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****

Time-dependent CP asymmetries in D (and B) decays

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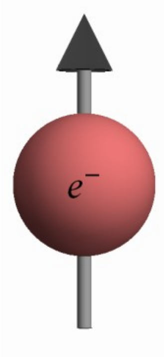

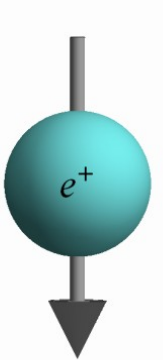

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Outline

Motivations

The CKM matrix and the UT's

Time-dependent formalism (correlated mesons)

Analysis of CP eigenstates

$D^0 \rightarrow K^+ K^-$, $\pi^+ \pi^-$,$\rho^0 \rho^0$

Uncorrelated D^0 mesons (Υ(4S) and LHCb)

Conclusions

Motivations (i)

- ➔Origin of CP violation is still one of the biggest questions in particle physics and cosmology today
- ➔CP violation has not yet been observed in charm, and a time-dependent analysis has not been done yet
- ➔Improvements in the precision and knowledge of the CKM unitarity triangle(s) is still possible
- ➔SuperB will offer a unique environment to perform precision tests of the standard model

CKM Matrix

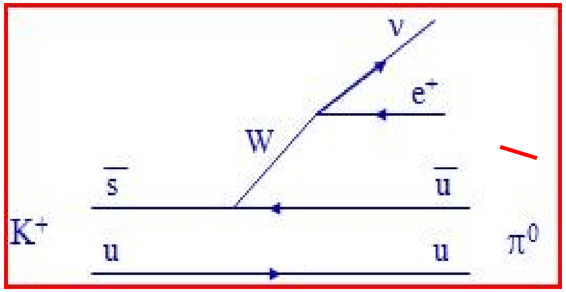
$$V_{CKM}=\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}=\begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23}-c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23}-s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23}-c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23}-s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix}$$

$c_{ij}=\cos\theta_{ij};s_{ij}=\sin\theta_{ij}$ $\delta=cp\ violating\ phase$ $s_{13}\ll s_{23}\ll s_{12}\ll 1(EXPERIMENTS)$

Wolfenstein parametrization

$$expansion\ \ in\ \ terms\ \ of\ \ \sin\theta_c:V_{us}=0.225=\lambda\rightarrow V_{ud}=1-\frac{\lambda^2}{2}+O(\lambda^3)$$

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



$$s_{12}=\lambda=\frac{|V_{us}|}{\sqrt{|V_{ud}|^2+|V_{us}|^2}};s_{23}=A\lambda^2=\lambda\left|\frac{V_{cb}}{V_{us}}\right|;$$

$$s_{13}e^{i\delta}=V_{ub}^{*}=A\lambda^3(\rho+i\eta)=A\lambda^3(\bar{\rho}+i\bar{\eta})\frac{\sqrt{1-A^2\lambda^4}}{(\sqrt{1-\lambda^2}1-A^2\lambda^4(\bar{\rho}+i\bar{\eta}))}$$

CKM-M may be forced to be unitary to all order in λ !!

Buras parametrization: λ^5

$$PDG \quad standard \quad parametriazation \quad with$$

$$s_{12}=\lambda\,, \quad s_{13}\sin\delta_{13}=A\lambda^3\eta\,, \quad \bar{\eta}=\eta[1-\frac{\lambda^2}{2}+O(\lambda^4)]$$

$$s_{23}=A\lambda^{2,} \quad s_{13}\cos\delta_{13}=A\lambda^3\rho\,, \quad \bar{\rho}=\rho[1-\frac{\lambda^2}{2}+O(\lambda^4)]$$

$$V_{CKM}=\begin{pmatrix} 1-\lambda^2/2-\lambda^4/8 & \lambda & A\lambda^3(\bar{\rho}-i\bar{\eta})+A\lambda^5(\bar{\rho}-i\bar{\eta})/2 \\ -\lambda+A^2\lambda^5[1-2(\bar{\rho}+i\bar{\eta})] & 1-\lambda^2/2-\lambda^4(1+4A^2)/8 & A\lambda^2 \\ A\lambda^3[1-(\bar{\rho}+i\bar{\eta})] & -A\lambda^2+A\lambda^4[1-2(\bar{\rho}+i\bar{\eta})]/2 & 1-A^2\lambda^4/2 \end{pmatrix}+O(\lambda^6)$$

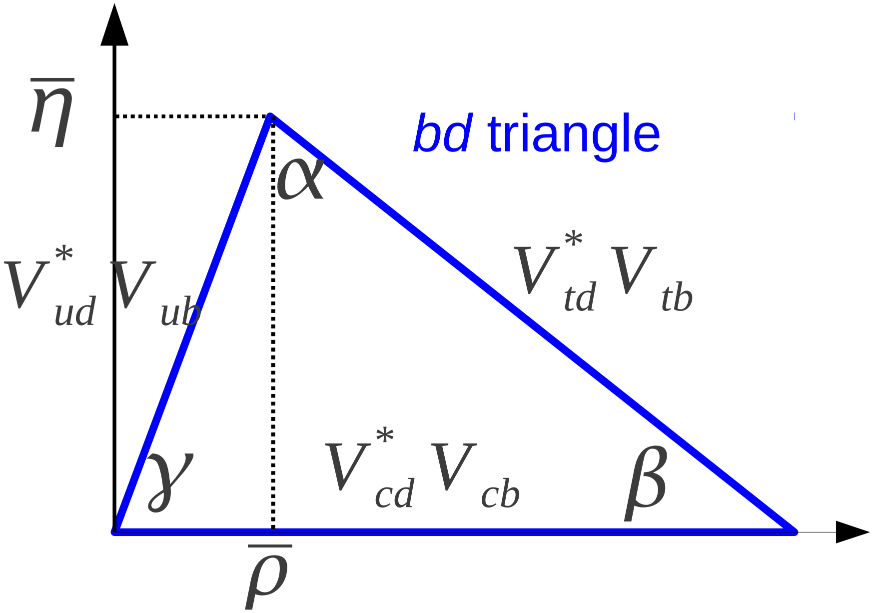
TAB 1

	UTFit	CKM Fitter
λ	0.22545 ± 0.00065	0.22543 ± 0.00077
A	0.8095 ± 0.0095	$0.812^{+0.013}_{-0.027}$
ρ	0.135 ± 0.021	$-------------$
η	0.367 ± 0.013	$-------------$
$\bar{\rho}$	0.132 ± 0.020	0.144 ± 0.025
$\bar{\eta}$	0.358 ± 0.012	$0.342+0.016$

Why do we express the matrix in terms of $\bar{\rho}\,\bar{\eta}$?

Unitarity triangles

Unitarity conditions of the CKM matrix are translated into 6 possible unitary triangles in the complex plane. We illustrate two here.



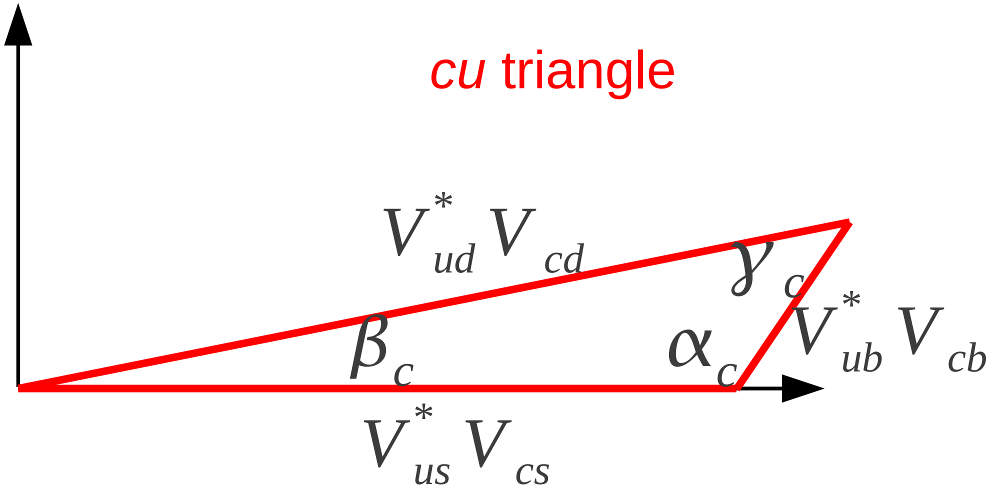
$$V^*_{ud}V_{ub}+V^*_{cd}V_{cb}+V^*_{td}V_{tb}=0$$

$$\alpha=arg[\frac{-V_{td}V^*_{tb}}{V_{ud}V^*_{ub}}]=(91.4\pm6.1)^o$$

$$\beta=arg[\frac{-V_{cd}V^*_{cb}}{V_{td}V^*_{tb}}]=(21.1\pm0.9)^o$$

$$\gamma=arg[\frac{-V_{ud}V^*_{ub}}{V_{cd}V^*_{cb}}]=(74\pm11)^o$$

FROM EXPERIMENTS



$$V^*_{ud}V_{cd}+V^*_{us}V_{cs}+V^*_{ub}V_{cb}=0$$

$$\alpha_c=arg[\frac{-V^*_{ub}V_{cb}}{V^*_{us}V_{cs}}]=(111.5\pm4.2)^o$$

$$\beta_c=arg[\frac{-V^*_{ud}V_{cd}}{V^*_{us}V_{cs}}]=(0.0350\pm0.0001)^o$$

$$\gamma_c=arg[\frac{-V^*_{ub}V_{cb}}{V^*_{ud}V_{cd}}]=(68.4\pm0.1)^o$$

AVERAGE OF VALUES IN TAB 1

What we are doing

Bigi and Sanda (hep-ph/9909479v2) pointed out that β_c is one of two other angles that should be measured (the other is β_s).

We explore the potential to study this (tri)angle for the first time.

It is unlikely we can measure β_c(<0.1 degrees) to high precision, but a larger value would signify new physics.

A TDCPV analysis can measure $2\beta_c + \Phi_{MIX}$. Current mixing phase average value is 10 degrees.

The mixing angle Φ_{MIX} is intrinsically interesting, and can, otherwise, only be measured in time-dependent Dalitz plot analyses of D0 to self-conjugate final states.

Time-dependent formalism (i)

Neutral meson systems exhibit mixing of mass eigenstates |P1,2> where:

$$i\frac{d}{dt}\begin{pmatrix}|P_1>\\|P_2>\end{pmatrix}=\begin{pmatrix}M_{11}-\frac{i}{2}\Gamma_{11} & M_{12}-\frac{i}{2}\Gamma_{12}\\ M_{12}^*-\frac{i}{2}\Gamma_{12}^* & M_{22}^*-\frac{i}{2}\Gamma_{22}^*\end{pmatrix}\begin{pmatrix}|P^0>\\|\overline{P^0}>\end{pmatrix}=H_{eff}\begin{pmatrix}|P^0>\\|\overline{P^0}>\end{pmatrix}$$

$$|P_{1,2}>=p|P^0>\pm q|\overline{P^0}>$$

$$q^2+p^2=1 \quad normalize \quad the \quad wavefunction$$

$$\frac{q}{p}=\sqrt{\frac{m_{12}^*-i\Gamma_{12}^*/2}{M_{12}-i\Gamma_{12}/2}}$$

$$H_{eff}=M-\frac{i}{2}\Gamma$$

$$M_{11}=M_{22},\Gamma_{11}=\Gamma_{22} \quad \leftarrow \quad CPT \quad INVARIANCE$$

$$M_{11}=M_{22},\Gamma_{11}=\Gamma_{22},\Im[\frac{\Gamma_{12}}{M_{12}}]=0 \quad \leftarrow CP \quad INVARIANCE$$

$$\Im[\frac{\Gamma_{12}}{M_{12}}]=0 \quad \leftarrow \quad T \quad INVARIANCE$$

$$\boxed{\frac{d}{dt}\langle\Psi(t)|\Psi(t)\rangle=-\langle\Psi(t)|\Gamma|\Psi(t)\rangle}$$

Time-dependent formalism (ii)

The time-dependence of decays of P^0 ($\overline{P^0}$) to final state |f > are:

$$\Gamma(P^0\to f)\propto e^{-\Gamma_1|\Delta t|}[\frac{h_+}{2}+\frac{\Re(\lambda_f)}{1+|\lambda_f|^2}h_-+e^{[\Delta\Gamma|\Delta t|/2]}(\frac{1-|\lambda_f|^2}{1+|\lambda_f|^2}\cos\Delta M\Delta t-\frac{2\Im(\lambda_f)}{1+|\lambda_f|^2}\sin\Delta M\Delta t)]$$

$$\overline{\Gamma}(\overline{P^0}\to f)\propto e^{-\Gamma_1|\Delta t|}[\frac{h_+}{2}+\frac{\Re(\lambda_f)}{1+|\lambda_f|^2}h_--e^{[\Delta\Gamma|\Delta t|/2]}(\frac{1-|\lambda_f|^2}{1+|\lambda_f|^2}\cos\Delta M\Delta t-\frac{2\Im(\lambda_f)}{1+|\lambda_f|^2}\sin\Delta M\Delta t)]$$

$$where: \quad h_{+-}=1\pm e^{\Delta\Gamma|\Delta t|}, \quad \lambda_f=\frac{q}{p}\frac{\overline{A}}{A}$$

λ_f very important!

We now obtain the time-dependent CP asymmetry

$$A(\Delta t)=\frac{\overline{\Gamma}(\Delta t)-\Gamma(\Delta t)}{\overline{\Gamma}(\Delta t)+\Gamma(\Delta t)}=2e^{\Delta\Gamma|\Delta t|/2}\frac{(|\lambda_f|^2-1)\cos\Delta M\Delta t+2\Im(\lambda_f)\sin\Delta M\Delta t}{(1+|\lambda_f|^2)h_++2h_-\Re(\lambda_f)}$$

But real life differs.. (due to mis-tag probability)

Mistag and Dilution

Non-trivial mis-tag probabilities from mis-reconstruction, wrongly associated slow pions, background, mixing of D meson used for tagging (small effect).

Mis-tag probability: ω (ω̄ for the anti-particle)
Dilution: D=1-2ω

If one defines: Δω=ω-ω̄
→the dilution becomes: D+Δω=1-2ω+Δω

One can account for mis-tag probabilities by considering the physical decay rate as function of Δt (correlated pairs):

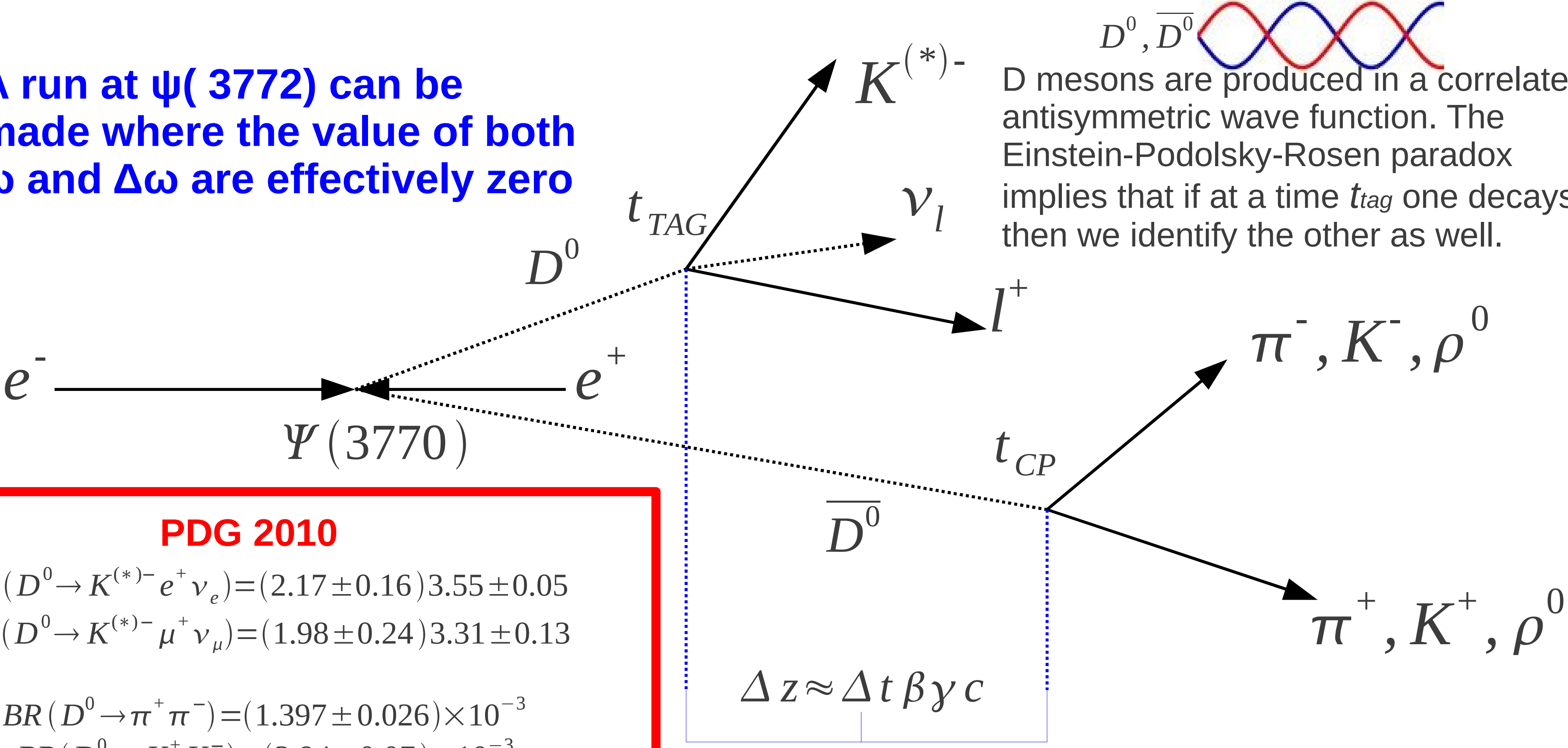
$$\Gamma^{Phys}(\Delta t) = (1-\overline{\omega})\,\Gamma(\Delta t) + \omega\,\overline{\Gamma}(\Delta t)$$
$$\overline{\Gamma}^{Phys}(\Delta t) = \overline{\omega}\,\Gamma(\Delta t) + (1-\omega)\,\overline{\Gamma}(\Delta t)$$

$$A^{Phys}(\Delta t) = \frac{\overline{\Gamma^{Phys}}(\Delta t) - \Gamma^{Phys}(\Delta t)}{\overline{\Gamma^{Phys}}(\Delta t) + \Gamma^{Phys}(\Delta t)} = -\Delta\omega + \frac{(D+\Delta\omega)\,e^{\Delta\Gamma|\Delta t|/2}(|\lambda_f|^2-1)\cos\Delta M\Delta t + 2\Im(\lambda_f)\sin\Delta M\Delta t}{(1+|\lambda_f|^2)h_+/2 + h_-\Re(\lambda_f)}$$

Semi-leptonic tagging

A run at ψ(3772) can be made where the value of both ω and Δω are effectively zero

D mesons are produced in a correlated antisymmetric wave function. The Einstein-Podolsky-Rosen paradox implies that if at a time t_{tag} one decays then we identify the other as well.



PDG 2010

$BR(D^0 \to K^{(*)-} e^+ \nu_e) = (2.17 \pm 0.16) 3.55 \pm 0.05$

$BR(D^0 \to K^{(*)-} \mu^+ \nu_\mu) = (1.98 \pm 0.24) 3.31 \pm 0.13$

$BR(D^0 \to \pi^+ \pi^-) = (1.397 \pm 0.026) \times 10^{-3}$

$BR(D^0 \to K^+ K^-) = (3.94 \pm 0.07) \times 10^{-3}$

At time t_{TAG} *the decays* $D \to K^{-(+)} l^{+(-)} \nu_l$ *account for* 11% *of all* D *decays and unambiguously assigns the flavour :* D^0 *is associated to a* l^+, $\overline{D^0}$ *is associated to a* l^-

Assuming PDG values for BR and CLEO_c efficiency for double tagging we expect with semi-leptonic tag ~158000 for $D^0 \to \pi^+ \pi^-$

Analysis of CP eigenstates (i)

When exploring CP violation, ignoring long distance effects, the parameter λ may be written as:

$$\lambda_f = \left|\frac{q}{p}\right| e^{i\phi_{MIX}} \left|\frac{\overline{A}}{A}\right| e^{i\phi_{CP}}$$

$$\phi_{MIX} : phase\ of\ D^0\overline{D^0}\ mixing$$

$$\phi_{CP} : overall\ phase\ of\ D^0 \rightarrow f_{CP}(eigenstate)$$

$$A = \ |T|\ \ e^{i(\phi_T+\delta_T)} + \ |CS|\ \ e^{i(\phi_{CS}+\delta_{CS})} + \ |W|\ \ e^{i(\phi_W+\delta_W)} + \sum_{q=d,s,b} |P_q|\ \ e^{(i\phi_q+\delta_q)}$$

The following processes, as we will see, are tree dominated

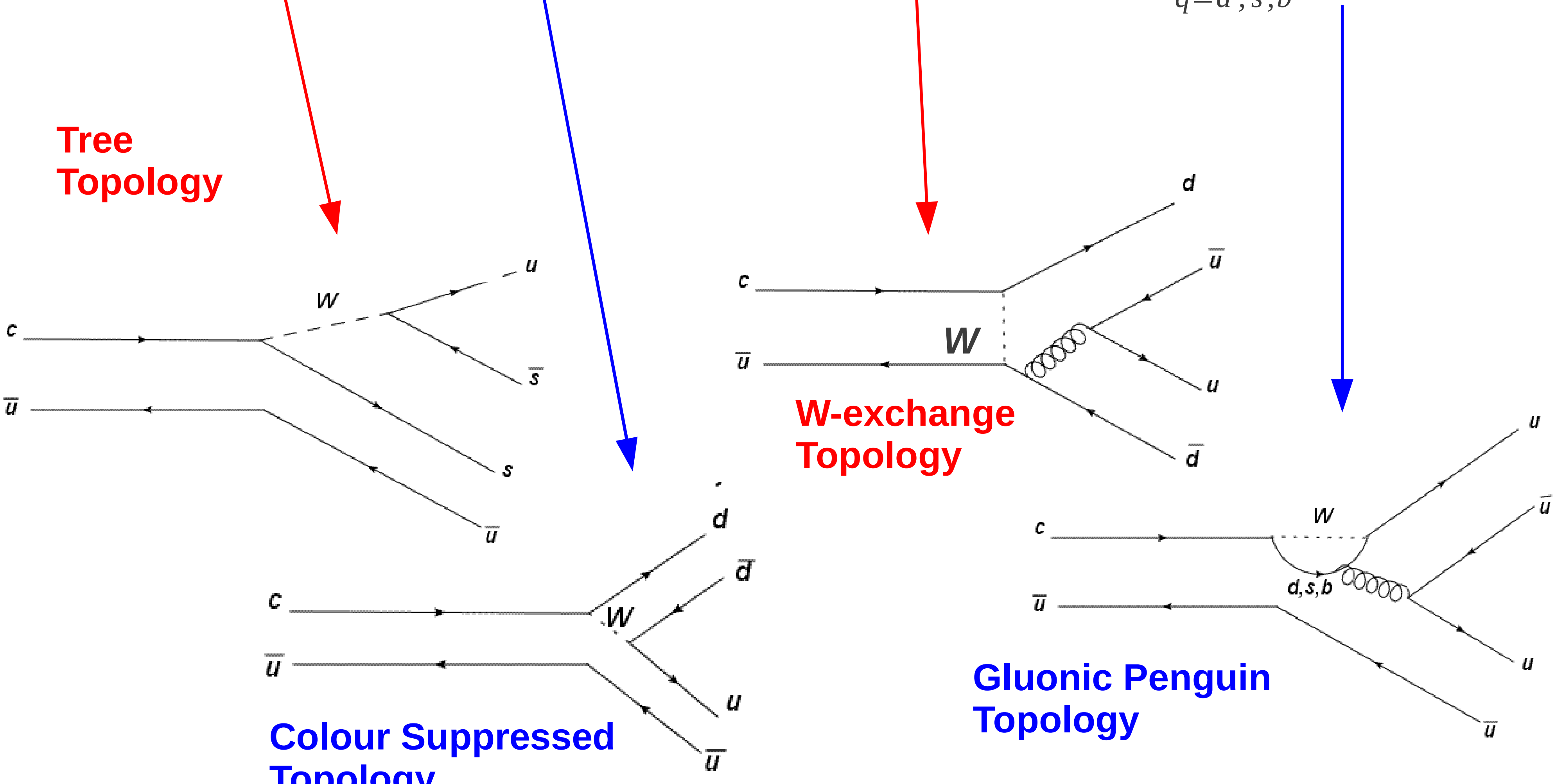
$$D^0 \rightarrow K^+K^-, \pi^+\pi^-, K^+K^-K^0, K^0\pi^+\pi^-$$

Assuming negligible the contribution due to P/CS/W amplitudes, then:

$$\boxed{\lambda_f = \left|\frac{q}{p}\right| e^{i\phi_{MIX}} e^{+2i\phi_T{}^W}}$$

Analysis of CP eigenstates (ii)

$$A=\boxed{|T|}\;e^{i(\phi_T+\delta_T)}+\boxed{|CS|}\;e^{i(\phi_{CS}+\delta_{CS})}+\boxed{|W|}\;e^{i(\phi_W+\delta_W)}+\sum_{q=d,s,b}\boxed{|P_q|}\;e^{(i\phi_q+\delta_q)}$$



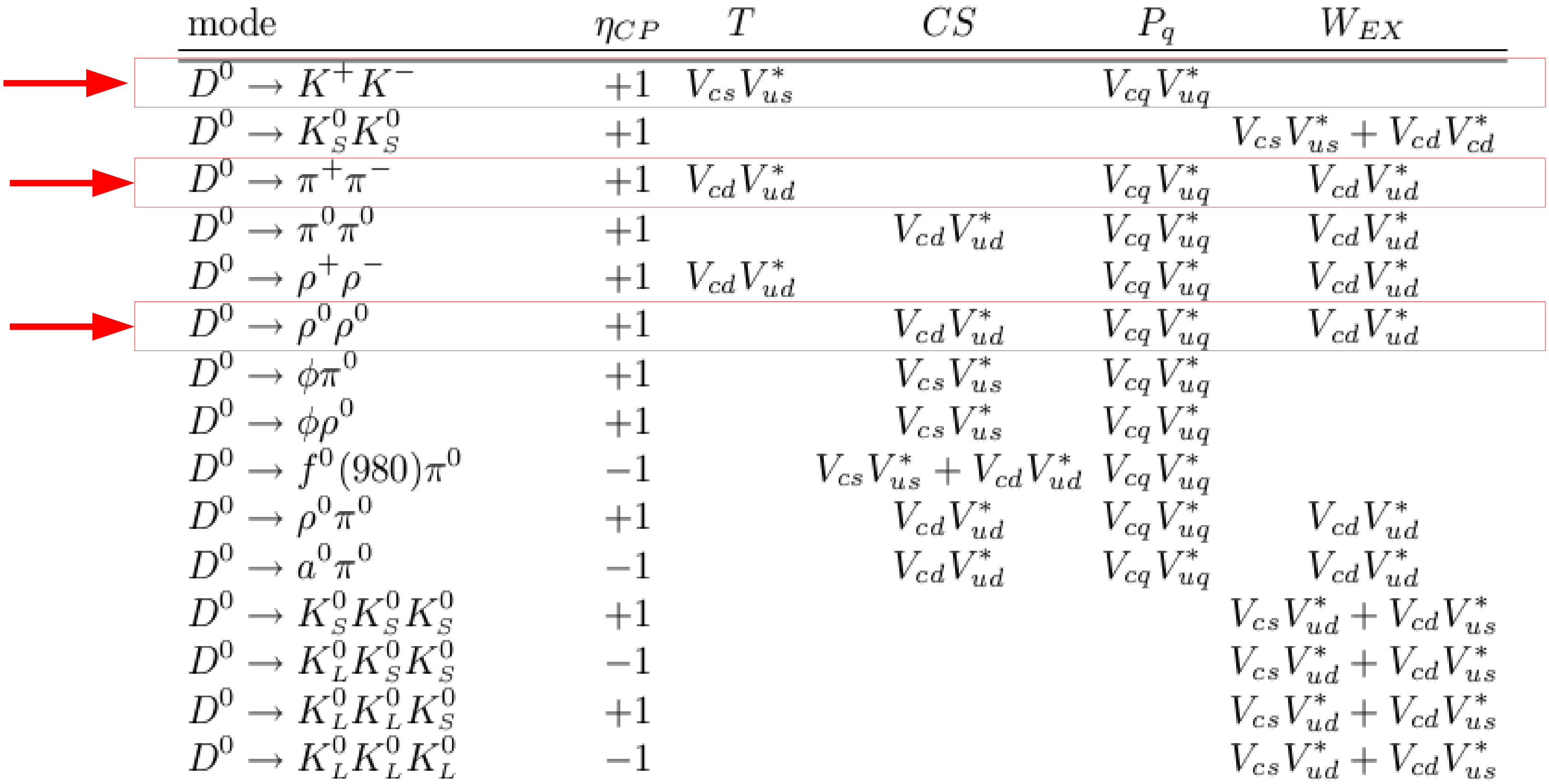
Tree Topology

W-exchange Topology

Colour Suppressed Topology

Gluonic Penguin Topology

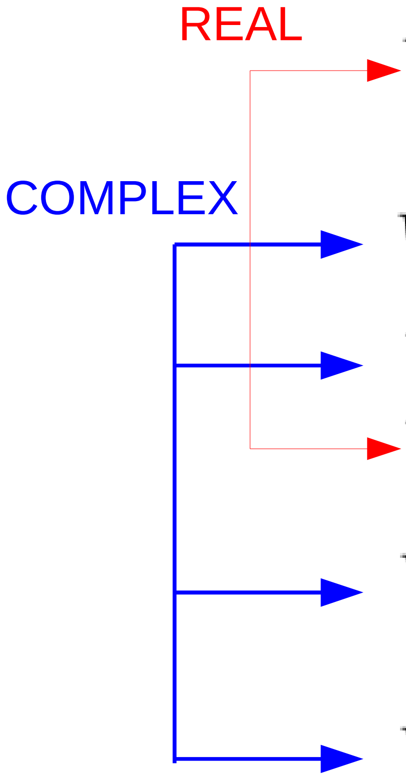
Analysis of CP eigenstates (iii)



mode	η_{CP}	T	CS	P_q	W_{EX}
$D^0 \rightarrow K^+K^-$	$+1$	$V_{cs}V^*_{us}$		$V_{cq}V^*_{uq}$	
$D^0 \rightarrow K^0_SK^0_S$	$+1$				$V_{cs}V^*_{us} + V_{cd}V^*_{cd}$
$D^0 \rightarrow \pi^+\pi^-$	$+1$	$V_{cd}V^*_{ud}$		$V_{cq}V^*_{uq}$	$V_{cd}V^*_{ud}$
$D^0 \rightarrow \pi^0\pi^0$	$+1$		$V_{cd}V^*_{ud}$	$V_{cq}V^*_{uq}$	$V_{cd}V^*_{ud}$
$D^0 \rightarrow \rho^+\rho^-$	$+1$	$V_{cd}V^*_{ud}$		$V_{cq}V^*_{uq}$	$V_{cd}V^*_{ud}$
$D^0 \rightarrow \rho^0\rho^0$	$+1$		$V_{cd}V^*_{ud}$	$V_{cq}V^*_{uq}$	$V_{cd}V^*_{ud}$
$D^0 \rightarrow \phi\pi^0$	$+1$		$V_{cs}V^*_{us}$	$V_{cq}V^*_{uq}$	
$D^0 \rightarrow \phi\rho^0$	$+1$		$V_{cs}V^*_{us}$	$V_{cq}V^*_{uq}$	
$D^0 \rightarrow f^0(980)\pi^0$	-1		$V_{cs}V^*_{us} + V_{cd}V^*_{ud}$	$V_{cq}V^*_{uq}$	
$D^0 \rightarrow \rho^0\pi^0$	$+1$		$V_{cd}V^*_{ud}$	$V_{cq}V^*_{uq}$	$V_{cd}V^*_{ud}$
$D^0 \rightarrow a^0\pi^0$	-1		$V_{cd}V^*_{ud}$	$V_{cq}V^*_{uq}$	$V_{cd}V^*_{ud}$
$D^0 \rightarrow K^0_SK^0_SK^0_S$	$+1$				$V_{cs}V^*_{ud} + V_{cd}V^*_{us}$
$D^0 \rightarrow K^0_LK^0_SK^0_S$	-1				$V_{cs}V^*_{ud} + V_{cd}V^*_{us}$
$D^0 \rightarrow K^0_LK^0_LK^0_S$	$+1$				$V_{cs}V^*_{ud} + V_{cd}V^*_{us}$
$D^0 \rightarrow K^0_LK^0_LK^0_L$	-1				$V_{cs}V^*_{ud} + V_{cd}V^*_{us}$

Analysis of CP eigenstates (iv)

Amplitude to order λ^6:



REAL

COMPLEX

$$V_{cs}V_{us}^* = \lambda - \frac{\lambda^3}{2} - \left(\frac{1}{8}+\frac{A^2}{2}\right)\lambda^5,$$

$$V_{cd}V_{ud}^* = -\lambda + \frac{\lambda^3}{2} + \frac{\lambda^5}{8} + \frac{A^2\lambda^5}{2}[1-2(\bar\rho+i\bar\eta)]$$

$$V_{cb}V_{ub}^* = A^2\lambda^5(\bar\rho+i\bar\eta),$$

$$V_{cd}V_{cd}^* = \lambda^2 - \lambda^6 A^2[1-2\bar\rho],$$

$$V_{cs}V_{ud}^* = 1-\lambda^2-\frac{A^2\lambda^4}{2}+A^2\lambda^6\left[\frac{1}{2}-\bar\rho-i\bar\eta\right]$$

$$V_{cd}V_{us}^* = -\lambda^2 + \frac{A^2\lambda^6}{2}[1-2(\bar\rho+i\bar\eta)].$$

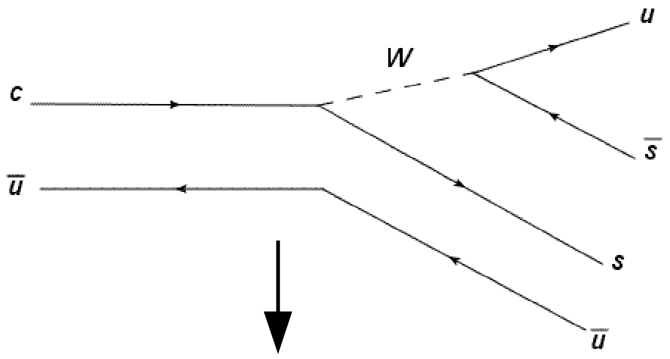
$V_{cb}V_{ub}^*$ *large phase* : $V_{ub}\rightarrow\gamma_c=\gamma$

$V_{cd}V_{ud}^*$ and $V_{cd}V_{us}^*$ *small phase* : $V_{cd}\rightarrow\beta_c$

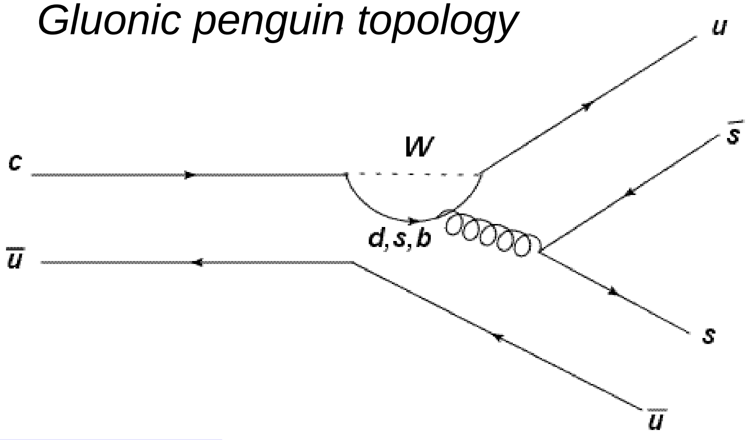
$V_{cs}V_{ud}^*$ *small phase entering at* $O(\lambda^6)$

$D^0 \rightarrow K^+ K^-$

Tree topology



Gluonic penguin topology



$$V_{cs}V_{us}^{*}$$

$$V_{cs}V_{us}^* = \lambda - \frac{\lambda^3}{2} - \left(\frac{1}{8}+\frac{A^2}{2}\right)\lambda^5$$

Real

$$\boxed{V_{cd}V_{ud}^{*}} + V_{cs}V_{us}^{*} + V_{cb}V_{ub}^{*}$$

Real **Negligible**

$$\boxed{V_{cd}V_{ud}^* = -\lambda + \frac{\lambda^3}{2} + \frac{\lambda^5}{8} + \frac{A^2\lambda^5}{2}[1-2(\bar{\rho}+i\bar{\eta})]}$$

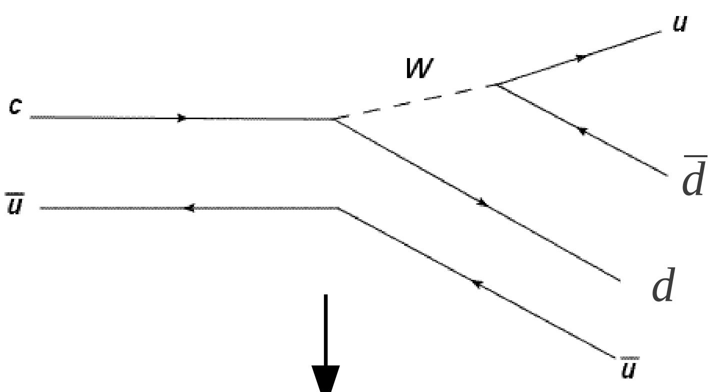
To first order one would expect to measure an asymmetry consistent with zero:

→ **cross check of detector reconstruction and calibration**

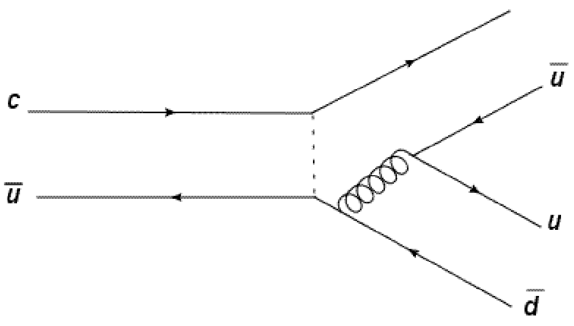
→ **ideal mode to use when searching for new physics (NP)**

$D^0 \rightarrow \pi^+ \pi^-$ (i)

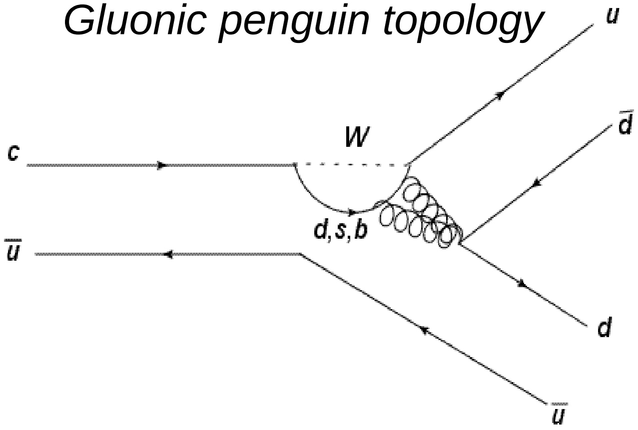
Tree topology



Weak Exchange (WE) topology



Gluonic penguin topology



$\boxed{V_{cd}V^*_{ud}}$

$\boxed{V_{cd}V^*_{ud}}$

$\boxed{V_{cd}V^*_{ud}} + V_{cs}V^*_{us} + V_{cb}V^*_{ub}$

Real **Negligible**

$$\boxed{V_{cd}V^*_{ud} = -\lambda + \frac{\lambda^3}{2} + \frac{\lambda^5}{8} + \frac{A^2\lambda^5}{2}[1-2(\bar{\rho}+i\bar{\eta})]} \longrightarrow V_{cd}V^*_{ud} \rightarrow \beta_c$$

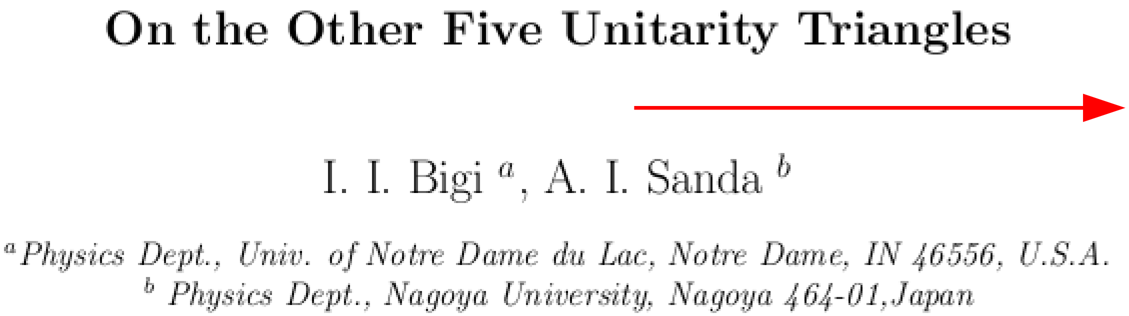
Penguin topologies are DCS loops while the Tree amplitude is CS

→ **Penguin contribution could in principle be ignored, but..**

→ **A complete theoretical analysis is necessary if one wants to extract the weak phase and disentangle the c → s → u penguin**

$D^0 \rightarrow \pi^+ \pi^-$ (ii)

hep-ph/9909479



On the Other Five Unitarity Triangles

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There are two Isospin amplitude contributing to the process $D^0 \rightarrow \pi^+ \pi^-$ and the situation is almost the same with respect to the process where $B^0 \rightarrow \pi\, \pi$.

$$A(\Delta t) = \frac{\bar{\Gamma}(\Delta t) - \Gamma(\Delta t)}{\bar{\Gamma}(\Delta t) + \Gamma(\Delta t)} = 2e^{\Delta\Gamma t/2} \frac{(|\lambda_f|^2 - 1)\cos\Delta M \Delta t + 2\Im(\lambda_f)\sin\Delta M \Delta t}{(1+|\lambda_f|^2)(1+e^{\Delta\Gamma\Delta t}) + 2\Re(\lambda_f)(1-e^{\Delta\Gamma\Delta t})}$$

$$when \quad \Delta\Gamma = 0 \rightarrow A(\Delta t) = -C\cos\Delta M \Delta t + S\sin\Delta M \Delta t$$

The difference between the process $D^0 \rightarrow \pi^+ \pi^-$ and the process where $B^0 \rightarrow \pi\, \pi$ is that $\Delta\Gamma \neq 0$. The effect is that instead of measuring S and C, one measure directly the real and imaginary part of λ_f:

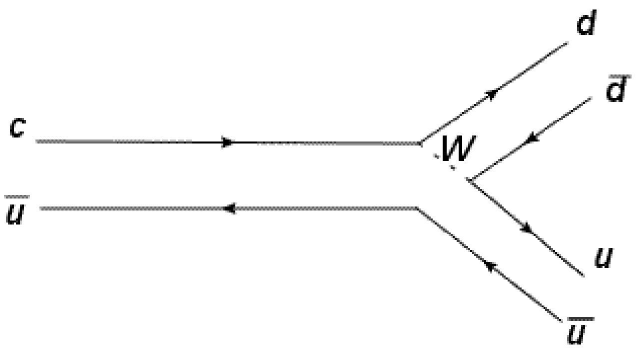
$$\lambda_f = \frac{q}{p} \frac{\bar{A}}{A}$$

If one wants relate precisely the weak phase to the observed CP asymmetry, to constrain the penguin pollution it becomes necessary to measure $D^0 \rightarrow \pi^+ \pi^-$,$D^+ \rightarrow \pi^+ \pi^0$,$D^0 \rightarrow \pi^0 \pi^0$

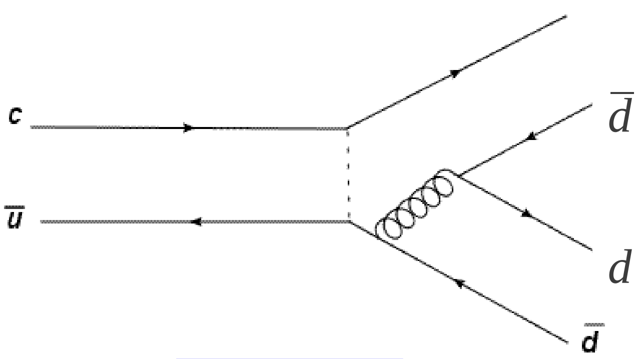
This will require an e^+e^- environment

$D^0 \to \rho^0 \rho^0$

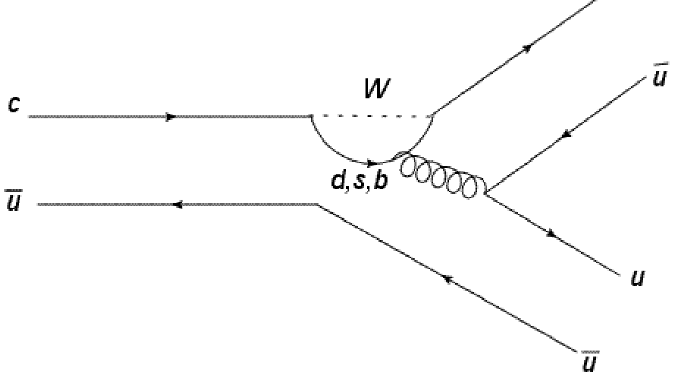
Color Suppressed (CS) Tree topology



Weak Exchange (WE) topology



Gluonic penguin topology



$\boxed{V_{cd} V^*_{ud}}$

$\boxed{V_{cd} V^*_{ud}}$

$\boxed{V_{cd} V^*_{ud}} + V_{cs} V^*_{us} + V_{cb} V^*_{ub}$

Real

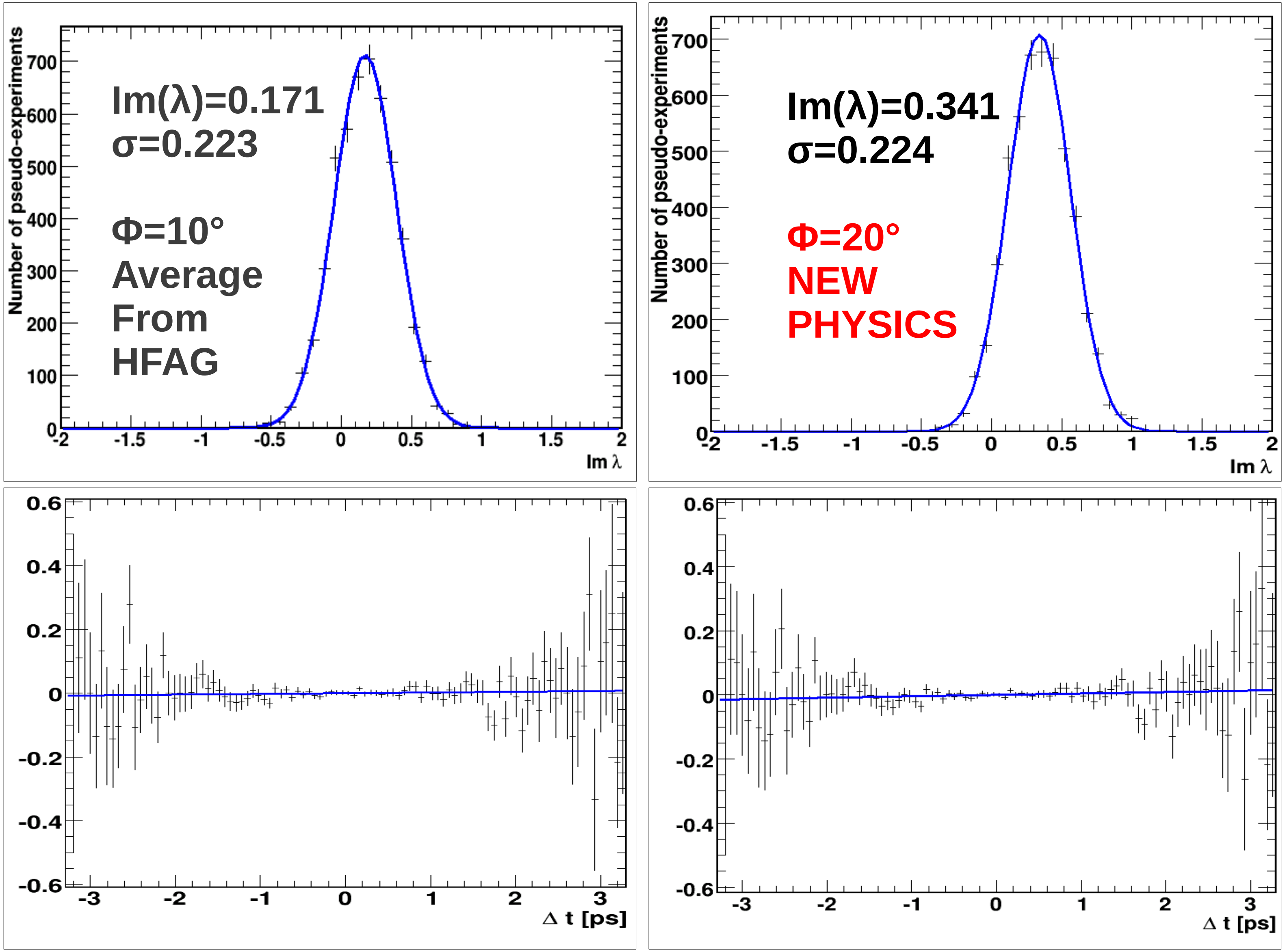
Negligible

$$\boxed{V_{cd}V^*_{ud} = -\lambda + \frac{\lambda^3}{2} + \frac{\lambda^5}{8} + \frac{A^2\lambda^5}{2}[1 - 2(\bar{\rho} + i\bar{\eta})]}$$

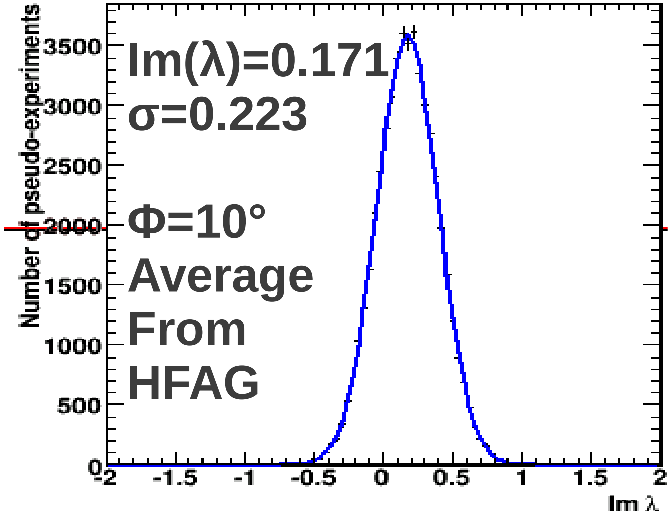
Similar situation as in $D^0 \to \pi^+ \pi^-$

Simulated performance of TDCPV at ψ(3770)

- $\Psi(3770)\,channel:$ $D_{tag}\rightarrow K^{-}e^{+}\nu_{e}$ $D^{0}\rightarrow\pi^{+}\pi^{-}$
- $SuperB\;3\;months\;at\;3770:\quad 500\;fb^{-1}$
- $Estimated\;\;yelds$ from $CLEO_{c}\,results:$ $158000\;D^{0}\rightarrow\pi^{+}\pi^{-}$
- $Adding\;D_{tag}\rightarrow K^{*}e^{+}\nu_{e}$ $double\quad the\;statistics$
- $More\;tagging\;modes$ $plus\;6\;months\;run\;at\;the$ $\Psi(3770)\,means\;6$ times $larger\;data\;sample$



Im(λ) vs. Re(λ)

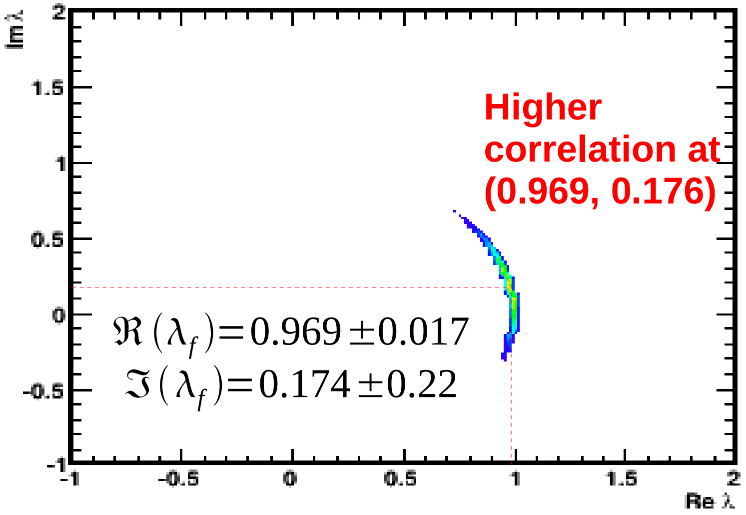


Im(λ)=0.171
σ=0.223

Φ=10°
Average
From
HFAG

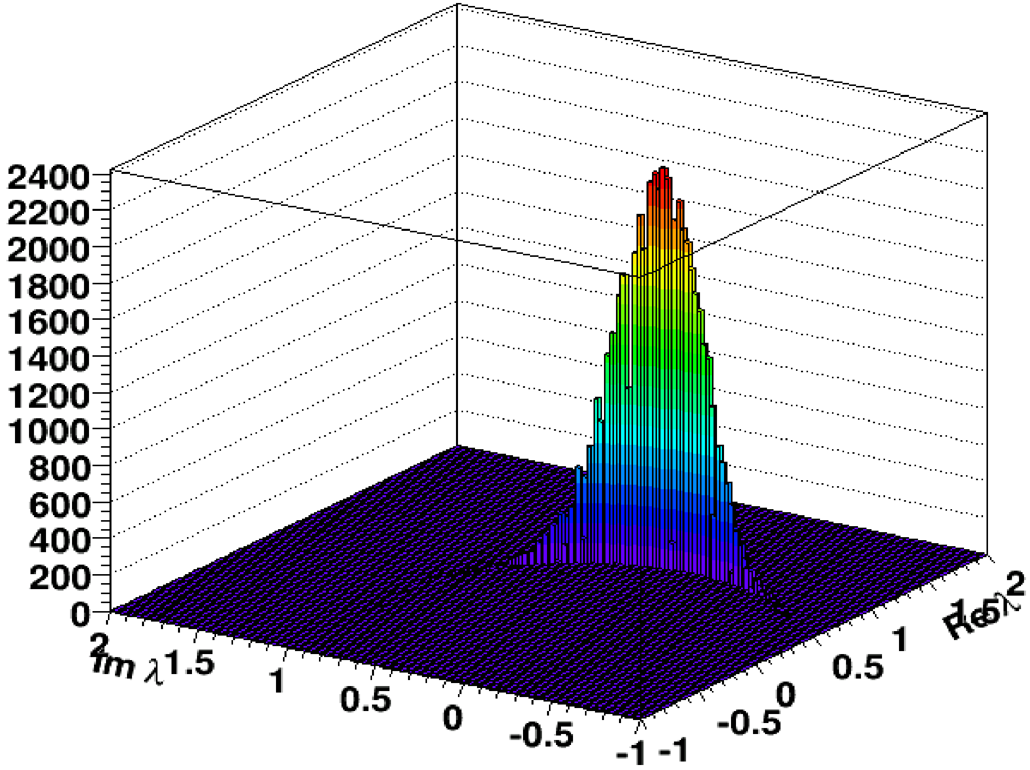
160000 $D^0 \to \pi^+ \pi^-$ equivalent to 0.5 ab^{-1}
We run 50000 pseudo-experiments
We expect :

$$\Re(\lambda_f)=0.985$$
$$\Im(\lambda_f)=0.174$$

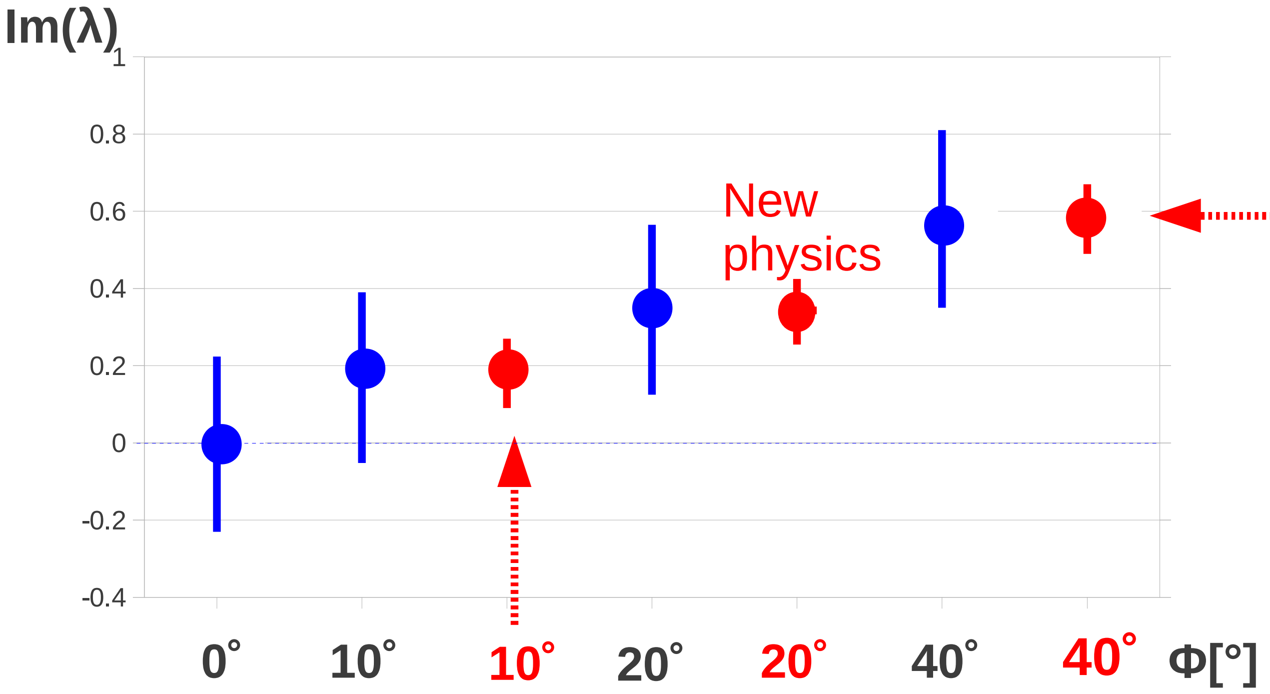


Higher correlation at (0.969, 0.176)

$$\Re(\lambda_f)=0.969\pm0.017$$
$$\Im(\lambda_f)=0.174\pm0.22$$



Imaginary part of λ vs Φ: CP-violation



New physics

6 times larger data sample

6 times larger data sample

Don't forget:

$$BR(D^0 \rightarrow \pi^+ \pi^-) = (1.397 \pm 0.026) \times 10^{-3}$$

$$BR(D^0 \rightarrow K^+ K^-) = (3.94 \pm 0.07) \times 10^{-3}$$

SLIDE 18: 6 months run!

As already seen, the value of λ is strictly dependent on the value of the phase Φ. The red dots show that a longer run or more tagging modes at Ψ(3770) would provide an higher precision (smaller error) for this measurement.

- **The precision does NOT depend on the value of the phase Φ.**

Uncorrelated D^0 mesons

$$A(t)=\frac{\overline{\Gamma}(t)-\Gamma(t)}{\overline{\Gamma}(t)+\Gamma(t)}=2e^{\Delta\Gamma t/2}\frac{(|\lambda_f|^2-1)\cos\Delta M\,t+2\Im(\lambda_f)\sin\Delta M\,t}{(1+|\lambda_f|^2)(1+e^{\Delta\Gamma t})+2\Re(\lambda_f)(1-e^{\Delta\Gamma t})}$$

Mistag probability and dilution become important

$$A^{Phys}(t)=\frac{\overline{\Gamma^{Phys}}(t)-\Gamma^{Phys}(t)}{\overline{\Gamma^{Phys}}(t)+\Gamma^{Phys}(t)}=+\Delta\omega+\frac{(D-\Delta\omega)e^{\Delta\Gamma t/2}(|\lambda_f|^2-1)\cos\Delta M\,t+2\Im(\lambda_f)\sin\Delta M\,t}{(1+|\lambda_f|^2)h_+/2+h_-\Re(\lambda_f)}$$

The flavour tagging is accomplished by identifying a “slow” pion in the processes (CP and CP conjugated):

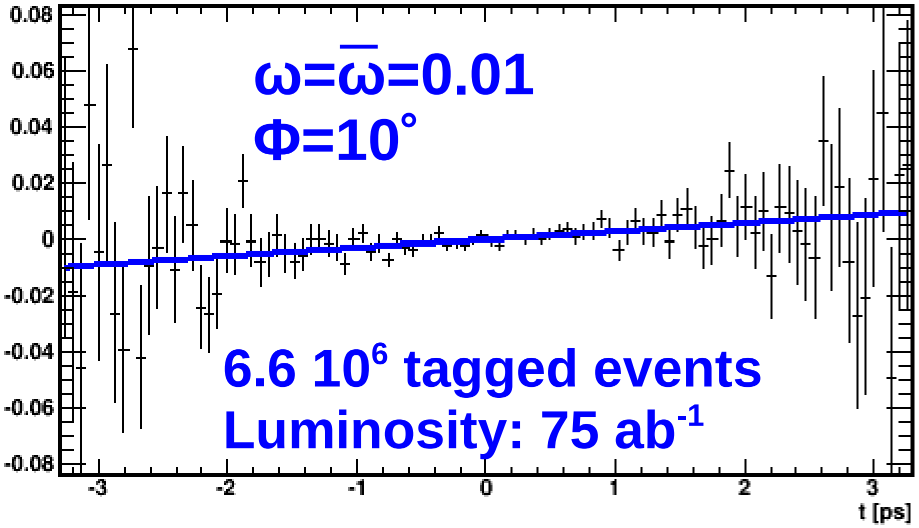
$$D^{*+}\rightarrow D^0\pi^+$$
$$D^{*-}\rightarrow \overline{D}^0\pi^-$$

SuperB at $\Upsilon(4S)$ and LHCb

D* from $e^+e^-\rightarrow c\overline{c}$ can be separated from those coming from B's by applying a momentum cut.
Clean environment.
More easier to separate prompt D* from B cascade than LHCb

D* mesons are secondary particles produced in the primary decay of a B meson.
High background level to keep under control.
Trigger efficiency.

Uncorrelated mesons: SuperB vs. LHCb

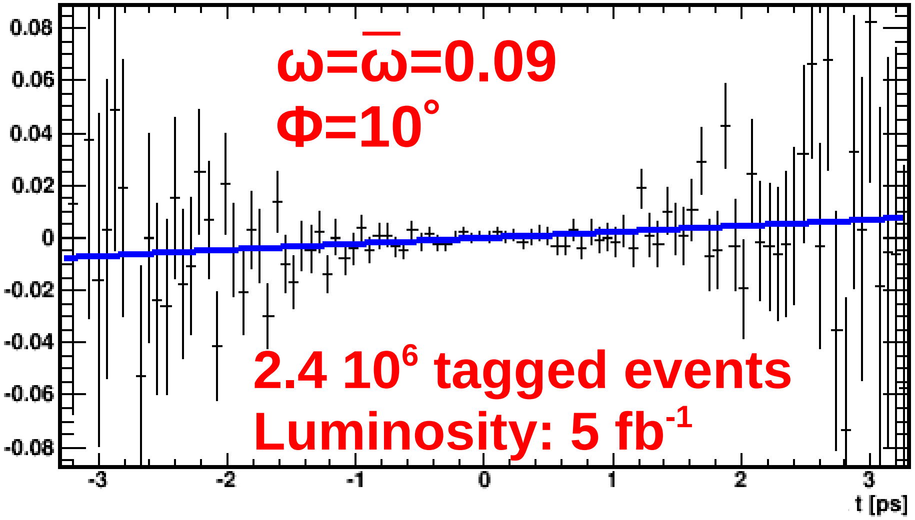


$\omega=\overline{\omega}=0.01$

$\Phi=10^{\circ}$

$6.6\ 10^{6}$ tagged events

Luminosity: 75 ab^{-1}

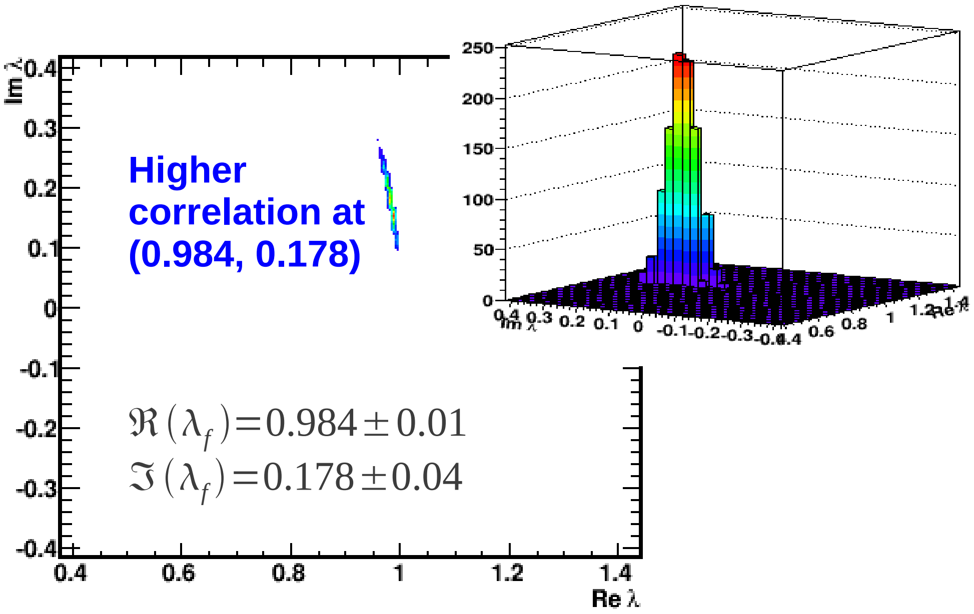


$\omega=\overline{\omega}=0.09$

$\Phi=10^{\circ}$

$2.4\ 10^{6}$ tagged events

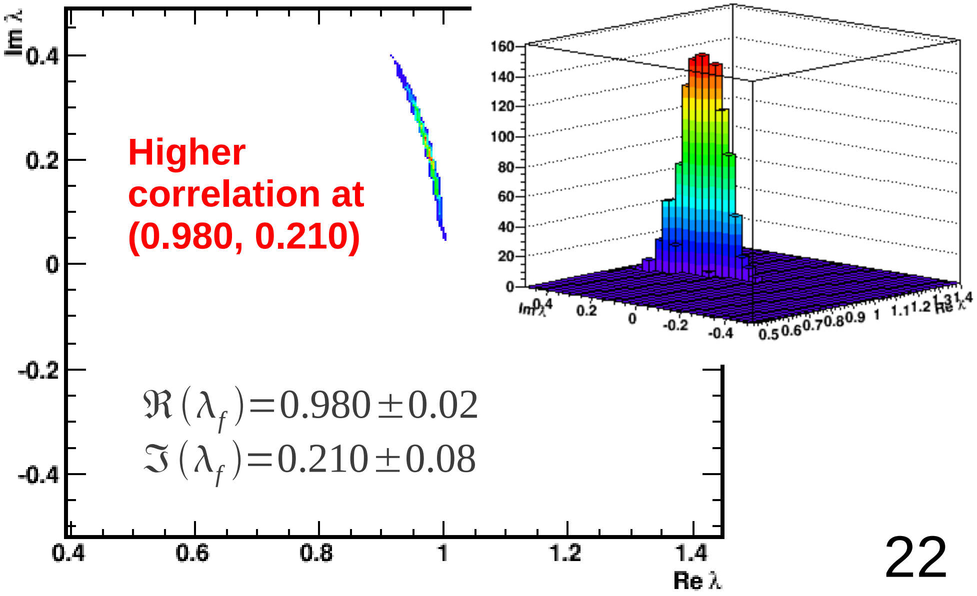
Luminosity: 5 fb^{-1}



Higher correlation at (0.984, 0.178)

$\Re(\lambda_f)=0.984\pm0.01$

$\Im(\lambda_f)=0.178\pm0.04$

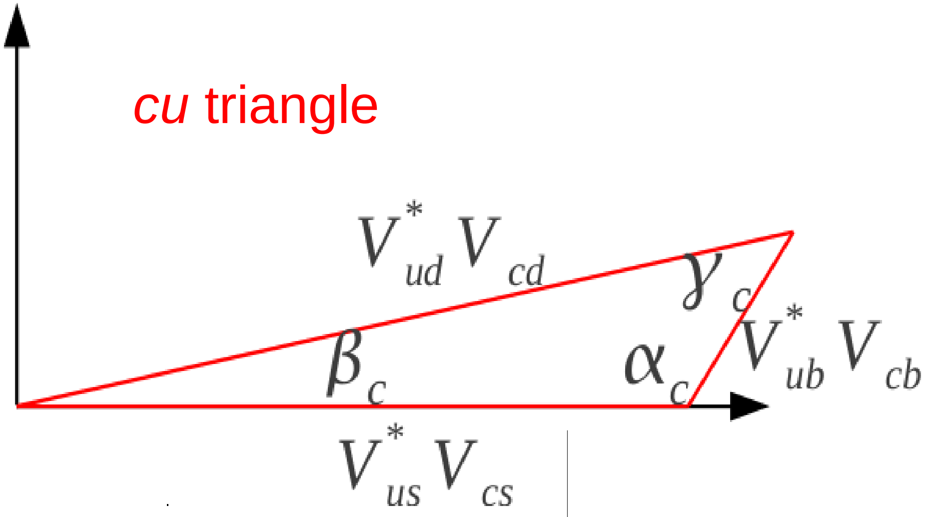


Higher correlation at (0.980, 0.210)

$\Re(\lambda_f)=0.980\pm0.02$

$\Im(\lambda_f)=0.210\pm0.08$

Constraint on the *cu* triangle



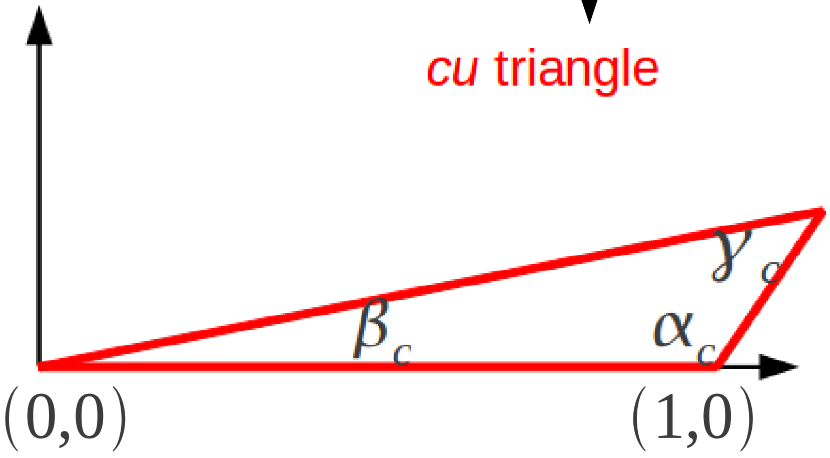
It is possible to constrain the apex of the *cu* triangle in two ways:

1) by constraining two internal angles
2) by measuring the sides

Normalizing the baseline to 1, so dividing by $V^*_{us}V_{cs}$

$$\gamma_c = (68.4 \pm 0.1)^o \quad \text{from}\ CKM\ prediction$$

$$+ any\ measurement\ of\ \beta_c \rightarrow constraint\ \ on\ \ the\ apex\ of\ the\ triangle$$



$$X + iY = 1 + \frac{A^2\lambda^5(\bar{\rho} + i\bar{\eta})}{\lambda - \lambda^3/2 - \lambda^5(1/8 + A^2/2)}$$

Using existing constraints on Wolfenstein parameters, we find:

$$X = 1.00025$$
$$Y = 0.00062$$

Conclusions

We are exploring time-dependent CP asymmetries in charm and we defined a measurement for the β_c angle in the charm UT.

After defining the tagging for charm, we have studied a number of possible final states.

Using the developed formalism we simulated pseudo-experiments assuming SuperB luminosity and we have shown that a possible measurement for TDCP asymmetries will be reasonable.

We simulated pseudo-experiments and applied the formalism for uncorrelated mesons for both SuperB and LHCb and we compared the obtained results. We highlight that a precision measurement of any time-dependent effect will require a detailed understanding of the background.

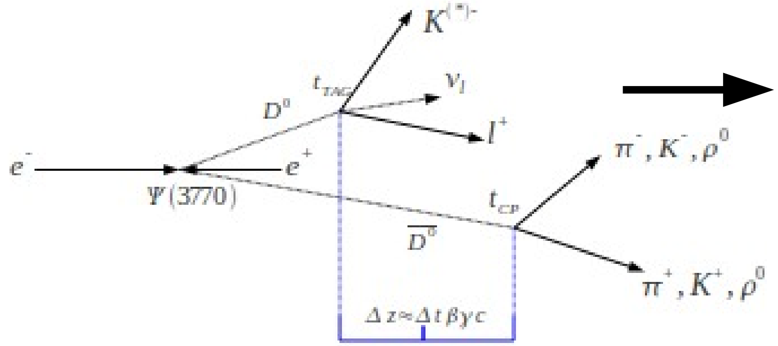
We define a test of the standard model by constraining the apex of the cu triangle

A larger run at charm threshold would provide a more precise measurement of β_c

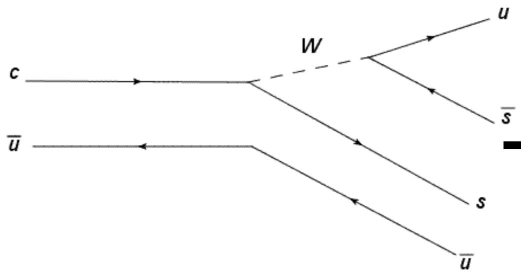
Conclusions: pictures

$$A^{Phys}(\Delta t)=\frac{\overline{\Gamma}^{Phys}(\Delta t)-\Gamma^{Phys}(\Delta t)}{\overline{\Gamma}^{Phys}(\Delta t)+\Gamma^{Phys}(\Delta t)}=-\Delta\omega+\frac{(D+\Delta\omega)e^{\Delta\Gamma|\Delta t|/2}(|\lambda_f|^2-1)\cos\Delta M\Delta t+2\Im(\lambda_f)\sin\Delta M\Delta t}{(1+|\lambda_f|^2)h_+/2+h_-\Re(\lambda_f)}$$

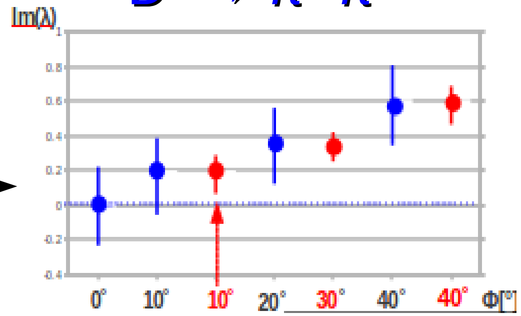
Semi-leptonic tagging

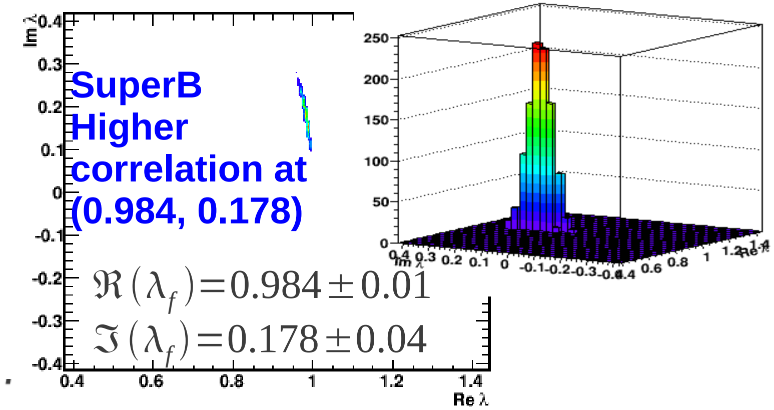


Tree Topology



$D^0 \rightarrow \pi^+ \pi^-$

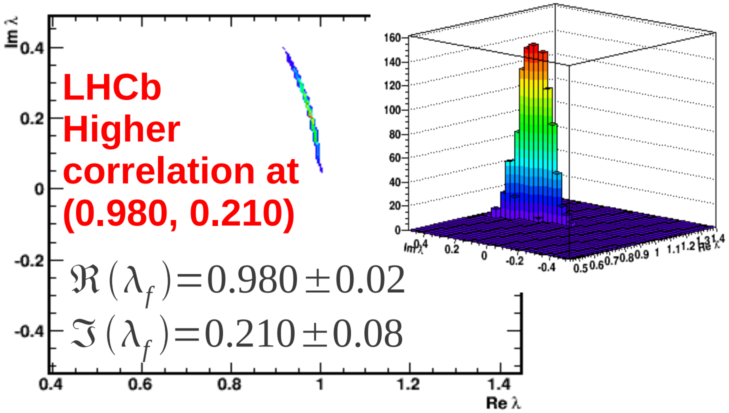




SuperB Higher correlation at (0.984, 0.178)

$\Re(\lambda_f)=0.984\pm0.01$

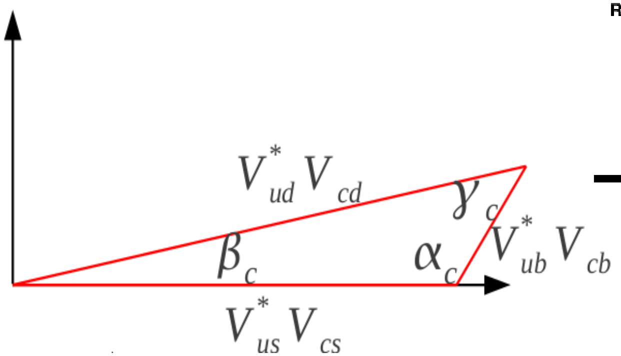
$\Im(\lambda_f)=0.178\pm0.04$



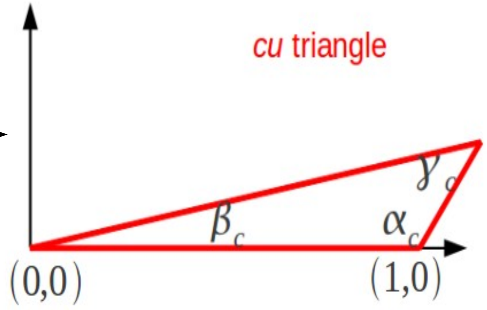
LHCb Higher correlation at (0.980, 0.210)

$\Re(\lambda_f)=0.980\pm0.02$

$\Im(\lambda_f)=0.210\pm0.08$



cu triangle



$$X+iY=1+\frac{A^2\lambda^5(\overline{\rho}+i\overline{\eta})}{\lambda-\lambda^3/2-\lambda^5(1/8+A^2/2)}$$

$X=1.00025$

$Y=0.00062$

Back up slide 1

B_d mesons (i)

All the time-dependent CP asymmetry measurements made on the assumption that **ΔΓ=0.** **What if ΔΓ≠0?**

$$A(\Delta t)=\frac{\overline{\Gamma}(\Delta t)-\Gamma(\Delta t)}{\overline{\Gamma}(\Delta t)+\Gamma(\Delta t)}=2e^{\Delta\Gamma t/2}\frac{(|\lambda_f|^2-1)\cos\Delta M\Delta t+2\Im(\lambda_f)\sin\Delta M\Delta t}{(1+|\lambda_f|^2)(1+e^{\Delta\Gamma\Delta t})+2\Re(\lambda_f)(1-e^{\Delta\Gamma\Delta t})}$$

$$when\quad \Delta\Gamma=0\rightarrow A(\Delta t)=-C\cos\Delta M\Delta t+S\sin\Delta M\Delta t$$

$$S=\frac{2\Im(\lambda_f)}{1+|\lambda_f|^2},\qquad C=\frac{1-|\lambda_f|^2}{1+|\lambda_f|^2}$$

Example distributions: B^0

$\tau = 1.525\times10^{-12}$ s

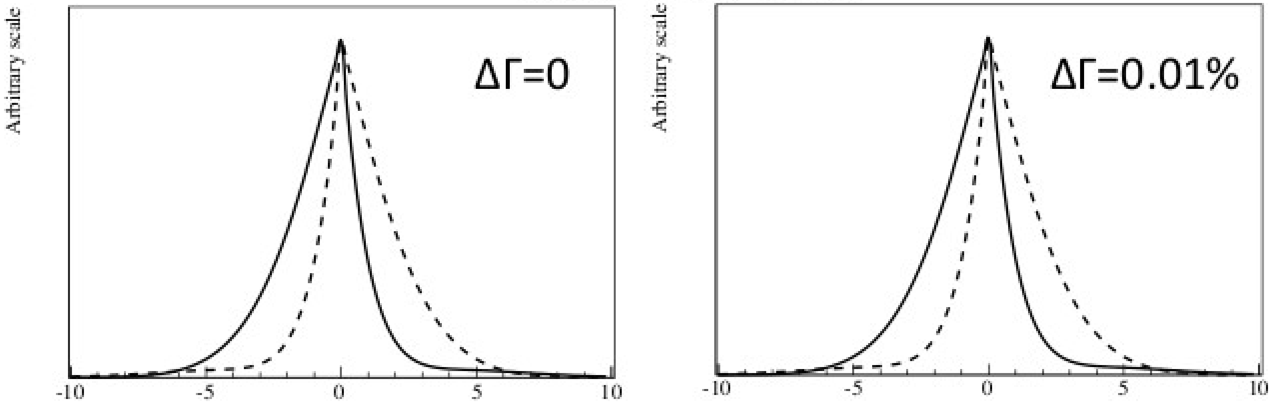
$\Gamma=1/\tau=0.656\times10^{12}$ /s

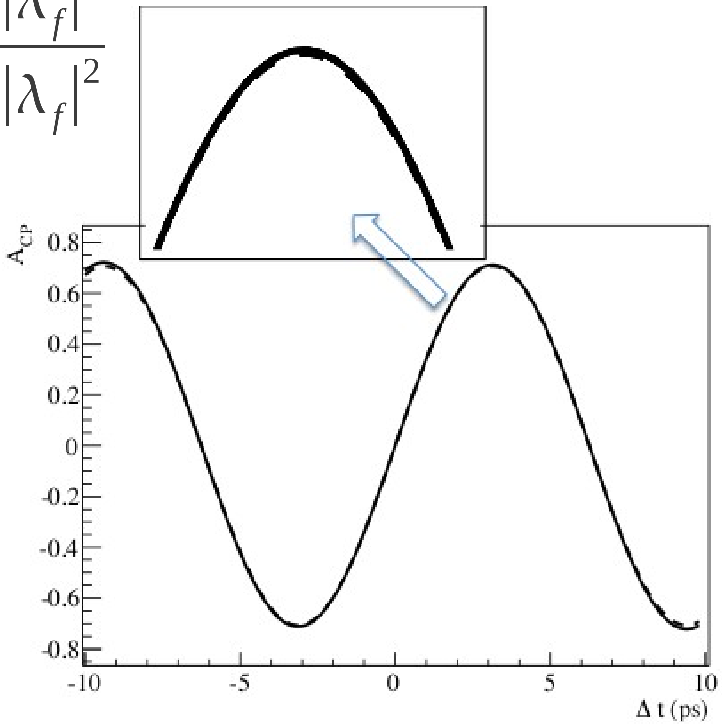
$\Delta m = 0.507\times10^{12}$ /s

$\Delta\Gamma <= 6.56\times 10^{9}$ /s

$(\Delta\Gamma/\Gamma = 0.01 [\pm0.037])$

Re(λ)=Im(λ)=1/√2



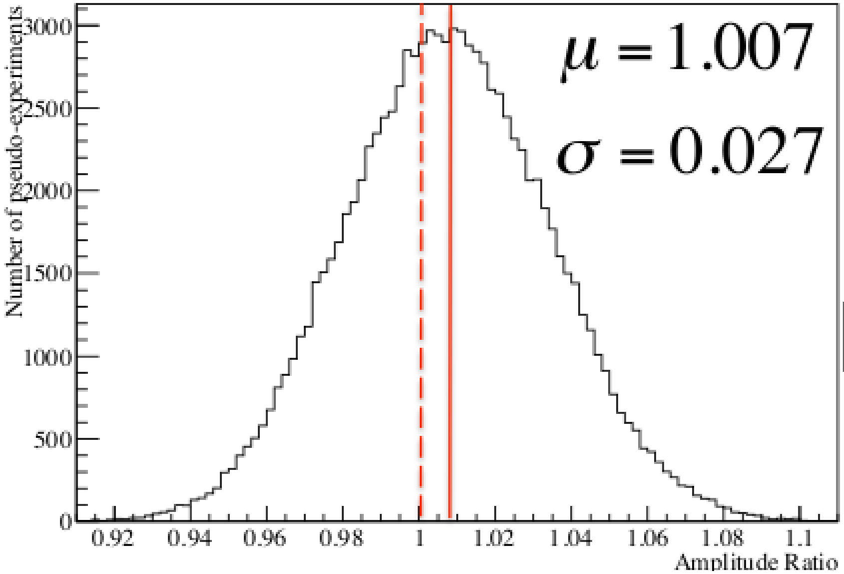


Back up slide 2

B_d mesons (ii)

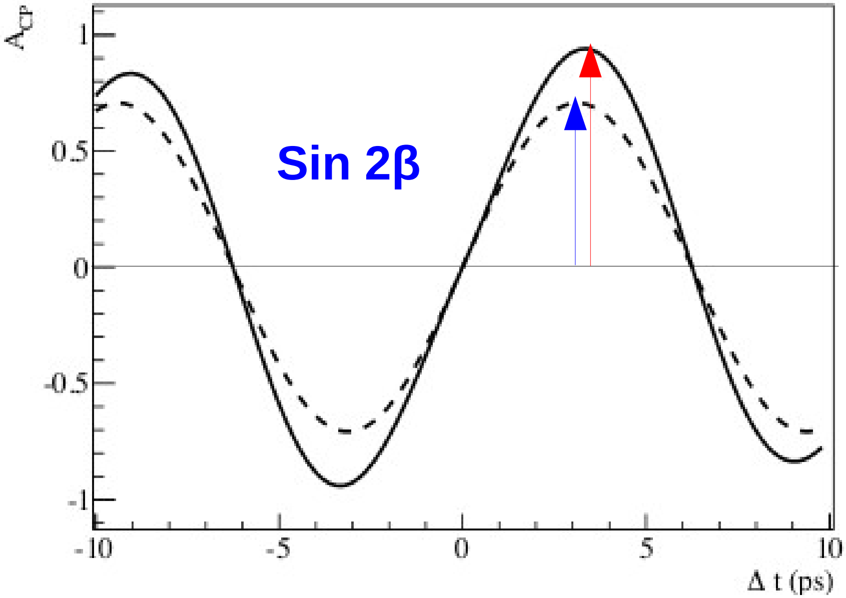
Example distributions: B^0

$\tau = 1.525\text{x}10^{-12}$ s
$\Gamma=1/\tau=0.656\text{x}10^{12}$ /s
$\Delta m = 0.507\text{x}10^{12}$ /s
$\Delta\Gamma <= 6.56\text{x}\ 10^{9}$ /s
($\Delta\Gamma/\Gamma = 0.01$ [±0.037])



Without better experimental determination, current measurements are at the level where we should be taking into account a possible non-zero $\Delta\Gamma/\Gamma$.

An extreme case: $\Delta\Gamma/\Gamma = 0.50$



Positive $\Delta\Gamma/\Gamma$ leads to an enhancement of the amplitude, a negative $\Delta\Gamma/\Gamma$ leads to a decrease.

Dashed line is $\Delta\Gamma$=0.

Back up slide 3

B_s mesons

Oscillation in Bs decays are extremely fast: SuperB will not be able to perform a time-dependent CP asymmetry analysis

With a large sample of events at Y(5S) the distribution of events as function of Δt would contain information on *Im*(λ) and *Re*(λ)

→ **informations on CPV related to TD measurements from hadron collider**

→ **particularly relevant for final states including neutral particles, such as $B_s^0 \rightarrow \eta' \Phi$, challenging measurement at hadron collider**

$$B_s \rightarrow \rho K_S^{0,} \quad D_s^{+(-)} K^{-(+)}; \qquad B_s \rightarrow D\Phi$$

LHCb can do these measurements well, since they have good time resolution
SuperB can probably measure asymmetries for Δt<0 vs. Δt>0

$B_s \rightarrow \pi^0 K_S^0$ The presence of the neutral pion and lack of informations to constrain the primary vertex: **excellent candidate for SuperB**

Thank you for your attention...
...and...