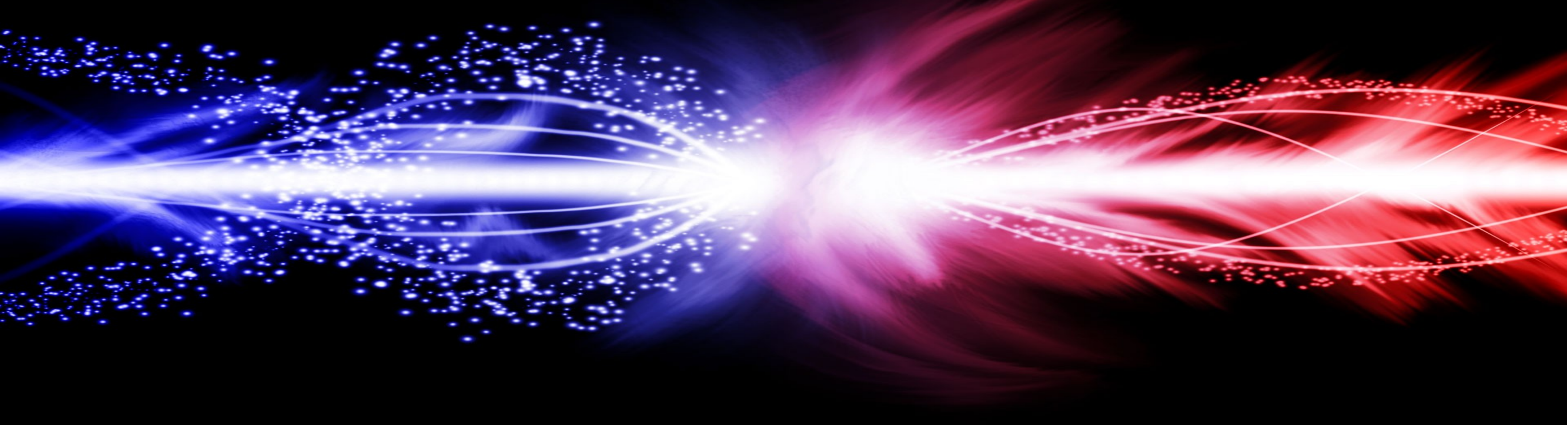
IOP Institute of Physics

2013 High Energy and Astro Particle Physics

Charm and New Physics Opportunities @ Colliders

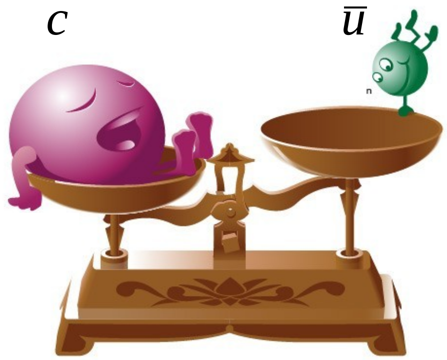


"A person who never made a mistake never tried anything new"

Institute Of Physics
Joint HEPP & APP workshop
Liverpool- UK
10/04/2012

Queen Mary University of London

Gianluca Inguglia
Queen Mary, University of London
g.inguglia@qmul.ac.uk,
gianluca.inguglia@cern.ch



$$D^0 \; meson$$
$$c-\bar{u} \quad bound \quad state$$
$$Mass \quad m = 1864.83 \pm 0.14 \; MeV$$
$$Mean \quad lifetime \quad \tau = 410.1 \pm 1.5 \, x \, 10^{-15} \, s$$
$$c\tau = 122.9 \, \mu m$$
$$I(J^P) = \frac{1}{2}(0^-)$$

- Charmonium Spectroscopy
- CP Violation
  - Direct
  - Indirect
  - Interference: charm unitarity triangle
- Mixing
- Rare decays

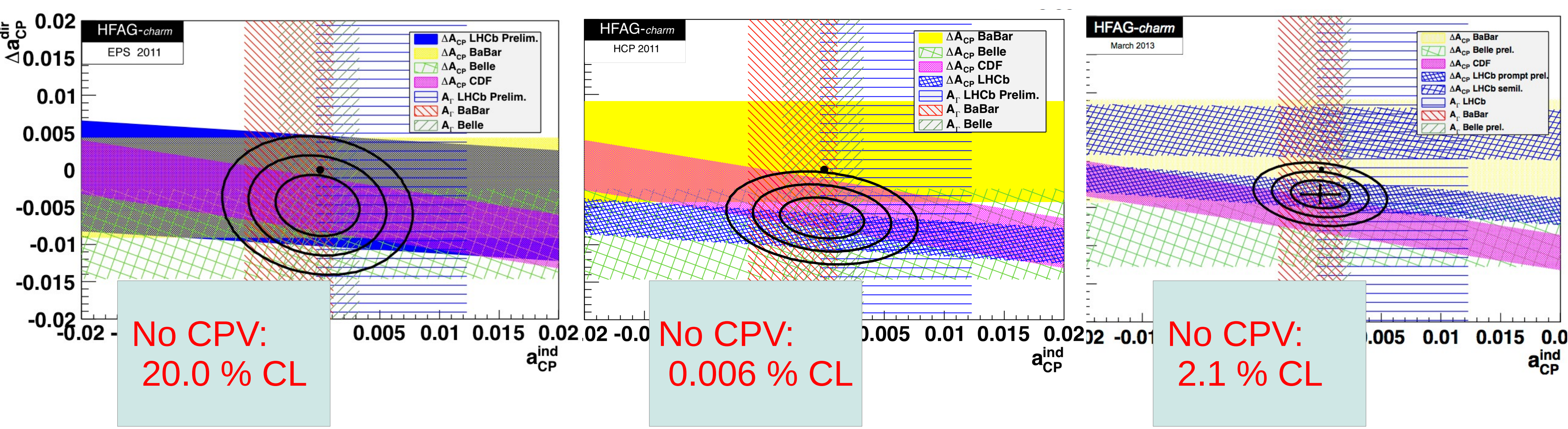
Here we concentrate on D^0 mesons, in particular to CP violation and mixing, and how to use related measurements to infer new physics

Tests discussed here can be performed in both hadron or electron/positron colliders

In past two years very interesting measurement aimed to test CP invariance in the charm sector have been performed by various collaborations: BaBar, Belle, CDF, LHCb...

In particular the decay channels $D^0 \rightarrow K^+ K^-, \pi^+ \pi^-$ have been used to construct the observable ΔA_{CP} :

$$\Delta A_{\mathrm{CP}} = A_{\mathrm{CP}}(K^+K^-) - A_{\mathrm{CP}}(\pi^+\pi^-) = \Delta A_{\mathrm{CP}}^{\mathrm{dir}} + \frac{\Delta\langle t\rangle}{\tau} A_{\mathrm{CP}}^{\mathrm{ind}}$$

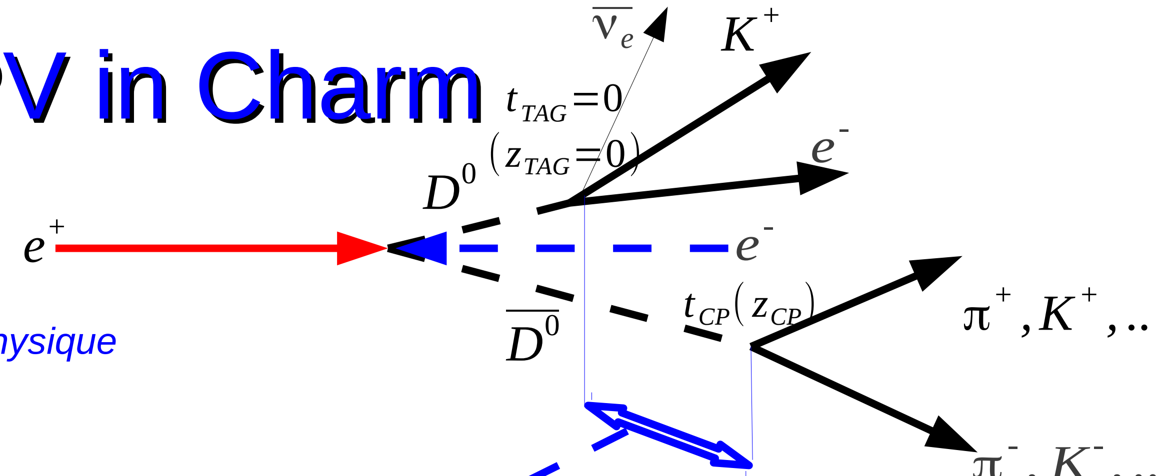


However, we think that a different approach should be taken. In particular a time-dependent analysis of D^0 mesons decay may help to clarify the most recent results and may open the door to the exploration of some "new territory"...

Time Dependent CPV in Charm

A. Bevan- G. Inguglia- B. Meadows:
*)Phys. Rev. **D** 84, 114009, arXiv:1106.5075

*)"The Time-Dependent CP Violation in Charm"
G. Inguglia, Proceedings of “Les Rencontres de physique de la vallee d'aoste” arXiv:1204.2303



$$\Delta t = \Delta z \beta \gamma c = (z_{CP} - z_{TAG}) \beta \gamma c$$

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

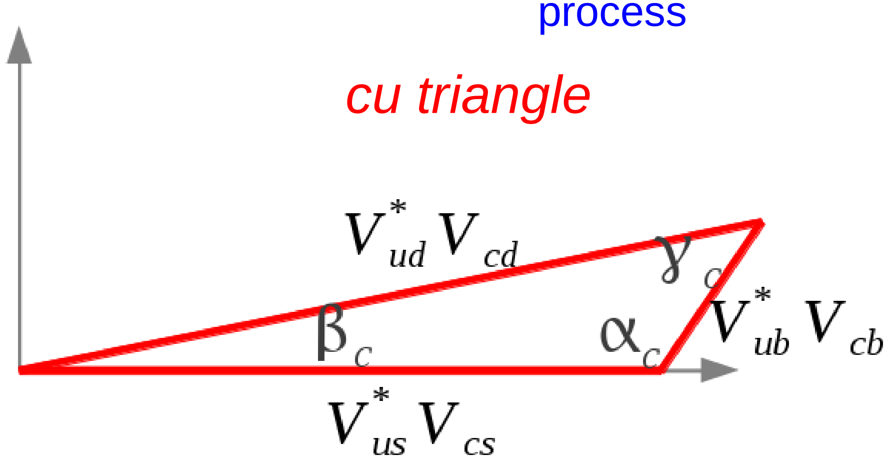
$$\lambda_f = \left|\frac{q}{p}\right| e^{i\varphi_{MIX}} \left|\frac{\overline{A}}{A}\right| e^{i\varphi_{CP}} = \left|\frac{q}{p}\right| e^{i\varphi_{MIX}} e^{-2i\varphi_T^W}$$

= if tree-dominated process

Remember mixing parameters:

$$x = \frac{\Delta M}{\Gamma}$$
$$y = \frac{\Delta \Gamma}{2\Gamma}$$

cu triangle



$$\alpha_c = arg\left[\frac{-V_{ub}^* V_{cb}}{V_{us}^* V_{cs}}\right] = (111.5 \pm 4.2)^o$$

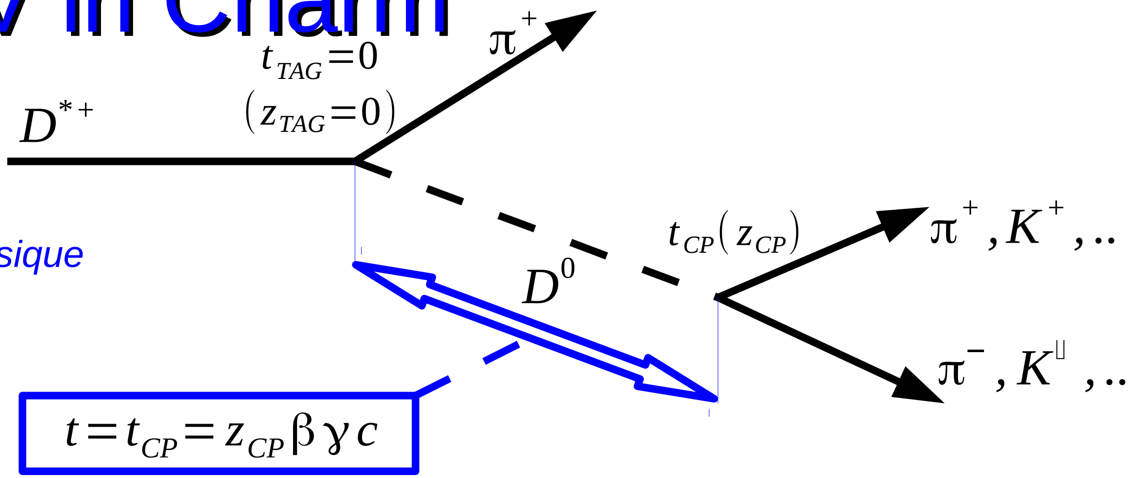
$$\beta_c = arg\left[\frac{-V_{ud}^* V_{cd}}{V_{us}^* V_{cs}}\right] = (0.0350 \pm 0.0001)^o$$

$$\gamma_c = arg\left[\frac{-V_{ub}^* V_{cb}}{V_{ud}^* V_{cd}}\right] = (68.4 \pm 0.1)^o$$

Time Dependent CPV in Charm

A. Bevan- G. Inguglia- B. Meadows:
*)*Phys. Rev.* ***D*** *84, 114009, arXiv:1106.5075*

*)"The Time-Dependent CP Violation in Charm"
G. Inguglia, Proceedings of “Les Rencontres de physique de la vallee d'aoste” arXiv:1204.2303



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

$$\lambda_f=\left|\frac{q}{p}\right|e^{i\varphi_{MIX}}\left|\frac{\overline{A}}{A}\right|e^{i\varphi_{CP}} = \left|\frac{q}{p}\right|e^{i\varphi_{MIX}}e^{-2i\varphi_T^W}$$

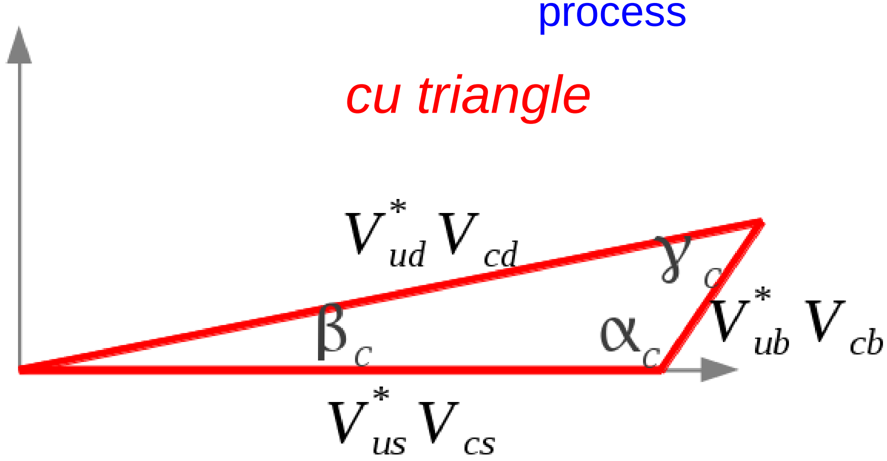
= if tree-dominated process

Remember mixing parameters:

$$x=\frac{\Delta M}{\Gamma}$$

$$y=\frac{\Delta\Gamma}{2\Gamma}$$

cu triangle



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

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

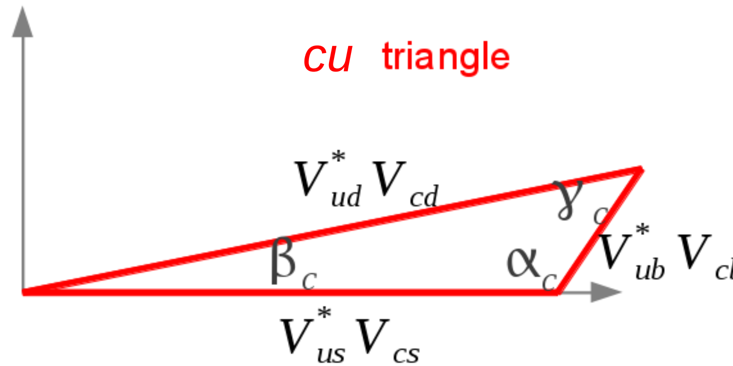
$$\gamma_c=arg\left[\frac{-V_{ub}^{*}V_{cb}}{V_{ud}^{*}V_{cd}}\right]=(68.4\pm0.1)^o$$

Numerical Results

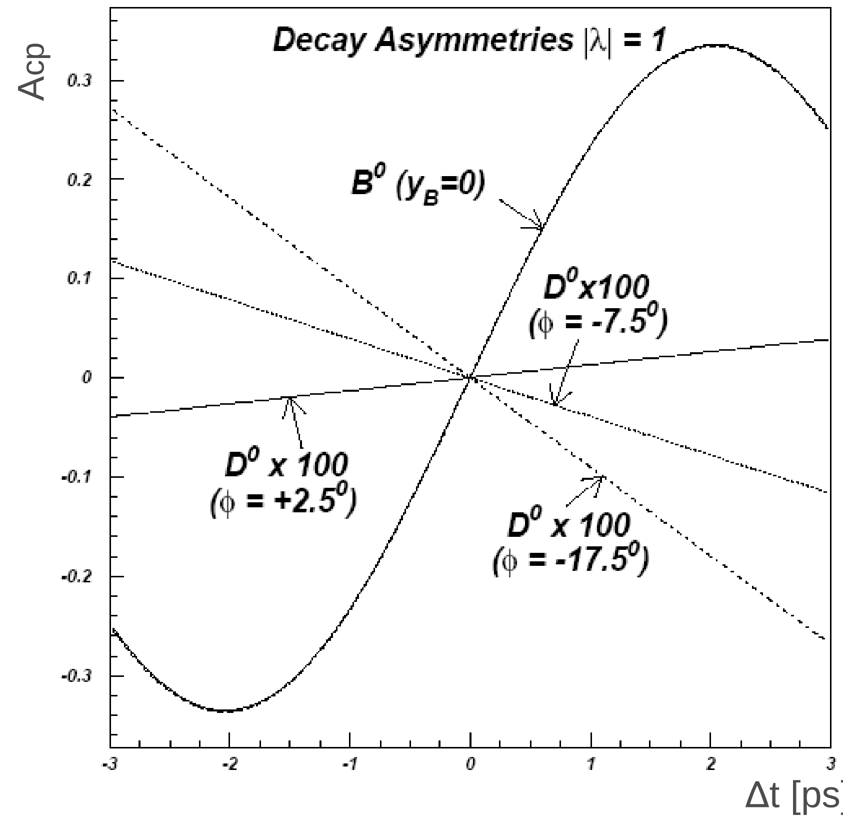
φ_{MIX} $\beta_{c,eff}$ x

Parameter	Super-Charm $\Psi(3770)$ SL	Super-Charm $\Psi(3770)$ SL+K	SuperB $\Upsilon(4S)$ $\pi_s^{\pm}$	LHCb $\pi_s^{\pm}$	Belle II $\pi_s^{\pm}$
$\sigma_{\phi_{\pi\pi}} = \sigma_{arg(\lambda_{\pi\pi})}$	5.7°	2.4°	2.2°	3.0°	2.8°
$\sigma_{\phi_{KK}} = \sigma_{arg(\lambda_{KK})}$	3.5°	1.4°	1.6°	1.8°	1.8°
$\sigma_{\beta_{c,eff}}$	3.3°	1.4°	1.4°	1.9°	1.7°

$\sigma_{\varphi_{KK}} = \sigma_{arg(\lambda_{KK})} = \sigma_{\varphi_{MIX}}$



Experiment/HFAG	$\sigma_x(\phi = \pm 10^o)$	$\sigma_x(\phi = \pm 20^o)$
Super$B$ $[\Upsilon(4S)]$		
$D^0 \to \pi^+\pi^-$	0.12%	0.06%
$D^0 \to K^+K^-$	0.08%	0.04%
Super$B$ $[\Psi(3770)]$		
$D^0 \to \pi^+\pi^-(SL)$	0.30%	0.15%
$D^0 \to \pi^+\pi^-(SL+K)$	0.13%	0.06%
$D^0 \to K^+K^-(SL)$	0.19%	0.10%
$D^0 \to K^+K^-(SL+K)$	0.08%	0.04%
LHCb		
$D^0 \to \pi^+\pi^-$ (1.1 fb^{-1})	0.40%	0.20%
$D^0 \to K^+K^-$ (1.1 fb^{-1})	0.22%	0.11%
$D^0 \to \pi^+\pi^-$ (5.0 fb^{-1})	0.15%	0.08%
$D^0 \to K^+K^-$ (5.0 fb^{-1})	0.09%	0.04%
Belle II		
$D^0 \to \pi^+\pi^-$	0.14%	0.07%
$D^0 \to K^+K^-$	0.10%	0.04%
HFAG	0.20%	

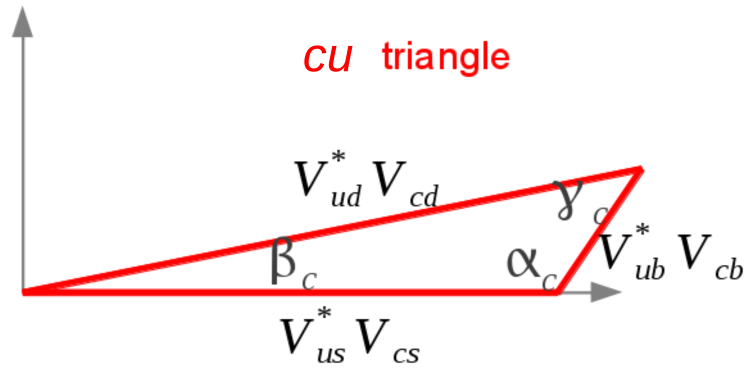


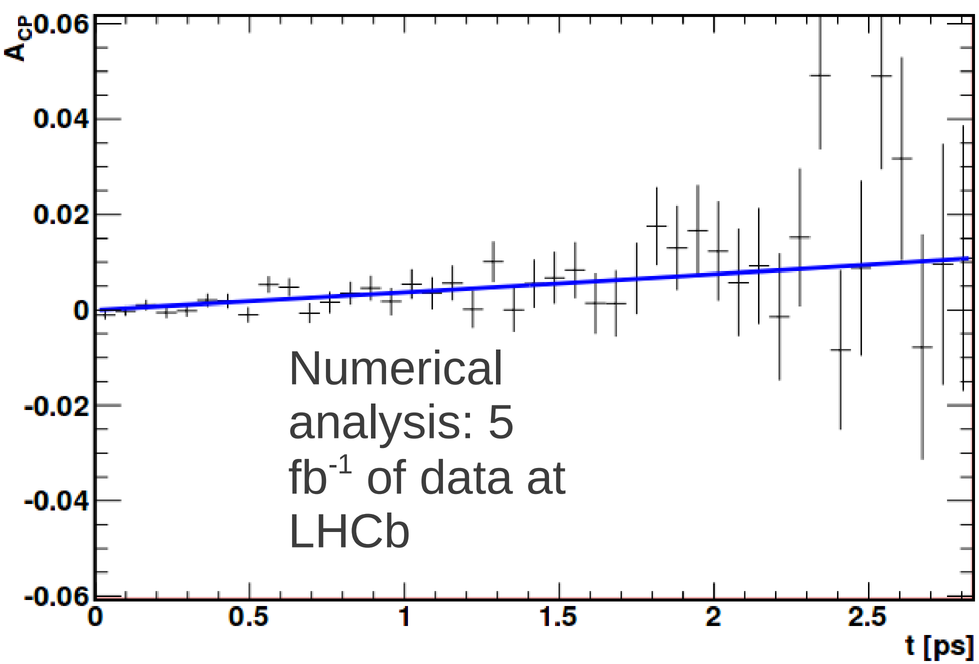
Numerical Results

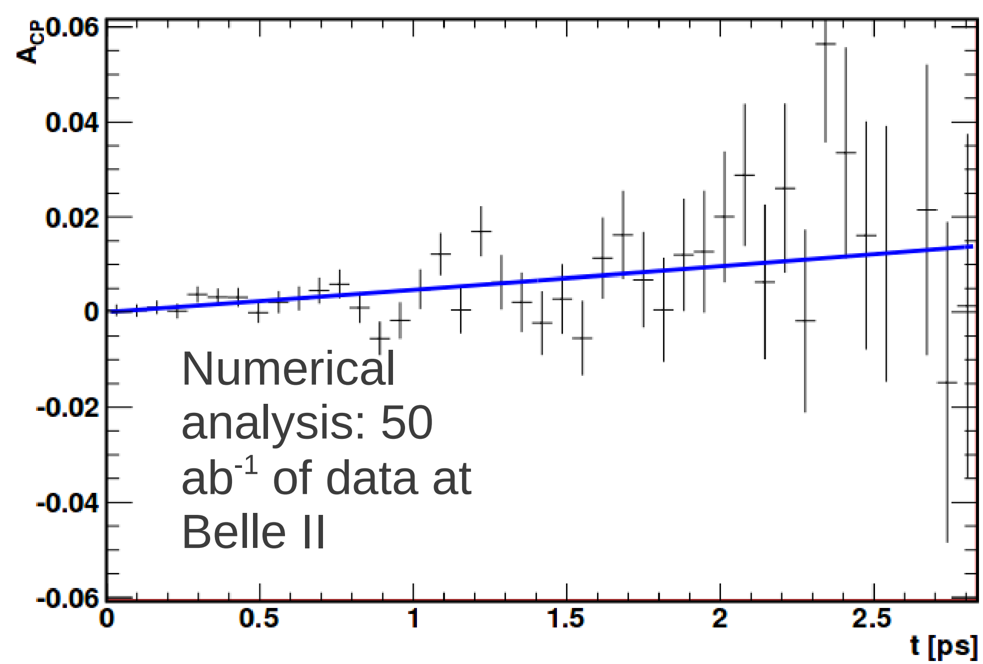
φ_{MIX} | $\beta_{c,eff}$ | x

Parameter	Super-Charm $\Psi(3770)$ SL	Super-Charm $\Psi(3770)$ SL+K	SuperB $\Upsilon(4S)$ $\pi_s^\pm$	LHCb $\pi_s^\pm$	Belle II $\pi_s^\pm$
$\sigma_{\phi_{\pi\pi}} = \sigma_{arg(\lambda_{\pi\pi})}$	5.7°	2.4°	2.2°	3.0°	2.8°
$\sigma_{\phi_{KK}} = \sigma_{arg(\lambda_{KK})}$	3.5°	1.4°	1.6°	1.8°	1.8°
$\sigma_{\beta_{c,eff}}$	3.3°	1.4°	1.4°	1.9°	1.7°

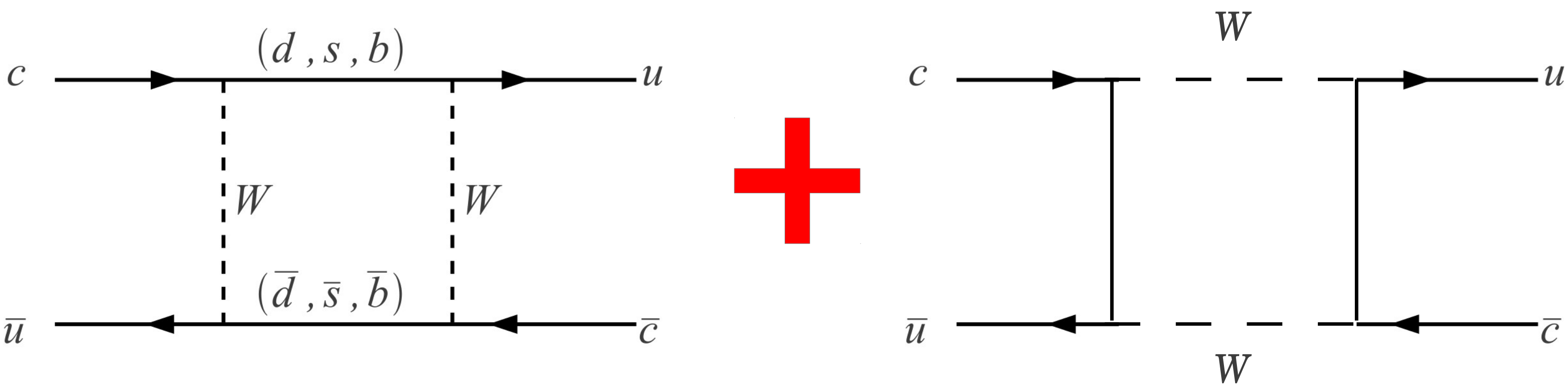
$$\sigma_{\varphi_{KK}} = \sigma_{arg(\lambda_{KK})} = \sigma_{\varphi_{MIX}}$$







Mixing in the standard model



For various reasons the SM cannot be considered as the ultimate theory of nature:

- **neutrinos** are predicted to be massless but they do exhibit mixing of flavour, and this means that they **must have mass** different by zero,
- **dark matter** particles and dark energy are not described in the theory,
- **gravity** is not included in the theory,
- **hierarchy** problem.

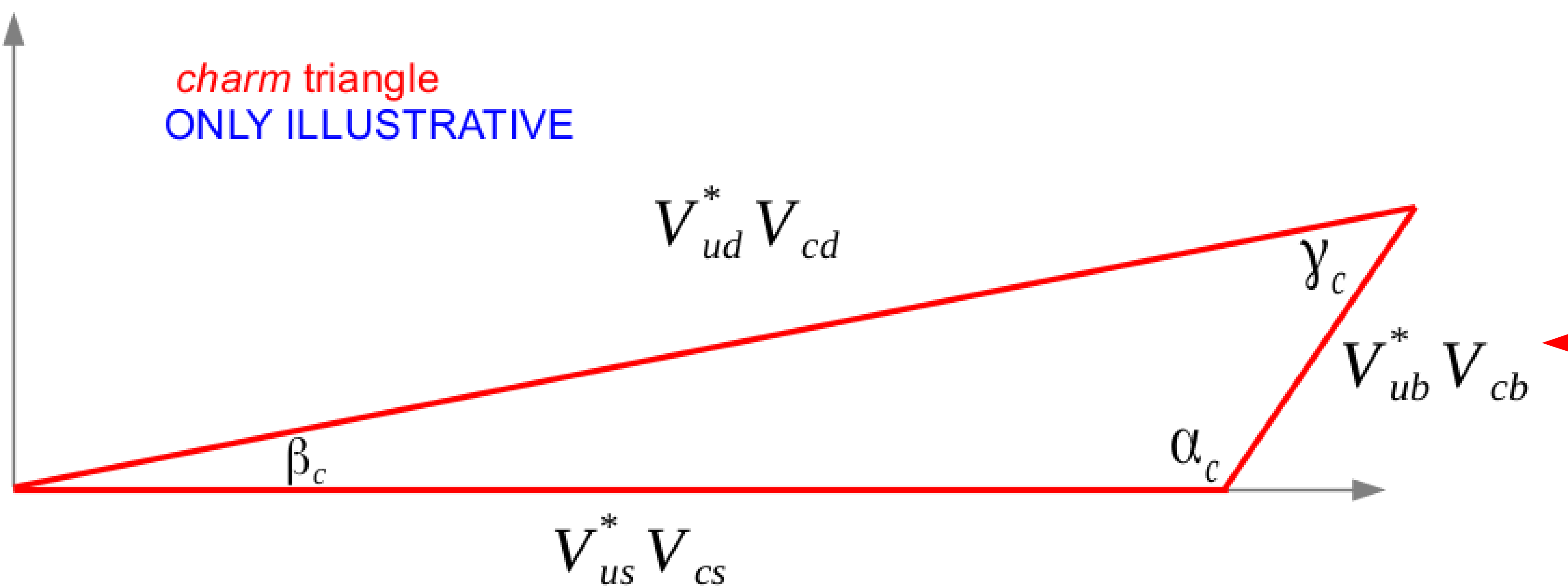
For these reasons the theory needs new testable developments...

Could New Physics be found in the charm triangle?

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

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

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



Could New Physics be found in the charm triangle?

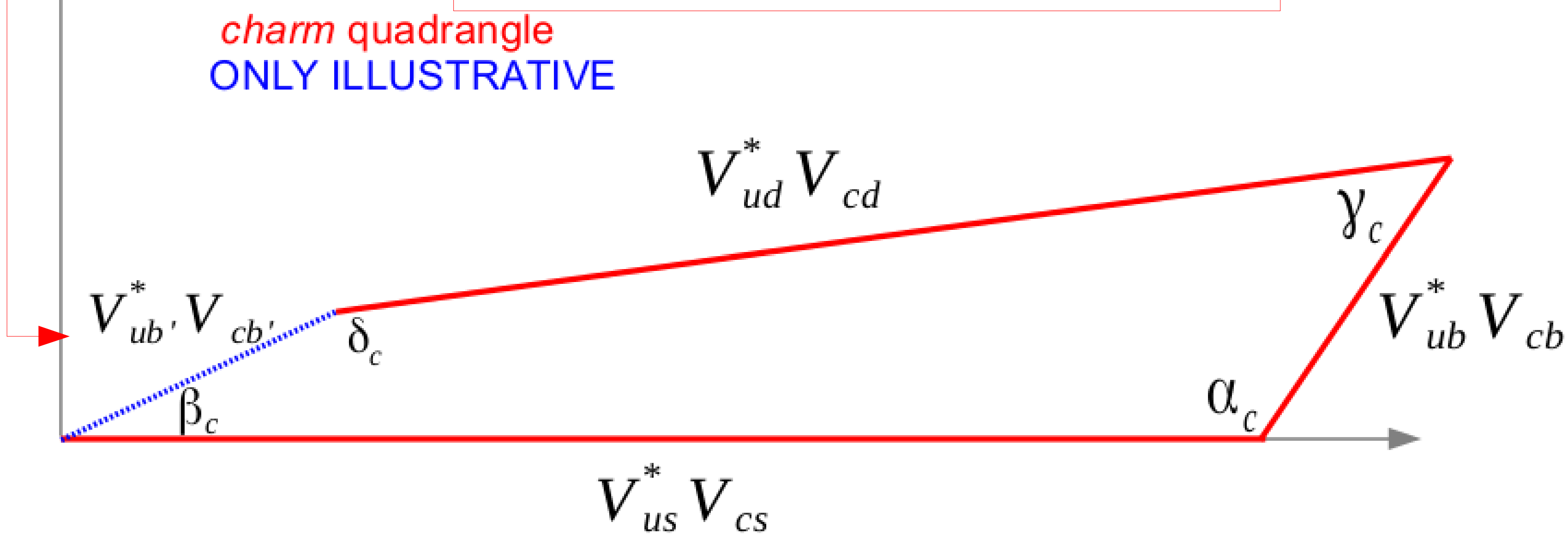
$$V_{CKM}^{4\text{th gen.}} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} & V_{ub'} \\ V_{cd} & V_{cs} & V_{cb} & V_{cb'} \\ V_{td} & V_{ts} & V_{tb} & V_{tb'} \\ V_{t'd} & V_{t's} & V_{t'b} & V_{t'b'} \end{pmatrix}$$

$$\beta_c = arg\left[\frac{-V_{ud}^{*} V_{cd}}{V_{us}^{*} V_{cs}}\right]$$

$$\begin{aligned} V_{ud}^{4gen} &= \cos\theta\cos W - e^{i(-\delta_2+\delta_3)}\sin V\sin W\sin\theta + Ae^{i\delta_3}(i\eta-\rho)\cos V\sin U\sin W\sin^3\theta \\ &\quad +O[\sin^6\theta], \end{aligned}$$

$$\begin{aligned} V_{cd}^{4gen} &= -e^{i(-\delta_2+\delta_3)}\cos\theta\sin V\sin W - \cos W\sin\theta - Ae^{i\delta_3}\cos V\sin U\sin W\sin^2\theta \\ &\quad +\frac{A^2\sin^4\theta}{2}[e^{i(-\delta_2+\delta_3)}\cos\theta\sin V\sin W + (1-2(i\eta+\rho)\cos\theta)\cos W\sin\theta] + O[\sin^6\theta] \end{aligned}$$

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



U(1)' extension of the SM and new tree level FCNC's

- The SM is a gauge theory of elementary particles and forces: **SU(3)xSU(2)xU(1)**.
- The SM group can be extended by adding an additional unitary group **U(1)'**.
- The U(1)' symmetry breaking generates a **new massive neutral boson, *X***.
- This requires an **extended Higgs** mechanism with a non-zero vev which couple to the three weak bosons and to the new *X* boson.
- We assume *X* is **leptophobic**.
- We assume *X* to be **flavour violating**.

$$\mathcal{L} = g J_3^\mu W_{3\mu} + g' J_Y^\mu B_\mu + g'' J_X^\mu C_\mu, \qquad (1)$$

where g, g', $W_{3\mu}$, B_μ are the usual couplings and gauge bosons for $SU(2)$ and $U(1)$, J_3^μ are J_Y^μ are their currents, and the terms g_X, J_X^μ and C_μ represents the coupling, current, and gauge boson for the new group $U'(1)$. the currents are defined as:

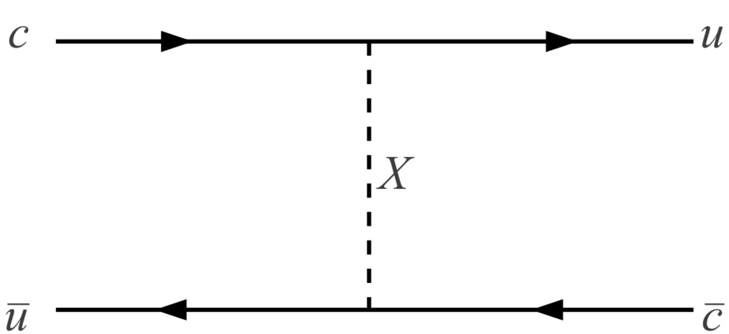
$$J_3^\mu = \sum_i \bar{f}_i \gamma^\mu [t_{3i_L} P_L + t3i_R P_R] f_i, \qquad (2)$$

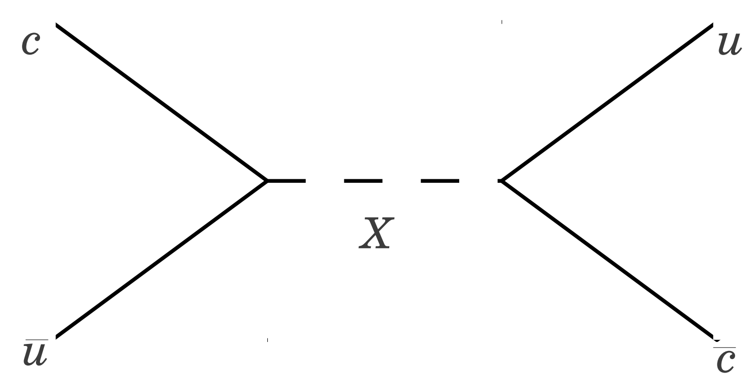
$$J_Y^\mu = \sum_i \bar{f}_i \gamma^\mu [y_{i_L} P_L + y i_R P_R] f_i, \qquad (3)$$

$$J_X^\mu = \sum_i \bar{f}_i \gamma^\mu [c_L(i) P_L + c_R(i) P_R] f_i. \qquad (4)$$

To have the correct electric charge, it has to be:

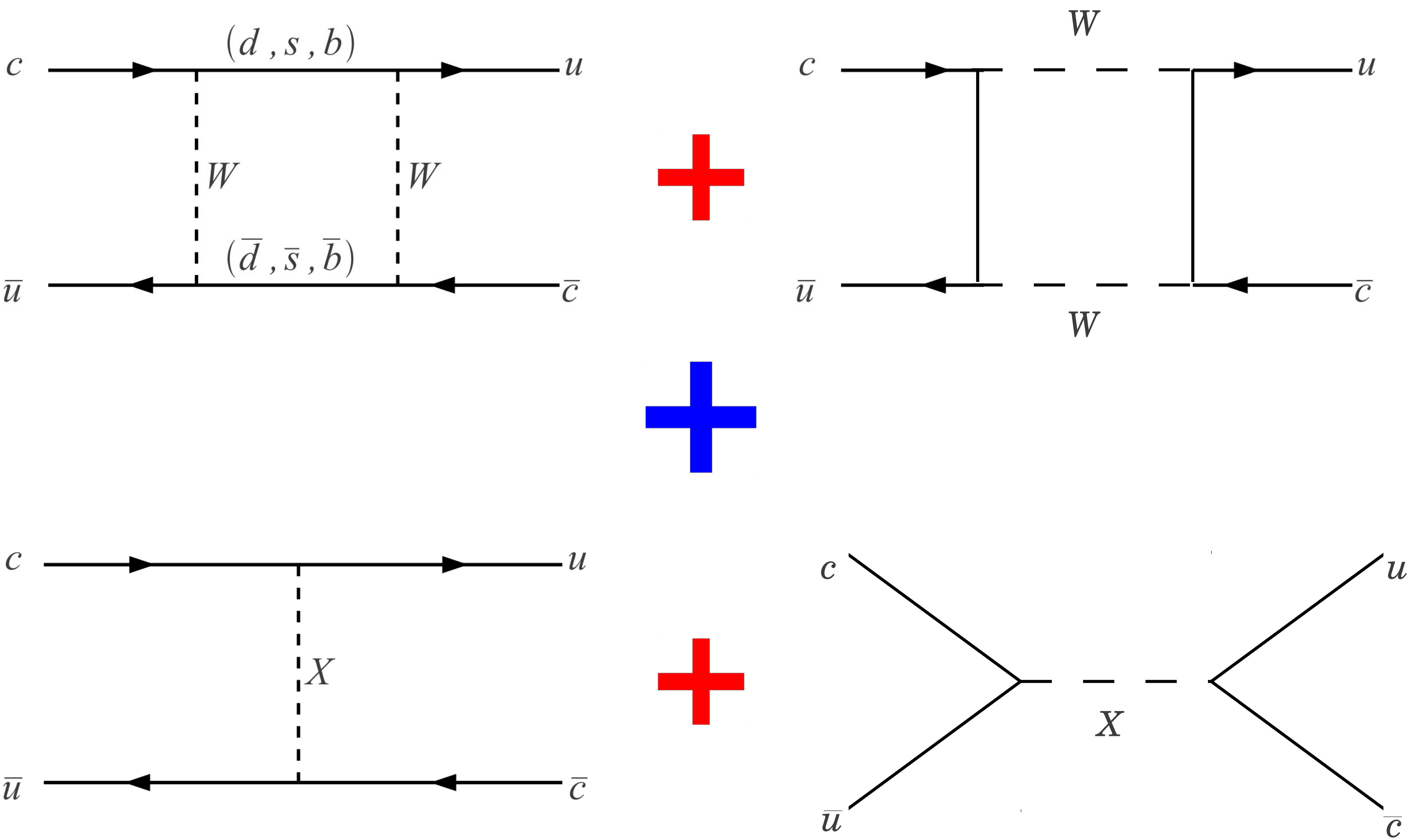
$$t_{3i_L} + y_{i_L} + c_L = t_{3i_R} + y_{i_R} + c_R = q(f_i), \qquad (5)$$





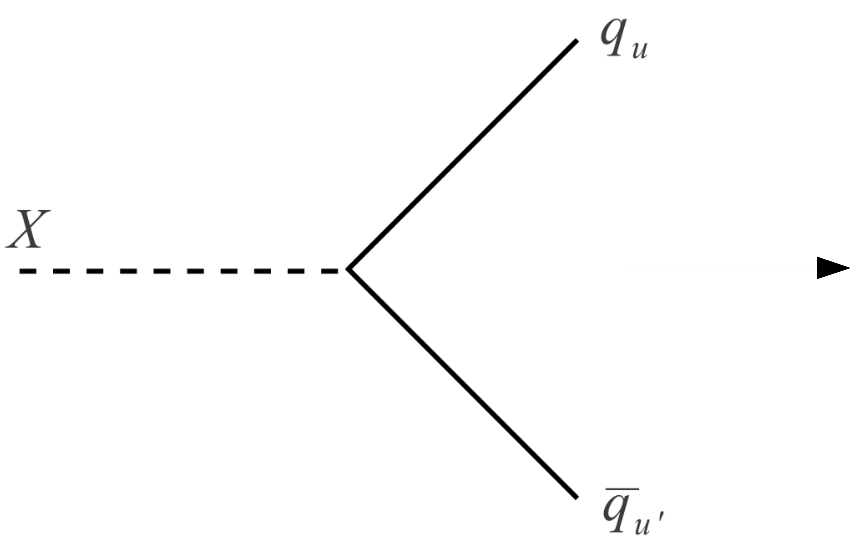
Bevan, Inguglia: work in progress...

Charm mixing in SU(3)xSU(2)xU(1)xU(1)'

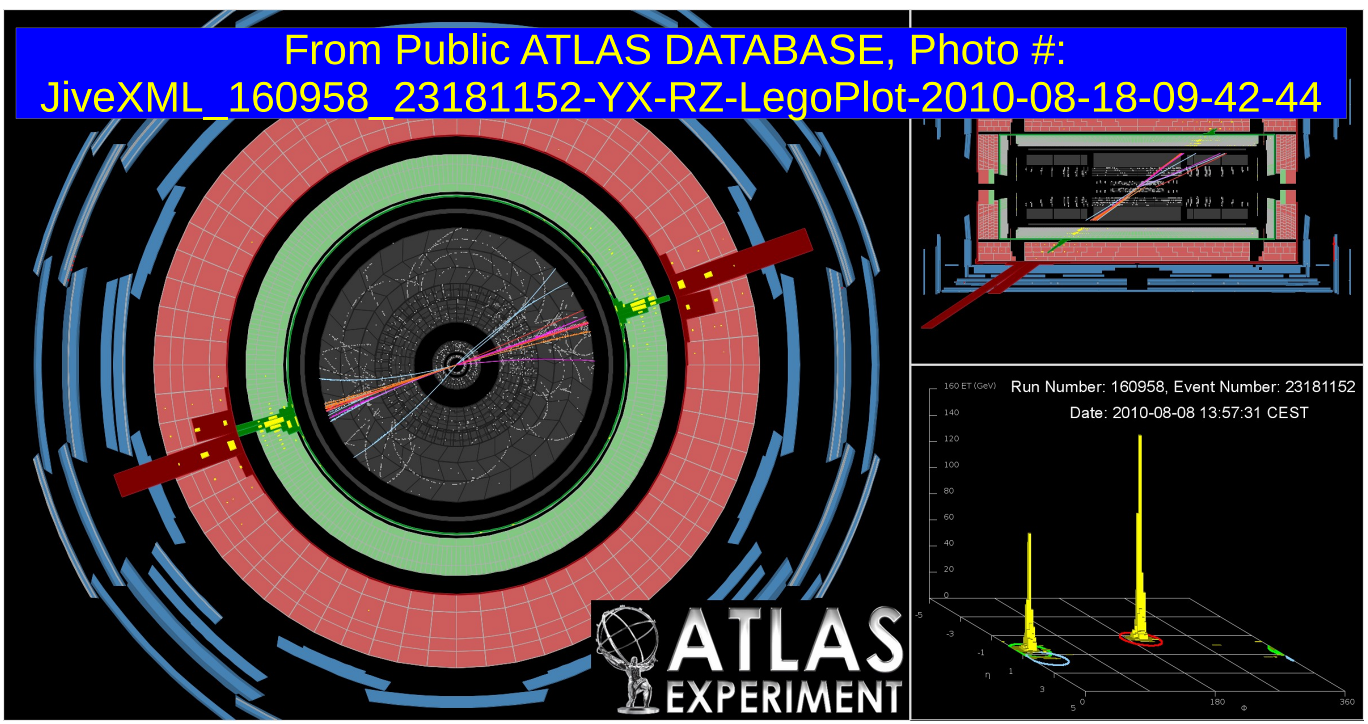


Neutral mesons mixing would be the result of the interference of the “box” amplitudes with the new tree level FCNC's mediated by the *X* boson.
Limits can be put here if one consider neutral B and K mixing. However charm mixing seems to point to large values.

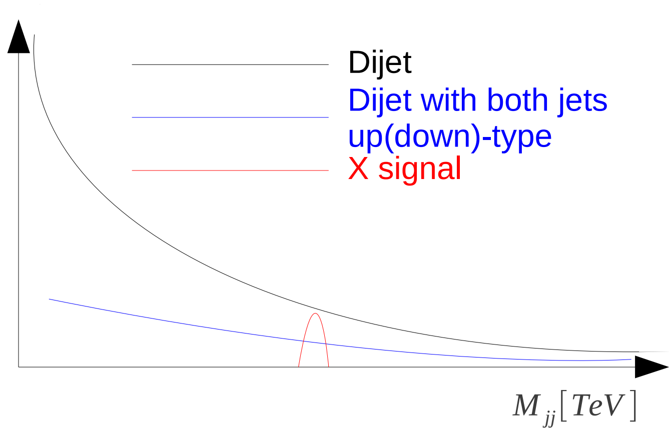
X-Boson: a possible direct test



Typically, such a boson, would decay violating flavour. In a high energy experiment, if produced, it could be possible to observe a signature in the DiJet invariant mass distribution (ATLAS-CMS) by requiring the two jets to be both up- or down-type. Not easy but tempting. Or by performing Di-Boson ($X \to ZZ$) studies in virtue of the Landau-Yang theorem



Example of Dijet event in the ATLAS detector



Conclusions

- **Time-dependent** analysis in charm decay has been discussed.
- One can test the SM by measuring angles of the **charm triangle**. Is there new physics in the charm system?
- Effects of a **4th generation** of fermions on charm triangle have been introduced.
- A **U'(1)** extension of the standard model has been introduced in which a new neutral ***X* boson** naturally arises, showing that mixing can be interpreted in terms of the interference of the different amplitude contributing to process including the **tree-level FCNC**.
- **Direct signatures** of such a *X* boson can be searched for at the **LHC**.

...Many Thanks...

"...Anyone who has never made a mistake has never tried anything new..."