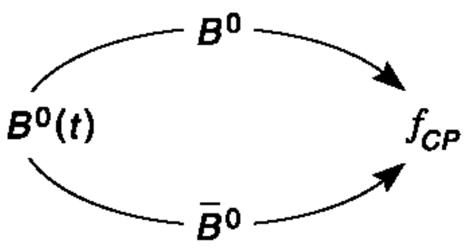
State of the knowledge of CKM in 2001 (CKM-fitter)

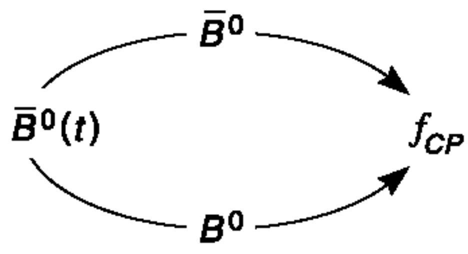




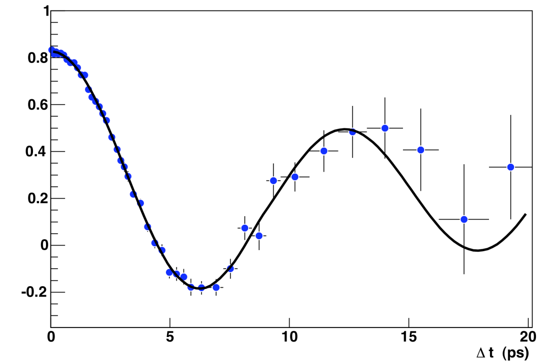
Measuring time-dependent CPV

Back to The Bigi & Sanda's method

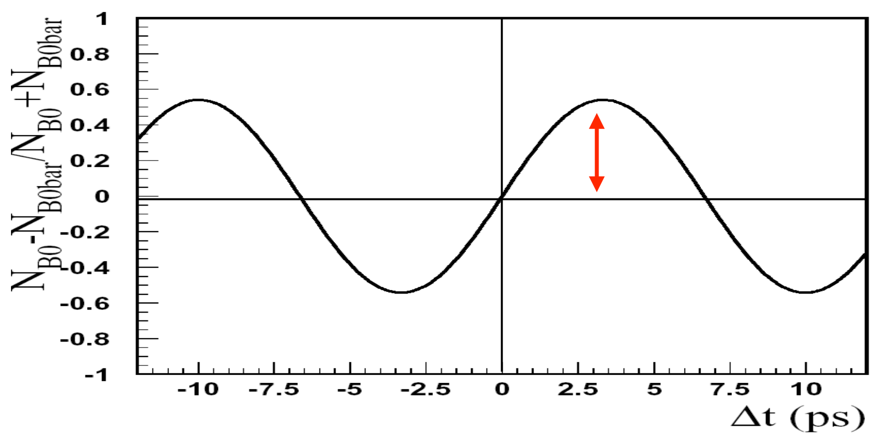




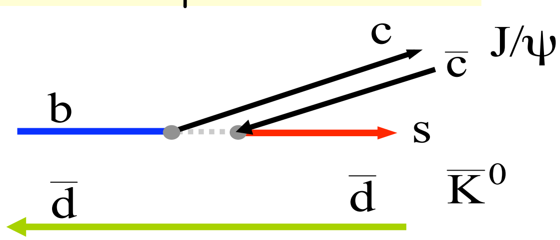
$B^0 \Leftrightarrow \bar{B}^0$ Oscillation at BaBar



$$A_{cp}(t) = \frac{\Gamma(B^0(t) \to f_{cp}) - \Gamma(\bar{B}^0(t) \to f_{cp})}{\Gamma(B^0(t) \to f_{cp}) + \Gamma(\bar{B}^0(t) \to f_{cp})} = \sin 2(\phi_m + \phi_D) \sin \Delta m t$$

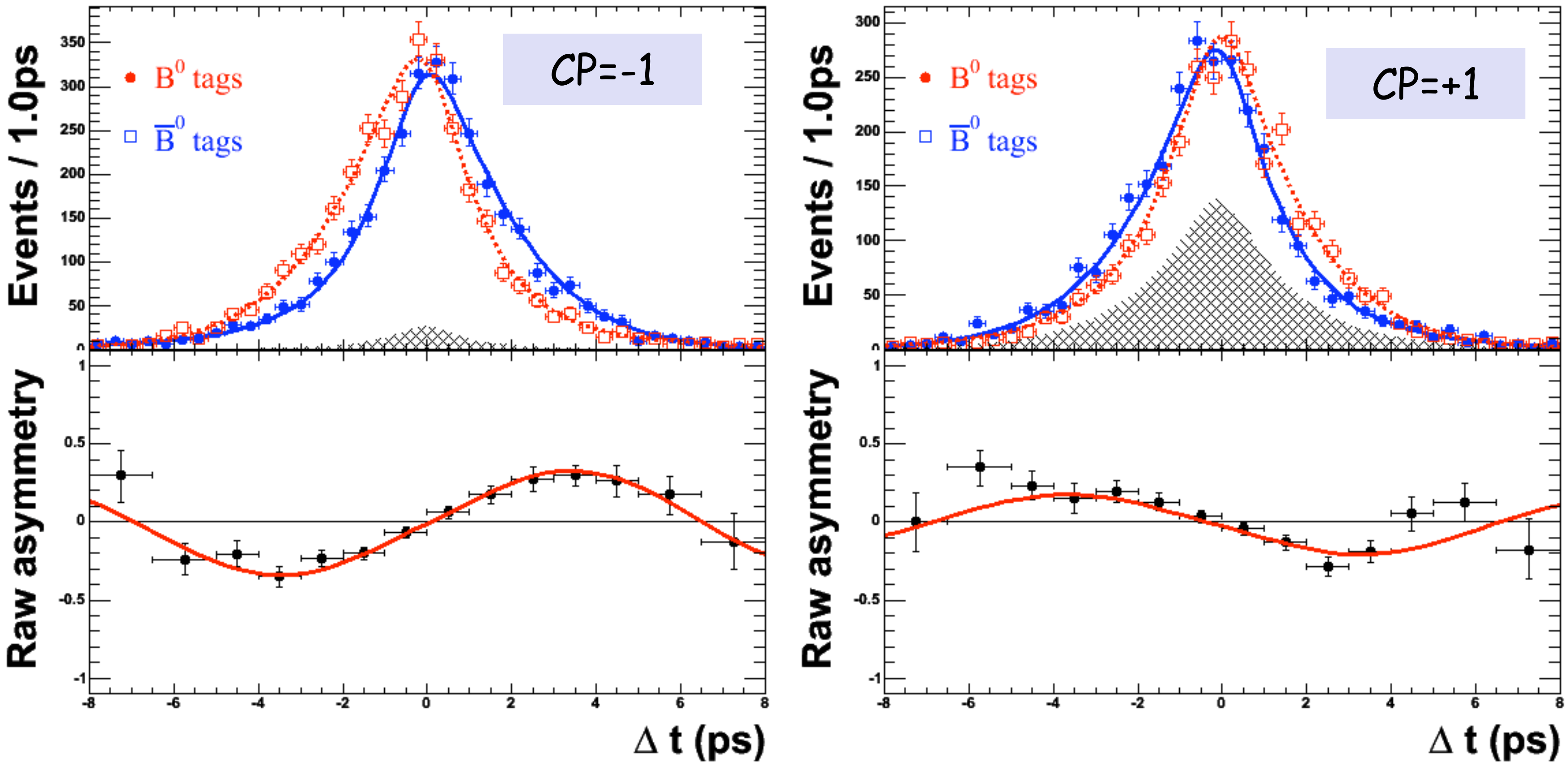


e.g. $f_{cp} \to J/\psi\, K^0_s$



$$A_{CP}(t) = -\eta_{CP} \sin 2\beta \sin(\Delta m t)$$

Measurement of sin2β

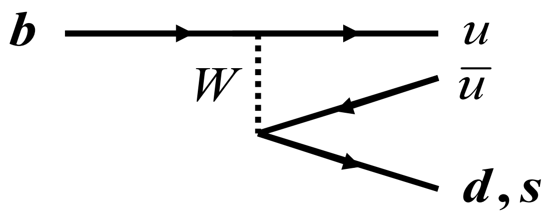


Sin2β=0.691 +/- 0.029(stat) +/- 0.014(syst)

$$\beta = (21.15^{+0.90}_{-0.88})^{O}$$

CLEO &Measurement of α: Penguins

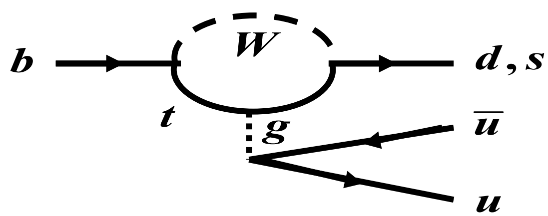
- The ideally b->u dominated decays [$B^- \to \pi\,\pi$: ($\pi^+\pi^-$, $\pi^+\pi^0$, $\pi^0\pi^0$), $\rho\pi$, $\rho\rho$] serve "golden" modes- analog of $J/\psi K_s$ for β



$$\lambda = \eta \frac{V_{tb}^{*} V_{td} V_{ub} V_{ud}^{*}}{V_{tb} V_{td}^{*} V_{ub}^{*} V_{ud}} = e^{i2\alpha}$$

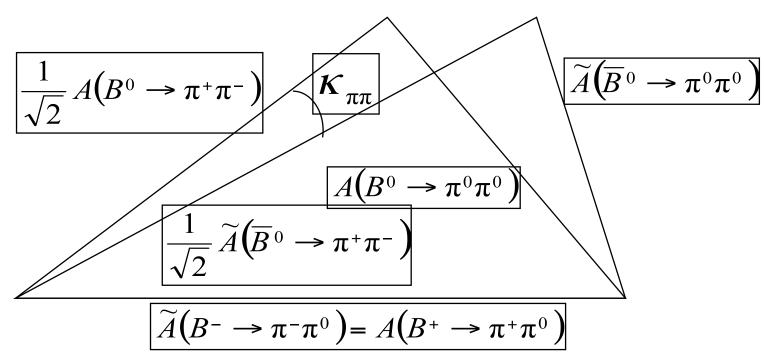
$$C = 0 \quad \& \quad S = \sin(2\alpha)$$

But in reality there are other contributors, which complicate life:



$$\lambda = e^{2i\alpha} \frac{1 + |\frac{P}{T}| e^{i\delta} e^{i\gamma}}{1 + |\frac{P}{T}| e^{i\delta} e^{-i\gamma}}$$

Isospin analysis to the rescue:
Need all elements of B^0 and $B^0 \to \pi\pi$
➔ α with 8- fold ambiguity [Gronau & London]



CLEO & measurement of α

Observation of B→Kπ: Gluonic penguins in B decays

•CLEO observed B→Kπ final states [PRL 80, 3456(1998)]

The Analyses involved π/K separation primarily using dE/dx

•Evidence for B→$\pi^+\pi^-$

[PRL 85, 515(2000)]

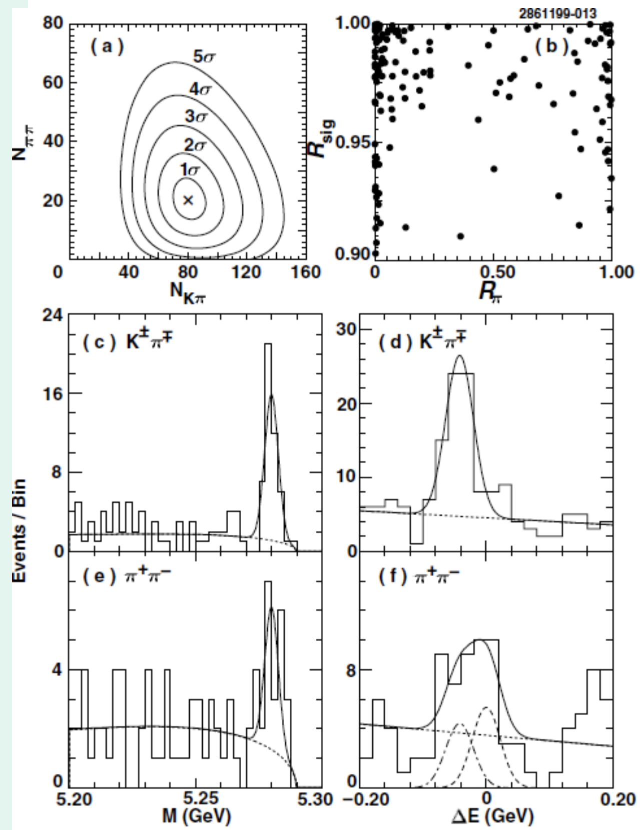
➢Large B→Kπ

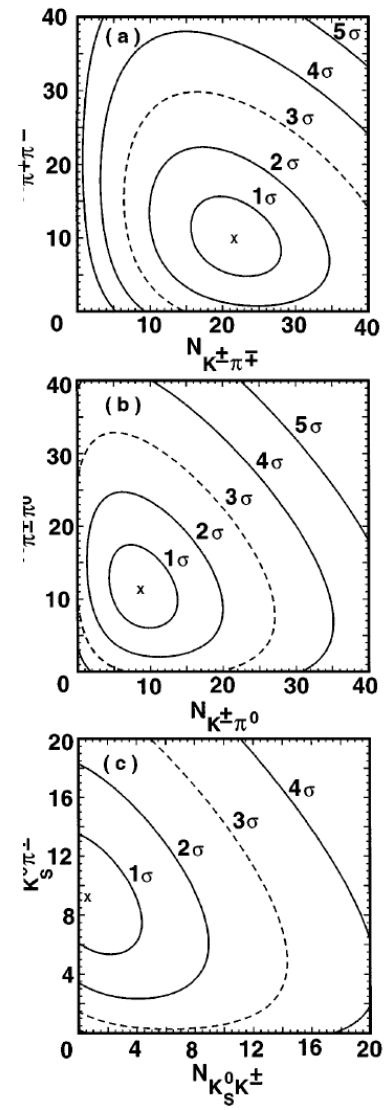
➢First evidence for gluonic penguins in B decays
➢Good news for Direct CPV

➢ B→$\pi\pi$ seen- at smaller Br than Cabibbo suppressed B->Kπ

➢Suggestive of of large penguin component in B->$\pi\pi$, as well.
Bad news for measuring α

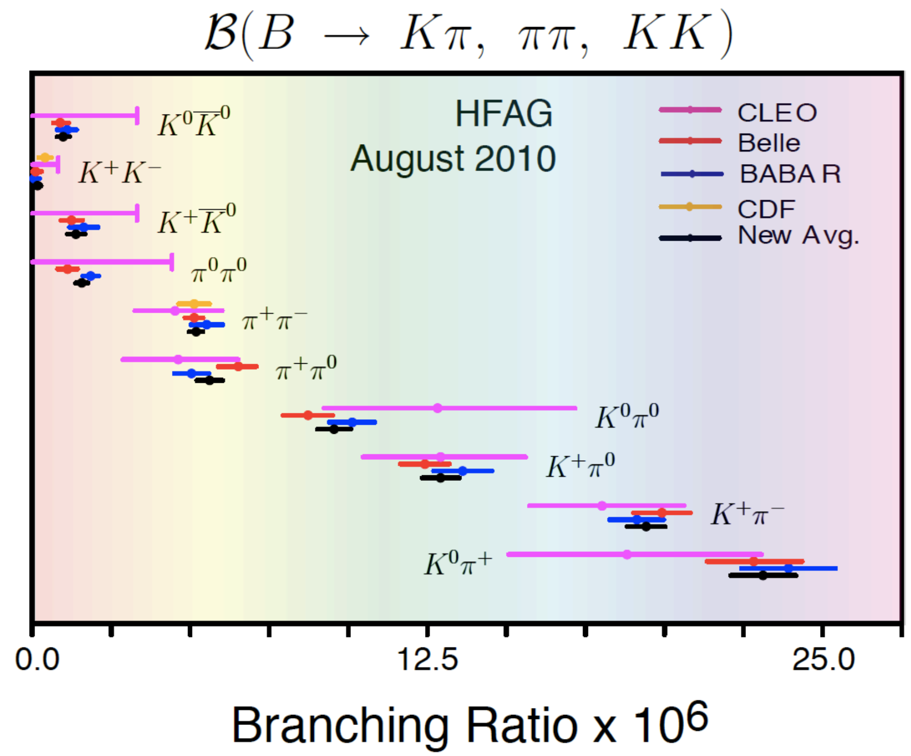
Confirmed by the observation of large B→$\pi^0\pi^0$ by BaBar (2003)



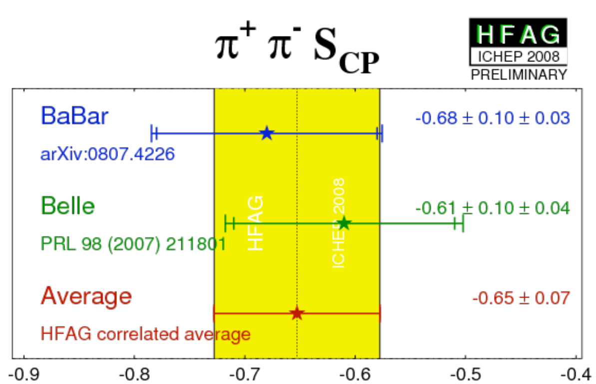


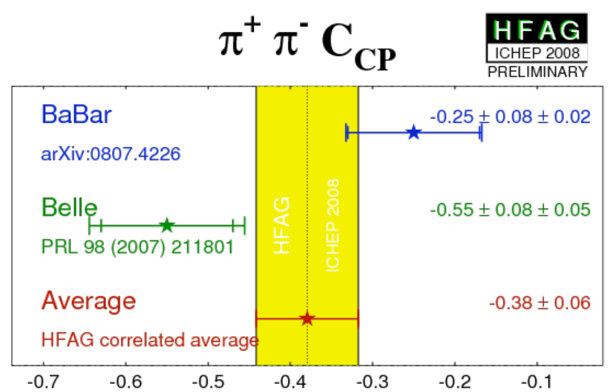
CLEO & measurement of α

- CLEO measurements were confirmed at the B factories
  - Observed $B \to \pi^0\pi^0$ large Br confirmed large penguins



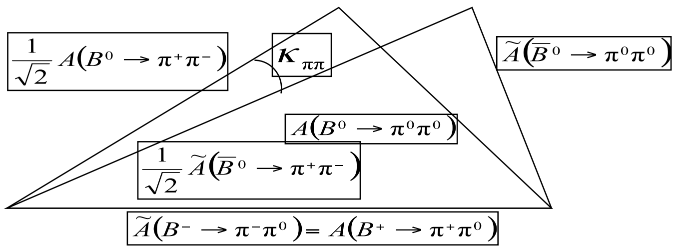
- BaBar & Belle expanded the program to Time-dependent CP asymmetries S & C as well as direct CPV in all channels





More on the story of α

Br& CPV in B→ππ

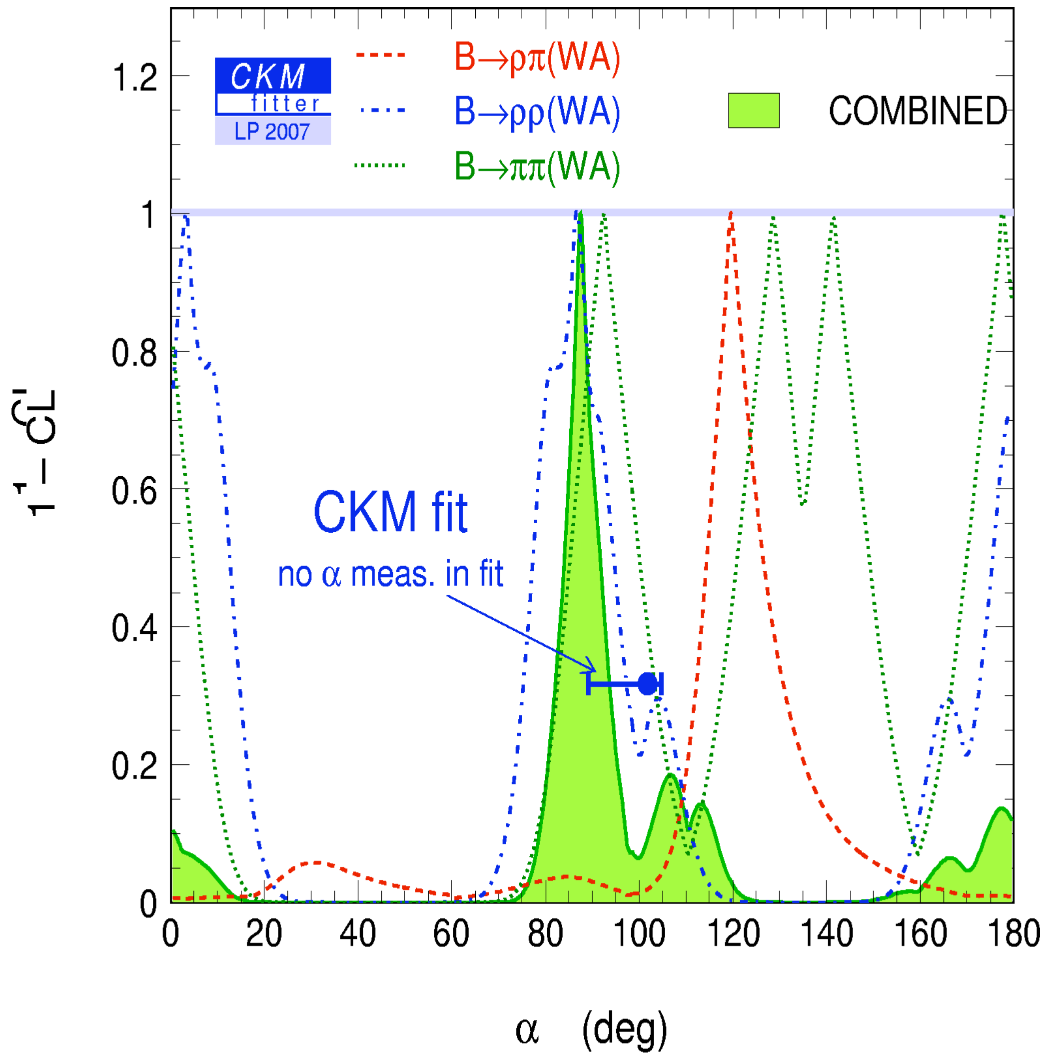


The full Time-dependent Dalitz Analysis of

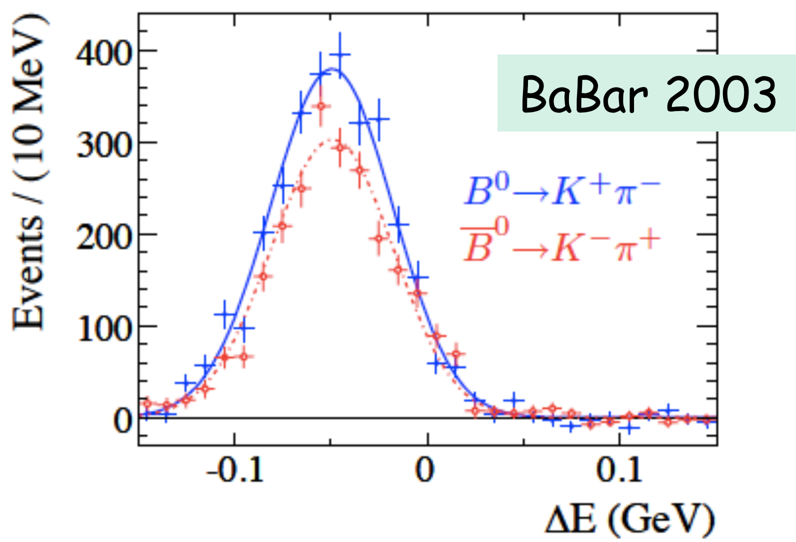
B→πππ($\rho^+\pi^-$, $\rho^-\pi^+$, $\rho^0\pi^0$, $\pi^+\pi^-\pi^0$)

The entire B→ρρ components for isospin analysis & Time-dependent CPV

B→πππ($\rho^+\rho^-$, $\rho^+\rho^0$, $\rho^0\rho^0$)



B→Kπ: 1st observation of Direct CP violation in B decays



$$\frac{N(\overline{B}^0 \to K^-\pi^+) - N(B^0 \to K^+\pi^-)}{N(\overline{B}^0 \to K^-\pi^+) + N(B^0 \to K^+\pi^-)}$$

$$= -0.107 \pm 0.016^{+0.006}_{-0.004}$$

The Kπ puzzle: One of the rare sources of tension with SM

$$A_{CP}(B^-(\bar{b}u) \to K^+\pi^0) - A_{CP}(B^0(\bar{b}d) \to K^+\pi^-) - = 0.148 \pm 0.028$$

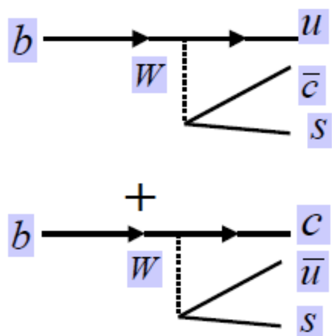
(HFAG-average)

Possible NP contributions or an innocent SM effect (e.g. large "color suppressed")

Needs a complete analysis of the B→Kπ system ($K^+\pi^-$, $K^+\pi^0$, $K^0\pi^0$, $K^0\pi^+$) system to rule out the SM hypothesis – current data consistent with SM.

CLEO & Measurement of γ : strong phases

γ is measured by exploiting direct CPV in modes involving :
b->c(us) & b->u(cs)



$B^- -> \bar{D}^0 K^-$

B-→(D->f) K-
f common to D^0 & $\overline{D^0}$

$B^- -> D^0 K^-$

$$A[B^- \to (D \to f)K^-] = A_c A_f e^{i(\delta_c + \delta_f)} + A_u A_{\bar{f}} e^{i(\delta_u + \delta_{\bar{f}} - \gamma)}$$

Rates and asymmetries depend on γ & strong phases $\delta_B = \delta_u - \delta_c$ & $\delta_D = \delta_f - \delta_{\bar{f}}$

f=D_{CP} (Gronau-London-Wyler)(GLW method) (small asymmetry)

f=DCSD (Atwood-Duniets-Soni)(ADS Method) (Need information on δ_D)

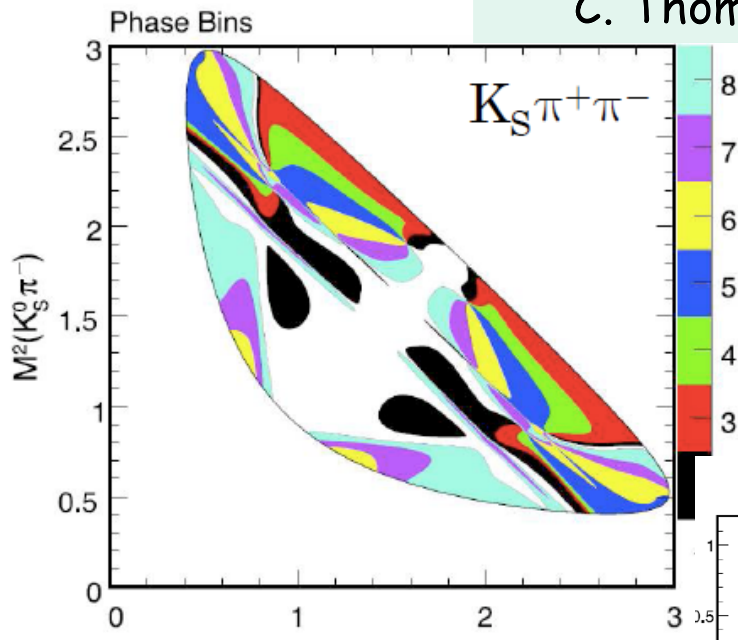
f= Dalitz analysis of $D^0 \to K_s \pi^+ \pi^-$ (GGSZ) (combines features of GLW & ADS depending on the location in Dalitz plot)- <u>the dominant method</u>

A major souce of uncertainties due to modelling of the D→$K_s\pi\pi$- Dalitz plot (amplitudes and the relative phases- currently modeled and obtained from flavor tagged D decays)- ~3-7°

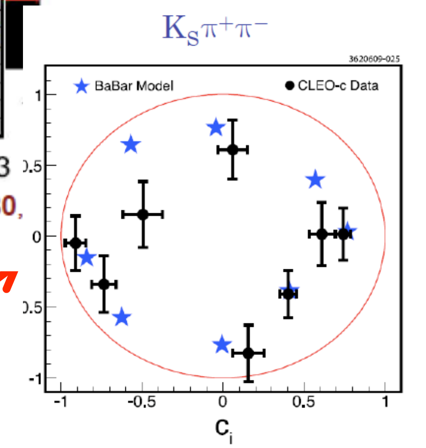
CLEO-c method for determining the strong phases

C. Thomas, FPCP2010

- CLEO-c uses coherently produced D^0D^0(bar) pairs to determine average cos(δ) and sin(δ) in bins of DP:
- Combination of flavor tagged, CP tagged and $K_s\pi^+\pi^-$ tagged events allows for a model independent- binned- measurement of the strong phase difference.
- Statistical error of CLEO-c replaces modeling errors- to improve with more data from BESS-III



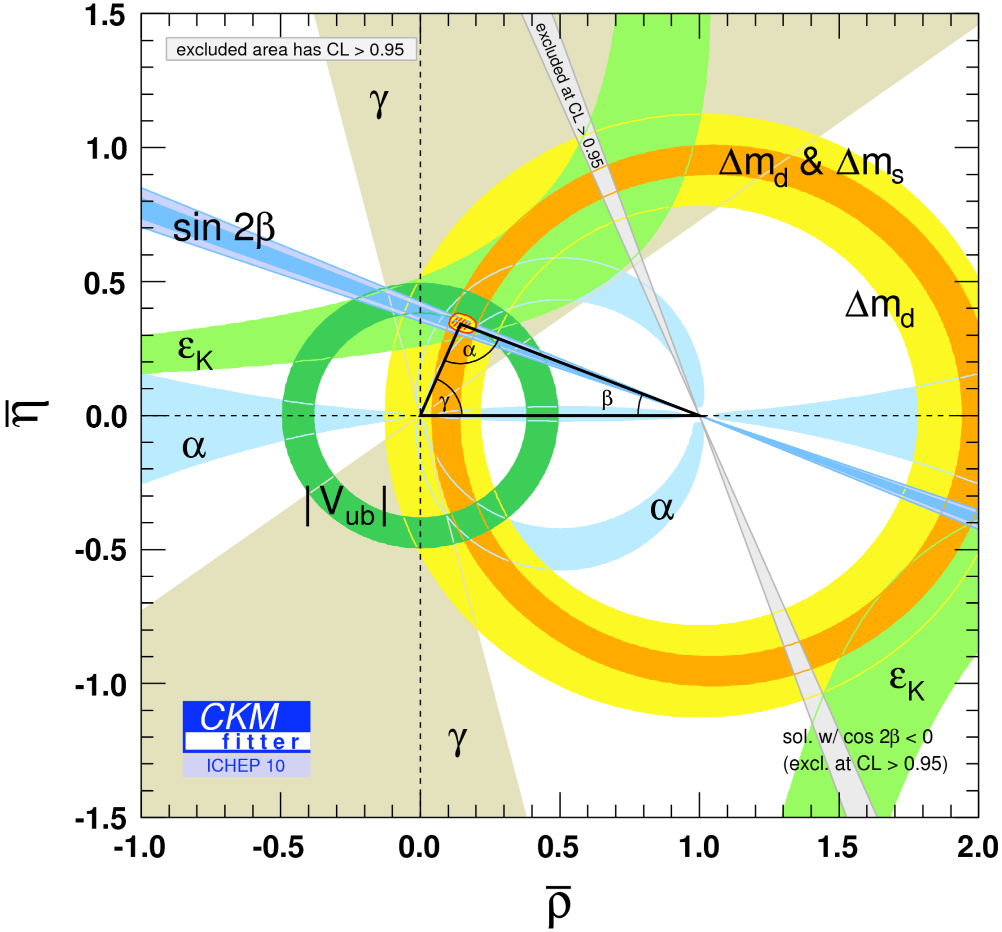
Phys. Rev. D **80**, 032002 (2009)



Compared with BaBar model

LHCb- as the custodian of the γ measurement in the next few years- can reach an accuracy of ~2°. CLEO-c/BESS-III results are expected to help limit modeling error in these measurements to this level or better (for D->Ks$\pi\pi$)

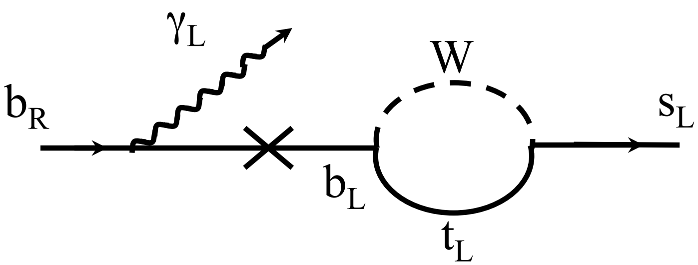
The Status of the CKM picture



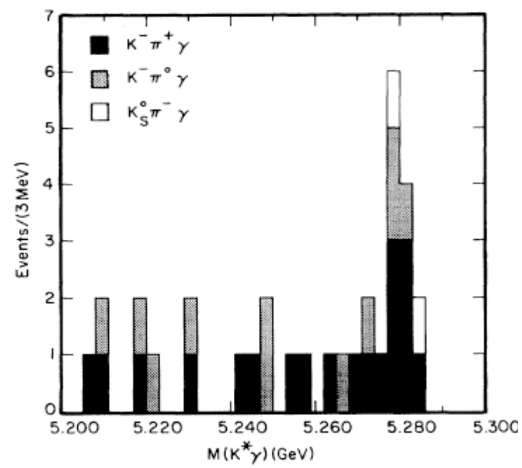
•CLEO remained a major contributor to measurements of $|V_{cb}|$ and $|V_{ub}|$ & helped develop new methods for improved theoretical treatment- including the use of b->sγ process to control the theoretical inputs. Both are now dominated by theoretical uncertainties. CLEO-c measurements of form factors & decay constants in D decays are expected to further help control theory errors.

Overall, good agreement between CP violating and CP conserving measurements

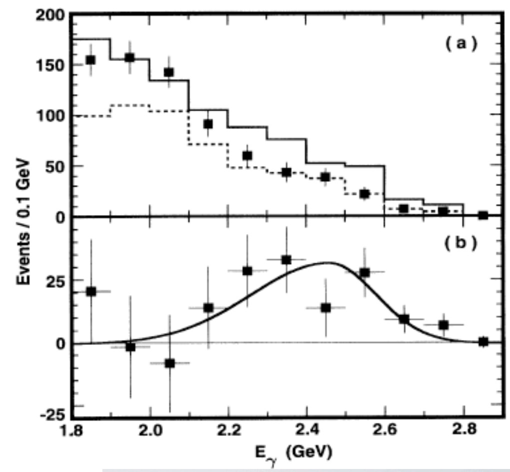
A major milestone in Flavor Physics:
CLEO's discovery of EW radiative B decays

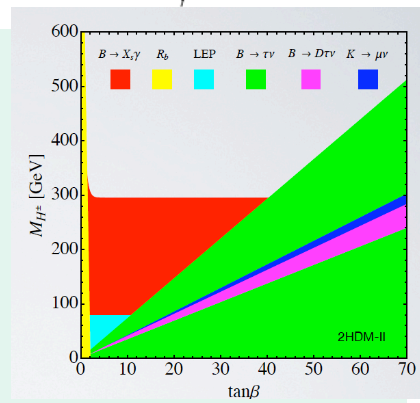


CLEO 1993



Inclusive b->sγ – 1995





A powerful probe of New Physics

Sensitive to charged Higgs, SUSY, extra dimension,……

Charged Higgs Mass>300 GeV in 2HDM –II

Consistency with SM sets sever constraints on models of New Physics:

Current status:

Theory: $$B(B \to X_s\gamma)_{NNLL}[E_\gamma > 1.6GeV) = (3.15 \pm 0.23) \times 10^{-4}$$

Expt(HFAG) $$B(B \to X_s\gamma)[E_\gamma > 1.6GeV) = (3..52 \pm 0.23 \pm 0.09) \times 10^{-4}$$

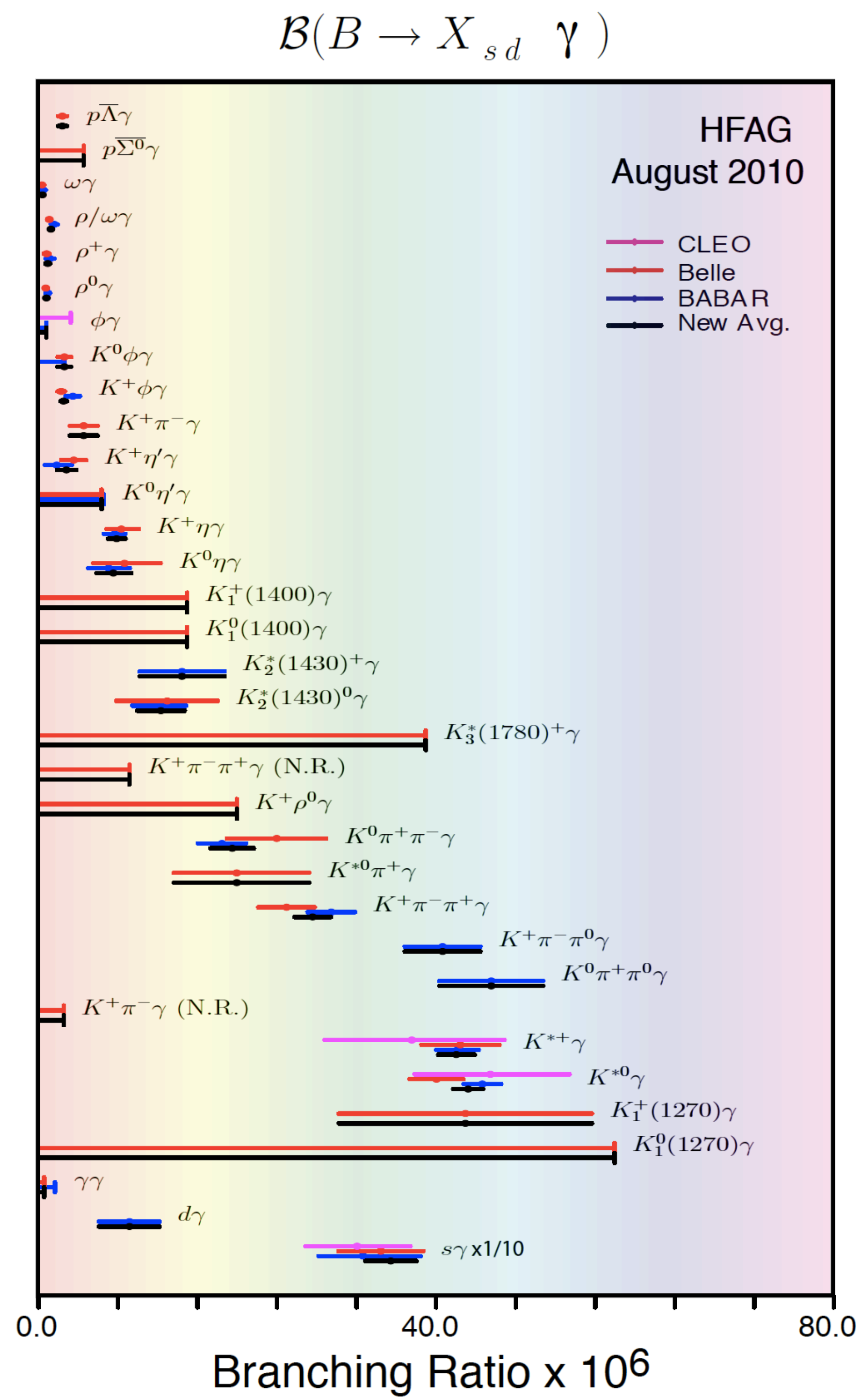
(error due to extrapolation to E>1.6)

•For the inclusive rate measurements CLEO remained competitive with B factories, where running was optimized for CPV measurements- not much continuum running. New methods, e.g., lepton tagging, were need to reduce BKG- at the cost of statistical power.

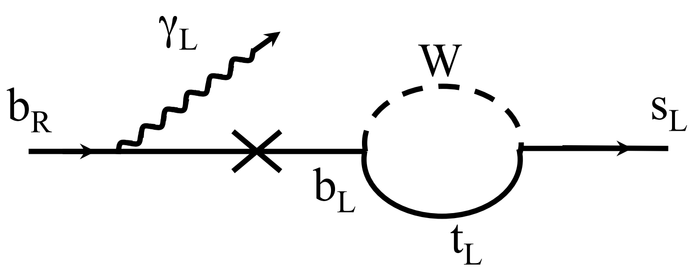
•Energy threshold have now been lowered to E>1.7 GeV (Belle).

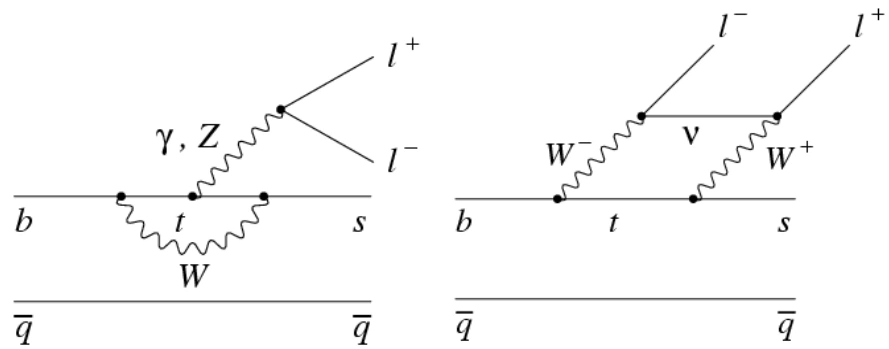
•Constraint on direct CPV: (in SM ~0)

$$A_{CP}(B \to X_s \gamma) = -0.012 \pm 0.028$$

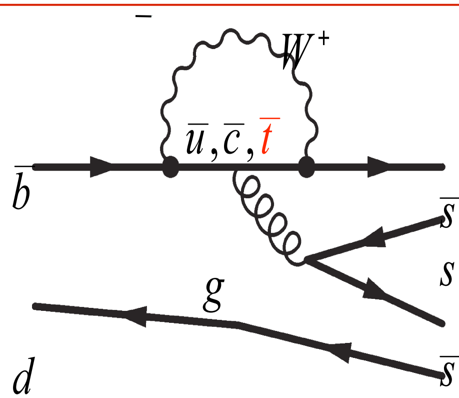


- Building on CLEO's discovery, B Factory experiments greatly expanded the reach of the radiative B decays

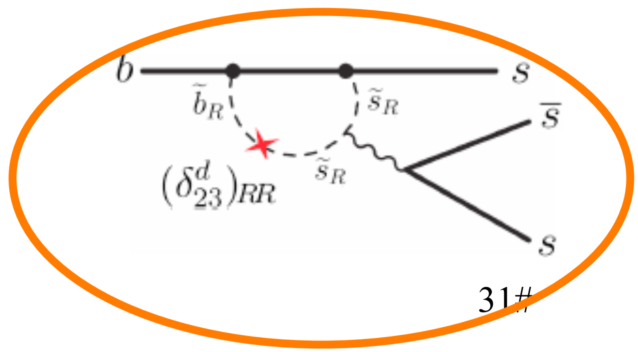




- Rates
- Photon helicity in b→$\gamma_L s$ (γ left-handed in SM)
- Direct CP violation – nearly zero in SM
- In B→K(*)ll- q^2 dependence of the rate; FB asymmetry of lepton, Longitudental polarization of K*, CPV in FB asymmetry, Isospin asymmetry,.. Search for modification of Wilson coefficients C7, C9, C10 & new operators
- B→Kνν −observation left to the SuperB experiments

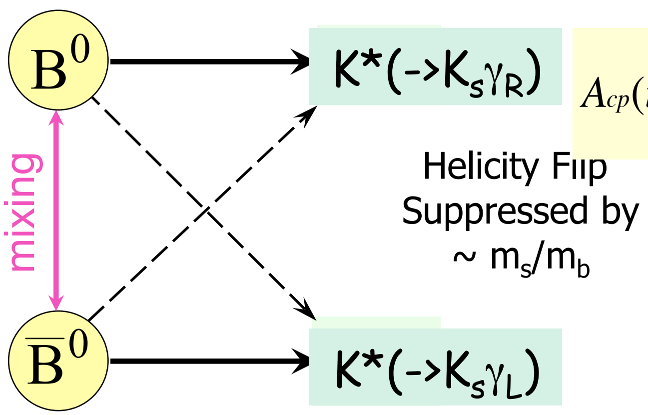


Observable: Rates, CPV, polarization,..



Example: Probing right-handed currents through radiative B penguins

For in $b \to \gamma_L s$ - employ time-dependent CP asymmetry to determine the helicity of photon: proposed by Atoowd, Gronau, & Soni (1997)



$$A_{cp}(t) = \frac{\Gamma(\bar{B}^0(t) \to f_{cp}\gamma) - \Gamma(B^0(t) \to f_{cp}\gamma)}{\Gamma(\bar{B}^0(t) \to f_{cp}\gamma) + \Gamma(B^0(t) \to f_{cp}\gamma)} = S_{f_{cp}\gamma} \sin \Delta mt - C_{f_{cp}\gamma} \cos \Delta mt$$

$$S_{K^*\gamma} \propto \eta_{cp} \frac{A[\bar{B}^0 \to K^{*0}(\to K_s^0 \pi)\gamma_R]}{A[\bar{B} \to K^{*0}(\to K_s^0 \pi)\gamma_L]} \sin 2\beta$$

In SM: $\mathbf{S_{K^*\gamma}}$ ~0.04

The value of $S_{K^*\gamma}$ is a measure of the presence a right-handed current in the process- present in many NP models.

Current data: $\mathbf{S_{K^*\gamma}} = -0.16 \pm 0.22$

With 50/ab at Super B experiments, expect: $\sigma(\mathbf{S_{K^*\gamma}})$~ 0.02

Flavor Physics in the LHC era

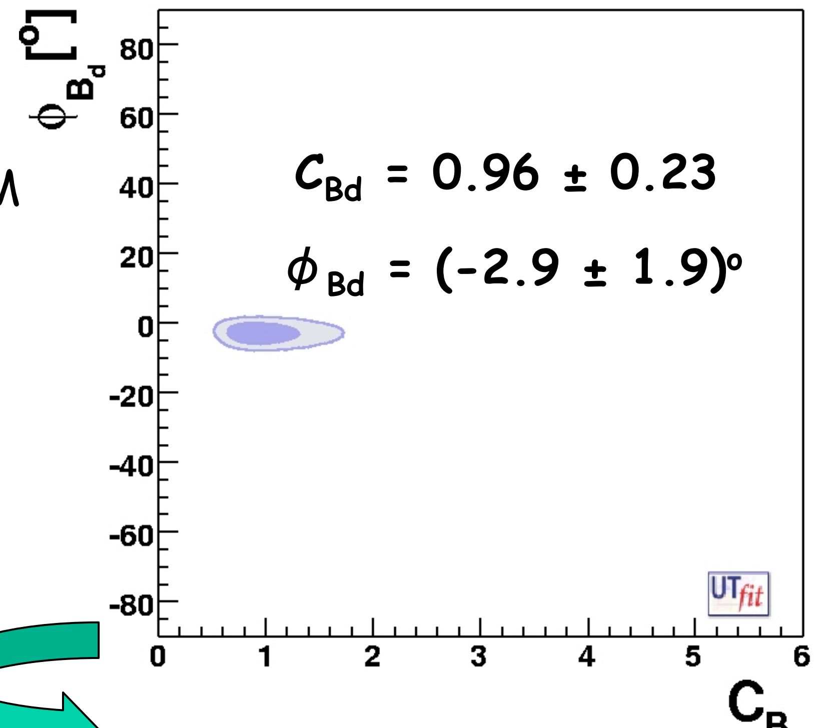
Continuing on CLEO's path

Any room for NP in the CKM parameters?

The global fits (CKMfitter and UTfit) have tried model independent methods to determine the size & phase of non-SM component.

e.g. Utfit, allows for deviation from SM mixing amplitude & phase::

$$C_{Bd} \; e^{2 i \phi_{Bd}} = \frac{\langle \overline{B}_d | H_{eff}^{full} | B_d \rangle}{\langle \overline{B}_d | H_{eff}^{SM} | B_d \rangle}$$



Sever constraint on additional contributions.
As long as the phase is near SM, some NP contribution is allowed but at around SM contribution or less.

NP implications of the flavor physics agreement with SM

For example see Y. Nir arXiv:0708.1872, or Grossman, Ligeti, Nir (arXiv: 0904.4262)

M. Bona et al (UTfit) hep-ph-0509219)

Allow for tree level ΔF=2 (FCNC) $\frac{z_{bs}}{\Lambda_{NP}^2}(\bar{s}_L\gamma_\mu b_L)^2$ altering mixing rate, CPV,..

Comparison with data:

Y. Nir et al

For z_{ij}=O(1), Scale of NP>>TeV

$$\Lambda_{\rm NP} \gtrsim \begin{cases} \sqrt{\mathcal{I}m(z_{sd})}\ 2\times 10^4\ TeV & \epsilon_K \\ \sqrt{z_{sd}}\ 1\times 10^3\ TeV & \Delta m_K \\ \sqrt{z_{cu}}\ 9\times 10^2\ TeV & \Delta m_D \\ \sqrt{z_{bd}}\ 4\times 10^2\ TeV & \Delta m_B \\ \sqrt{z_{bs}}\ 7\times 10^1\ TeV & \Delta m_{B_s} \end{cases}$$

For NP at ~ TeV, suppressed FCNC

$$\begin{aligned} \mathcal{I}m(z_{sd}) &\lesssim 6\times 10^{-9}\ (\Lambda_{\rm NP}/TeV)^2, \\ z_{sd} &\lesssim 8\times 10^{-7}\ (\Lambda_{\rm NP}/TeV)^2, \\ z_{cu} &\lesssim 1\times 10^{-6}\ (\Lambda_{\rm NP}/TeV)^2, \\ z_{bd} &\lesssim 6\times 10^{-6}\ (\Lambda_{\rm NP}/TeV)^2, \\ z_{bs} &\lesssim 2\times 10^{-4}\ (\Lambda_{\rm NP}/TeV)^2. \end{aligned}$$

It is clear that Flavor Physics is already sensitive to NP at energy scales well above TeV & has as an interesting message on the NP flavor structure.

A program for Precision Flavor Physics

- If New Physics is found at LHC, then its flavor structure must satisfy the current sever constraints. This structure needs to discovered:
  - New CPV phases
  - Flavor interactions involving right-handed currents
  - FCNC processes could be present at the lowest level
  - Lepton Flavor Violation in charged leptons,….

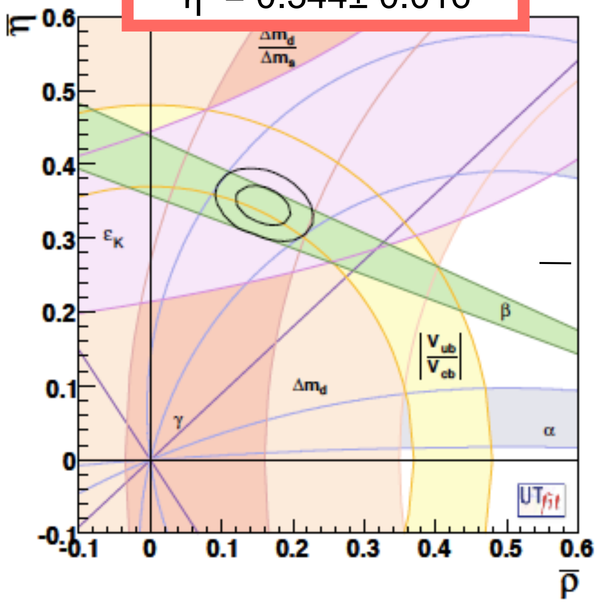
- If no New Physics is found at the TeV energy regime:
  - Then, Flavor physics will serve as a powerful way of probing physics at much higher energies.

The key experimental handles:

- CKM parameters (aiming for O(1%) level)
- FCNC processes
- Lepton Flavor Violation

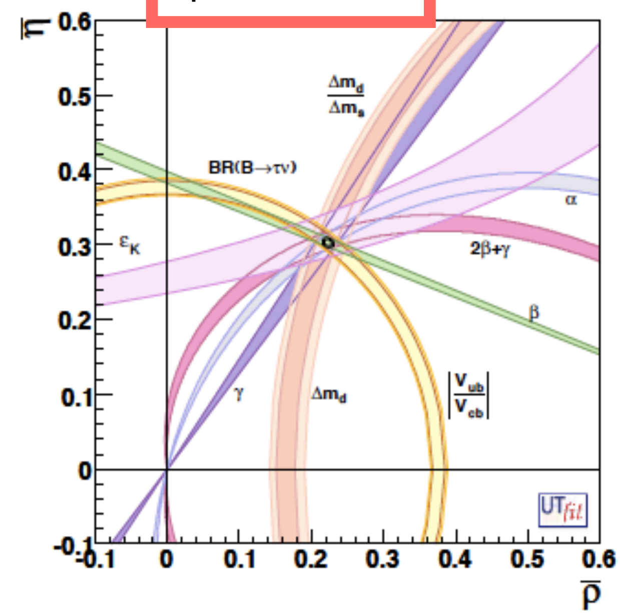
ρ = 0.163 ± 0.028
η = 0.344± 0.016

CKM @ 10%



ρ = ± 0.0028
η = ± 0.0024

CKM @ 1%



•<u>This is an enormous undertaking for both experiment & theory:</u>
To reach this goal, accuracy of the theoretical inputs must match the experimental precision:

- ➢Improved Lattice QCD calculations of decay constants & form factors are needed for B mixing parameters, leptonic decays, $|V_{ub}|$, $|V_{cb}|$,..

- ➢The experience of B factories shows that: we need comprehensive measurements of all channels connected through known symmetries, e.g. Isospin, SU(3) etc. (The stories of α & γ – involving many channels- are good examples)

Next generation of Flavor Experiments

At LHC:

- LHCb:

  At $L\sim 2\times10^{32}/cm^2/s$

  Expect ~10/fb in 5 yrs

  Incoming rate $\sim 10^{12}$ B's/Yr(2/fb)

  +trigger

  B_d, B_u, B_s, B_c, Λ_b,...

  Excellent early results has already appeared

- ATLAS and CMS

  The main focus on

  $B_s \rightarrow \mu\mu$

  (SM $Br\sim 3\times10^{-9}$)

- In planning: (Super B factories)
- Asymmetric energy $e^+ + e^-$ colliders to operate in the $\Upsilon(4S)$ region as well as in the charm threshold region. Low emmittance beams (with crab waist scheme).
  - SuperB, Italy
  - Super KEKB in Japan
- At $L \sim 10^{36}$ /s/cm2

  Aiming for a data set of ~ 50 to 75/ab in 5 yrs of running.
  - $\sim 10^{11}$ B decays
  - $\sim 10^{11}$ tau decays
  - $\sim 10^{11}$ charm decays

  ➔BaBar+Belle (~1.4/ab) : $\sim 10^{9}$ B's

  ❖ polarized beam(s) are also considered.

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In Race to Build New Particle Smasher, Japan Gets $100 Million Head Start Over Italy

by Adrian Cho on 22 June 2010, 6:01 PM | Permanent Link | 0 Comments

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Things are heating up in a race to build a new type of particle smasher known as a "super B factory." The Japanese government will invest $100 million to transform the KEKB collider at the Japanese particle-physics laboratory, KEK, in Tsukuba, into Super KEKB, which will smash electrons into positrons at 40 times the rate of the current accelerator, physicists working on the project say. Meanwhile, researchers in the United States and Italy are hoping the Italian government will soon approve plans to build a similar, competing machine.

To be spent over the next 3 years, the money granted by the Japanese government will cover only a fraction of the $350 million needed to complete the Super KEKB upgrade. Nevertheless, it suggests that the new government, which came to power in a general election last August and is led by the Democratic Party of Japan, is enthusiastic for the project, say Peter Krizan, a physicist at the Jožef Stefan Institute and University of Ljubljana in Slovenia. The project got its start under the previous government, led by the Liberal Democratic Party.

But KEK researchers are not alone in their quest for a super B factory. Researchers from Italy and the United States have proposed building in Italy a machine called SuperB using parts from a defunct accelerator in the United States. That project made a list of 14 that, according to an Italian press report, Italy's Ministry of Education, Universities and Research has drafted for the Italian government as part of its €15 billion national research plan for 2010 through 2012.

SuperB would use the massive magnets from the idle PEP-II collider at SLAC National Accelerator Laboratory in Menlo Park, California; would cost about €450 million; would smash particles at a slightly higher rate; and would used a spin-polarized electron beam, says David Hitlin, a physicist at the California Institute of Technology in Pasadena who works on the project. Researchers are hoping that the Italian government will give the project the go-ahead in the next few months, he says.

The dueling proposals continue a spirited competition that began in 1999, when PEP-II and KEKB started blasting out odd and fleeting particles called B mesons. Those particles are particularly fruitful to study because they can be used to probe a very slight asymmetry between matter and antimatter called charge-parity violation, which had only been seen before in particles called K mesons. The measurements of a few billion B mesons at the B factories enable experimenters to confirm the explanation of charge-parity violation essentially guessed by Japanese theorists Makoto Kobayashi and Toshihide Maskawa in 1972. On the basis of those measurements, Kobayashi and Maskawa shared the Nobel Prize in physics in 2008.

CERN Courier

CERN COURIER

Jan 25, 2011

Italian government approves SuperB

The Italian government has selected the SuperB project as one of its "flagship projects" in Italy for the coming years and has delivered initial funding as a part of a multiyear programme. Proposed by INFN, the project has already attracted interest from many other countries, with physicists from Canada, Germany, France, Israel, Norway, Poland, Russia, Spain, the UK and the US already taking part in the design effort (**CERN Courier** December 2010 p8 (http://cerncourier.com/cws/article/cern/44347)).

SuperB will be an asymmetric electron–positron collider with a peak luminosity of 10^{36} cm^{-2} s^{-1}. Such a high luminosity will allow the indirect exploration of new effects in the physics of heavy quarks and flavours at energy scales up to 10–100 TeV, through the studies at only 10 GeV in the centre-of-mass of large samples of B, D and τ decays. At full power, SuperB should be able to produce 1000 pairs of B mesons, the same number of τ pairs and several thousands of D mesons every second.

The key advances in the collider design come from recent successes at the DAΦNE collider at INFN/Frascati, at PEP-II at SLAC and at KEKB at KEK. These include new concepts in beam manipulation at the interaction region known as the "crab waist" scheme, which has been tested at DAΦNE (**CERN Courier** January/February 2009 p17 (http://cerncourier.com/cws/article/cern/37329)).

The aim of the SuperB project is to conduct top-level basic research, while developing innovative techniques with an important impact for technology and other research areas. In this respect, the Instituto Italiano di Tecnologia is co-operating on SuperB with INFN. The accelerator will also be used as a high-brilliance light source, equipped with several photon channels, allowing the scientific programme to include the physics of matter and biotechnology.

Conclusions

- CLEO's legacy continues: Flavor physics is entering the precision phase and is poised to serve as a major partner with LHC in uncovering the flavor structure of the New Physics that may emerge at TeV scale.

Thank you, David, for your leadership and immense contribution to this endeavor, and for mentoring and supporting so many of us in the past three decades.