Present and future of B-Factories

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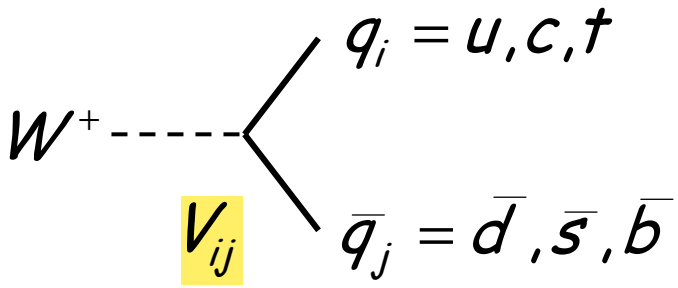
IFAE Catania – 1/4/2005

CKM Matrix and CP violation

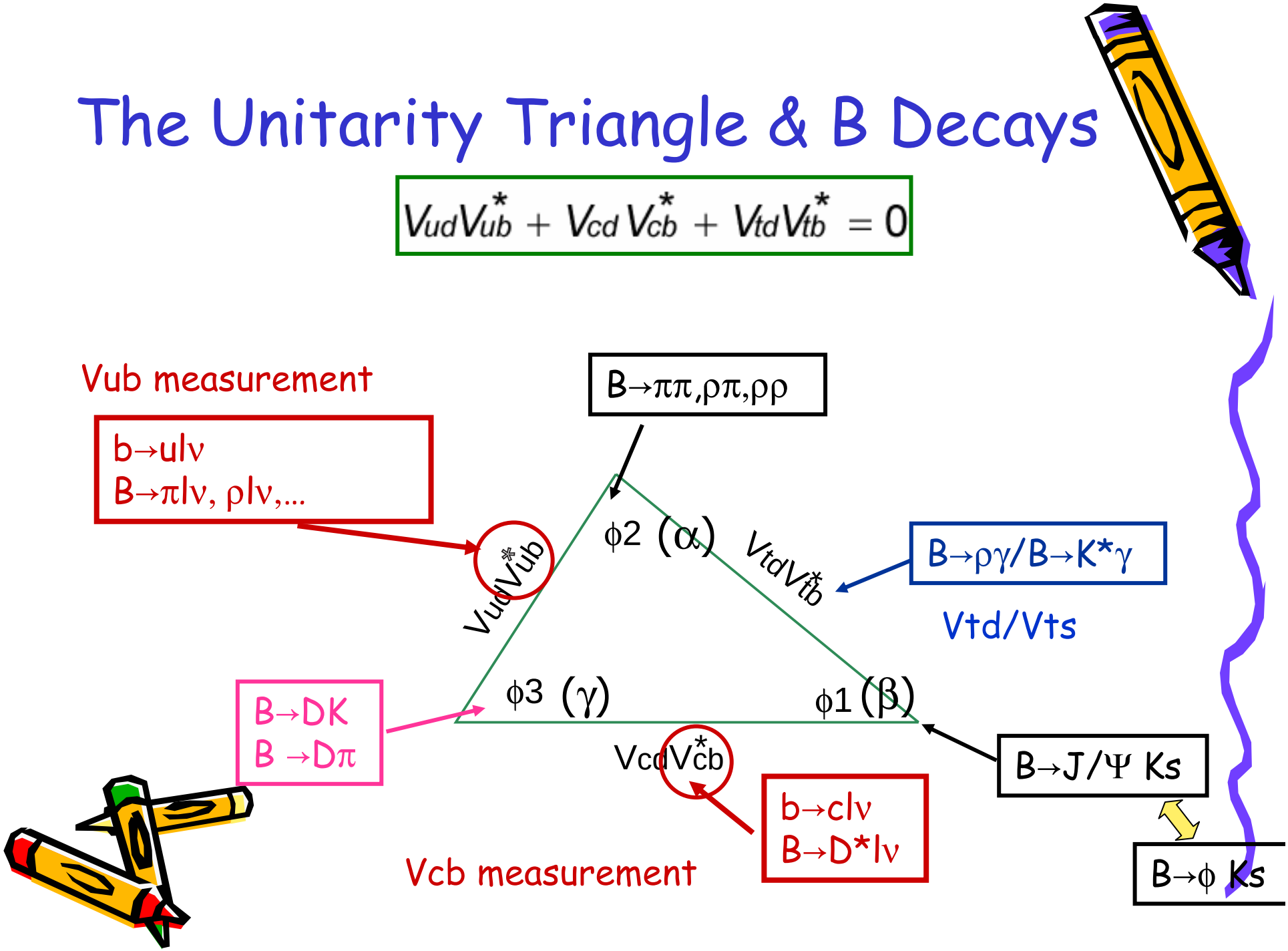


$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub}^* \\ V_{cd} & V_{cs} & V_{cb}^* \\ V_{td} & V_{ts} & V_{tb}^* \end{pmatrix}$$

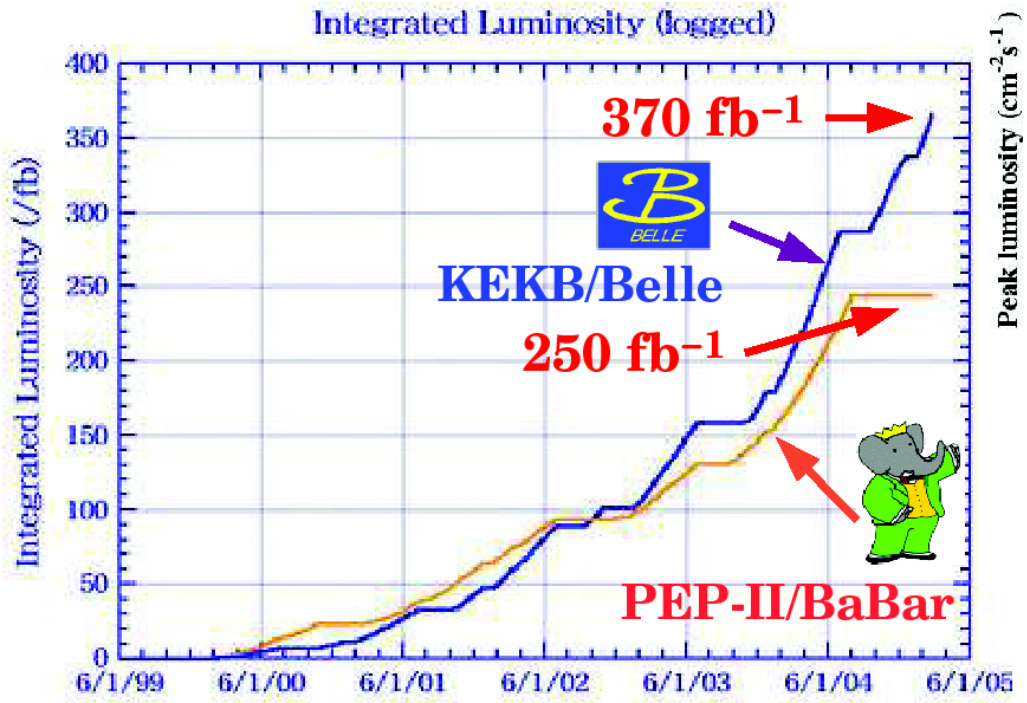
$$V_{Wolf.} = \begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$

The Unitarity Triangle & B Decays

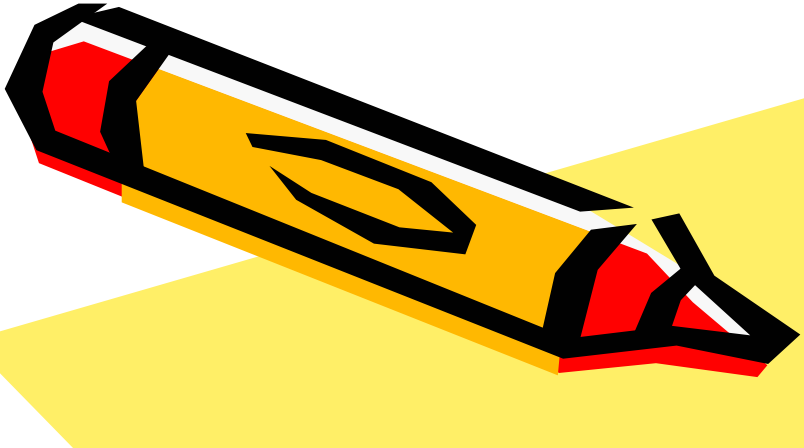
$$V_{ud}V_{ub}^{*} + V_{cd}V_{cb}^{*} + V_{td}V_{tb}^{*} = 0$$



B-Factories: status and plans



- ~600fb^{-1} accumulated by BaBar+Belle
- BaBar short of ~100fb-1 due to security accident
- Plan to have ~500fb^{-1}/exp by Summer 2006
- Future scenarios
  - BaBar running till 2008 (1ab-1 accumulated)
  - Belle planning to upgrade machine with 1-2 years stop : 2-3 ab^{-1}/year starting 2010
  - "sudden SuperBF" (10^{36}) ? Where? (not SLAC)

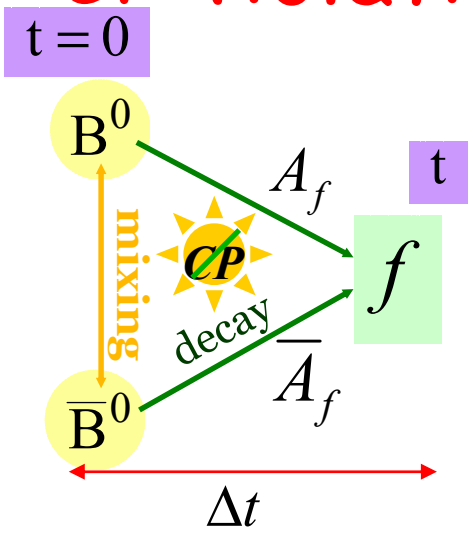


Primers

Time dependent CP

"Recoil Physics"

CP violation in mixing and decay



Consider B decays to a mode *f*

$$\wp(B^0(t) \to f) \sim$$

$$1+\lambda^2 \pm (1-\lambda^2)\cos(\Delta M t) \pm 2\,\mathrm{Im}(\lambda)\sin(\Delta M t)$$

f is not necessarily a CP eigenstate

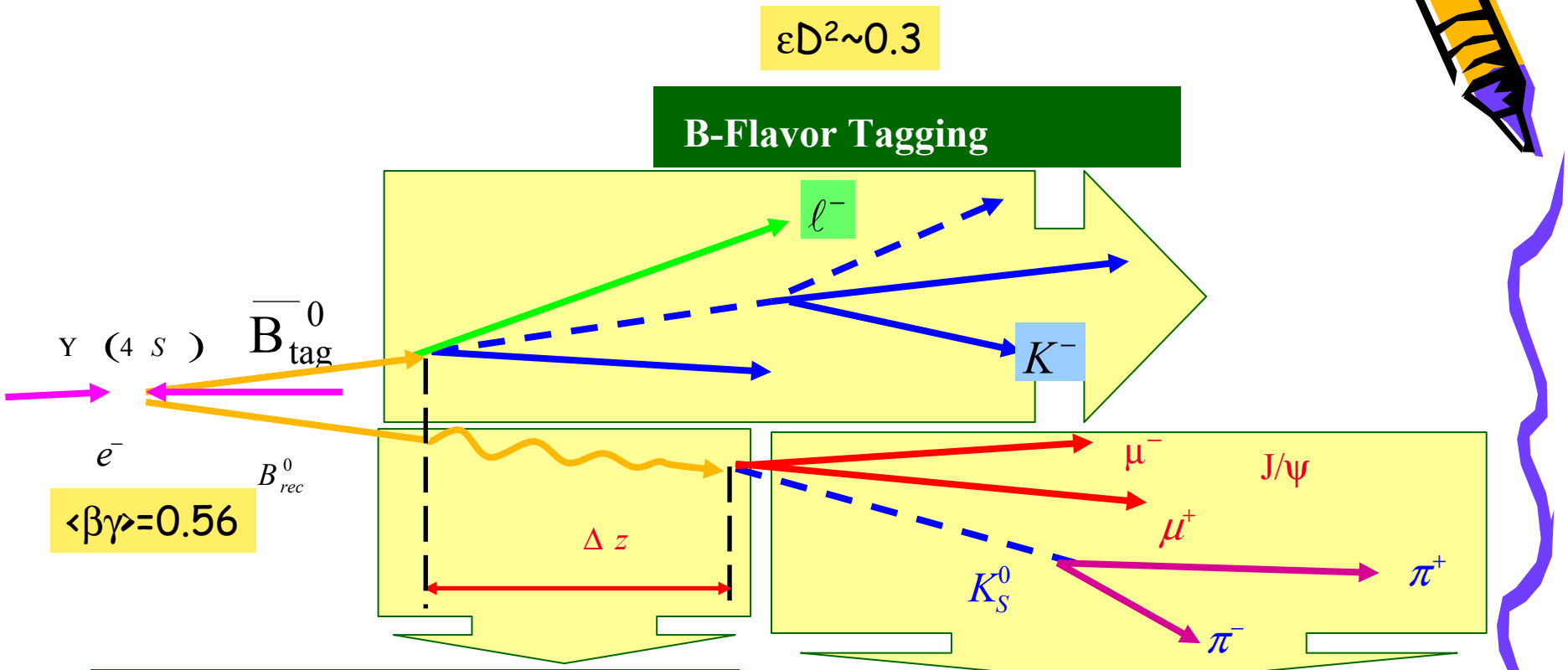
$$\lambda = \frac{A(\overline{B} \to f)V_{td}^* V_{tb}}{A(B \to f)V_{td}V_{tb}^*} \cong \frac{\overline{A}}{A} e^{-i2\beta}$$

Mixing phase

Examples:

	f	$Arg(\frac{\overline{A}}{A})$	$\lvert\lambda\rvert$	output
mixing	$B_0 \to l\nu X, D^{(*)}\pi,\rho,a_1$	0	~0	ΔM_d
"sin2β"	$B_0 \to J/\Psi K^0 + \phi K^0$	0	1	sin2β
"sin2α"	$B_0 \to \pi\pi,\rho\rho,\pi\pi\pi$	~(-2γ)	~1	sin2α
sin(2β+γ)	$B_0 \to D^{(*)+}\pi^-$	~(-γ)	~0.02	sin(2β+γ)

Time Dependent CP: technique



Accurate and unbiased measurement of the vertices

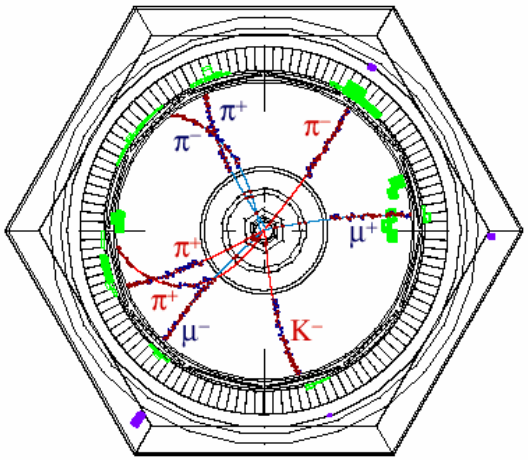
Low BR (10^{-5}) means high luminosity

Physics on the recoil

The high luminosity and the high number of fully reconstructed B's opens a brand new world in B physics!

Fully reconstruct one of the Bs and study the remaining of the event ➔ **close kinematics**, missing energy reconstruction

$\overline{B}^0 \to D^{*+}\pi^-$ $B^0 \to \psi(2S)K^0_s$



$D^{*+} \to D^0\pi^+$ $\psi(2S) \to \mu^+\mu^-$

$D^0 \to K^-\pi^+$ $K^0_s \to \pi^+\pi^-$

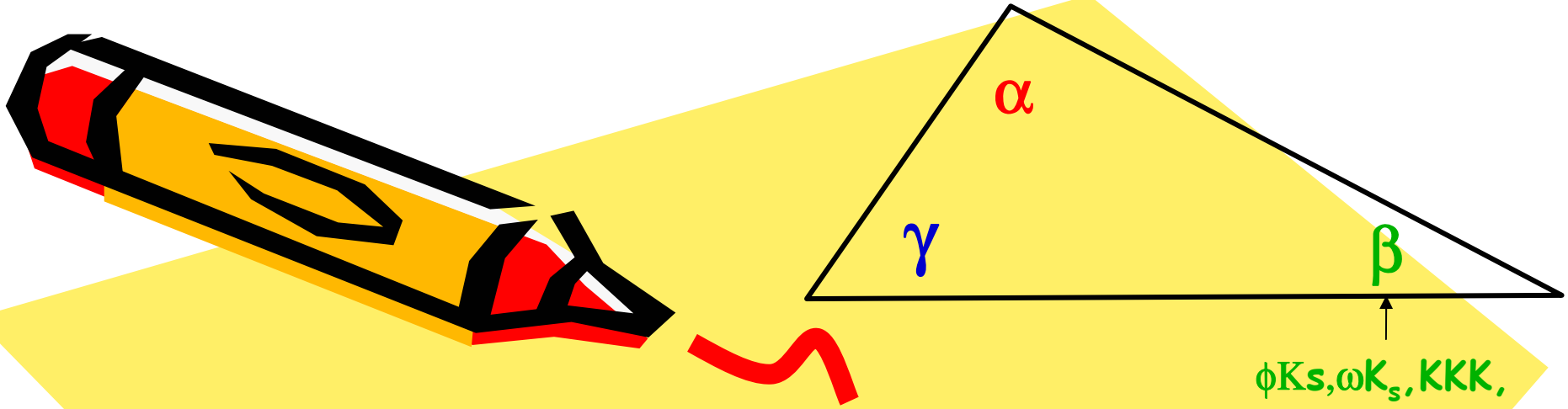
Tag types

Semileptonic $D^{(*)}l(n\pi)$ 5K/fb^{-1}

Hadronic $D^{(*)}$ X 3K/fb-1

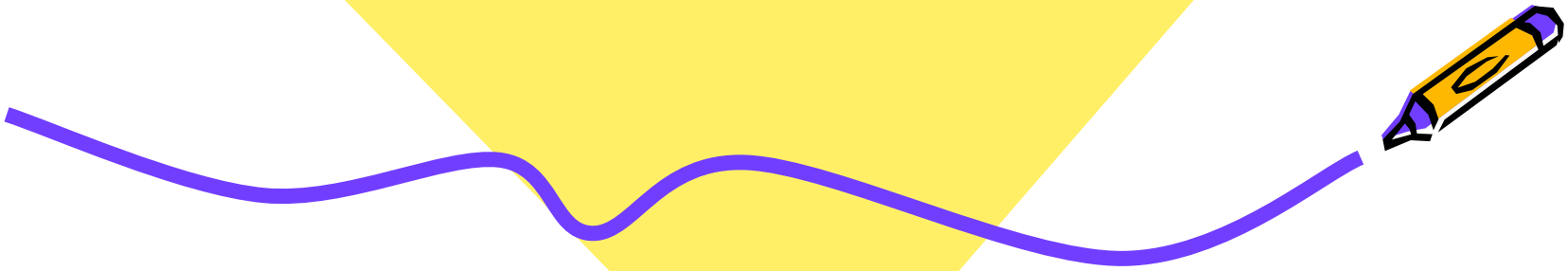
efficiency *purity*

$X = n\pi + m\pi^0 + pK + qK_s$

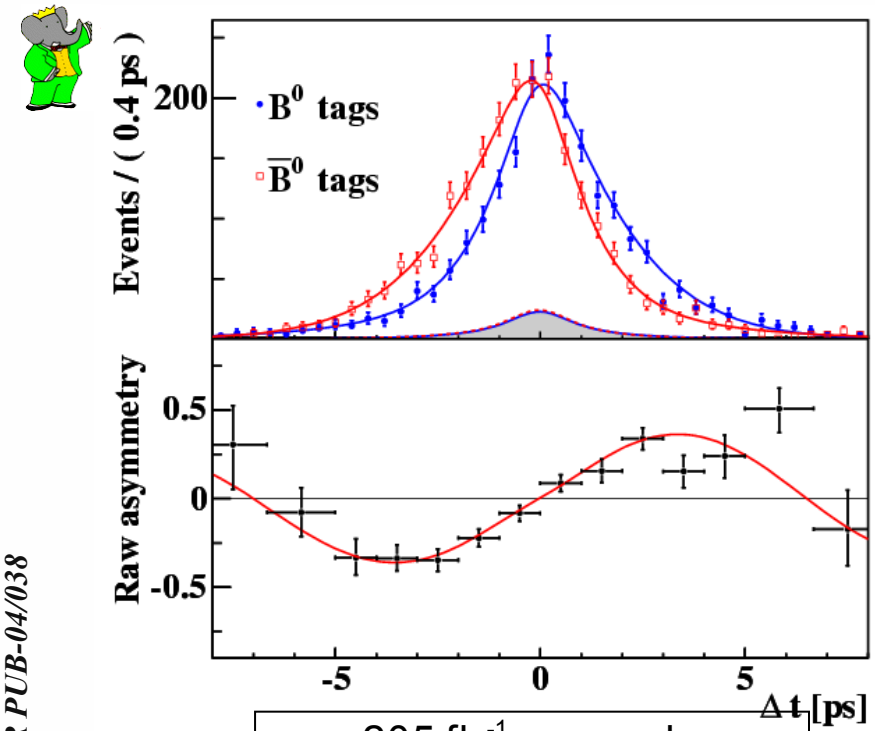


Measurements of β

New physics and penguins



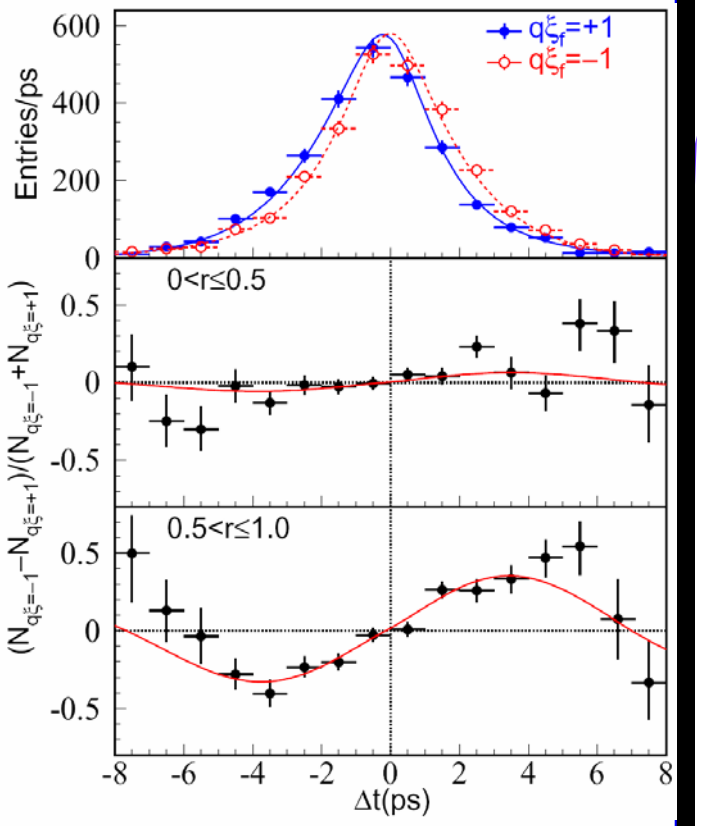
sin2β from charmonium K^0_S



205 fb^{-1} on peak:
227M$B\bar{B}$ (7730 CP) events

BABAR PUB-04/038

sin 2β = +0.722 ± 0.040 ± 0.023
$|\lambda| = |\bar{A} / A| = 0.950 \pm 0.031 \pm 0.013$



140 fb^{-1} on peak:

152M$B\bar{B}$ (4347 CP) events

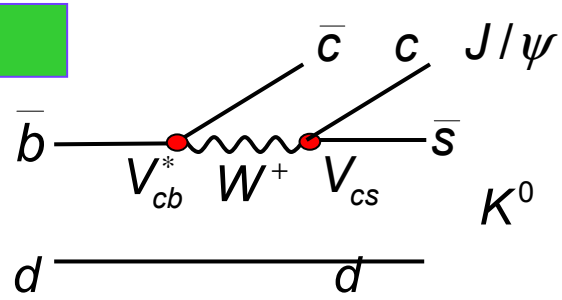
BELLE CONF-0436
HEPEX-0408111 v. 2

sin 2β = +0.728 ± 0.056 ± 0.023
$|\lambda| = |\bar{A} / A| = 1.007 \pm 0.041 \pm 0.033$

Penguins and new physics

- Golden-tree and penguin modes:

Tree:

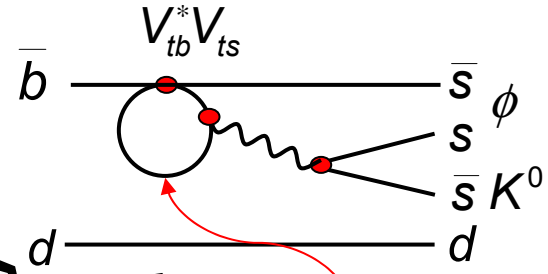


$$b \to c\bar{c}s$$

$$\lambda_{J/\psi Ks} = +\left(\frac{q}{p}\right)_B \left(\frac{V_{cb}V_{cs}^*}{V_{cb}^*V_{cs}}\right)\left(\frac{p}{q}\right)_K = -e^{-2i\beta}$$

In SM: $\lambda_{J/\psi Ks} = \lambda_{\phi Ks}$ $\begin{cases} S_{J/\psi Ks} = S_{\phi Ks} = \sin 2\beta \\ C_{J/\psi Ks} = C_{\phi Ks} = 0 \end{cases}$

Penguin:



W + New Physics?

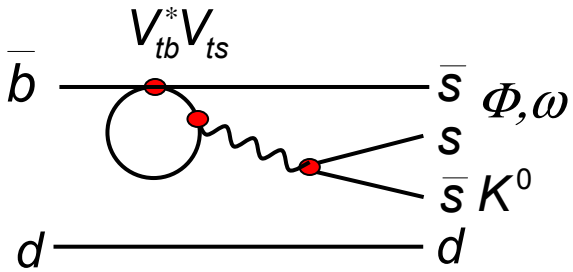
$$b \to s\bar{s}s$$

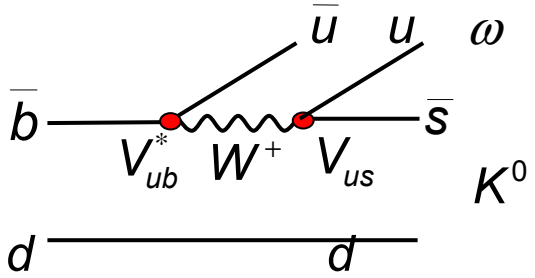
$$\lambda_{\phi Ks} = +\left(\frac{q}{p}\right)_B \left(\frac{V_{tb}V_{ts}^*}{V_{tb}^*V_{ts}}\right)\left(\frac{p}{q}\right)_K \approx -e^{-2i\beta}$$

In general case of New Physics:

$\lambda_{J/\psi Ks} \neq \lambda_{\phi Ks}$ $\begin{cases} S_{J/\psi Ks} \neq S_{\phi Ks} \\ C_{J/\psi Ks} \neq C_{\phi Ks} \end{cases}$

Not so easy …





Recent idea: POPOPO'
Gershon, Hazumi
hep-ph/0402097

Precise SM prediction

$\phi K_s, K_s K_s K_s$

PREFERRED BY THEORY

Unknown Tree Pollution

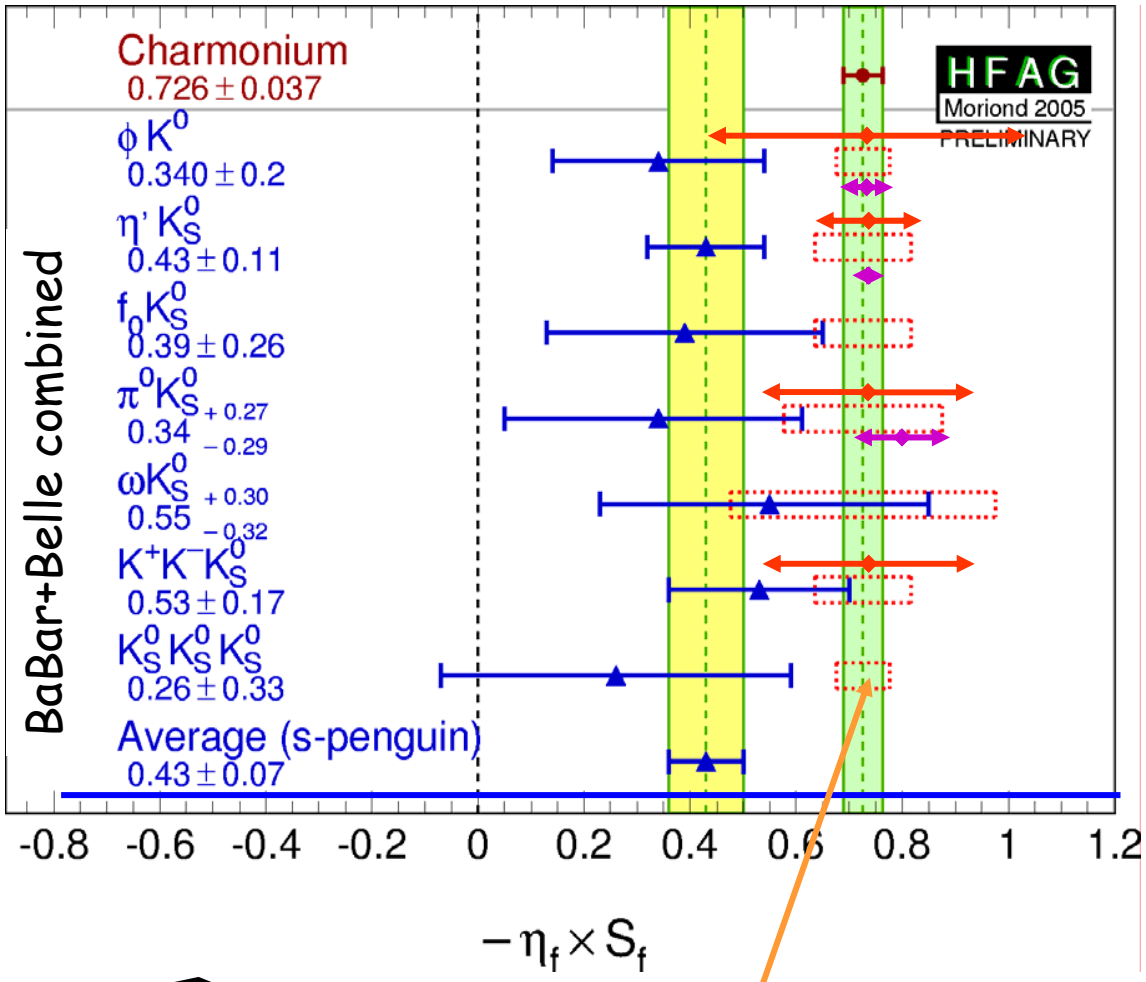
$f_0 K_s, \eta' K_s, K^+K^-K_s$

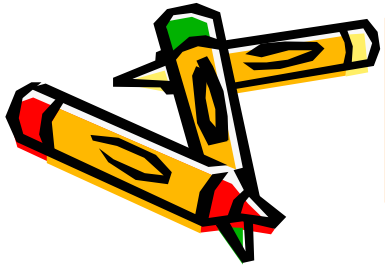
Large Tree Pollution

$\omega K_s, K_s \pi^0$

PREFERRED BY EXPERIMENT

b→s penguins and SM





naive upper limit based on CKM (λ^2) and loop/tree (= 0.2-0.3) suppression *[Kirkby,Nir, Phys. Lett. B592 (PDG review);Hoecker, hep-ex/0410069]*

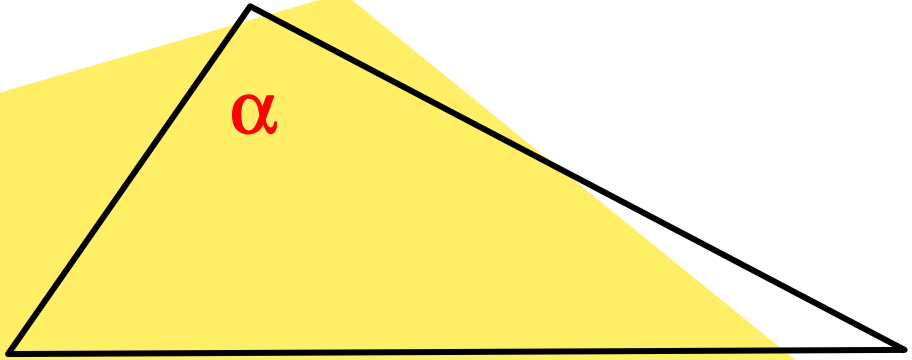
SM model predictions for $\sin 2\beta_{eff}$-$\sin 2\beta$ have been evaluated for some modes:

model independent upper limits based on SU(3) flavor symmetry and measured *b→ dqq* B.R. *[Grossman et al,Phys Rev D58; Grossman et al., Phys Rev D68; Gronau, Rosner, Phys.Lett. B564; Gronau et al., Phys.Lett.B579; Gronau, at al. Phys.Lett.B596; Chiang at al., Phys.Rev.D70]*

estimate of deviations based on QCD motivated specific models *[Beneke at al., NPB591; Buras et al. NPB697; Ciuchini at al.,hep-ph/0407073]*

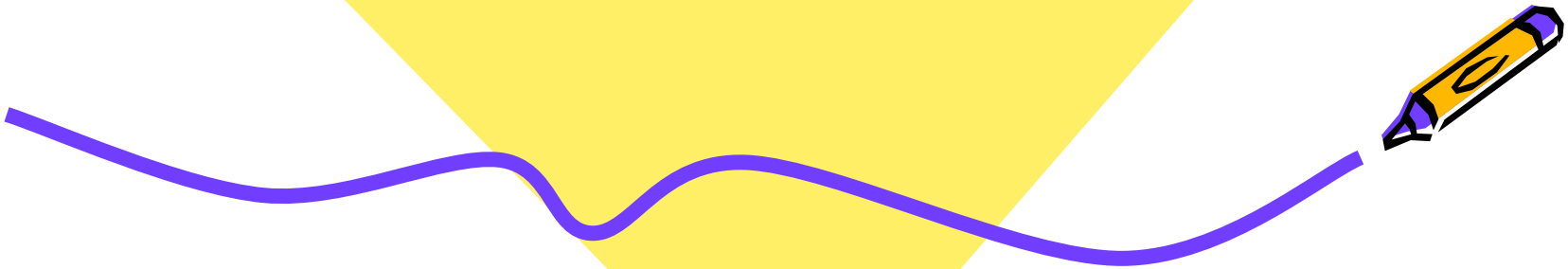
Deviation from SM:
No theory error: 3.7 σ
Naïve theory errors: 2.9 σ

WHAT IS BEHIND THE CORNER?
NEW PHYSICS OR NEW CALCULATIONS?

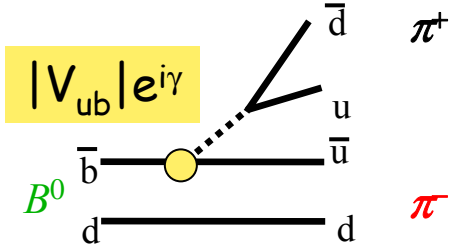


Measurements of α

Better than ever dreamt of



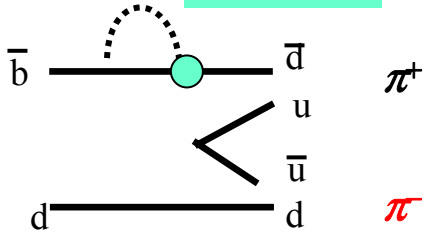
Measuring α: $B \to \pi^+\pi^-$



Tree is promising because

$$\frac{T}{\bar{T}} = \frac{V_{ub}^*}{V_{ub}} = e^{-2i\gamma}$$

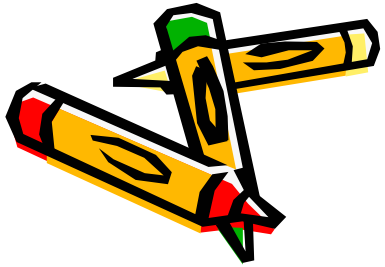
… but penguin has a different phase



$$\lambda = e^{-2i\beta}\frac{\bar{T}+\bar{P}}{T+P} = e^{-2i\alpha}\frac{1+\frac{\bar{P}}{\bar{T}}}{1+\frac{P}{T}} = re^{-i(2\alpha+K_{\pi\pi})}$$

Is P large?

YES (large Kπ Branching Fraction)



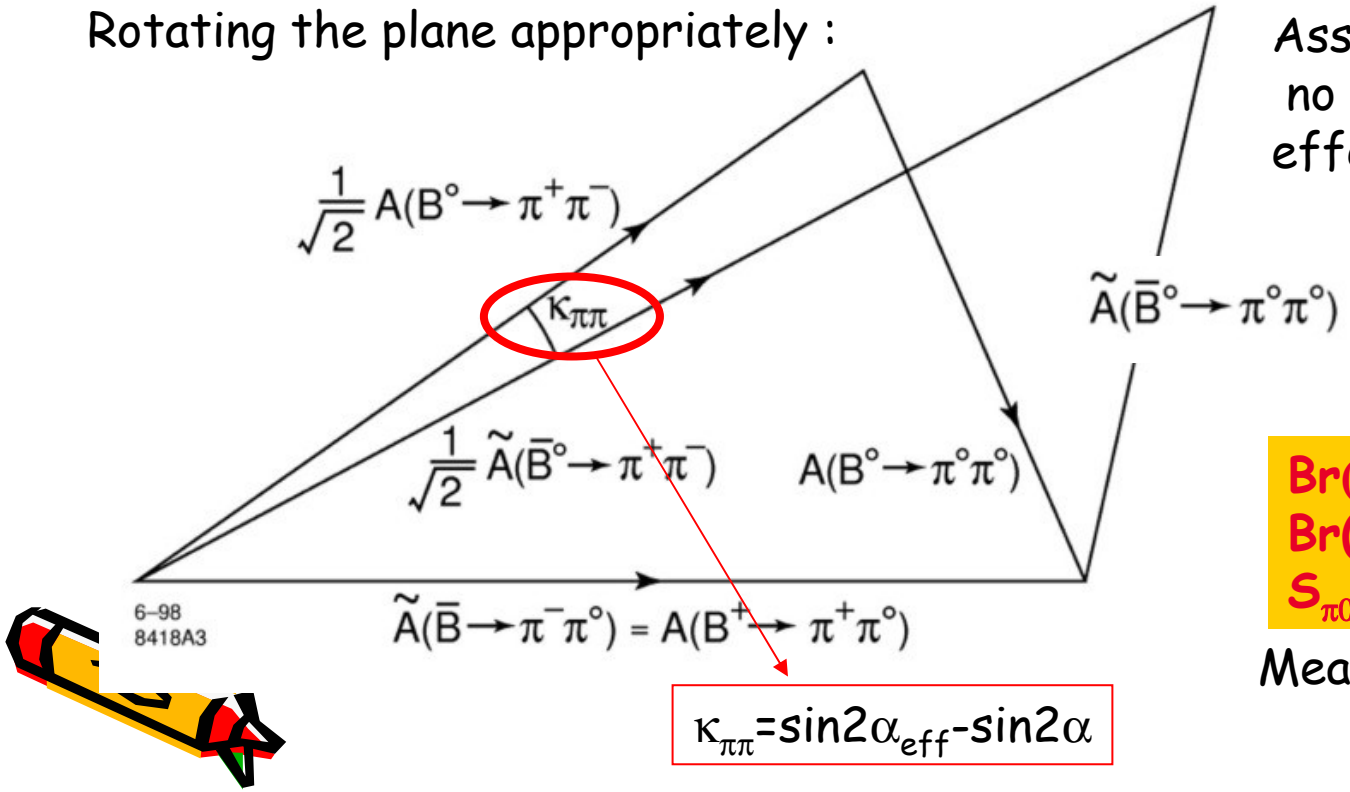
Isospin analysis

Two relationships in the complex plane :

$$\frac{1}{\sqrt{2}}A(B^0 \to \pi^+\pi^-) + A(B^0 \to \pi^0\pi^0) = A(B^+ \to \pi^+\pi^0)$$

$$\frac{1}{\sqrt{2}}A(\bar{B}^0 \to \pi^+\pi^-) + A(\bar{B}^0 \to \pi^0\pi^0) = A(B^- \to \pi^-\pi^0)$$

Rotating the plane appropriately :



$\kappa_{\pi\pi}=\sin 2\alpha_{eff}-\sin 2\alpha$

Assumption:
no isospin breaking effects:

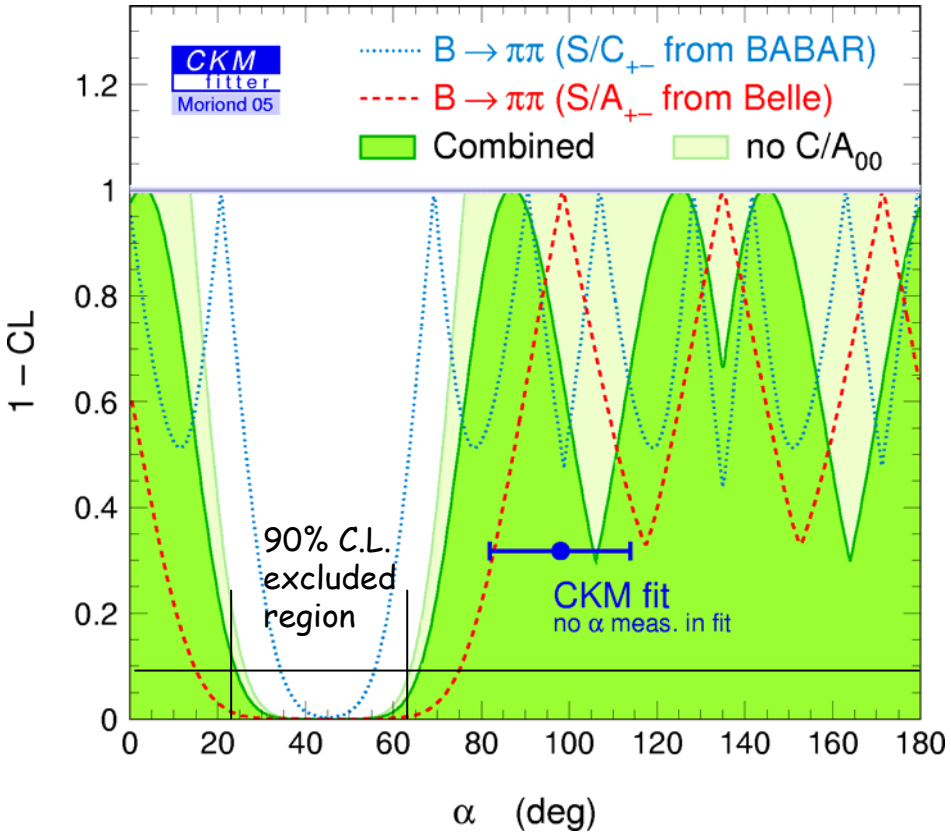
- EW penguins estimated to have effects at ~2°
- π^0–η (ρ–ω) mixing?

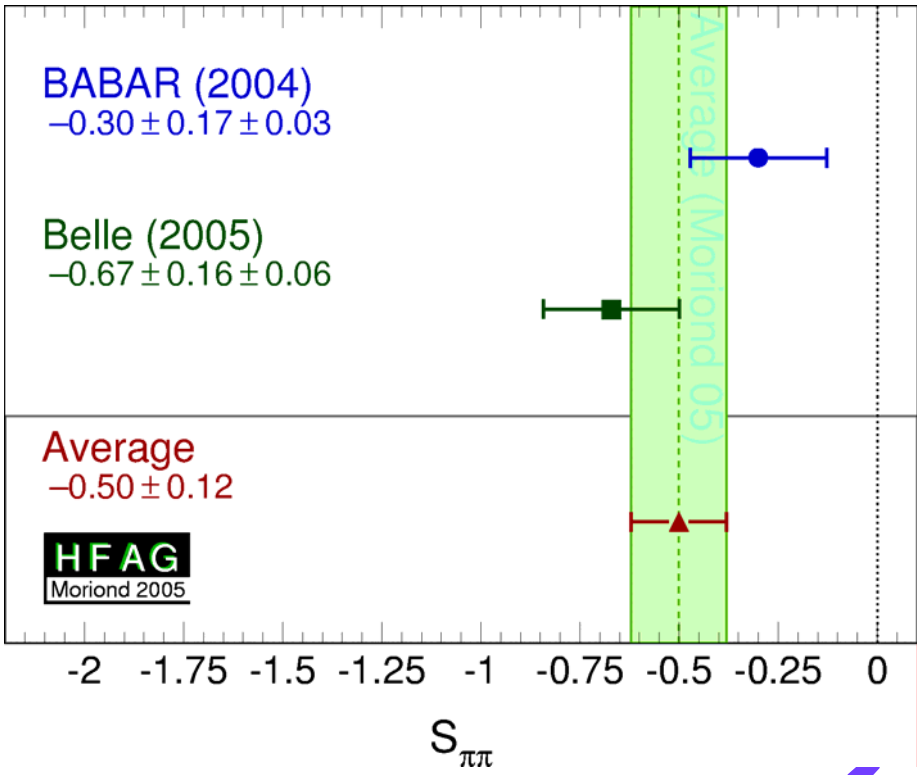
$Br(B^0 \to \pi^0\bar{\pi}^0)$, $Br(B^0 \to \pi^0\pi^0)$ and $S_{\pi^0\pi^0}$ critical

Measure them or prove them small!

sin2α from ππ

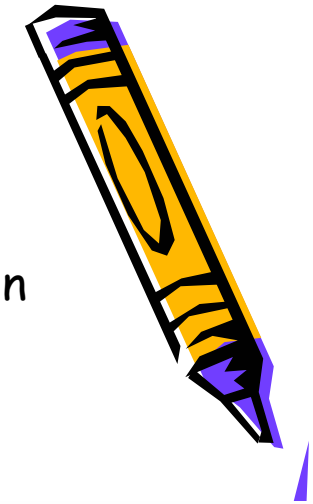
Good News : BaBar and Belle agree better





Bad News : Br($\pi^0\pi^0$) so large that $\sigma(\alpha)\sim 35^\circ$ for a while

α from $B \to \pi\pi\pi^0$

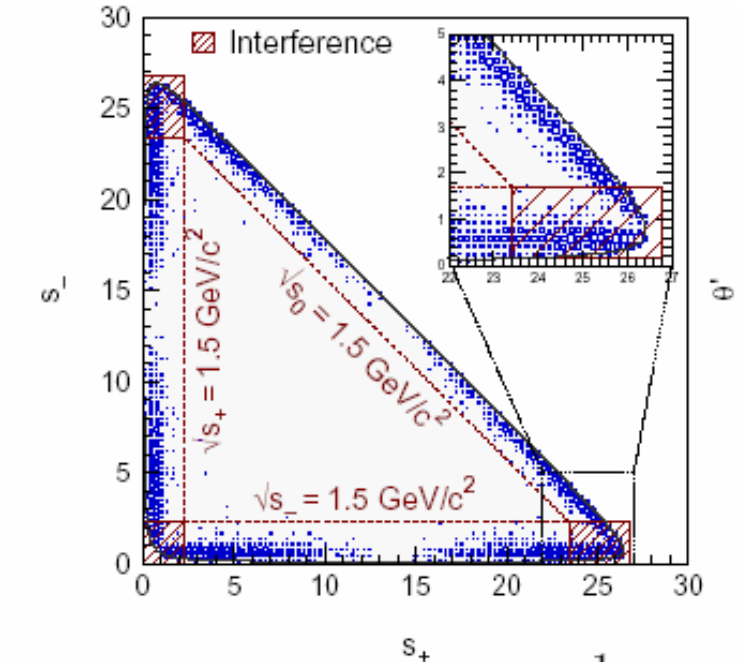


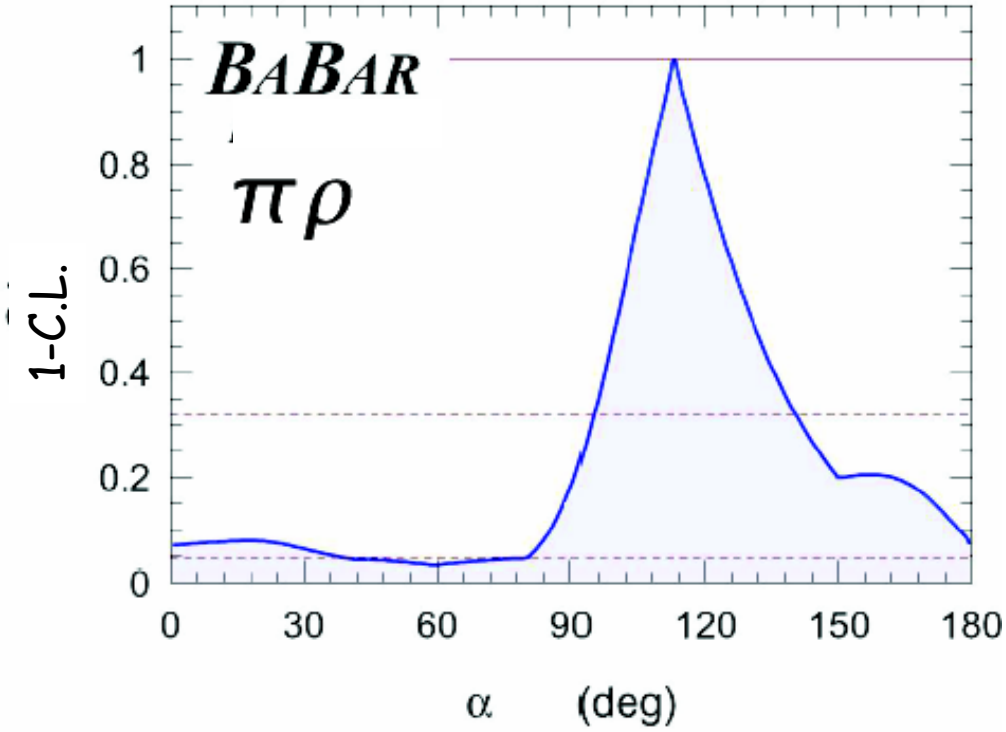
Bad News: same diagrams as $B \to \pi\pi$, measure α with penguin pollution

Good News: strong phase different in each point of the Dalitz plot allows extraction of penguin and therefore α

Assumptions:

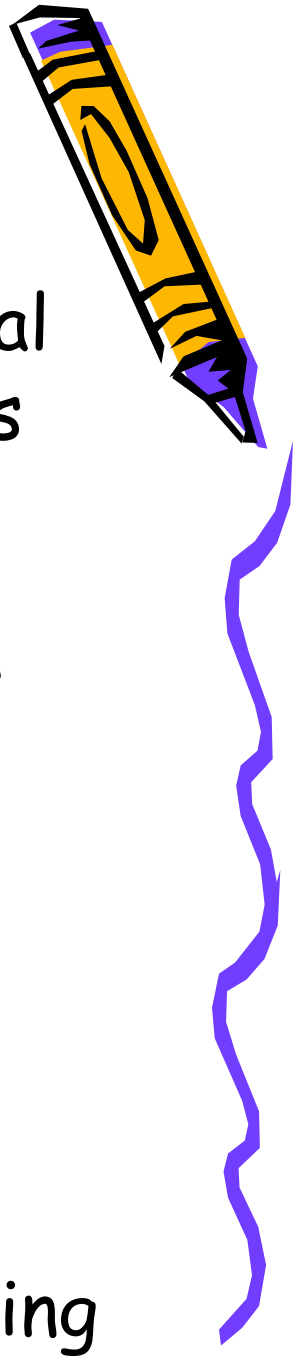
- only $\rho(770,1450,1700)\pi$ states considered
- same P/T for each wave





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

B→ρρ : measuring α



Same diagrams as ππ BUT 4-body (ρ→ππ) final states with two vector intermediate states

- 4-body amplitude analysis
  - replaced by quasi-two-body approach
    - Interferences and higher resonances studied in detail and found to be negligible
- Angular and time dependent analysis

$$f_L(\rho^+\rho^-) = 0.978 \pm 0.014^{+0.020}_{-0.028}$$

- Isospin analysis to get α
  - Neglect I=1 amplitude and isospin breaking

ρρ results

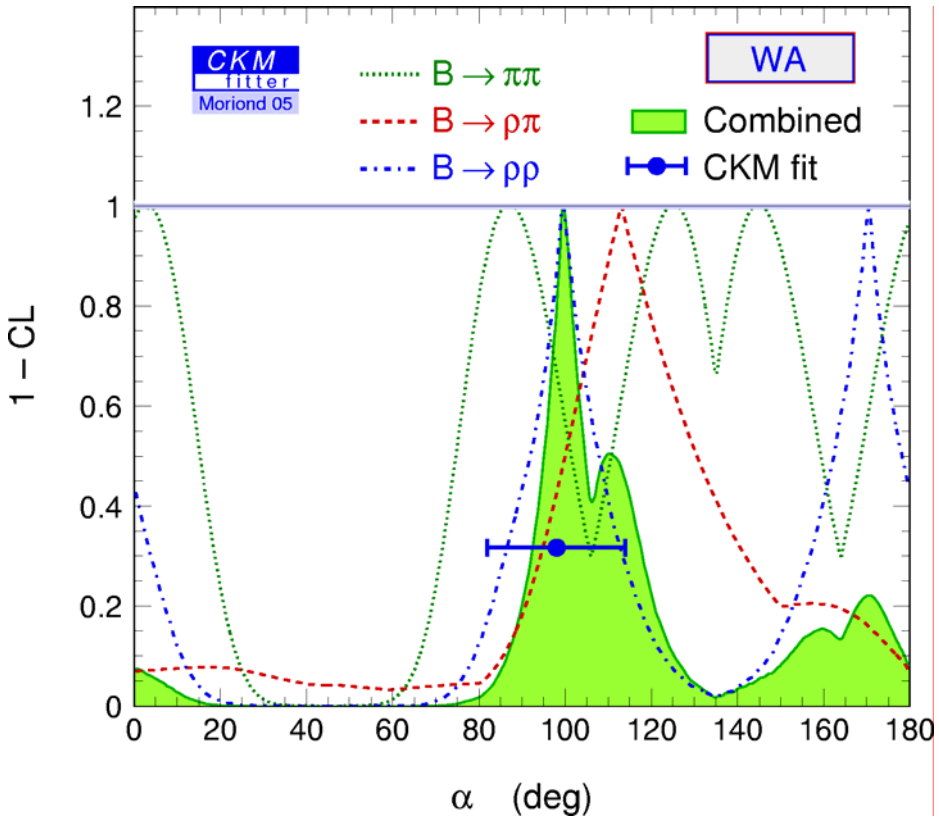
TD CP analysis

$$S_{Long} = -0.33 \pm 0.24^{+0.08}_{-0.14}$$

$$C_{Long} = -0.03 \pm 0.18 \pm 0.09$$

Br($\rho^+\rho^-$)	(30±6) 10-6
Br($\rho^+\rho^0$)	(26±6) 10-6
Br($\rho^0\rho^0$)	<1.1 10-6

Isospin analysis

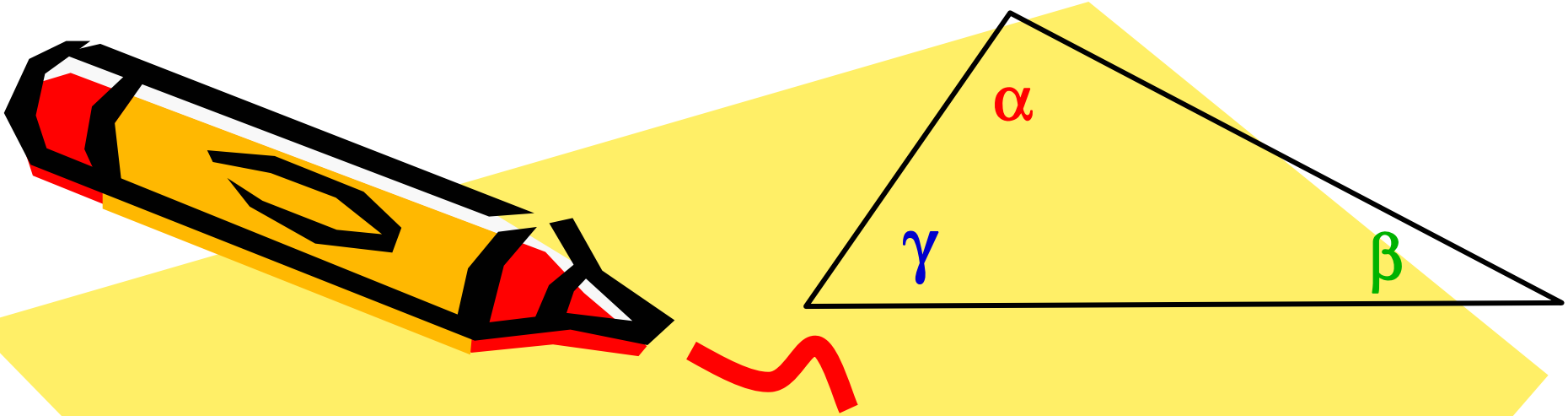


$\alpha = (100 \pm 13)°$

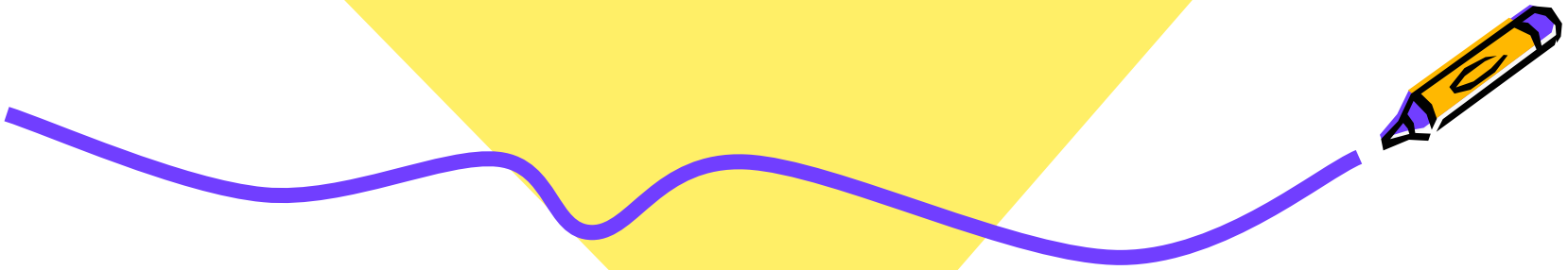
ρρ only

$\alpha = (101^{+16}_{-9})°$

All measurements



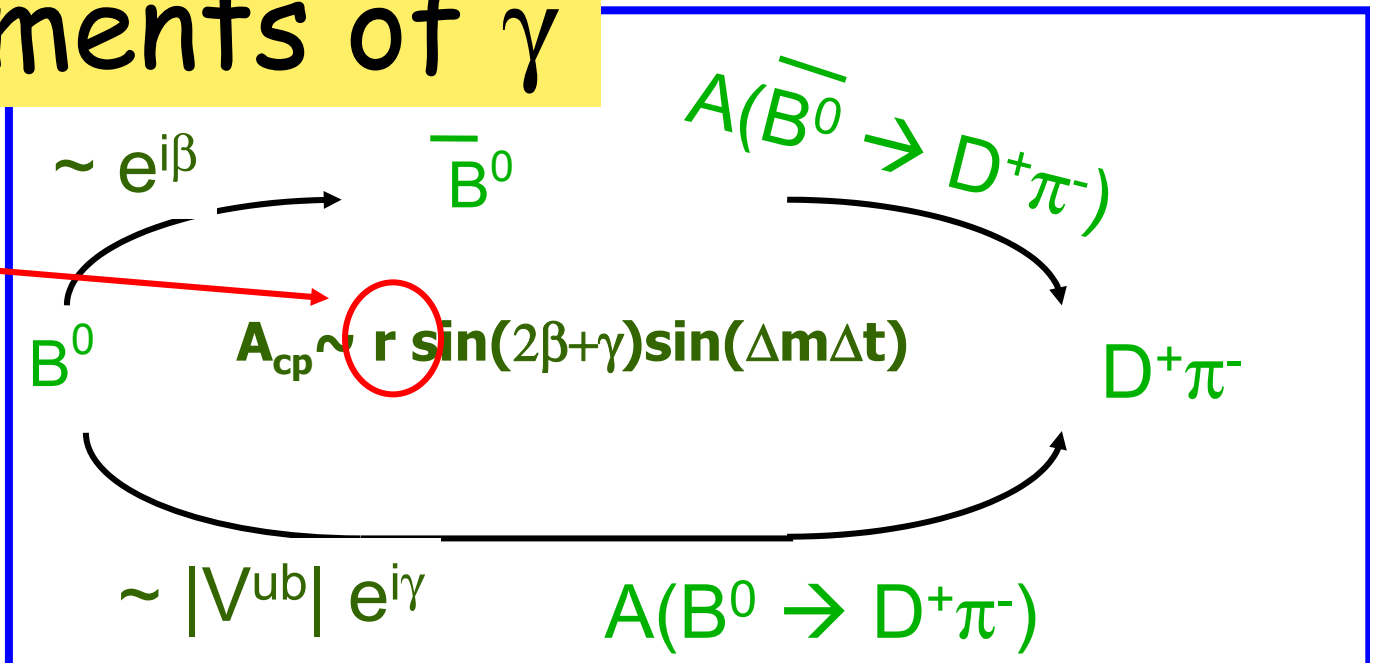
Measurements of γ



Measurements of γ

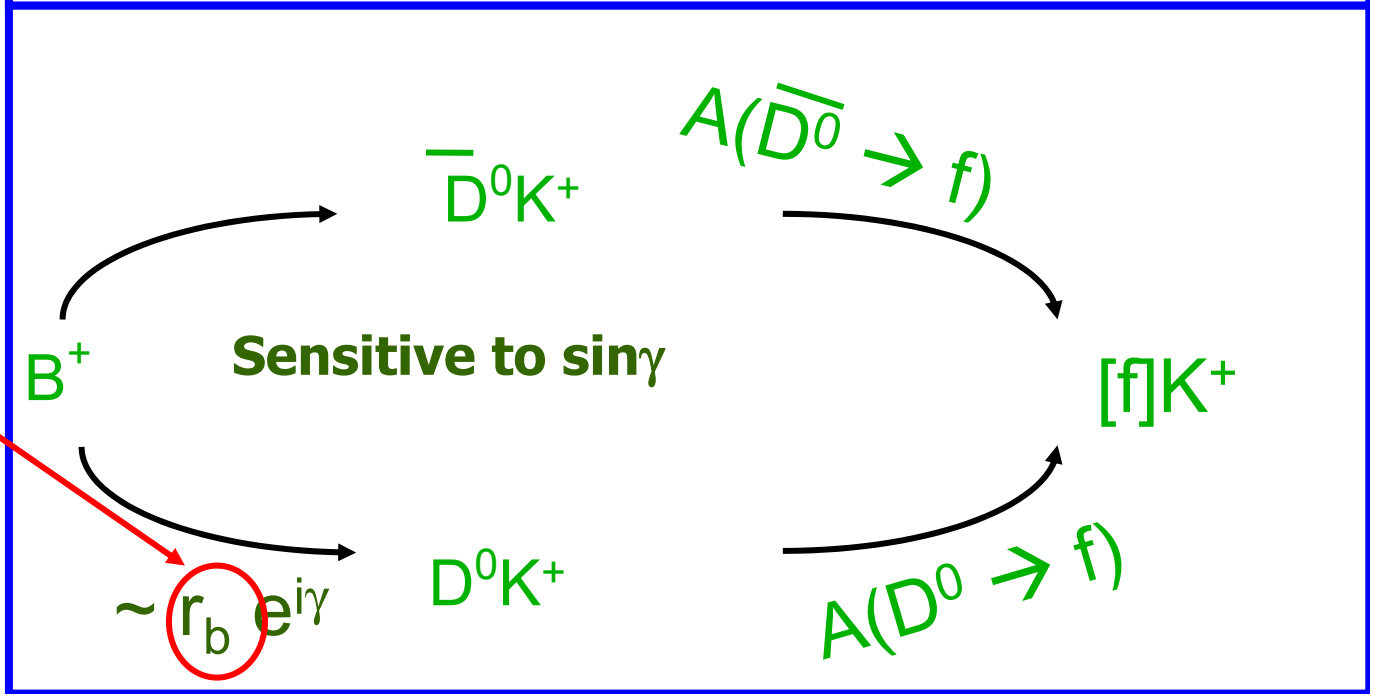
Critical parameter

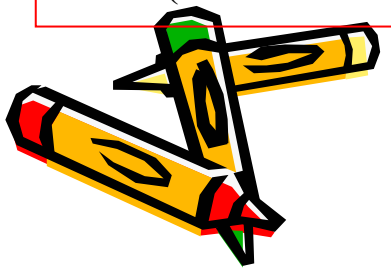
$$r = \frac{A(B^0 \to D^{(*)+}\pi^-)}{A(B^0 \to D^{(*)-}\pi^+)} \sim 0.02$$



Critical parameter

$$r_b = \frac{A(B^+ \to D^0 K^+)}{A(B^+ \to \overline{D^0} K^+)} \sim 0.1$$

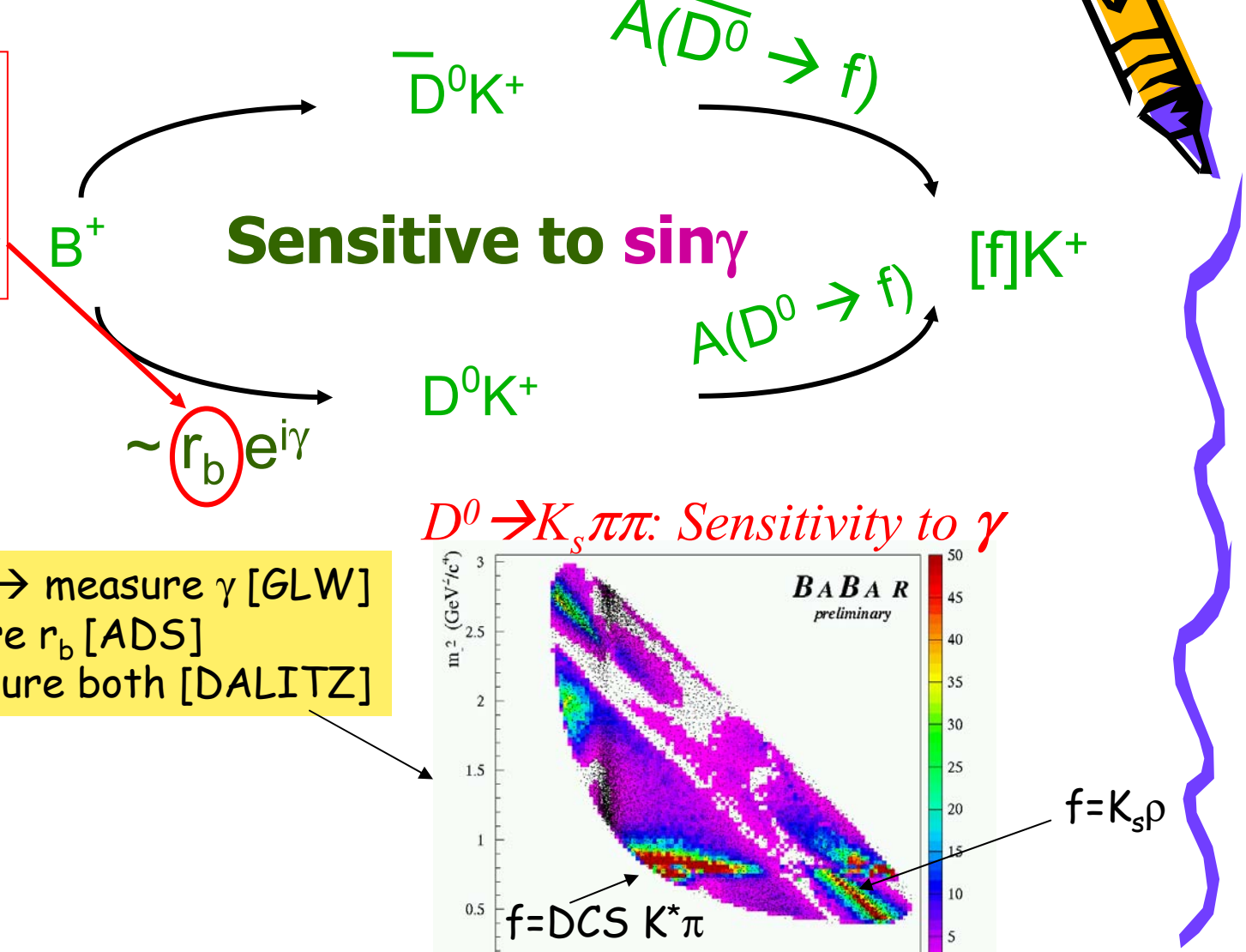




D^0K : the idea

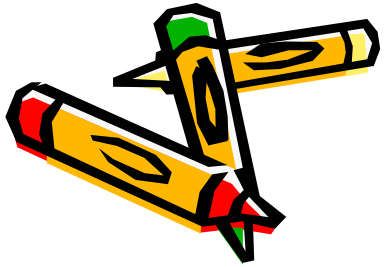
Critical parameter

$$r_b = \frac{A(B^+ \to D^0 K^+)}{A(B^+ \to \overline{D^0} K^+)} \sim 0.1$$

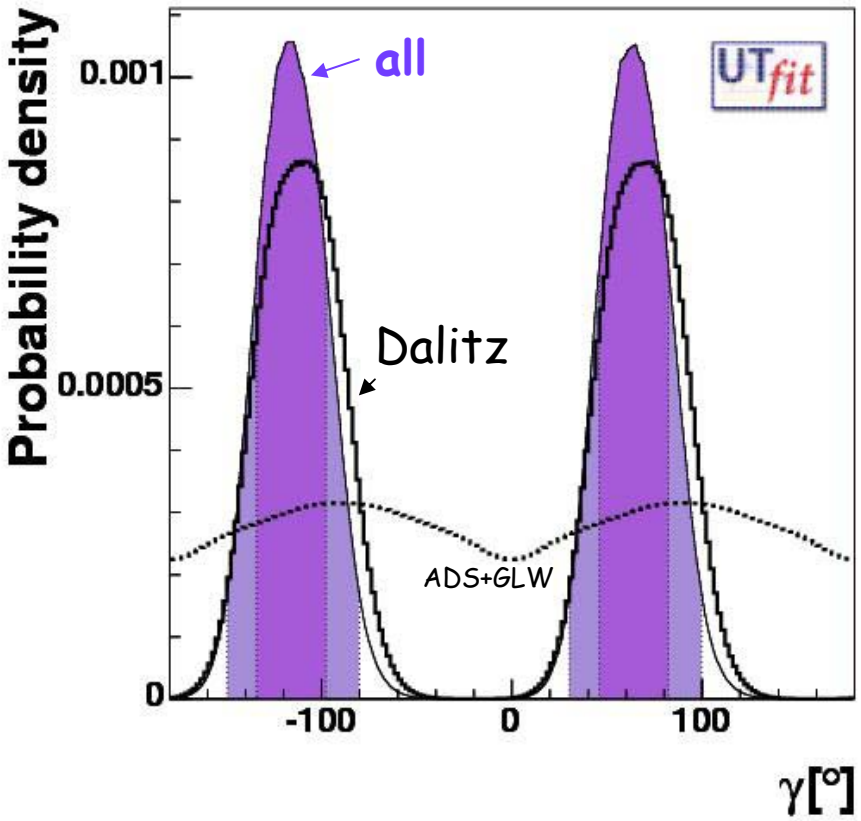


f= CP eigenstate → measure γ [GLW]
f= DCS → measure r_b [ADS]
f=3-body → measure both [DALITZ]

$D^0 \to K_s\pi\pi$: *Sensitivity to* γ



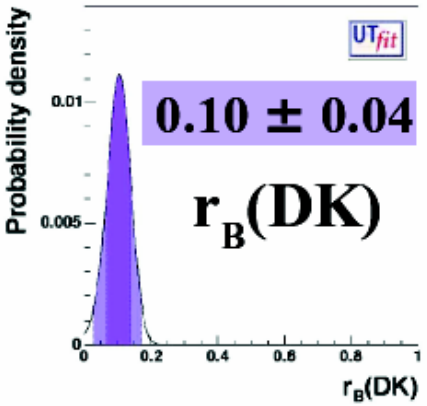
D^0 K : results

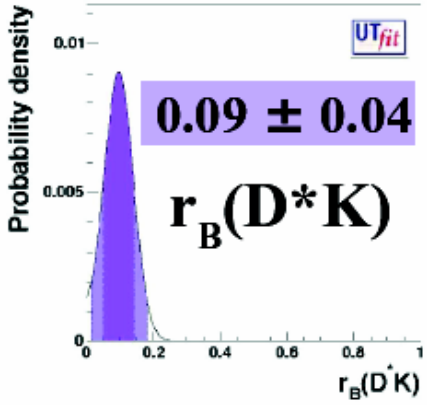


BaBar+Belle

$$\gamma = (64 \pm 18)^\circ$$

$D^0 \to K_s\pi\pi$ is the most constraining but how will Dalitz error scale?

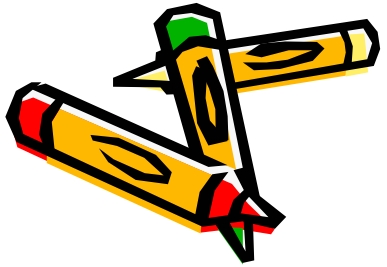




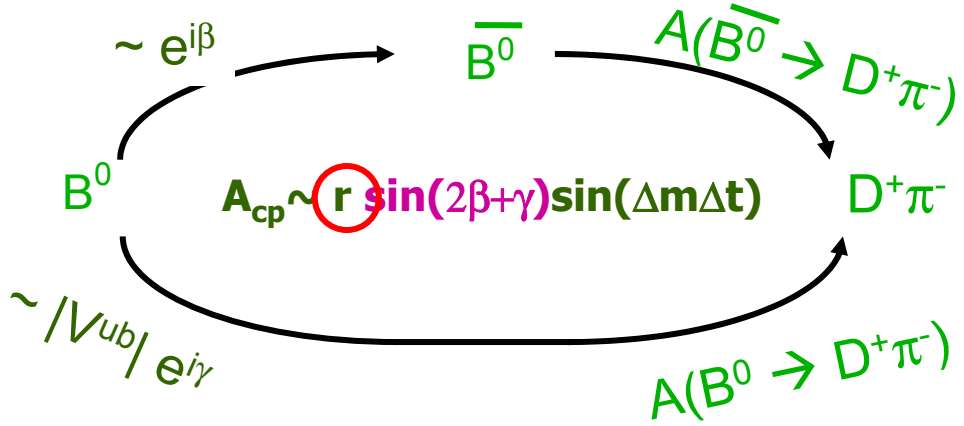
Measured values of r much smaller than predicted

Further developments of Dalitz analysis

- Extend to more modes
  - $\pi\pi\pi^0$ (Cabibbo suppressed), $K_s\pi\pi\pi^0$
- Apply a method independent of the Dalitz structure (irreducible error)
  - Interactions with CLEO-c (D^0 CP sample) starting
- Asymptotically seems to be the most promising method for long term



Time-dep analysis for self-tagging modes



Critical parameter

$$r = \frac{A(B^0 \to D^{(*)+}\pi^-)}{A(B^0 \to D^{(*)-}\pi^+)} \sim 0.02$$

4 amplitudes + dependence on tag-side CP violation

$$\Gamma\left(B \to D^{(*)}\pi\right) \propto 1 + \xi_m \cos(\Delta m\,\Delta t) - \left[\xi_t\, a + \xi_m c + \xi_t \xi_m b\right]\sin(\Delta m \Delta t)$$

ξ_m = 1(-1) for events tagged as unmixed (mixed)

ξ_t = 1(-1) for B_{tag} identified as $B^0(\bar{B}^0)$

r', δ' are the ratio and phase difference between the b→u and b→c amplitudes in the B_{tag} decay. r'= 0 in lepton tags.

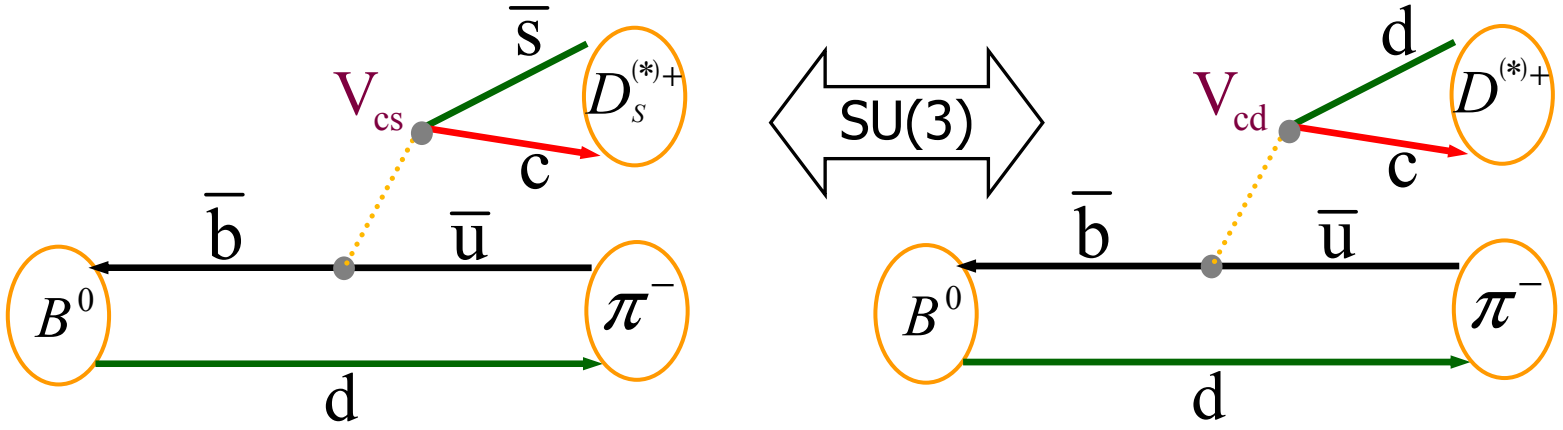
$a = 2r \sin(2\beta+\gamma) \cos\delta$

$b = 2r' \sin(2\beta+\gamma) \cos\delta'$

$c = 2 \cos(2\beta+\gamma)\,(r \sin\delta - r' \sin\delta')$

Neglecting $O(r^2, r'^2)$ terms

Estimation of r

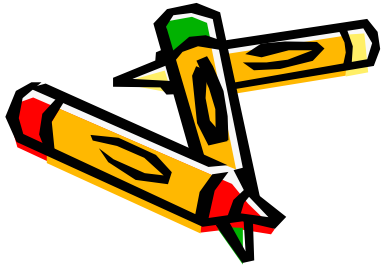


First attempt : utilize $B \to D_s \pi$ which is the SU(3) conjugate

$$r_{(*)} \approx \sqrt{\frac{Br(B^0 \to D_s^{(*)+}\pi^-)}{Br(B^0 \to D^{(*)-}\pi^+)}} \left|\frac{V_{cd}}{V_{cs}}\right| \frac{f_{D^{(*)}}}{f_{D_S^{(*)}}}$$

Note: $D\pi,\rho$ measurements already presented

$r(D\pi) = 0.019 \pm 0.004$ $\quad r(D^*\pi) = 0.015^{+0.004}_{-0.006}$ $\quad r(D\rho) = 0.003 \pm 0.006$



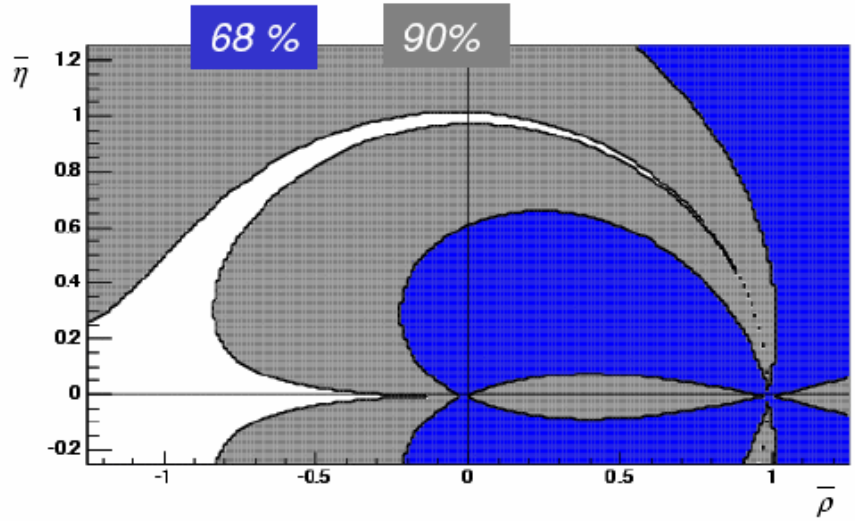
UNDER DISCUSSION

1) SU(3) symmetry may not hold
2) Annihilations/W-exchange diagrams are neglected

sin2β+γ results and perspectives

$$2\beta+\gamma=(88^{+40}_{-39})^{o}$$

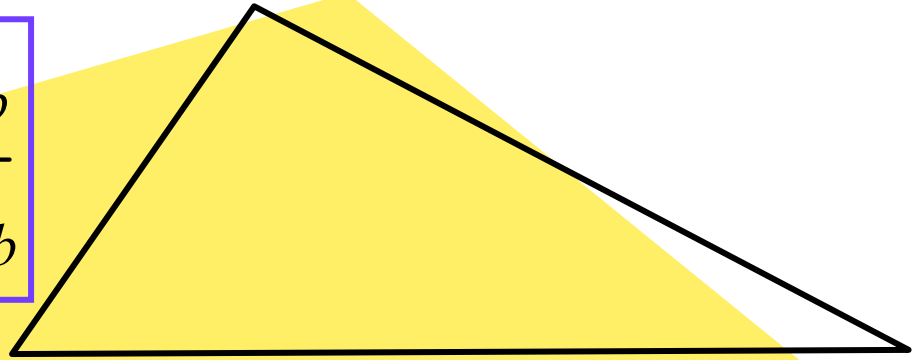
BaBar+Belle



Measurement of r casts a shadow to this measurement

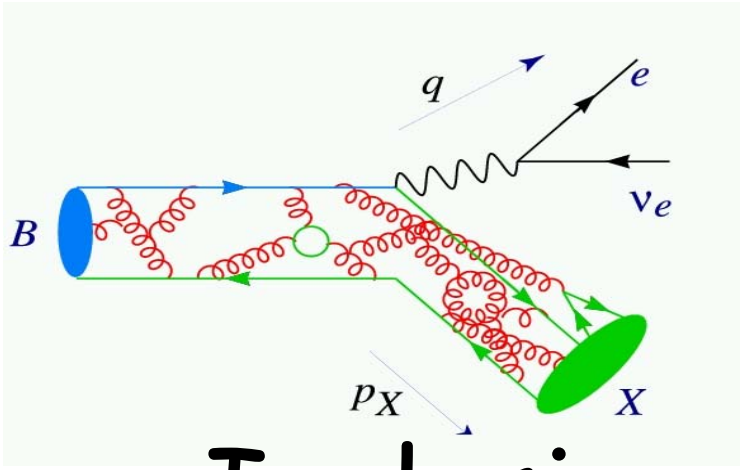
- looking for model independent solutions
  - side measurements to estimate annihilations/ SU(3) breaking
- D^0K^0 more promising mode (r~0.4 can be measured, although OPE based studies show r=0.26±0.16)
  http://ckm2005.ucsd.edu/WG/WG5/thu2/Sordini-WG5-S3.pdf

$$\frac{V_{ub}}{V_{cb}}$$



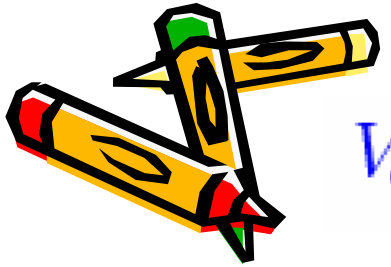
Measurements of V_{cb} & V_{ub}

Including b→sγ studies
and search for B→τν

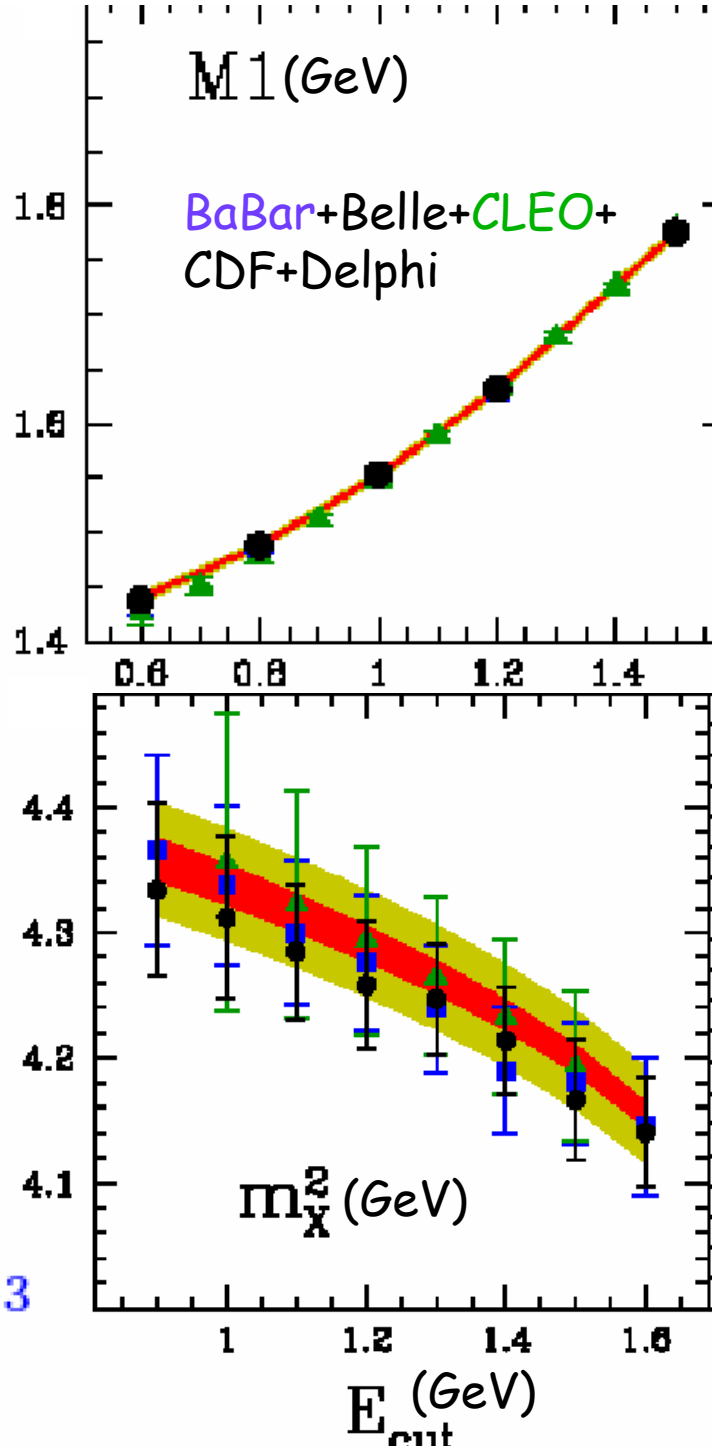


Inclusive V_{cb}

- Moments of m_X and E_l give sensitivity to b,c quark masses, V_{cb} and other theory parameters
- BaBar published Vcb with a 1.8% error ~1 year ago
- Belle's data now available (prelim.)

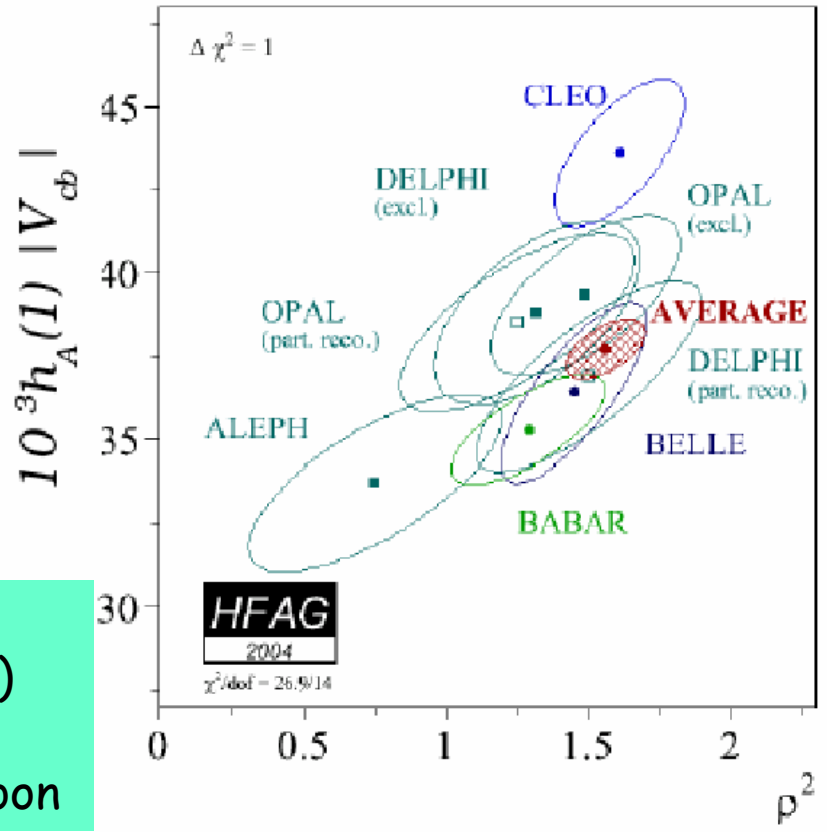


$$V_{cb} = (4.144 \pm 0.043) \cdot 10^{-3}$$



Exclusive Vcb

Measure B→D$^{(*)}$lν BF in bins of the speed of D meson in B frame

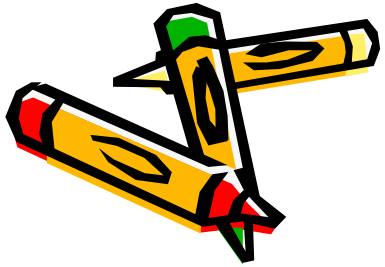


B→D*lν:

- low internal consistency (χ^2/DOF=27/14)
- correlated errors bound to go down
  - Updated FF measurements coming soon

$$V_{cb} = (41.4 \pm 1.0 \pm 1.8)10^{-3}$$

$$= (39.1 \pm 3.6 \pm 1.3)10^{-3}$$

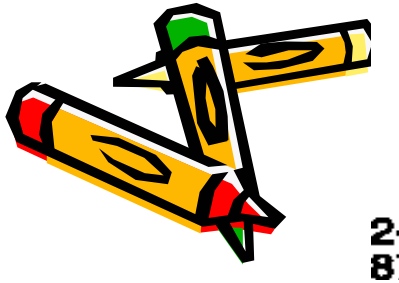


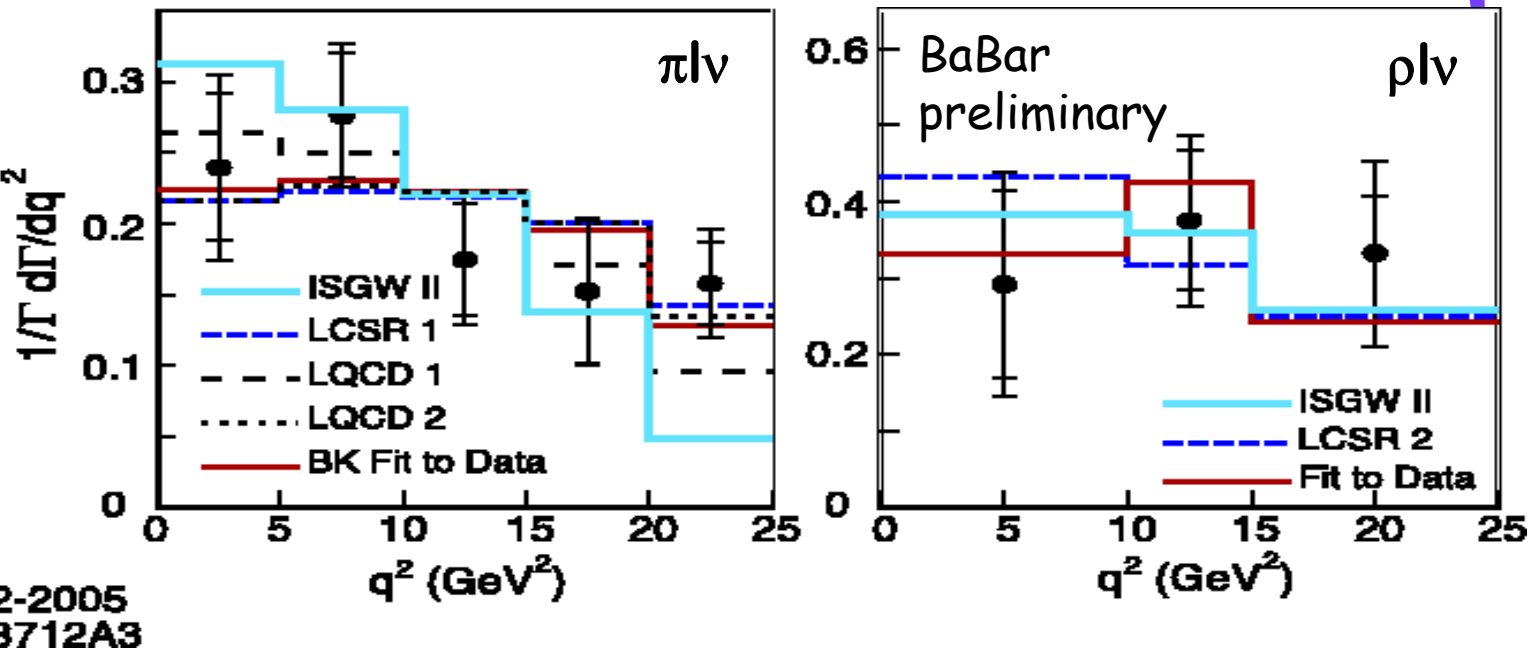
B→Dlν:

- large statistical errors
- tagged samples?

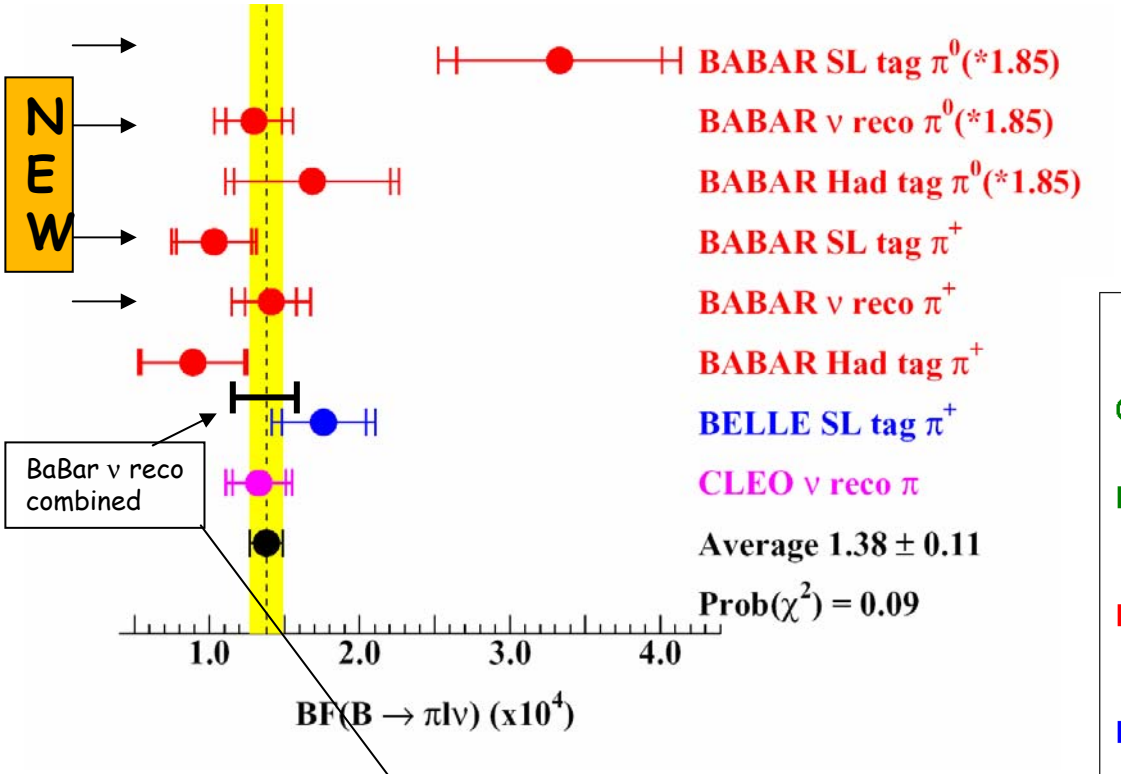
Exclusive $B \to X_u l \nu$ decays

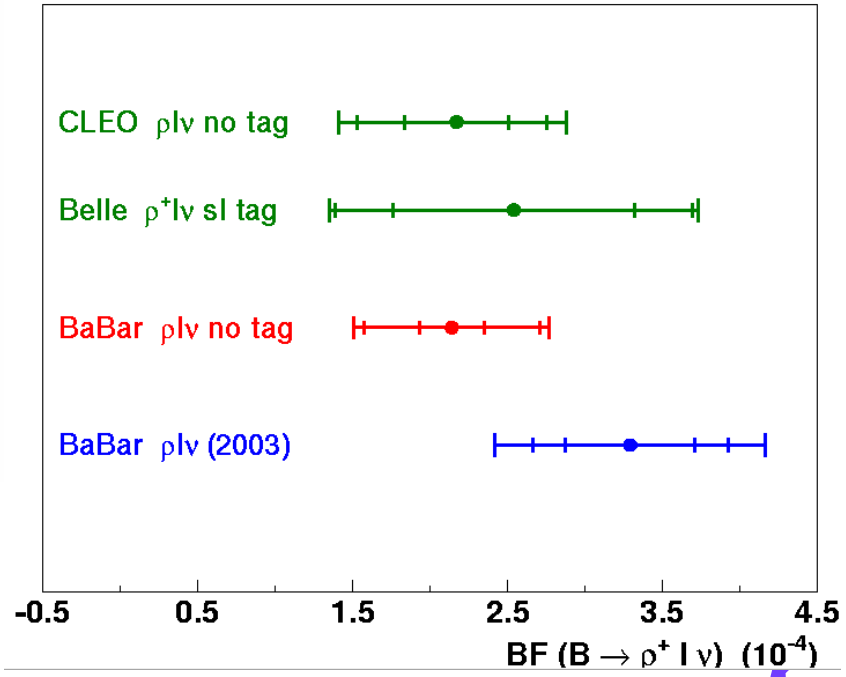
- Reconstruct $X_u = \pi, \rho, \ldots$ and estimate neutrino momentum with missing momentum. Several techniques:
  - Untagged : no requests on recoil ➔ high efficiency, large background
  - Tagged measurements: hadronic or semileptonic ➔ better *S/B*, lower statistics
- New theoretical progress: measure BF in $q^2 = m_{l\nu}$ bins ➔ sensitive to Form Factors





Exclusive V_{ub} Results





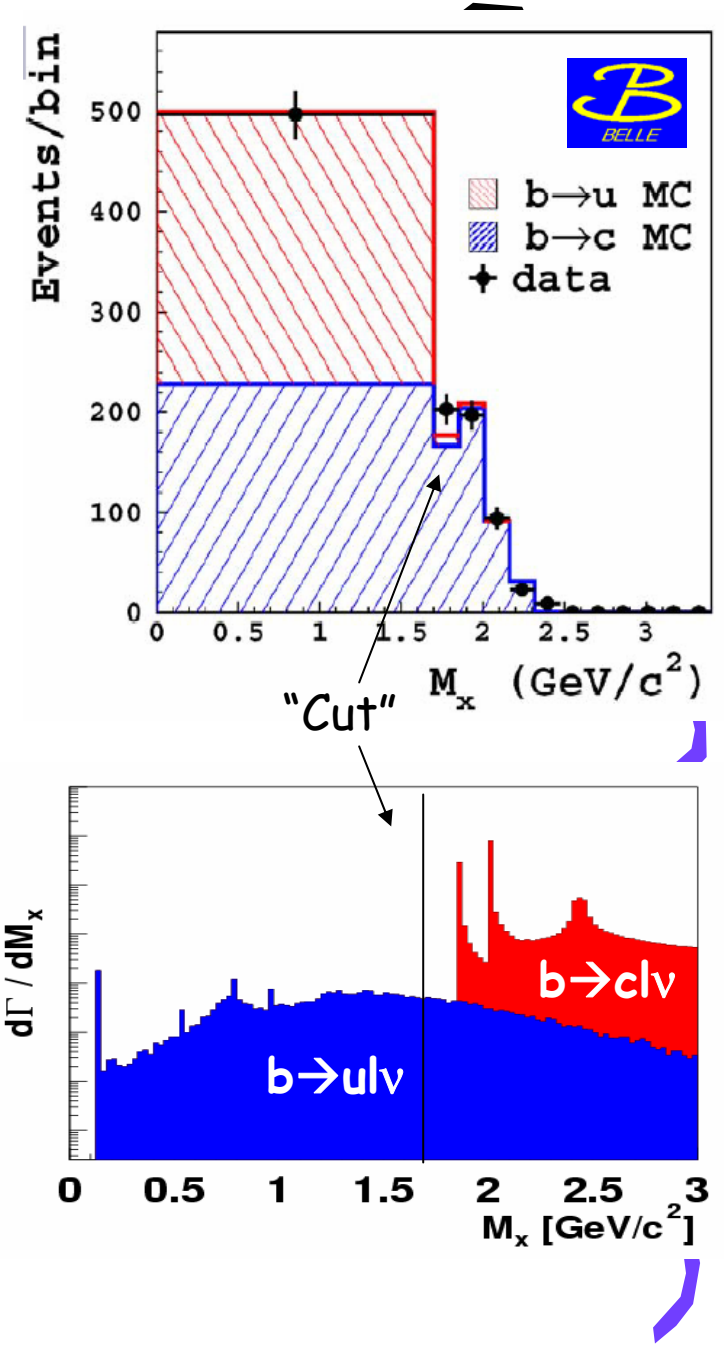
$V_{ub}=3.82\pm0.14_{st}\pm0.24_{sys}\pm0.11_{th}\pm0.57_{FF}$

17% error

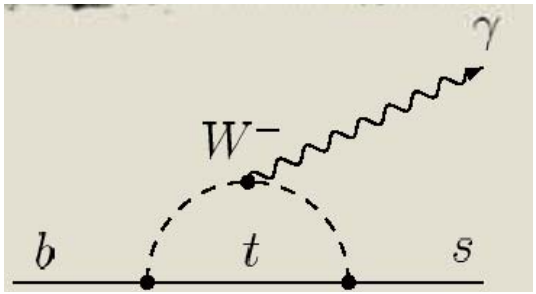
BaBar πlν only: combination not yet available

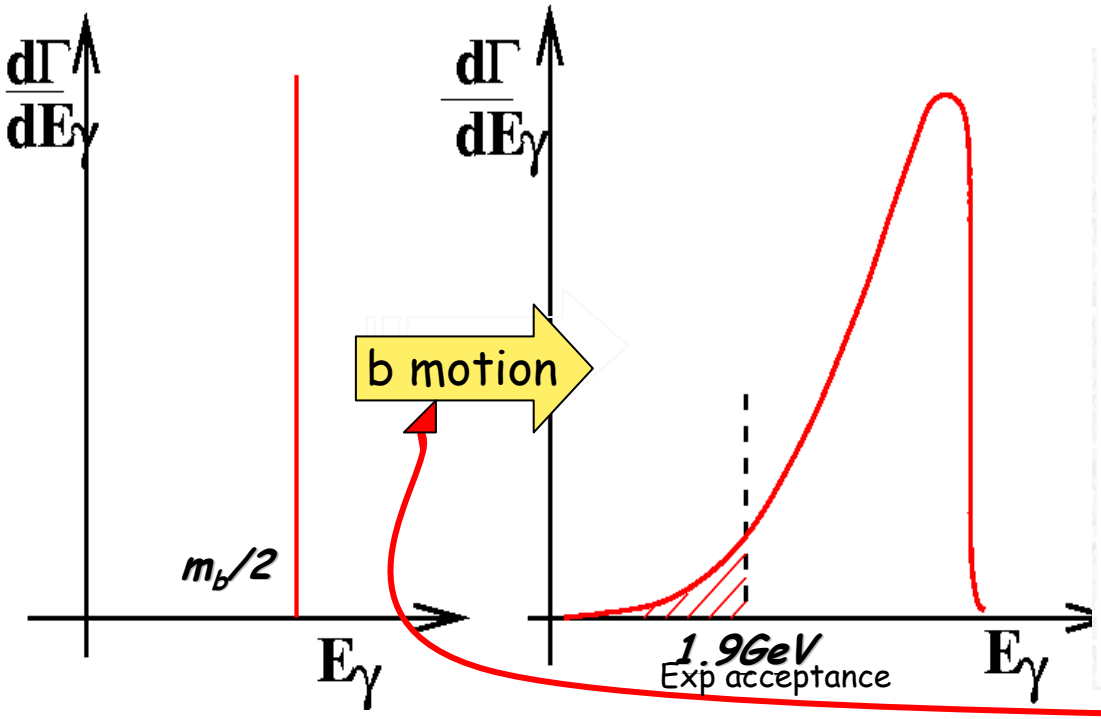
Inclusive b→ulν

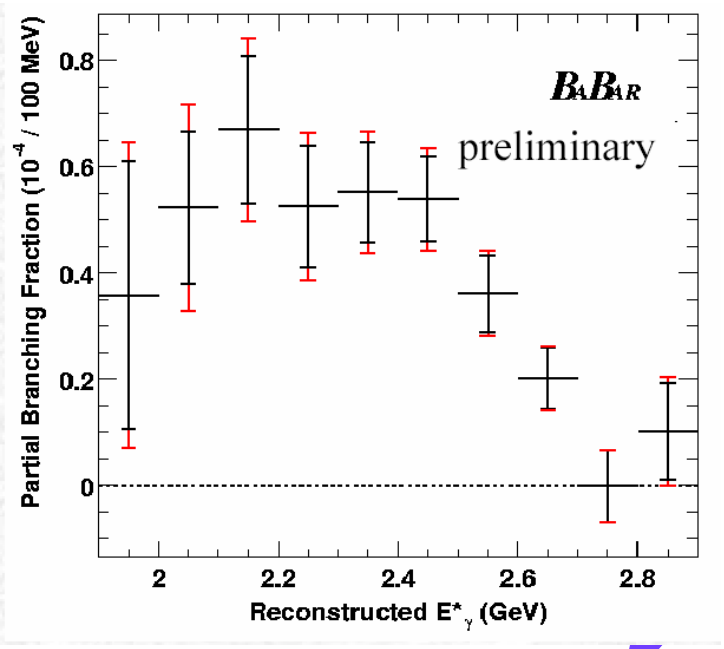
- BR(b→ulν) ⇔ Vub is an 'easy' conversion (~5% error)
- Background rejection requires cuts. Extrapolation to full rate was the real challenge so far. We need the differential rate (in terms of P_X,P_W,P_l) as input to MC simulation
- Theoretical errors can be reduced
  - by measuring as many theory parameters as possible in samples as close as possible to b→ulν.
  - By reducing the dependence of the analysis on the theory



Role b→s γ

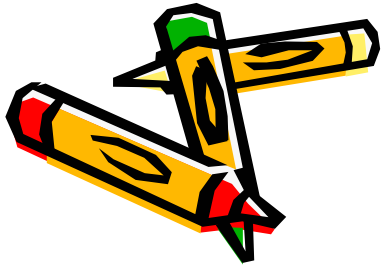




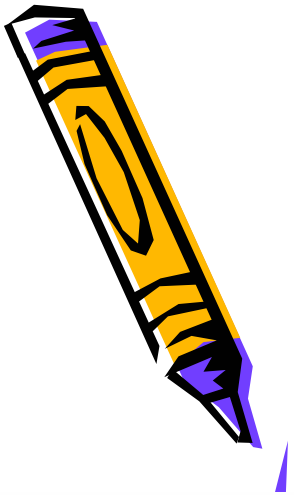


Largest uncertainty on V_{ub} comes from b motion inside B meson ➔ b→sγ allows to measure it:

- Look inclusively for a high energy monochromatic photon and measure the energy in the B meson rest frame

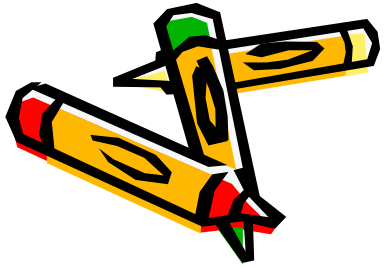


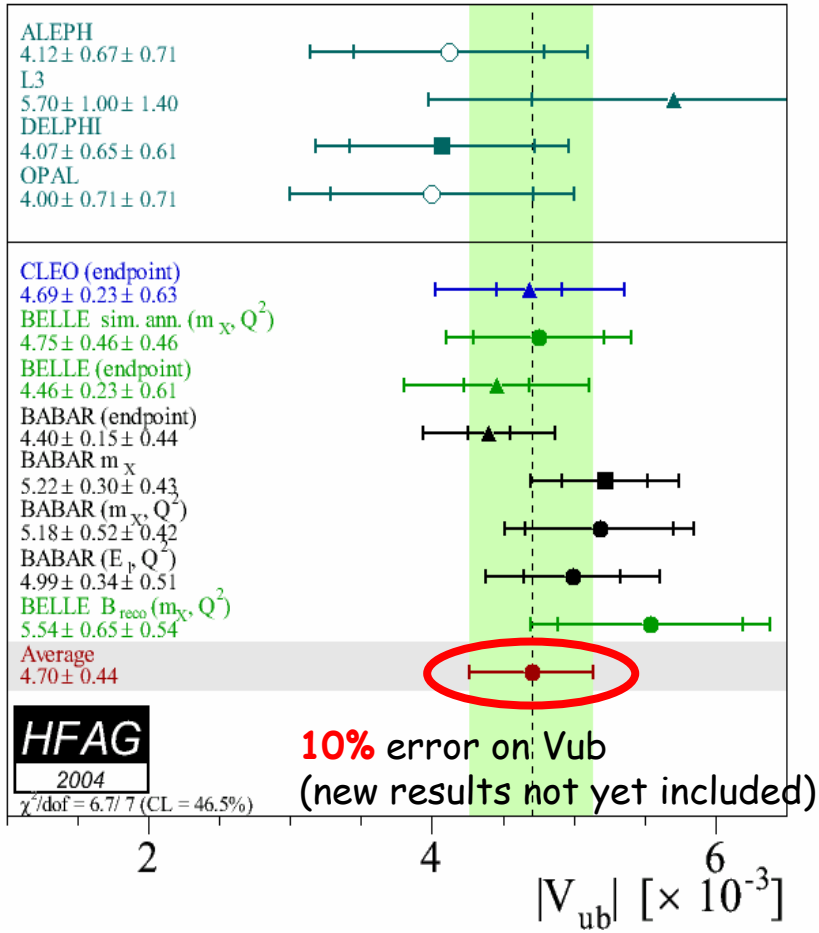
VERY recent developments



- Several new b→ulν results with new discriminating variables
  - BaBar: m_X-Q^2,Q^2-E_l,E_l,
  - Belle: m_X-Q^2,P^+,E_l
- Two new b→sγ photon energy spectra
  - fully inclusive
  - Sum of exclusive final states

- Lot's of ongoing developments/discussion
- Weak annihilations under study





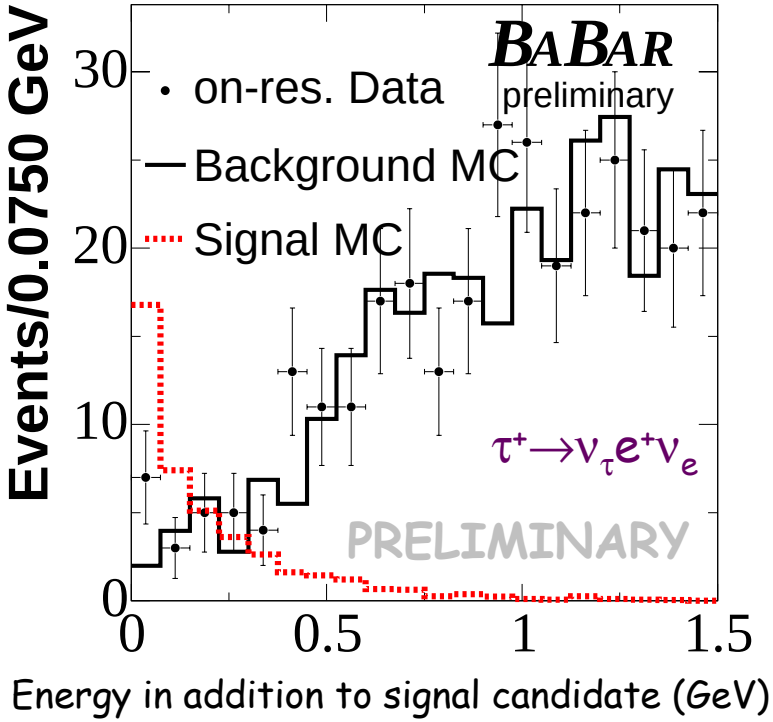
B → τν

Purely leptonic B decay. Standard Model branching ratio

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

Provide direct measurement of B meson decay constant

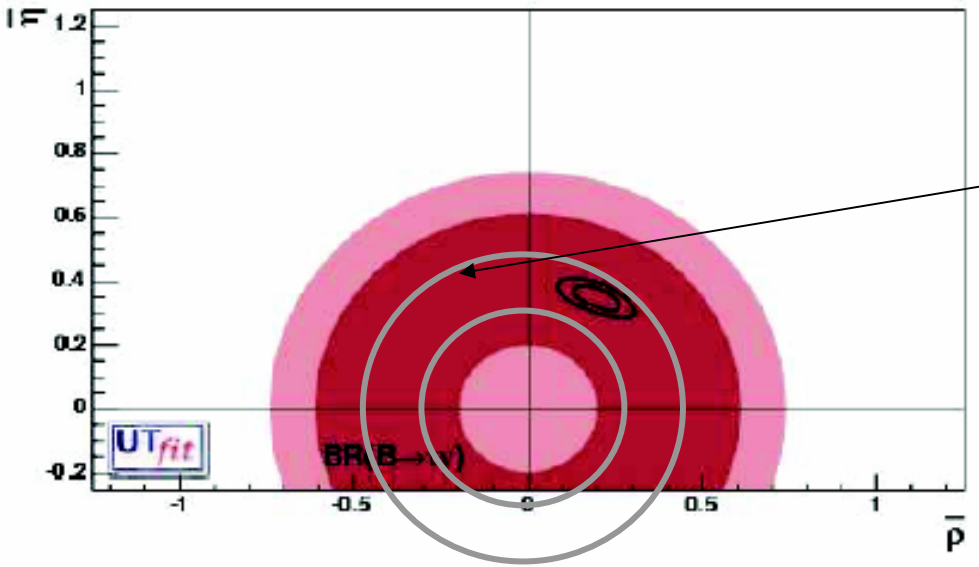
f_B = 0.196 ± 0.032 GeV (PDG 2004, Lattice QCD)



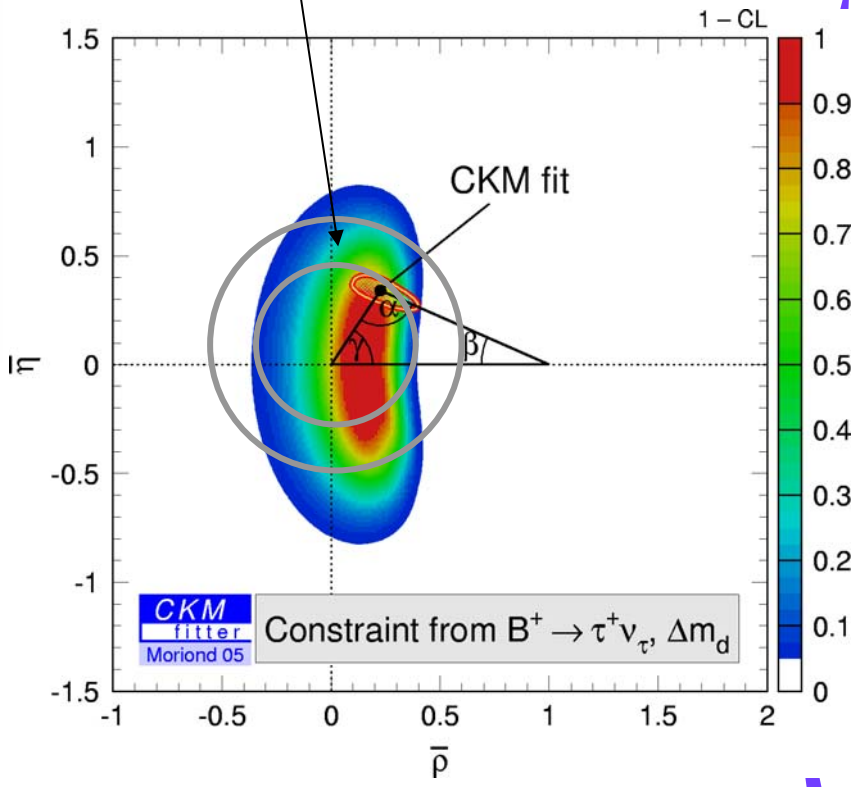
No evidence for signal

BR(B→τν) < 2.6 10⁻⁴ at 90% CL

B → τν: CKM constraints



Constraints on box parameter (currently lattice) and V_{ub}



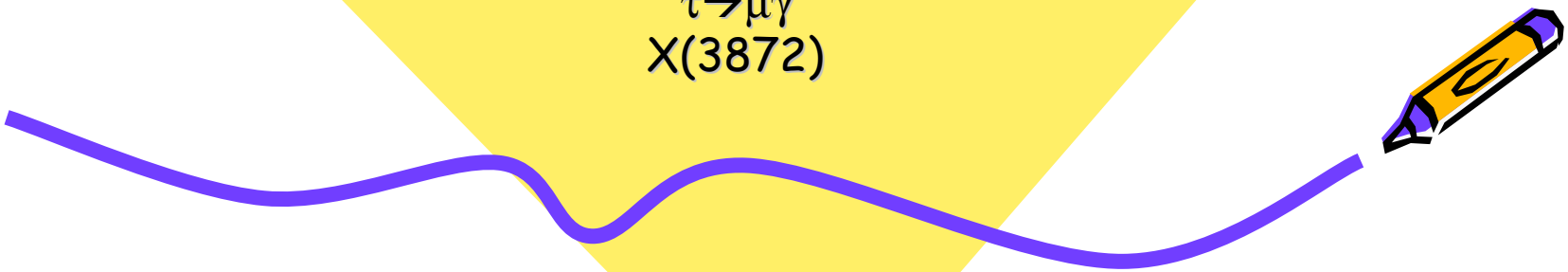
Getting close to expected region !

Search for new physics

K*ll

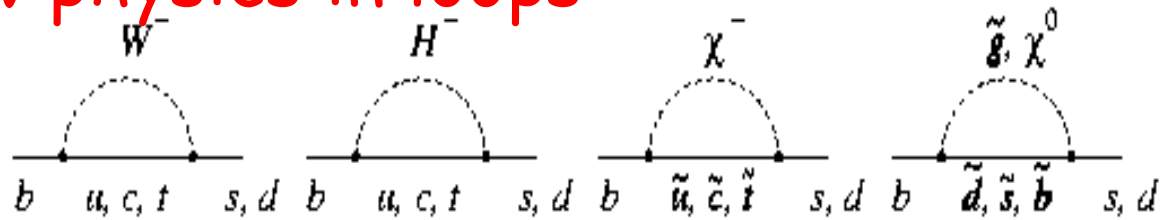
$\tau \rightarrow \mu\gamma$

X(3872)



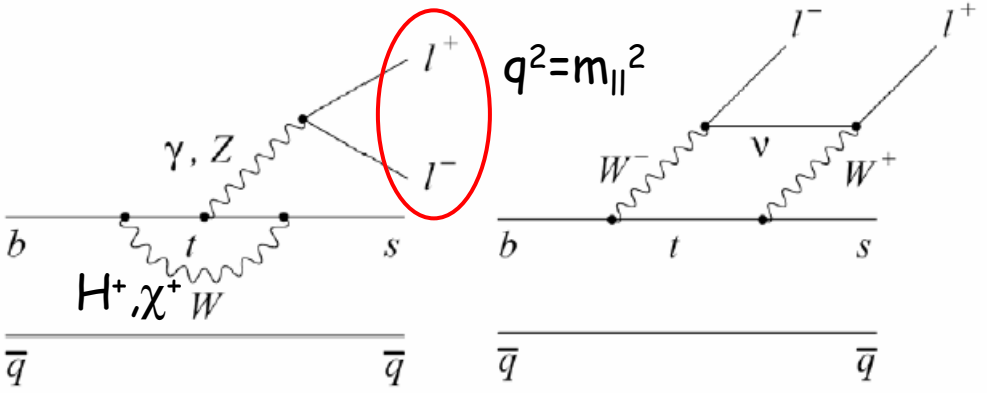
Got new physics?

- New physics in loops

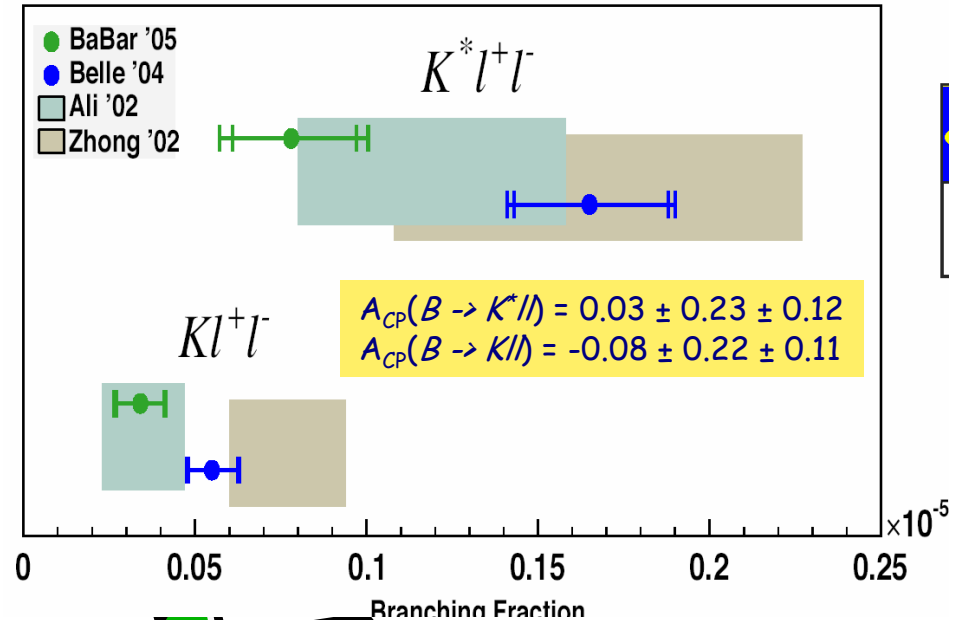


  - Probe with $b \to s\gamma^{(*)}$ processes
- Lepton flavour violation
  - $\tau \to \mu\gamma$
- Recent observations of new mesons
  - Towards a new spectroscopy ?
  - New studies on the X(3872) state

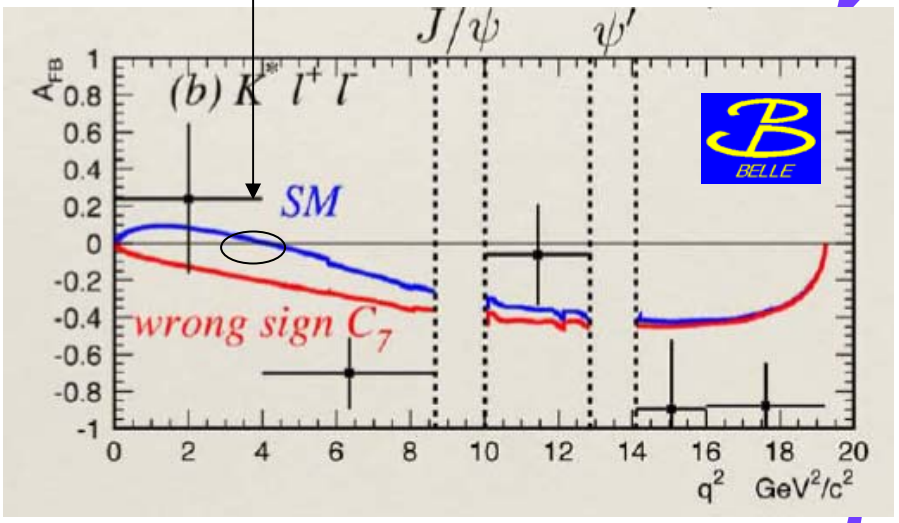
B→K(*)ll



Interference between the two processes could signal new physics

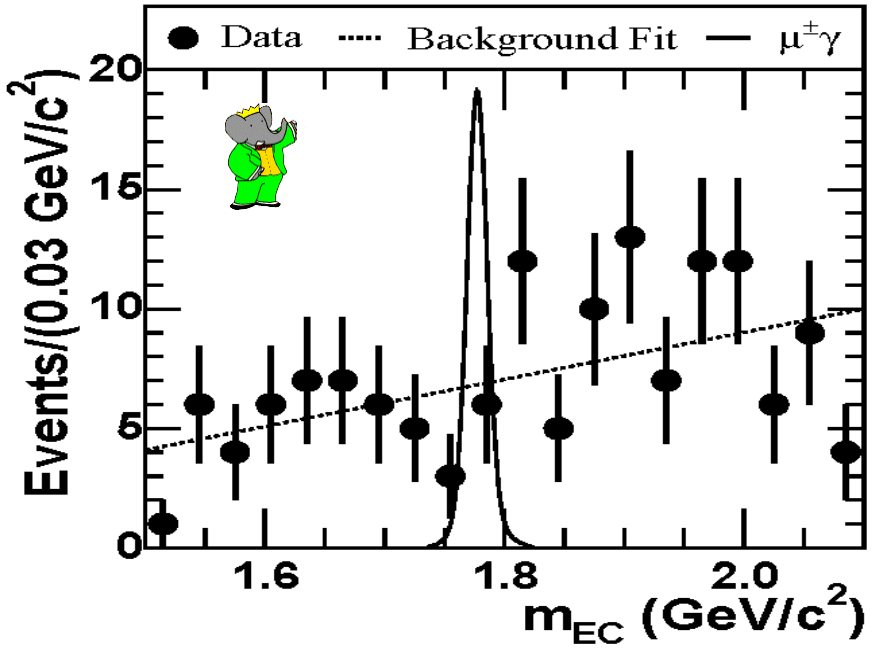


Well known zero



Lepton Flavour Violation Search in $\tau^{\pm} \rightarrow \mu^{\pm}\gamma$

- BaBar/Belle are also τ factories. $\sigma_{\tau\tau} = 0.89 \pm 0.02$ nb.
- Lepton Flavour Violation
  - Some supersymmetric models predict rates for $\tau^{\pm} \rightarrow \mu^{\pm}\gamma$ ~10^{-6}
  - …but rates from most Standard Model (SM) extensions are much lower.
  - Any observation of this mode would indicate new physics.
- Search for $\tau^{+}\tau^{-}$ decays with:
  - non-SM decay of τ with isolated μ and γ with invariant mass of τ in one hemisphere and τ
  - SM decay of other τ to 1 or 3 charged pions.



$$BR(\tau \rightarrow \mu\gamma) < 0.7 \times 10^{-7} [BaBar]$$
$$BR(\tau \rightarrow \mu\gamma) < 3.1 \times 10^{-7} [Belle]$$

Towards a new spectroscopy(?)

Recent observations of new states (DsJ, X(3872),Y(3940)…) several models have been developed

- We are at a stage where we can start to discriminate among them

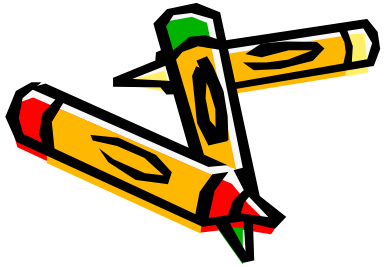
e.g molecular model predicts highly suppressed $B^0 \rightarrow X(3872)K_s$

E. Braaten, M. Kusunoki
hep-ph/0412268

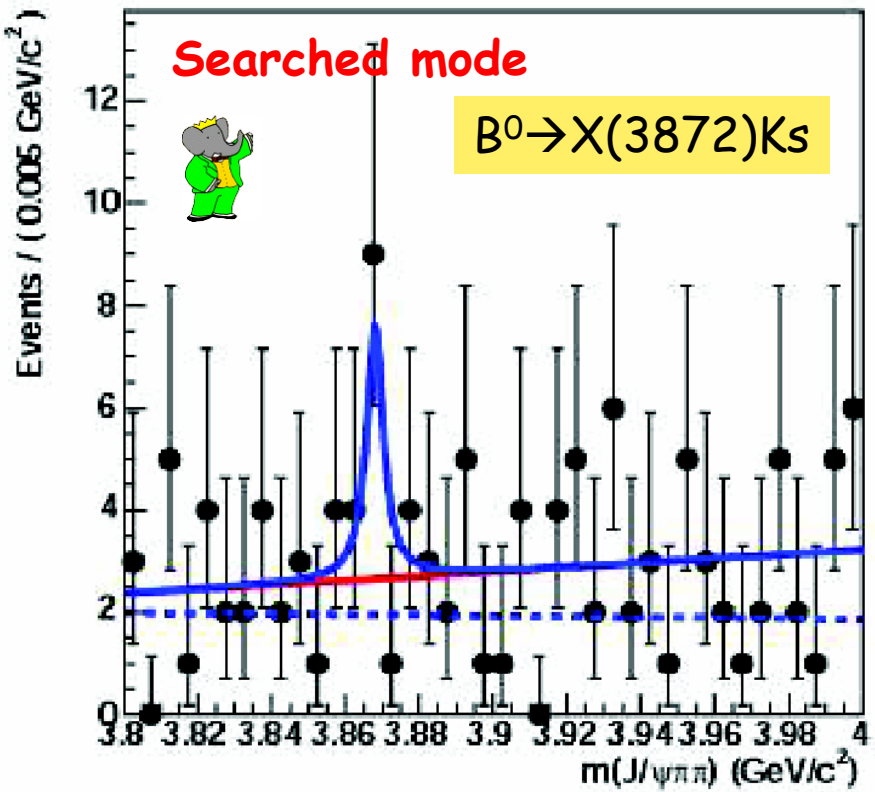
4-quark model predicts different masses between X(3872) in B^0 and B^+ decays

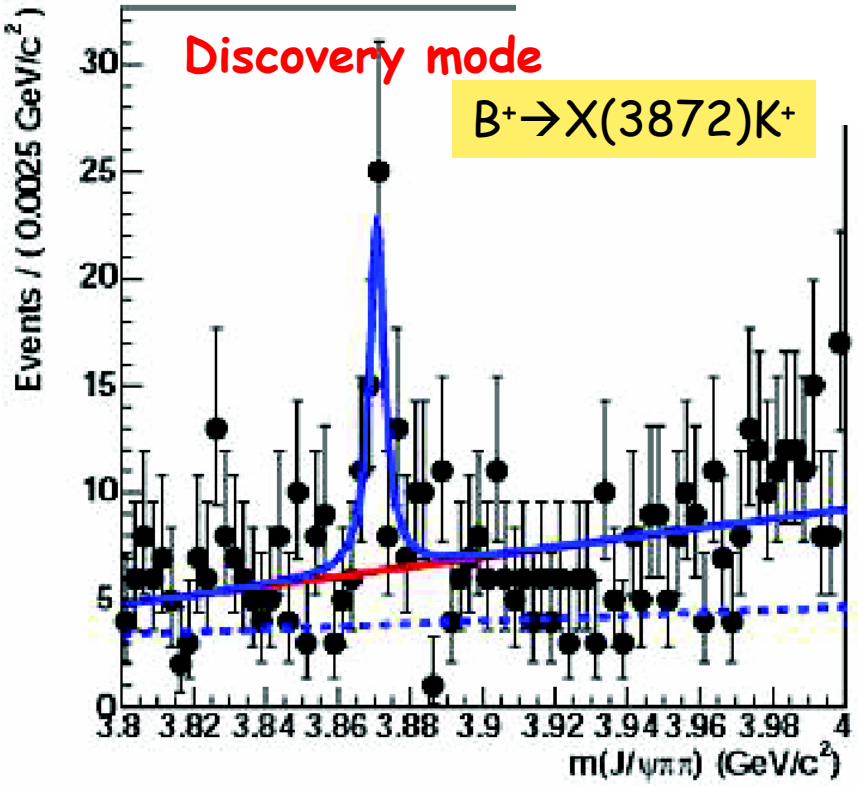
$$|\Delta M| > 5 \text{ MeV}$$

L. Maiani, F. Piccinini.
A.D. Polosa, V. Riquer
PRD 71 (2005) 014028



Search for $B^0 \to X(3872)K_s$





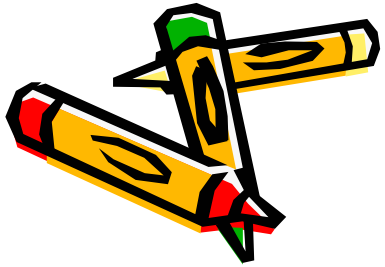
$N=8.4\pm4.5 \quad 2.7\sigma$

$m_X=(3868.6\pm1.2)MeV$

$N=51\pm14 \quad 6.9\sigma$

$m_X=(3871.3\pm0.6)MeV$

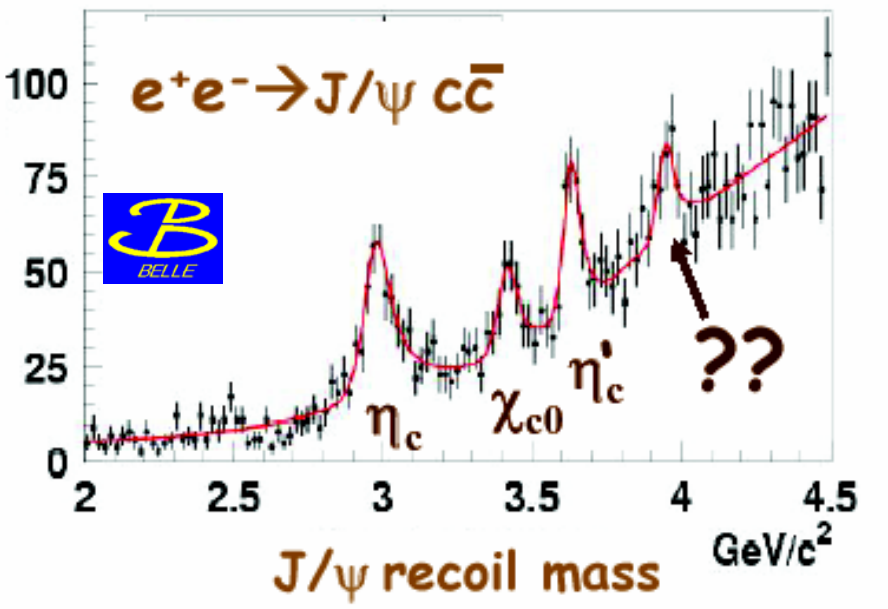
$\Delta M=(2.7\pm1.3\pm0.2)MeV$



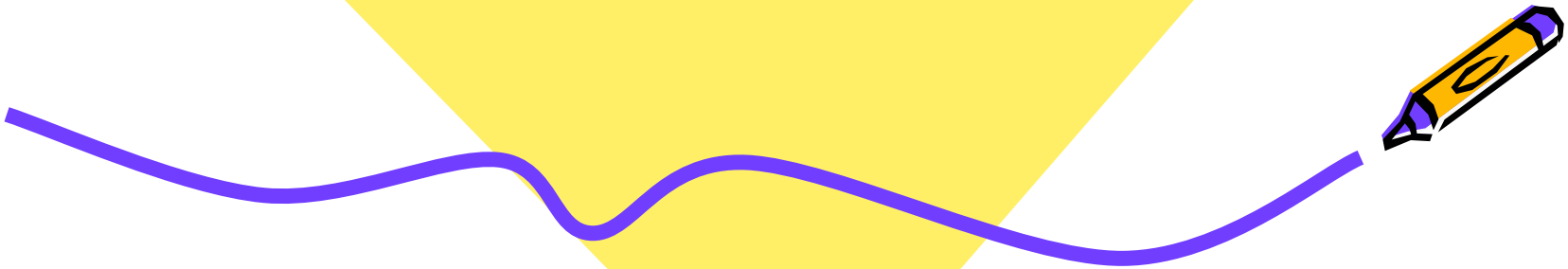
+$Br(X \to J/\psi\pi\pi) > 4\%$ @ 90% C.L (from $B \to XK$ study)

Y(3940)

- New state observed by Belle last summer
  - DD decays favored (why then narrow? 4-quarks?)

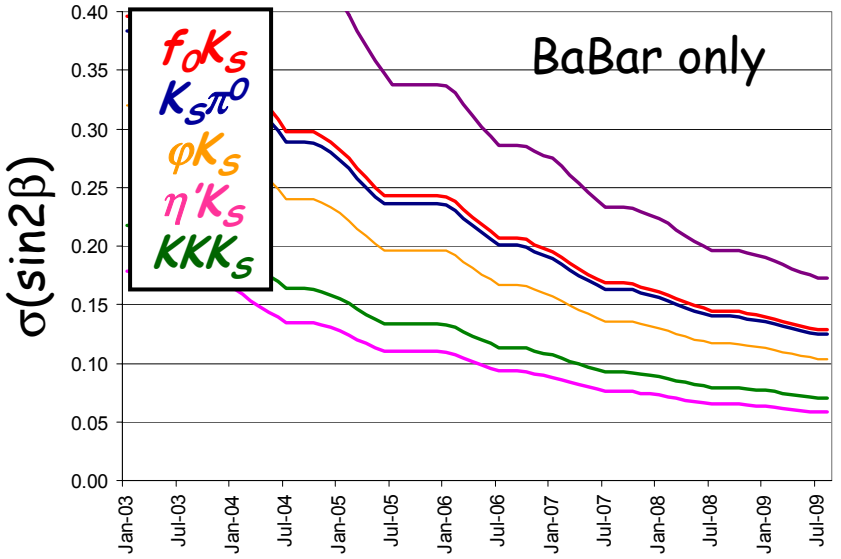


Future perspectives

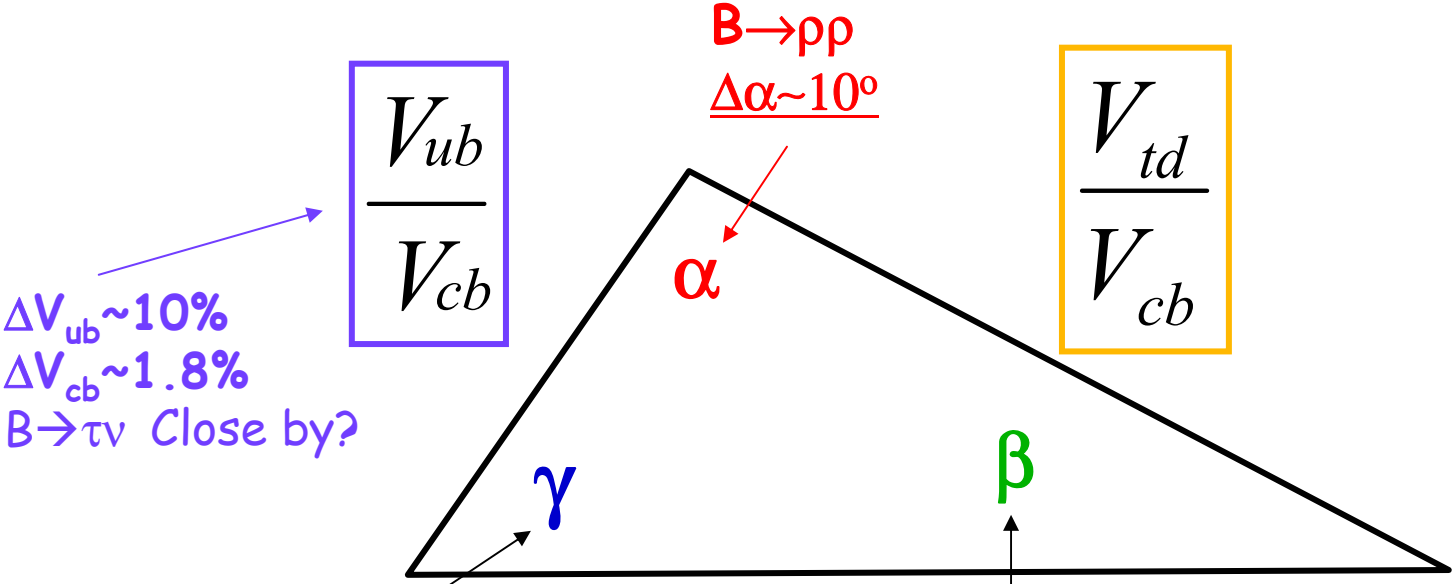


Expectations in 2008 ($L_{Belle+BaBar}$~2ab^{-1})

1. Measurements of β
   - NP discovery potentialities depend on
     - Central value
     - Theoretical errors
   - If everything stays as is ~6σ in 2008
2. Measurements of α
   - Biggest uncertainty: BF($B\to\rho^0\rho^0$)
   - $\sigma(\alpha)$~4° in 2008
3. Measurements of γ
   - Biggest uncertainty: error on Dalitz/ Model independent
   - $\sigma(\gamma)$~7° in 2008



Summary



+ new physics searches

Sensitivity to angles is beyond any expectation
By 2008 all three angles will have precision measurements