

Recherche de nouvelle physique  
dans des désintégrations de  
mésons beaux en trois corps  
sans particule charmée

Thomas Grammatico, Eli Ben-Haim, Matthew Charles



# Mon sujet

Recherche de nouvelle physique dans des désintégrations de mésons beaux en trois corps sans particule charmée

Search for New Physics in three-body charmless B-meson decays

# Mon sujet

Physique de la beauté sans charme

Charmless beauty physics

# Mon sujet

Physique de la beauté



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# Physique de la beauté sans charme

## Standard Model of Elementary Particles

		three generations of matter (fermions)			interactions / force carriers (bosons)	
		I	II	III		
mass		$\approx 2.2 \text{ MeV}/c^2$	$\approx 1.28 \text{ GeV}/c^2$	$\approx 173.1 \text{ GeV}/c^2$	0	$\approx 124.97 \text{ GeV}/c^2$
charge		$\frac{2}{3}$	$\frac{2}{3}$	$\frac{2}{3}$	0	0
spin		$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	0
		<b>u</b> up	<b>c</b> charm	<b>t</b> top	<b>g</b> gluon	<b>H</b> higgs
		$\approx 4.7 \text{ MeV}/c^2$	$\approx 96 \text{ MeV}/c^2$	$\approx 4.18 \text{ GeV}/c^2$	0	
		$-\frac{1}{3}$	$-\frac{1}{3}$	$-\frac{1}{3}$	0	
		$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	
<b>QUARKS</b>		<b>d</b> down	<b>s</b> strange	<b>b</b> bottom	<b><math>\gamma</math></b> photon	
		$\approx 0.511 \text{ MeV}/c^2$	$\approx 105.66 \text{ MeV}/c^2$	$\approx 1.7768 \text{ GeV}/c^2$	$\approx 91.19 \text{ GeV}/c^2$	
		-1	-1	-1	0	
		$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	
		<b>e</b> electron	<b><math>\mu</math></b> muon	<b><math>\tau</math></b> tau	<b>Z</b> Z boson	
		$< 2.2 \text{ eV}/c^2$	$< 0.17 \text{ MeV}/c^2$	$< 18.2 \text{ MeV}/c^2$	$\approx 80.39 \text{ GeV}/c^2$	
		0	0	0	$\pm 1$	
		$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	
<b>LEPTONS</b>		<b><math>\nu_e</math></b> electron neutrino	<b><math>\nu_\mu</math></b> muon neutrino	<b><math>\nu_\tau</math></b> tau neutrino	<b>W</b> W boson	

**GAUGE BOSONS**  
VECTOR BOSONS

**SCALAR BOSONS**

# Physique de la beauté sans charme

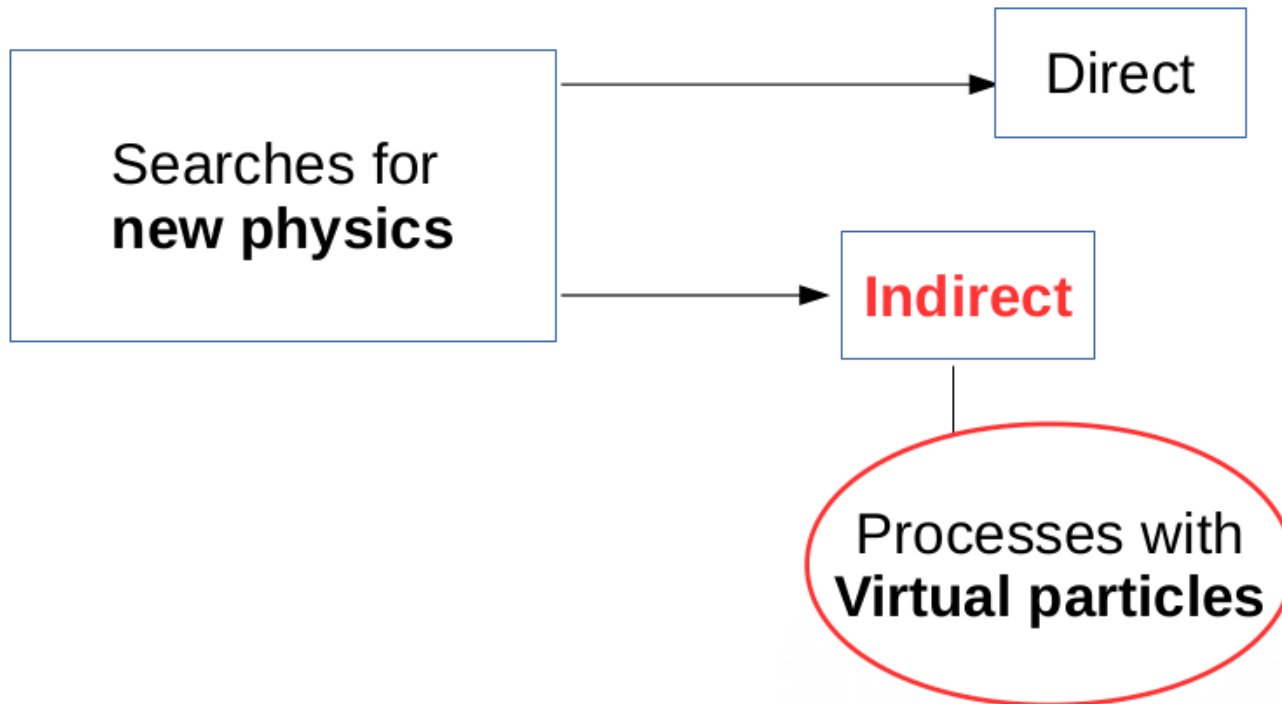
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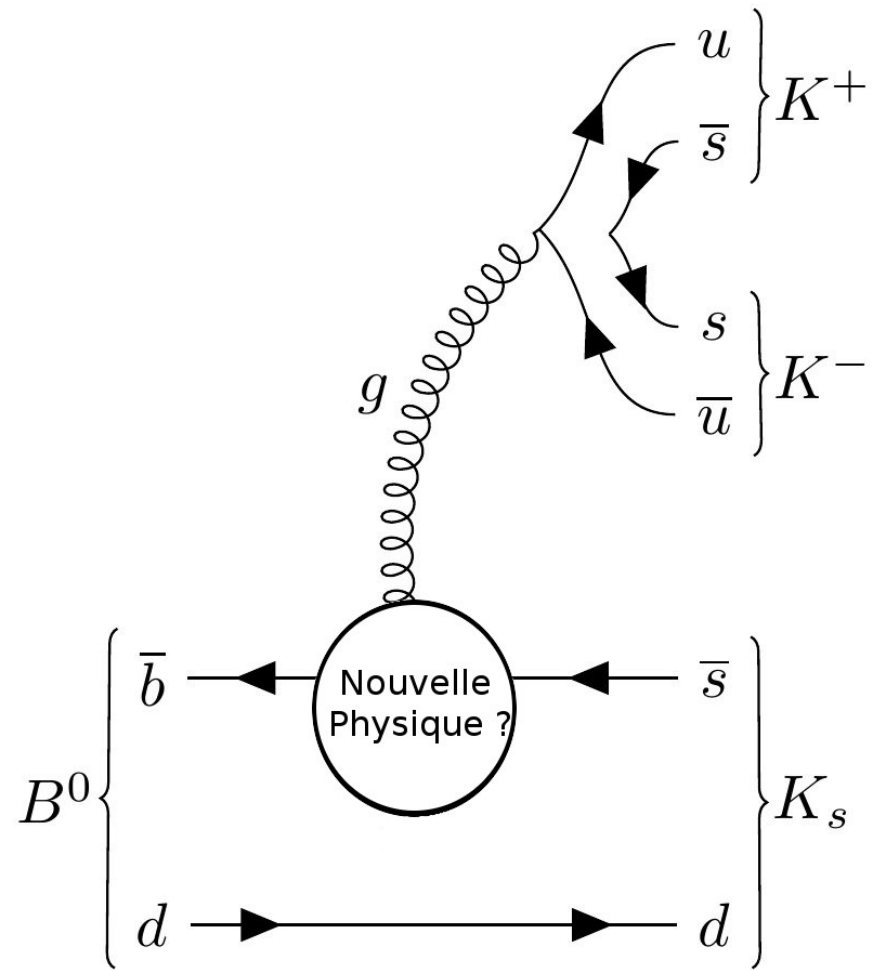
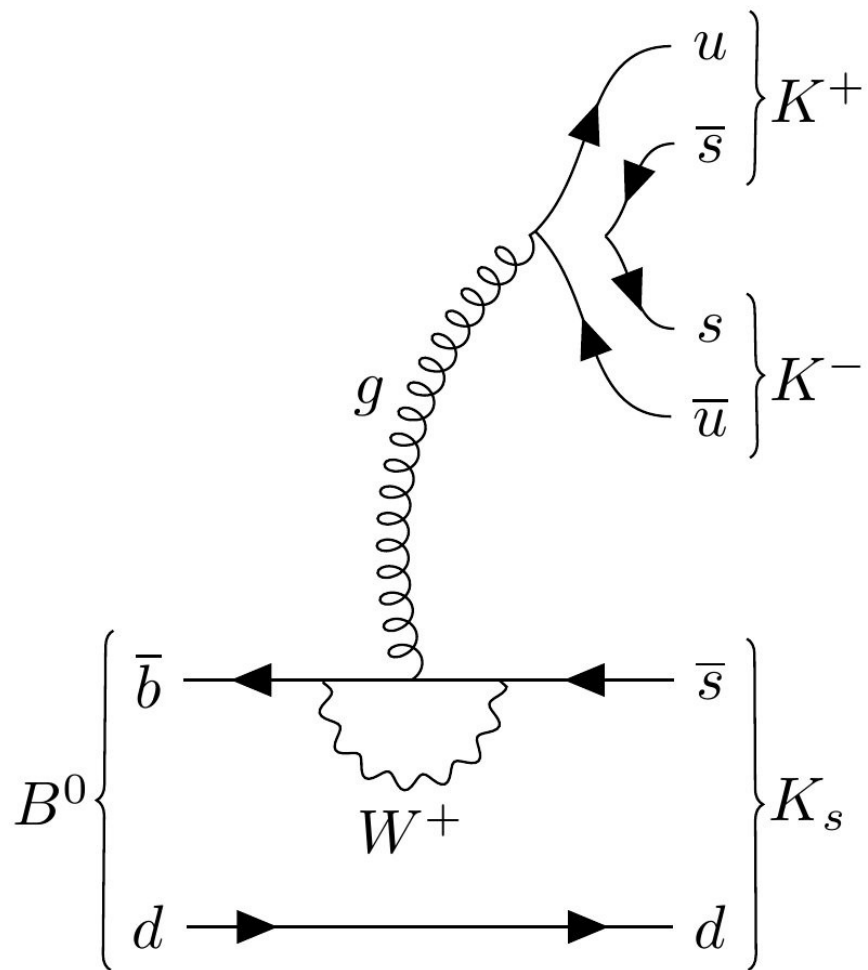
GAUGE BOSONS  
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# Pourquoi ?

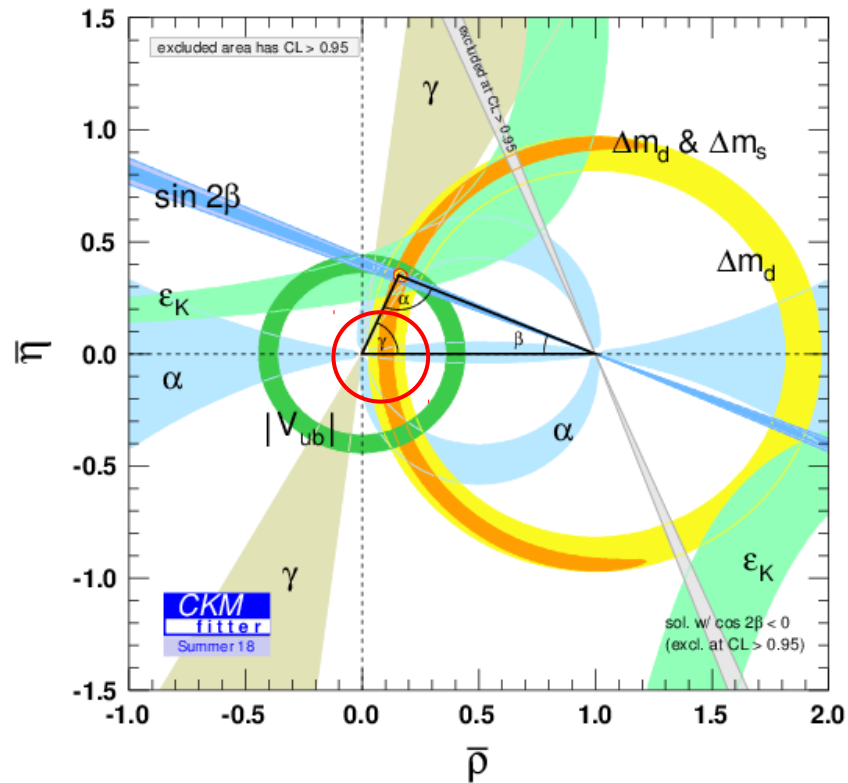


# Pourquoi ?





# Extraire $\gamma$ des désintégrations du méson B en trois corps sans particule charmée



# Extraire $\gamma$ des désintégrations du méson B en trois corps sans particule charmée

$$\left( \begin{array}{cc} \boxed{\begin{array}{l} V_{ud} = 1 - \lambda^2/2 \\ V_{cd} = -\lambda \\ V_{td} = A\lambda^3(1 - \rho - i\eta) \end{array}} & \begin{array}{l} V_{us} = \lambda \\ V_{cs} = 1 - \lambda^2/2 \\ V_{ts} = -A\lambda^2 \end{array} & \boxed{\begin{array}{l} V_{ub} = A\lambda^3(\rho - i\eta) \\ V_{cb} = A\lambda^2 \\ V_{tb} = 1 \end{array}} \end{array} \right) + O(\lambda^4)$$

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

$(\bar{\rho}, \bar{\eta})$

$$\left| \frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*} \right|$$

$$\left| \frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*} \right|$$

$\alpha = \phi_2$

$\gamma = \phi_3$

$\beta = \phi_1$

$(0,0)$

$(1,0)$

$$\gamma \equiv \arg\left(\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$$

## Et pour quoi faire ?



- Tester une nouvelle méthode d'extraction de  $\gamma$
- Sensible à NP
- $\gamma$  présente de larges incertitudes ;  $\alpha = (86.4_{-4.3}^{+4.5})^\circ$ ,  $\beta = (22.14_{-0.67}^{+0.69})^\circ$ ,  $\gamma = (72.1_{-5.7}^{+5.4})^\circ$

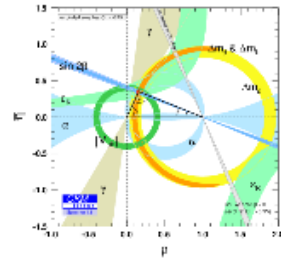
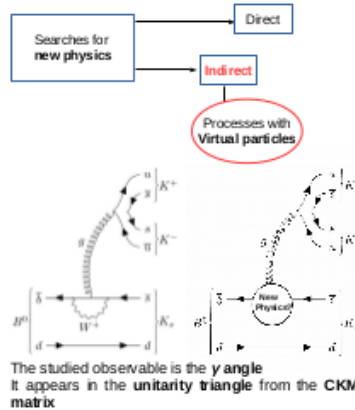
- Test a new  $\gamma$  extraction method
- Sensitive to NP
- $\gamma$  has large uncertainties ;  $\alpha = (86.4_{-4.3}^{+4.5})^\circ$ ,  $\beta = (22.14_{-0.67}^{+0.69})^\circ$ ,  $\gamma = (72.1_{-5.7}^{+5.4})^\circ$

# Extracting $\gamma$ from three-body charmless B-meson decays

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LPNHE

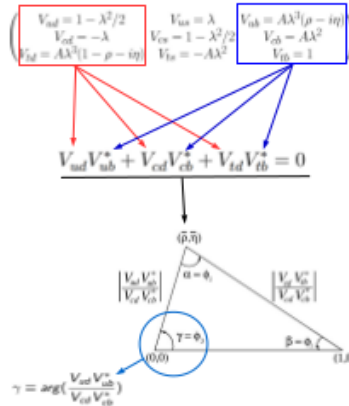


## Overview



## CKM matrix and unitarity triangle

The CKM matrix describes the couplings between the quarks, here in Wolfenstein parametrization



## Extracting $\gamma$ Basics of the method

The method is based on three-body charmless B meson decays (loop processes) [1]

Decay amplitudes contain strong and weak dynamics

$$A(B^0 \rightarrow K^+ K^- \pi^0)_{\text{loop}} = T_{\text{loop}}(e^{i\alpha} + P_{\text{loop}} e^{i\alpha} - \{P_{\text{loop}}^* e^{i\alpha} - P_{\text{loop}}\} e^{i\gamma})$$

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$\gamma$  can be extracted if there are more observables than theoretical parameters

By imposing flavour SU(3) symmetry, the number of parameters is reduced

Penguin and tree diagrams are now proportional

$$P_{EW\alpha} = \kappa T_{\alpha} \text{ et } P_{EW\alpha}^C = \kappa C_{\alpha}$$

In this framework 6 states can be built :

$$|S\rangle \propto |123\rangle + |231\rangle + |312\rangle + |321\rangle + |213\rangle + |132\rangle$$

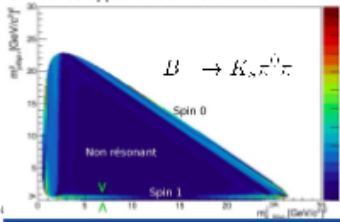
$$|A\rangle \propto |123\rangle + |231\rangle + |312\rangle - |321\rangle - |213\rangle - |132\rangle$$

Four mixed states

## Amplitude analysis in the Dalitz Plane

In the three-body case : more degrees of freedom, with spin 0 particles, Dalitz plane are needed

Amplitude depends on two invariant squared masses  
Structures appear due to resonances



## Observables and theoretical parameters

Antisymmetric states  
3 observables :  
 $X(m_{\pi^0}^2, m_{\pi^\pm}^2) = |\lambda_{1A}(m_{\pi^0}^2, m_{\pi^\pm}^2)|^2 + |\lambda_{2A}(m_{\pi^0}^2, m_{\pi^\pm}^2)|^2$   
 $Y(m_{\pi^0}^2, m_{\pi^\pm}^2) = |\lambda_{1A}(m_{\pi^0}^2, m_{\pi^\pm}^2)|^2 - |\lambda_{2A}(m_{\pi^0}^2, m_{\pi^\pm}^2)|^2$   
 $Z(m_{\pi^0}^2, m_{\pi^\pm}^2) = \text{Im}[\lambda_{1A}(m_{\pi^0}^2, m_{\pi^\pm}^2)\lambda_{2A}(m_{\pi^0}^2, m_{\pi^\pm}^2)^*]$

5 decay channels :  
 $B^0 \rightarrow K^+ \pi^+ \pi^-$ , X et Y  
 $B^0 \rightarrow K^0 \pi^+ \pi^-$ , X et Y  
 $B^0 \rightarrow K^0 \pi^0 \pi^0$ , X, Y et Z  
 $B^0 \rightarrow K^+ \pi^0 \pi^-$ , X et Y  
 $B^0 \rightarrow K^0 K^+ K^-$ , X, Y et Z

This results in 12 observables and 10 parameters [1]:

- 5 effective diagrams :
- 5 diagrams magnitude
- 4 strong relative phase
- 1 weak phase

$$A(B^0 \rightarrow K^+ K^- \pi^0)_{\text{loop}} = T_{\text{loop}}(e^{i\alpha} + P_{\text{loop}} e^{i\alpha} - \{P_{\text{loop}}^* e^{i\alpha} - P_{\text{loop}}\} e^{i\gamma})$$

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## How to extract $\gamma$

We want to perform a fit on a given point of the Dalitz plane

Fix  $\gamma$  to consecutive values  $[0^\circ, 360^\circ]$ , other parameters are free with random value

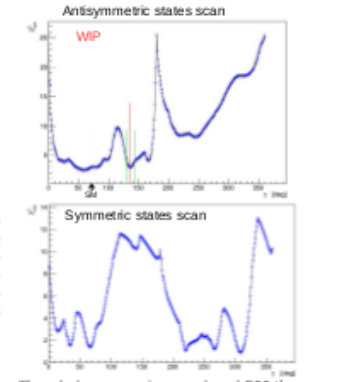
Hundreds of such fit are realized on a given point of the Dalitz Plane

For each fit, the lowest chi squared is kept  $\rightarrow \gamma$  Scan

From chi squared profile we extract minima

Many points over the Dalitz plot are used to reduce statistical uncertainties

## Results



The whole process is reproduced 500 times

From this we obtain minima and their uncertainties. For the fully symmetric states[2] :

- $\gamma_1 = [12.9^{+8.5}_{-8.5}] \text{ (stat)} \pm 1.3 \text{ (syst)}^\circ$
- $\gamma_2 = [36.6^{+6.0}_{-6.1}] \text{ (stat)} \pm 2.6 \text{ (syst)}^\circ$
- $\gamma_3 = [68.9^{+8.6}_{-8.6}] \text{ (stat)} \pm 2.4 \text{ (syst)}^\circ$
- $\gamma_4 = [223.2^{+10.0}_{-7.5}] \text{ (stat)} \pm 1.0 \text{ (syst)}^\circ$
- $\gamma_5 = [206.4^{+9.2}_{-10.8}] \text{ (stat)} \pm 1.9 \text{ (syst)}^\circ$
- $\gamma_6 = [307.5^{+6.0}_{-8.1}] \text{ (stat)} \pm 1.1 \text{ (syst)}^\circ$

## References

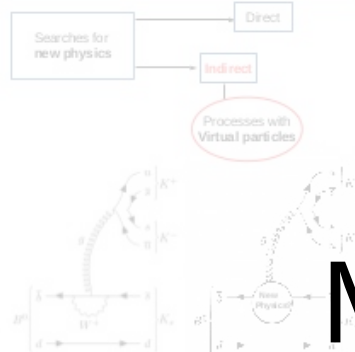
[1] London et al. Phys. Lett. B, 728, 206 (2014) and private communication  
 [2] Emilie Bertholet, Eli Ben-Haim, Bhubanjyoti Bhattacharya, Matthew Charles, David London, Extraction of the CKM phase  $\gamma$  using charmless 3-body decays of B mesons, arXiv:1812.06194[hep-ph]

# Extracting $\gamma$ from three-body charmless B-meson decays

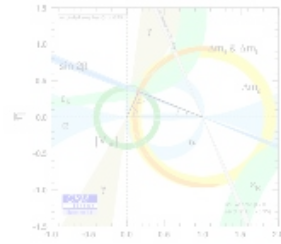
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## Overview



The studied observable is the  $\gamma$  angle. It appears in the unitarity triangle from the CKM matrix



## CKM matrix and unitarity triangle

The CKM matrix describes the couplings between the quarks, here in Wolfenstein parametrization

$$\begin{pmatrix}
 V_{ud} & V_{us} & V_{ub} \\
 V_{cd} & V_{cs} & V_{cb} \\
 V_{td} & V_{ts} & V_{tb}
 \end{pmatrix}
 \approx
 \begin{pmatrix}
 1 - \lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\
 -\lambda & 1 - \lambda^2/2 & A\lambda^2 \\
 A\lambda^3(1 - \rho - i\eta) & -A\lambda^2 & 1
 \end{pmatrix}$$

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



## Extracting $\gamma$ Basics of the method

The method is based on three-body charmless B-meson decays (loop processes) [1]

Decay amplitudes contain **strong** and **weak** dynamics

$$\begin{aligned}
 \mathcal{A}(B \rightarrow K^+ K^0) &= \mathcal{A}^{\text{tree}} + \mathcal{A}^{\text{loop}} + \mathcal{A}^{\text{res}} \\
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$\gamma$  can be extracted if there are more observables than theoretical parameters

Imposing flavour SU(3) symmetry, the number of parameters is reduced. This allows us to use fewer diagrams and low professional

In this framework 6 states can be built:  
 $|S\rangle \propto |123\rangle + |231\rangle + |312\rangle + |321\rangle + |213\rangle + |132\rangle$   
 $|A\rangle \propto |123\rangle + |231\rangle + |312\rangle - |321\rangle - |213\rangle - |132\rangle$   
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## Observables and theoretical parameters

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- 5 decay channels:
  - $B^+ \rightarrow K^+ \pi^+ \pi^-$ , X et Y
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This results in 12 observables and 10 parameters [1]:

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Merci ! :)