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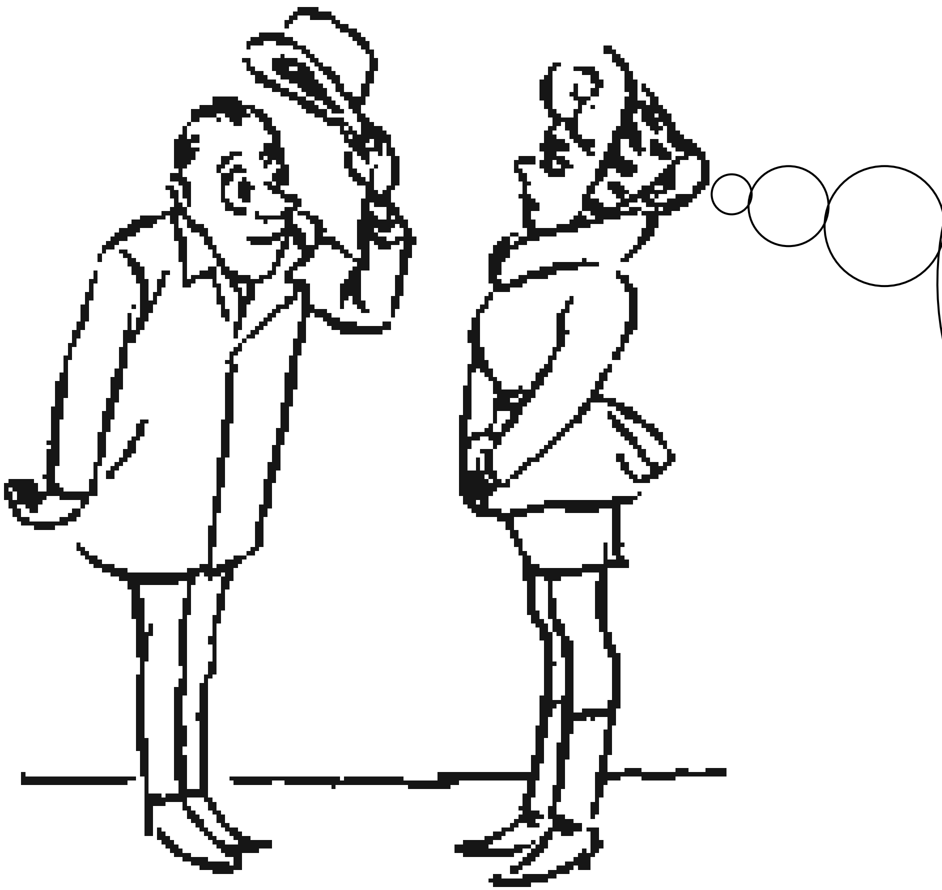
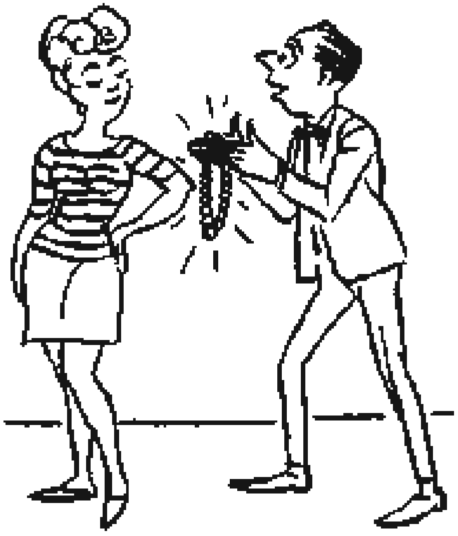
Introduction to the Heavy Flavor session

XLIst Rencontres de Moriond March 18-25 2006
QCD and Hadronic interactions at high energy

Introduction of the Heavy Flavour gentleman to the QCD at La Thuile





Background of Heavy Flavor

- Excellent Detectors (in the past, present and nearest future)

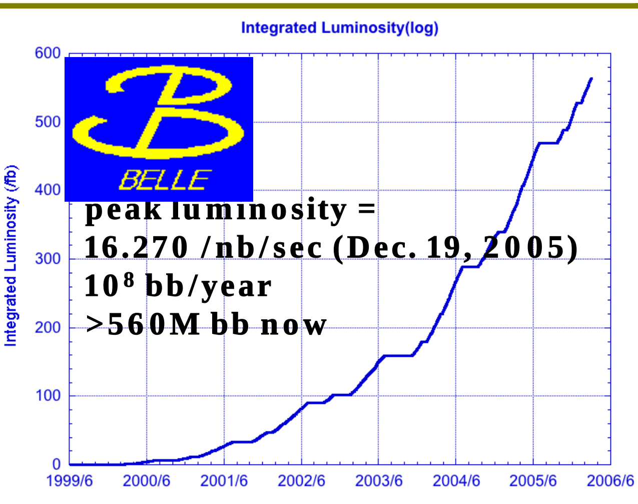
  BELLE/BaBar, CLEO-c, BES & BESII,

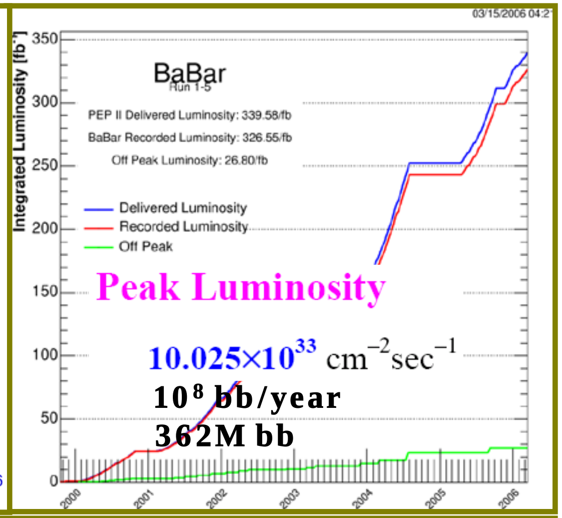
  CDF/D0 (Tevatron), LHCb

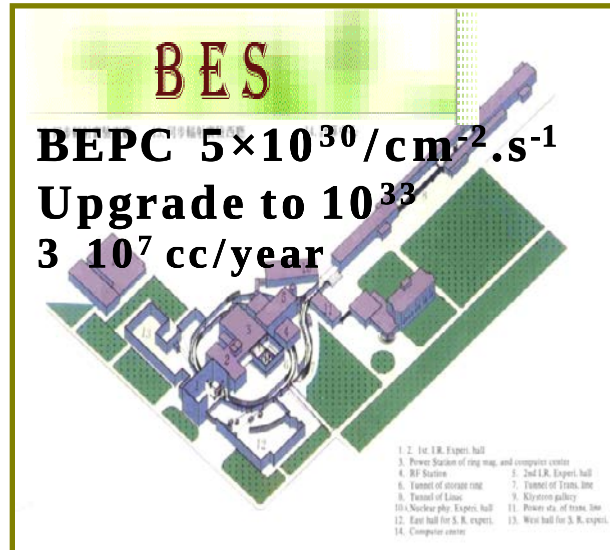
- Huge DATA Samples

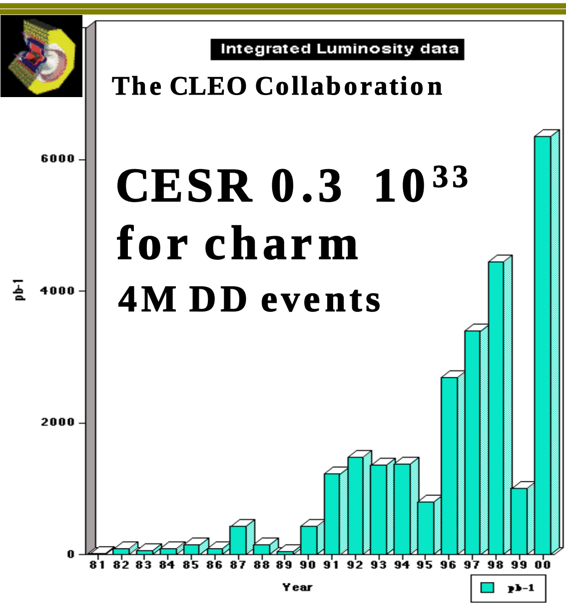
- Many experimental observables

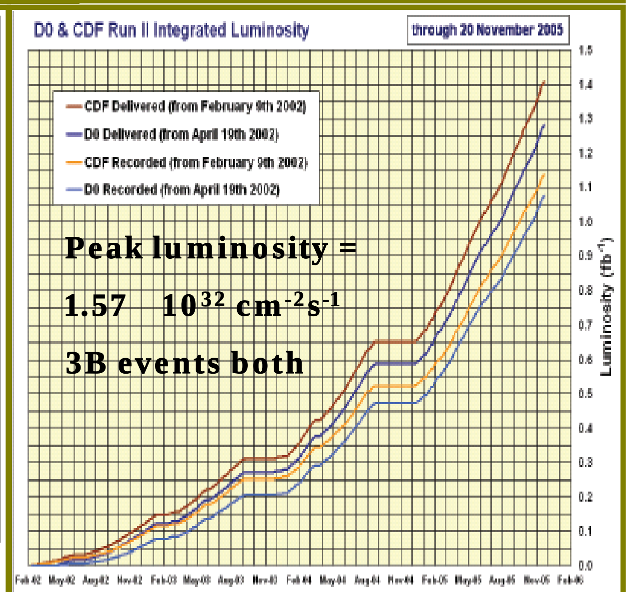
Existing data samples and prospects







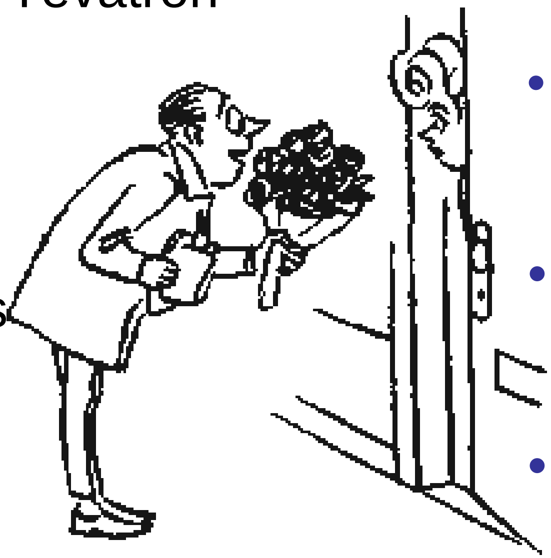




LHCb 10^{12} bb/year

Many experimental observables
Topics discussed at this conference include:

- Measurement of the masses, lifetimes and Mixings (Bs mixing) at the Tevatron
- Rare B decays
  B → baryon decays
- D and Ds hadronic decays
  Determination of $f_{D,Ds}$
- Spectroscopy of charmed mesons and baryons
- Observation of new resonances
- Dalitz analyses of B and D decays
- Results on charmonium and bottomonium with CLEO & BESII
  New observations and multiquark candidates at BESII



- Calculation of B to s gamma and Xs $\ell\ell$
- Threshold resumed spectra in B to Xu $\ell\nu$ NLO
- Polarization in B decays to vector final states

Baryonic B decays with b→c

Mode	Belle (10^{-4})	CLEO (10^{-4})
$\overline{B}^0 \to D^{*+} n\bar{p}$		$14.5^{+3.4}_{-3.0} \pm 2.7$
$\overline{B}^0 \to D^{*+} p\bar{p}\pi^-$		$6.5^{+1.3}_{-1.2} \pm 1.0$
$\overline{B}^0 \to D^{*0} p\bar{p}$	$1.20^{+0.33}_{-0.29} \pm 0.21$	
$\overline{B}^0 \to D^0 p\bar{p}$	$1.18 \pm 0.15 \pm 0.16$	
$B^- \to \Lambda_c^+ \bar{p}\pi^-\pi^0$		$18.1 \pm 2.9^{+2.2}_{-1.6} \pm 4.7$
$\overline{B}^0 \to \Lambda_c^+ \bar{p}\pi^+\pi^-$	$10.3 \pm 0.9 \pm 1.2 \pm 2.7$	$16.7 \pm 1.9^{+1.9}_{-1.6} \pm 4.3$
$B^- \to \Lambda_c^+ \bar{p}\pi^-$	$2.01 \pm 0.15 \pm 0.20 \pm 0.52$	$2.4 \pm 0.6^{+0.19}_{-0.17} \pm 0.6$
$B^- \to \Sigma_c(2455)^{++} \bar{p}\pi^-\pi^-$		$2.8 \pm 0.9 \pm 0.5 \pm 0.7$
$B^- \to \Sigma_c(2455)^0 \bar{p}\pi^+\pi^-$		$4.4 \pm 1.2 \pm 0.5 \pm 1.1$
$\overline{B}^0 \to \Sigma_c(2455)^{++} \bar{p}\pi^-$	$1.15 \pm 0.22 \pm 0.14 \pm 0.30$	$3.7 \pm 0.8 \pm 0.7 \pm 0.8$
$\overline{B}^0 \to \Sigma_c(2455)^0 \bar{p}\pi^+$	$0.97 \pm 0.21 \pm 0.12 \pm 0.05$	$2.2 \pm 0.6 \pm 0.4 \pm 0.5$
$B^- \to \Sigma_c(2455)^0 \bar{p}\pi^0$		$4.2 \pm 1.3 \pm 0.4 \pm 1.0$
$\overline{B}^0 \to \Sigma_c(2520)^{++} \bar{p}\pi^-$	$1.04 \pm 0.24 \pm 0.12 \pm 0.27$	
$\overline{B}^0 \to \Sigma_c(2520)^0 \bar{p}\pi^+$	$0.33 \pm 0.19 \pm 0.04 \pm 0.09$	
$B^- \to \Lambda_c^+ \bar{\Lambda}_c^- K^-$	$6.5^{+1.0}_{-0.9} \pm 0.8 \pm 3.4$	
$\overline{B}^0 \to \Lambda_c^+ \bar{\Lambda}_c^- \overline{K}^0$	$7.9^{+2.9}_{-2.3} \pm 1.2 \pm 4.2$	

2-body baryonic B decays

Mode	BaBar	Belle	CLEO
$\overline{B}^0 \to p\bar{p}$	$< 2.7 \times 10^{-7}$	$< 4.1 \times 10^{-7}$	$< 1.4 \times 10^{-6}$
$\overline{B}^0 \to \Lambda\bar{\Lambda}$		$< 6.9 \times 10^{-7}$	$< 1.2 \times 10^{-6}$
$B^- \to \Lambda\bar{p}$	$< 1.5 \times 10^{-6}$	$< 4.9 \times 10^{-7}$	$< 1.5 \times 10^{-6}$

Mode	Belle	CLEO
$\overline{B}^0 \to \Lambda_c^+ \bar{p}$	$(2.2^{+0.6}_{-0.5} \pm 0.3 \pm 0.6) \times 10^{-5}$	$< 0.9 \times 10^{-4}$
$B^- \to \Sigma_c(2455)^0 \bar{p}$	$(3.7 \pm 0.7 \pm 0.4 \pm 1.0) \times 10^{-5}$	
$B^- \to \Sigma_c(2520)^0 \bar{p}$	$< 2.7 \times 10^{-5}$	
$B^- \to \Lambda_c^+ \bar{\Delta}^{--}$	$< 1.9 \times 10^{-5}$	
$B^- \to \Xi_c^0 (\to \Xi^- \pi^+) \bar{\Lambda}_c^-$	$(4.8^{+1.0}_{-0.9} \pm 1.1 \pm 1.2) \times 10^{-5}$	
$\overline{B}^0 \to \Xi_c^+ (\to \Xi^- \pi^+ \pi^+) \bar{\Lambda}_c^-$	$(9.3^{+3.7}_{-2.8} \pm 1.9 \pm 2.2) \times 10^{-5}$	

$\Xi_c \underline{\Lambda}_c \sim 10^{-3}$ >> $\Lambda_c \underline{p} \sim 10^{-5}$ >> $\Lambda \underline{p} \le 10^{-7}$

Baryonic B decays

To be understood:

- Three-body baryonic B decays have larger branching fraction than two-body decays
- Strong enhancement toward the baryon-antibaryon mass threshold
  - intermediate gluonic resonant states
  - non-perturbative QCD effects of the quark fragmentation
- **Huge rate of doubly charmed baryon modes !!!**

Spectroscopy of charmed mesons ***(recent results on Ds mesons)***

- 4 states $D_s(1968)$, $D_s^*(2112)$, $D_{s1}(2536)$, $D_{s2}^*(2573)$ in good agreement with theoretical predictions
- 2 new states discovered by BaBar and CLEO with masses significantly lower than predictions:

  $D_{sJ}^*(2317)^+ \rightarrow D_s+\pi^0$

  $D_{sJ}(2460)^+ \rightarrow D_s^* +\pi^0$

  Isospin violation decays
- BELLE confirmed both new D_s states and found them in the decays of B meson.
- Need to determine quantum numbers – will be discussed today
- SELEX reported a state (at M=2632 MeV) that decays into $D_s^+\eta$ and D^0K^+ (not seen at B factories)

Good candidates for missing 0^+, 1^+ $c\bar{s}$ states
Low mass has to be understood !!!

Charmed baryon spectroscopy

Recent results:

- Update on charm baryon masses: Λ_c^+ *(high precision measurement)* and $\Xi_c^{+,0}$

- Discovery of $\Sigma_c(2800)$ isotriplet decaying to $\Lambda_c^+\pi$
  Tentatively have $J^P = 3/2^-$ decaying to $\Lambda_c^+\pi$ in D-wave
  Mass difference is ok but width (Γ~15 MeV) is larger than expected

- First observation of Ω_c in a single decay channel ($\Omega\pi^+$)
  with $>5\sigma$ significance. First observation of production in B decays

- **We are waiting for the discovery of new states at this conference**

Observation of new resonances *X,Y,Z …*

X(3872) observed by BELLE in $B^+ \to K^+ (J/\psi\pi^+\pi^-)$
Confirmed by CDF, D0, BaBar
wa: M=3871.9 0.5 MeV/c^2

What is that: charmonium, DD* molecule, tetraquarks… ???

$$\frac{Br(X \to \gamma J/\psi)}{Br(X \to \pi^+\pi^- J/\psi)} = 0.14 \pm 0.05$$

$$\frac{Br(X \to \pi^+\pi^-\pi^0 J/\psi)}{Br(X \to \pi^+\pi^- J/\psi)} = 1.0 \pm 0.4 \pm 0.3$$

→ C(X(3872)) = +1
large isospin violation
More on quantum numbers at this conference

$$0.13 < \frac{B(B^0 \to K^0 X(3872))}{B(B^- \to K^- X(3872))} < 1.10 \quad \text{at } 90\% \text{ CL}$$

For DD* molecule expected ratio ~0.1
factorization and isospin symmetry

For the mixture of Xu and Xd tetraquarks the ratio can vary as a function of mixing angle

Other new states

- $Y(4260)$ discovered by BaBar in $e^+e^- \rightarrow \gamma_{ISR} Y(4260) \rightarrow \gamma_{ISR}\ \pi^+\pi^- J/\psi$
  (allowed only for $J^{PC} = 1^{--}$)
  CLEO observed direct production of $Y(4260)$:
  $$e^+e^- \rightarrow Y(4260) \rightarrow \pi^+\pi^- J/\psi$$
  \+ observation of $Y(4260) \rightarrow \pi^0\pi^0 J/\psi$
  \+ evidence of $Y(4260) \rightarrow K^+K^- J/\psi$

- $Z(3930)$ observed by BELLE: $\gamma\gamma \rightarrow Z(3930) \rightarrow D\bar{D}$

- $Y(3940)$ observed by BELLE: $B \rightarrow KY(3940) \rightarrow K\omega J/\psi$
  $BR(B \rightarrow YK) \times BR(Y \rightarrow \omega J/\psi) \sim 7 \times 10^{-5}$

- $X(3940)$ observed by BELLE in $e^+e^- \rightarrow X(3940) J/\psi$
  no signal is seen in $\omega J/\psi$ channel

Request of Heavy Flavor to QCD

Help to search for a New Physics !!!

Quark Mixing in the Standard Model

Cabibbo **K**obayashi **M**askawa (CKM) Matrix

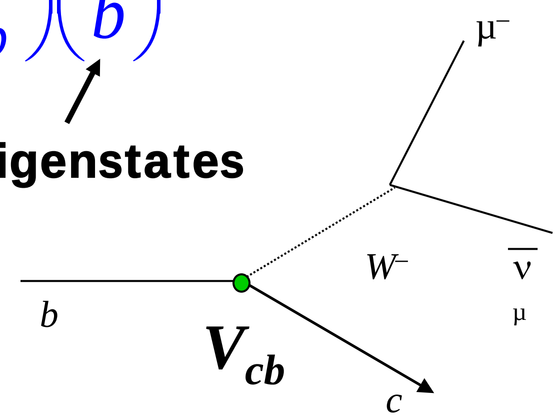
weak eigenstates

CKM Matrix:

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

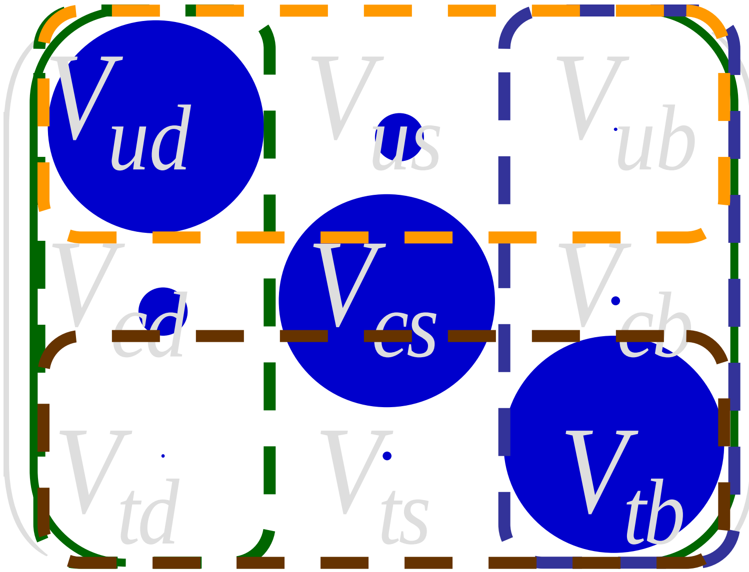
mass eigenstates

- complex
- unitary
  - 4 parameters:
    - 3 Euler angles
    - 1 Phase → ~~CP~~



Unitarity Test of the CKM-Matrix:

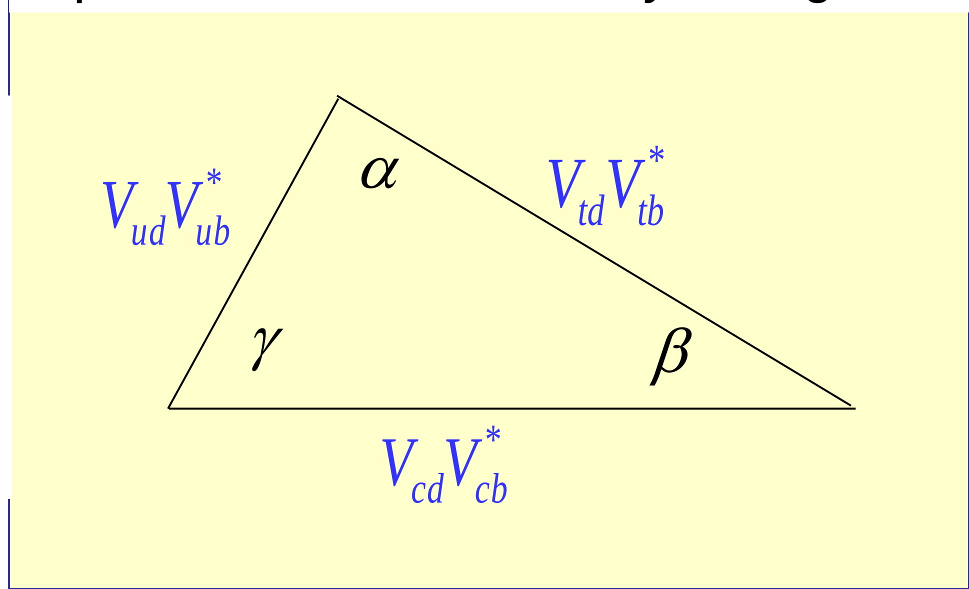
6 unitarity conditions



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

$$V_{ud} \cdot V_{td}^{*} + V_{us} \cdot V_{ts}^{*} + V_{ub} \cdot V_{tb}^{*} = 0$$

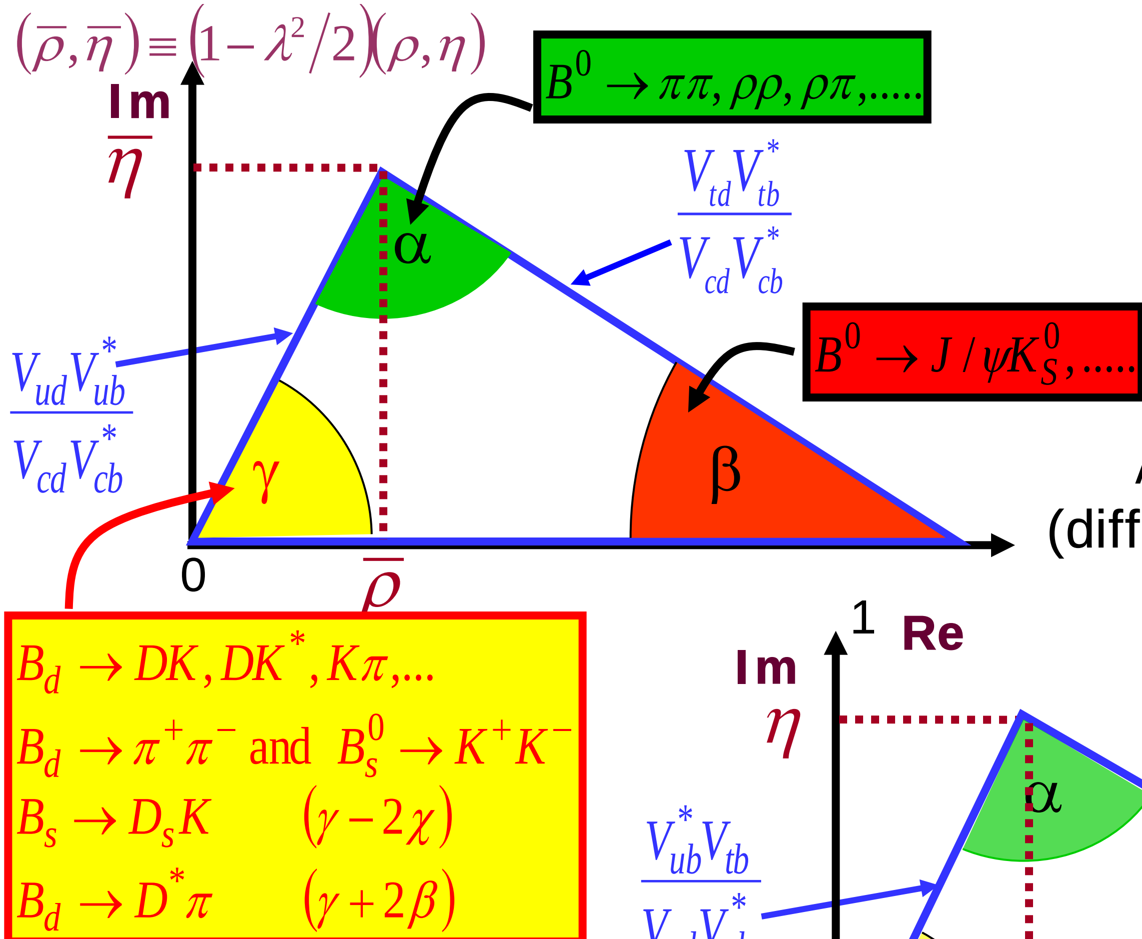
Representation as „Unitarity Triangles“:



6 triangles are possible, all with the same area. However, 4 of them are almost degenerated and do not allow a sensitive unitarity test.

Sensitive tests: $\Rightarrow B_d$ - and B_s -mesons

Unitarity Triangles



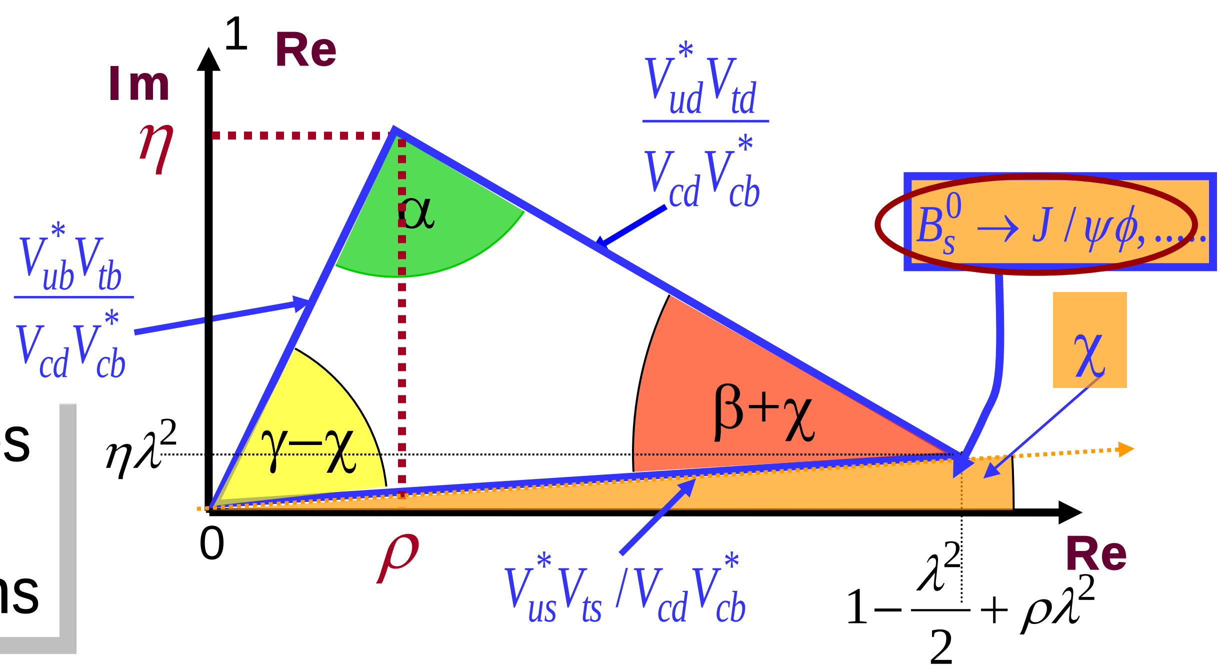
β: B_d mixing phase

χ: B_s mixing phase

γ: weak decay phase

Wolfenstein: $V_{ub} = e^{-i\gamma}$

Almost identical triangles
(differences at the percent level)

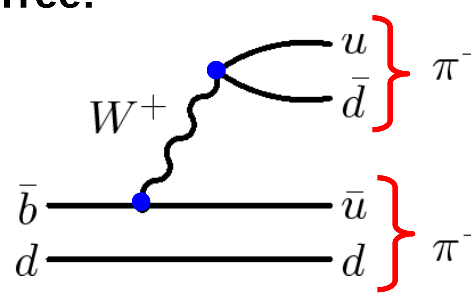


Precision Test requires measurements with B_u-, B_d-, and B_s-mesons

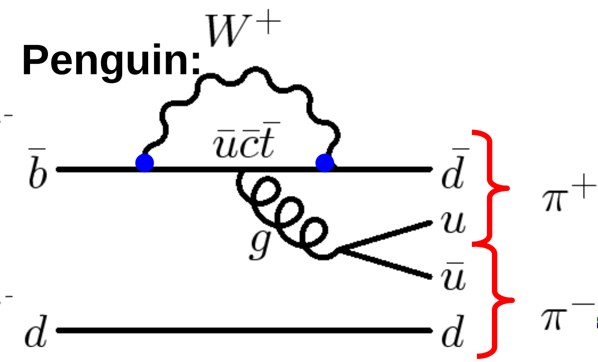
Determination of α/φ_2

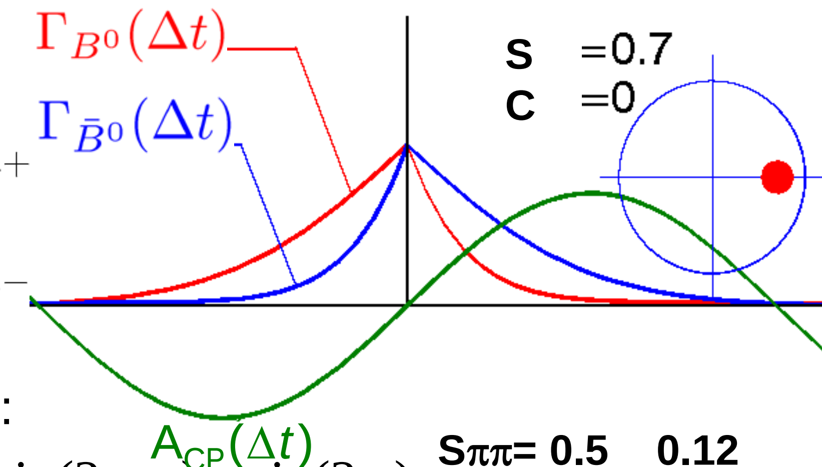
Time-dependent CP asymmetry: $A(\Delta t) = S\sin(\Delta m_d \Delta t) - C\cos(\Delta m_d \Delta t)$

Tree:



Penguin:





Without penguin:

$C = 0 \qquad S = \sin(2\alpha)$

Including penguin:

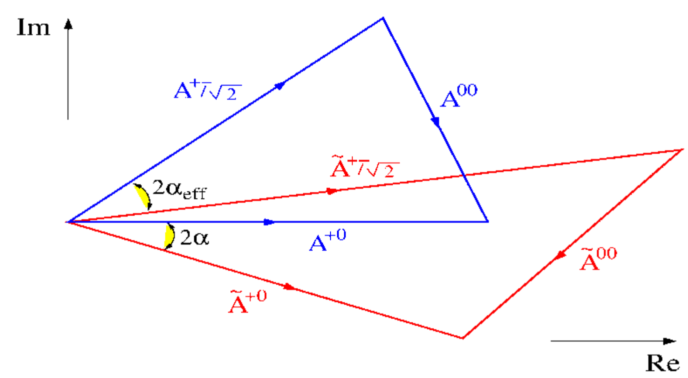
$C \neq 0 \qquad S = \sqrt{1 - C^2}\sin(2\alpha_{\text{eff}}) \neq \sin(2\alpha)$

$S_{\pi\pi}$= 0.5 0.12
$C_{\pi\pi}$=-0.37±0.10
2.3σ diff. between BELLE and BaBar

Use isospin relations to estimate the penguin contribution: Gronau-London, PRL, 65, 3381 (1990)
Lipkin *et al.*, PRD 44, 1454 (1991)

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

Neglecting EWP,
$h^+ h^0$ (I=2)=pure tree $\quad A^{+0} = A^{-0}$



Comments on the precision of the CKM triangle elements

- **β / φ_1** : present accuracy – 1 degree; theoretically clean since penguins contribute with the same phase

- **α / φ_2** : present accuracy (~12) is limited by experiment. $B \to \rho\rho$ currently is the most perspective channel. It will be very difficult to go down to a few degree measurement both experimentally and theoretically.
  Request to theory: estimate a contribution from electroweak penguins

- **|VudVub* / VcdVcb*|** : To separate the $b \to u$ from $b \to c$ one has to apply cuts on leptonic energy, hadronic invariant mass or lepton invariant mass.
  New dynamical scale, so called hardness (~1G
  Combined analysis of $b \to u l \nu$ and $b \to s \gamma$; use of experimentally measured hadronic momenta.
  An accuracy of ~5% is a theoretical challenge
  Already now the precision is limited by theory.

Comments on the precision of the CKM triangle elements

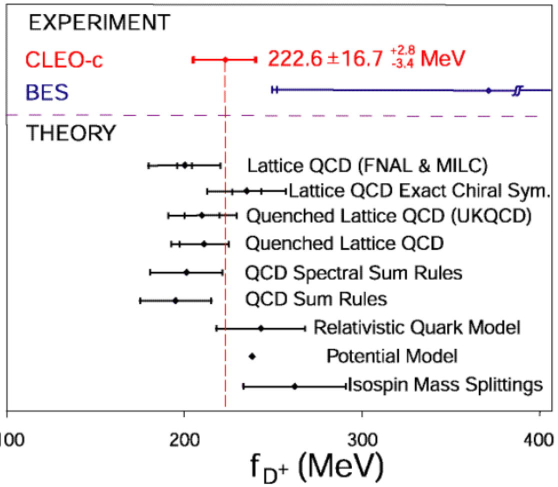
- **γ/φ_3** : Theoretically very clean measurement since only tree amplitudes contribute. Experimentally can be measured in many channells → possibility for cross-checks

  Current precision is limited by statistics. Using GLW method the Daliz- analysis of $B^- \rightarrow DK^-$ with $D \rightarrow K_S \pi^+ \pi^-$ gives precision of ~17   (see A.Bondar talk at EW Moriond).

  In future after a 5 years of LHCb operation 1   precision can be achieved !!!

- **|VtdVtb*/VcdVcb*|** : |Vtd/Vts| is determined by:

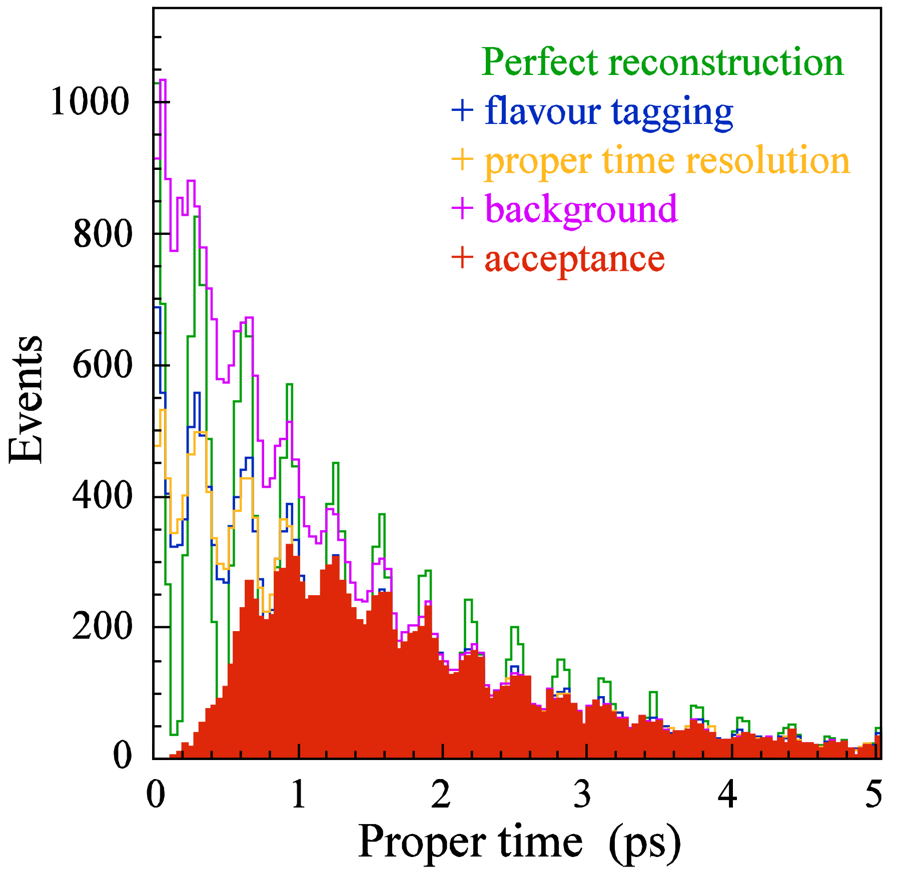
$$\left|\frac{V_{td}}{V_{ts}}\right| = \xi \sqrt{\left(\frac{M_{B_s}}{M_{B_d}}\right)\left(\frac{\Delta M_d}{\Delta M_s}\right)} \qquad \xi = \frac{\sqrt{\hat{B}_{B_s}} f_{B_s}}{\sqrt{\hat{B}_{B_d}} f_{B_d}}$$



CLEO will measure f(D)/f(Ds) with a precision of a *few %* !!!
Perfect way to calibrate *LQCD* calculations experimentally.
The measurement of ΔMs is long awaited result → wait for D0 talk tonight. *Preferred value 19ps^{-1} is well above the expected sensitivity 14 ps^{-1}*
10 times more data needed for 3σ measurement !!!

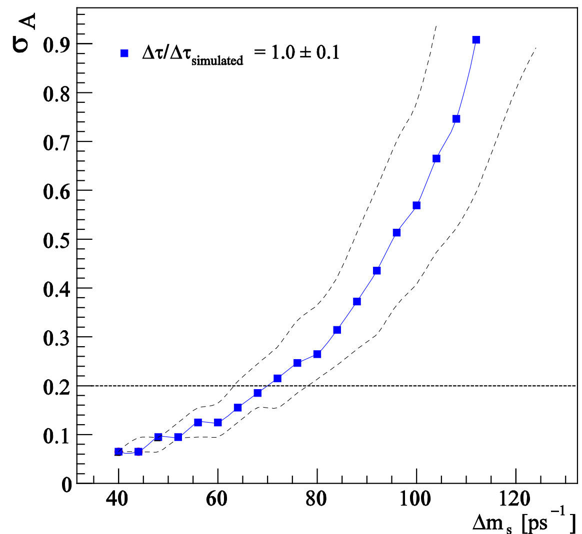
→ **Good prospects to measure the side with a *few % accuracy***

LHCb sensitivity to Bs oscillations



Use mode: Bs → Ds-p+
Plot made for 1 year of data
(80k selected events) for
Δms = 20 ps-1 (SM preferred)
Oscillations are clearly seen !!!

5 s observation of Bs oscillation
for *Δms* < 68 ps-1 (in one year)
→ LHCb could exclude *full* SM range
Once observed, precise value
is obtained: σstat(*Δms*) ~ 0.01 ps-1



Last Slide

We are looking forward :

- for exciting discussions at this conference
  and in future
- for further experimental and theoretical progress
  to discover **NEW PHYSICS**