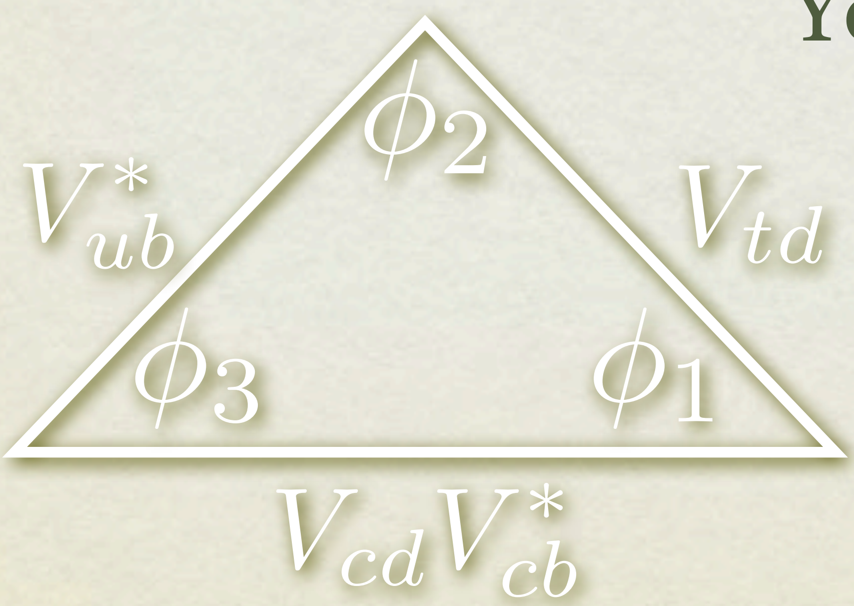
CKM Unitarity Test in Belle

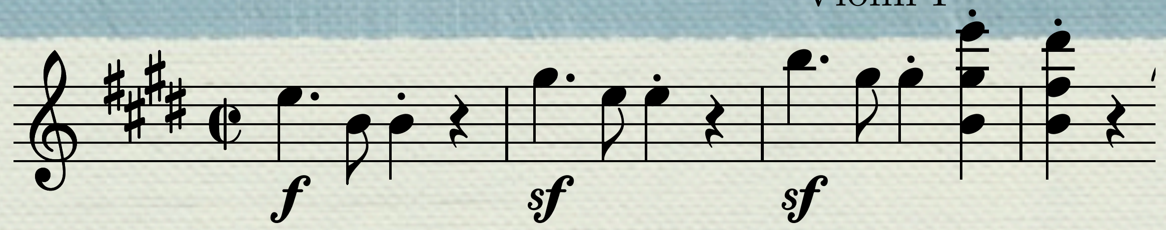


Youngjoon Kwon
Yonsei Univ.

OUTLINE

- Overture
  - *a brief introduction as if you are a 1st-year grad. student*
- The measurements
  - CKM angles
  - CKM sides -- *very brief*
- A few “tensions”
- Conclusion & Epilogue

Violin I



Overture

To B, or not to B: that is the question

- adapted from W. Shakespeare

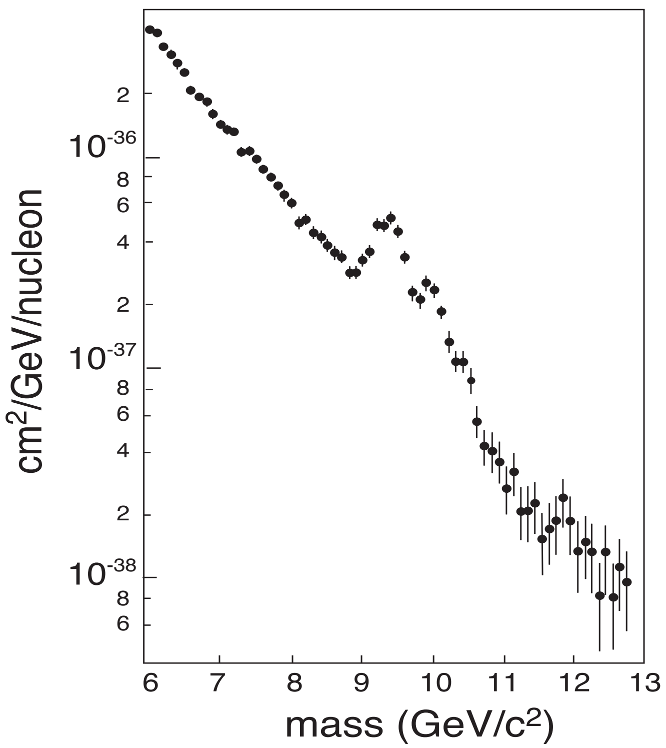

Beauty and the Beast
Belle
BaBar

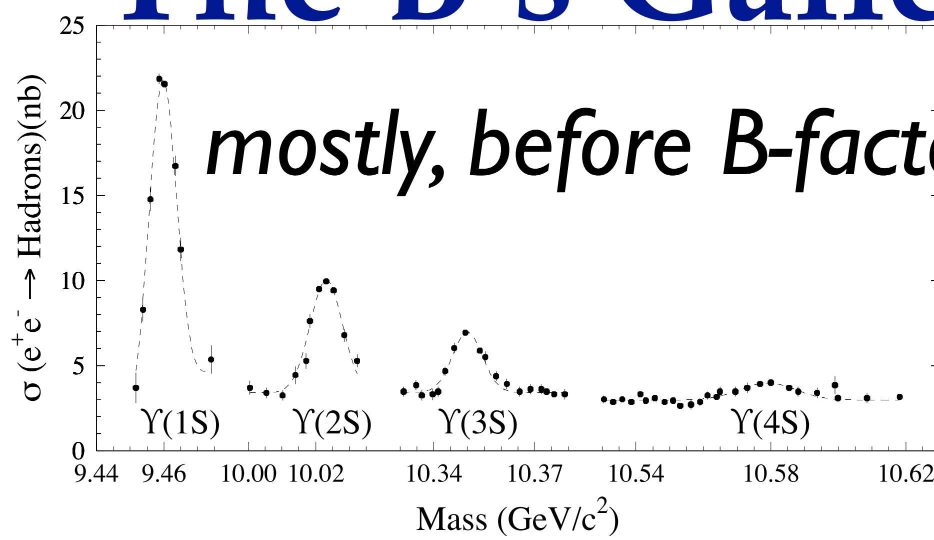
Historical Milestones

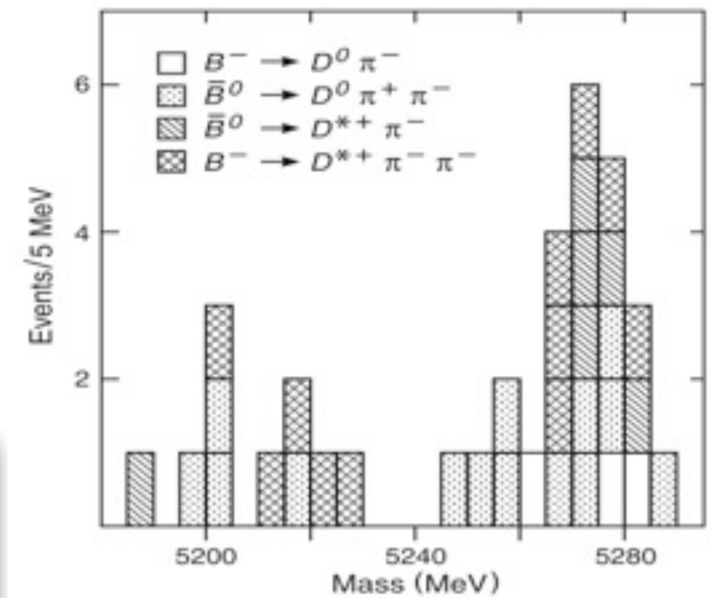
- 1957 Parity violation in ^{60}Co
- 1964 CP violation in K^0
- 1967 Sakharov's 3 conditions
- 1973 KM mechanism
- 1977 Discovery of b quark
- ~1980 Proposal for B-factory
- 1987 B^0 mixing
- 1999 B-factories (Belle, BaBar) started
- 2001 CP violation in B^0
- 2004 Direct CP violation in B^0
- 2006 B_s mixing
- 2008 (1/2) Nobel Physics prize to K & M

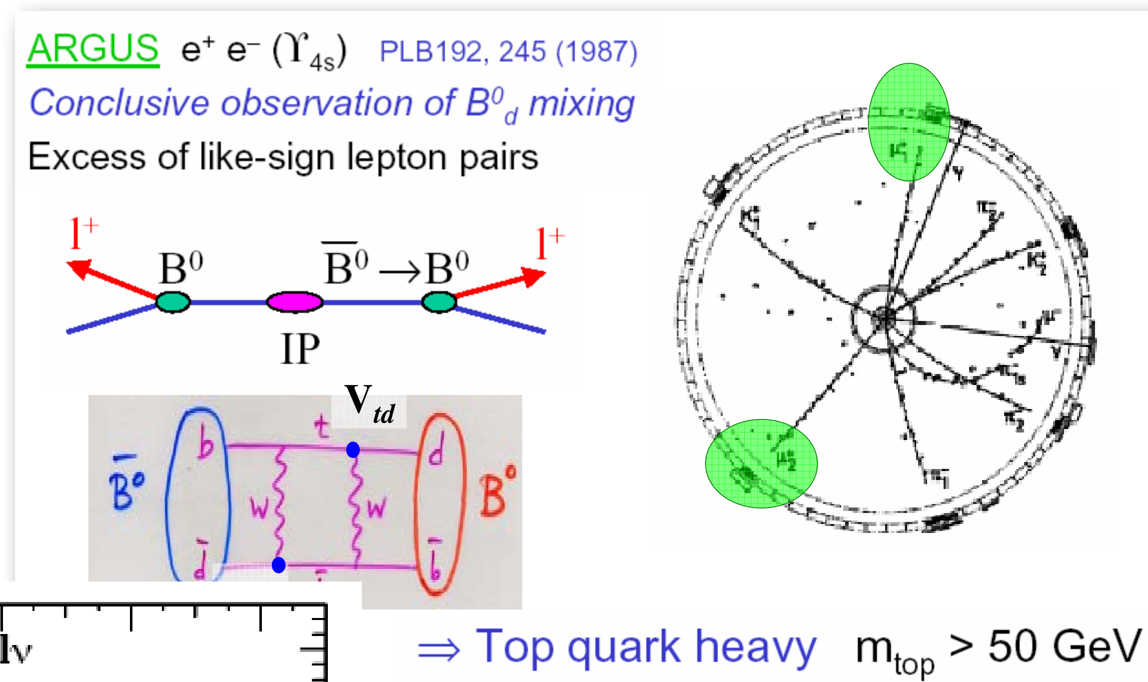
The B's Gallery

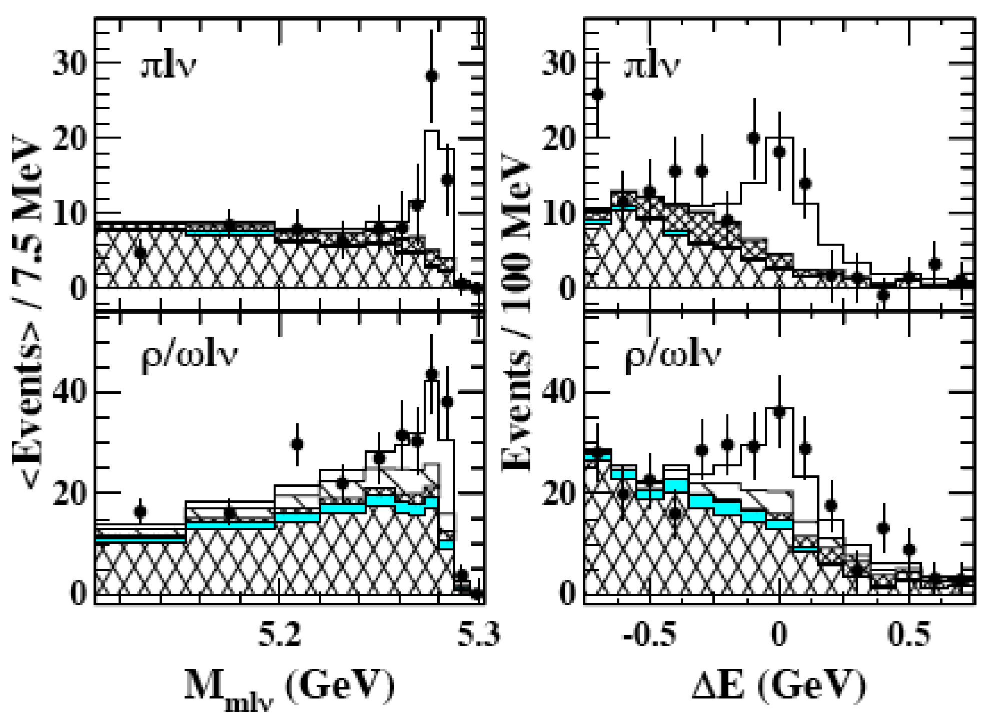
mostly, before B-factories

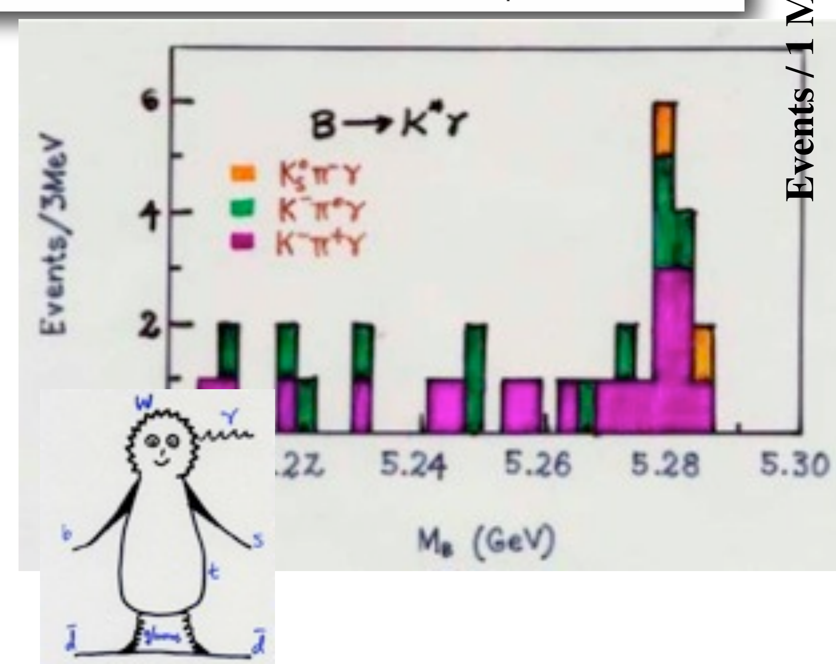


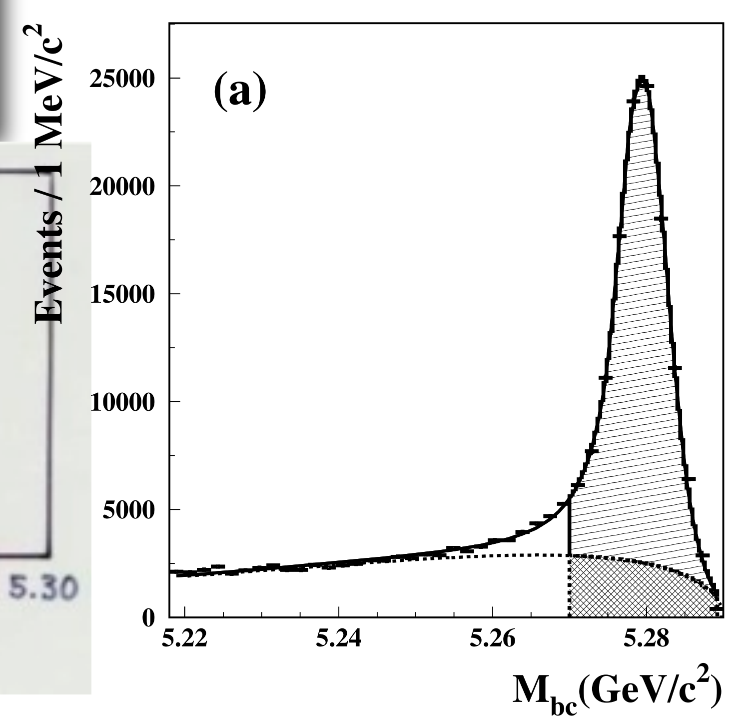










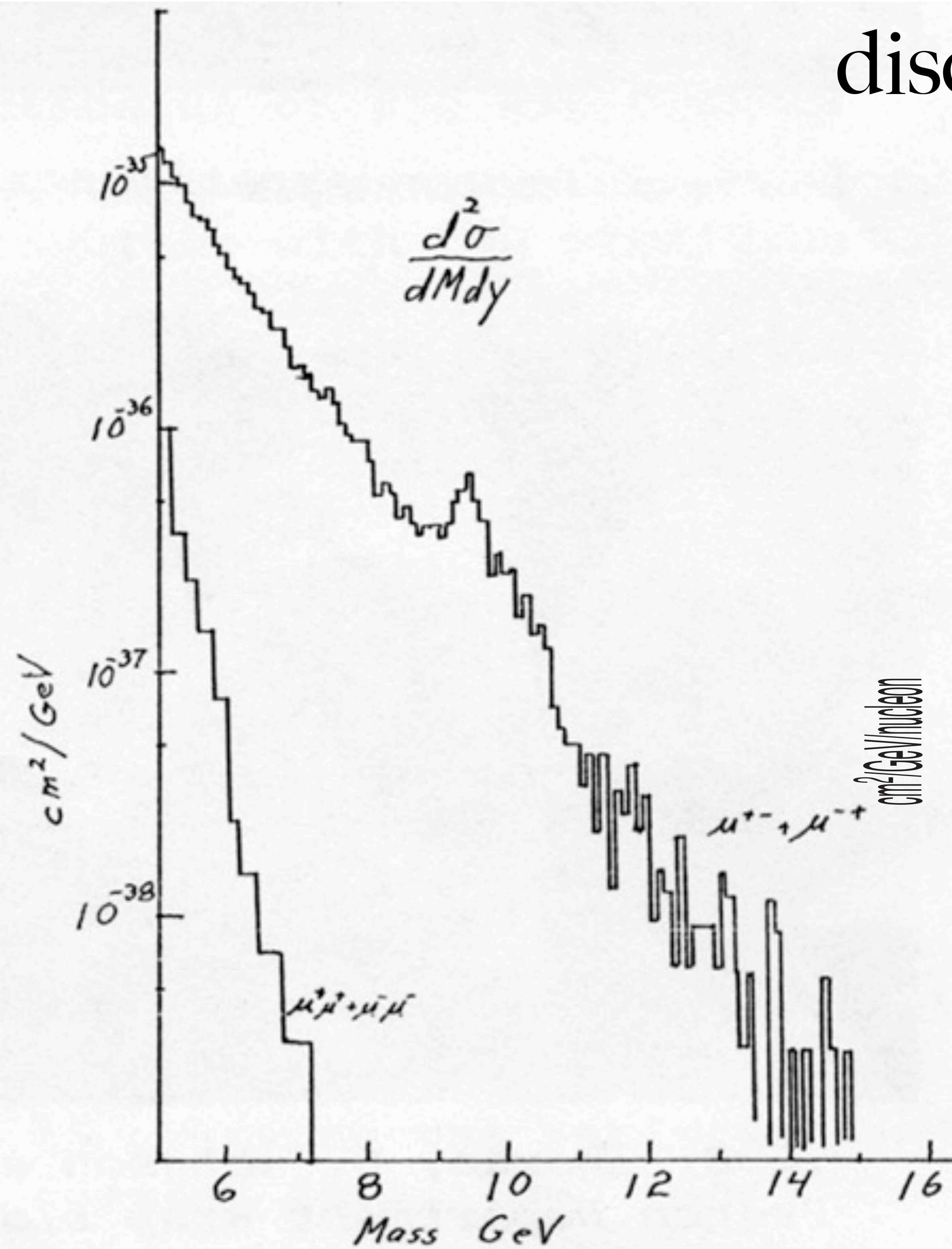


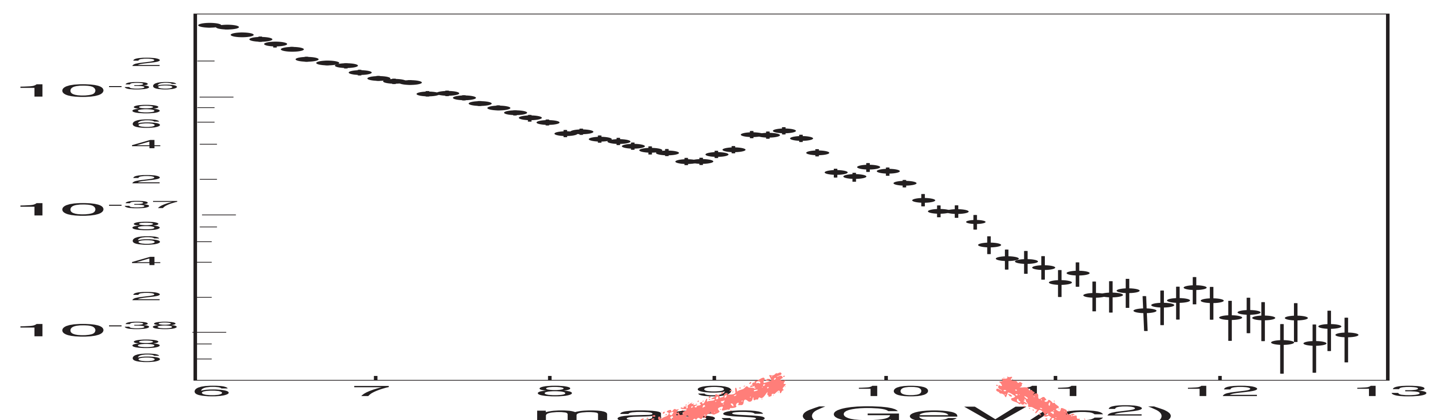
discovery of Υ resonances

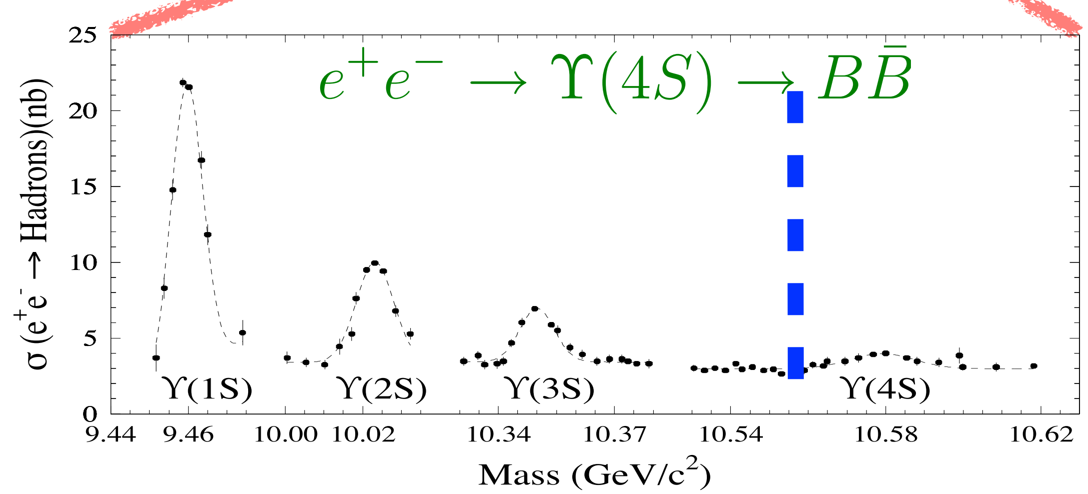
PRL 39, 252 (1977)

$$pN \to \mu^+\mu^- X$$

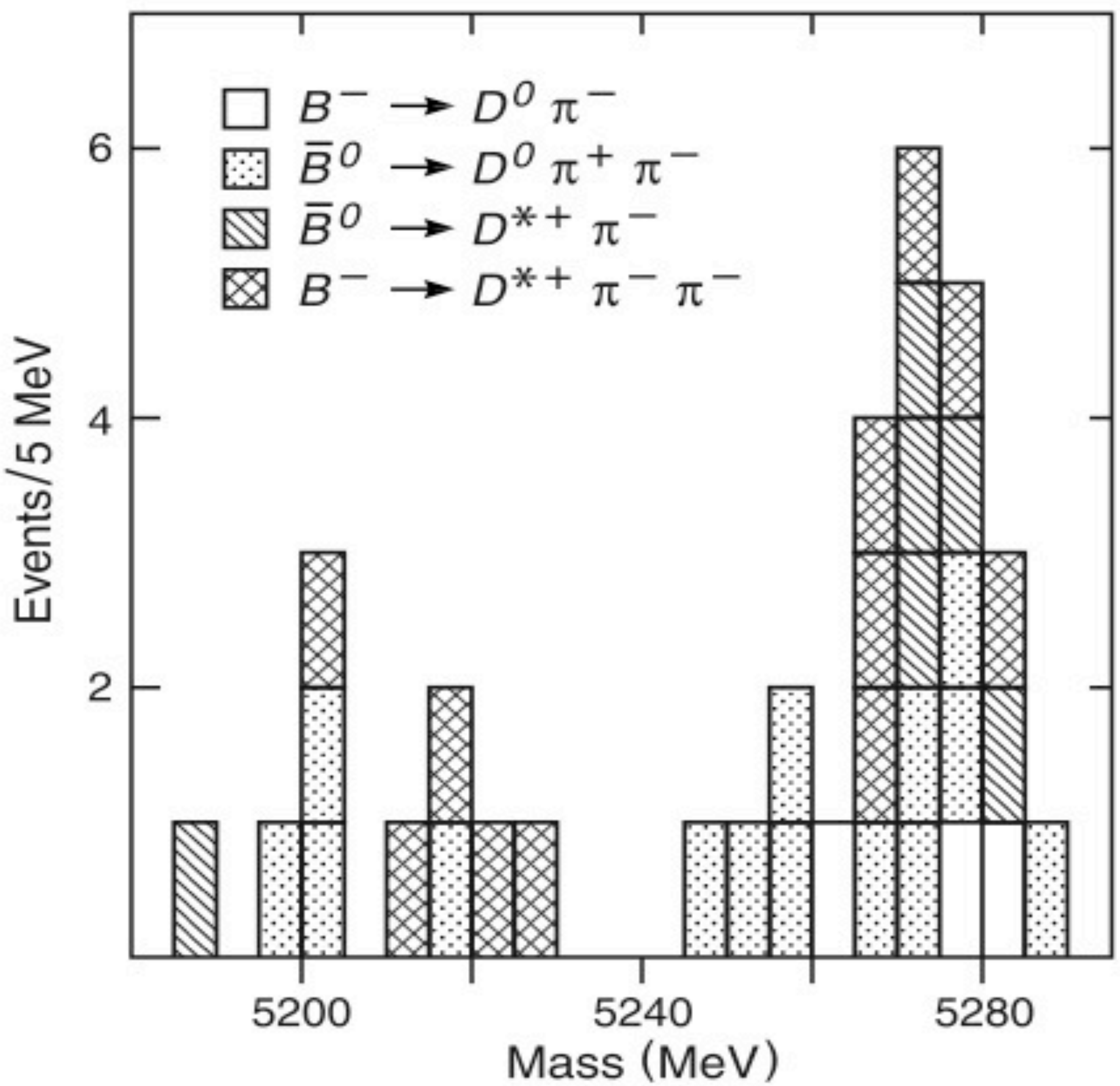
@ 400 GeV







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



discovery of ***B*** mesons (CLEO)

PRL 50, 881 (1983)

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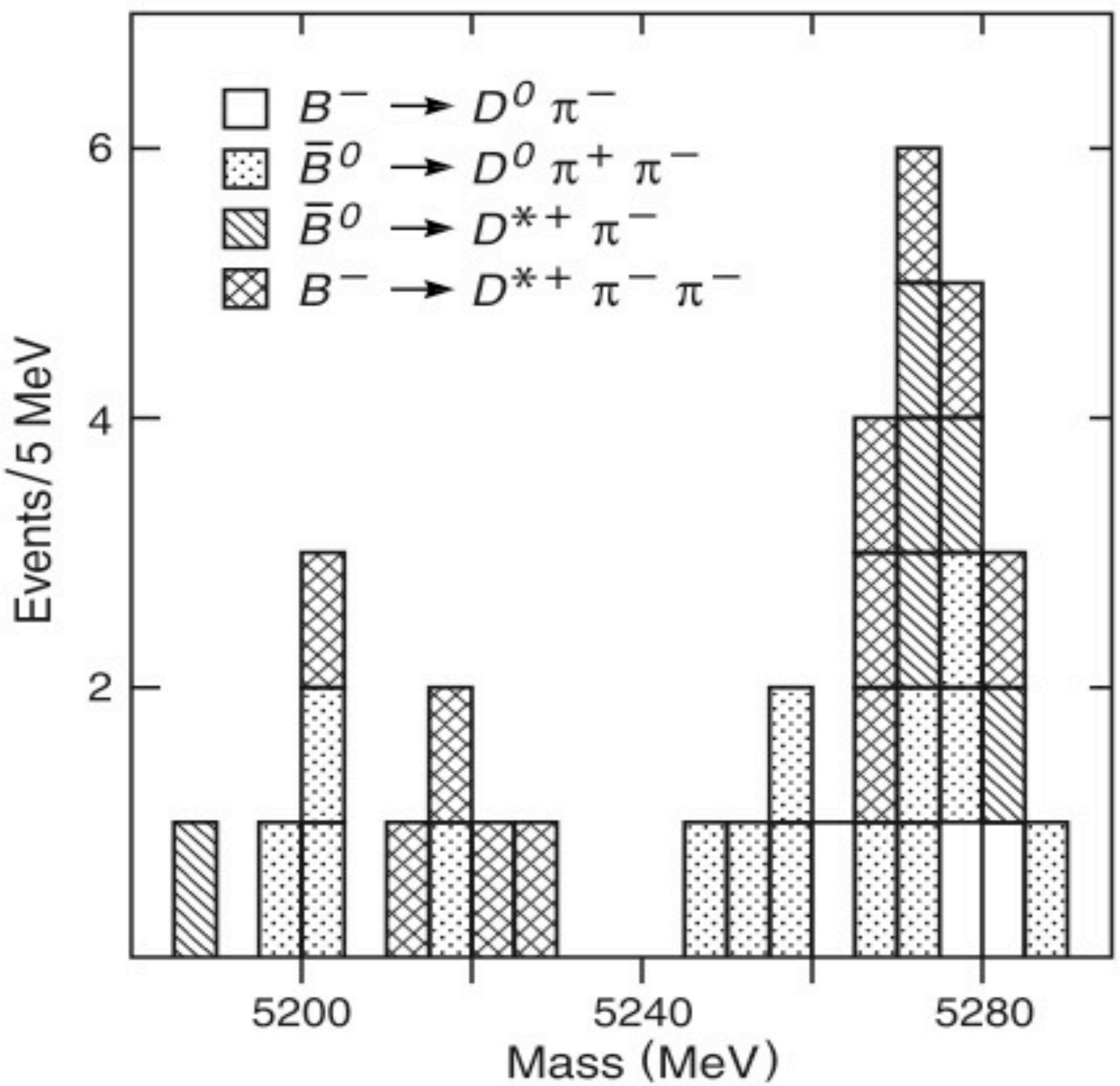
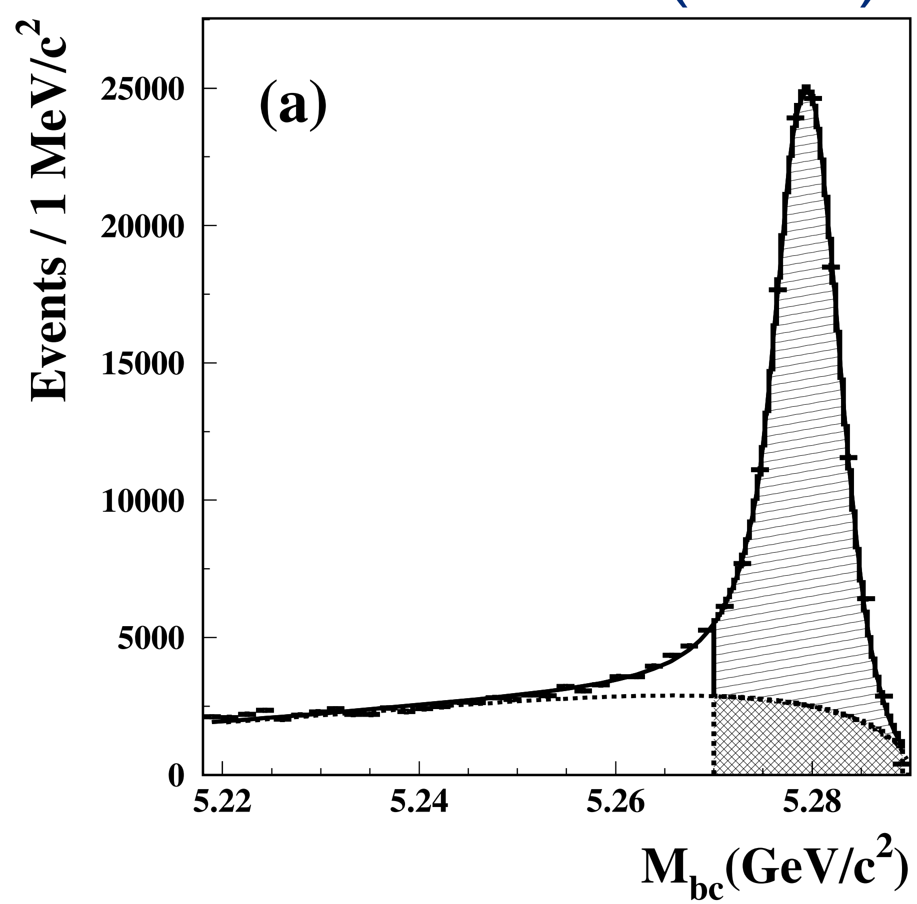


discovery of ***B*** mesons (CLEO)

PRL 50, 881 (1983)

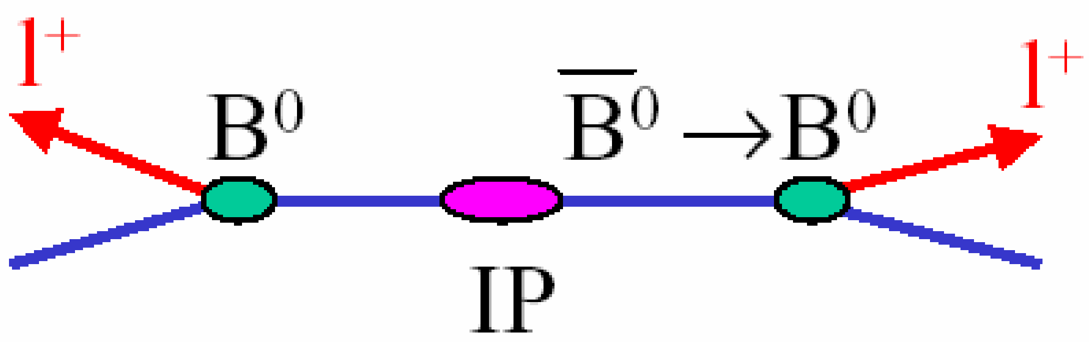
Belle (2005)

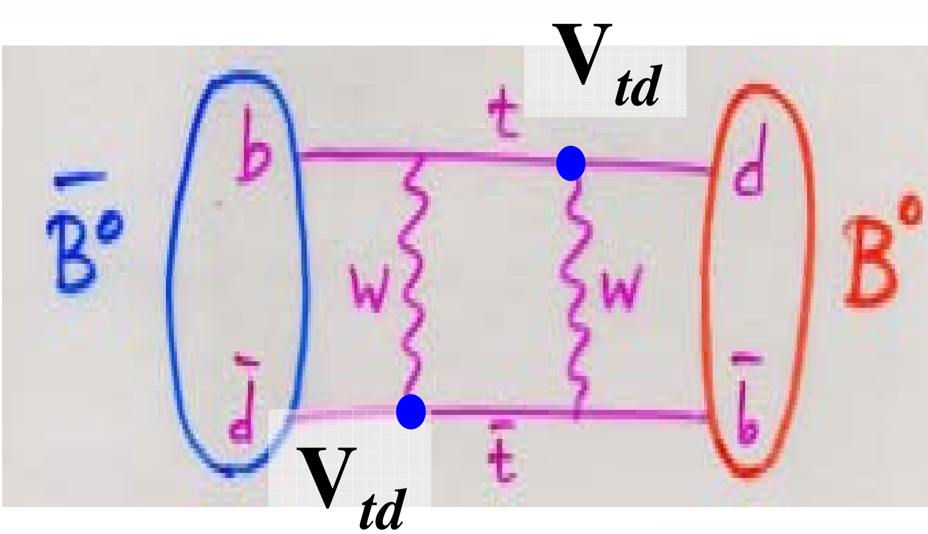


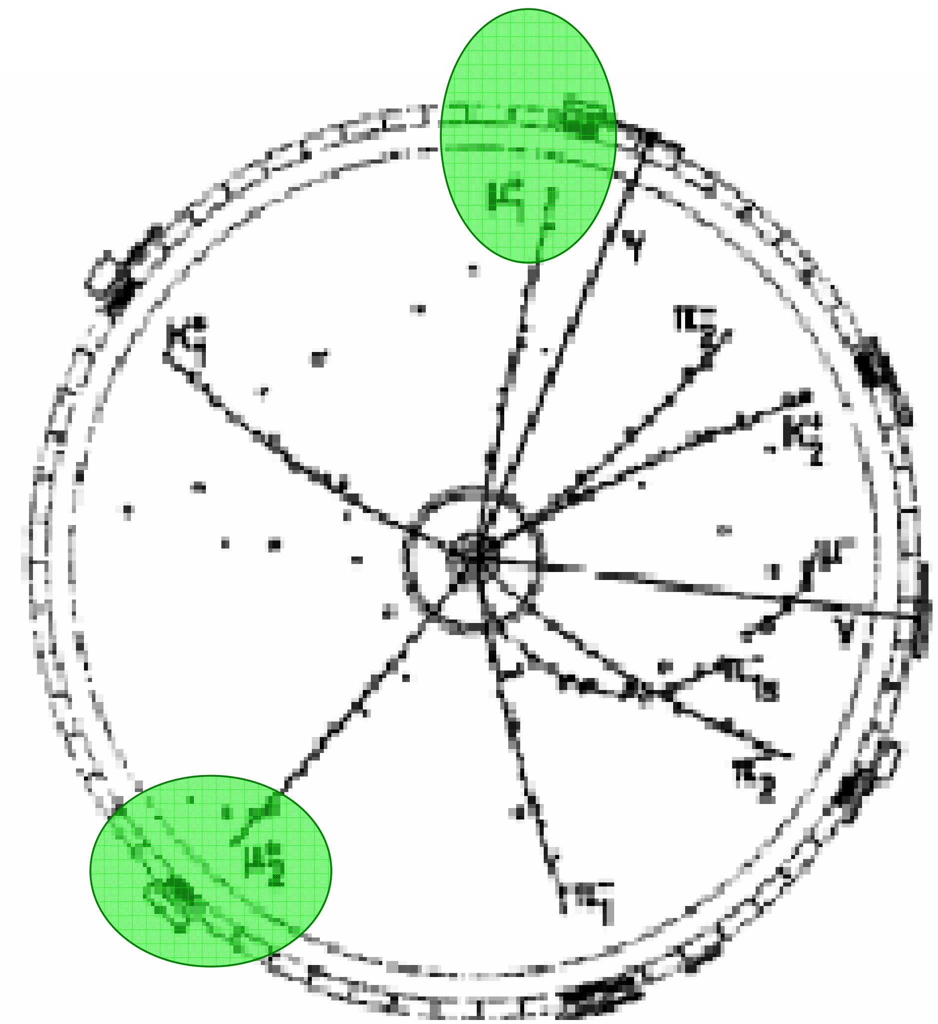
ARGUS $e^+ e^- (\Upsilon_{4s})$ PLB192, 245 (1987)

Conclusive observation of B^0_d mixing

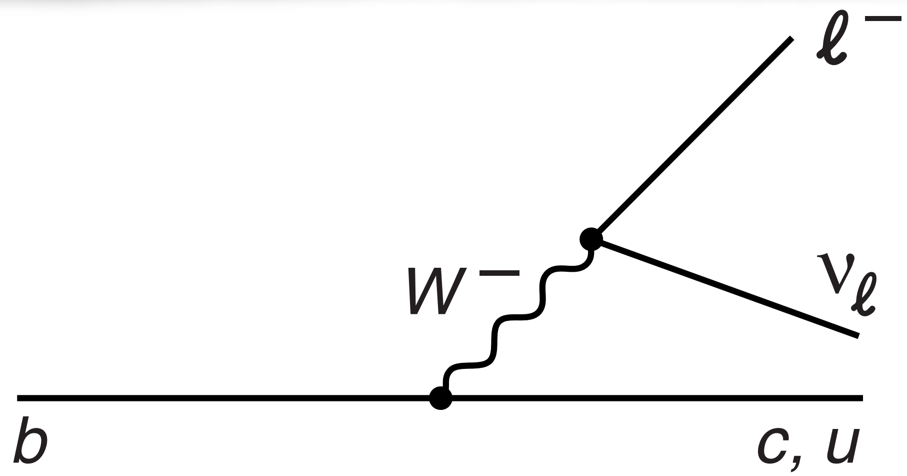
Excess of like-sign lepton pairs







$\Rightarrow$ Top quark heavy $m_{top} > 50$ GeV



How to B?

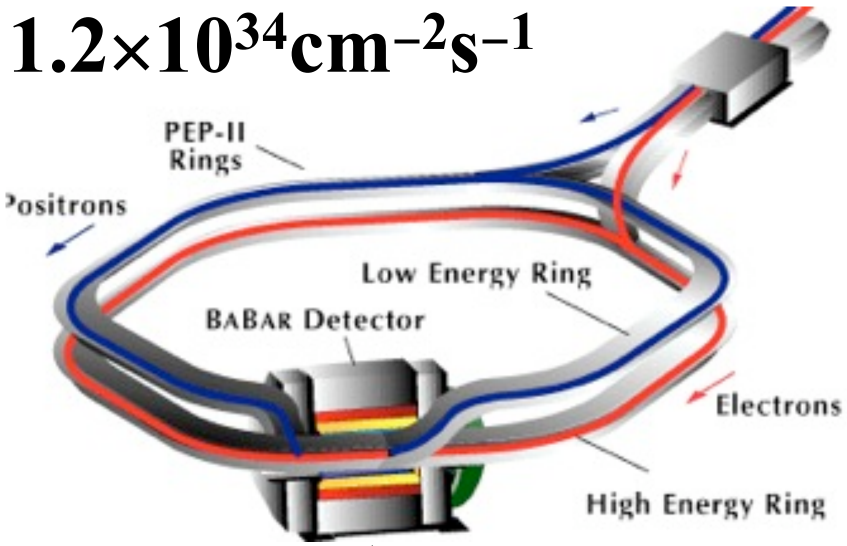
- e+e- B-factories (Belle/BaBar)
  - clean environment, w/ tight kinematic constr.
  - need to boost the B mesons

    --> use asymmetric beams (e.g. 8 + 3.5)
  - main performers so far
- High-E hadron collisions (Tevatron/LHC)
  - very large production cross-section
  - but, bkg'd is large, too

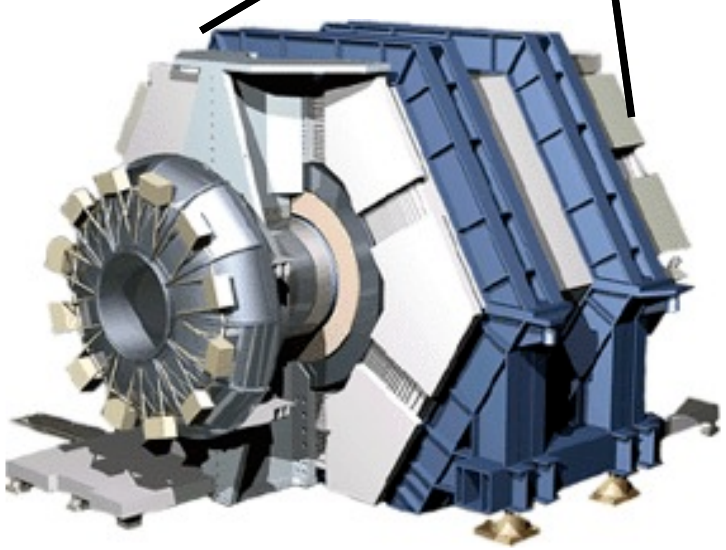
Two asymmetric B-factories

PEP-II at SLAC

9GeV (e^-) × 3.1GeV (e^+)
peak luminosity:
$1.2 \times 10^{34} cm^{-2}s^{-1}$

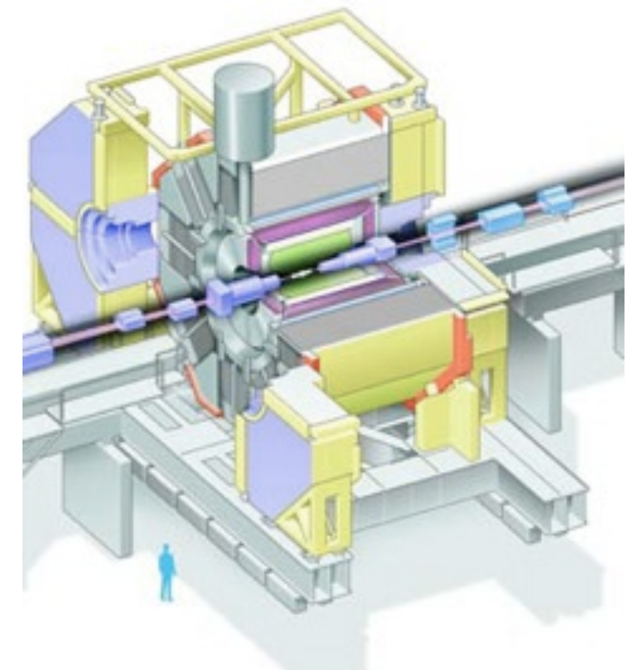


BaBar

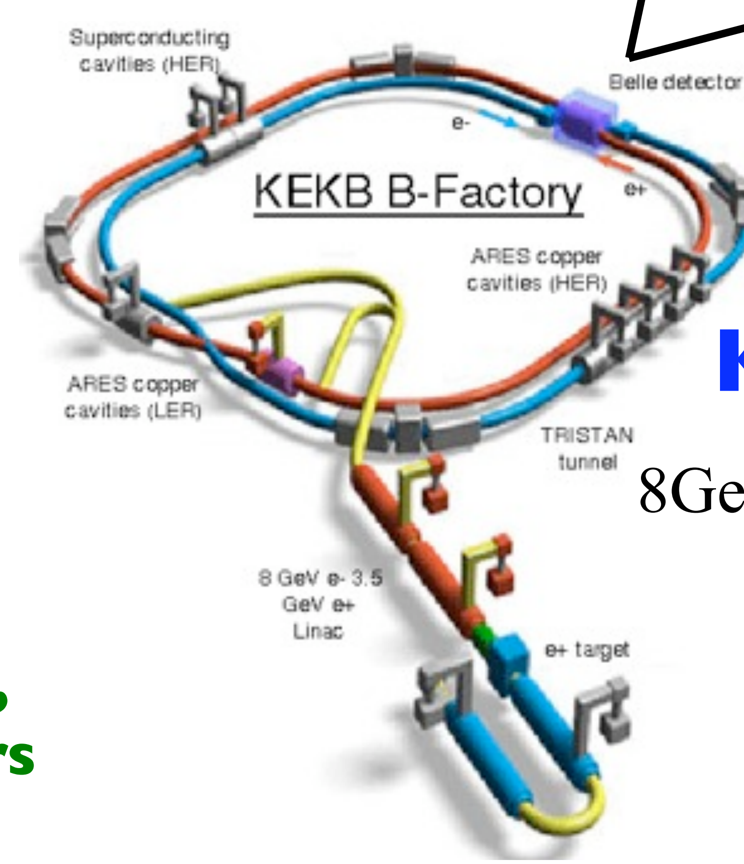


11 nations,
80 institutes,
~600 members

13 countries,
57 institutes,
~400 members

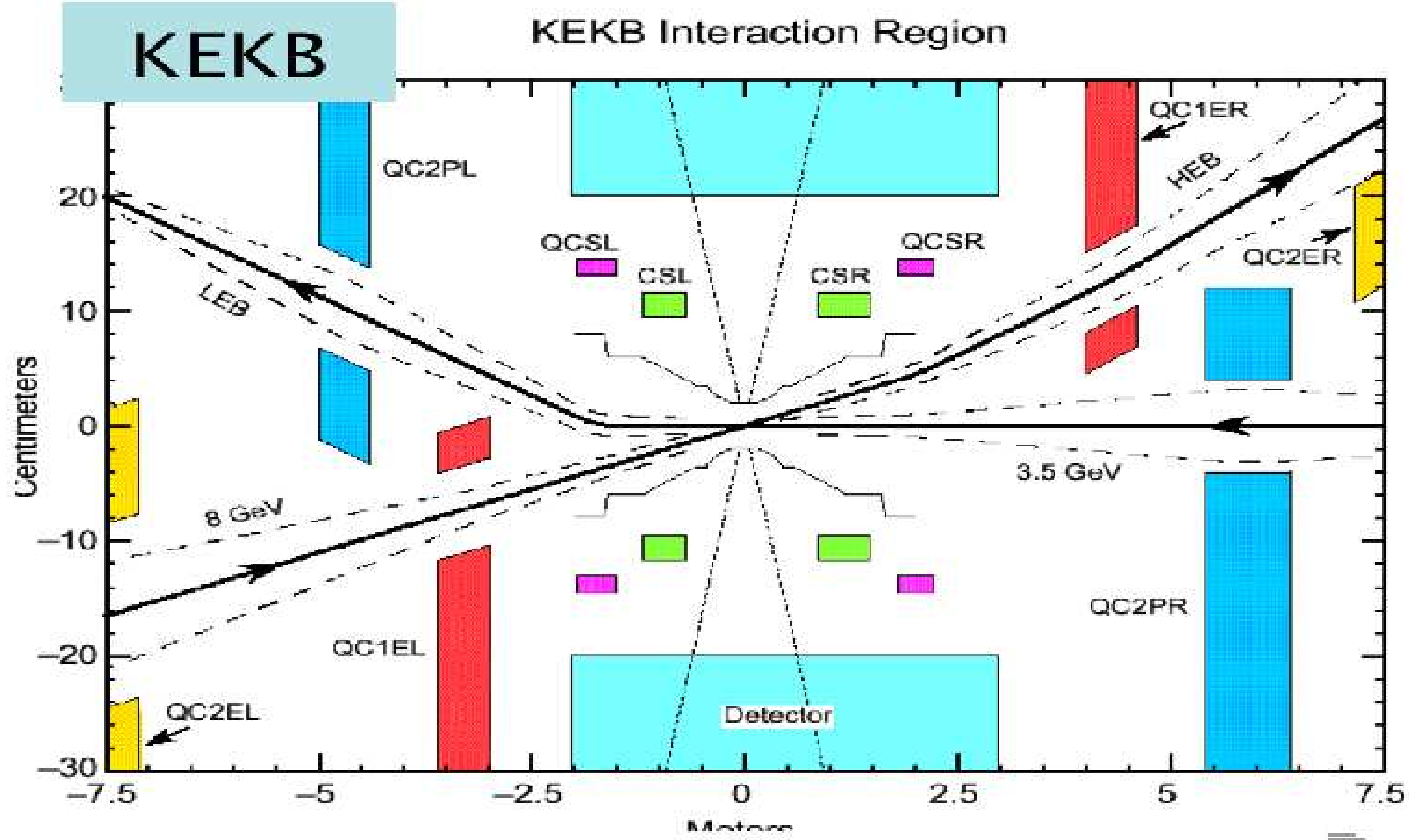


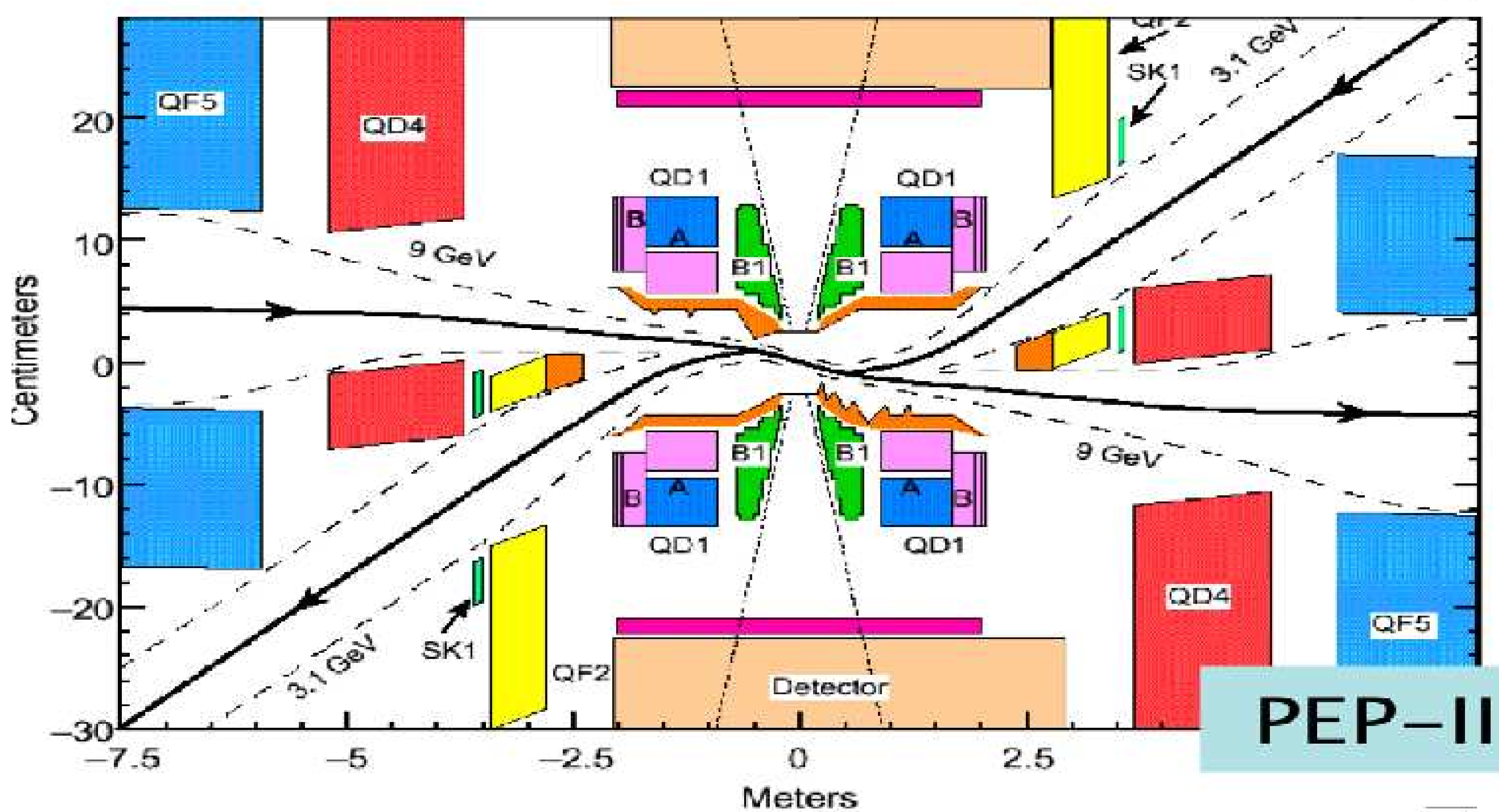
Belle



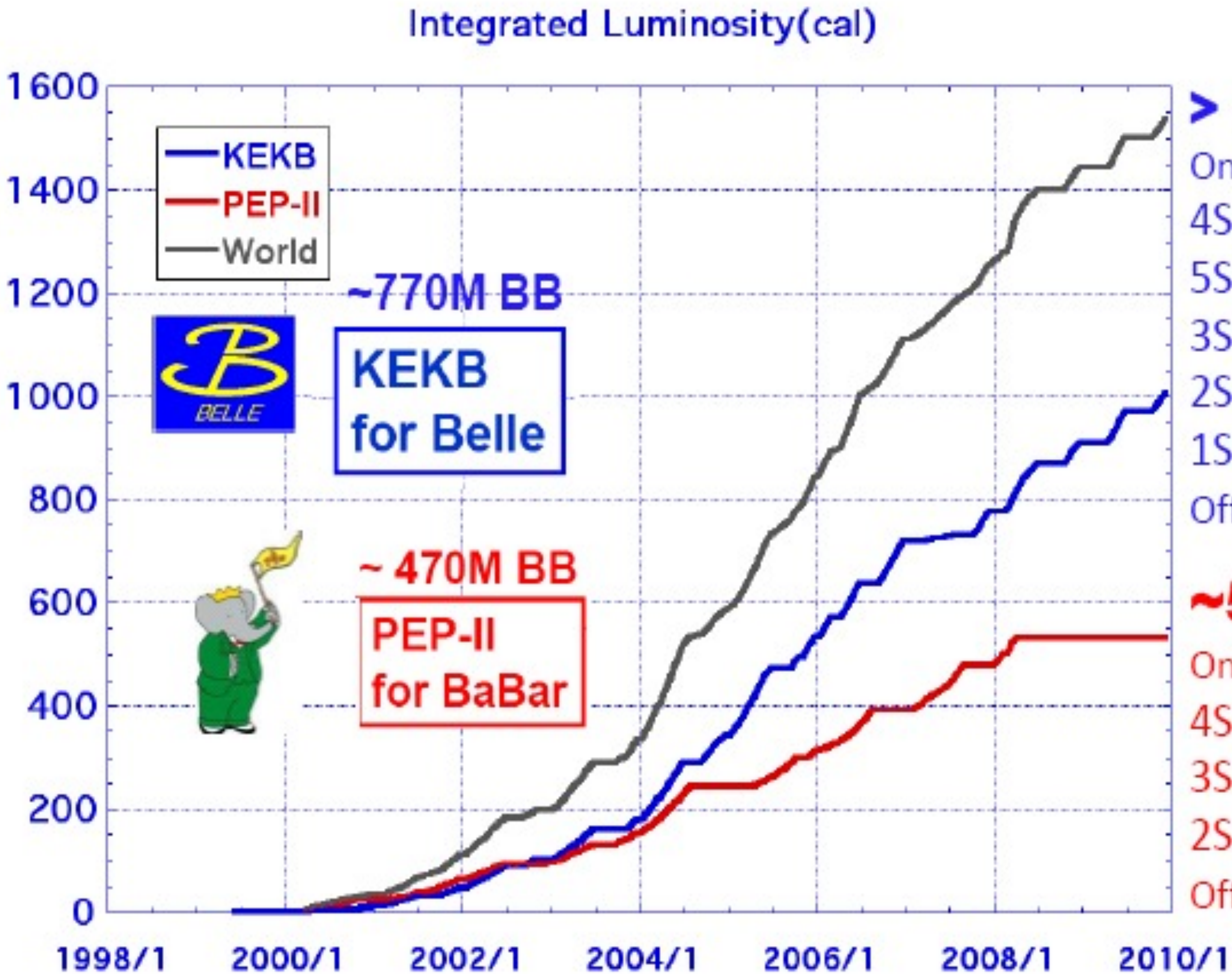
KEKB at KEK

8GeV (e^-) × 3.5GeV (e^+)
peak luminosity:
$2.1 \times 10^{34} cm^{-2}s^{-1}$
world record


KEKB
KEKB Interaction Region
QC2PL
QC1ER
HEB
QCSL
QCSR
CSL
CSR
QC2ER
LEB
8 GeV
3.5 GeV
QC2PR
QC1EL
QC2EL
Detector
Centimeters
Meters
20
10
0
−10
−20
−30
−7.5
−5
−2.5
0
2.5
5
7.5


QF5
QD4
SK1
3.1 GeV
QD1
B
A
B1
9 GeV
QF2
Detector
PEP−II
Centimeters
Meters
20
10
0
−10
−20
−30
−7.5
−5
−2.5
0
2.5

Belle/BaBar Luminosities



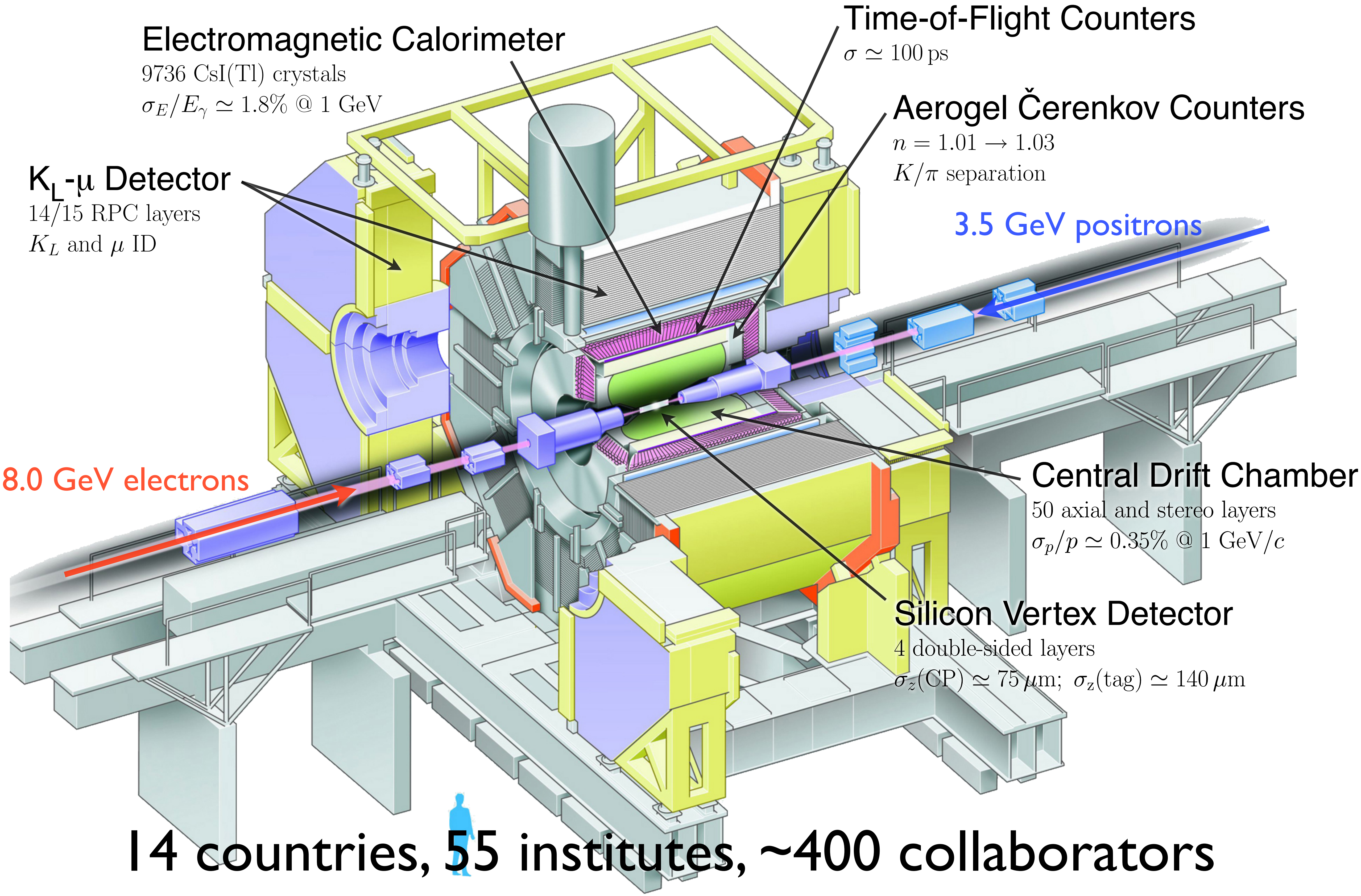
> 1.0 ab^{-1}

On-resonance samples:
4S: 711 fb^{-1}
5S: 121 fb^{-1}
3S: 3.0 fb^{-1}
2S: 24 fb^{-1}
1S: 5.7 fb^{-1}
Off-resonance: 87 fb^{-1}

~553 fb^{-1}

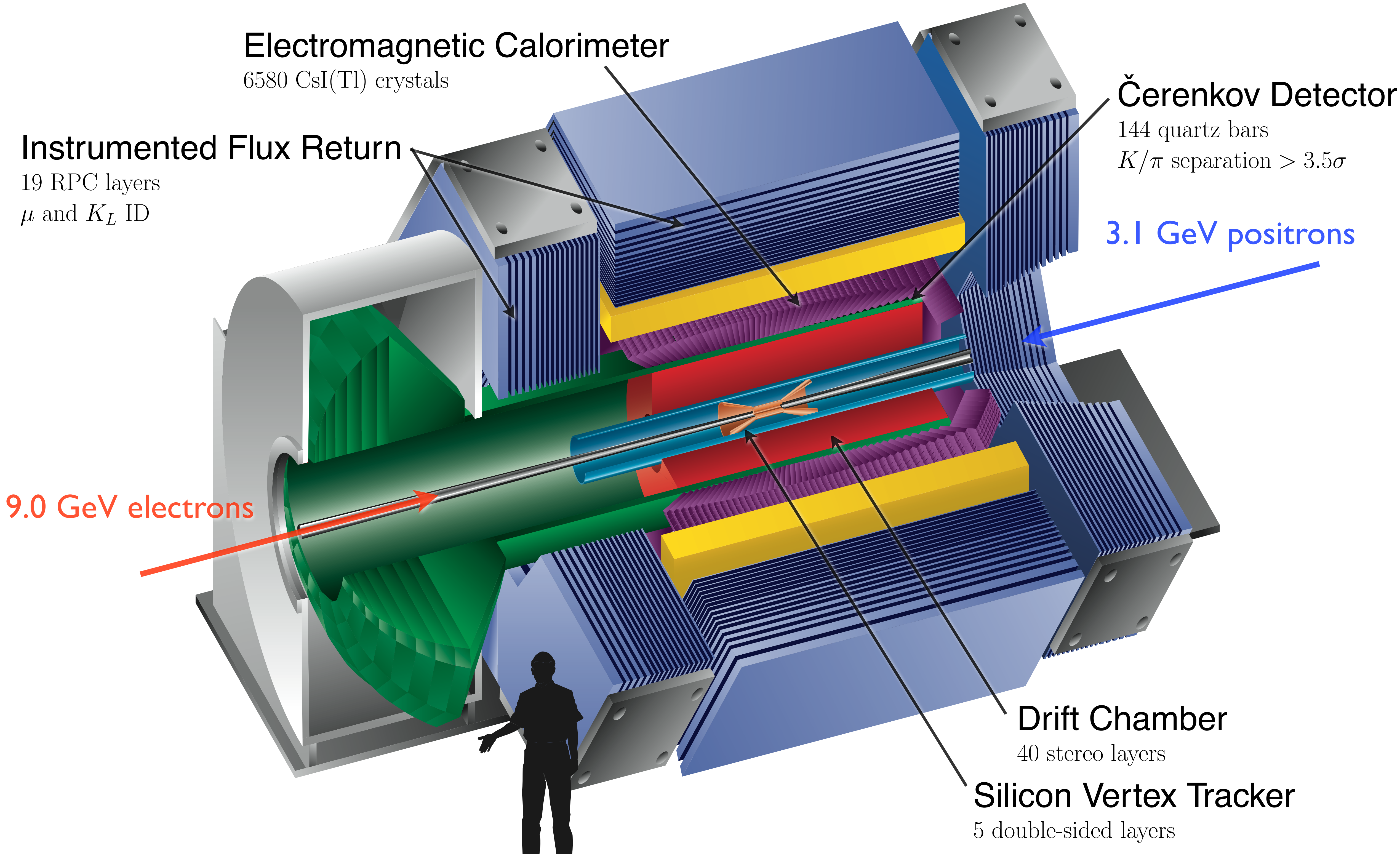
On-resonance samples:
4S: 433 fb^{-1}
3S: 30 fb^{-1}
2S: 14 fb^{-1}
Off-resonance: 54 fb^{-1}

Belle detector



14 countries, 55 institutes, ~400 collaborators

BABAR detector



11 countries, 80 institutes, ~600 collaborators

Kobayashi-Maskawa (KM) ansatz

"CPV is due to an irreducible phase in the quark mixing matrix in 3 generations"

. of Theoretical Physics, Vol. 49, No. 2, February 1973

CP-Violation in the Renormalizable Theory of Weak Interaction

Makoto KOBAYASHI and Toshihide MASKAWA

Department of Physics, Kyoto University, Kyoto

(Received September 1, 1972)

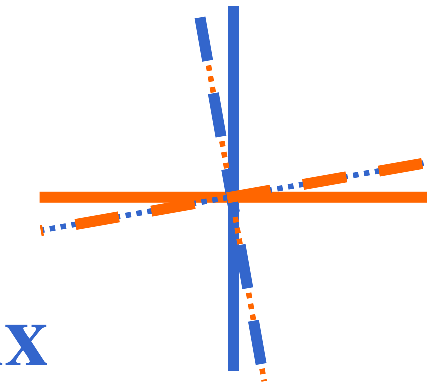
In a framework of the renormalizable theory of weak interaction, problems of CP-violation are studied. It is concluded that no realistic models of CP-violation exist in the quartet scheme without introducing any other new fields. Some possible models of CP-violation are also discussed.

When we apply the renormalizable theory of weak interaction[1] to the hadron system, we have some limitations on the hadron model. It is well known that there exists, in the case of the triplet model, a difficulty of the strangeness changing neutral current and that the quartet model is free from this difficulty. Fur-

First 3rd-gen. particle (τ) seen in 1975

Flavor mixing and CKM matrix

- For quarks,
  - weak interaction eigenstates ≠ mass eigenstates
  - mixing of quark flavors through a **unitary matrix**



$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \left(\mathrm{V_{CKM}}\right)\begin{pmatrix} d \\ s \\ b \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}\begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

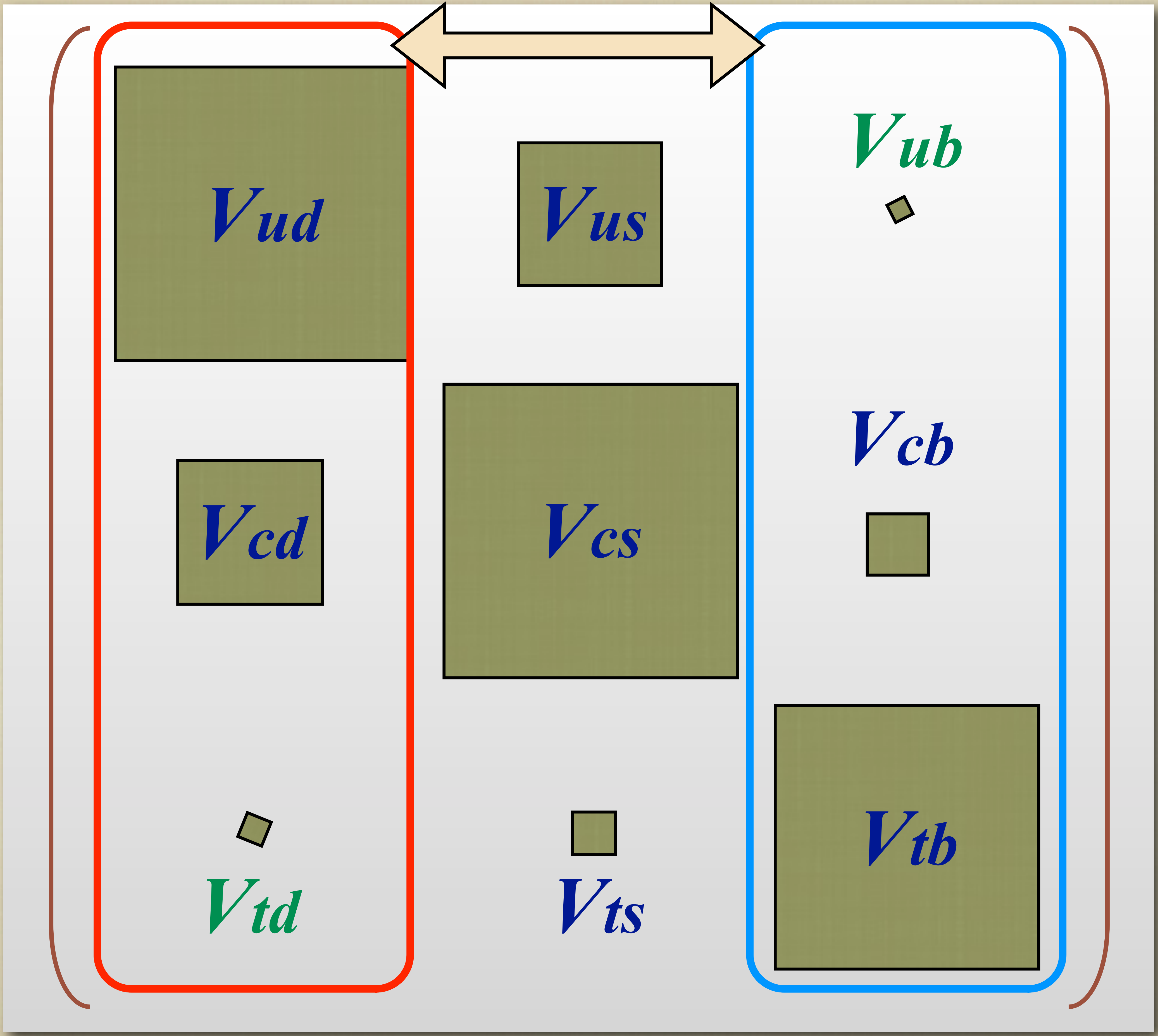
Wolfenstein parametrization

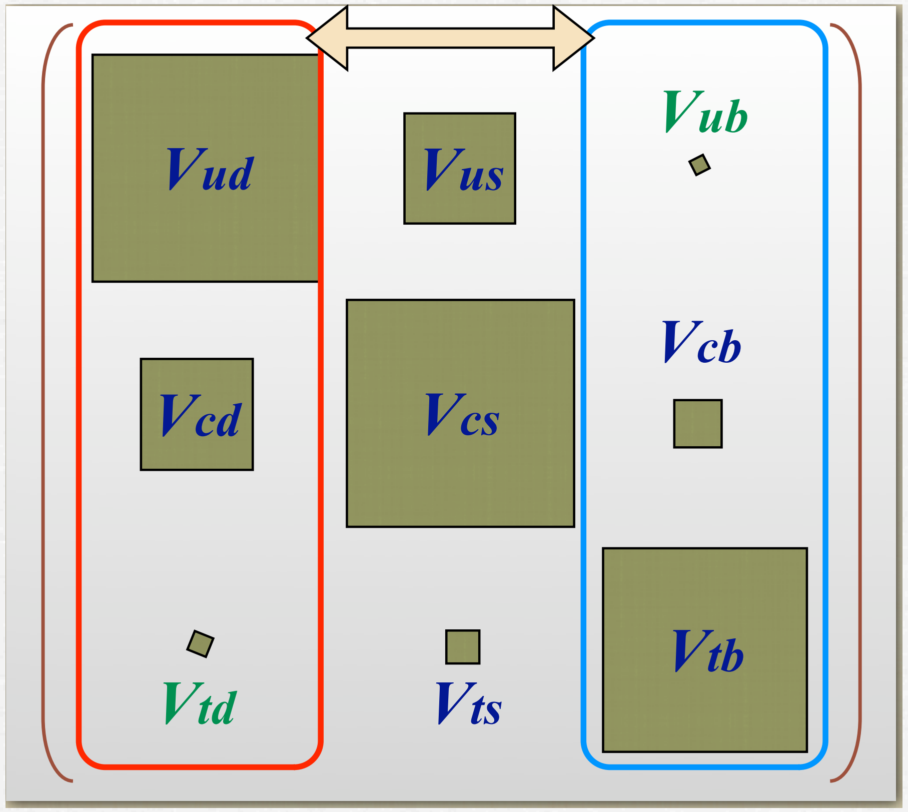
$$\mathrm{V_{CKM}} \approx \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

$|\lambda| \approx O(0.1)$

3 real parameters (λ, A, ρ) and 1 phase (η)

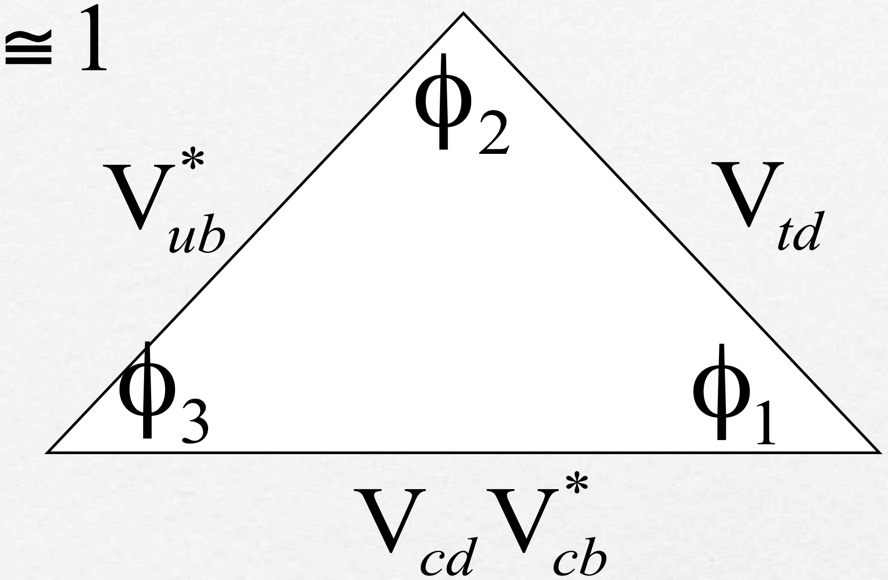
Test of Unitarity





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

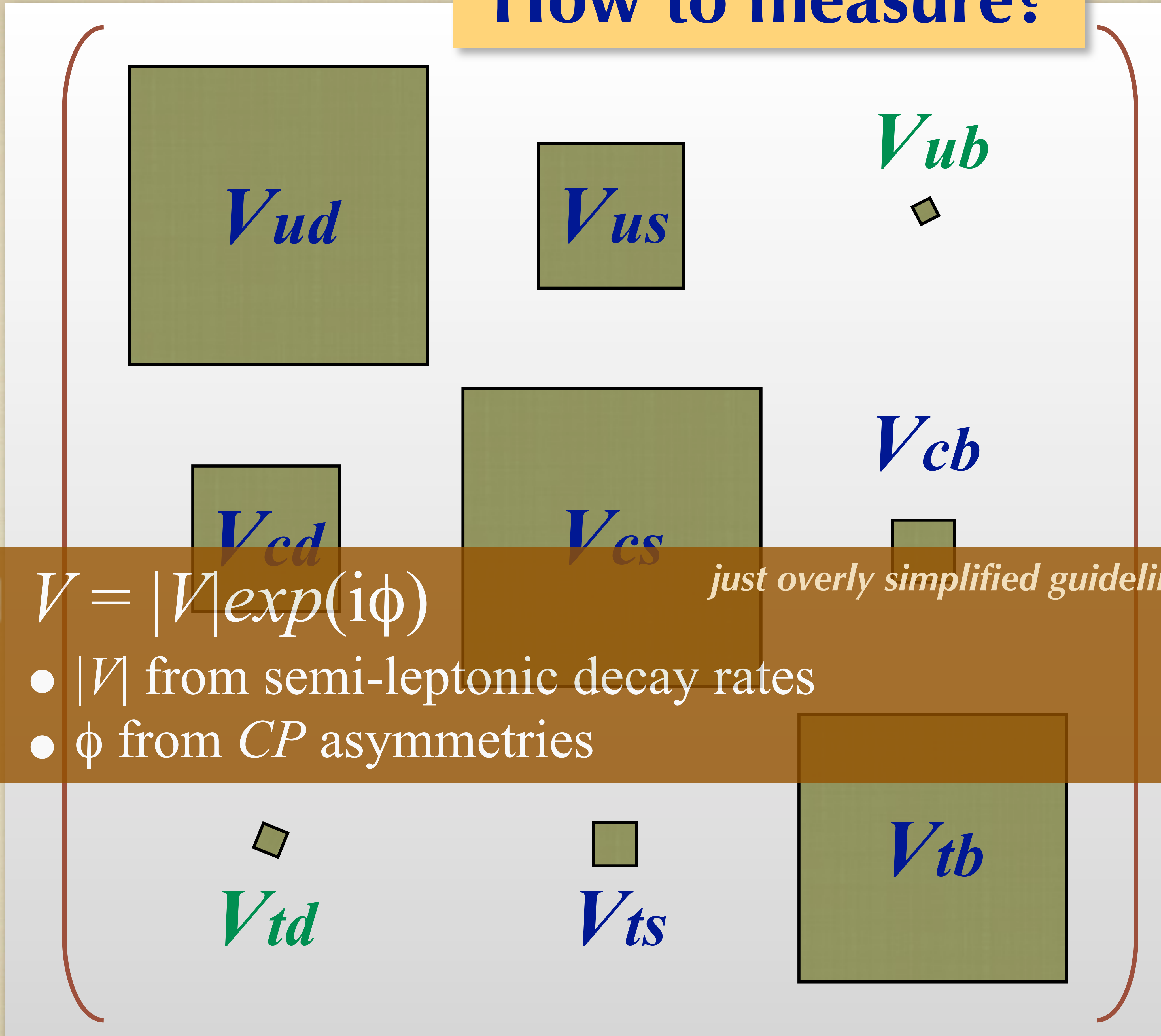
$$V_{ud} \cong V_{tb} \cong 1$$



Unitarity triangle angles			
BABAR:	β	α	γ
BELLE:	ϕ_1	ϕ_2	ϕ_3
This talk:	易	難	魔

Z. Ligeti, from plenary talk @ ICHEP 2004

How to measure?



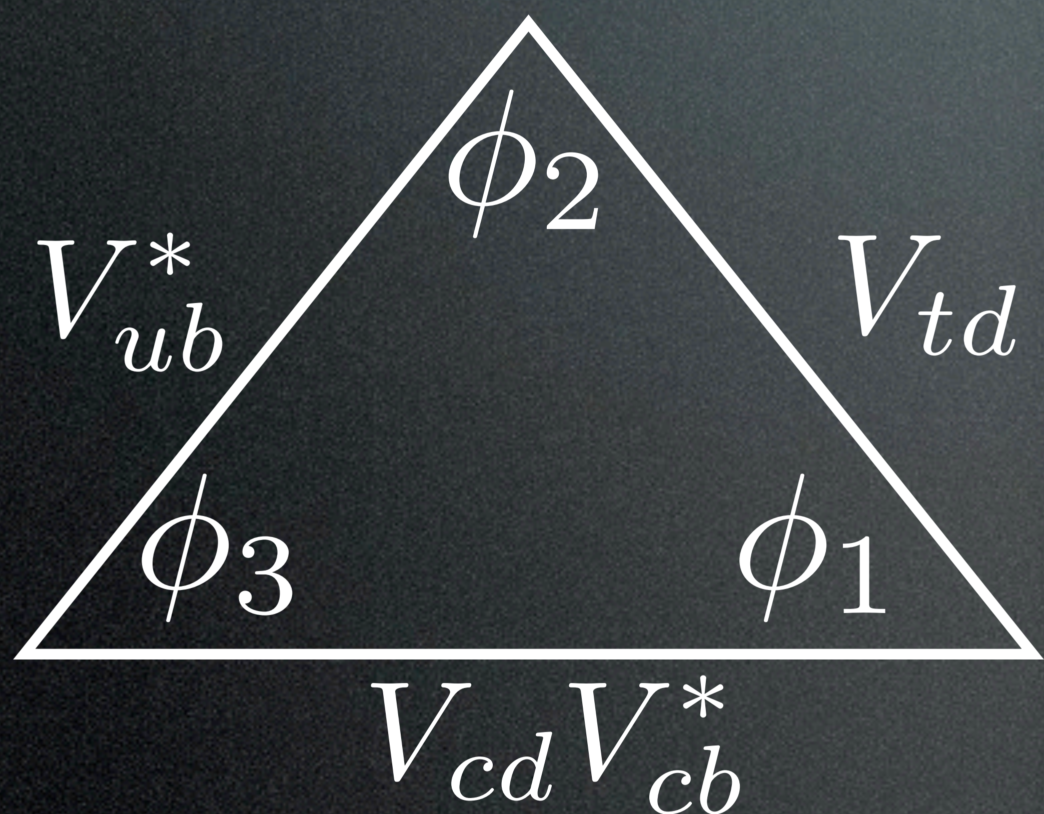
just overly simplified guidelines

$V = |V| exp(i\phi)$

- $|V|$ from semi-leptonic decay rates
- ϕ from *CP* asymmetries

Measuring the CKM anlges

- Extract the three angles through time-dependent A_{CP} meas'mt.



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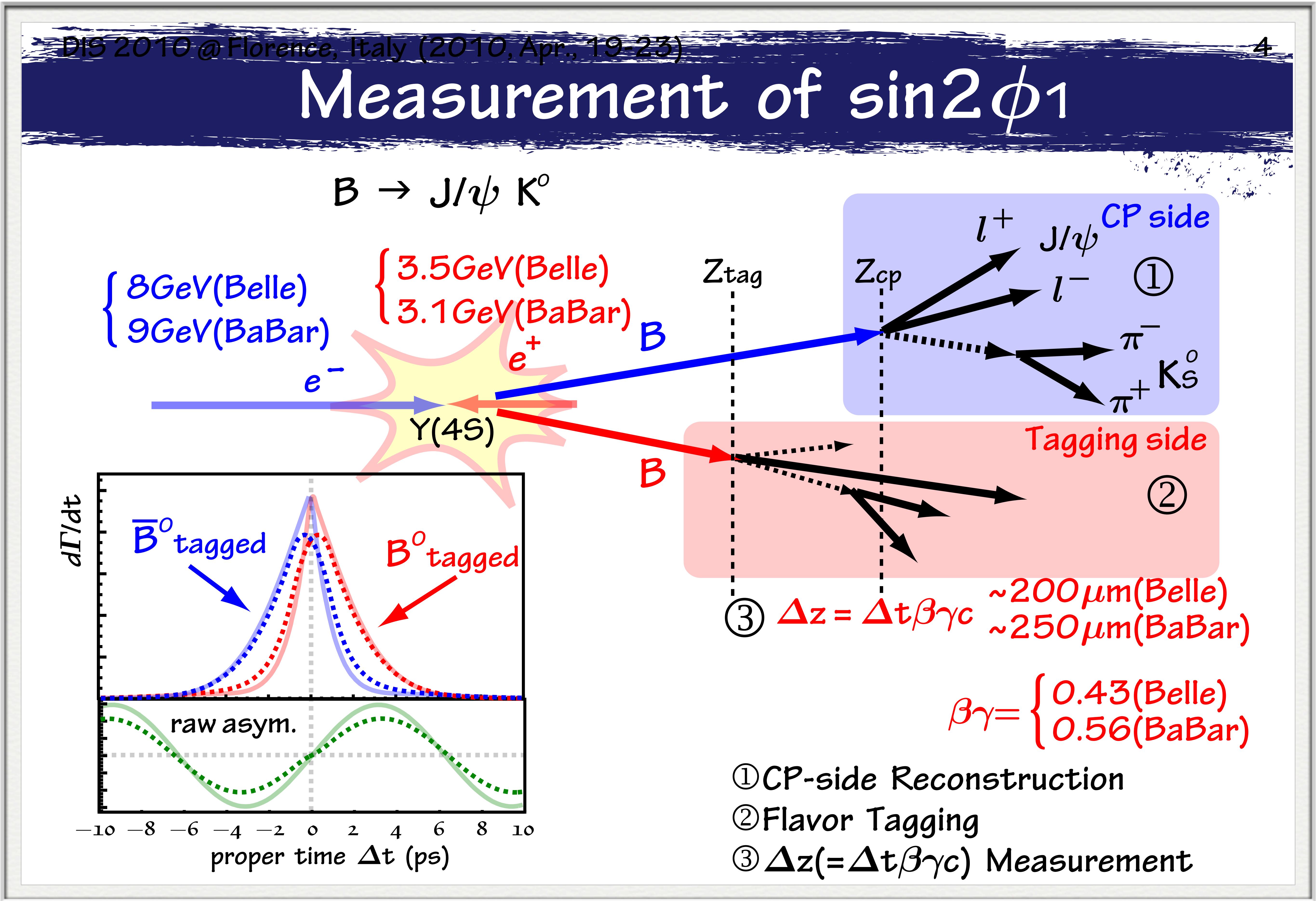
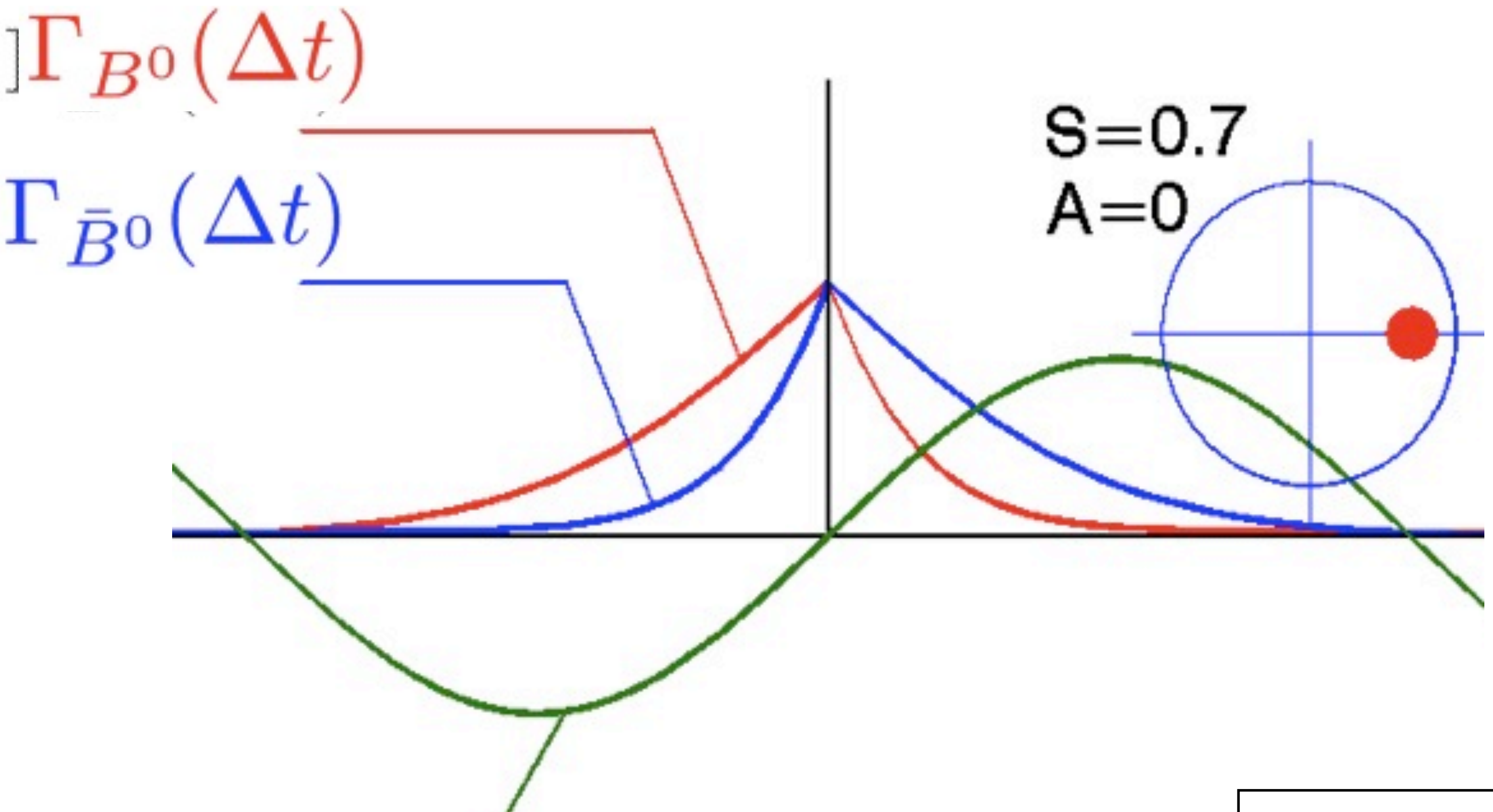

DIS 2010 @ Florence, Italy (2010, Apr., 19-23)
4
Measurement of sin2φ1
B → J/ψ K0
8GeV(Belle)
9GeV(BaBar)
3.5GeV(Belle)
3.1GeV(BaBar)
e−
e+
Υ(4S)
B
B
Ztag
Zcp
CP side
l+
J/ψ
l−
①
π−
KS0
π+
Tagging side
②
③ Δz = Δtβγc
~200μm(Belle)
~250μm(BaBar)
βγ= 0.43(Belle)
0.56(BaBar)
dΓ/dt
B̄0 tagged
B0 tagged
raw asym.
−10 −8 −6 −4 −2 0 2 4 6 8 10
proper time Δt (ps)
①CP-side Reconstruction
②Flavor Tagging
③Δz(=Δtβγc) Measurement

T-dep't CPV in B^0 decays



$$A_{CP}(\Delta t)$$
$$\equiv \frac{\Gamma_{\bar{B}^0}(\Delta t) - \Gamma_{B^0}(\Delta t)}{\Gamma_{\bar{B}^0}(\Delta t) + \Gamma_{B^0}(\Delta t)}$$
$$= \mathcal{S} \sin \Delta m \Delta t + \mathcal{A} \cos \Delta m \Delta t$$

Mixing-induced CPV

Direct CPV

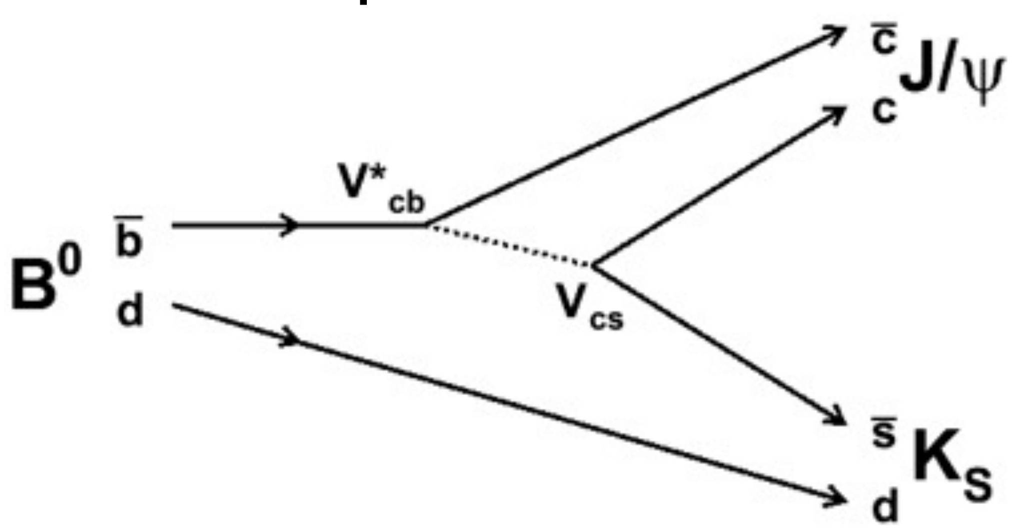
e.g. for J/ψ *Ks*
$\mathcal{S} = -\xi_{CP} \sin 2\phi_1 = +\sin 2\phi_1$
$\mathcal{A} = 0$
to a good approximation
(ξ_{CP} : CP eigenvalue)

($\mathcal{A} = -C$ a la BaBar)

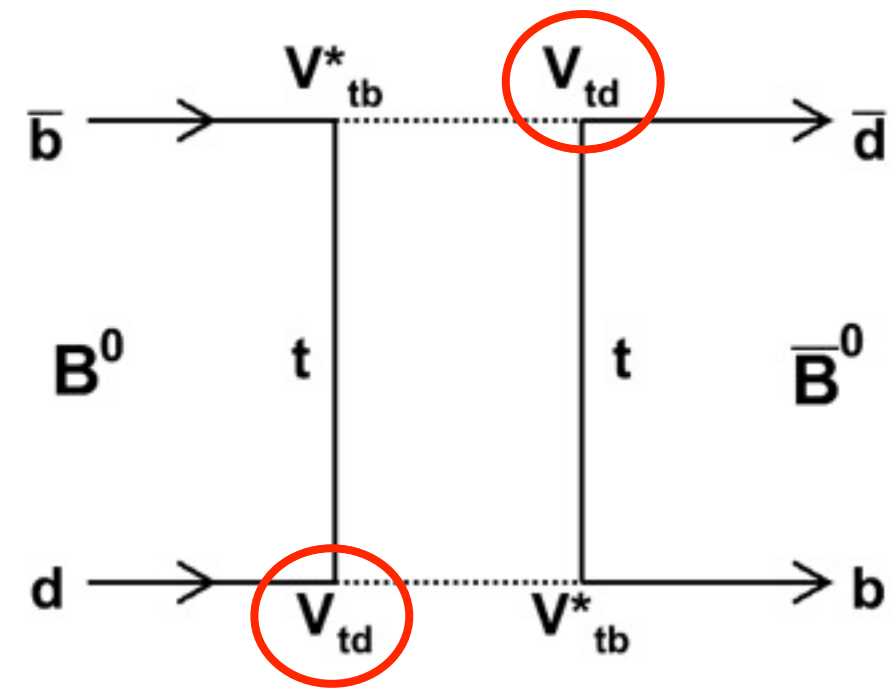
The Golden mode for ϕ_1

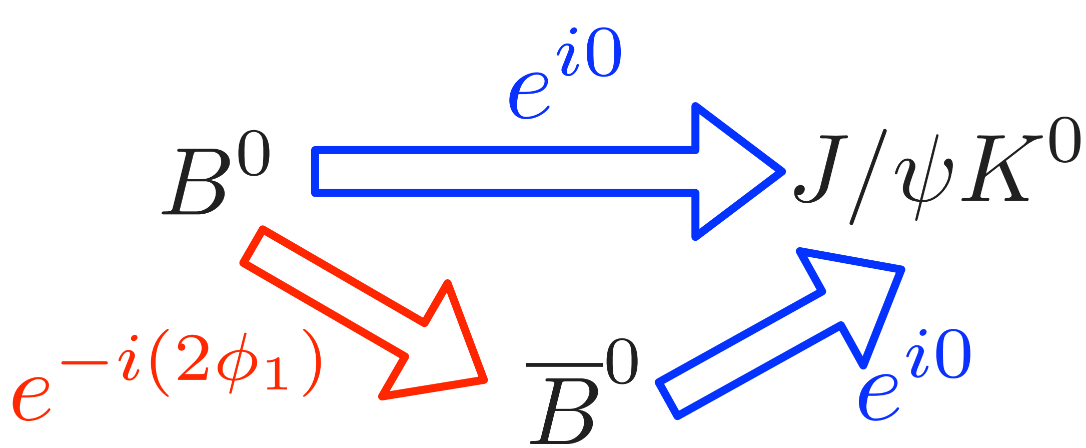
$B^0 \to J/\psi K^0$: high rate, theoretically clean

No CKM phase e^{i0}

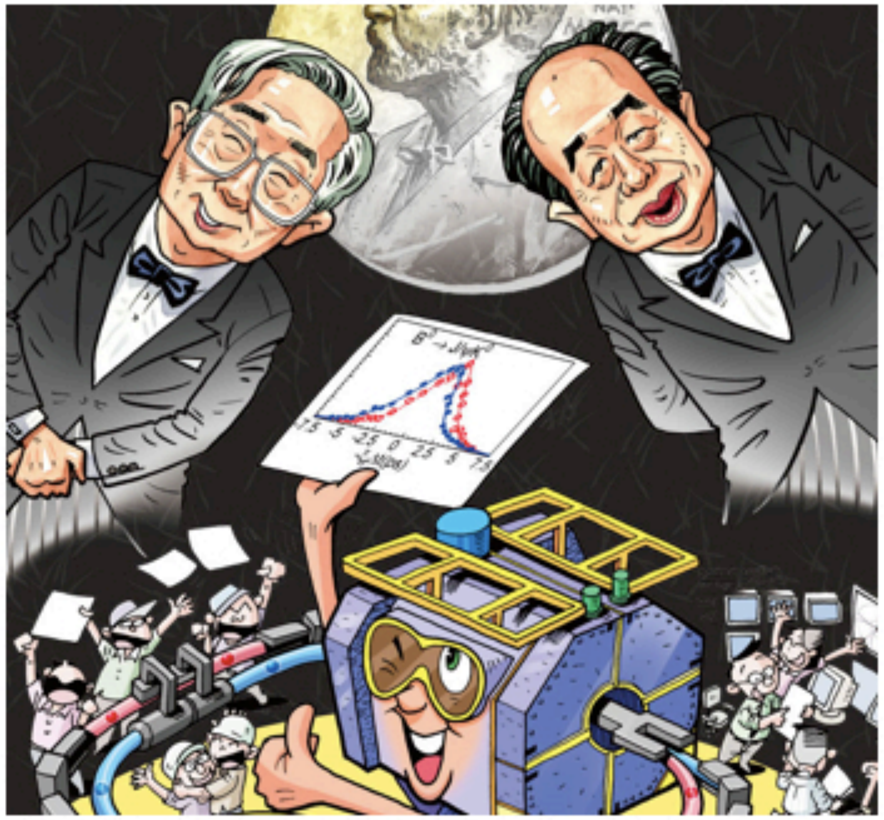


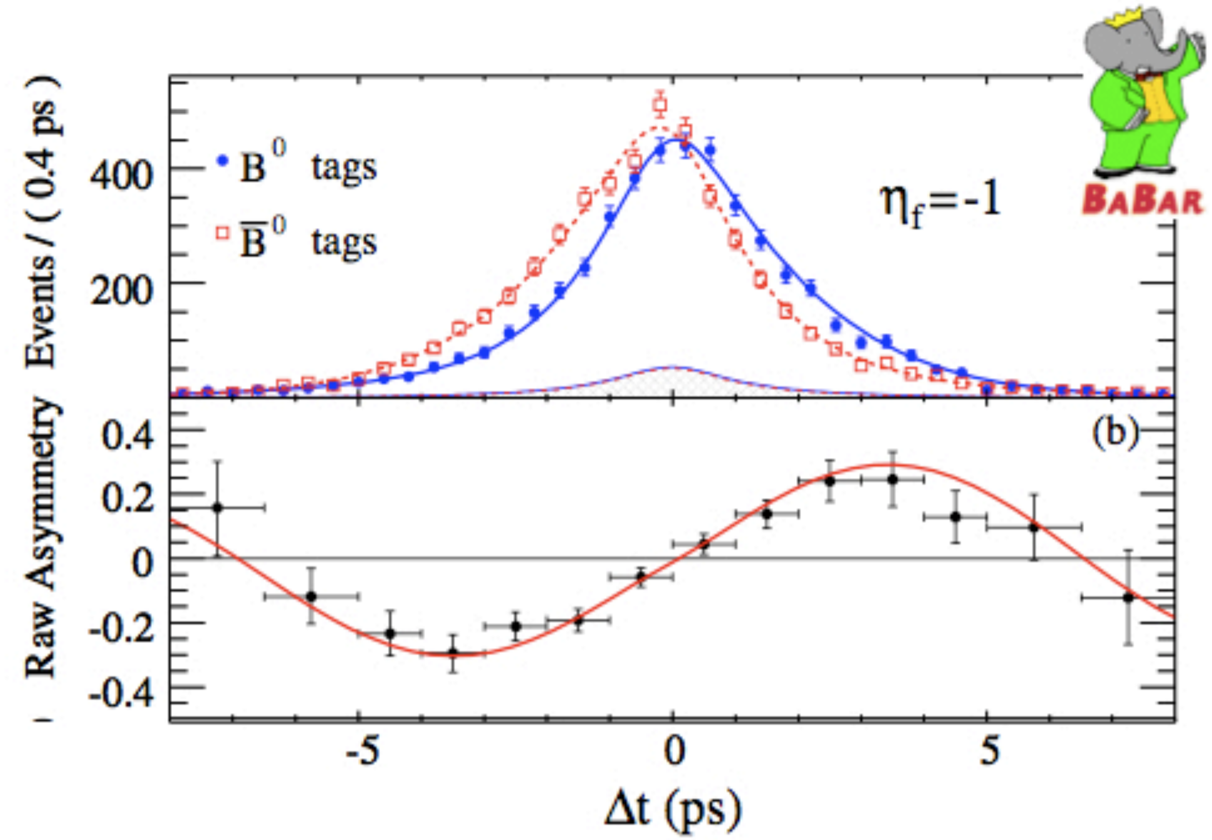
Two V_{td} vertices $e^{-i(2\phi_1)}$





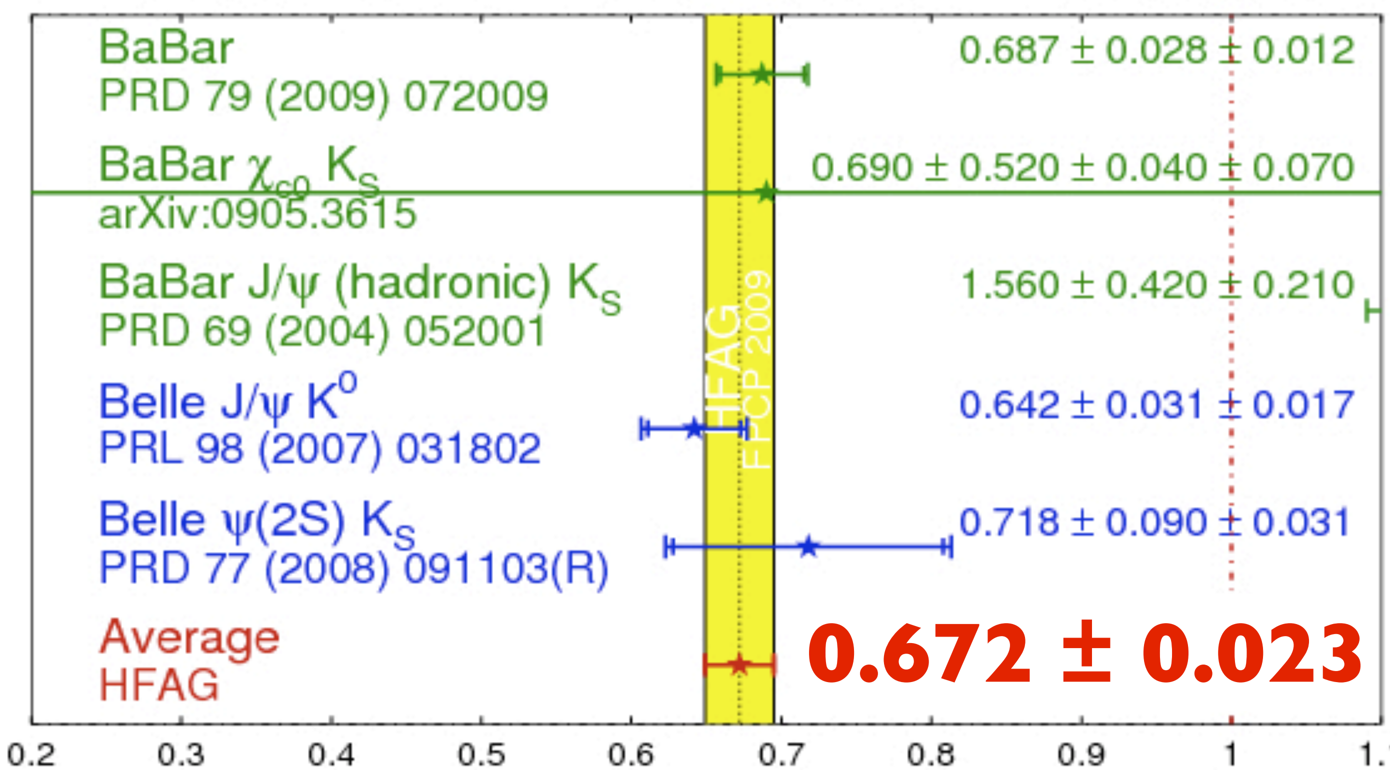
Note: true for any B^0 decay with no phase from decay amplitude

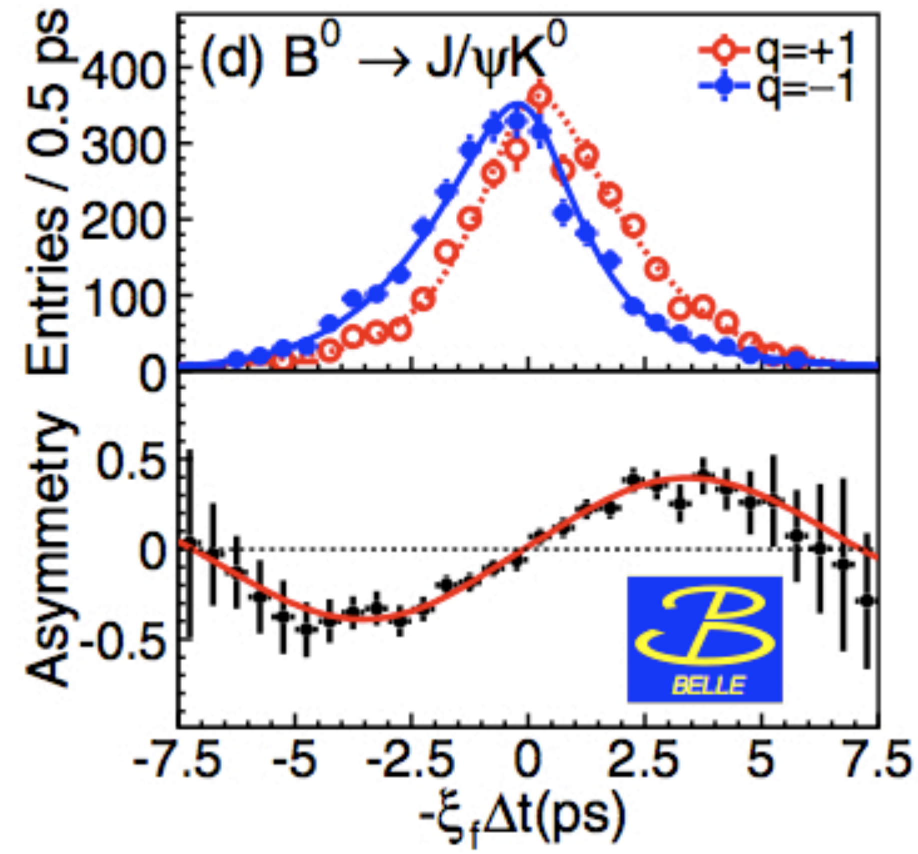




$\sin(2\beta) \equiv \sin(2\phi_1)$

HFAG
FPCP 2009
PRELIMINARY

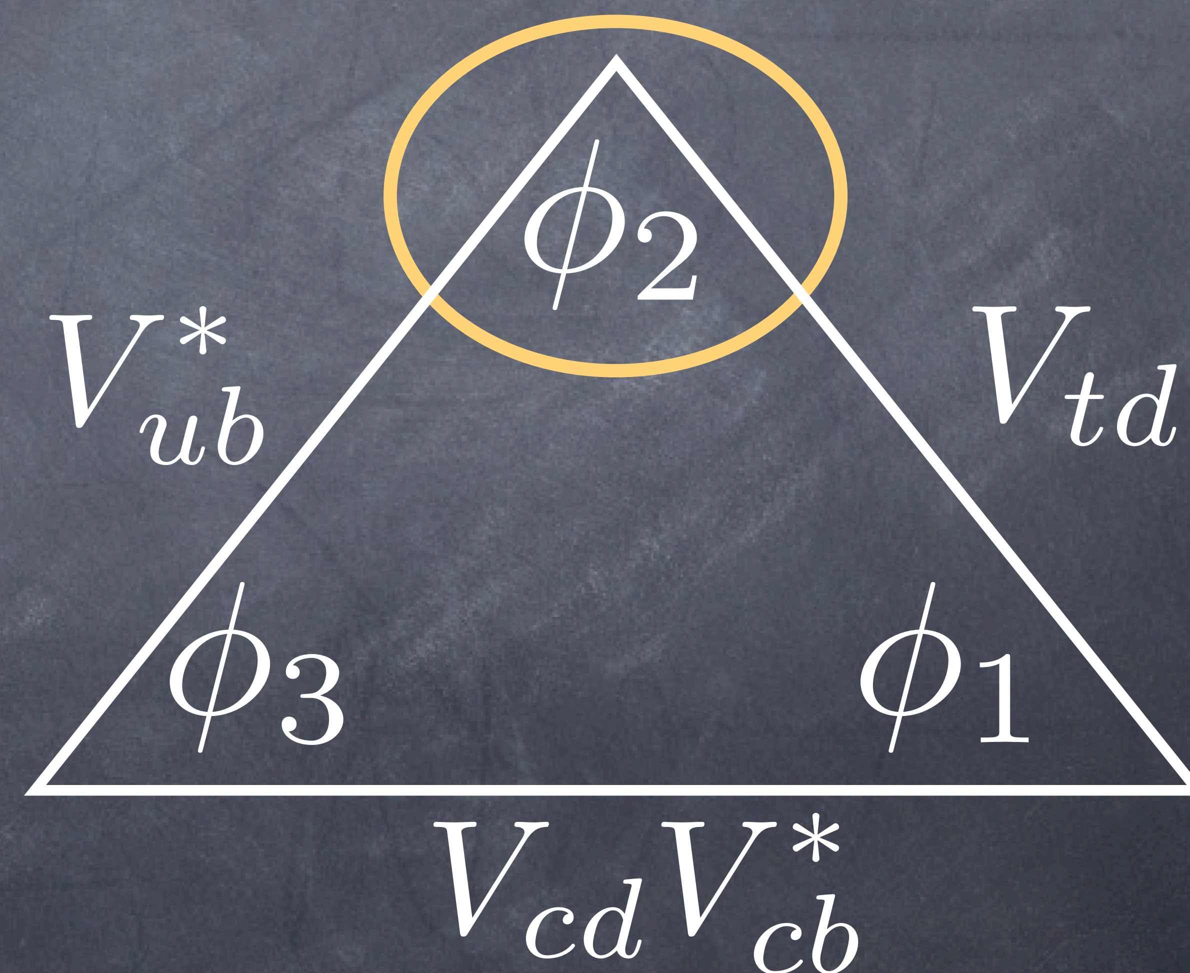




Other angles?

Unitarity triangle angles

BABAR:	β	α	γ
BELLE:	ϕ_1	ϕ_2	ϕ_3
	易	難	魔



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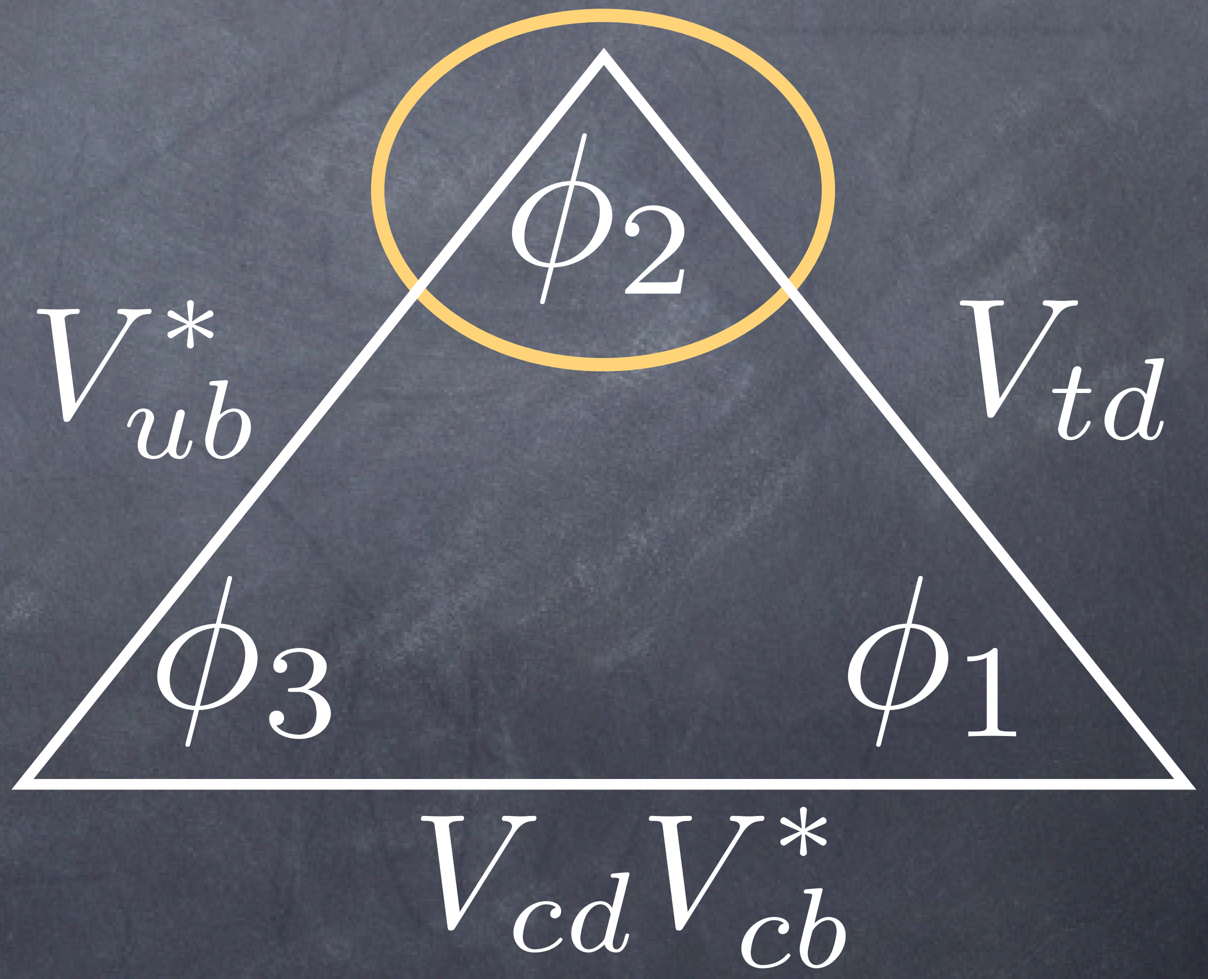

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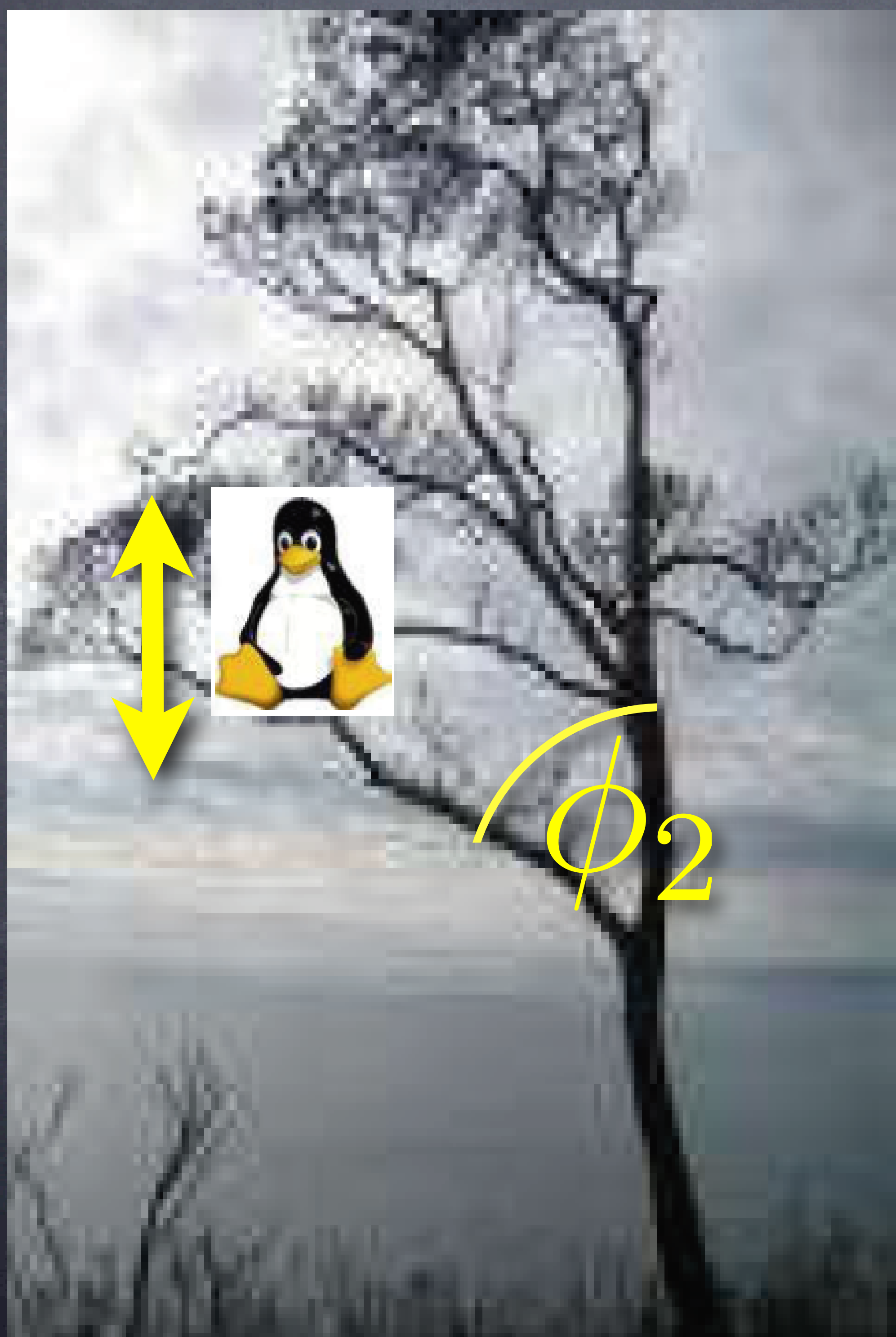

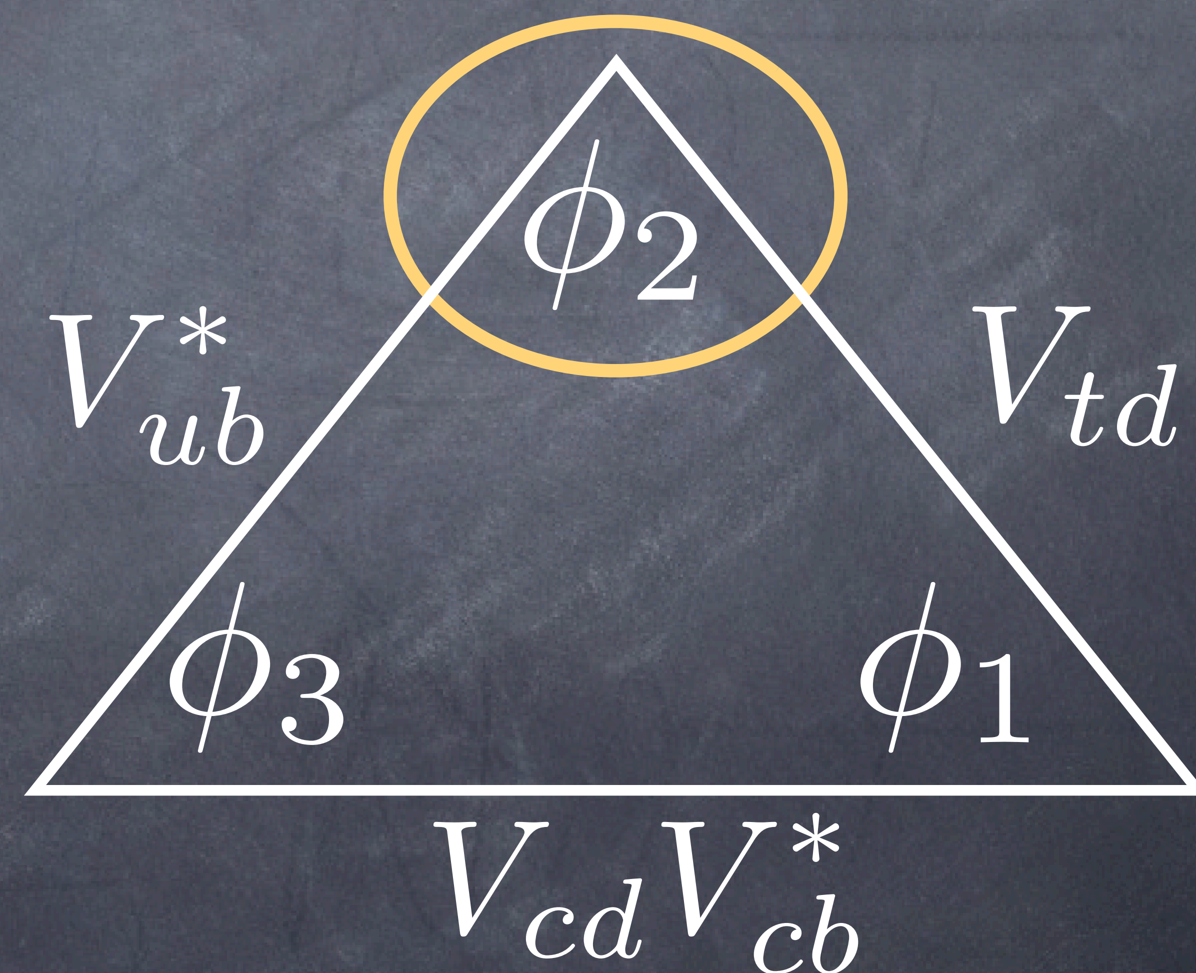

The Penguin Decays

- (effective) Flavor-Changing Neutral-Current process occurring at the loop level

  - forbidden at tree level in the SM

- sensitive to NP in the loop

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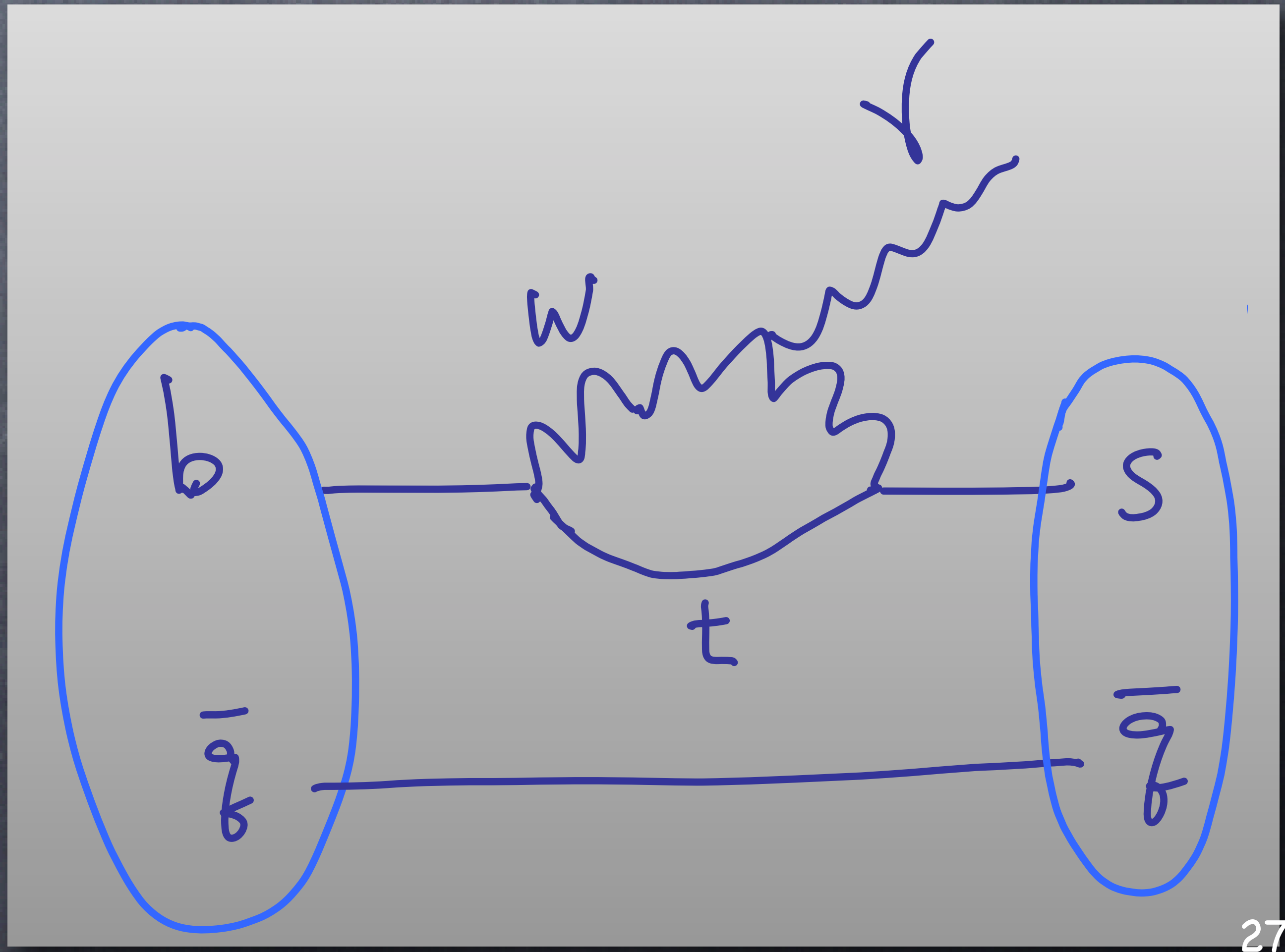
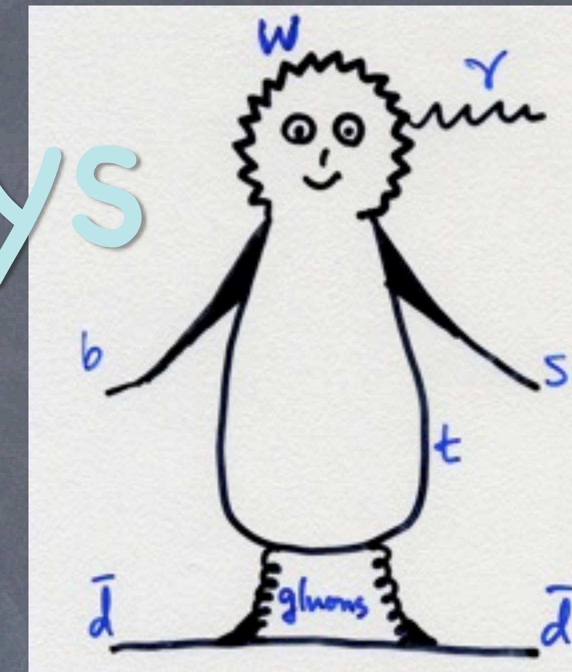


The Penguin Decays



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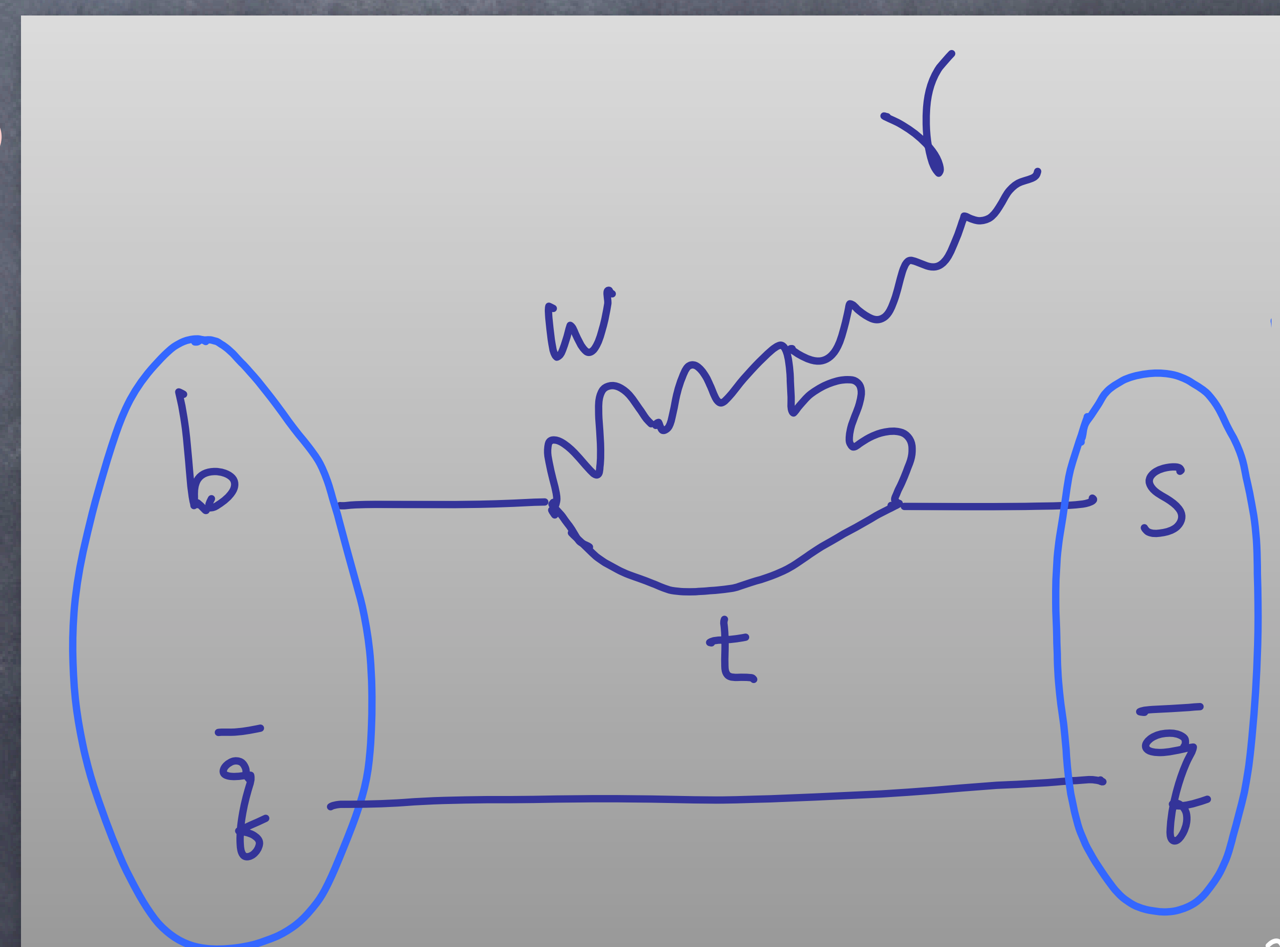


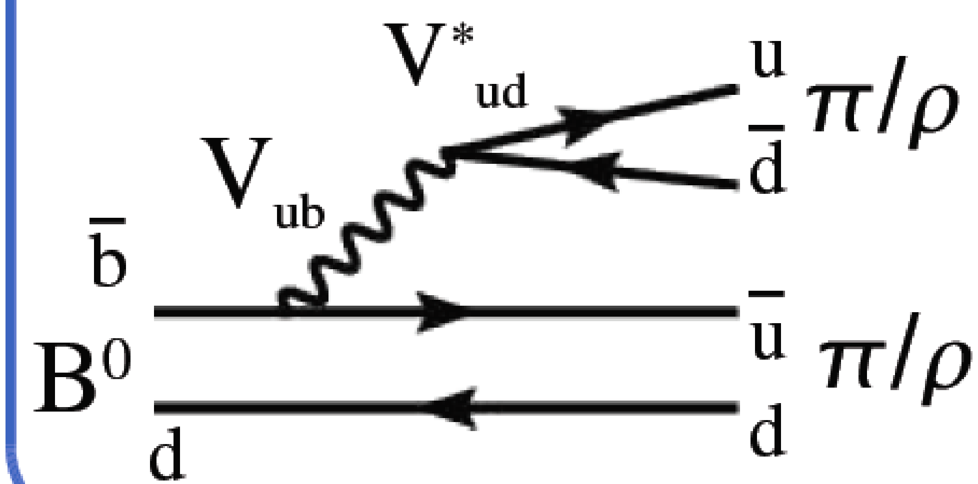
to measure ϕ_2

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

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

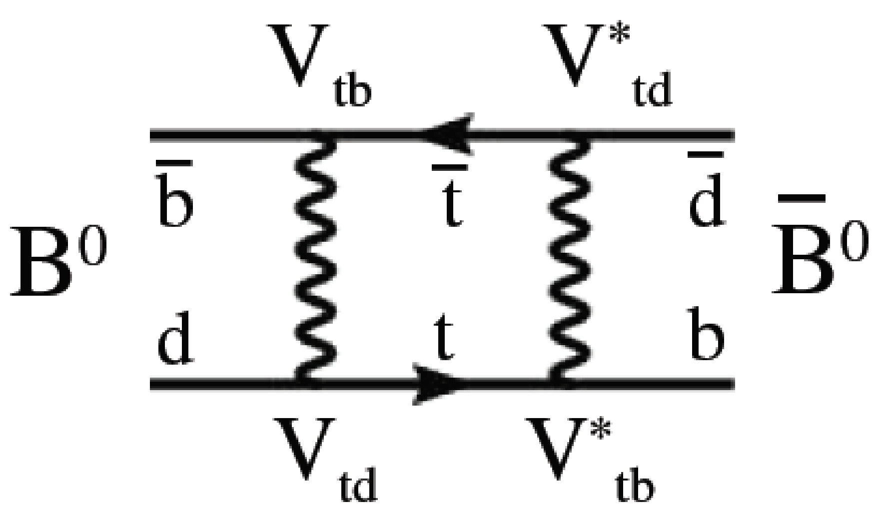
$B^0 \to \pi^+ \pi^-$

Tree diagram



ϕ_2

Mixing



Two phases

- mixing: V_{td} --> ϕ_1
- tree: V_{ub} --> ϕ_3

$$180^\circ - (\phi_1 + \phi_3) \Rightarrow \phi_2$$

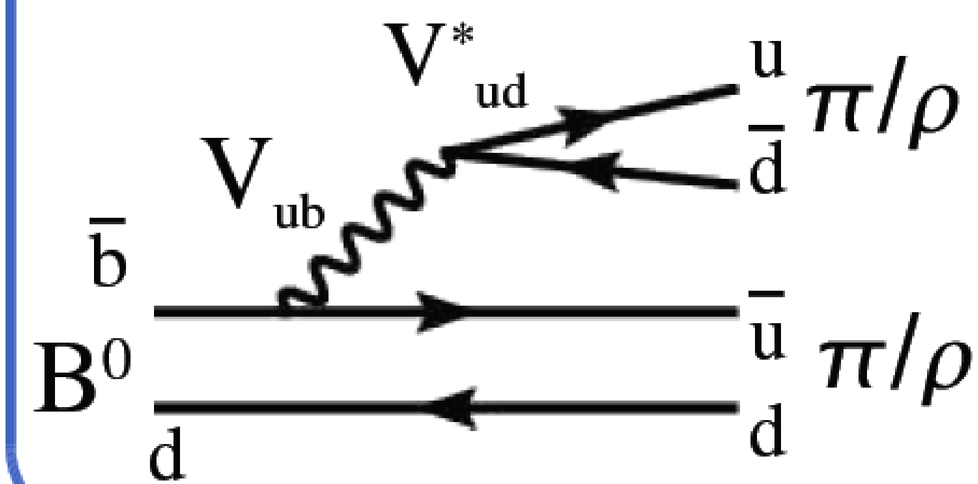
penguin's shaking a tree...

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

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

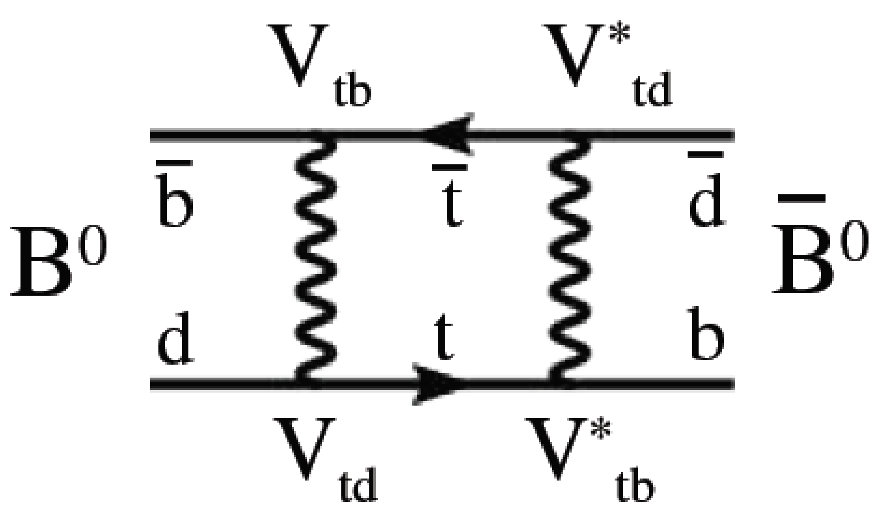
$B^0 \to \pi^+ \pi^-$

Tree diagram

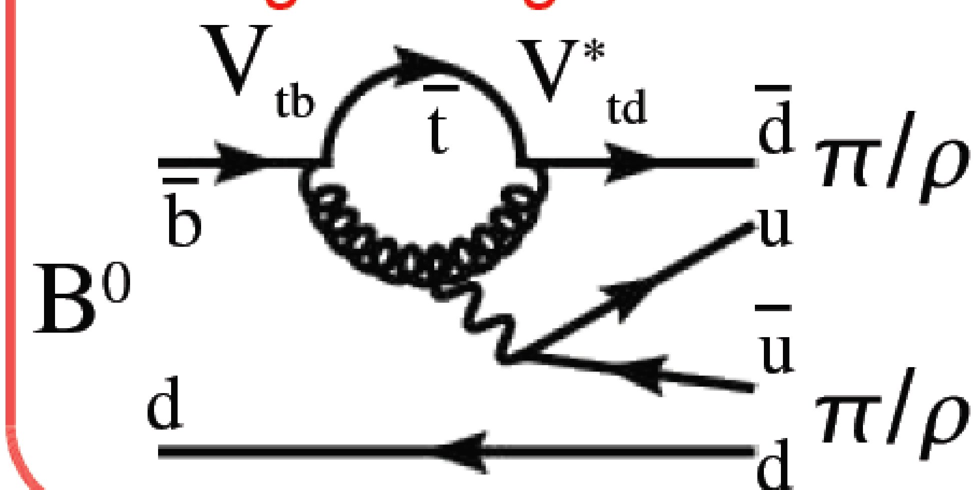


ϕ_2

Mixing



Penguin diagram



0

What shall we do?

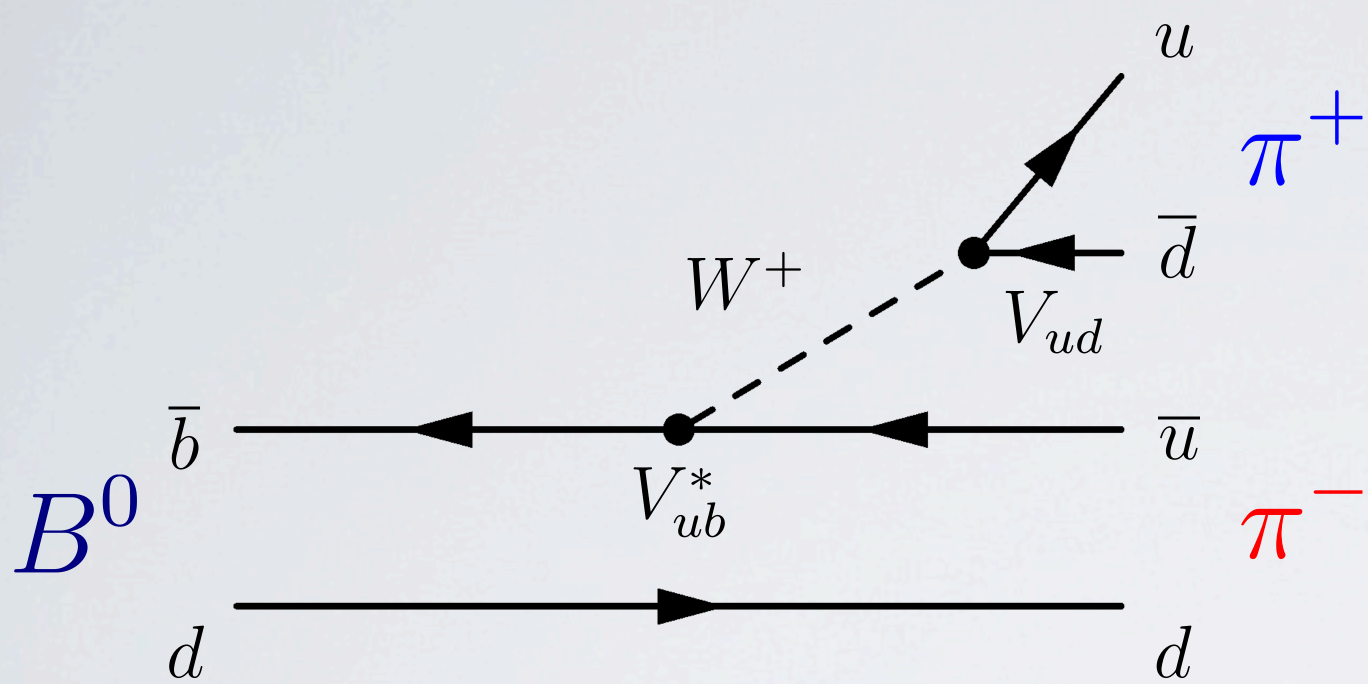
Isospin Analysis

Gronau & London, PRL 65, 3381 (1990)

- Model-independent (symmetry-dependent) method
- SU(2) breaking effect well below present statistical errors

"Penguin pollution" can be removed

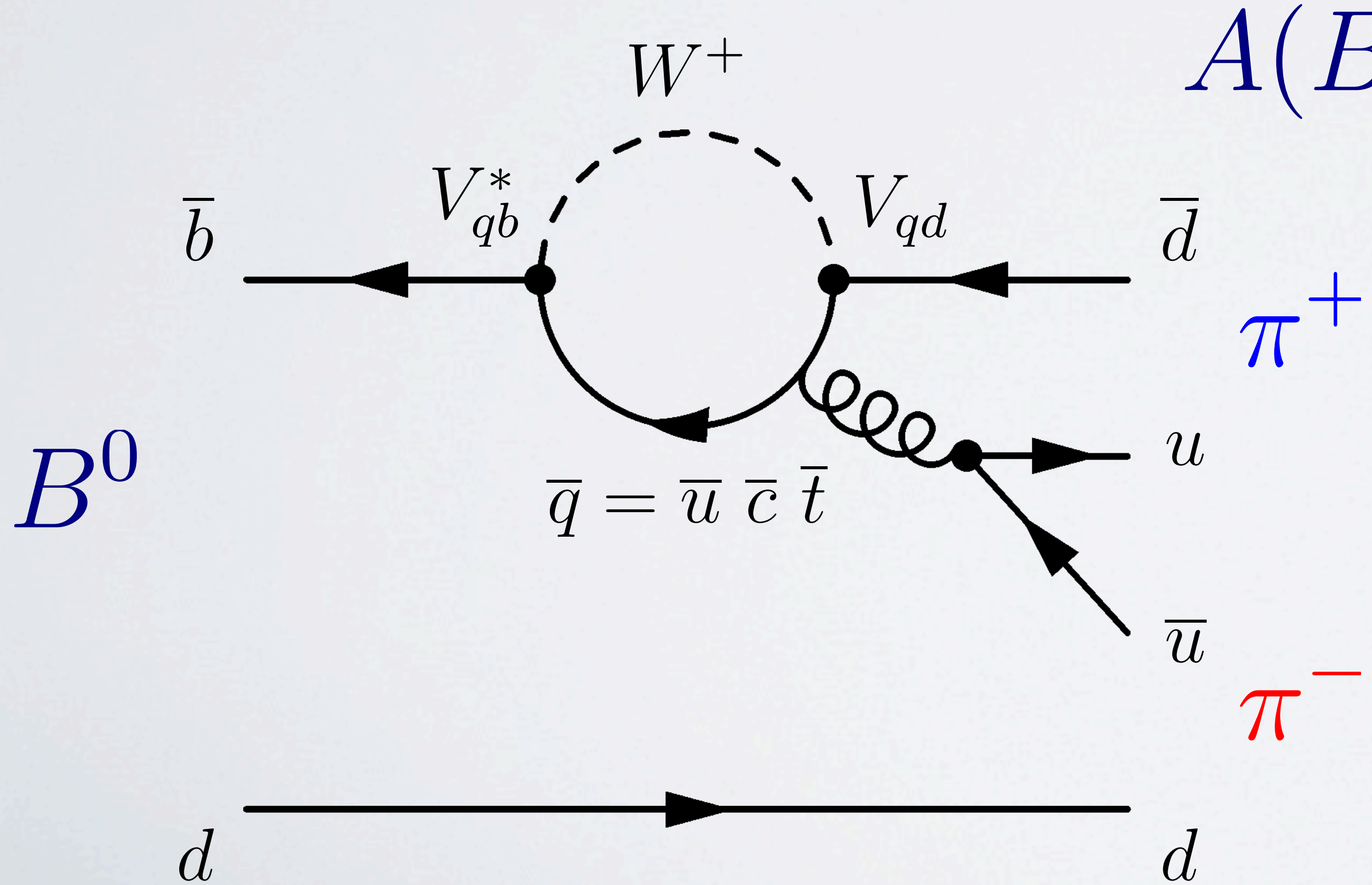
Isospin for $B^0 \to \pi^+\pi^-$



$I(B^0) = (½, -½)$

$I(\pi^+) = (1, +1)$

$I(\pi^-) = (1, -1)$

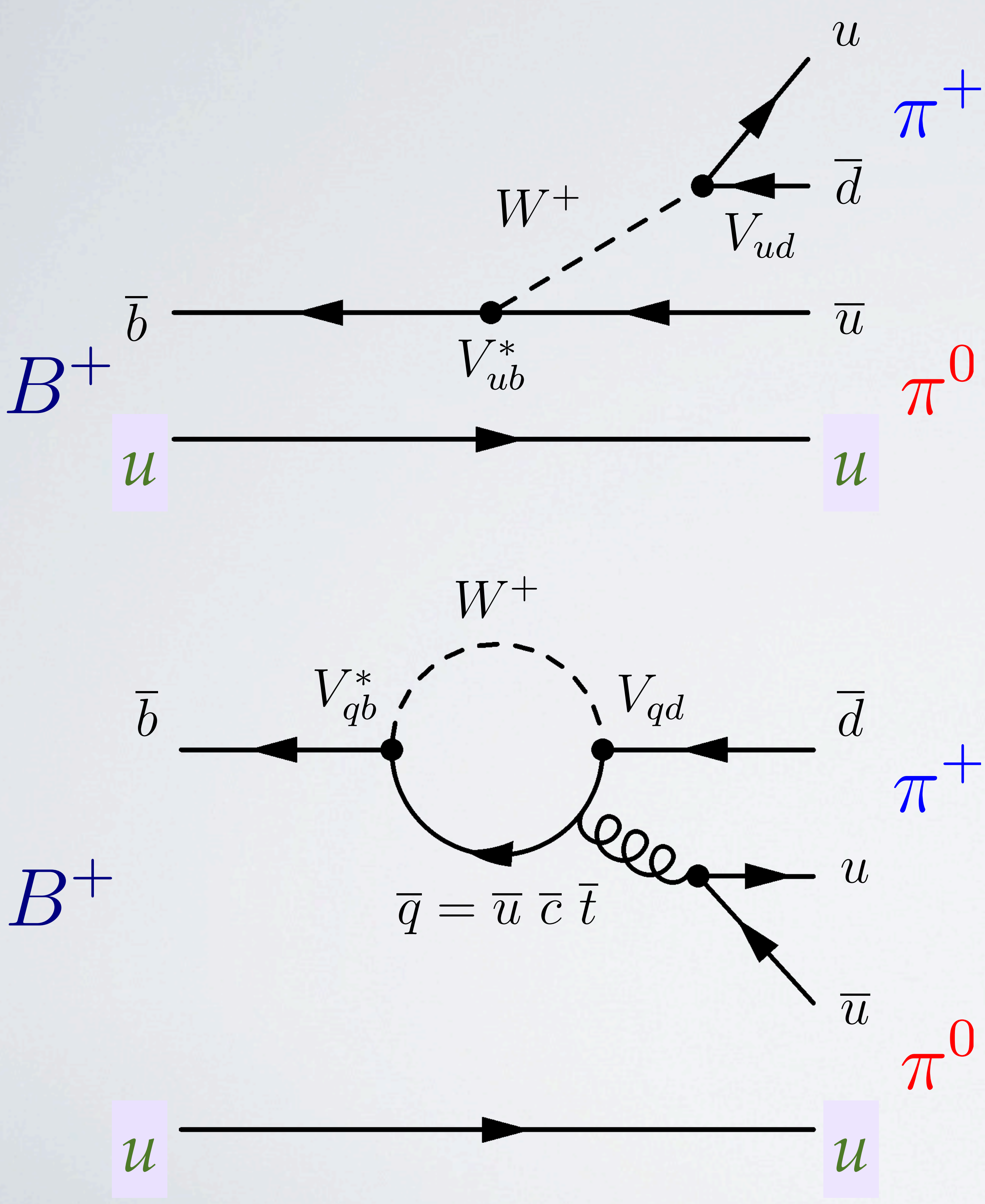


$$A(B^0 \to \pi^+\pi^-) \propto A_{\frac{3}{2},2} \oplus A_{\frac{1}{2},0}$$

due to bosonic symmetry, $I \neq 1$ in the $B \to \pi\,\pi$ final state

for gluonic transition, $\Delta I = 0$.
$\therefore I \neq 2$ for gluonic penguins.

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



$I(B^+) = (½, ½)$
$I(\pi^+) = (1, +1)$
$I(\pi^0) = (1, 0)$

no penguin!

$$A(B^+ \to \pi^+\pi^0) \propto A_{\frac{3}{2},2}$$

due to bosonic symmetry, I ≠ 1 in the B -> π π final state

for gluonic transition, ΔI = 0.
∴ I ≠ 2 for gluonic penguins.

- **from the BaBar physics book**

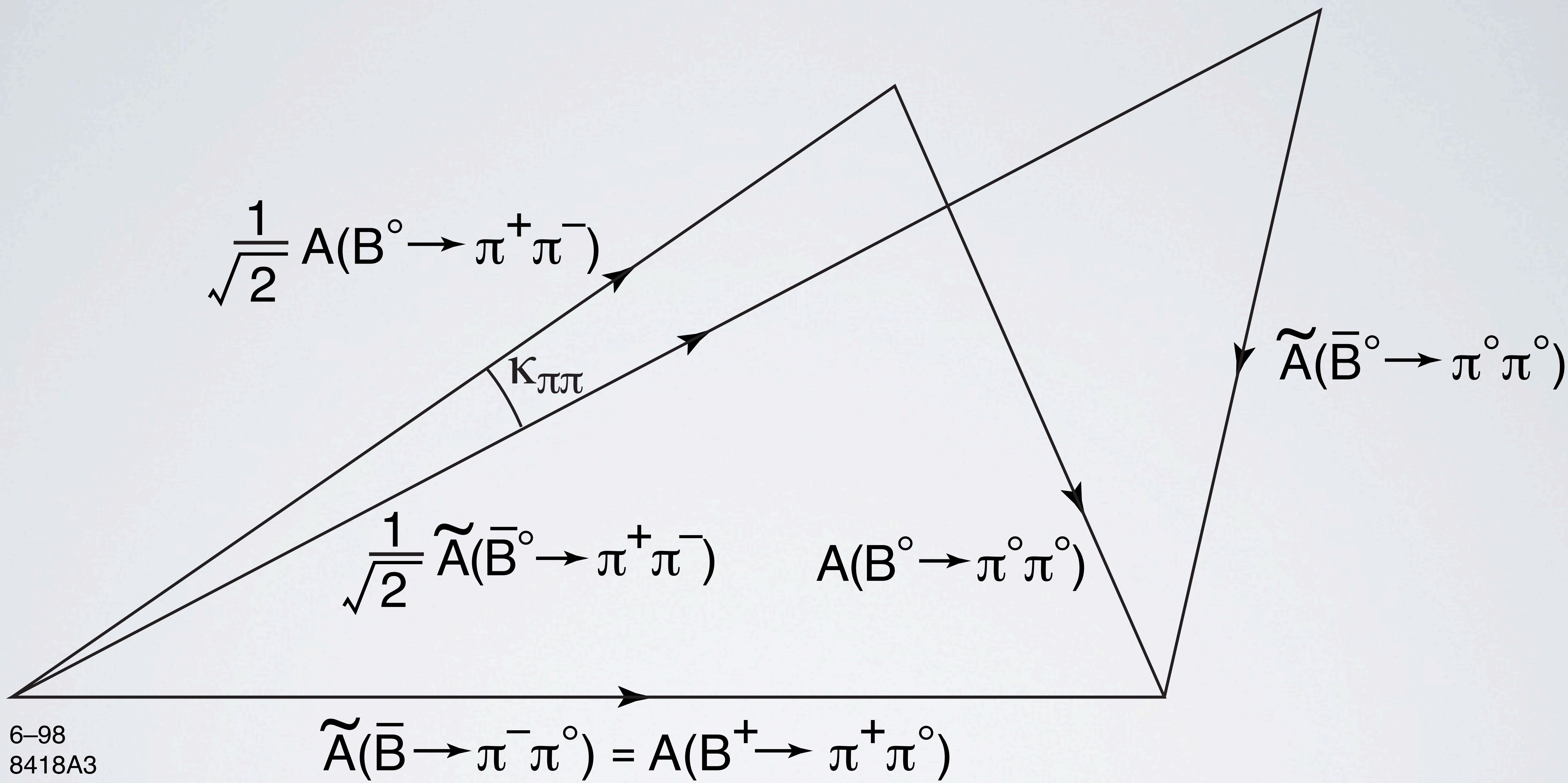
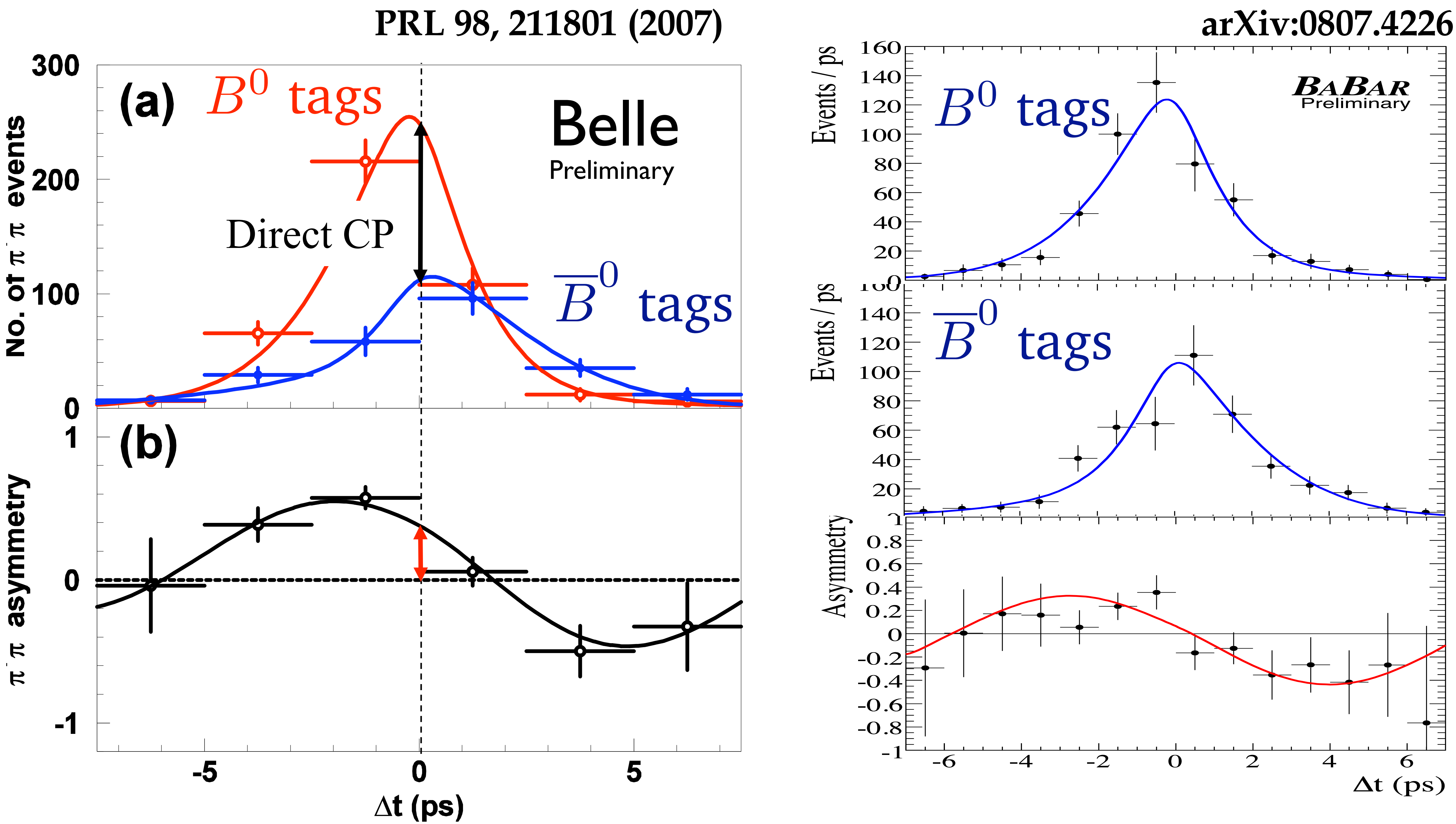


Figure 6-1. *Isospin analysis of $B \to \pi\pi$ decays.*

and similar isospin analyses for B -> ρ ρ, etc.

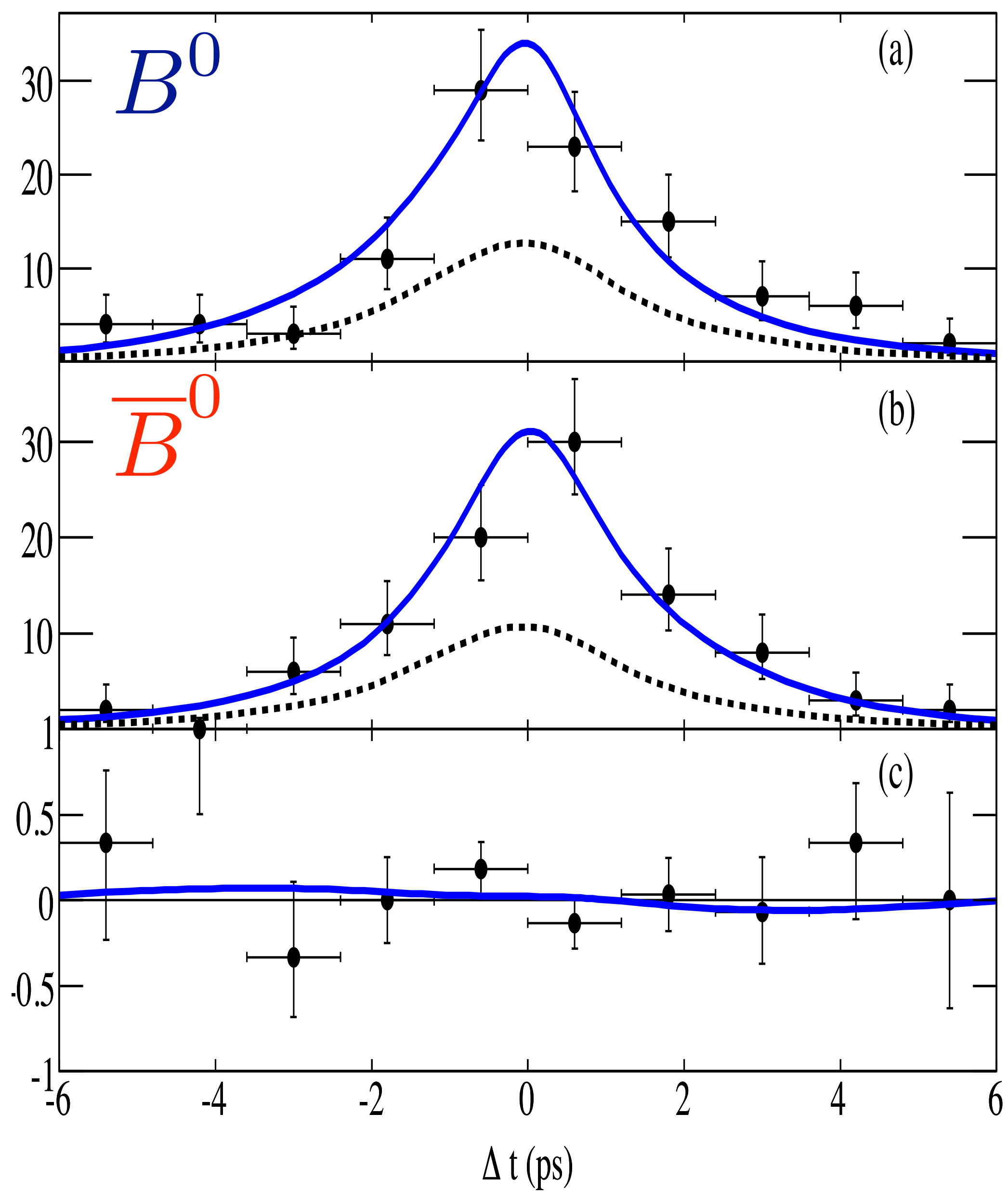
$A_{CP}(\Delta t)$ from $B^0 \to \pi^+\pi^-$



$$C_{CP} \neq 0 \Rightarrow S_{CP} = \sqrt{1 - C_{CP}^2}\,\sin(2\phi_2^{\rm eff})$$

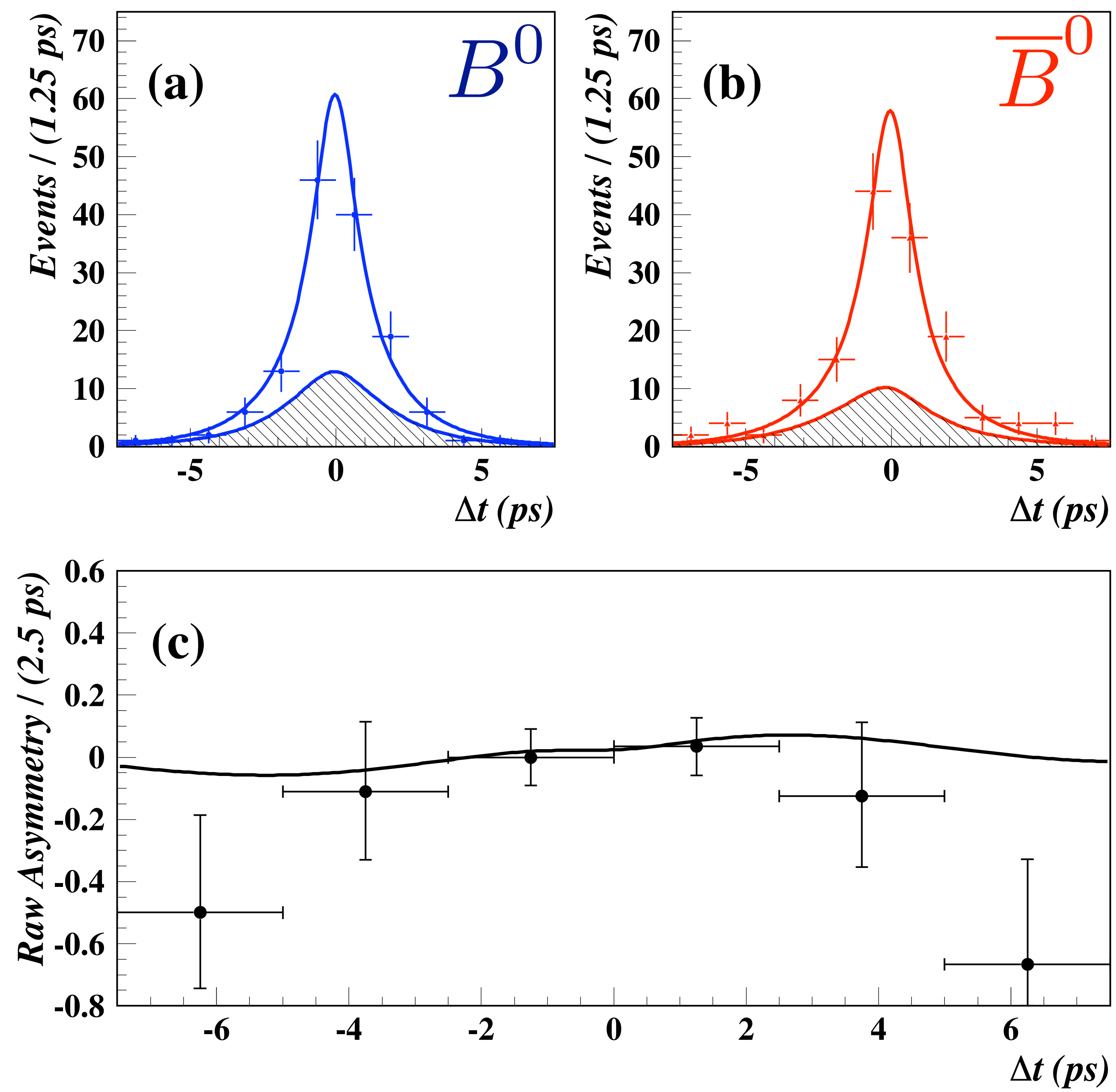
ϕ_2 from $B^0 \to \rho^+\rho^-$

***BABAR*, PRD 76, 052007 (2007)**



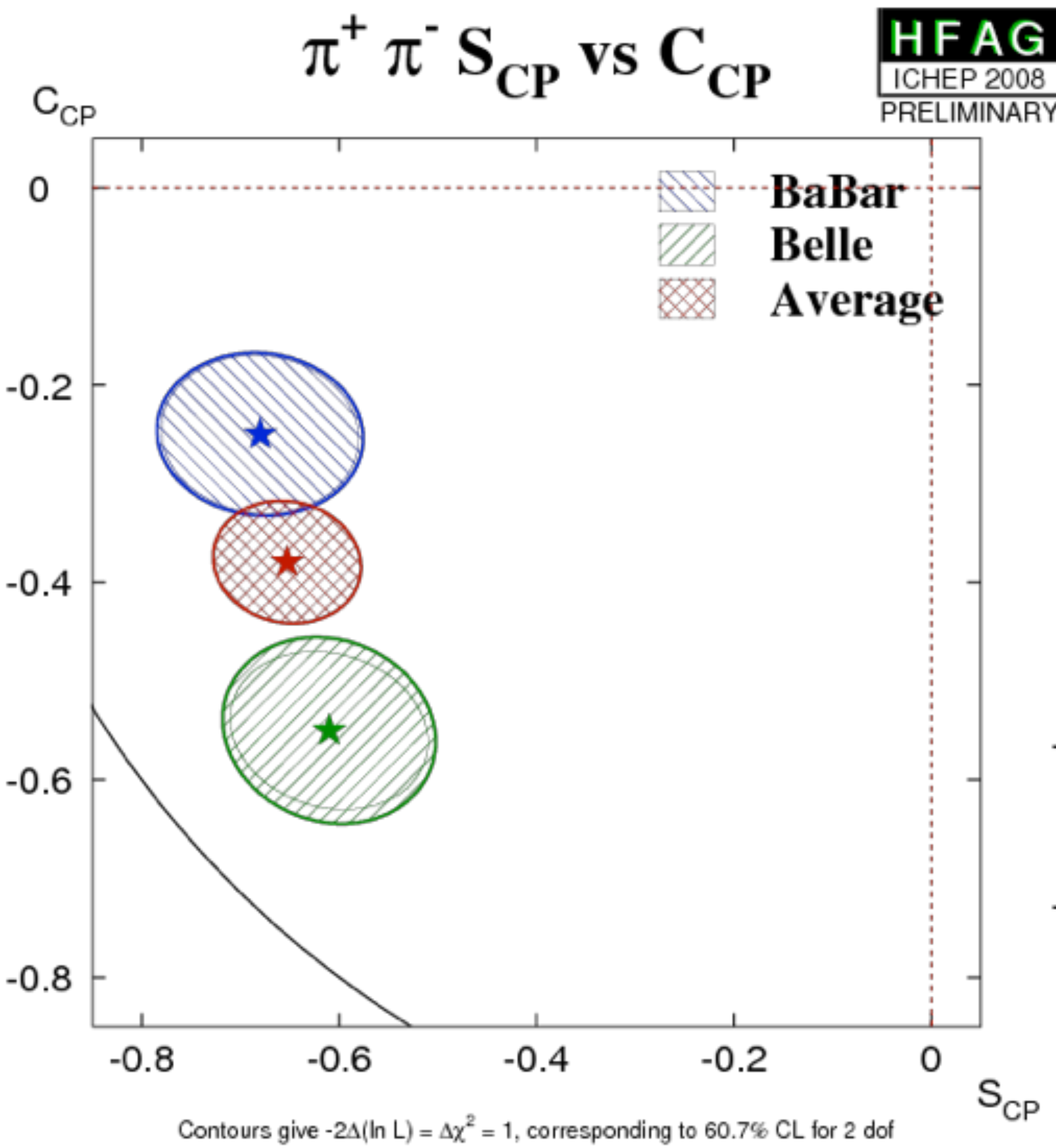
$$\mathcal{B}(B^0 \to \rho^+\rho^-) = (25.5 \pm 2.1(\text{stat})^{+3.6}_{-3.9}(\text{syst}))\times 10^{-6},$$
$$f_L = 0.992 \pm 0.024(\text{stat})^{+0.026}_{-0.013}(\text{syst}),$$
$$S_{\text{long}} = -0.17 \pm 0.20(\text{stat})^{+0.05}_{-0.06}(\text{syst}),$$
$$C_{\text{long}} = 0.01 \pm 0.15(\text{stat}) \pm 0.06(\text{syst}).$$

Belle, PRD 76, 011104 (2007)

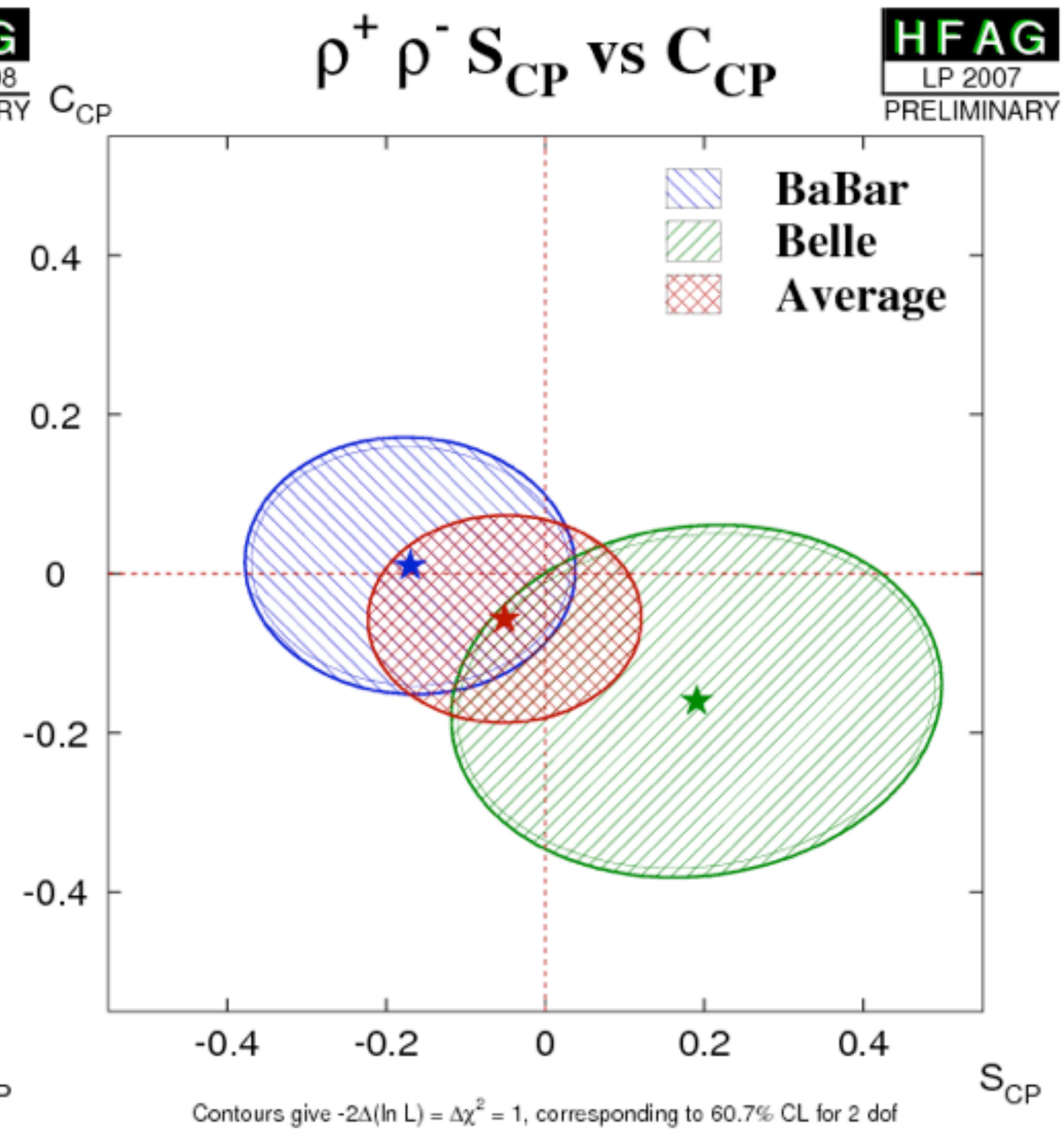


$$\mathcal{A}_L = 0.16 \pm 0.21\,(\text{stat}) \pm 0.07\,(\text{syst})$$
$$\mathcal{S}_L = 0.19 \pm 0.30\,(\text{stat}) \pm 0.07\,(\text{syst})$$

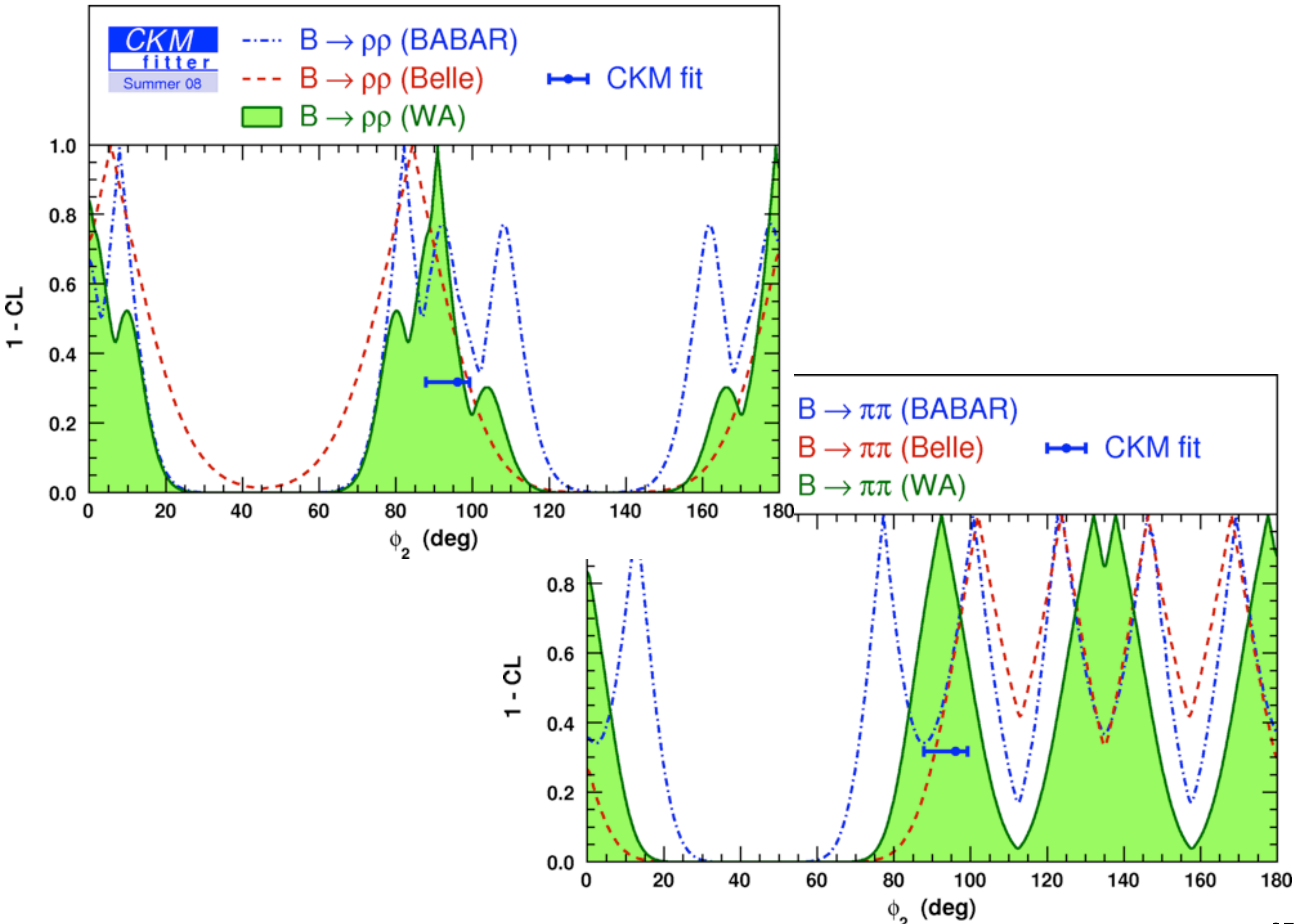
A, S : both consistent with 0

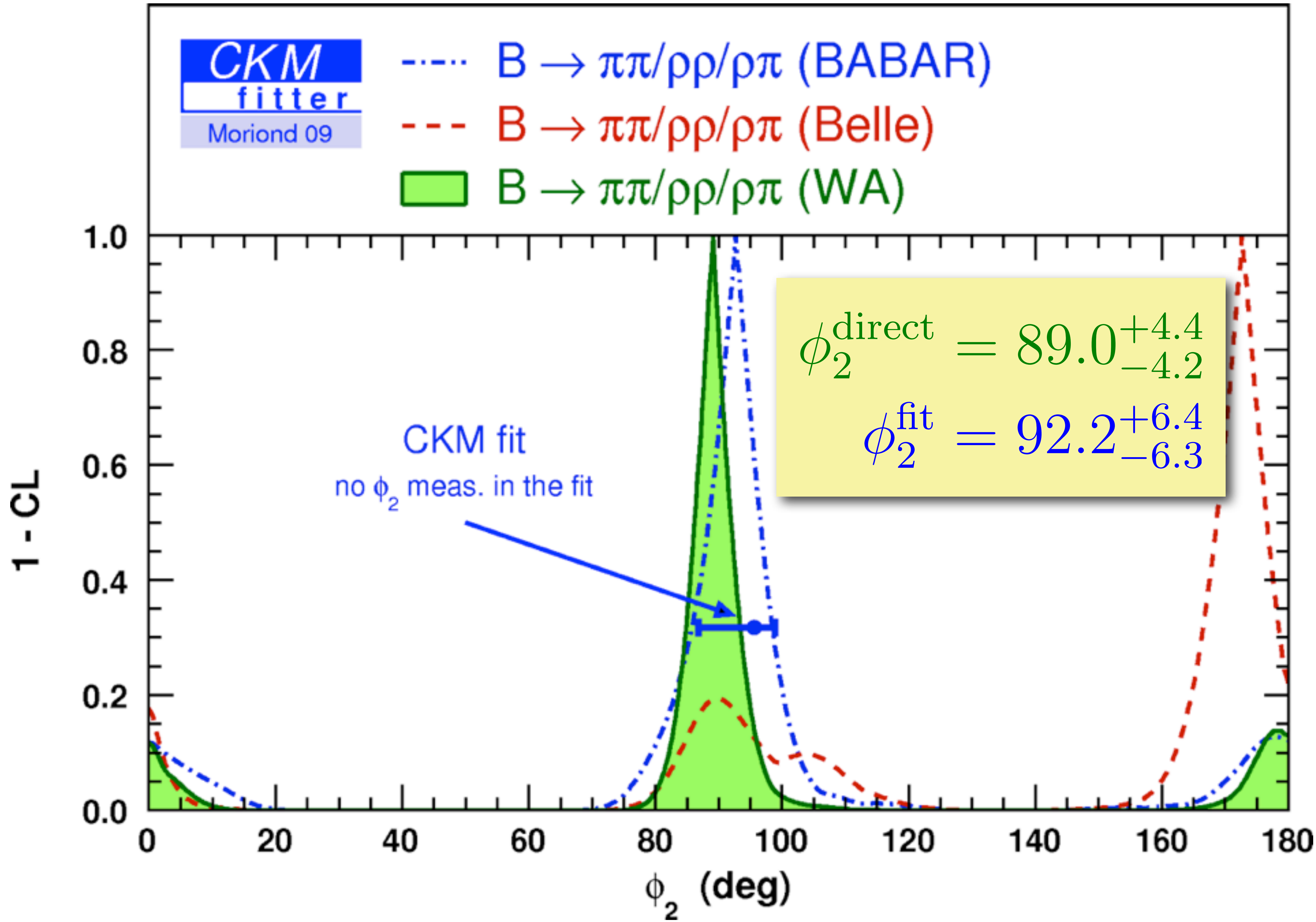


$\pi^+ \pi^- S_{CP}$ vs C_{CP}
HFAG
ICHEP 2008
PRELIMINARY
C_{CP}
0
-0.2
-0.4
-0.6
-0.8
-0.8
-0.6
-0.4
-0.2
0
S_{CP}
BaBar
Belle
Average
Contours give $-2\Delta(\ln L) = \Delta\chi^2 = 1$, corresponding to 60.7% CL for 2 dof



$\rho^+ \rho^- S_{CP}$ vs C_{CP}
HFAG
LP 2007
PRELIMINARY
C_{CP}
0.4
0.2
0
-0.2
-0.4
-0.4
-0.2
0
0.2
0.4
S_{CP}
BaBar
Belle
Average
Contours give $-2\Delta(\ln L) = \Delta\chi^2 = 1$, corresponding to 60.7% CL for 2 dof

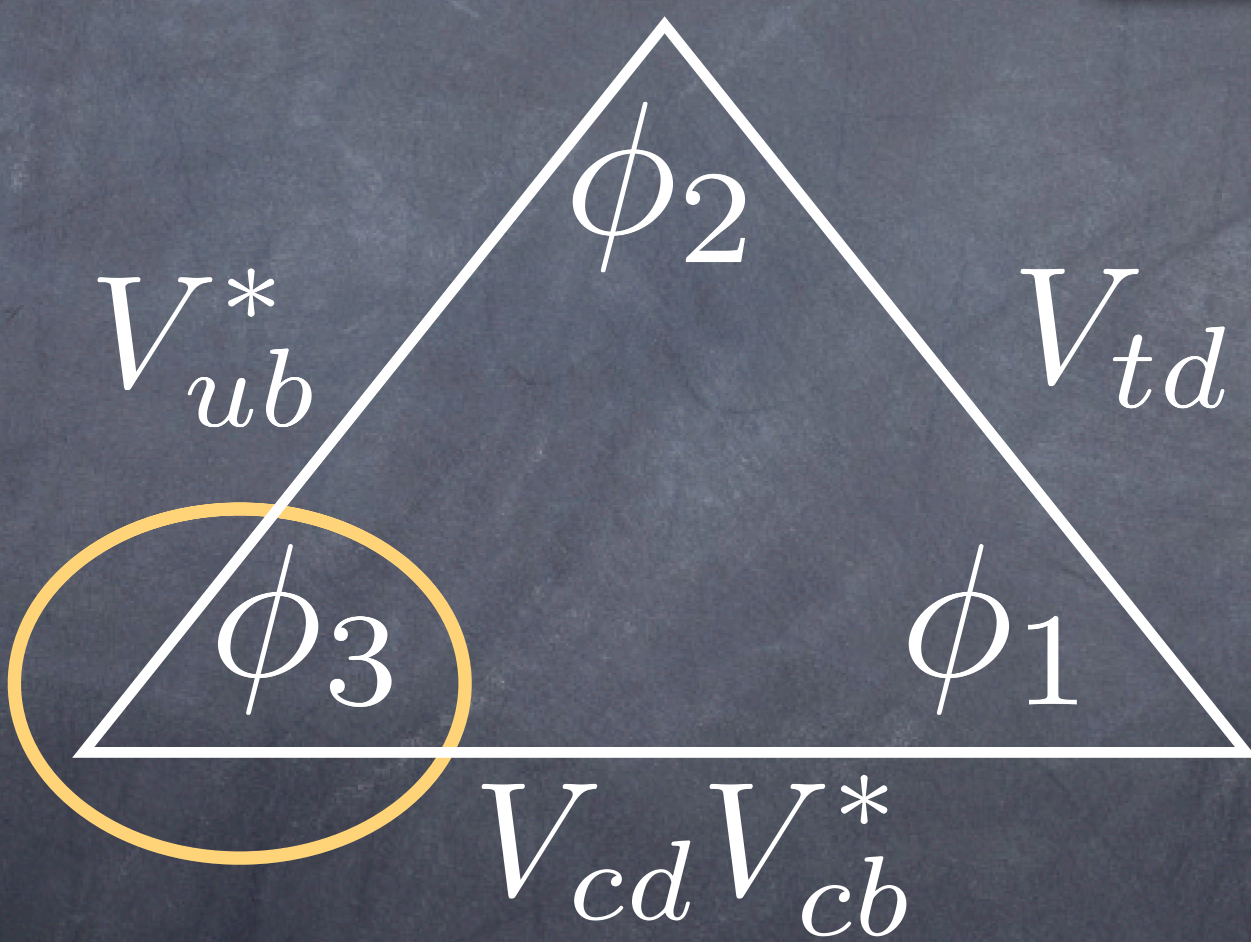

CKM fitter
Summer 08
B → ρρ (BABAR)
B → ρρ (Belle)
B → ρρ (WA)
CKM fit
1 - CL
1.0
0.8
0.6
0.4
0.2
0.0
0
20
40
60
80
100
120
140
160
180
ϕ_2 (deg)
B → ππ (BABAR)
B → ππ (Belle)
B → ππ (WA)
CKM fit
1 - CL
0.8
0.6
0.4
0.2
0.0
0
20
40
60
80
100
120
140
160
180
ϕ_2 (deg)



CKM fitter
Moriond 09
B → ππ/ρρ/ρπ (BABAR)
B → ππ/ρρ/ρπ (Belle)
B → ππ/ρρ/ρπ (WA)
$\phi_2^{\rm direct} = 89.0^{+4.4}_{-4.2}$
$\phi_2^{\rm fit} = 92.2^{+6.4}_{-6.3}$
CKM fit
no ϕ_2 meas. in the fit
1 - CL
ϕ_2 (deg)
1.0
0.8
0.6
0.4
0.2
0.0
0
20
40
60
80
100
120
140
160
180

Other angles?

Unitarity triangle angles			
BABAR:	β	α	γ
BELLE:	ϕ_1	ϕ_2	ϕ_3
	易	難	魔



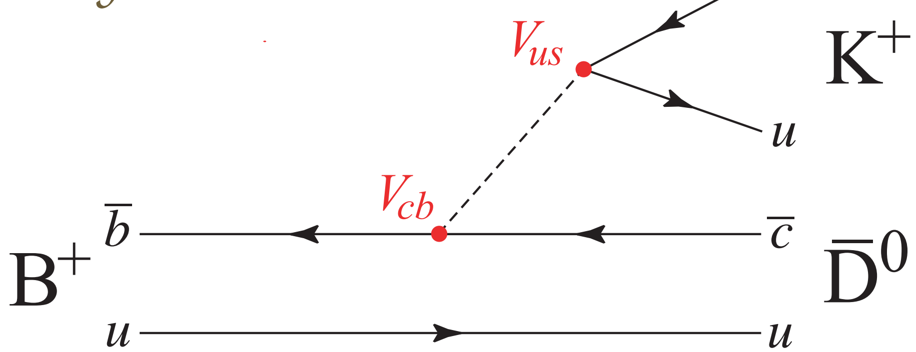
GLW: Gronau, London, Wyler (2001)

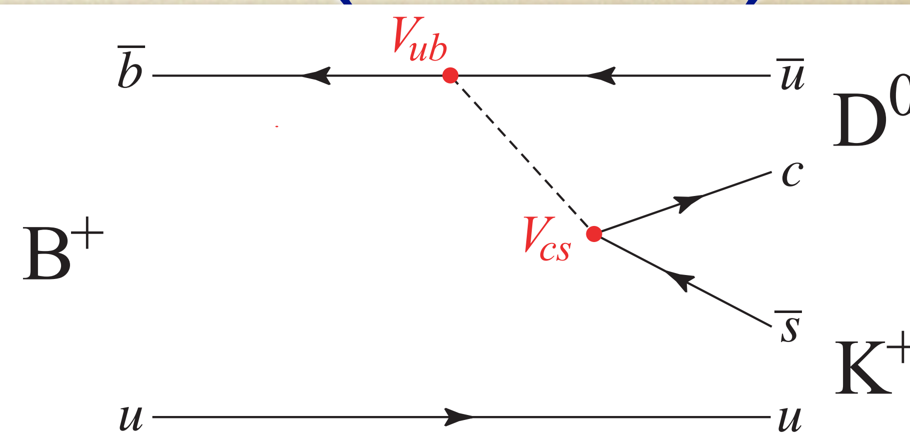
ADS: Atwood, Dunietz, Soni (1997)

GGSZ: Giri, Grossman, Soffer, Zupan (2003)

ϕ_3 from CPV in B -> DK (GGSZ)

slide by L. Piilonen, SSI(2009)



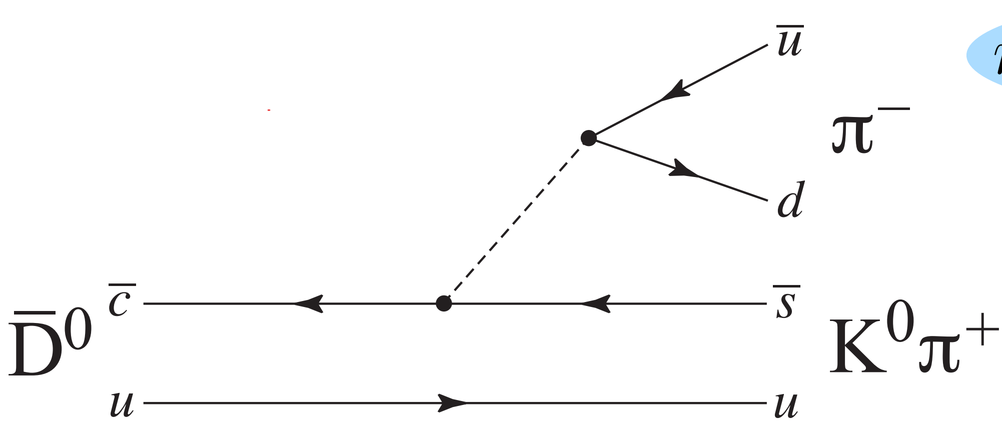


- If both D^0 and $\overline{D}^0$ decay into the same final state (e.g., $K_s\pi^+\pi^-$), then $B^+ \to D^0K^+$ and $B^+ \to \overline{D}^0K^+$ amplitudes interfere. The mixed state is

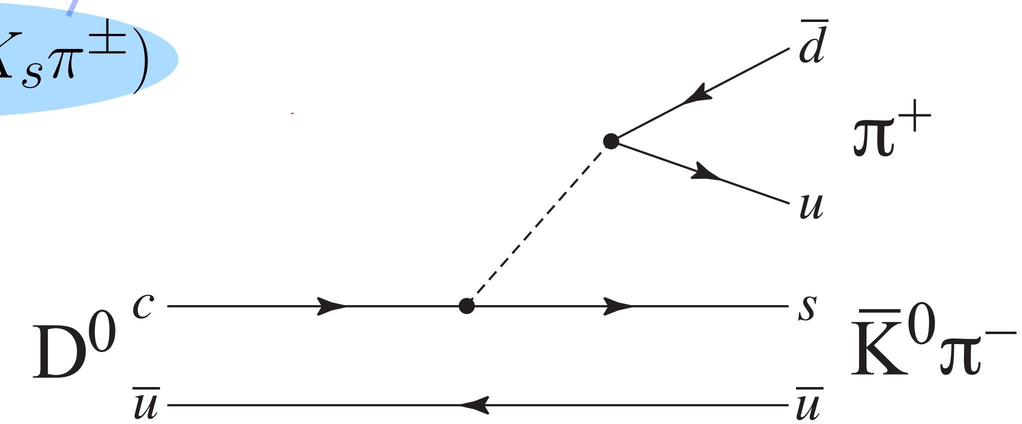
$$|\widetilde{D}^0\rangle = |\overline{D}^0\rangle + re^{i(\delta+\phi_3)}|D^0\rangle$$

- $B^+ \to \widetilde{D}^0K^+$ matrix element: $\mathcal{M}_+ = f(m_+^2, m_-^2) + re^{i(\delta+\phi_3)}f(m_-^2, m_+^2)$
- $B^- \to \overline{\widetilde{D}}^0K^-$ matrix element: $\mathcal{M}_- = f(m_-^2, m_+^2) + re^{i(\delta-\phi_3)}f(m_+^2, m_-^2)$

$m_\pm = m(K_s\pi^\pm)$



$f(m_+^2,\, m_-^2)$



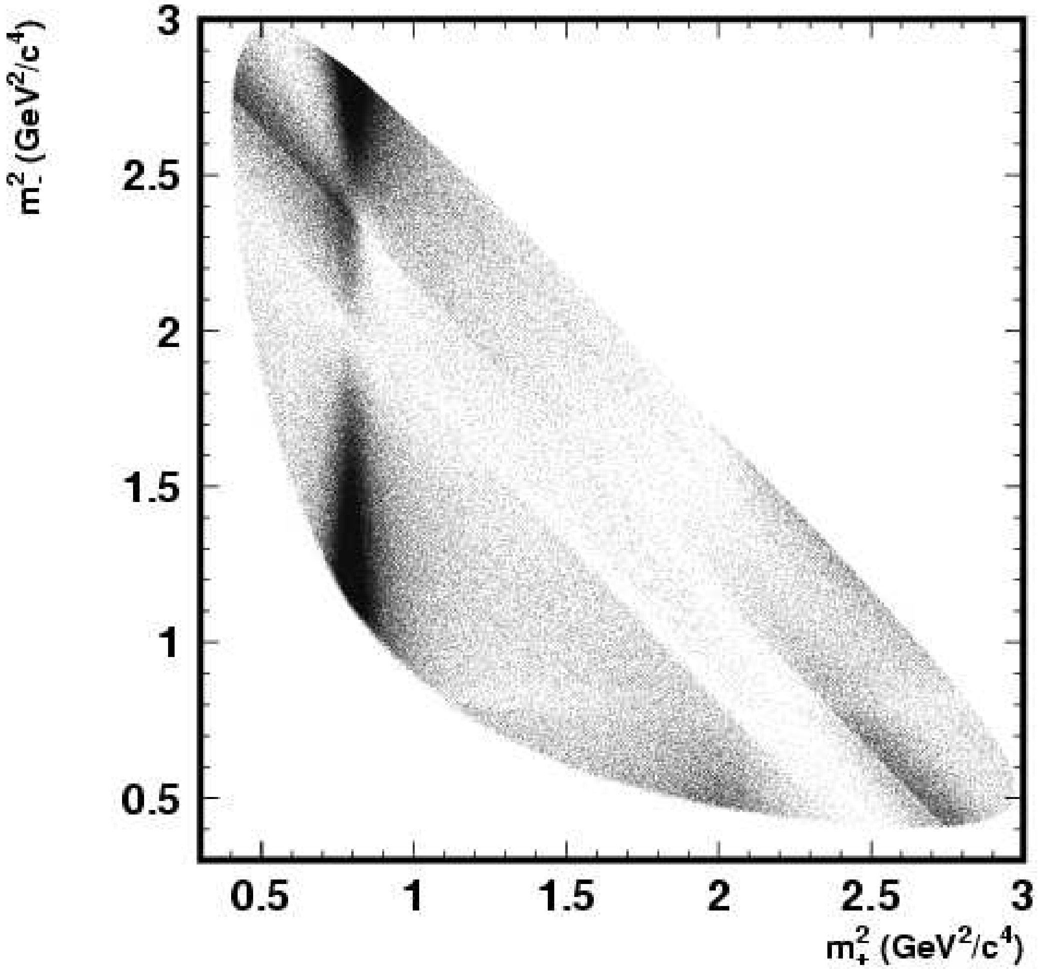
$f(m_-^2,\, m_+^2)$

B$^\pm$ → no mixing, no *t*-dependence

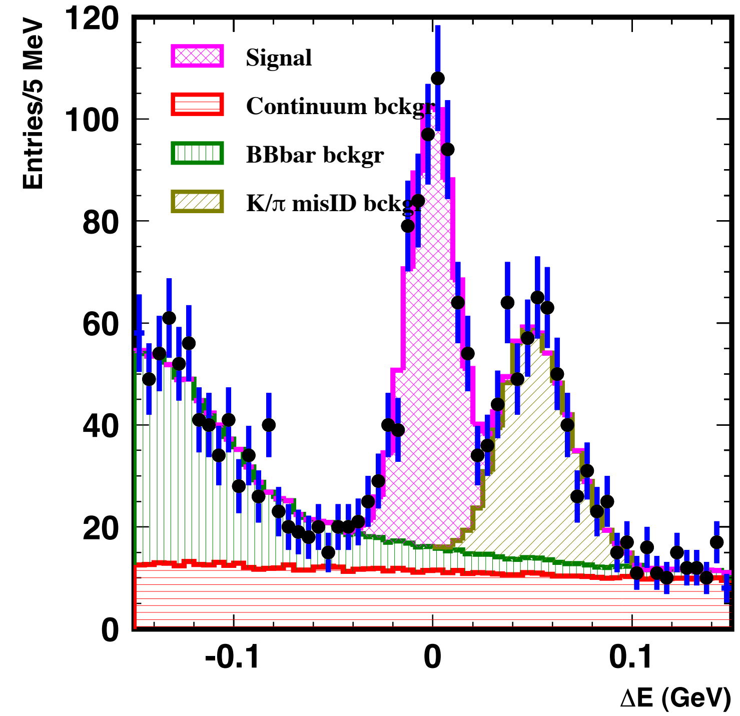
D decays do not involve V_{ub} or V_{td} → no contribution to phase

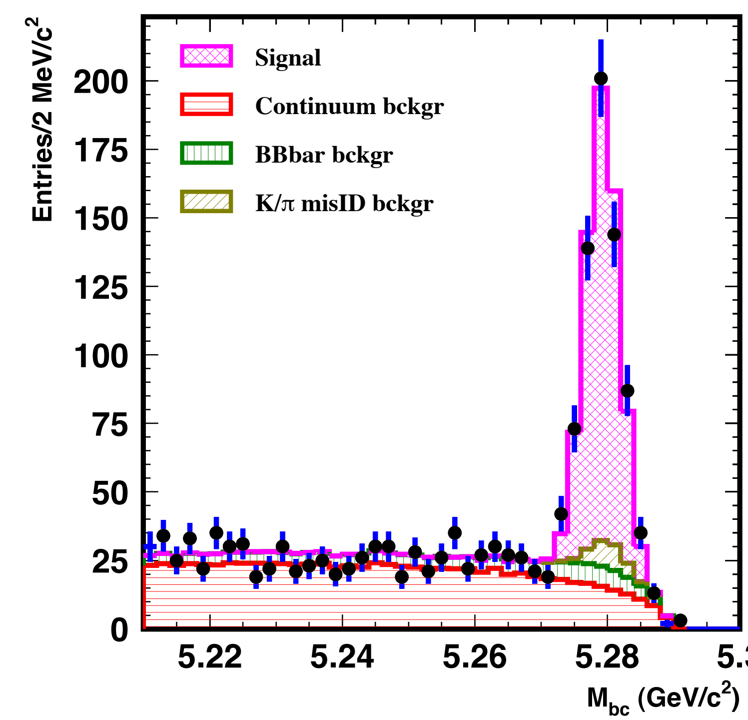
The GGSZ method

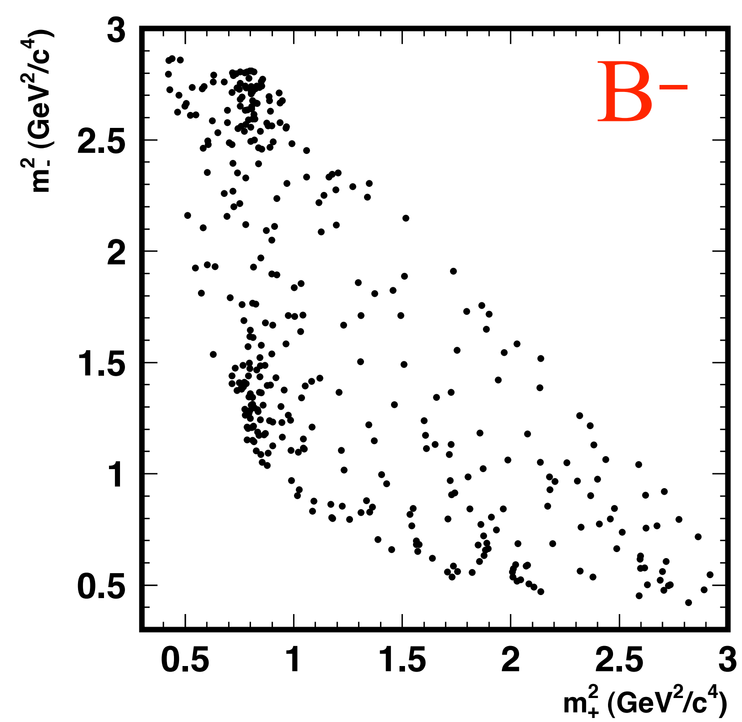
Map out the Dalitz plot
from all D^0 decays

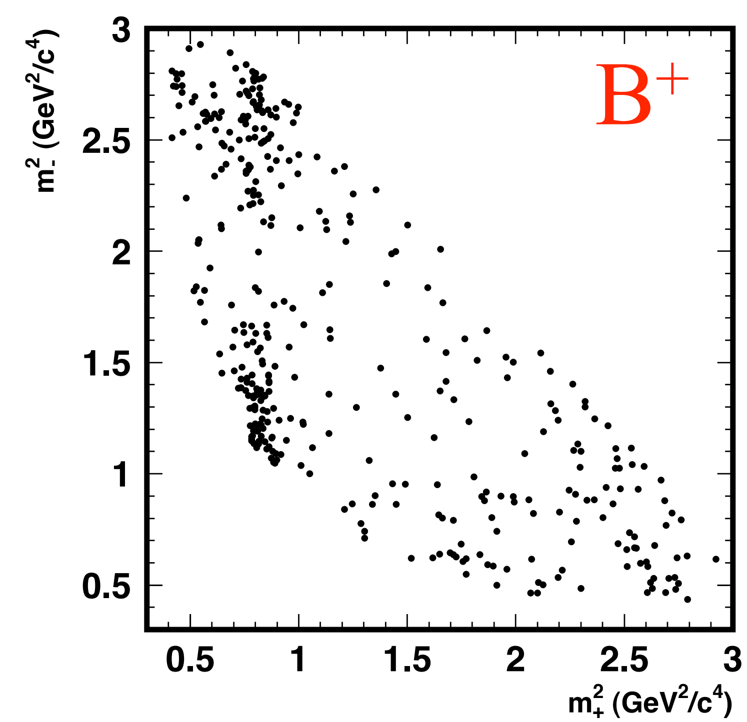


Look for differences in $B^\pm \to D^0 K^\pm$ plots









Belle; hep-ex/0803.3375

Results from GGSZ method

Express in terms of measurables from $B^{\pm}$

$$x_{\pm} = r_B \cos(\delta_B \pm \phi_3)$$

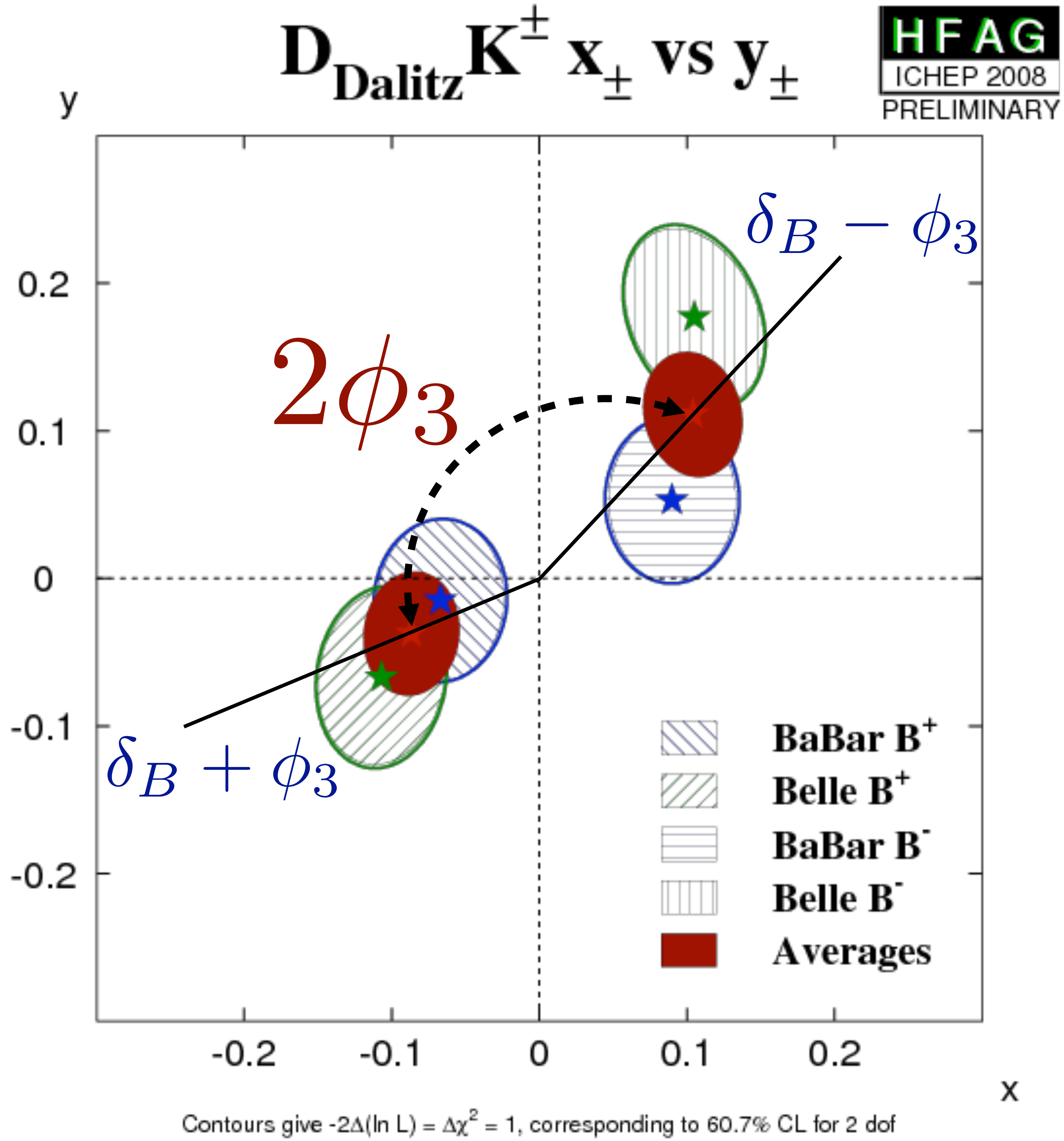
$$y_{\pm} = r_B \sin(\delta_B \pm \phi_3)$$

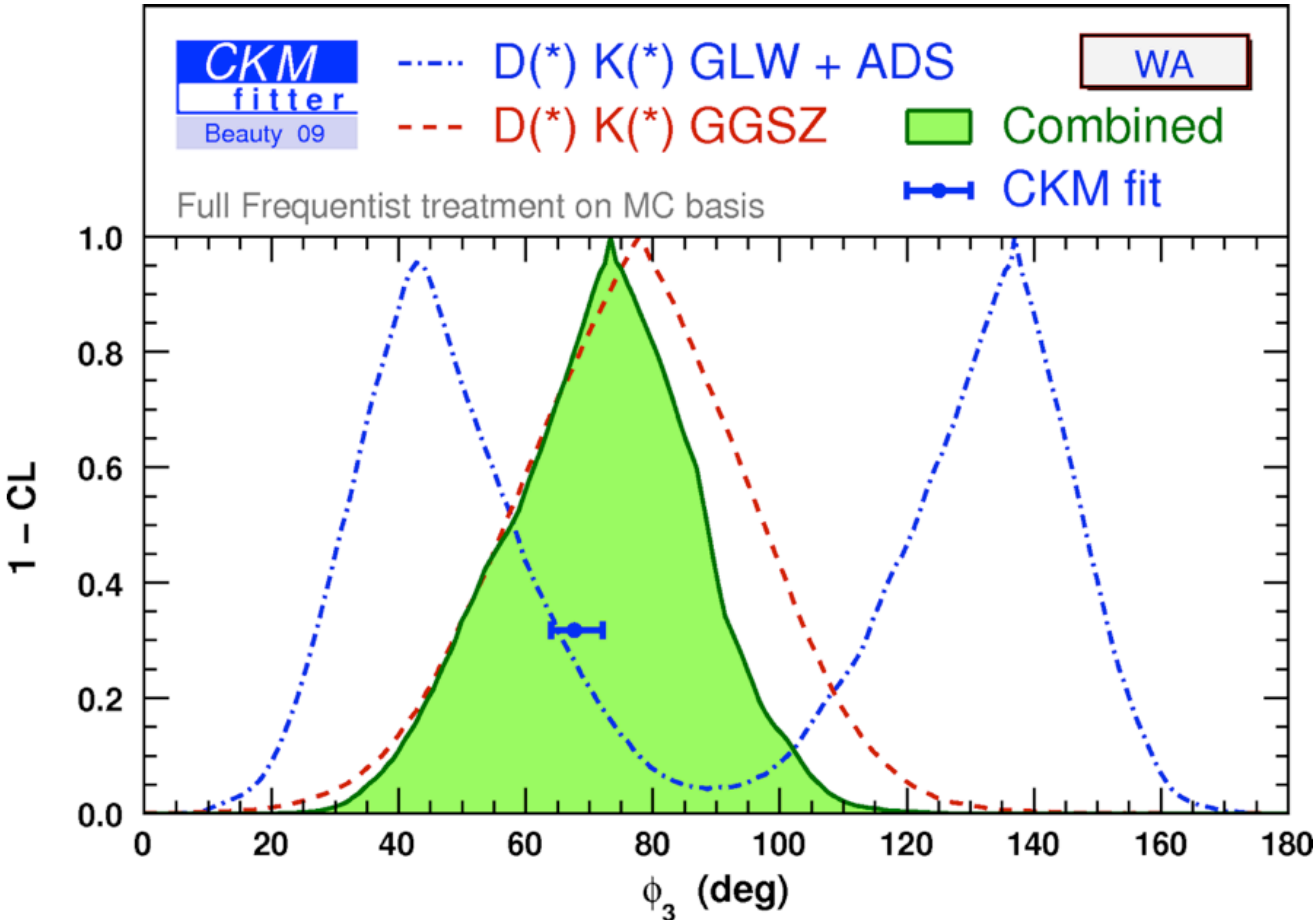
r_B : ratio of D/$\bar{\text{D}}$ ampl.

= 0.16±0.07

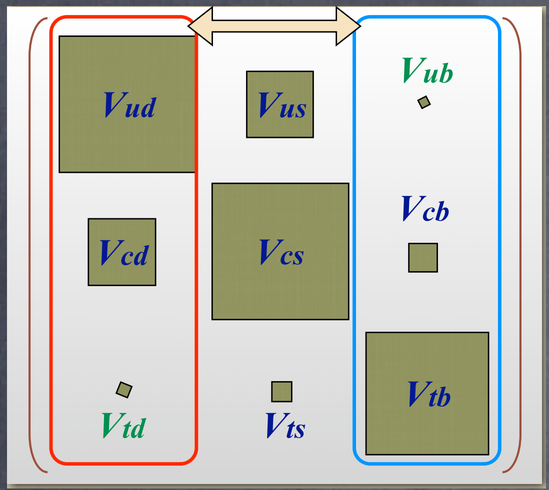
δ_B : D/$\bar{\text{D}}$ relative phase

Different r_B, δ_B for each mode $D^{(*)}K^{(*)}$

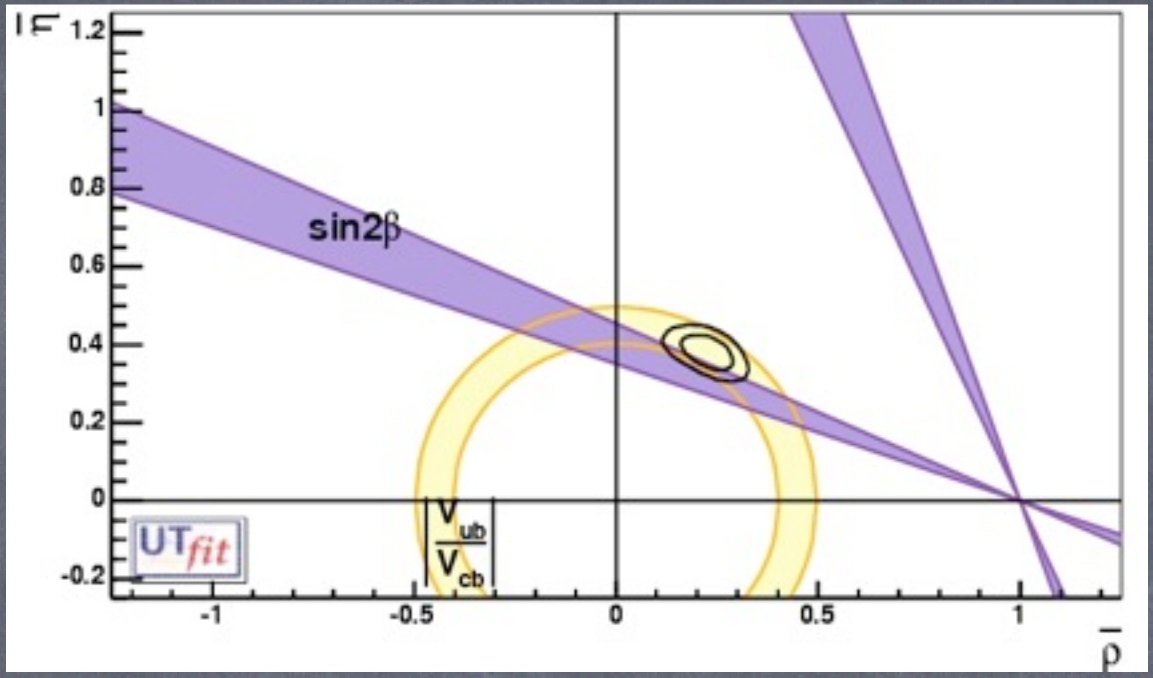


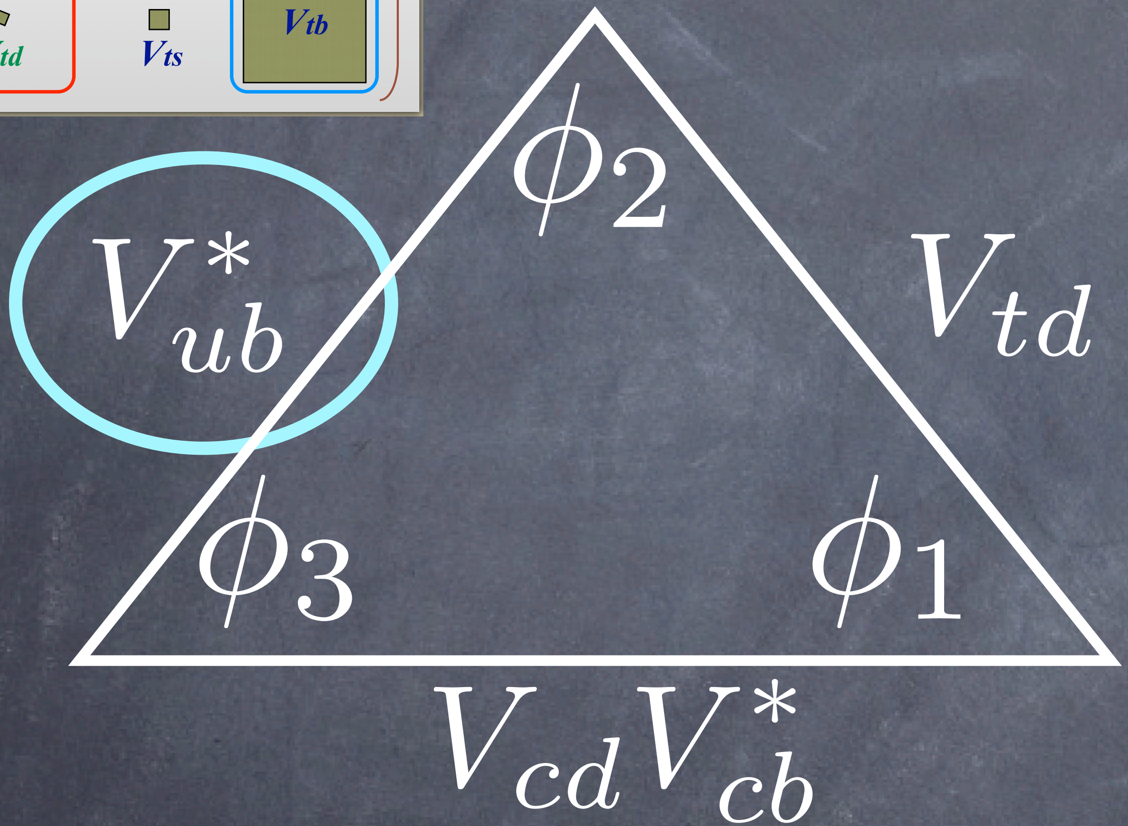


Indirect: $\phi_3 = 67.7^{+4.5}_{-3.7}(^\circ)$ Combined: $\phi_3 = 75^{+19}_{-22}(^\circ)$



The Sides





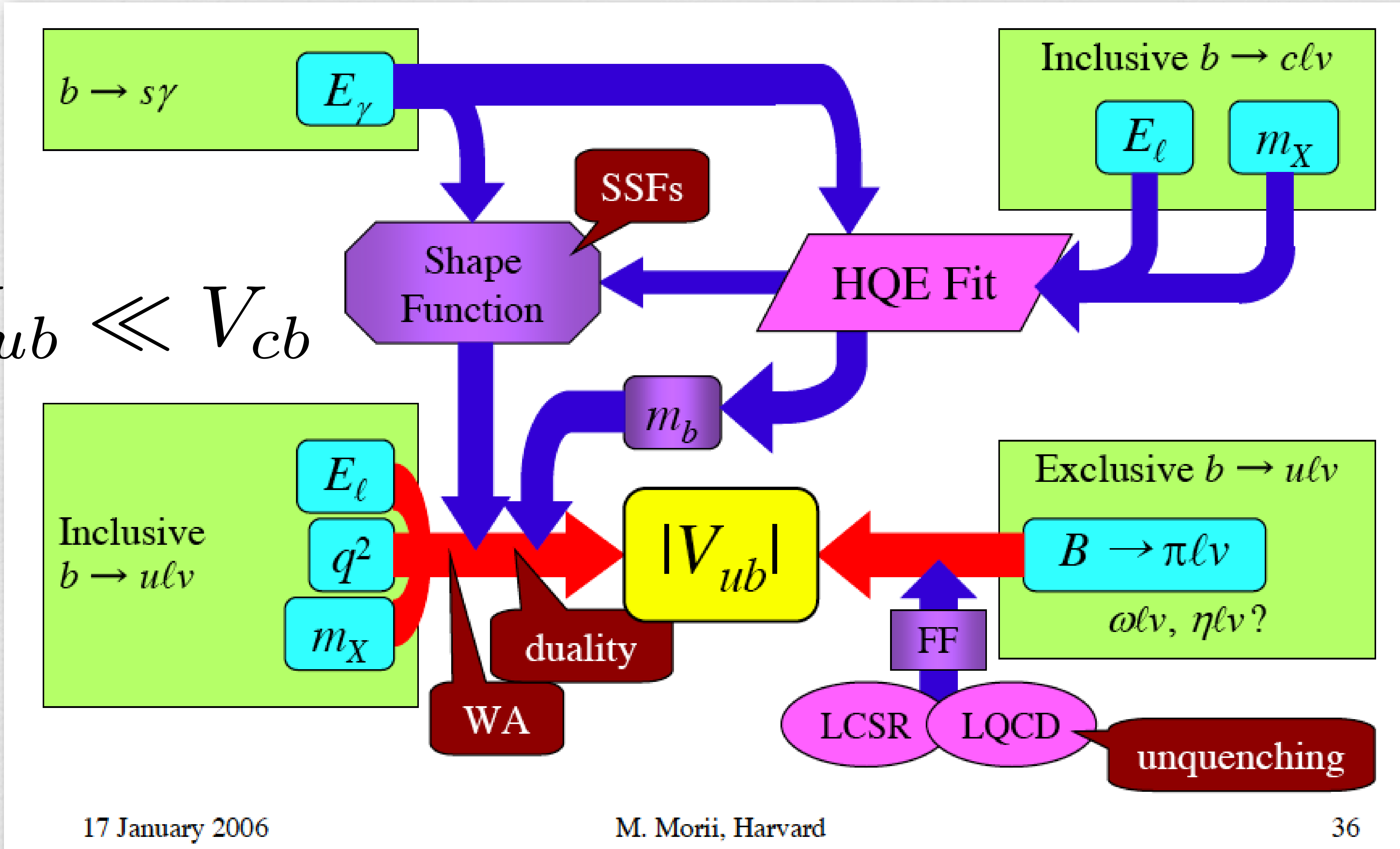
- V_{td}
  - $B \to X_d\gamma$
  - B_s mixing
- V_{cb}
  - $\mathcal{O}(1\%)$ precision

just overly simplified guidelines

- $V = |V| exp(\mathrm{i}\phi)$
  - $|V|$ from semi-leptonic decay rates $\Gamma_{X\ell\nu} \propto |V_{ij}|^2$
  - ϕ from *CP* asymmetries

Roadmap for V_{ub} - *"Morri's chart"*

$$V_{ub} \ll V_{cb}$$



Exclusive Analyses

- need form-factors for the non-pert. QCD effect

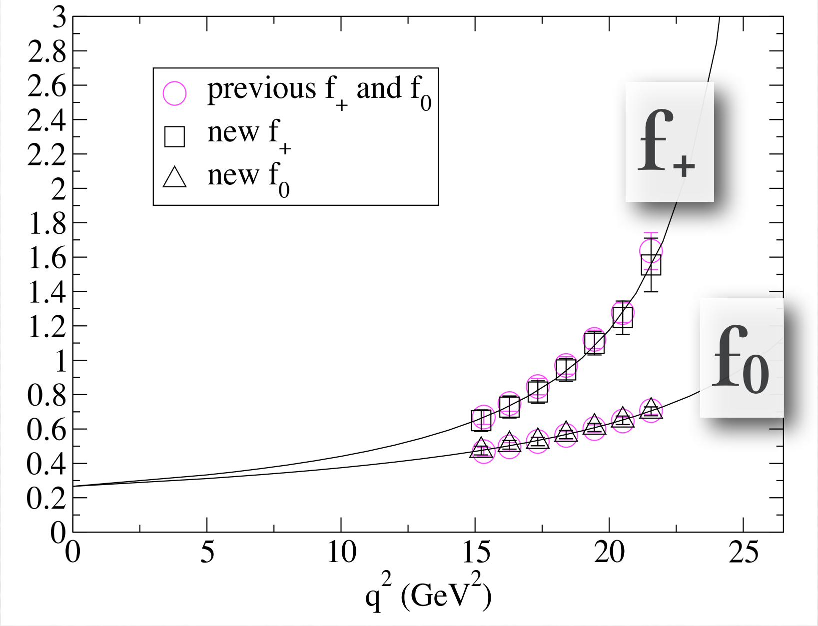
Hadronic current H^μ for $\bar{B}^0 \to \pi^+ \ell^- \bar{\nu}$:

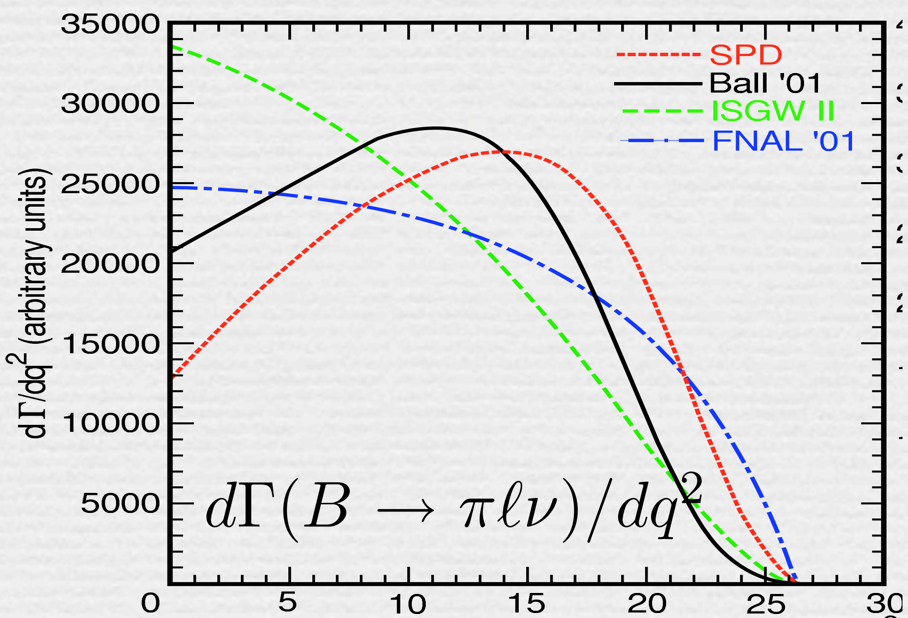
$$H^\mu = \langle \pi^+(p')|u\gamma^\mu b|\bar{B}^0(p)\rangle = f^+(q^2)(p+p')^\mu$$

In the limit of massless lepton,

$$\frac{d\Gamma(B\to\pi\ell\nu)}{dq^2 d\cos\theta_\ell} = |V_{ub}|^2 \frac{G_F^2}{32\pi^3} |\vec{p}_\pi|^3 \sin^2\theta_\ell \left|f^+(q^2)\right|^2$$

HPQCD, PRD73, 074502 (2006)



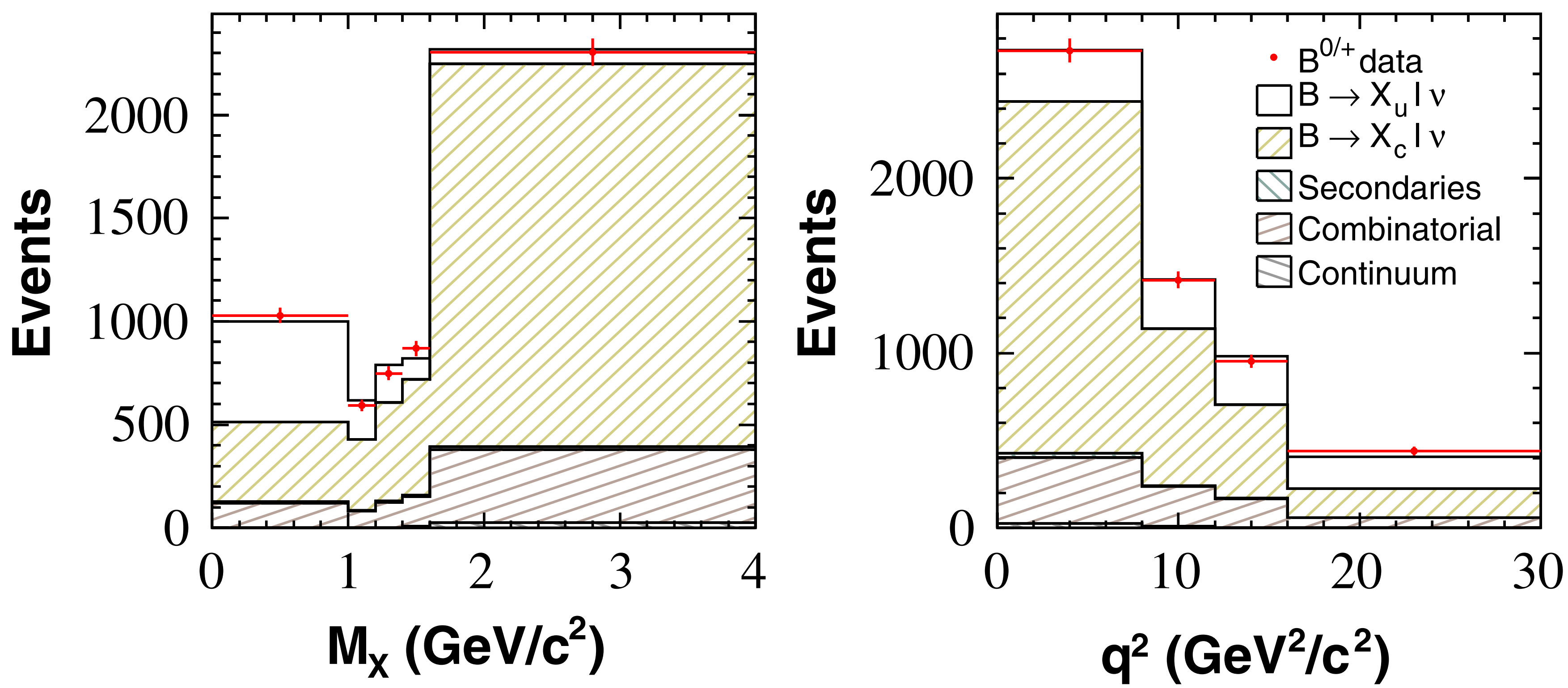


large variations among models

- Form-factor models based on
  - Relativistic quark models (ISGW2)
  - LCSR for low q2
  - LQCD for high q2

How well can we measure the q^2 dist. for $B \to X_u l \nu$?

$B \to X_u \ell^+ \nu$ (incl. anal.)



using Boosted Decision Tree multivariate method

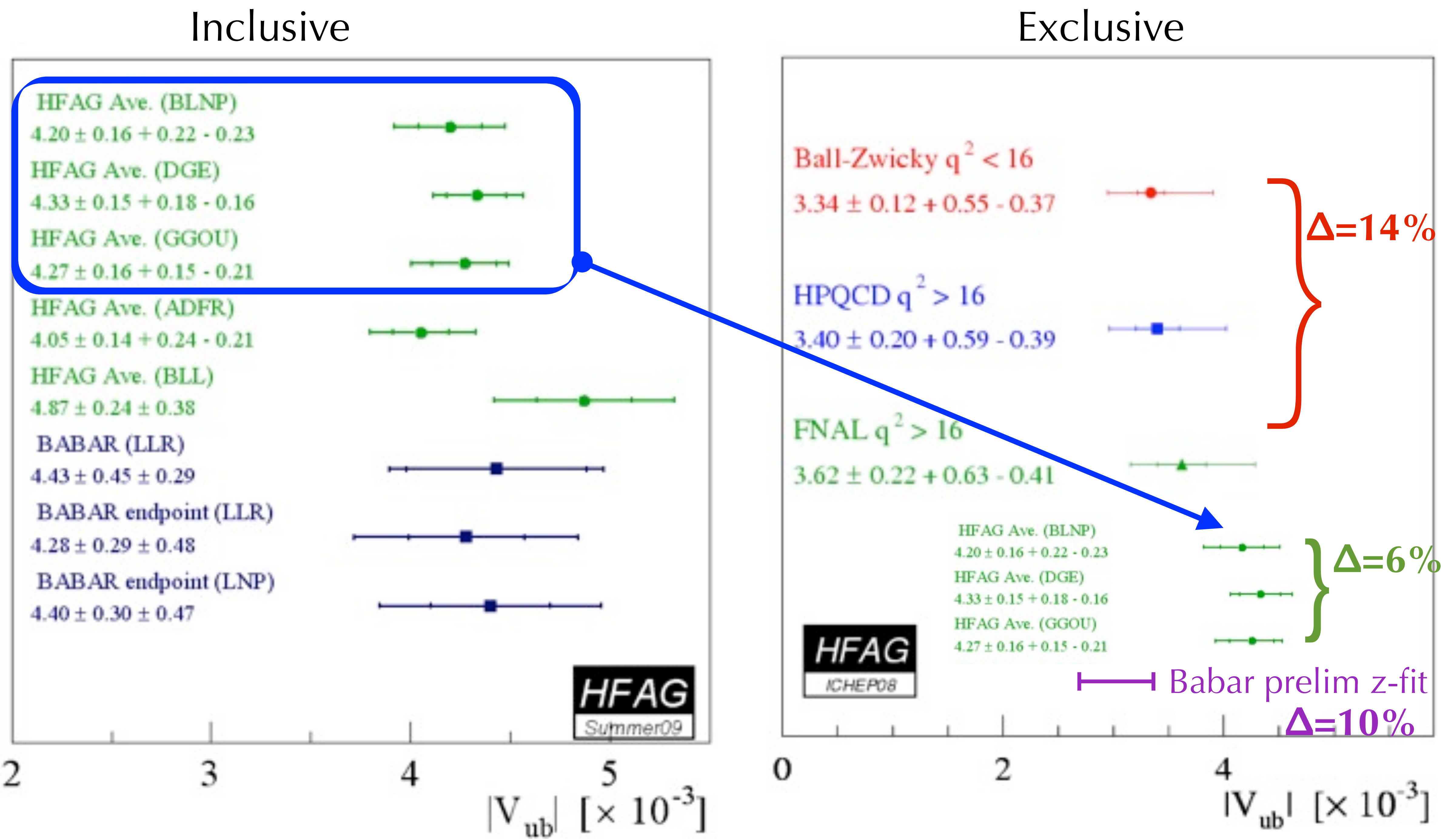
$$\Delta\mathcal{B}(p_\ell^{*B} > 1.0) = 1.963 \times (1 \pm 0.088 \pm 0.081) \times 10^{-3}$$

TABLE II. Values for $|V_{ub}|$ with relative errors (in %).

Theory	$\lvert V_{ub}\rvert \times 10^3$	Stat	Syst	m_b	Th.
BLNP [5]	4.37	4.3	4.0	$^{+3.1}_{-2.7}$	$^{+4.3}_{-4.0}$
DGE [6]	4.46	4.3	4.0	$^{+3.2}_{-3.3}$	$^{+1.0}_{-1.5}$
GGOU [7]	4.41	4.3	4.0	1.9	$^{+2.1}_{-4.5}$

most precise single measurement of V_{ub}

$|V_{ub}|$ summary Inclusive vs. Exclusive



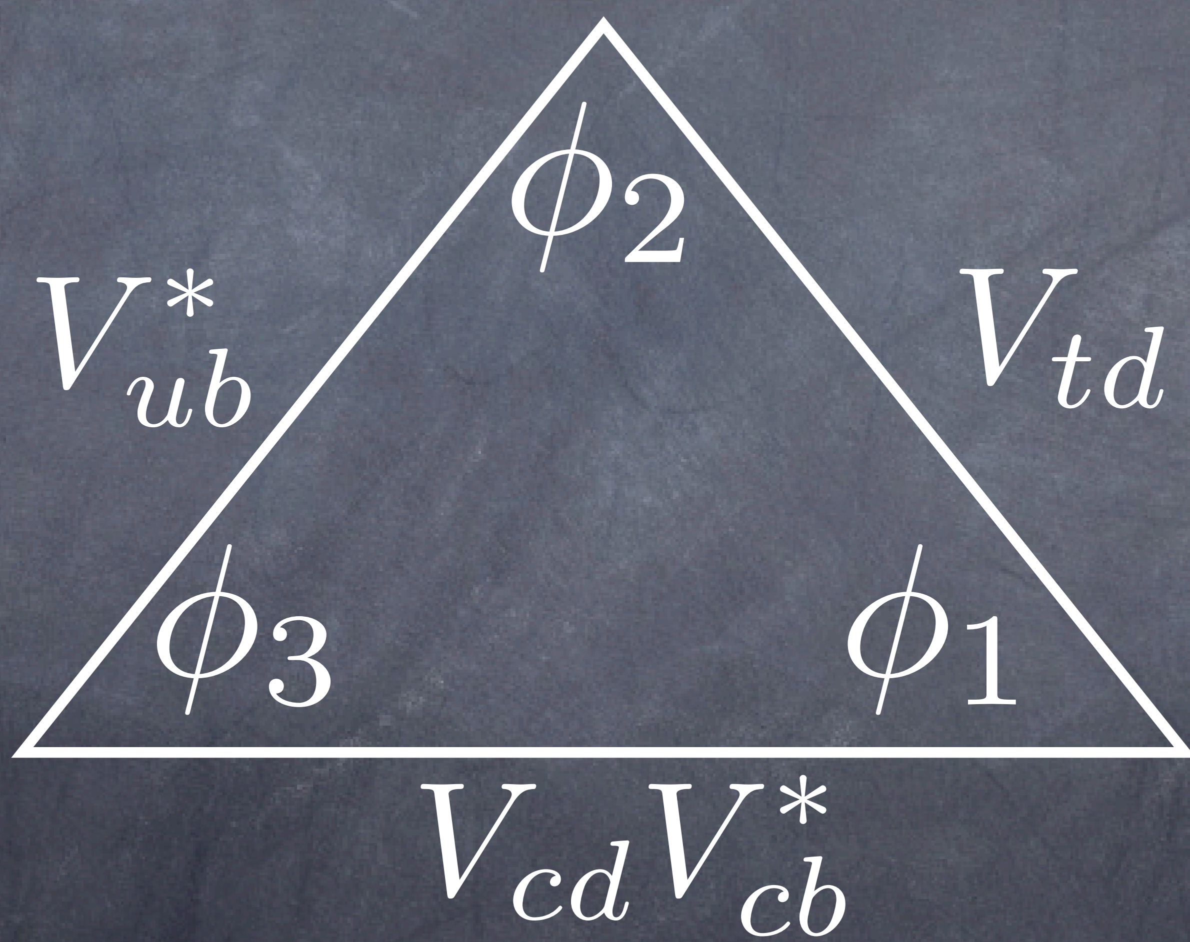
Exclusive < Inclusive ~1-2σ, Greater discrepancy with *z*-fit.

What did we learn?

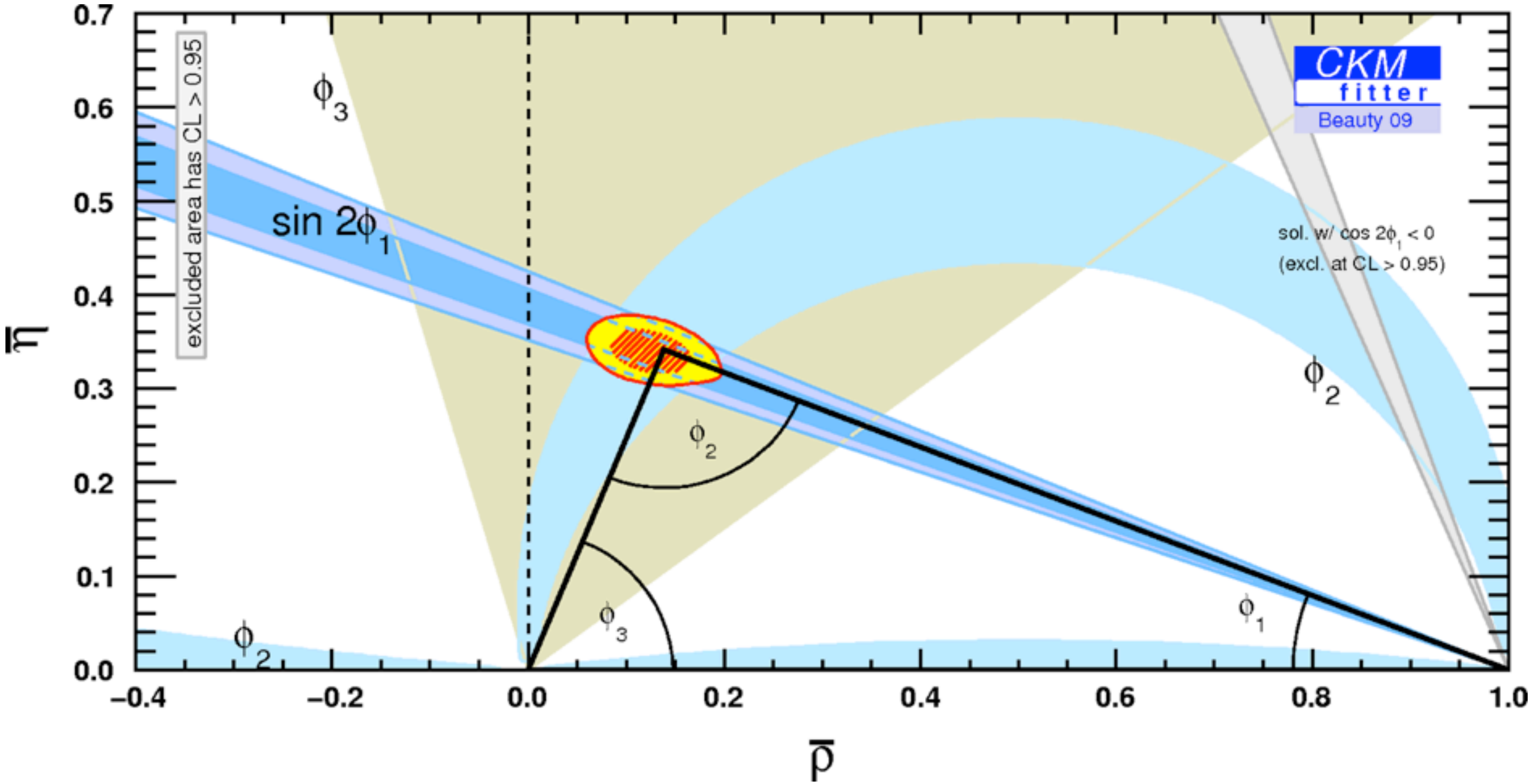
- V_{ub} from inclusive avg. give O(6%) error
  - restricted phase-space is much better understood
  - check with many complementary meas'mts.
- Exclusive analyses catch up
  - powerful B-tagging
  - improved ν-recon. --> fine-binned q2 dist.
  - unquenched L-QCD
- Systematics (esp. for SF param.) will improve with more statistics --> Belle-II !

Status of the CKM Δ

Unitarity triangle angles			
BABAR:	β	α	γ
BELLE:	ϕ_1	ϕ_2	ϕ_3
	易	難	魔

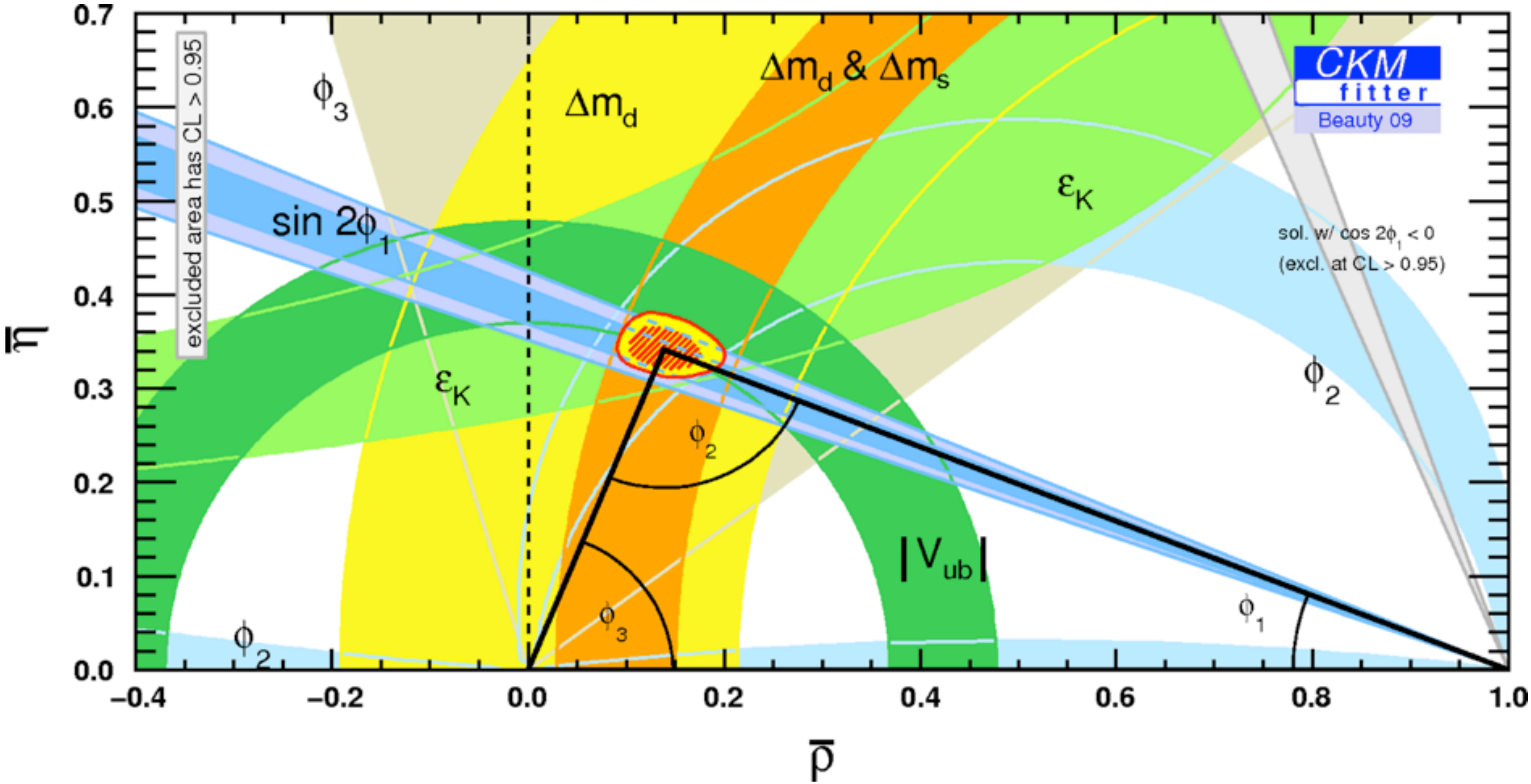


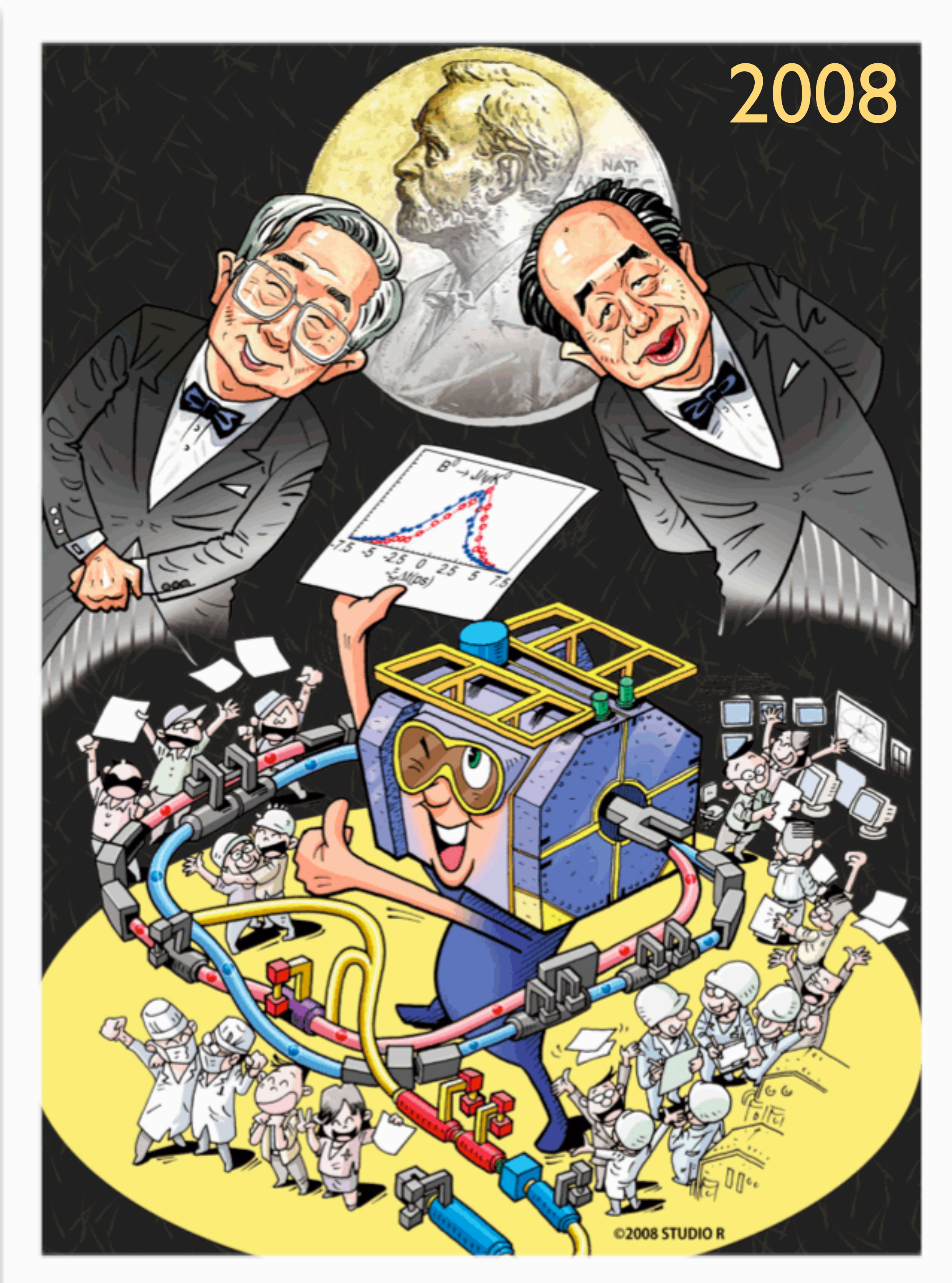
angles only



CKM fitter
Beauty 09
excluded area has CL > 0.95
sin 2φ1
φ3
φ2
φ1
sol. w/ cos 2φ1 < 0
(excl. at CL > 0.95)
η̄
ρ̄
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
–0.4
–0.2
0.0
0.2
0.4
0.6
0.8
1.0

with everything





- Critical role of the *B*-factories in the verification of the KM hypothesis was recognized and cited by the Nobel Foundation
- A single irreducible phase in the weak int. matrix accounts for most of the *CP* violation observed in the *K*'s and in the *B*'s
- *CP*-violating effects in the B sector are $\mathcal{O}(1)$ rather than $\mathcal{O}(10^{-3})$ as in the K^0 system.

Any Tensions?

Any Tensions?

- Two "tensions" in CPV measurements
  - ϕ_1 from $b \to s$ Penguin
  - Direct CPV in $B \to K^+ \pi$

Any Tensions?

- Two "tensions" in CPV measurements
  - ϕ_1 from $b \to s$ Penguin
  - Direct CPV in $B \to K^+ \pi$
- V_{ub} tension with
  - $B^+ \to \tau^+ \nu$

Any Tensions?

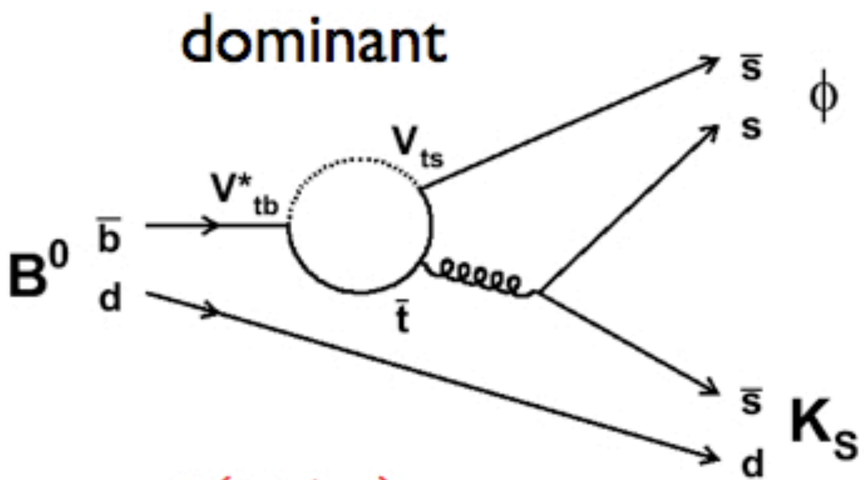
- Two "tensions" in CPV measurements
  - ϕ_1 from $b \to s$ Penguin
  - Direct CPV in $B \to K^+ \pi$
- V_{ub} tension with
  - $B^+ \to \tau^+ \nu$

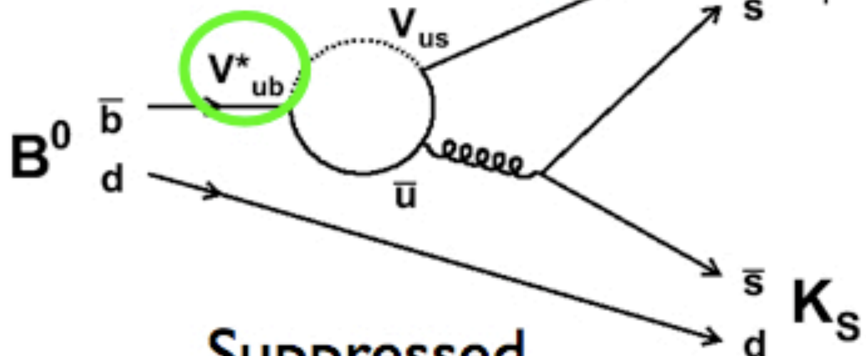
If confirmed, these could be potential hints for NP...

ΔS puzzle

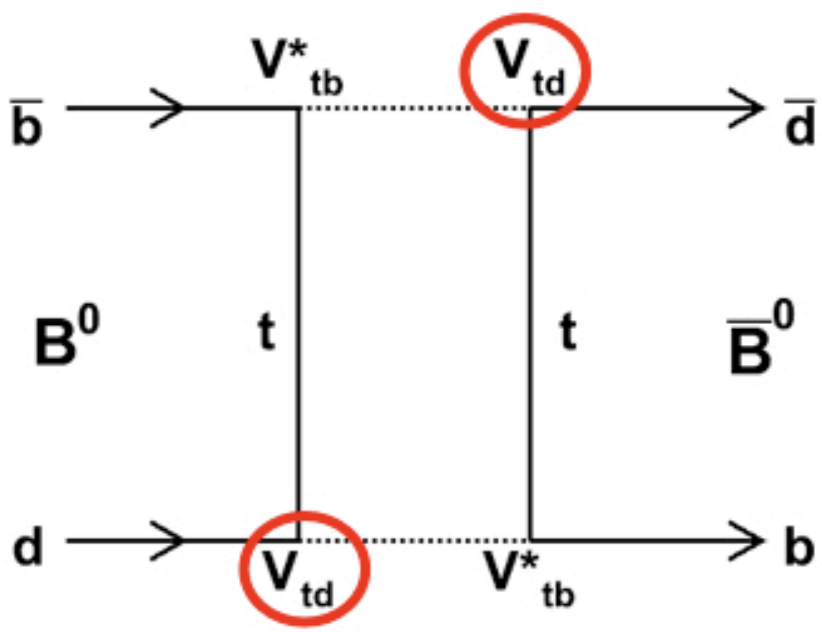
ϕ_1 from $b \to s\bar{s}s$

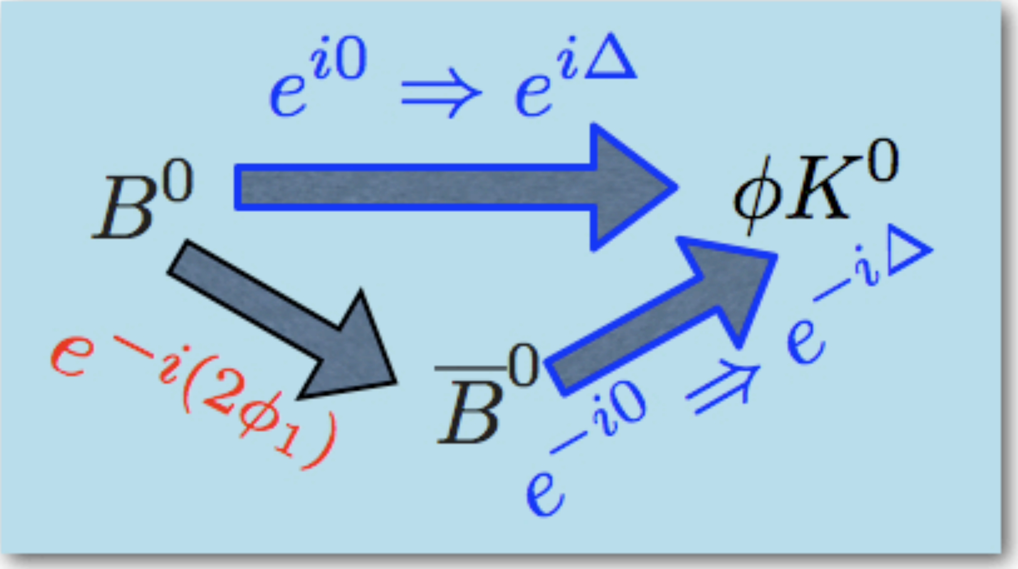
e.g. $B^0 \to \phi K_S$





Two V_{td} vertices $e^{-i(2\phi_1)}$

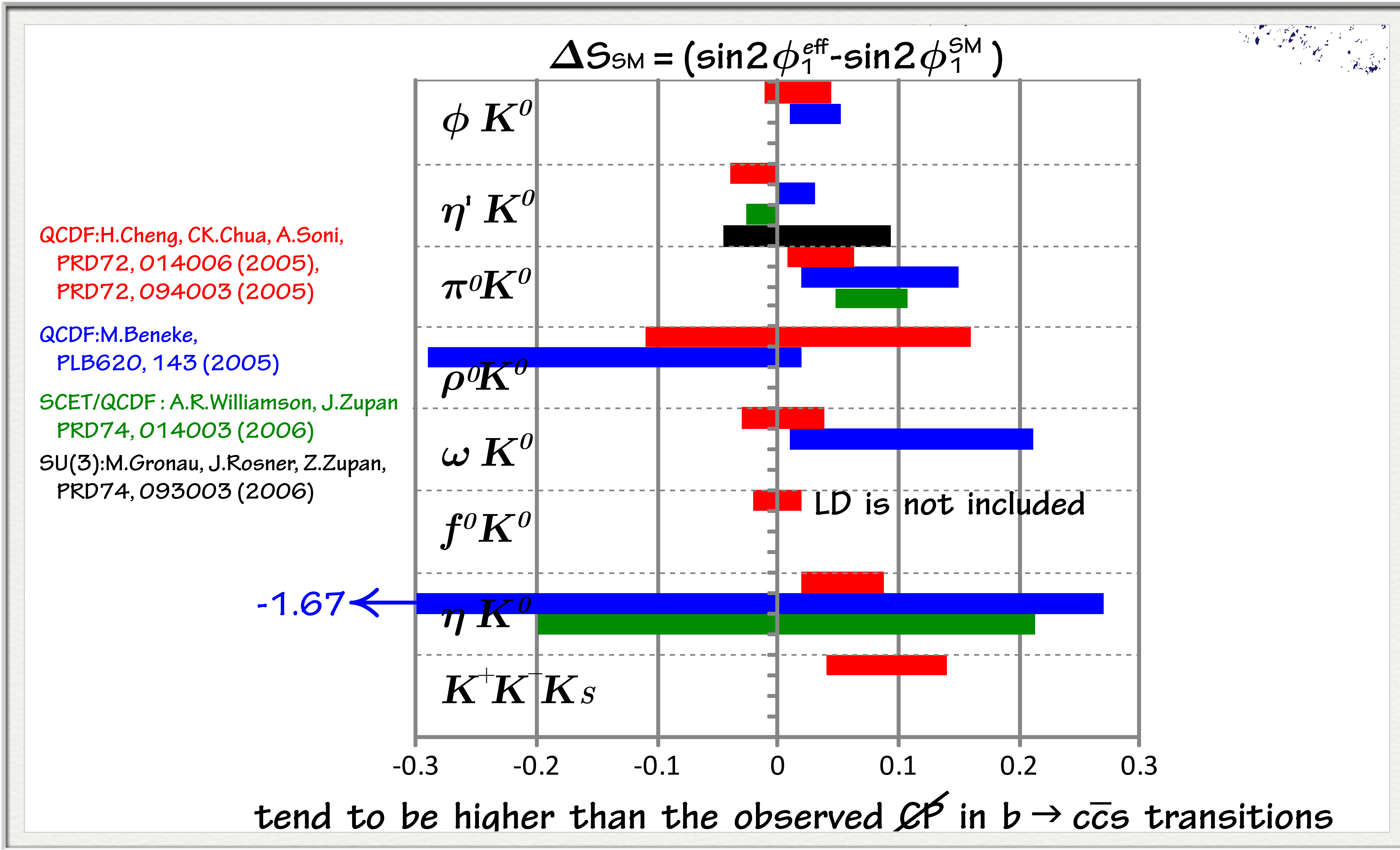




Relative phase = $e^{i2(\phi_1+\Delta)} \neq e^{i2\phi_1}$

$\sin(2\phi_{1\text{eff}}) \neq \sin(2\phi_1)$

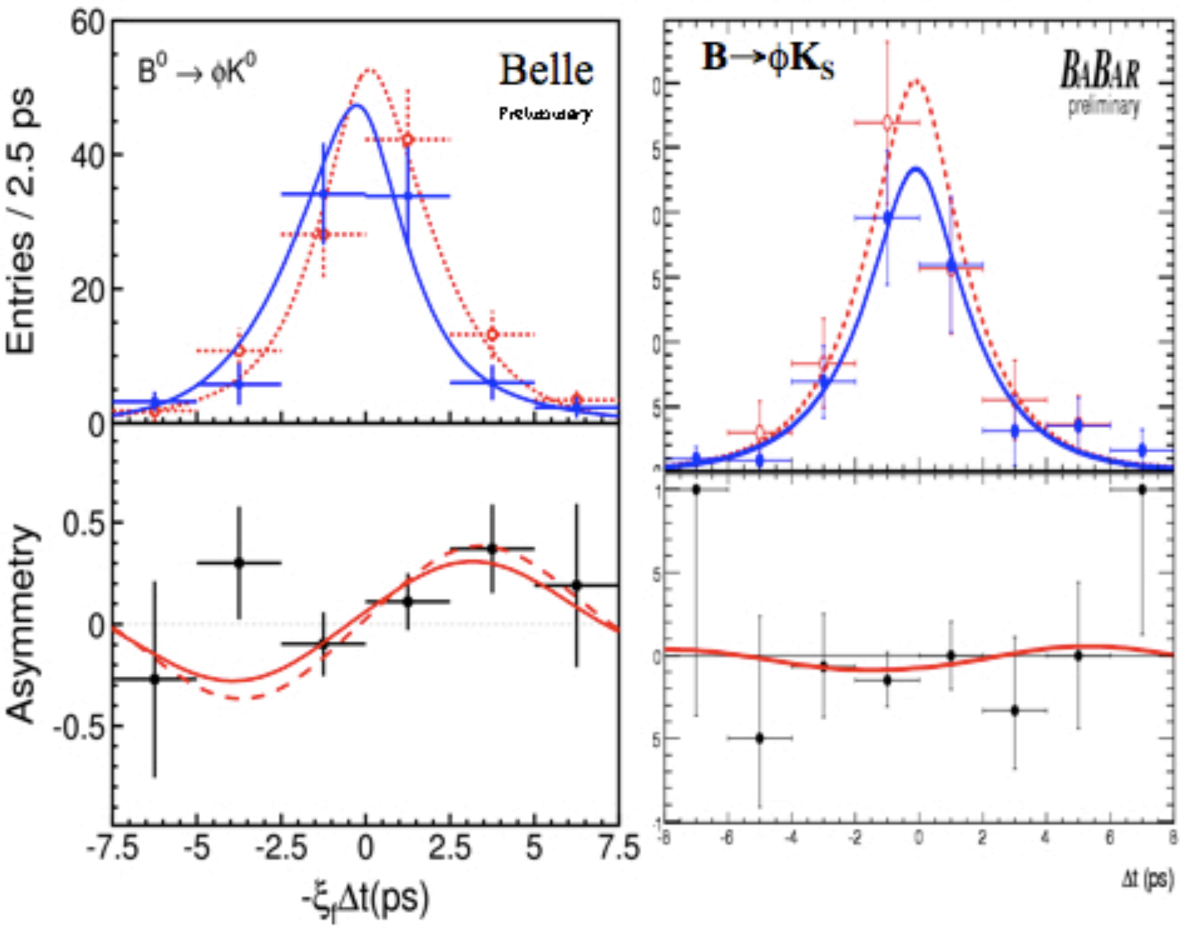
$\Delta \sin 2\phi_1^{\rm eff}$ by $b \to s$ penguin (SM)



slide by T. Hara for DIS 2010

$B \to \phi K_S$ and $B \to \eta' K_S$

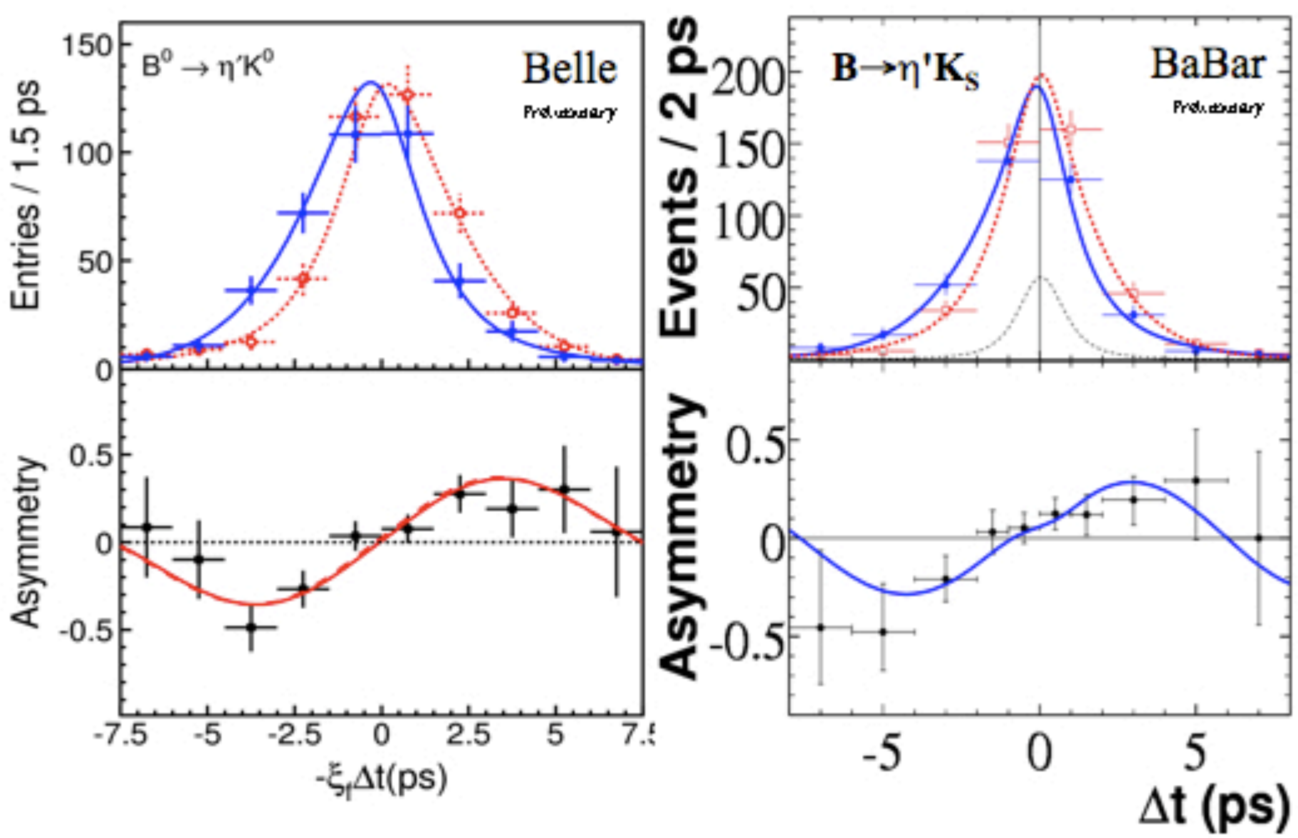
$B \to \phi K_S$: B.F. = $(4.3 \pm 0.6) \times 10^{-6}$



Even with small rates,

clear CP violation observed in penguin decays

$B \to \eta' K_S$: B.F. = $(3.4 \pm 0.2) \times 10^{-5}$

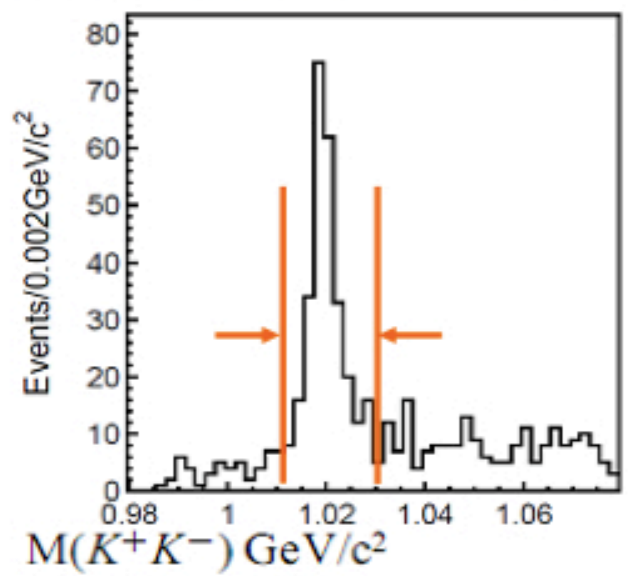


(In 2003, > 3σ effect seen in $B \rightarrow \phi K_S$ with low stats)

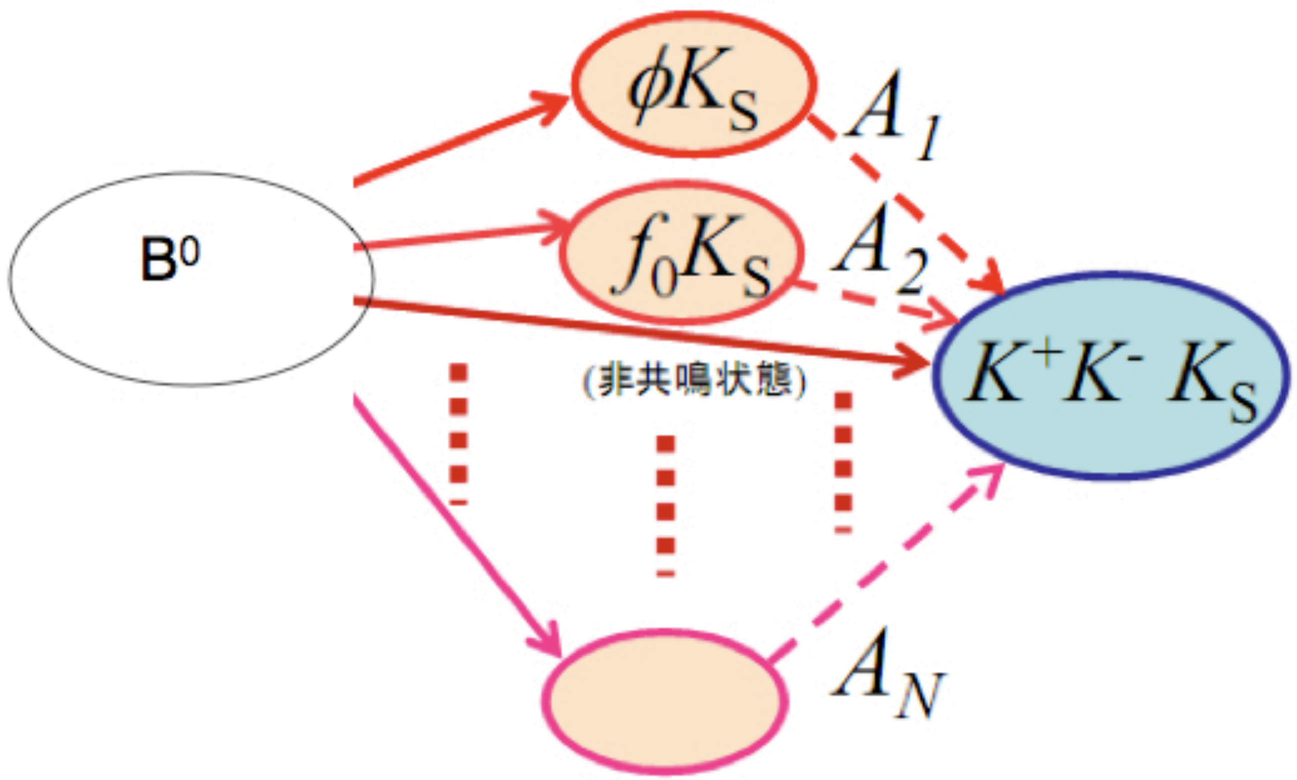
Latest generation of $b \rightarrow s$ time dependent CPV analyses

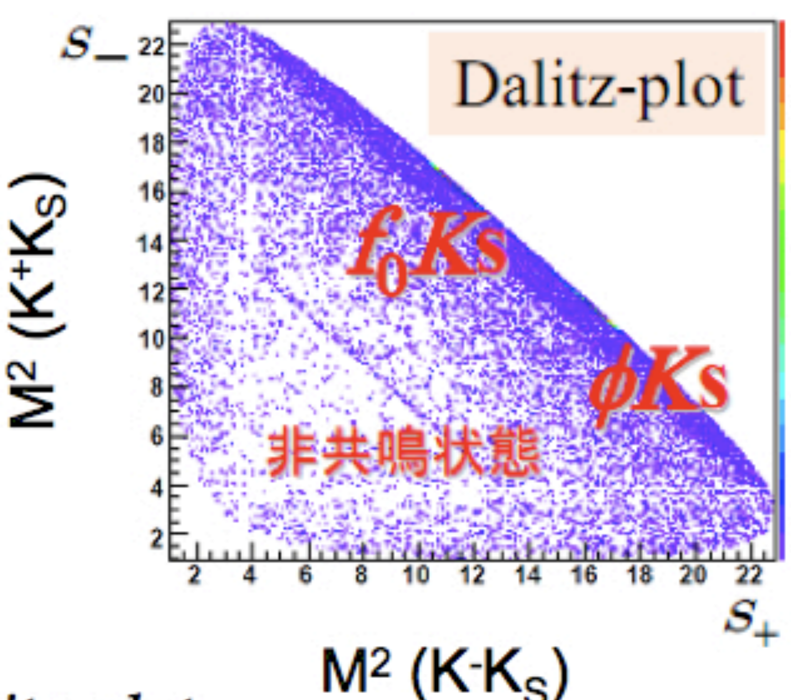
- more data and **advanced analysis** for three-body decay modes

(Quasi-2body アプローチ)

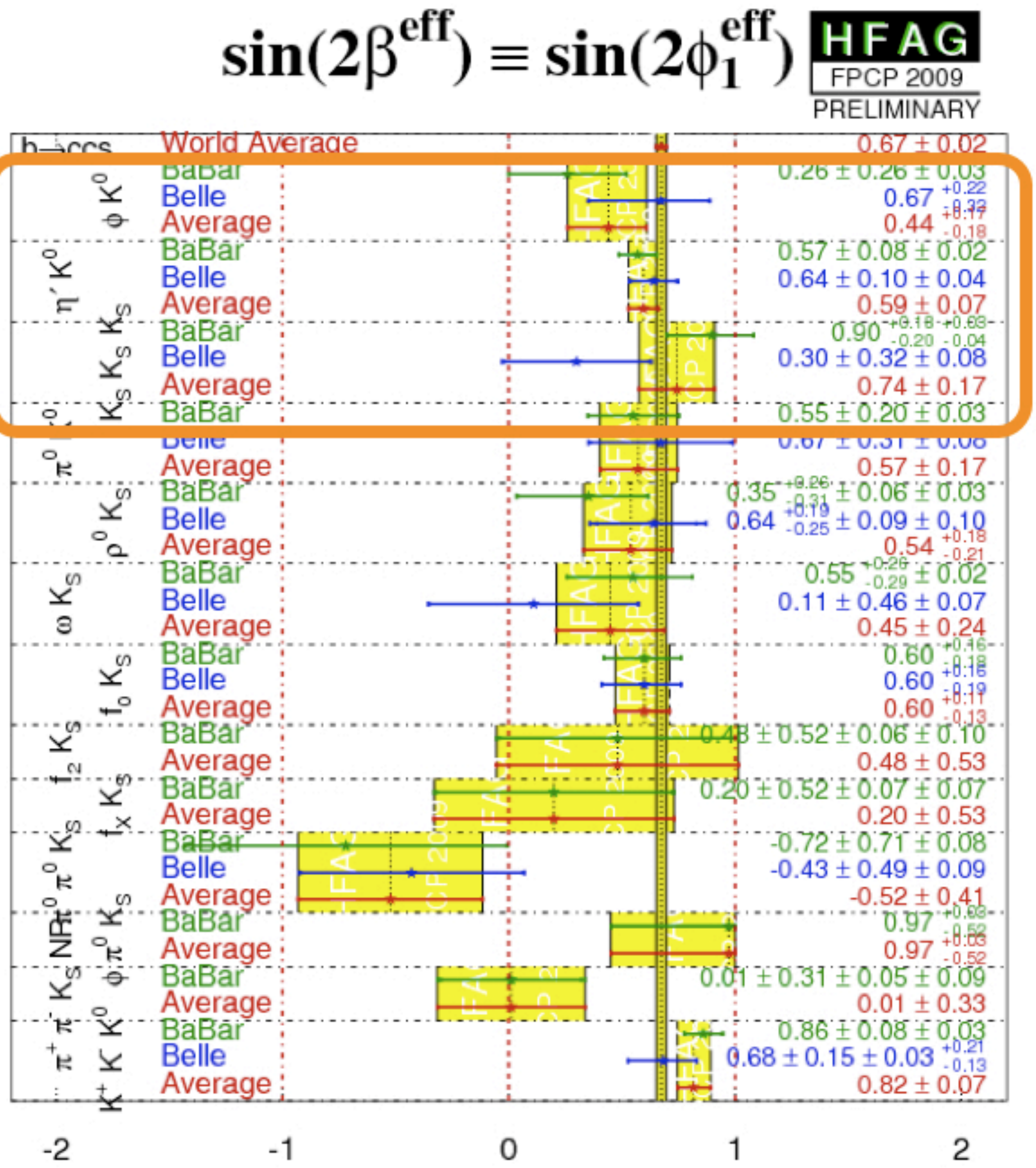


Previous 'slice and dice' analyses have been modified. Now use time-dependent Dalitz analyses with interference between multiple common final states for tCPV in ϕK_S and $f_0 K_S$

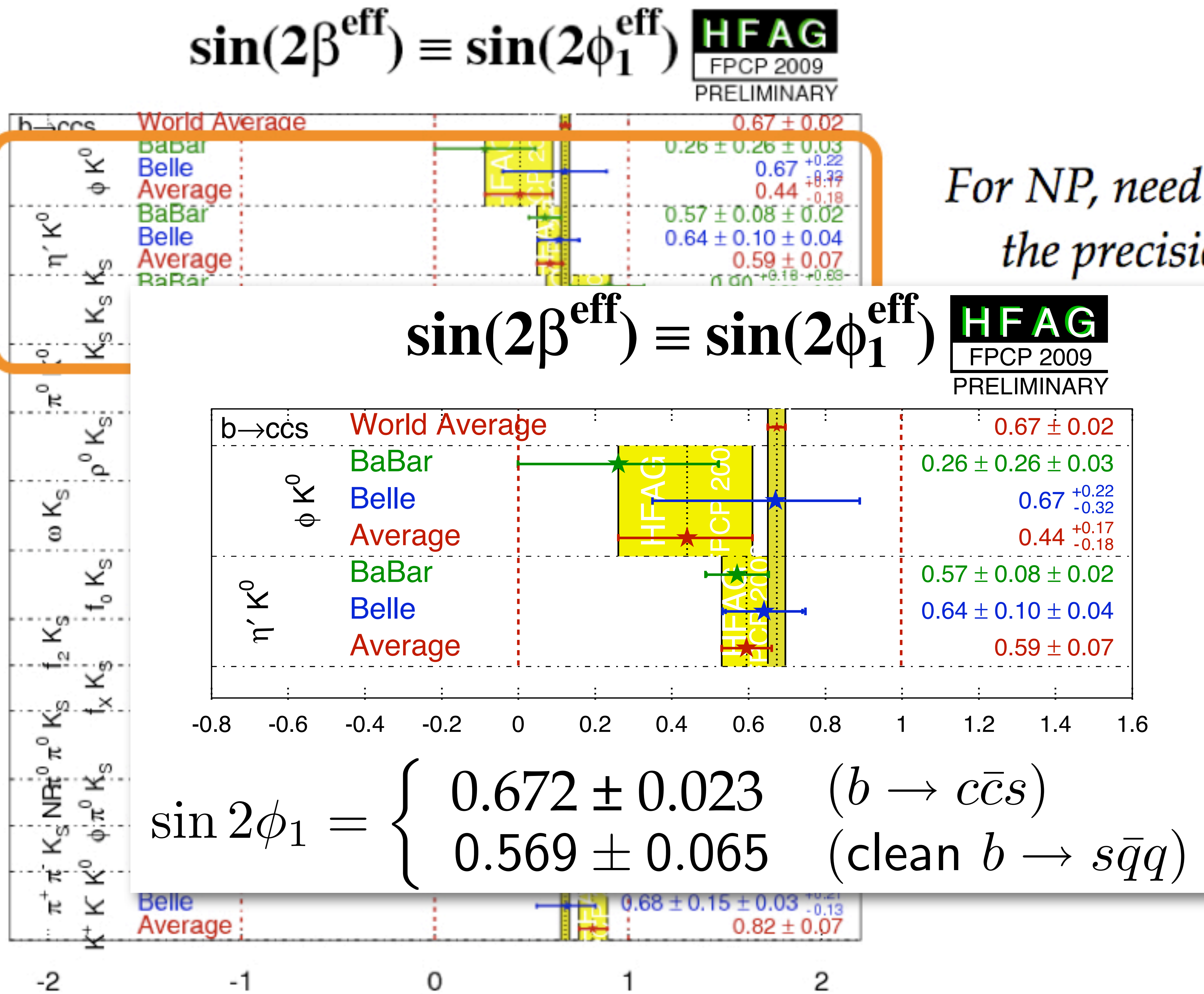




need a model of resonances that contribute in the Dalitz plot



For NP, need to improve the precision of the golden modes



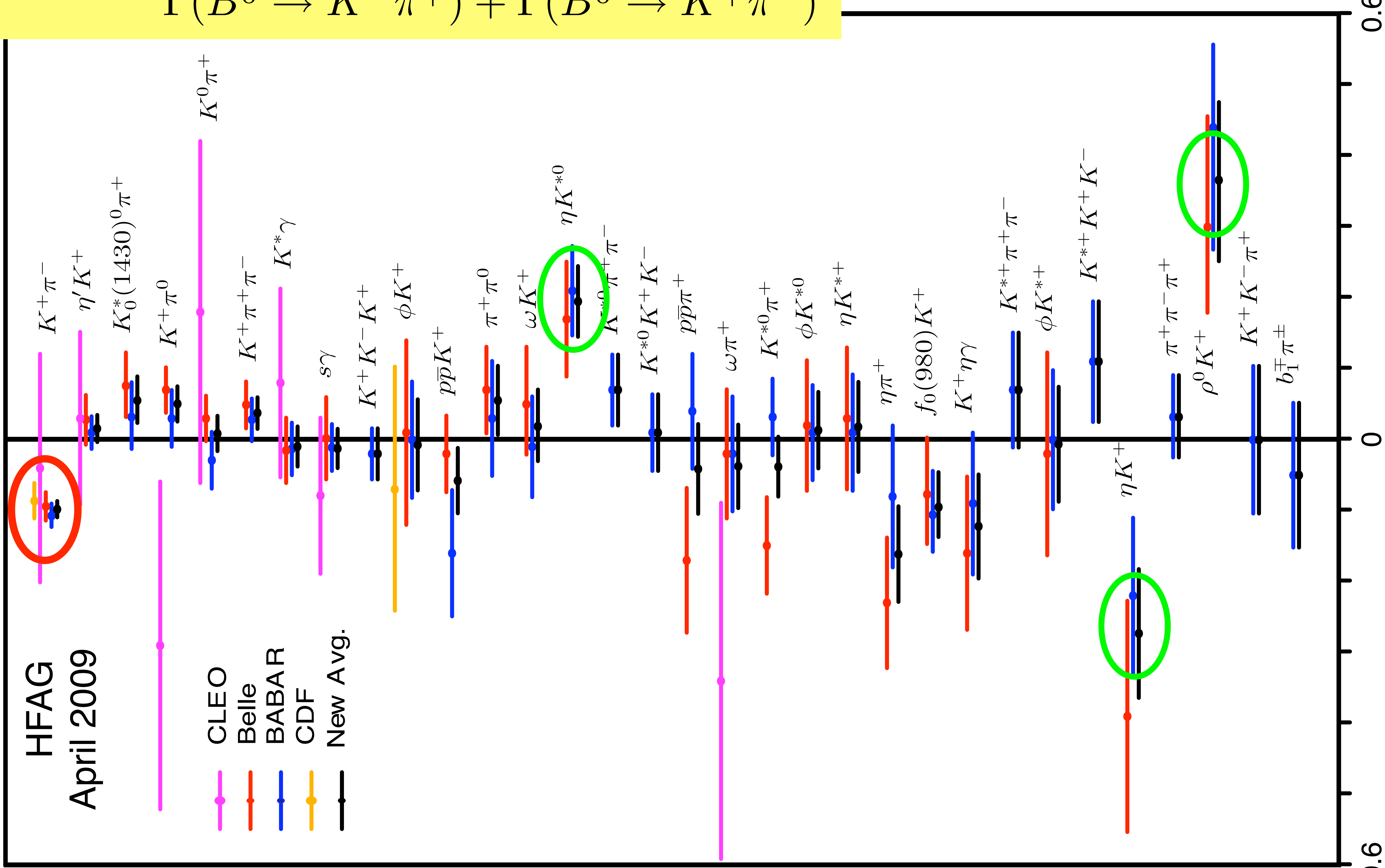
$$\sin 2\phi_1 = \begin{cases} 0.672 \pm 0.023 & (b \to c\bar{c}s) \\ 0.569 \pm 0.065 & (\text{clean } b \to s\bar{q}q) \end{cases}$$

For NP, need to improve the precision of the ... modes

$K\pi$ puzzle

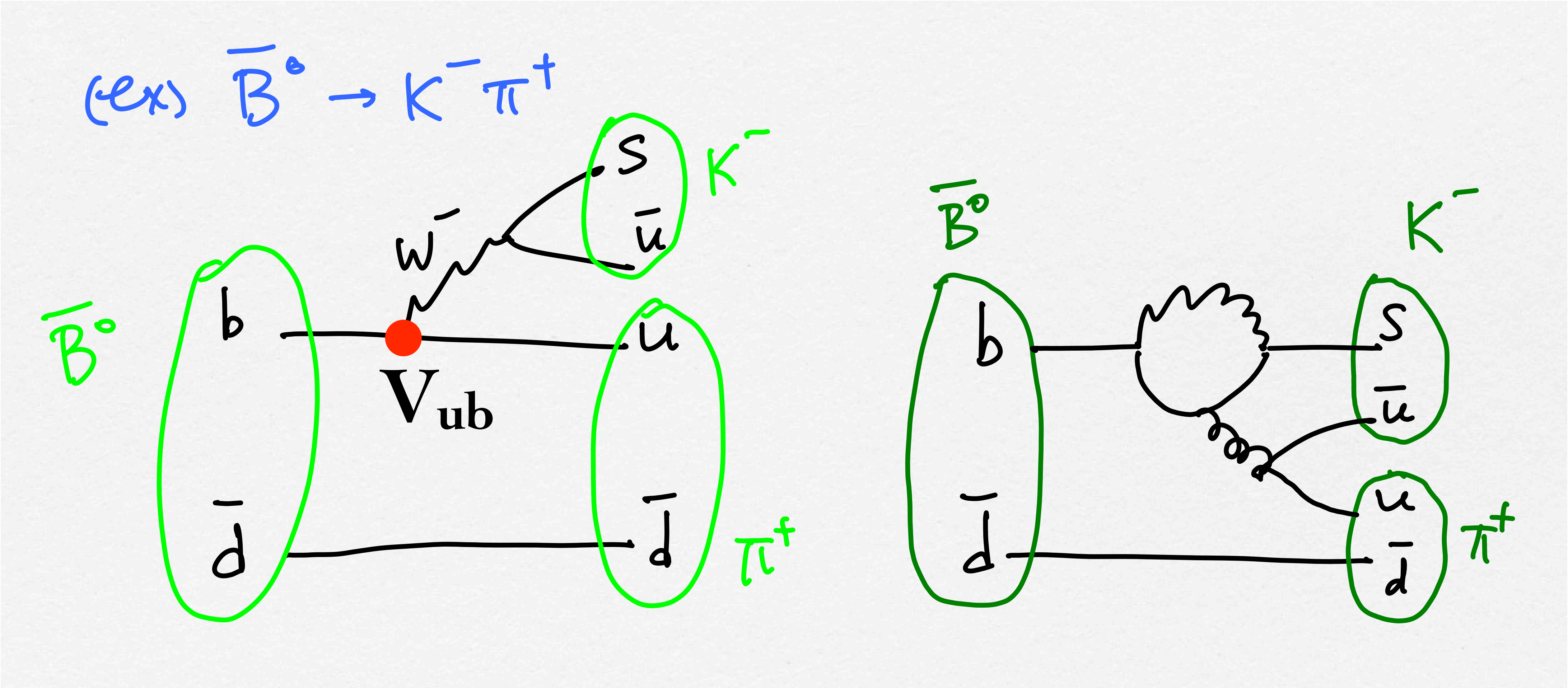
$$A_{K^-\pi^+} \equiv \frac{\Gamma(\bar{B}^0 \to K^-\pi^+) - \Gamma(B^0 \to K^+\pi^-)}{\Gamma(\bar{B}^0 \to K^-\pi^+) + \Gamma(B^0 \to K^+\pi^-)}$$

< 0 by $\sim 8\sigma$



CP asymmetry in charmless hadronic *B* decays

CP violation in $B \to K\pi$



CPV in $B^0 \to K^+\pi^-$ is *not unexpected*, but ...

Direct CPV in $B \to K\pi$

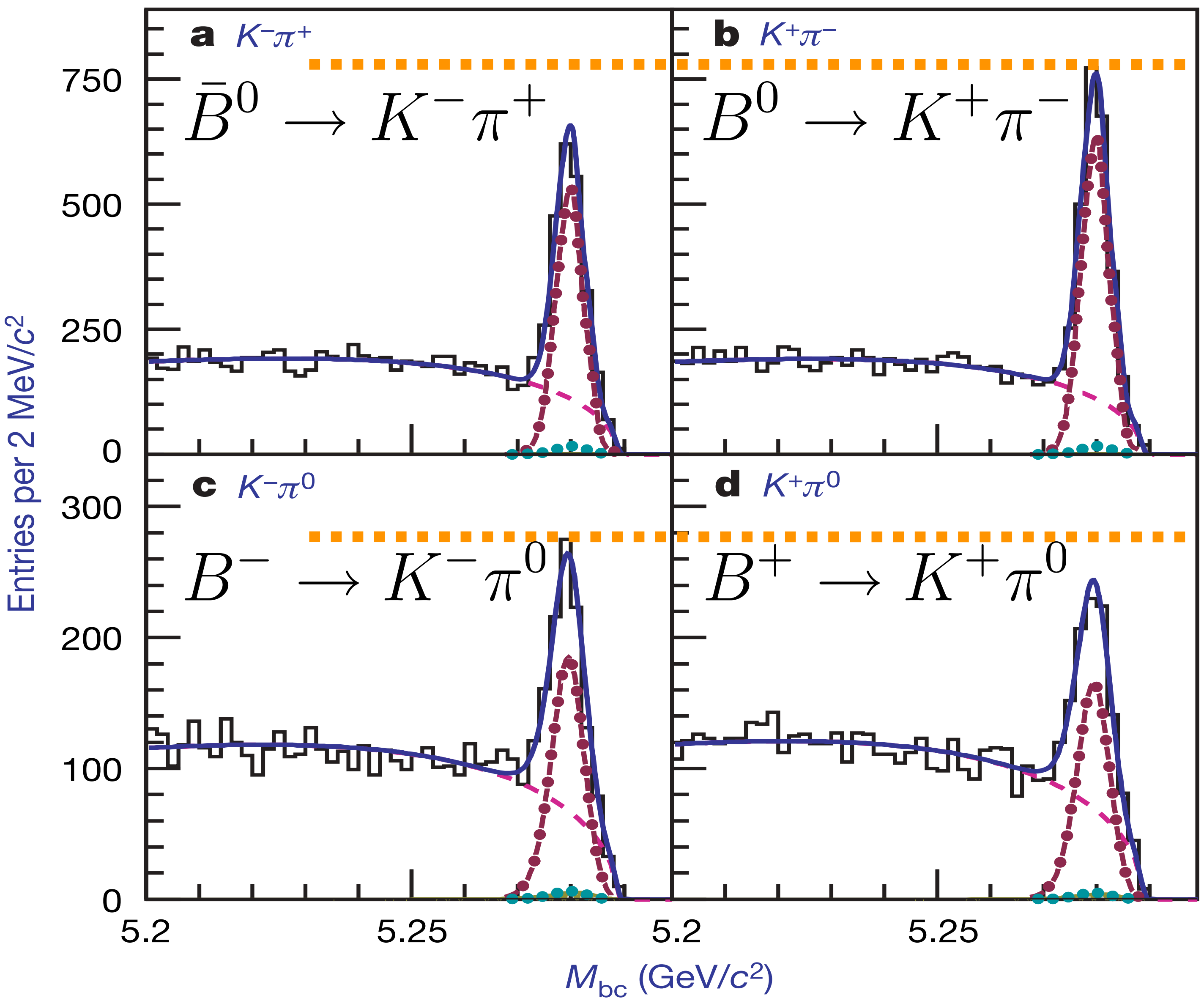


Figure 2 | M_{bc} projections for $K^-\pi^+$ (a), $K^+\pi^-$ (b), $K^-\pi^0$ (c) and $K^+\pi^0$ (d). Histograms are data, solid blue lines are the fit projections, point-dashed lines are the signal components, dashed lines are the continuum background, and grey dotted lines are the $\pi^\pm\pi$ signals that are misidentified as $K^\pm\pi$. The M_{bc} projections are made by requiring $|\Delta E| < 0.06$ GeV for $K^\pm\pi^\mp$ and $-0.14 < \Delta E < 0.06$ GeV for $K^\pm\pi^0$.

$$N_{B\bar{B}} = 535 \times 10^6$$

BELLE

$$\mathcal{A}_{K^\pm\pi^\mp} \equiv \frac{N(\bar{B}^0 \to K^-\pi^+) - N(B^0 - K^+\pi^-)}{N(\bar{B}^0 \to K^-\pi^+) + N(B^0 \to K^+\pi^-)}$$
$$= -0.094 \pm 0.018 \pm 0.008$$

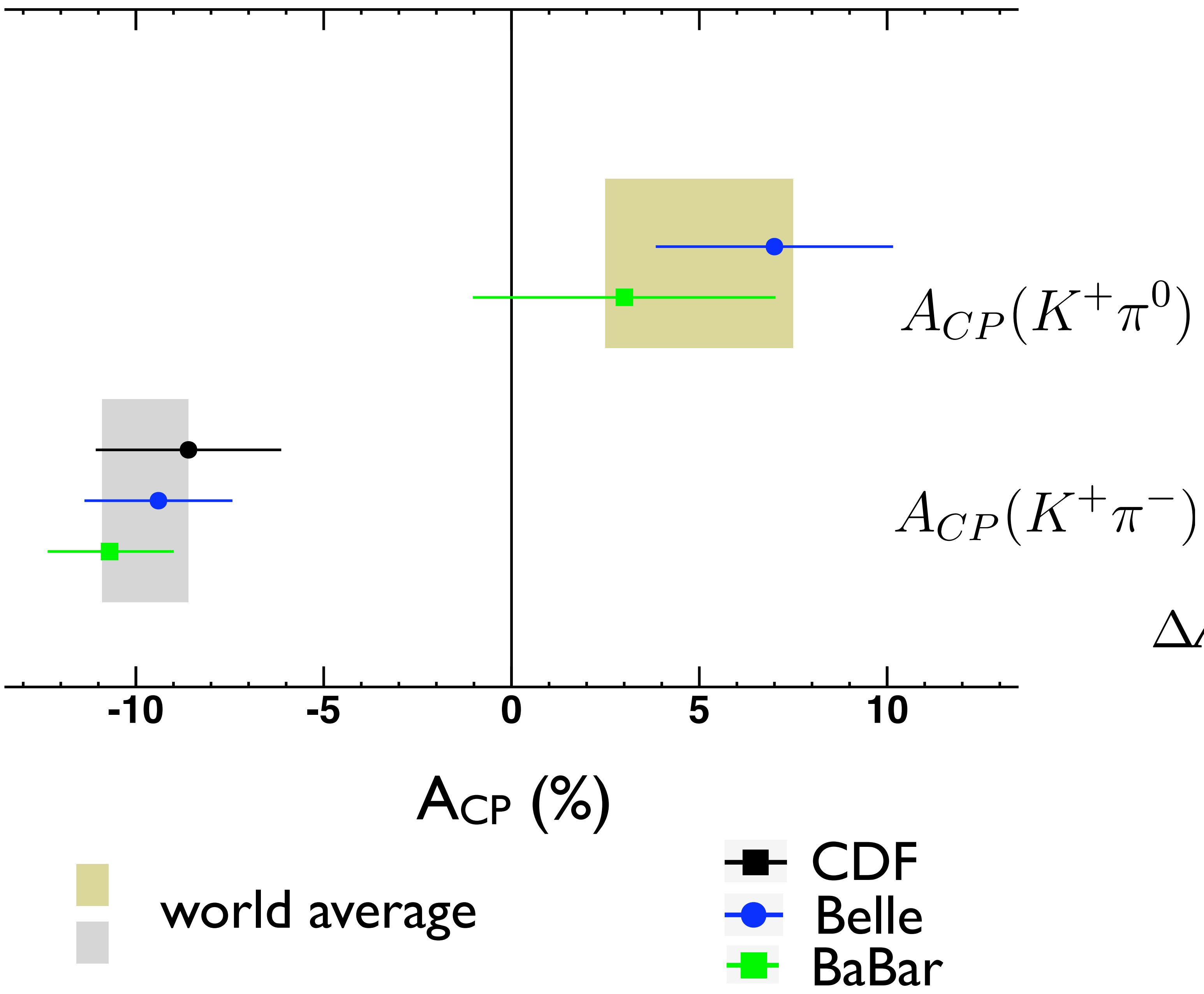
$$\mathcal{A}_{K^\pm\pi^0} = +0.07 \pm 0.03 \pm 0.01$$

$$\mathcal{A}_{K^\pm\pi^0} - \mathcal{A}_{K^\pm\pi^\mp} = +0.164 \pm 0.037$$

a 4.4 σ effect!

Nature 452, 332 (2008)

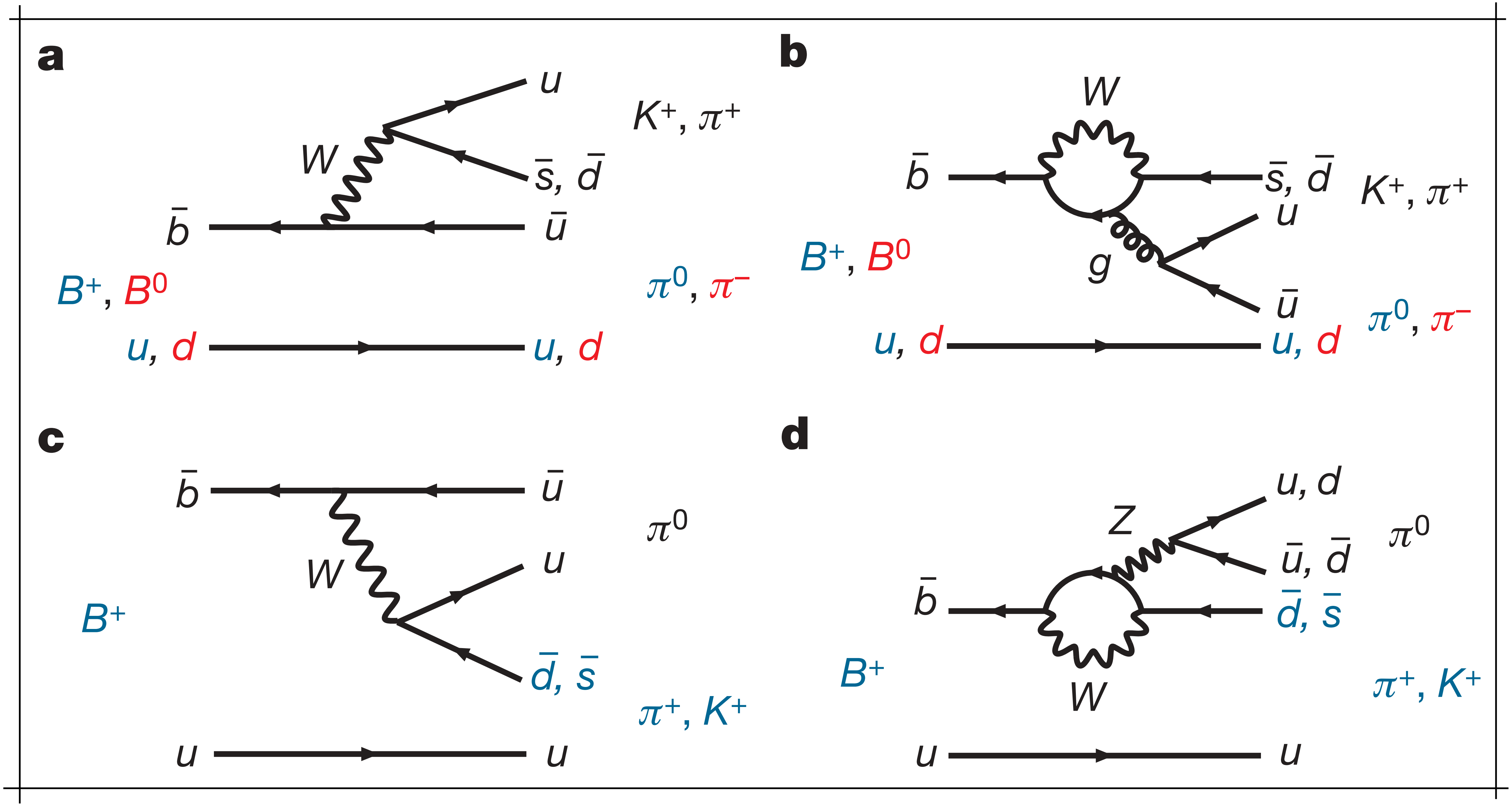
$A_{\rm CP}(K\pi)$ current status



$$\Delta A_{K\pi} \equiv A_{\rm CP}(K^+\pi^-) - A_{\rm CP}(K^+\pi^0)$$
$$= -0.147 \pm 0.028$$

a 5.3σ effect!

Diagrams for $B \to K\pi$



Conjectures for $\Delta A_{CP} \neq 0$

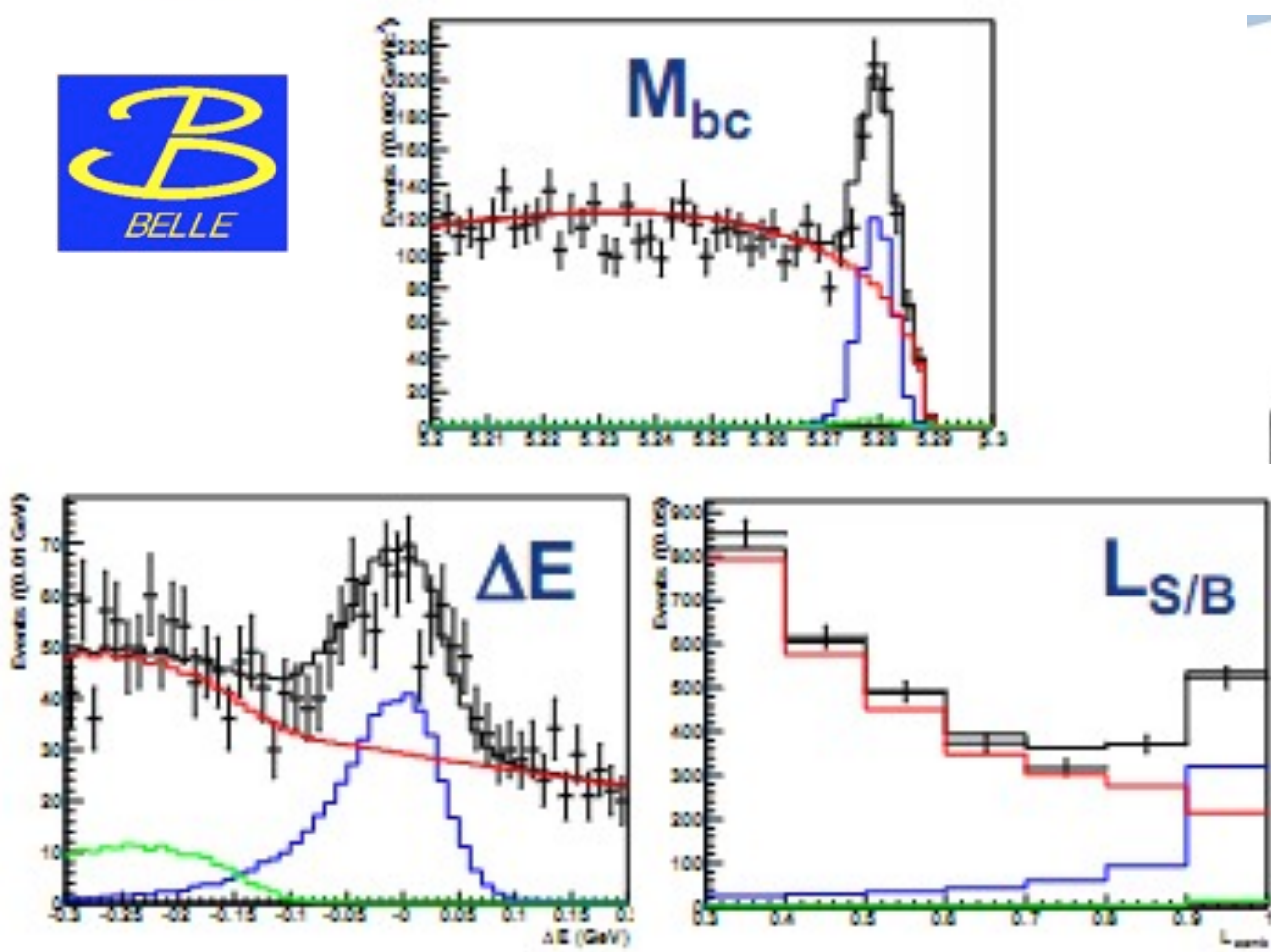
- Enhanced color-suppressed tree?
  - Can it be bigger than color-favored tree?

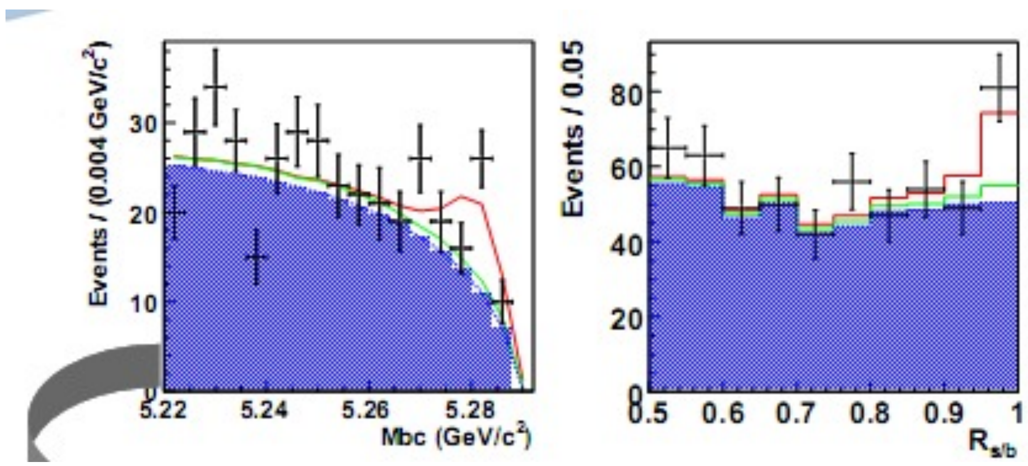
- EW penguin?
  - EWP has negligible CP phase in SM, hence cannot affect ΔA by much
  - perhaps, picking up a new CP phase from NP?

I would love to talk about all the wonderful results on EWP, but I simply don't have time for it today...

one *important but poorly constrained* piece in the puzzle

$B \to K_S^0 \pi^0$ +1st obs. of $B \to K_L^0 \pi^0$

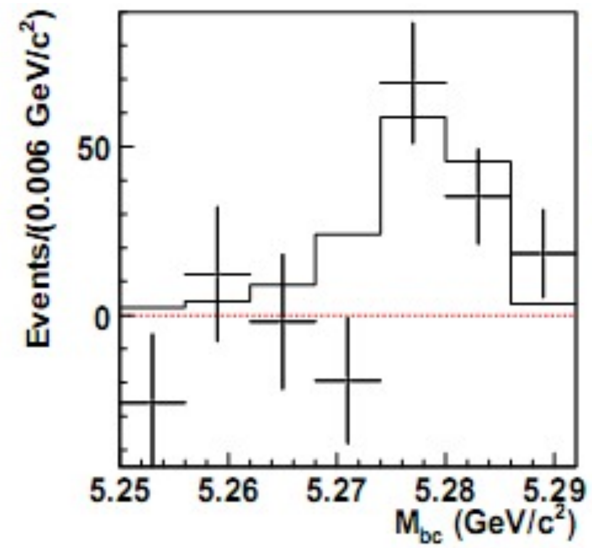




3-d fit gives a signal of 657±37 events

Use flavor tagging to distinguish B0 and anti-B^0

(Using K_S^0 decays that are inside the SVD, we measure TCPV)



285±52±57 (3.7σ incl. systematics)

These modes will be very difficult at a hadron machine

Model-indep. detection of NP in the $B \to K\pi$ system

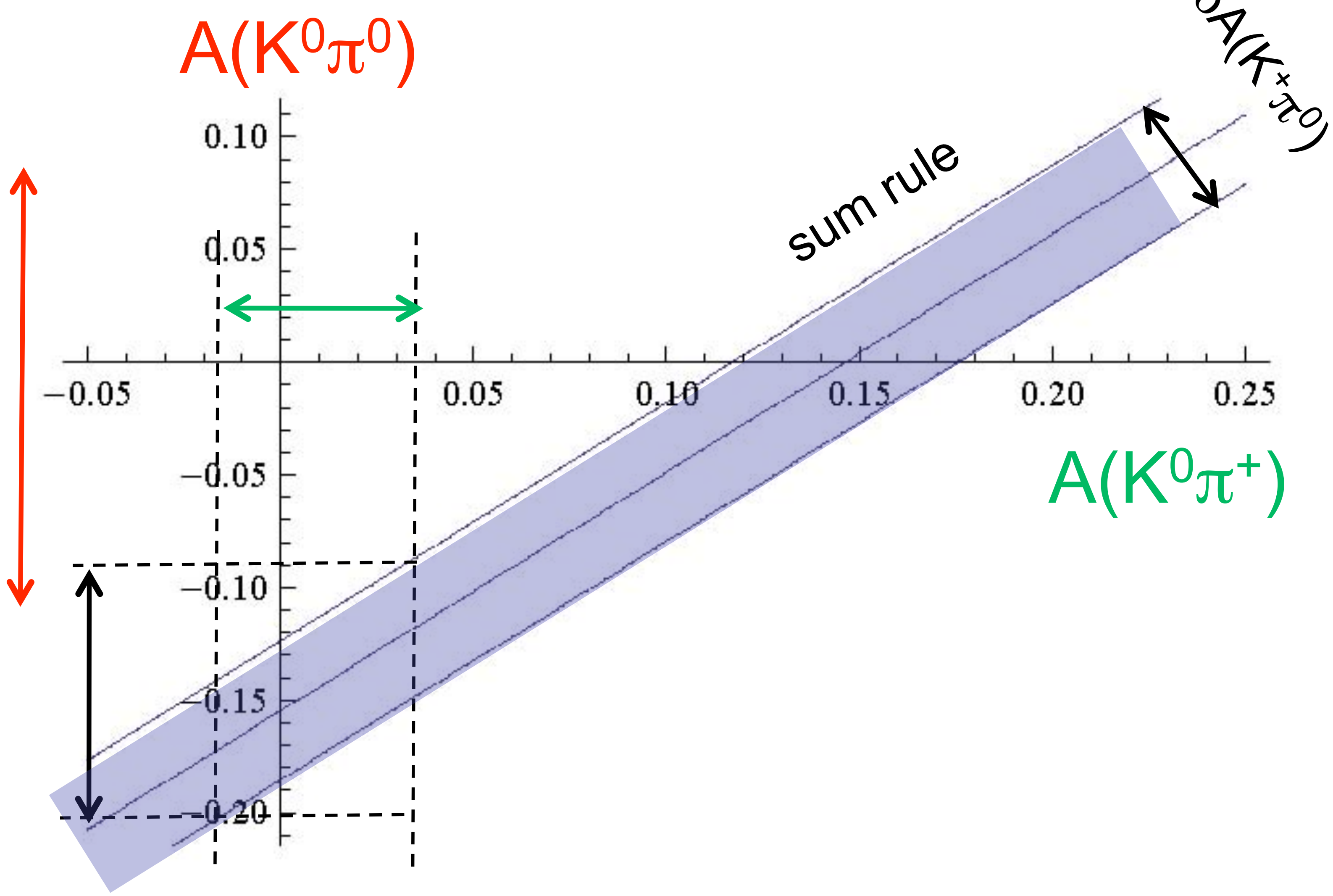
$$\mathcal{A}_{CP}(K^+\pi^-) + \mathcal{A}_{CP}(K^0\pi^+)\frac{\mathcal{B}(K^0\pi^+)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_0}{\tau_+} = \mathcal{A}_{CP}(K^+\pi^0)\frac{2\mathcal{B}(K^+\pi^0)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_0}{\tau_+} + \mathcal{A}_{CP}(K^0\pi^0)\frac{2\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)}$$

$B \to K\pi$ HFAG, ICHEP08

$A(K^0\pi^+)=0.009 \pm 0.025$
$A(K^+\pi^0)=0.050 \pm 0.025$
$A(K^+\pi^-)=-0.098 \pm 0.012$
$A(K^0\pi^0)=-0.01 \pm 0.10$

measured (HFAG)

expected (sum rule)



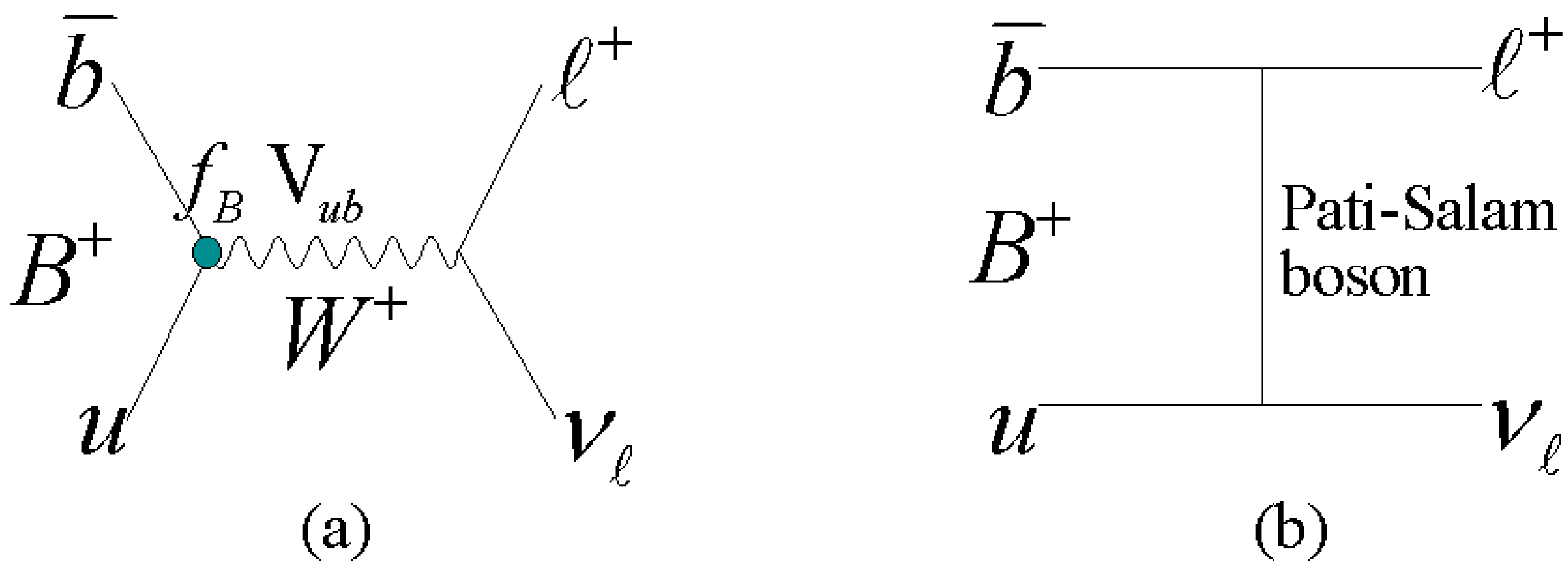
Sum rule proposed by:
M. Gronau, PLB 627, 82 (2005); D. Atwwod, A. Soni, PRD 58, 036005 (1998).

$$B^+ \to \tau^+ \nu$$

PRL 97, 251801 (2006)
arXiv:0809.3834 (2008)

PRD 77, 011107 (2008)
arXiv:0809.4027

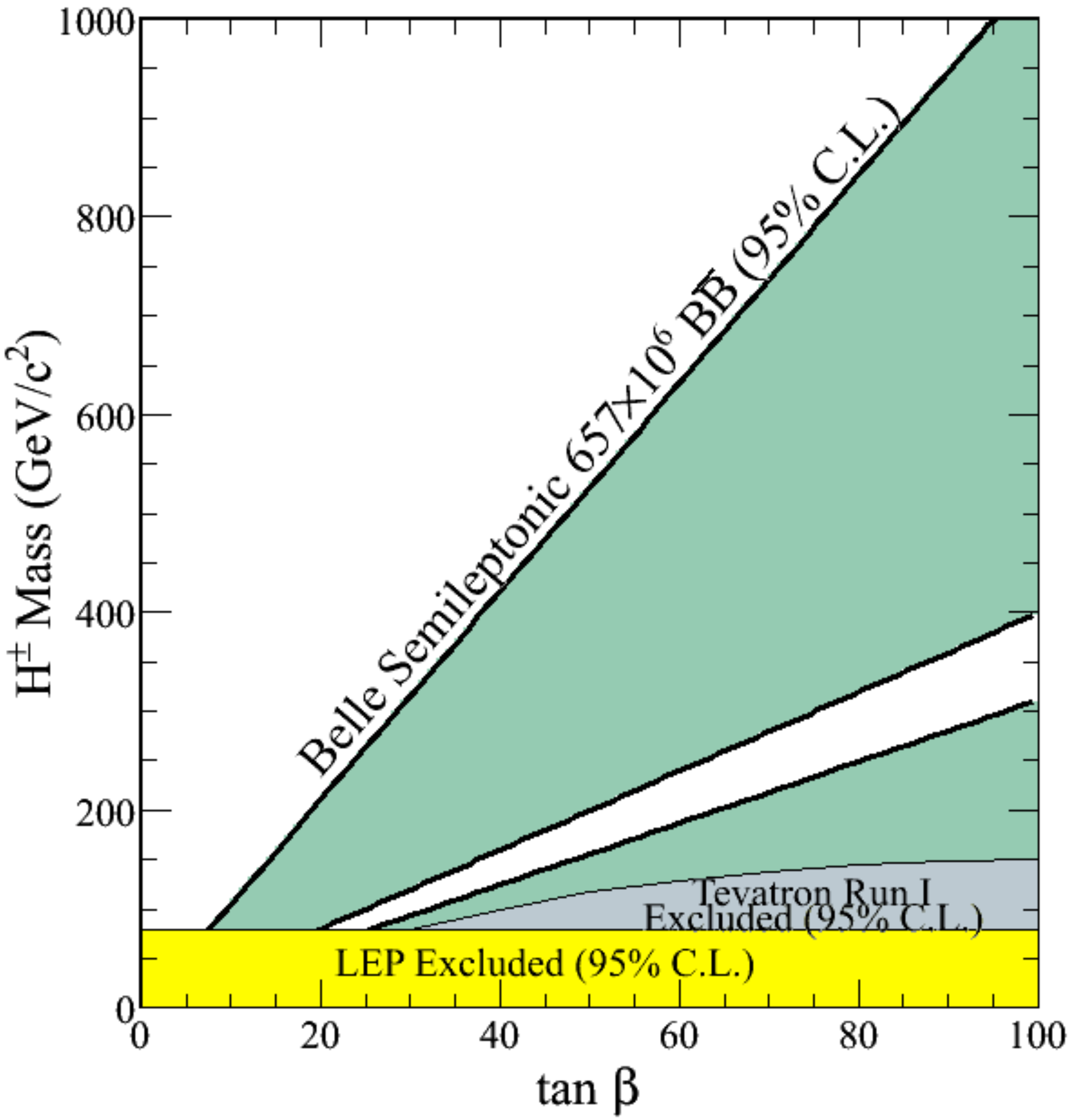
Motivations for $B^+ \to \ell^+\nu$



$$\Gamma(B^+ \to \ell^+\nu) = \frac{G_F^2 m_B m_\ell^2}{8\pi}\left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2$$

- very clean place to measure f_B (or V_{ub}?) and/or search for new physics (e.g. H^+, LQ)
- but, helicity-suppressed: $\Gamma(B^+ \to e^+\nu) \ll \Gamma(B^+ \to \mu^+\nu) \ll \Gamma(B^+ \to \tau^+\nu)$

$(B^+ \to \tau^+\nu)$ Constraints on new physics

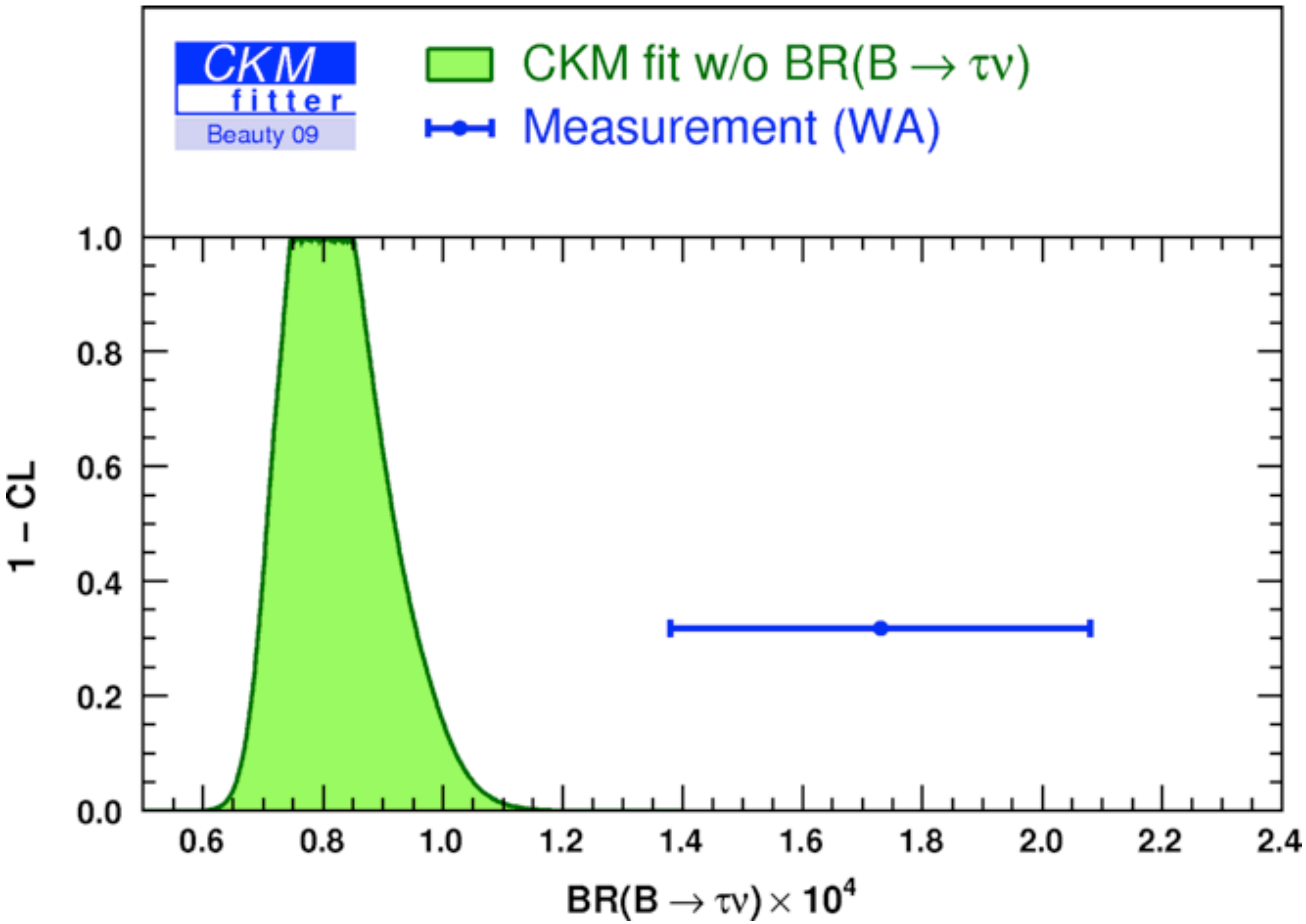


- Hou, PRD 48, 2342 (1993)

$$r_H \equiv \frac{\mathcal{B}(B^+ \to \tau^+\nu)}{\mathcal{B}(B^+ \to \tau^+\nu)_{\rm SM}} = \left(1 - \frac{m_B^2}{m_H^2}\tan^2\beta\right)^2$$

- (Figure) from Belle SL-tag results

$(B^+ \to \tau^+ \nu)$ compared with CKM fit



- $\mathcal{B}_{\text{SM}} \propto (f_B |V_{ub}|)^2$
- f_B cancels if taken ratio with B^0 mixing
- provides a constraint on V_{ub} in CKM △ fit
- ∃ a tension?

Concluding Remarks

B-Factories have confirmed the large CP violation

in particular, $B \to c\bar{c}K^0$ modes : $\sin 2\phi_1 = 0.672 \pm 0.023$

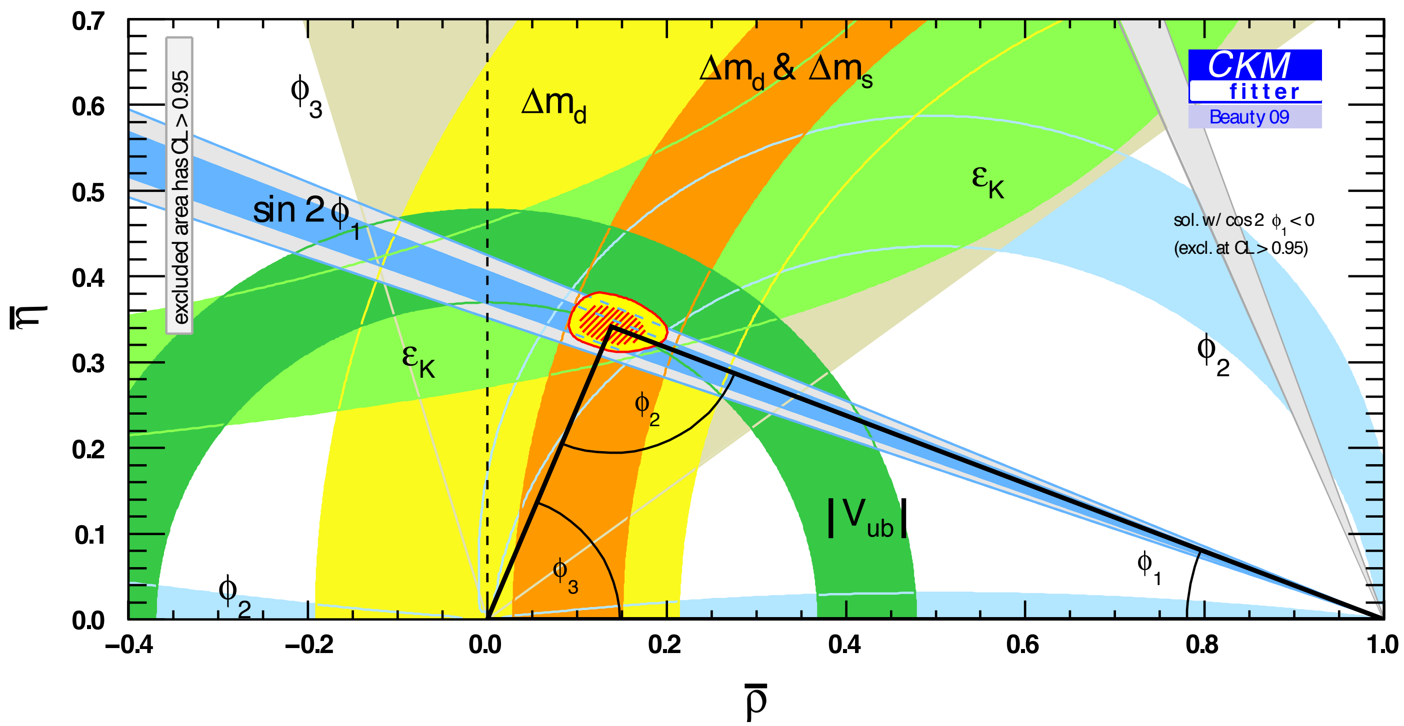
high precision !

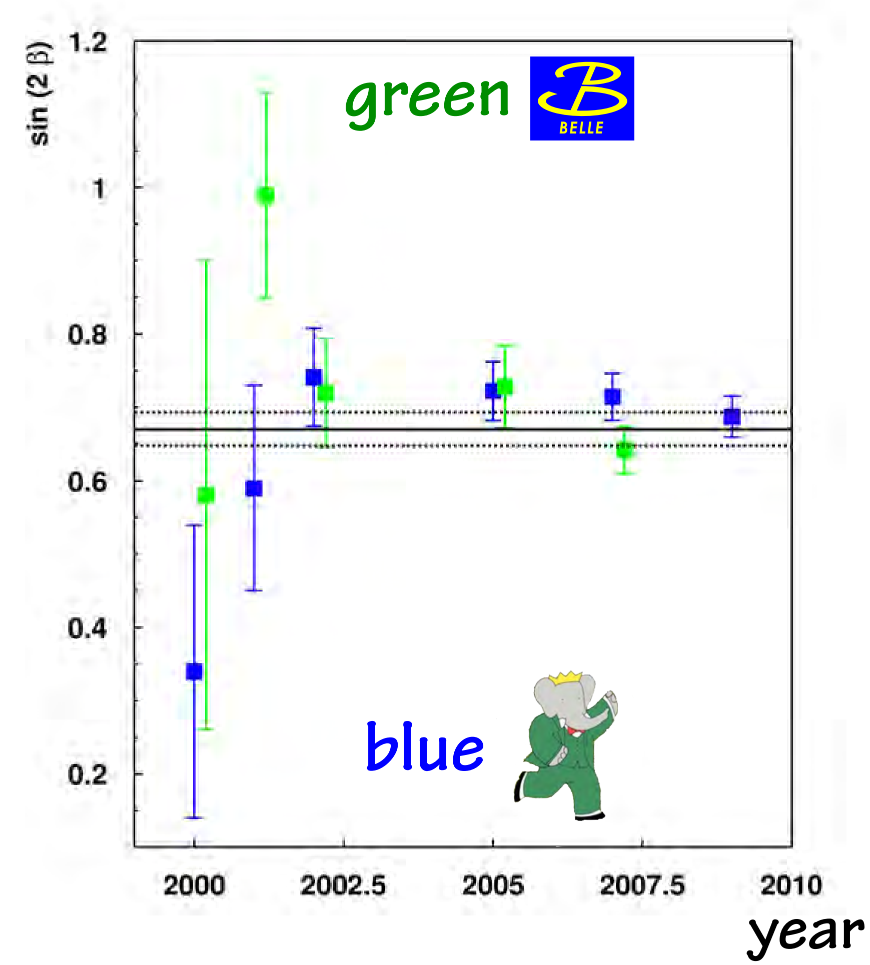
Now, the reference for the new physics search

http://ckmfitter.in2p3.fr/

O.Long @ Moriond, EW, 2010

$$\phi_1 = 21.15^{+0.90}_{-0.88}{}^\circ$$
$$\phi_2 = 89.0^{+4.4}_{-4.2}{}^\circ$$
$$\phi_3 = 69^{+19}_{-21}{}^\circ$$





Concluding Remarks

- Status of the "tension"s
  - There are a few interesting results from the B-factory experiments indicating hints of something unknown...
    - ★ leptonic B decays
    - ★ hadronic penguin decays
    - ★ NP or not-NP, we do not have clear understanding, yet
- What's ahead
  - (*although I didn't say a word about it...*) The case for flavor physics in the LHC era is still compelling
  - LHC, esp. LHCb experiment will be great tools for heavy-flavor physics
  - But some aspects, e.g. modes with neutrino(s), will require Super-B (i.e. **Belle-II**)

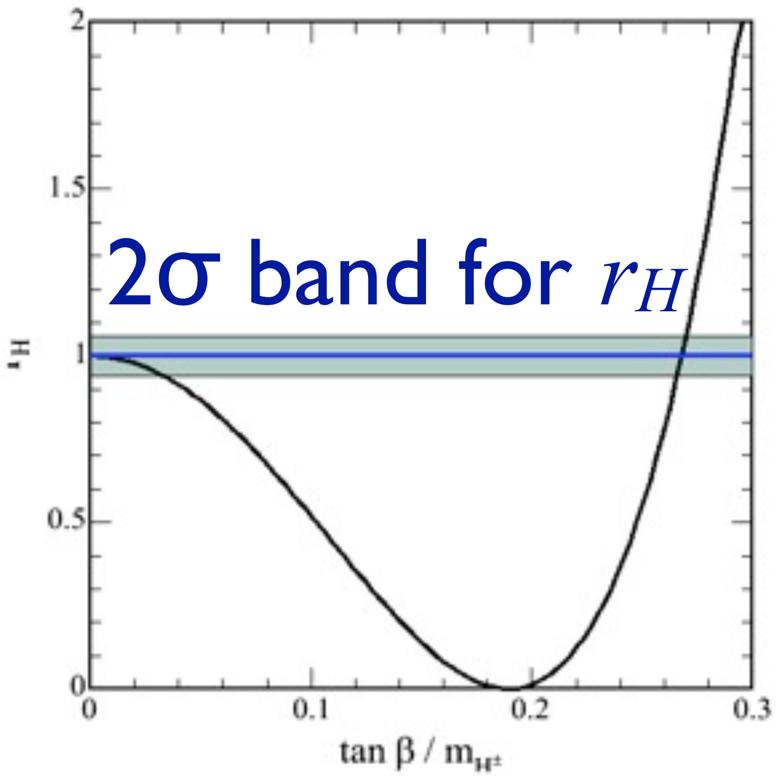
Future prospects

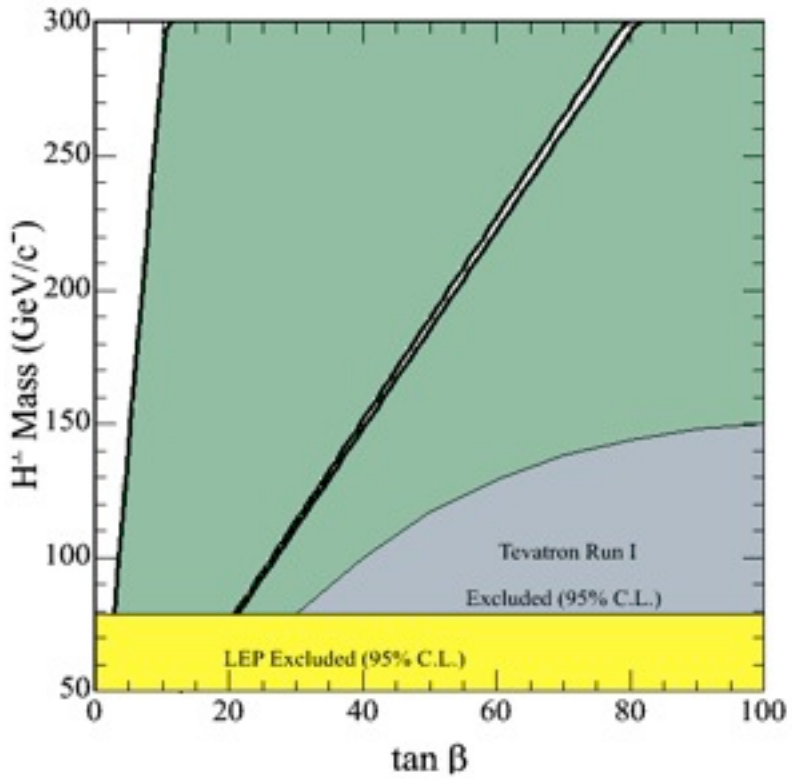
extrapolations

$\int L\,dt$	$\Delta B(B\to\tau\nu)$	$\Delta\lvert V_{ub}\rvert$
414 fb^{-1}	36%	7.5%
5 ab^{-1}	10%	5.8%
50 ab^{-1}	3%	4.4%

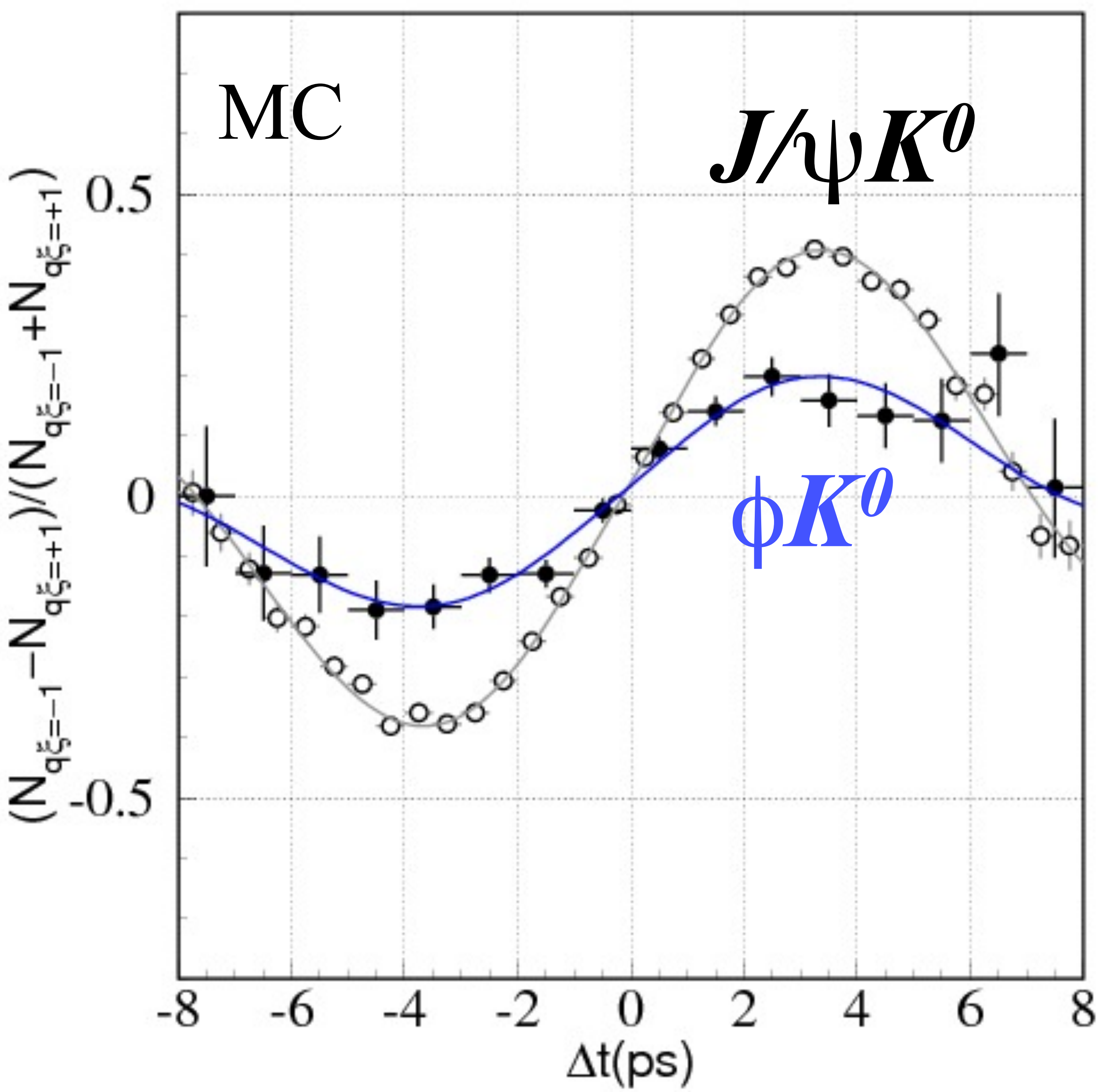
Δf_B(LQCD) = 5% (?)

for 50 ab^{-1}
assuming
$\Delta|V_{ub}| = 0$ & $\Delta f_B = 0$





Extrapolation: $B \to \phi K^0$ at 50/ab with present WA values

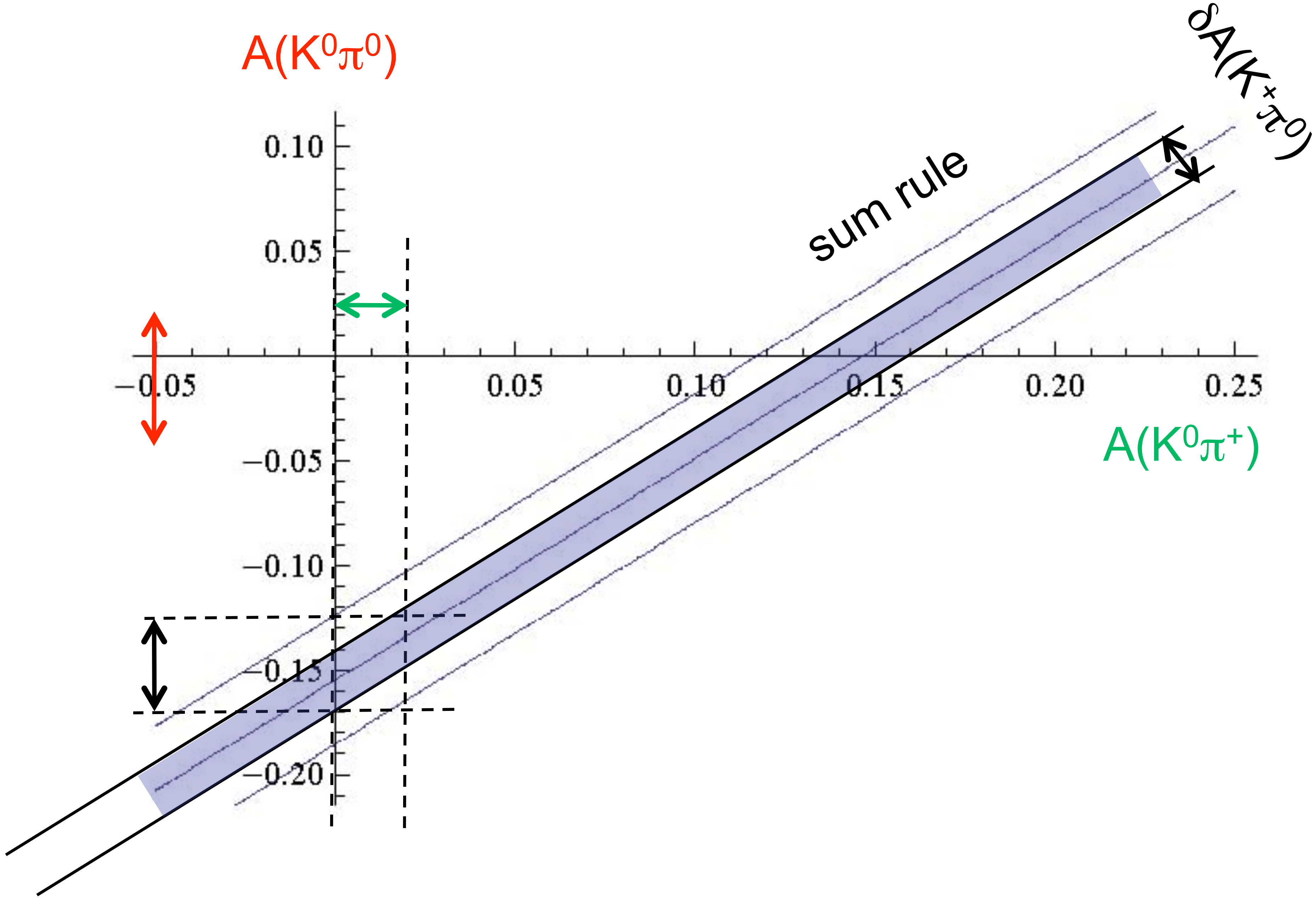


This would establish the existence of a NP phase

Compelling measurement in a clean mode

on $K\pi$ puzzle

e.g. Belle II, 50 ab^{-1}



Epilogue

What we call the beginning is often the end
And to make an end is to make a beginning.
...

We shall not cease from exploration
And the end of all our exploring
Will be to arrive where we started
And know the place for the first time.
Through the unknown, unremembered gate
When the last of earth left to discover
Is that which was the beginning
...

T. S. Elliot, from "Four Quartets"

The (still) open questions

- Why flavors; why 3?
- Why the mass & mixing patterns?
- Why/how did the antimatter disappear?
- ...

- Questions may remain unanswered even if SUSY or new physics is found at LHC and/or Super-B...
- But, step-by-step experimental approach in flavor physics, esp. in B physics is definitely needed to address these grand questions

Flavour Observables Sensitive to New Physics

$\Delta m_K \quad \epsilon_K \quad \epsilon'/\epsilon_K \quad B(K_L \to \pi^0 \nu \bar{\nu}) \quad B(K^+ \to \pi^+ \nu \bar{\nu}) \quad B(K^+ \to l^+ \nu)$

$\Delta m_d \quad A_{SL}(B_d) \quad S(B_d \to J/\psi K_S) \quad S(B_d \to \phi K_S)$

$\alpha(B \to \pi\pi, \rho\pi, \rho\rho) \quad \gamma(B \to DK) \quad CKM \; fits$

$\Delta m_s \quad A_{SL}(B_s) \quad S(B_s \to J/\psi \phi) \quad S(B_s \to \phi\phi)$

$B(b \to s\gamma) \quad A_{CP}(b \to s\gamma) \quad S(B^0 \to K_S \pi^0 \gamma) \quad S(B_s \to \phi\gamma)$

$B(b \to d\gamma) \quad A_{CP}(b \to d\gamma) \quad A_{CP}(b \to (d+s)\gamma) \quad S(B^0 \to \rho^0 \gamma)$

$B(b \to s l^+ l^-) \quad B(b \to d l^+ l^-) \quad A_{FB}(b \to s l^+ l^-) \quad B(b \to s \nu \bar{\nu})$

$B(B_s \to l^+ l^-) \quad B(B_d \to l^+ l^-) \quad B(B^+ \to l^+ \nu)$

$B(\mu \to e\gamma) \quad B(\mu \to e^+ e^- e^+) \quad (g-2)_\mu \quad \mu \; EDM$

$B(\tau \to \mu\gamma) \quad B(\tau \to e\gamma) \quad B(\tau^+ \to l^+ l^- l^+) \quad \tau \; CPV \quad \tau \; EDM$

$B(D^+_{(s)} \to l^+ \nu) \quad x_D \; y_D \quad charm \; CPV$

6

... add your favourite here ...

from Tim Gershon's talk in Coseners Workshop (2007)

Will be Studied at Belle-II

Δm_K ϵ_K ϵ'/ϵ_K $B(K_L \to \pi^0 \nu \bar{\nu})$ $B(K^+ \to \pi^+ \nu \bar{\nu})$ $B(K^+ \to l^+ \nu)$

Δm_d $A_{SL}(B_d)$ $S(B_d \to J/\psi K_S)$ $S(B_d \to \phi K_S)$

$\alpha(B \to \pi\pi, \rho\pi, \rho\rho)$ $\gamma(B \to DK)$ $CKM\ fits$

Δm_s $A_{SL}(B_s)$ $S(B_s \to J/\psi \phi)$ $S(B_s \to \phi\phi)$

$B(b \to s\gamma)$ $A_{CP}(b \to s\gamma)$ $S(B^0 \to K_S \pi^0 \gamma)$ $S(B_s \to \phi\gamma)$

$B(b \to d\gamma)$ $A_{CP}(b \to d\gamma)$ $A_{CP}(b \to (d+s)\gamma)$ $S(B^0 \to \rho^0 \gamma)$

$B(b \to s l^+ l^-)$ $B(b \to d l^+ l^-)$ $A_{FB}(b \to s l^+ l^-)$ $B(b \to s \nu \bar{\nu})$

$B(B_s \to l^+ l^-)$ $B(B_d \to l^+ l^-)$ $B(B^+ \to l^+ \nu)$

$B(\mu \to e\gamma)$ $B(\mu \to e^+ e^- e^+)$ $(g-2)_\mu$ $\mu\ EDM$

$B(\tau \to \mu\gamma)$ $B(\tau \to e\gamma)$ $B(\tau^+ \to l^+ l^- l^+)$ $\tau\ CPV$ $\tau\ EDM$

$B(D^+_{(s)} \to l^+ \nu)$ x_D y_D $charm\ CPV$

8

from Tim Gershon's talk in Coseners Workshop (2007)

Epilogue

"Imagine if Fitch and Cronin had stopped at the 1% level, how much physics would have been missed"

–A. Soni@Super KEKB proto-collaboration meeting

A lesson from history

"A special search at Dubna was carried out by E. Okonov and his group. They did not find a single $K_L \to \pi^+ \pi^-$ event among 600 decays into charged particles [12] (Anikira et al., JETP 1962). At that stage the search was terminated by the administration of the Lab. The group was unlucky."

-Lev Okun, "The Vacuum as Seen from Moscow"

$$(1964)\ \mathcal{B} = 2 \times 10^{-3}$$

A failure of imagination, or lack of patience?

Thank you!