Model of the W-external emission topology in the $D_s^+ \to 3K$ decay

David Alejandro Barón Ospina

David.Baron@ific.uv.es

Universitat de Valencia (UV)- Institut de física corpuscular (IFIC)

CPAN

2024

Special acknowledge

- Patricia Camargo Magalhães, Campinas State University, Brazil.

- Diego Alejandro Milanes Carreño, National University of Colombia, University of technology and engineering, Peru.

Document available at:

https://repositorio.unal.edu.co/handle/unal/85546

Gen—T

IFIC INSTITUT DE FÍSICA CORPUSCULAR

VNIVERSITAT DE VALÈNCIA

Outline

1) Motivation

2) The $D_S^+ \to K^+K^-K^+$ decay

3) Conclusions and perspectives

Outline

1) Motivation

2) The $D_S^+ \to K^+K^-K^+$ decay

3) Conclusions and perspectives

Motivation

Motivation

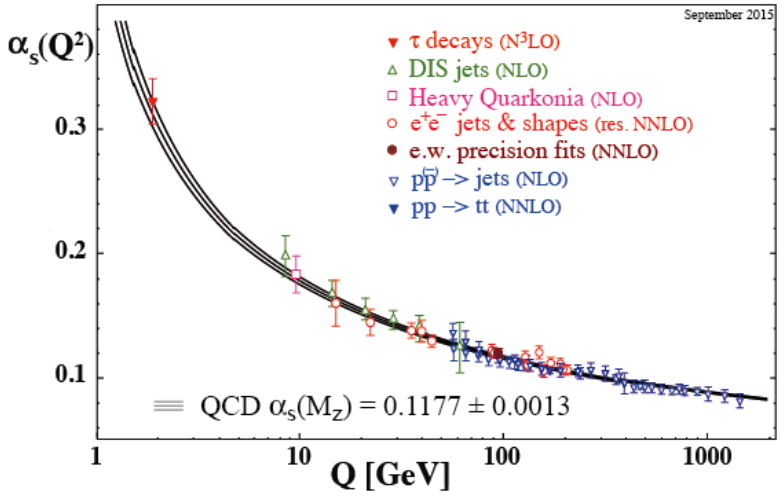


Image taken from :
https://www.researchgate.net/figure/Summary-of-measurements-of-a-s-as-a-function-of-the-energy-scale-Q-The-respective-degree_fig2_287249926

Motivation

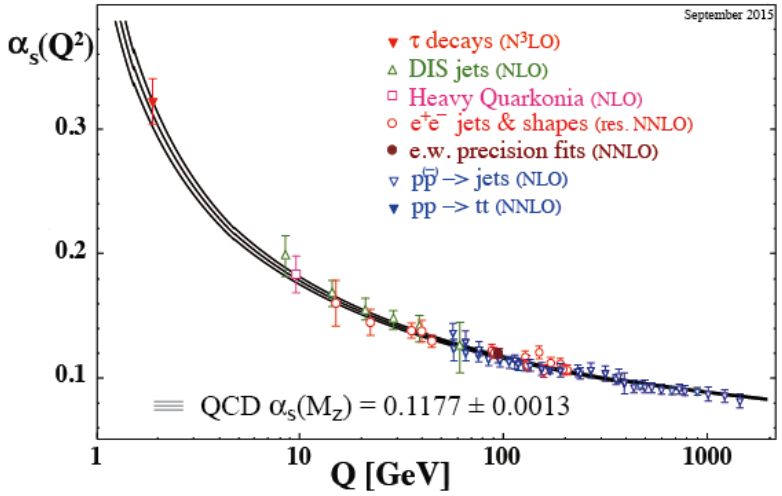


Image taken from :
https://www.researchgate.net/figure/Summary-of-measurements-of-a-s-as-a-function-of-the-energy-scale-Q-The-respective-degree_fig2_287249926

Degrees of freedom

Motivation

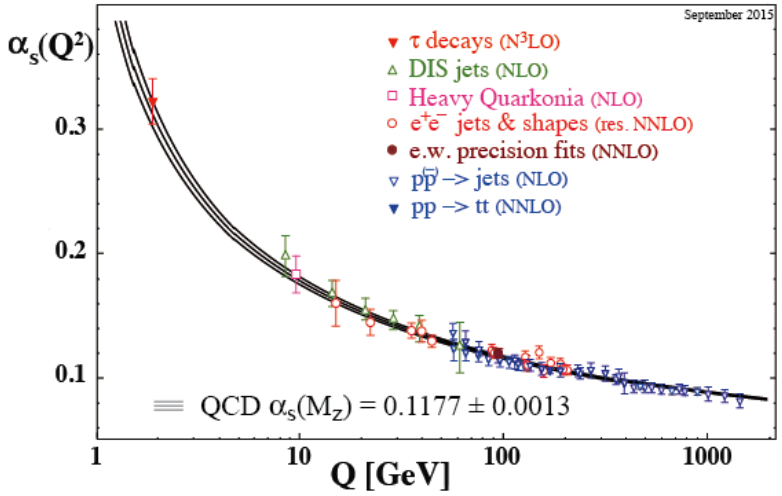


Image taken from :
https://www.researchgate.net/figure/Summary-of-measurements-of-a-s-as-a-function-of-the-energy-scale-Q-The-respective-degree_fig2_287249926

Degrees of freedom

$$u, d, s, c, b, t$$

Motivation

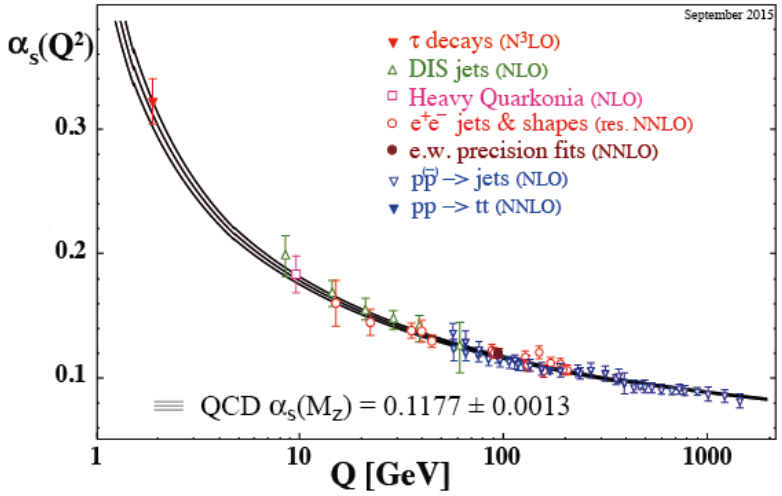


Image taken from :
https://www.researchgate.net/figure/Summary-of-measurements-of-a-s-as-a-function-of-the-energy-scale-Q-The-respective-degree_fig2_287249926

Degrees of freedom

$$u, d, s, c, b, t \quad !$$

Motivation

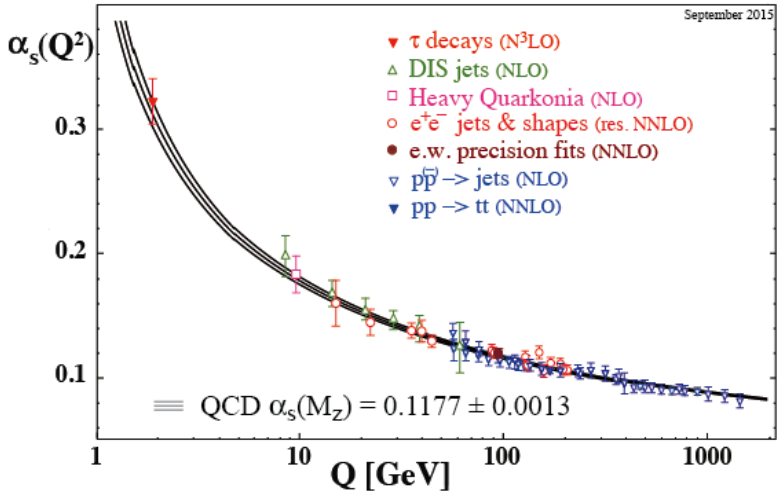


Image taken from :
https://www.researchgate.net/figure/Summary-of-measurements-of-a-s-as-a-function-of-the-energy-scale-Q-The-respective-degree_fig2_287249926

Degrees of freedom

$$u, d, s, c, b, t \quad !$$

New degrees of freedom

Gen—T

IFIC INSTITUT DE FÍSICA CORPUSCULAR

VNIVERSITAT DE VALÈNCIA

Motivation

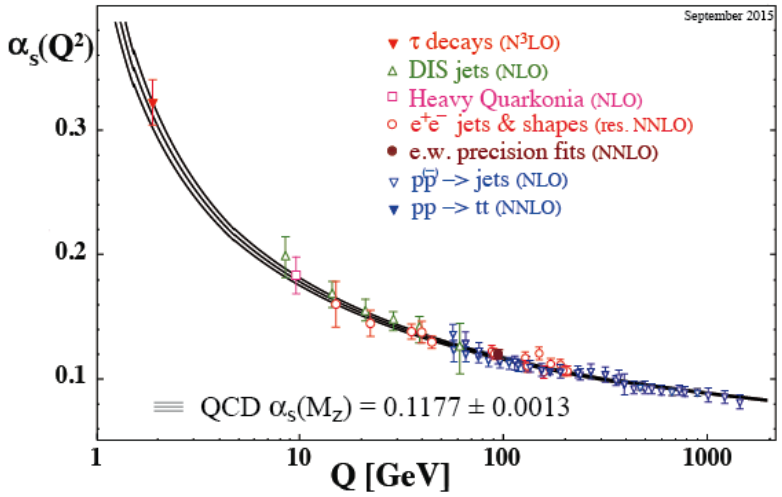


Image taken from :
https://www.researchgate.net/figure/Summary-of-measurements-of-a-s-as-a-function-of-the-energy-scale-Q-The-respective-degree_fig2_287249926

Degrees of freedom

$$u, d, s, c, b, t \quad !$$

New degrees of freedom

$$\pi, K, \eta, D, B, ...$$

Motivation

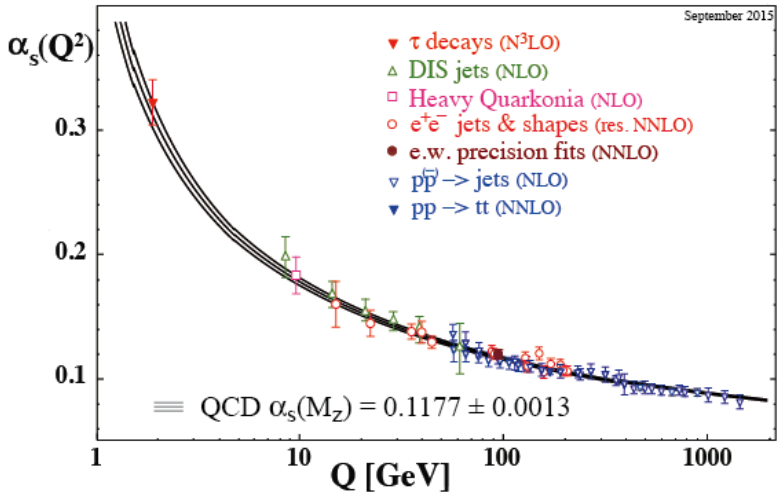


Image taken from :
https://www.researchgate.net/figure/Summary-of-measurements-of-a-s-as-a-function-of-the-energy-scale-Q-The-respective-degree_fig2_287249926

Degrees of freedom

$$u, d, s, c, b, t \quad !$$

New degrees of freedom

$$\underbrace{\pi, K, \eta}_{\chi pt}, D, B, ...$$

Motivation

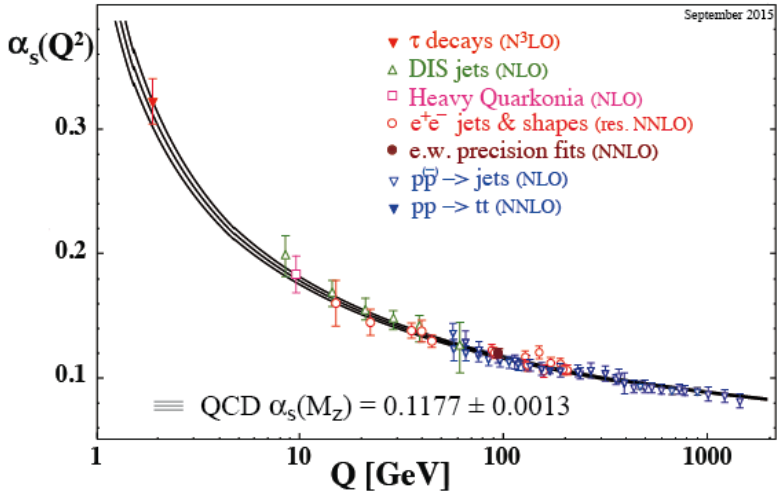


Image taken from :
https://www.researchgate.net/figure/Summary-of-measurements-of-a-s-as-a-function-of-the-energy-scale-Q-The-respective-degree_fig2_287249926

Degrees of freedom

$$u, d, s, c, b, t \quad !$$

New degrees of freedom

$$\underbrace{\pi, K, \eta}_{\chi pt}, D, B, \ldots..$$

1) Motivation

2) The $D_S^+ \to K^+K^-K^+$ decay

3) Conclusions and perspectives

1) Motivation

2) The $D_S^+ \to K^+K^-K^+$ decay

3) Conclusions and perspectives

The $D_s^+ \to K^+K^-K^+$ decay

The $D_s^+ \to K^+K^-K^+$ decay

Topologies

The $D_s^+ \to K^+K^-K^+$ decay

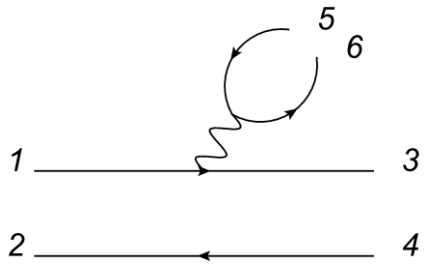
Topologies

L. Chau. Quark Mixing in Weak Interactions, 1983

The $D_s^+ \to K^+K^-K^+$ decay

Topologies

L. Chau. Quark Mixing in Weak Interactions, 1983

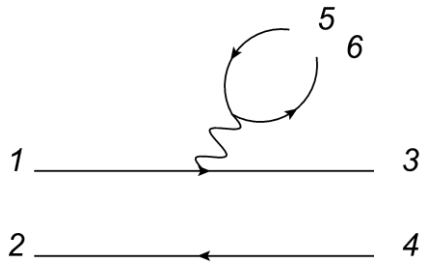


External W-emission

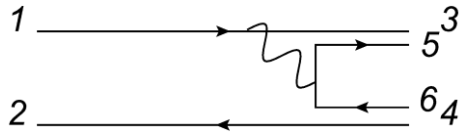
The $D_s^+ \to K^+K^-K^+$ decay

Topologies

L. Chau. Quark Mixing in Weak Interactions, 1983



External W-emission

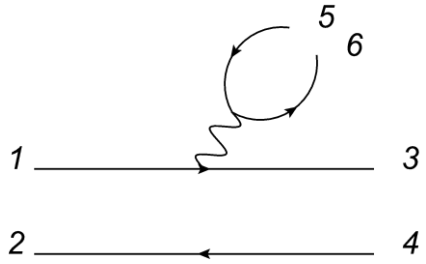


Internal W-emission

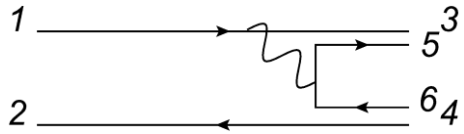
The $D_s^+ \to K^+K^-K^+$ decay

Topologies

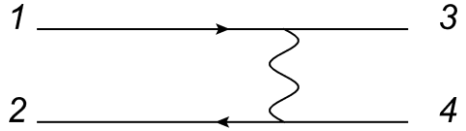
L. Chau. Quark Mixing in Weak Interactions, 1983



External W-emission



Internal W-emission

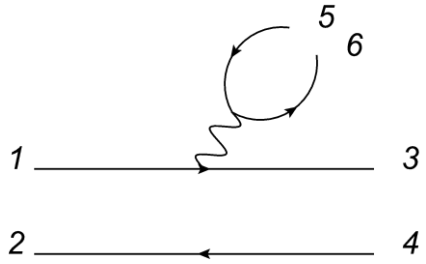


W-exchange

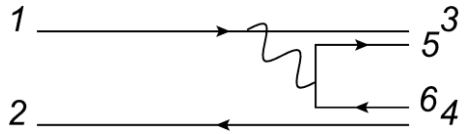
The $D_s^+ \to K^+K^-K^+$ decay

Topologies

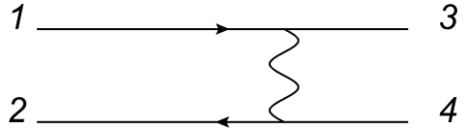
L. Chau. Quark Mixing in Weak Interactions, 1983



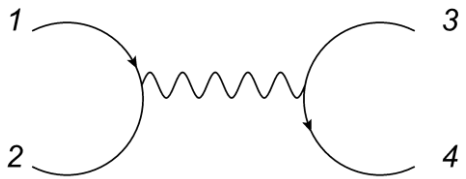
External W-emission



Internal W-emission



W-exchange



W-annihilation

Gen—T

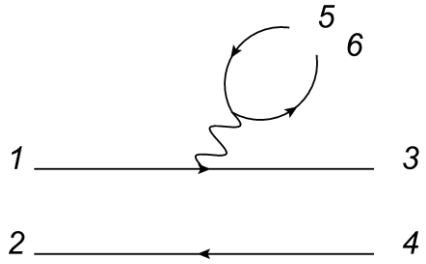
IFIC INSTITUT DE FÍSICA CORPUSCULAR

VNIVERSITAT DE VALÈNCIA

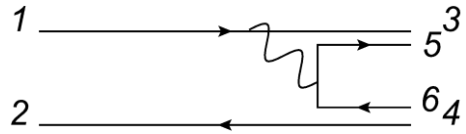
The $D_s^+ \to K^+K^-K^+$ decay

Topologies

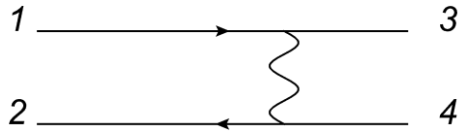
L. Chau. Quark Mixing in Weak Interactions, 1983



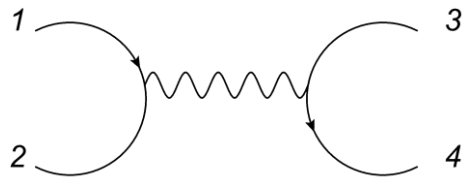
External W-emission



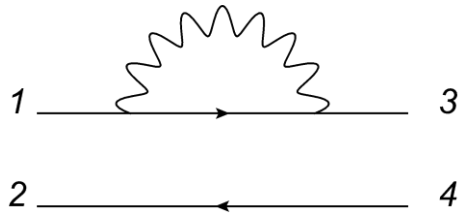
Internal W-emission



W-exchange



W-annihilation

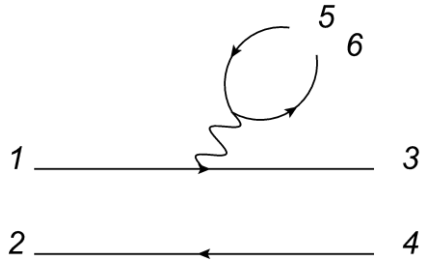


Penguin

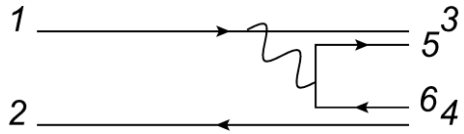
The $D_s^+ \to K^+K^-K^+$ decay

Topologies

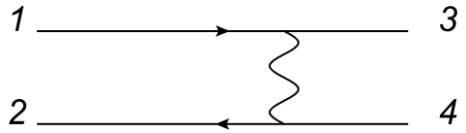
L. Chau. Quark Mixing in Weak Interactions, 1983



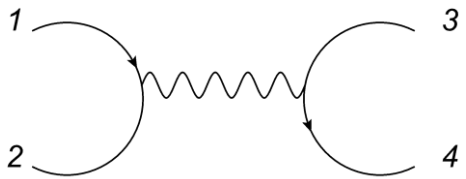
External W-emission



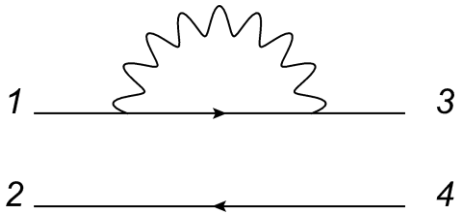
Internal W-emission



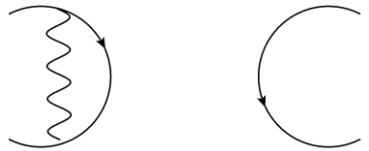
W-exchange



W-annihilation



Penguin

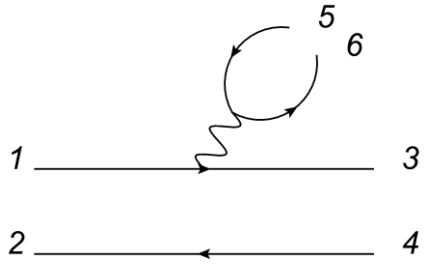


Sideways Penguin

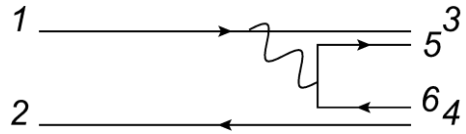
The $D_s^+ \to K^+K^-K^+$ decay

Topologies

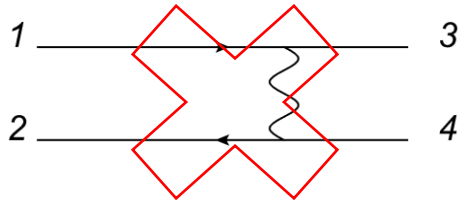
L. Chau. Quark Mixing in Weak Interactions, 1983



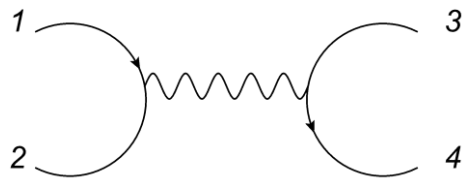
External W-emission



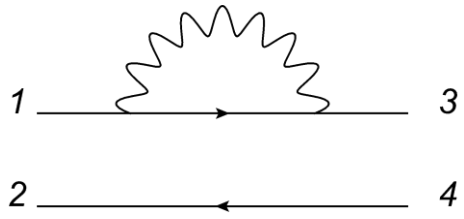
Internal W-emission



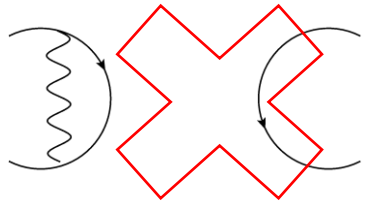
W-exchange



W-annihilation



Penguin



Sideways Penguin

Gen—T

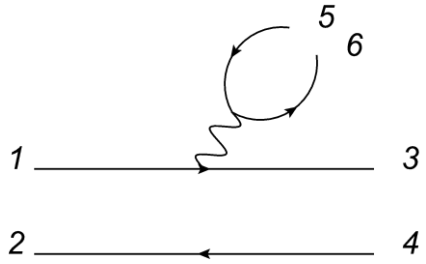
IFIC INSTITUT DE FÍSICA CORPUSCULAR

VNIVERSITAT DE VALÈNCIA

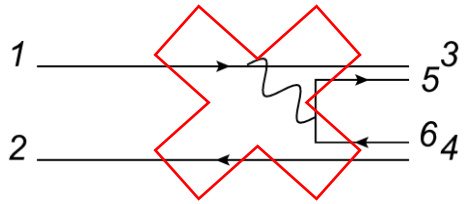
The $D_s^+ \to K^+K^-K^+$ decay

Topologies

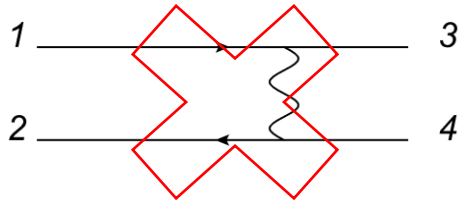
L. Chau. Quark Mixing in Weak Interactions, 1983



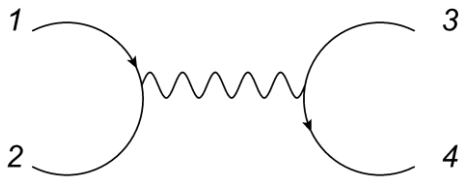
External W-emission



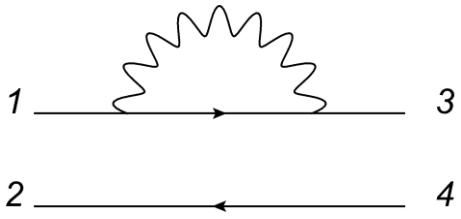
Internal W-emission



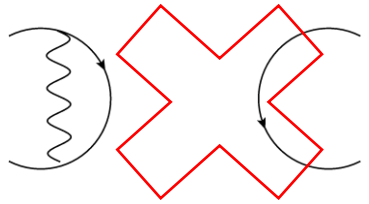
W-exchange



W-annihilation



Penguin

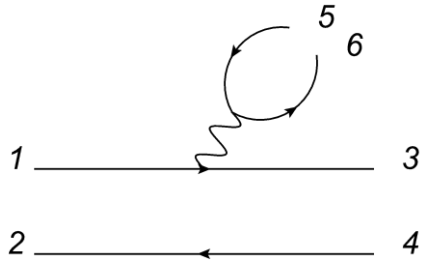


Sideways Penguin

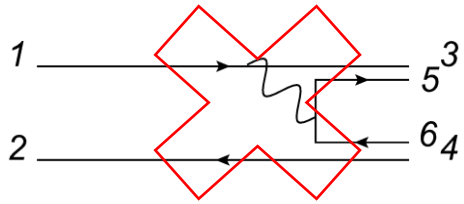
The $D_s^+ \to K^+K^-K^+$ decay

Topologies

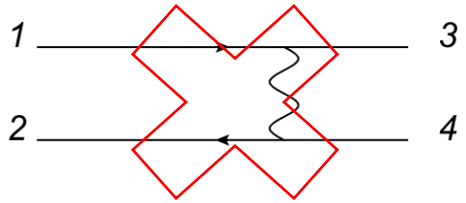
L. Chau. Quark Mixing in Weak Interactions, 1983



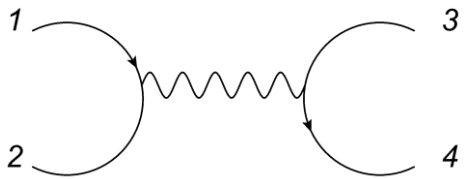
External W-emission



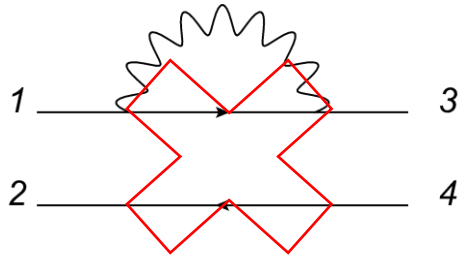
Internal W-emission



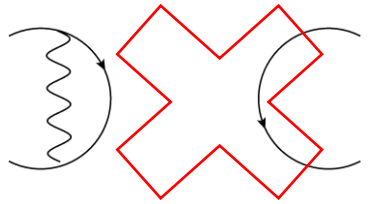
W-exchange



W-annihilation



Penguin

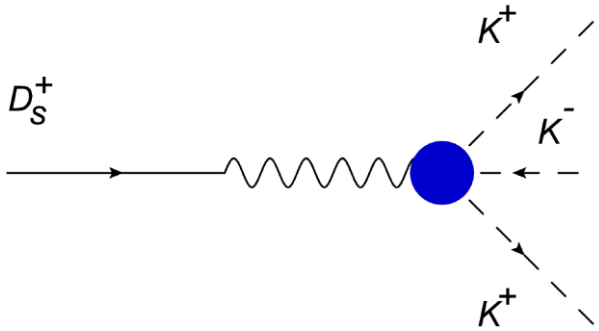


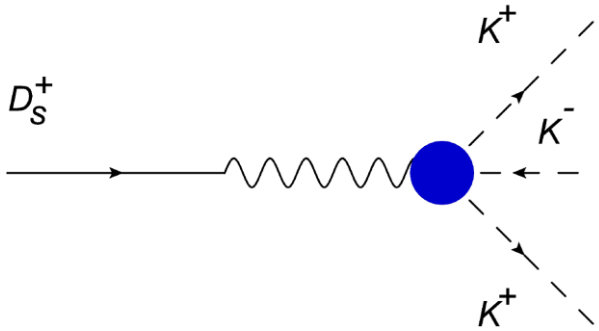
Sideways Penguin

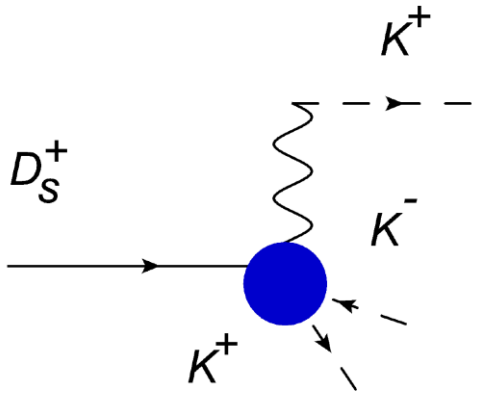
Gen—T

IFIC
INSTITUT DE FÍSICA CORPUSCULAR

VNIVERSITAT DE VALÈNCIA


D_s^+
K^+
K^-
K^+

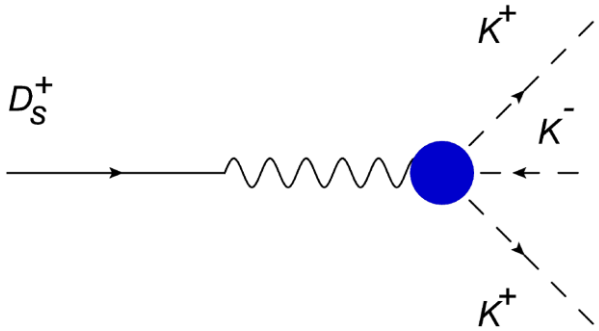


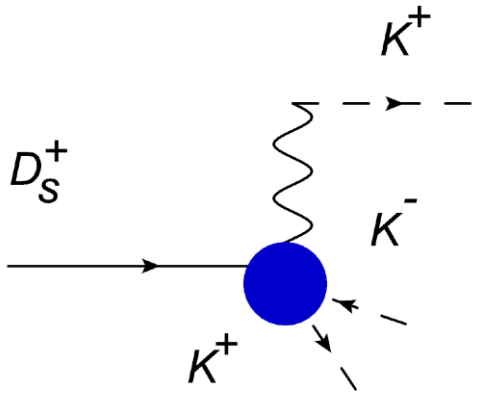


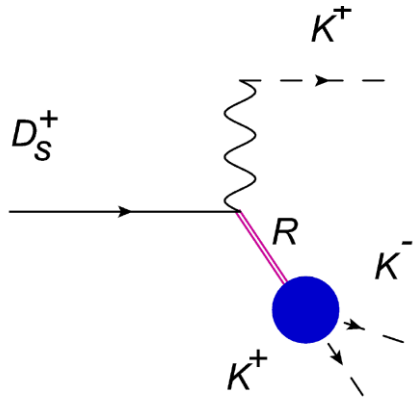
Gen—T

IFIC INSTITUT DE FÍSICA CORPUSCULAR

VNIVERSITAT DE VALÈNCIA



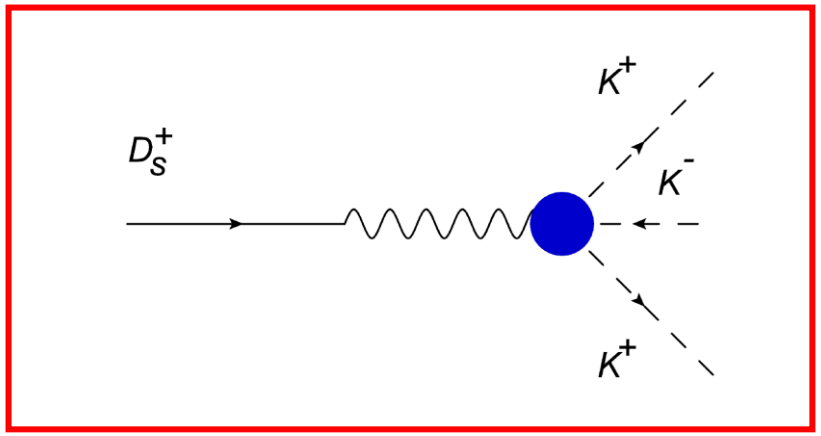




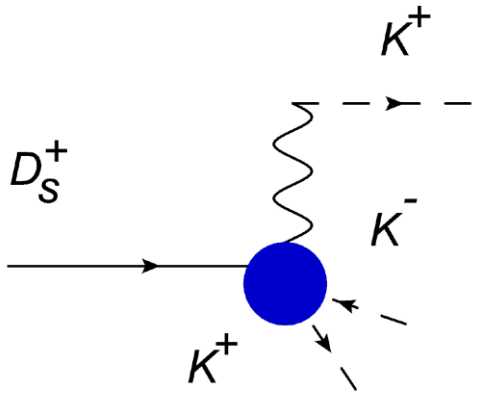
Gen—T

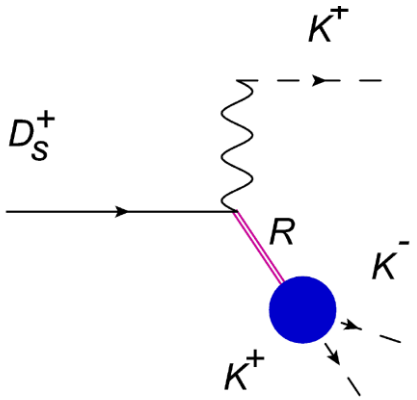
IFIC INSTITUT DE FÍSICA CORPUSCULAR

VNIVERSITAT DE VALÈNCIA



R. T. Aude et al. Multimeson model for the $D^+ \to K^+K^-K^+$ decay amplitude, 2018

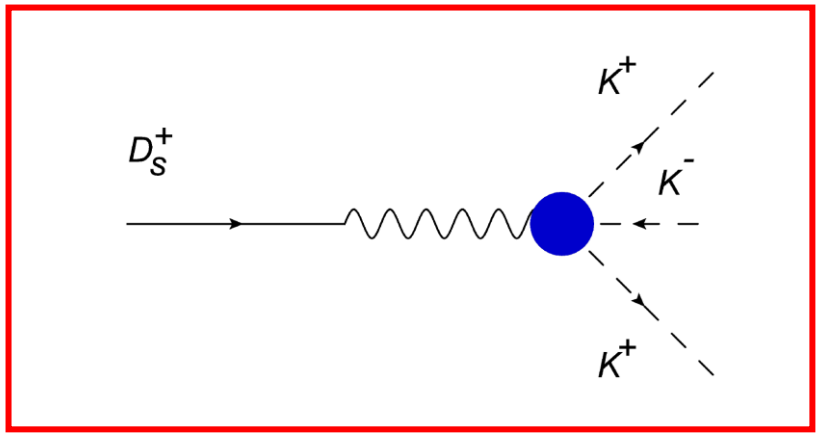




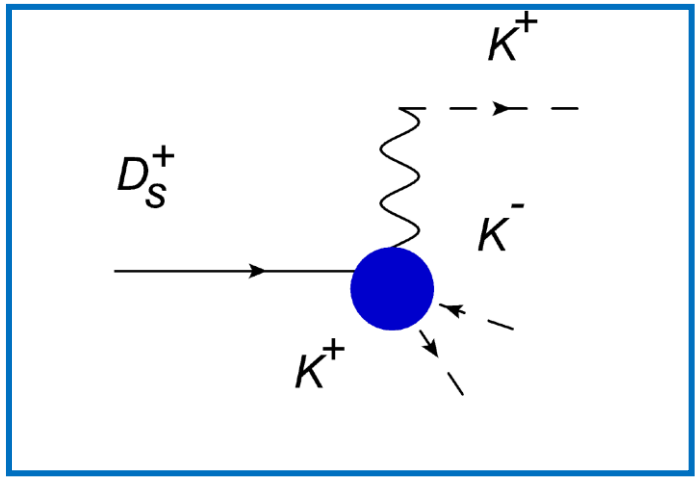
Gen—T

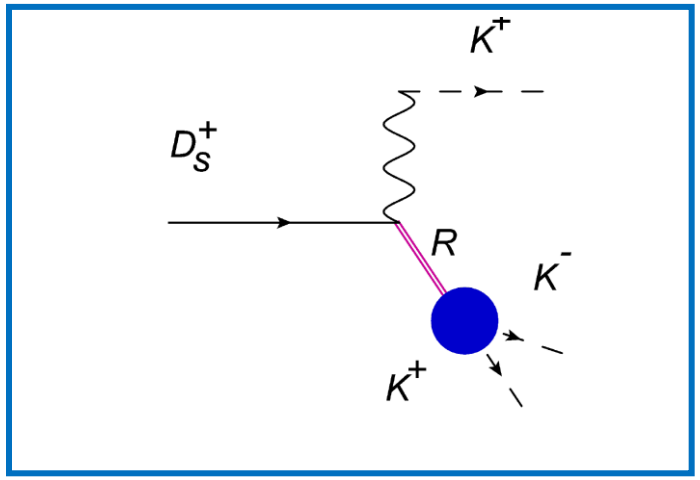
IFIC INSTITUT DE FÍSICA CORPUSCULAR

VNIVERSITAT DE VALÈNCIA



R. T. Aude et al. Multimeson model for the $D^+ \to K^+K^-K^+$ decay amplitude, 2018

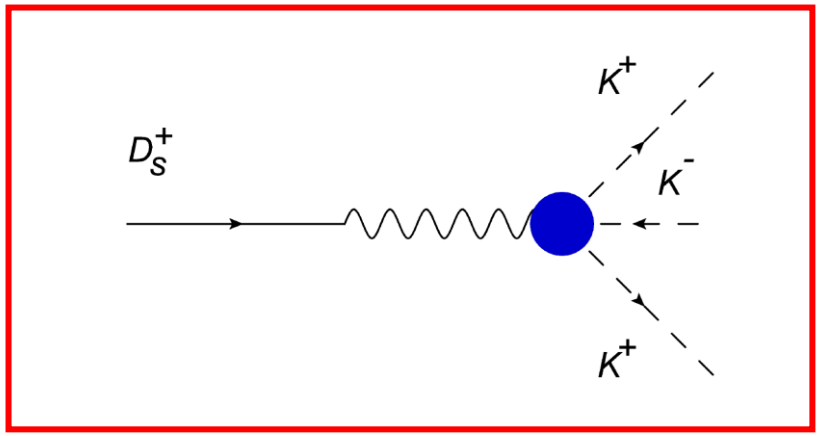




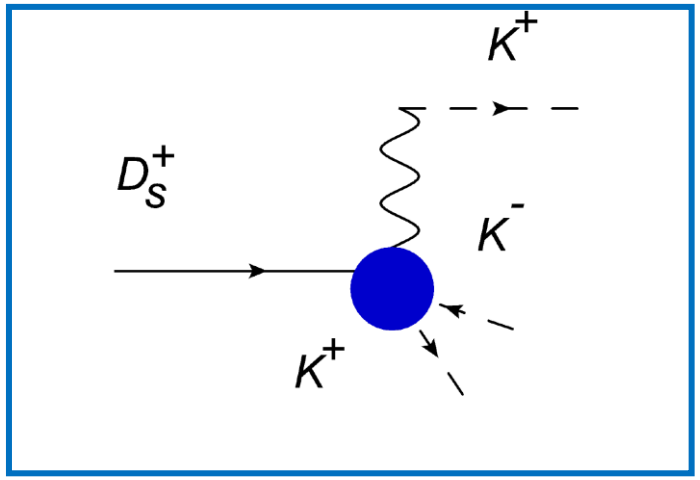
Gen—T

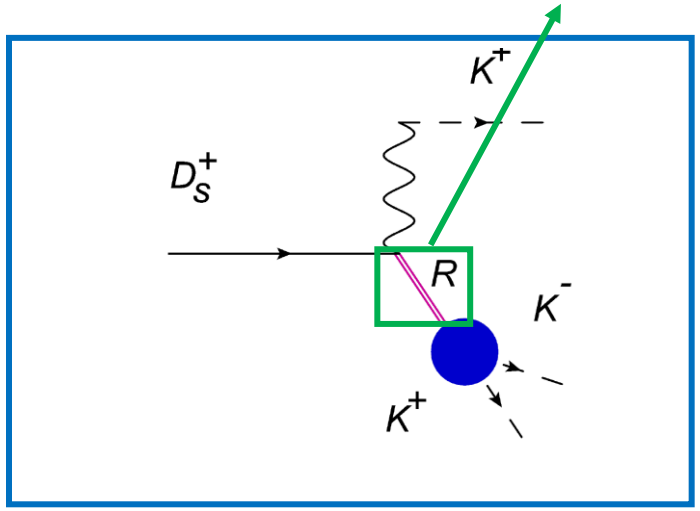
IFIC INSTITUT DE FÍSICA CORPUSCULAR

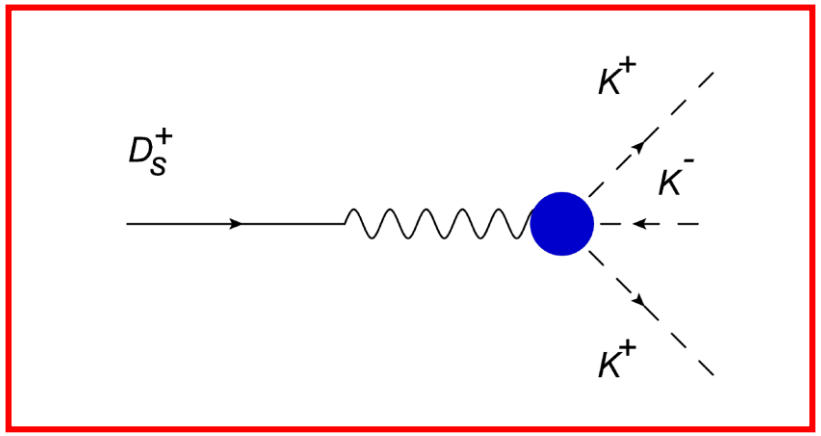
VNIVERSITAT DE VALÈNCIA



R. T. Aude et al. Multimeson model for the $D^+ \to K^+K^-K^+$ decay amplitude, 2018

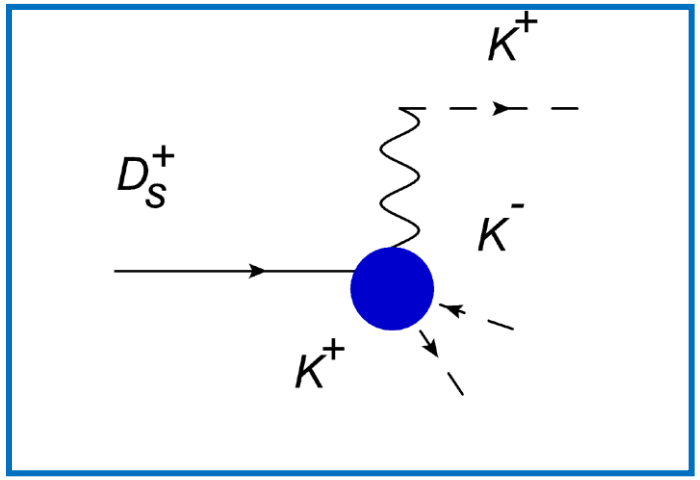


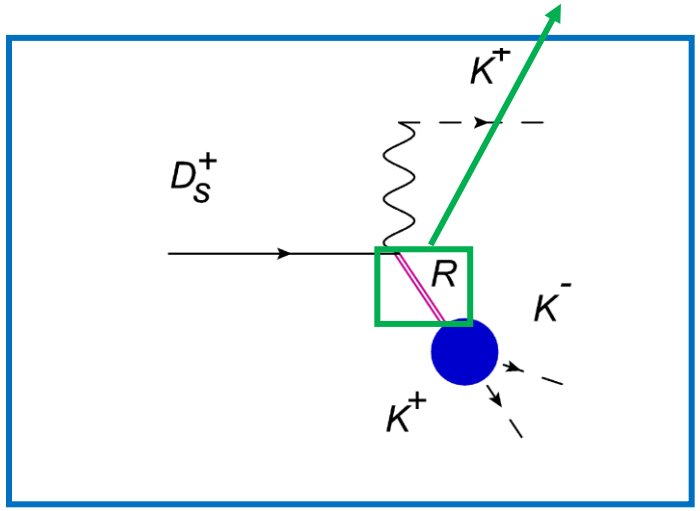




R. T. Aude et al. Multimeson model for the $D^+ \to K^+K^-K^+$ decay amplitude, 2018

$\phi(1020), f_0(980), f_0(1370)$



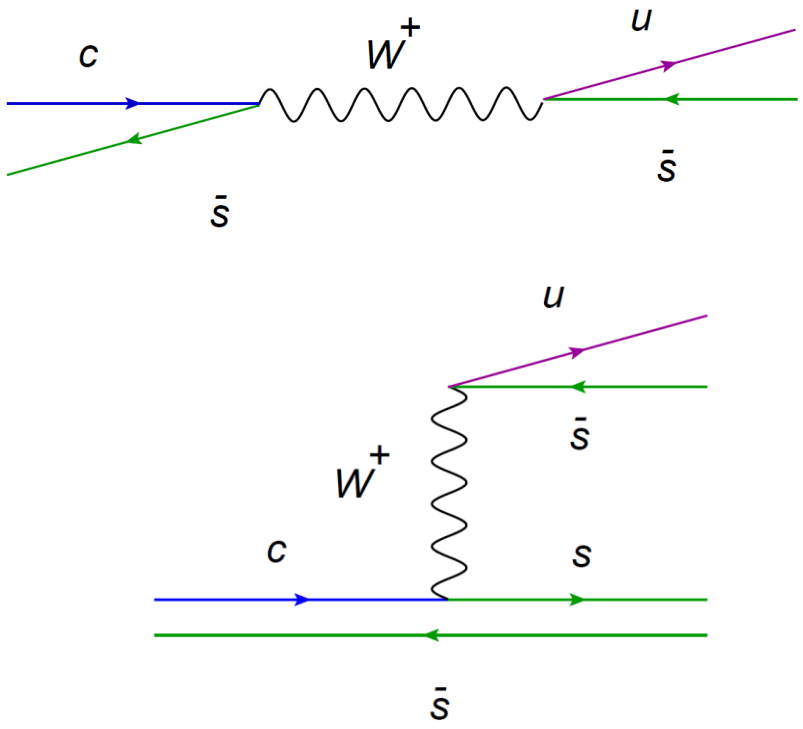


Gen—T

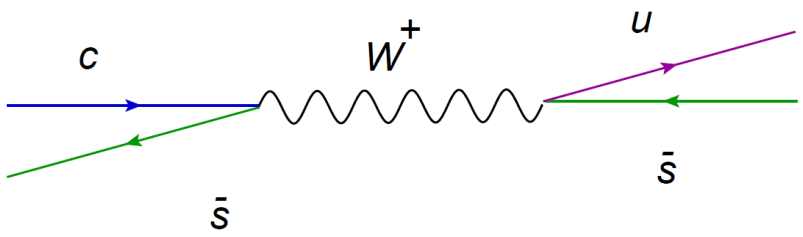
IFIC
INSTITUT DE FÍSICA CORPUSCULAR

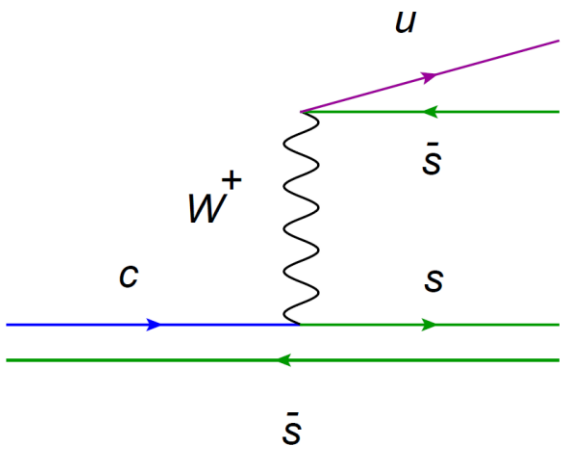
VNIVERSITAT DE VALÈNCIA

$$D_S^+ \to K^+ K^- K^+$$

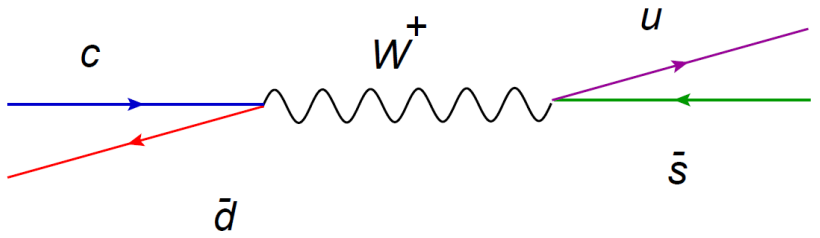


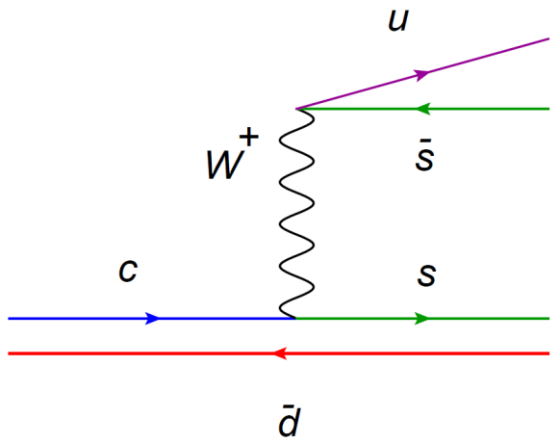
$$D_S^+ \to K^+K^-K^+$$





$$D^+ \to K^+K^-K^+$$



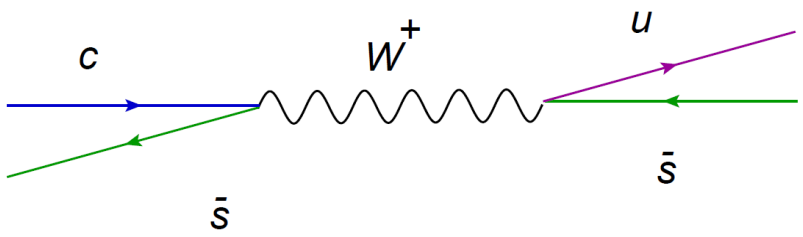


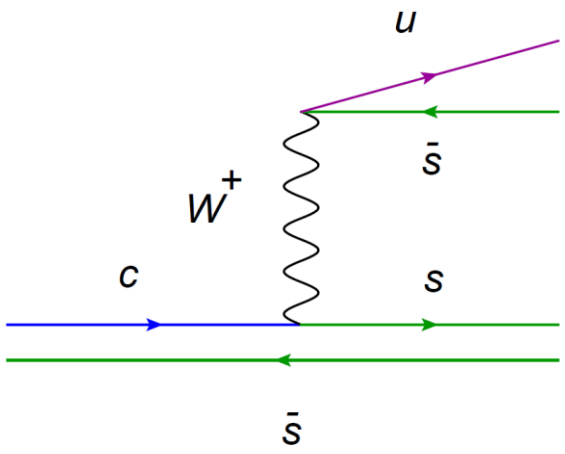
Gen—T

IFIC INSTITUT DE FÍSICA CORPUSCULAR

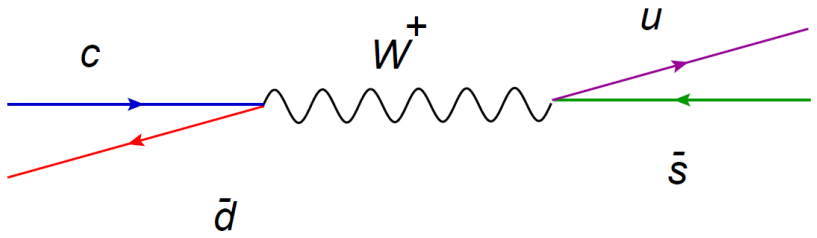
VNIVERSITAT DE VALÈNCIA

$$D_S^+ \to K^+K^-K^+$$



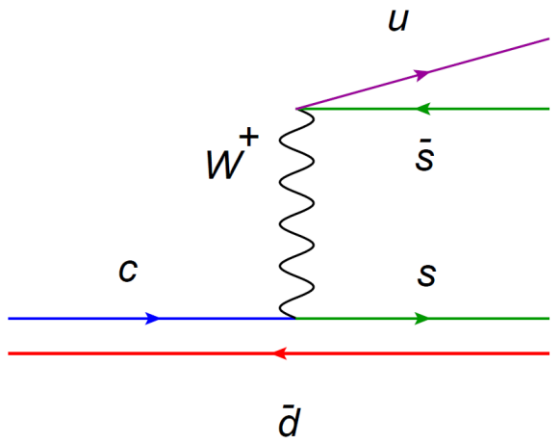


$$D^+ \to K^+K^-K^+$$



Additional

interactions needed!

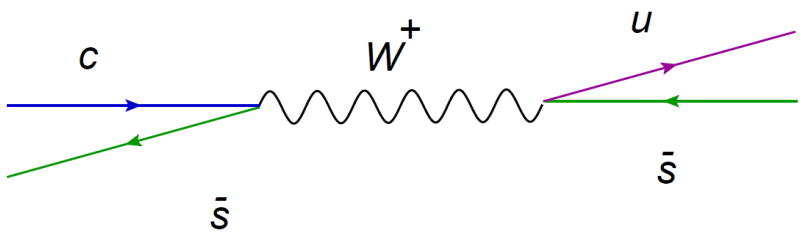


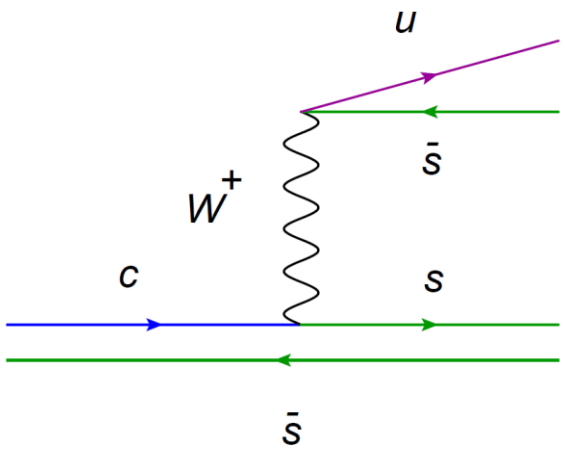
Gen—T

IFIC INSTITUT DE FÍSICA CORPUSCULAR

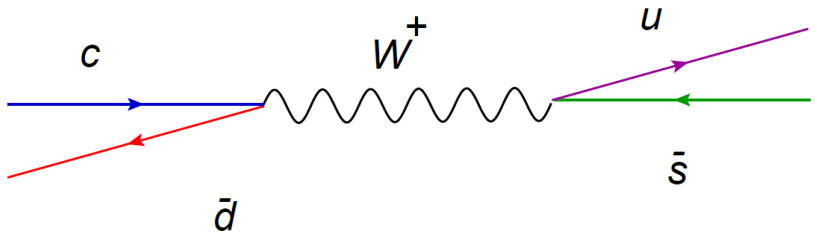
VNIVERSITAT DE VALÈNCIA

$$D_S^+ \to K^+K^-K^+$$

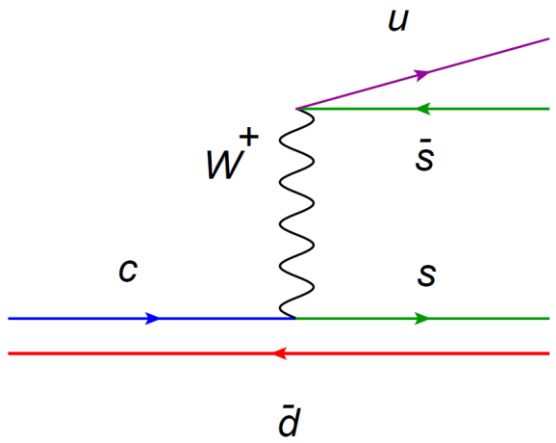




$$D^+ \to K^+K^-K^+$$

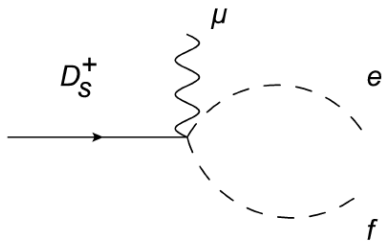


Additional interactions needed!

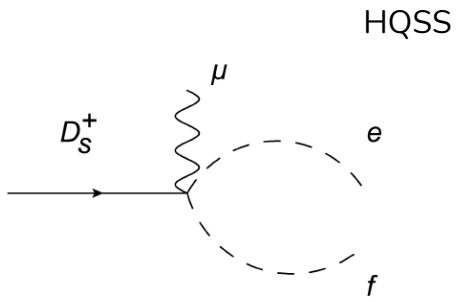


L. Roca and E.Oset. Scalar resonances in the $D^+ \to K^-K^+K^+$ decay, 2020

Model: weak vertex

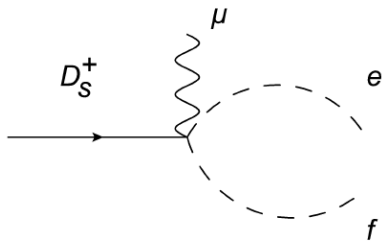


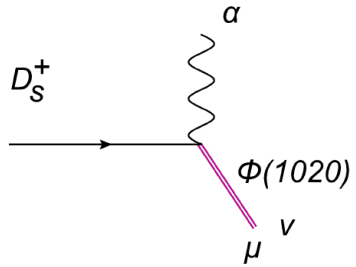
Model: weak vertex



Model: weak vertex

HQSS





$$\approx V_{cs}^* g \sin\theta \left(f_{(V)} \delta^{\alpha\nu} P_D^{\mu} - (\mu \leftrightarrow \nu) \right)$$

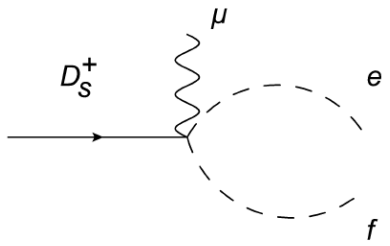
Gen—T

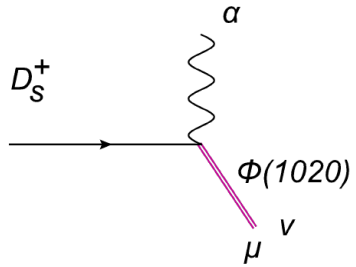
IFIC INSTITUT DE FÍSICA CORPUSCULAR

VNIVERSITAT DE VALÈNCIA

Model: weak vertex

HQSS



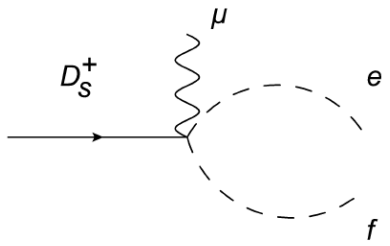


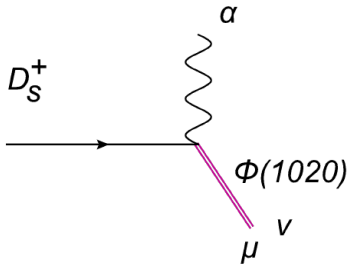
$$\approx V_{cs}^* g \sin\theta \left(f_{(V)} \delta^{\alpha\nu} P_D^\mu - (\mu \leftrightarrow \nu) \right)$$

$$\begin{aligned} |f_0(980)\rangle &= \cos\varepsilon\,|S_1\rangle + \sin\varepsilon\,|S_8\rangle\,, \\ |f_0(1370)\rangle &= -\sin\varepsilon\,|S_1\rangle + \cos\varepsilon\,|S_8\rangle \end{aligned}$$

Model: weak vertex

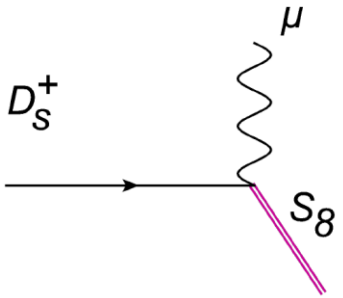
HQSS



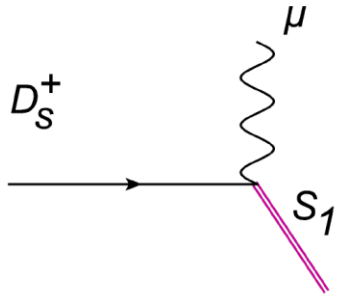


$$\approx V_{cs}^* g \sin\theta \left(f_{(V)} \delta^{\alpha\nu} P_D^\mu - (\mu \leftrightarrow \nu) \right)$$

$$\begin{aligned} |f_0(980)\rangle &= \cos\varepsilon\,|S_1\rangle + \sin\varepsilon\,|S_8\rangle\,, \\ |f_0(1370)\rangle &= -\sin\varepsilon\,|S_1\rangle + \cos\varepsilon\,|S_8\rangle \end{aligned}$$



$$\approx V_{cs}^* g f_{(so)} P_D^\mu$$



$$\approx V_{cs}^* g f_{(ss)} P_D^\mu$$

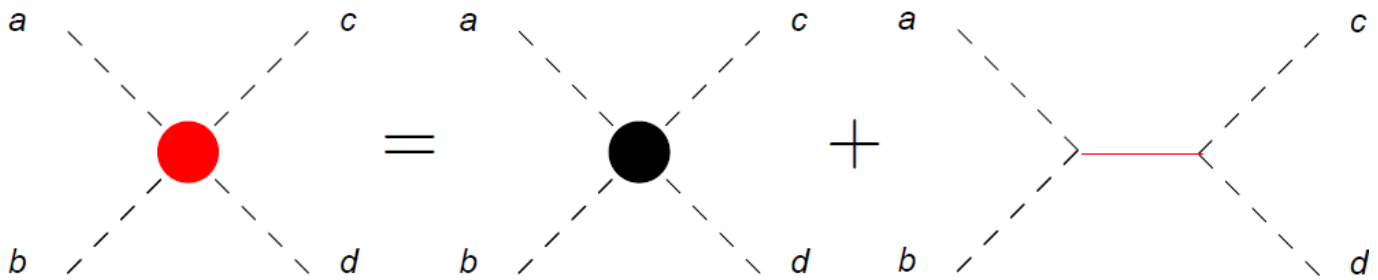
Gen—T

IFIC INSTITUT DE FÍSICA CORPUSCULAR

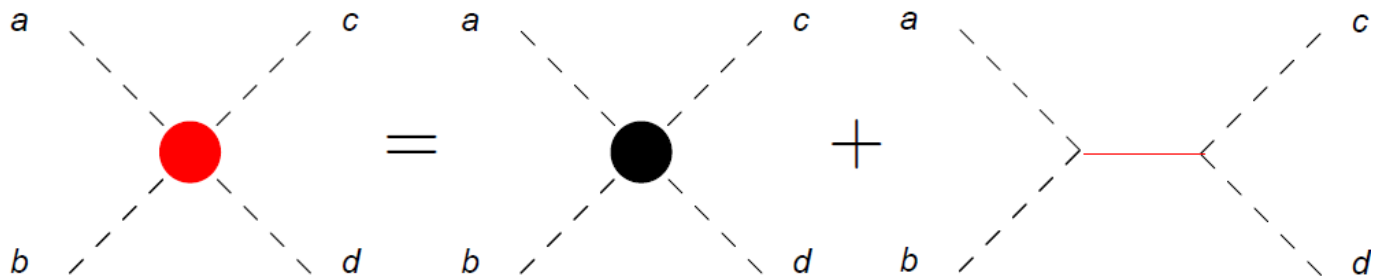
VNIVERSITAT DE VALÈNCIA

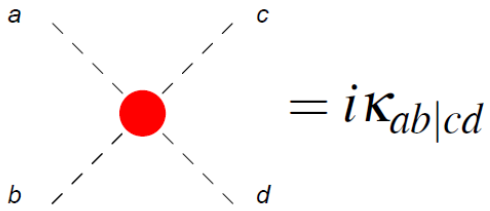
Model: Final states interactions (FSI)

Model: Final states interactions (FSI)



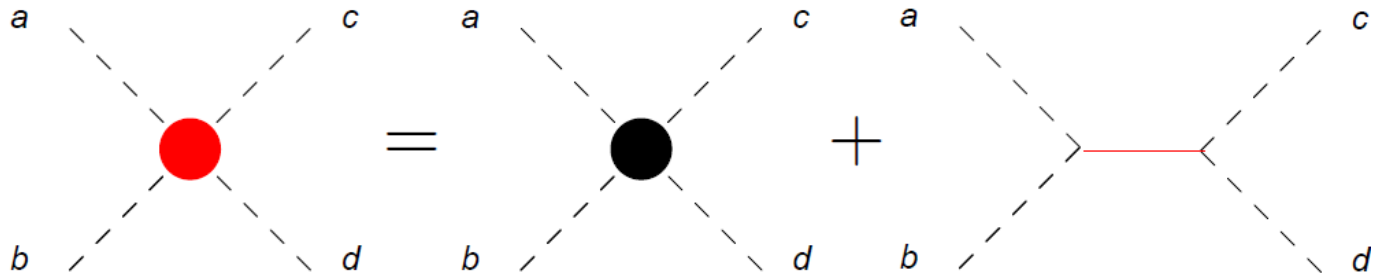
Model: Final states interactions (FSI)

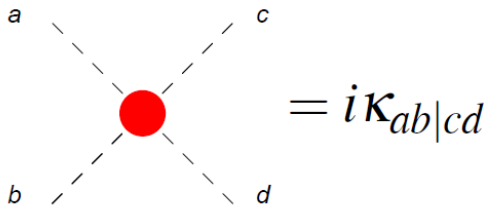




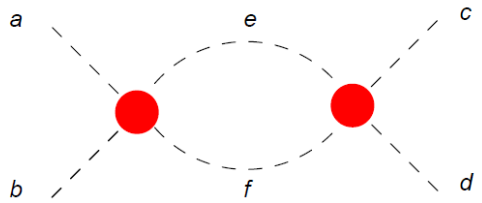
$$= i\kappa_{ab|cd}$$

Model: Final states interactions (FSI)





$$= i\kappa_{ab|cd}$$



$$= \sum_{ef} i\kappa_{ab|ef}(-\Omega_{ef})\kappa_{ef|cd}$$

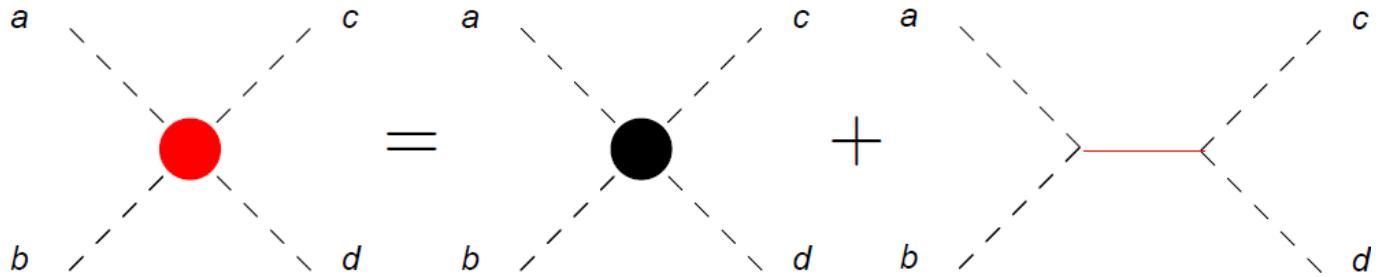
$$= \sum_{ef} i\kappa_{ab|ef}M_{ef|cd},$$

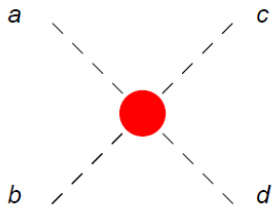
Gen—T

IFIC INSTITUT DE FÍSICA CORPUSCULAR

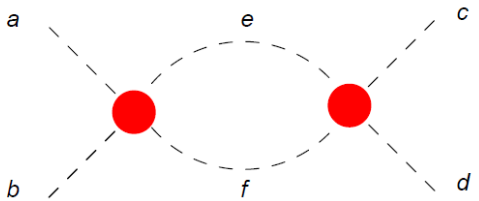
VNIVERSITAT DE VALÈNCIA

Model: Final states interactions (FSI)





$$= i\kappa_{ab|cd}$$



$$= \sum_{ef} i\kappa_{ab|ef}(-\Omega_{ef})\kappa_{ef|cd}$$

$$= \sum_{ef} i\kappa_{ab|ef} M_{ef|cd},$$

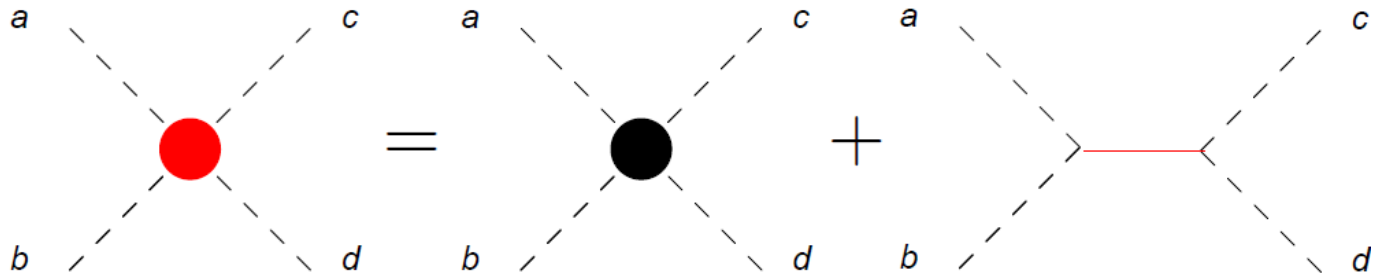
$$\sum_{ef} i\kappa_{ab|ef}(\delta_{ef|cd} + M_{ef|cd} + M^2_{ef|cd} + ...) = \sum_{ef} i\kappa_{ab|ef} \sum_{n=0}^{\infty} M^n_{ef|cd}$$

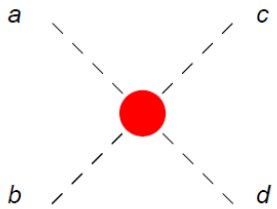
Gen—T

IFIC INSTITUT DE FÍSICA CORPUSCULAR

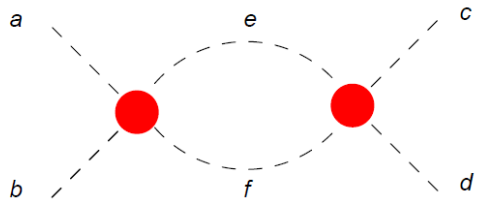
VNIVERSITAT DE VALÈNCIA

Model: Final states interactions (FSI)





$$= i\kappa_{ab|cd}$$



$$= \sum_{ef} i\kappa_{ab|ef}(-\Omega_{ef})\kappa_{ef|cd}$$

$$= \sum_{ef} i\kappa_{ab|ef}M_{ef|cd},$$

$$\sum_{ef} i\kappa_{ab|ef}(\delta_{ef|cd} + M_{ef|cd} + M^2_{ef|cd} + ...) = \sum_{ef} i\kappa_{ab|ef} \sum_{n=0}^{\infty} M^n_{ef|cd}$$

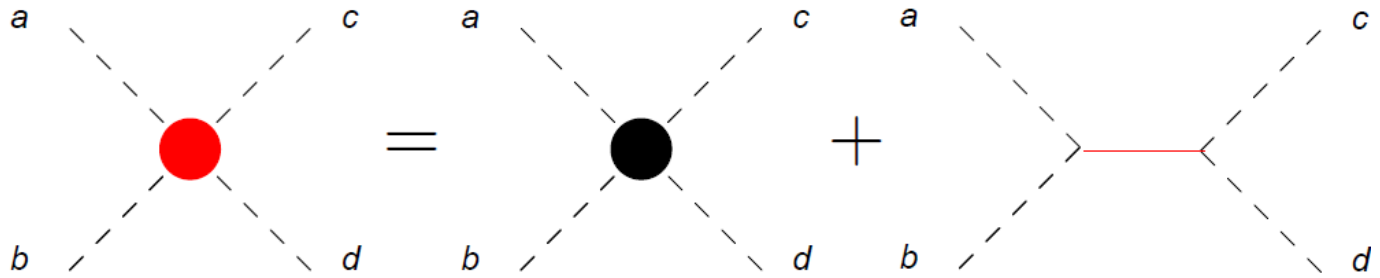
$$\langle ab|cd\rangle = \sum_{ef} i\kappa_{ab|ef}\left(\frac{1}{1-M}\right)_{ef|cd}$$

Gen—T

IFIC INSTITUT DE FÍSICA CORPUSCULAR

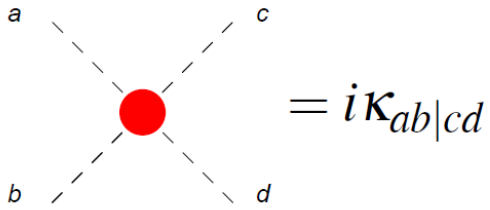
VNIVERSITAT DE VALÈNCIA

Model: Final states interactions (FSI)

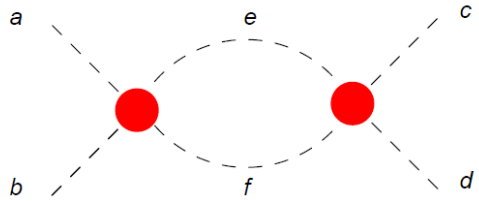


P.C Magalhães et al.

Multibody decay analyses -- a new phenomenological model for meson-meson subamplitudes, 2020



$$= i\kappa_{ab|cd}$$



$$= \sum_{ef} i\kappa_{ab|ef}(-\Omega_{ef})\kappa_{ef|cd}$$

$$= \sum_{ef} i\kappa_{ab|ef} M_{ef|cd},$$

$$\sum_{ef} i\kappa_{ab|ef}(\delta_{ef|cd} + M_{ef|cd} + M^2_{ef|cd} + ...) = \sum_{ef} i\kappa_{ab|ef} \sum_{n=0}^{\infty} M^n_{ef|cd}$$

$$\langle ab|cd\rangle = \sum_{ef} i\kappa_{ab|ef} \left(\frac{1}{1-M}\right)_{ef|cd}$$

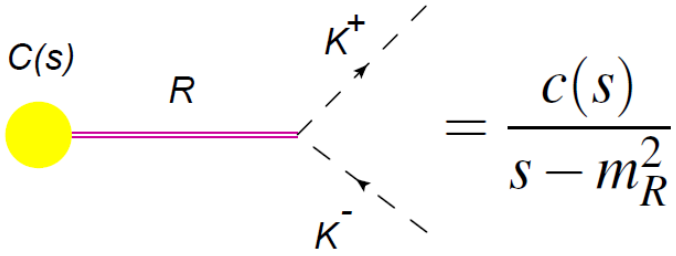
Gen—T

IFIC INSTITUT DE FÍSICA CORPUSCULAR

VNIVERSITAT DE VALÈNCIA

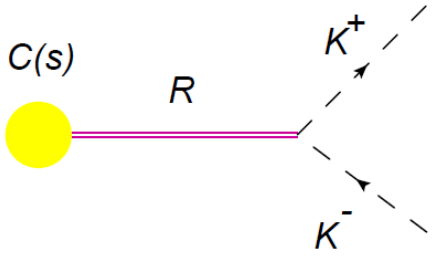
Model: Why FSI?

Model: Why FSI?

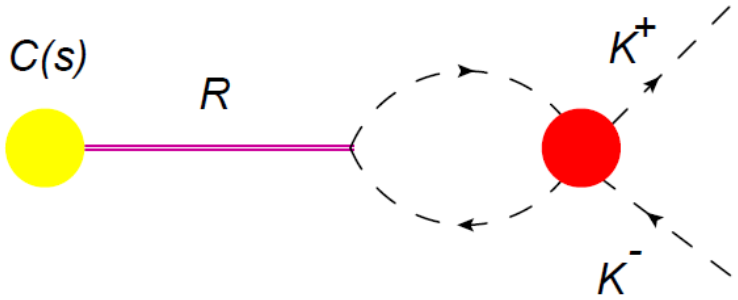


$$= \frac{c(s)}{s - m_R^2}$$

Model: Why FSI?

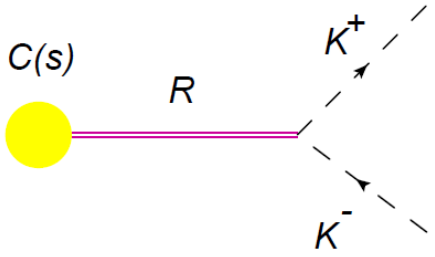


$$= \frac{c(s)}{s - m_R^2}$$

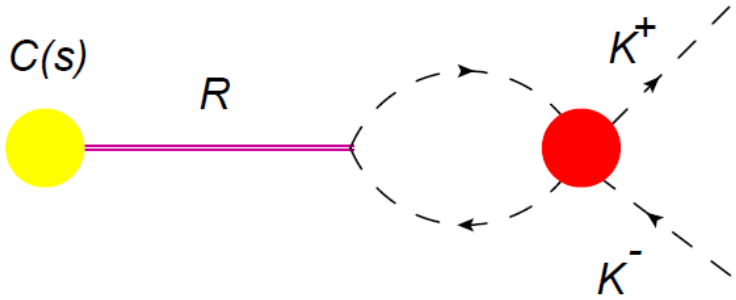


$$= \frac{c(s)}{(s - m_R^2)(1 + \Omega\kappa)}$$

Model: Why FSI?



$$= \frac{c(s)}{s - m_R^2}$$



$$= \frac{c(s)}{(s - m_R^2)(1 + \Omega\kappa)}$$

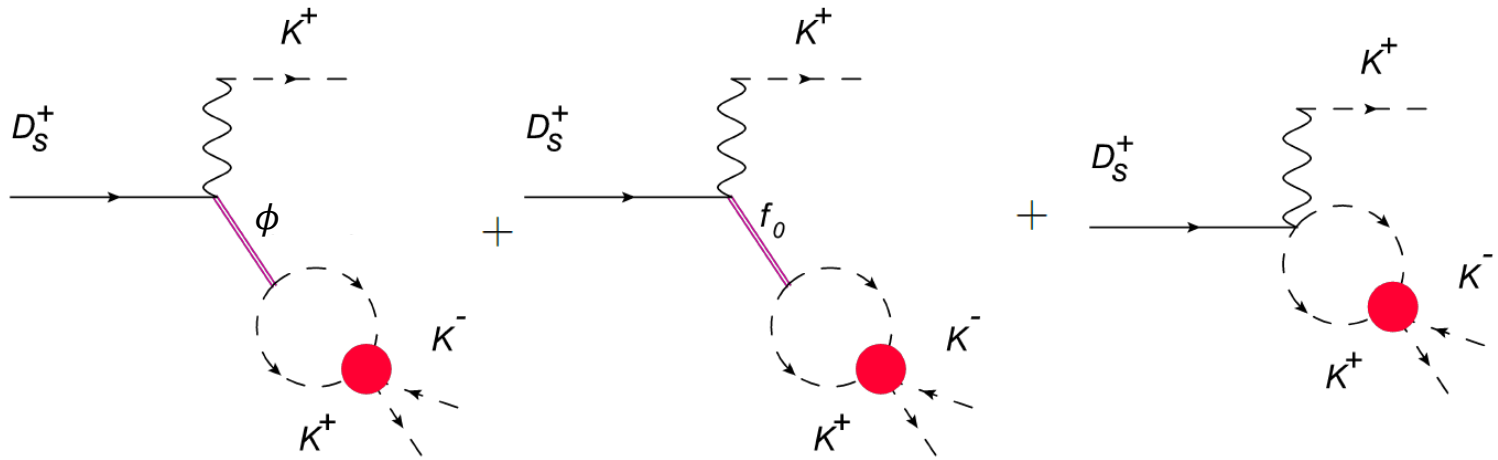
I. The interaction kernel times the pole is not zero at the mass of the resonance

II. Considering only the imaginary part of the loop (K matrix approximation) a width to the resonance propagator is given

Decay amplitude

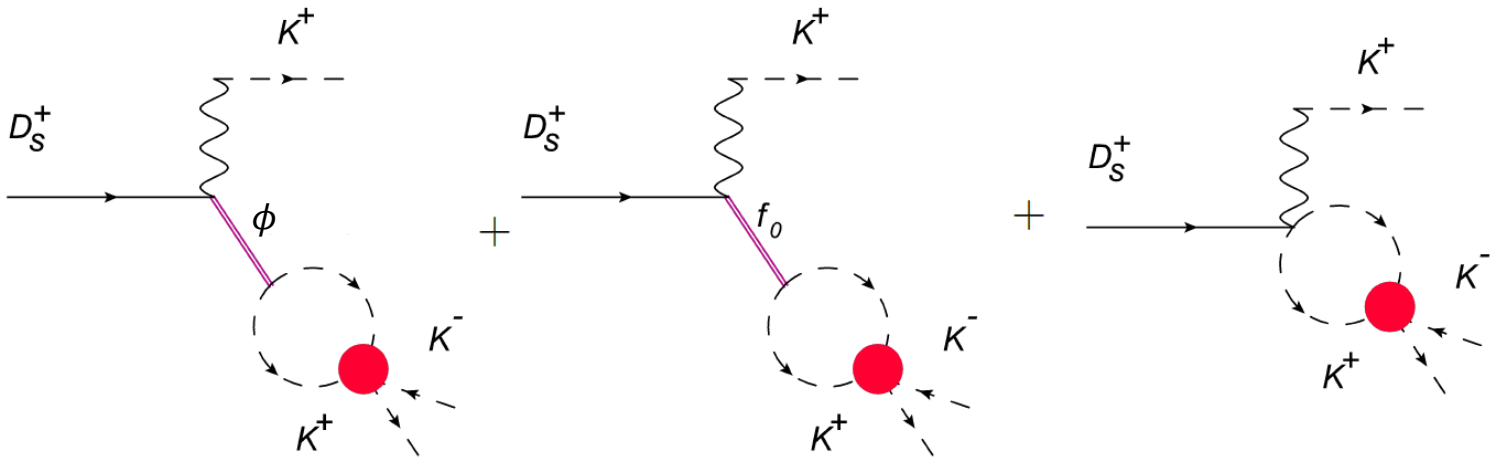
Decay amplitude

$$\langle K^- K^+ K^+ | D_s^+ \rangle =$$



Decay amplitude

$$\langle K^- K^+ K^+ | D_s^+ \rangle =$$



Parameter	Value		
m_π	0.1395GeV	m_K	0.4937GeV
m_D	1.9685GeV	m_ϕ	1.0194GeV
m_{f_a}	0.980GeV	m_{f_b}	1.370GeV
f	0.093GeV	f_D	0.216MeV
c_d	0.032GeV	c_m	0.042GeV
$\tilde{c}_d$	0.018GeV	$\tilde{c}_m$	0.025GeV
G_V	0.066GeV	f_{ss}	1.7
f_{so}	1.7	$\sin\theta$	0.605
f_V	1	$2n$	$\frac{\pi}{3}$

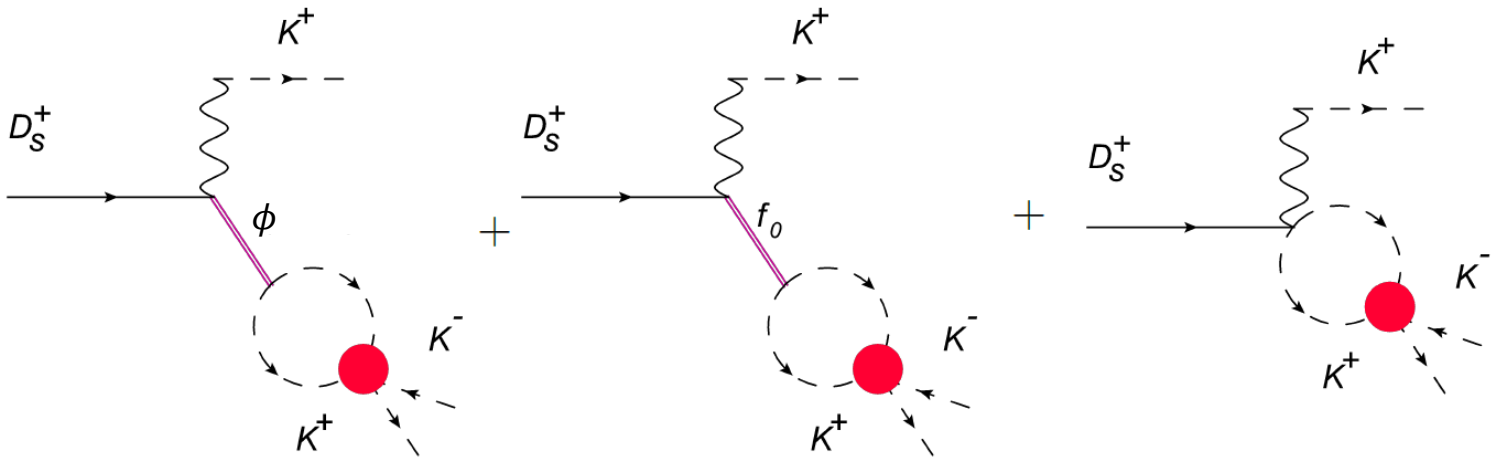
Gen—T

IFIC INSTITUT DE FÍSICA CORPUSCULAR

VNIVERSITAT DE VALÈNCIA

Decay amplitude

$$\langle K^- K^+ K^+ | D_s^+ \rangle =$$



J. Gasser et al. Chiral perturbation theory: expansions in the mass of the strange quark, 1984

Parameter	Value		
m_π	0.1395GeV	m_K	0.4937GeV
m_D	1.9685GeV	m_ϕ	1.0194GeV
m_{f_a}	0.980GeV	m_{f_b}	1.370GeV
f	0.093GeV	f_D	0.216MeV
c_d	0.032GeV	c_m	0.042GeV
$\tilde{c}_d$	0.018GeV	$\tilde{c}_m$	0.025GeV
G_V	0.066GeV	f_{ss}	1.7
f_{so}	1.7	$\sin\theta$	0.605
f_V	1	$2n$	$\frac{\pi}{3}$

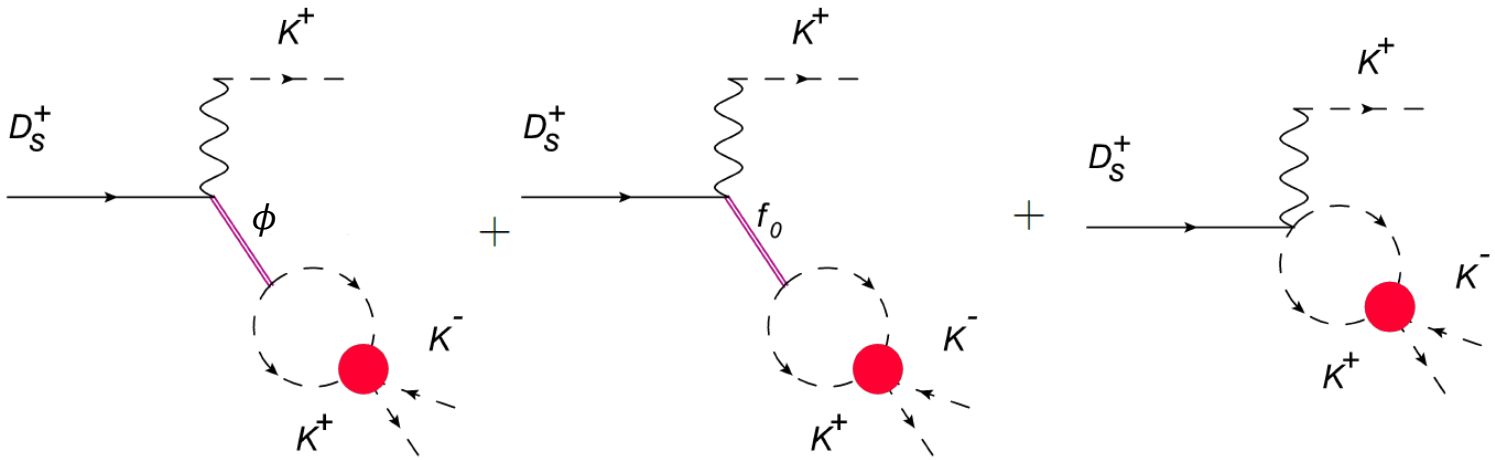
Gen—T

IFIC INSTITUT DE FÍSICA CORPUSCULAR

VNIVERSITAT DE VALÈNCIA

Decay amplitude

$$\langle K^- K^+ K^+ | D_s^+ \rangle =$$



J. Gasser et al. Chiral perturbation theory: expansions in the mass of the strange quark, 1984

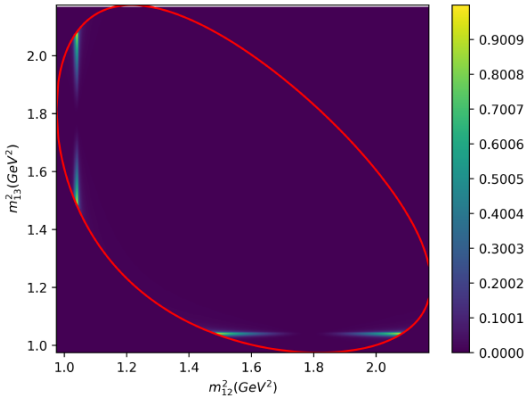
Parameter	Value		
m_π	0.1395GeV	m_K	0.4937GeV
m_D	1.9685GeV	m_ϕ	1.0194GeV
m_{f_a}	0.980GeV	m_{f_b}	1.370GeV
f	0.093GeV	f_D	0.216MeV
c_d	0.032GeV	c_m	0.042GeV
$\tilde{c}_d$	0.018GeV	$\tilde{c}_m$	0.025GeV
G_V	0.066GeV	f_{ss}	1.7
f_{so}	1.7	$\sin\theta$	0.605
f_V	1	$2n$	$\frac{\pi}{3}$

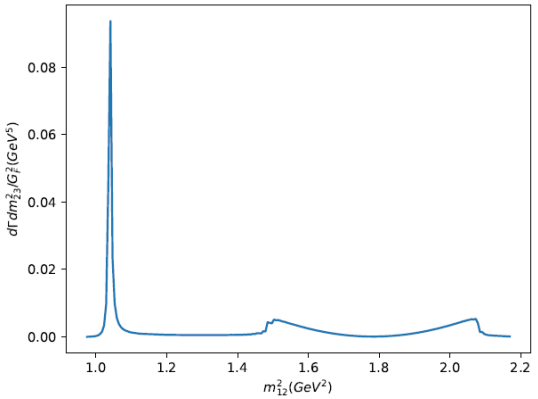
G. Ecker et al. The role of resonances in chiral perturbation theory, 1988

Main results

Main results

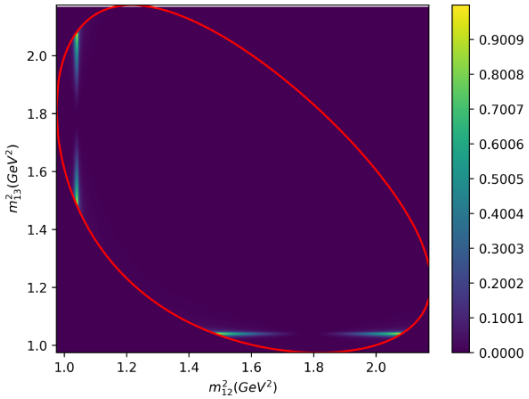
$[\phi]$

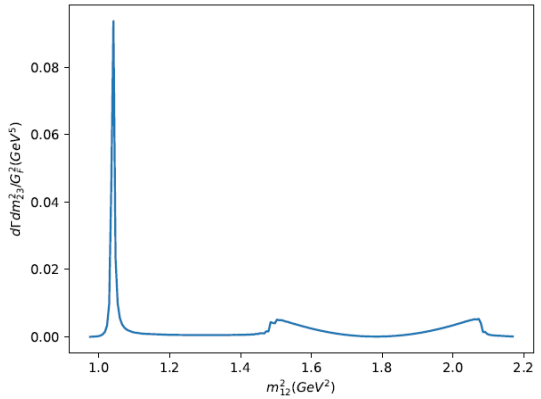




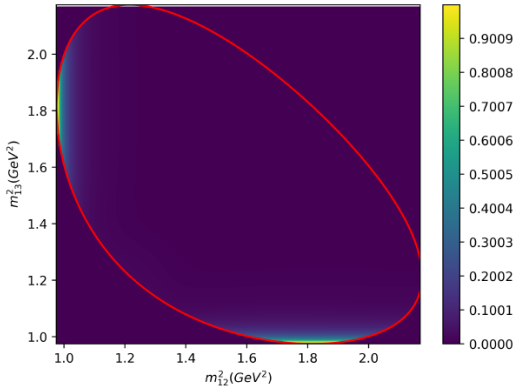
Main results

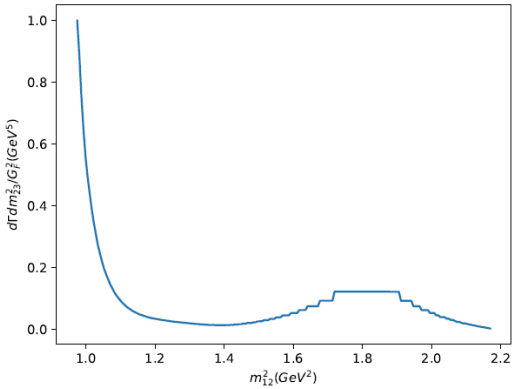
$[\phi]$





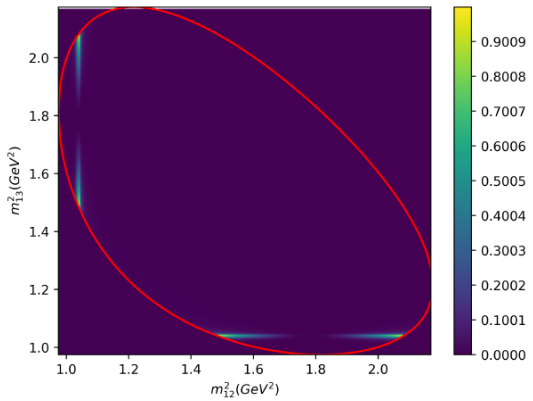
$[f_0]$

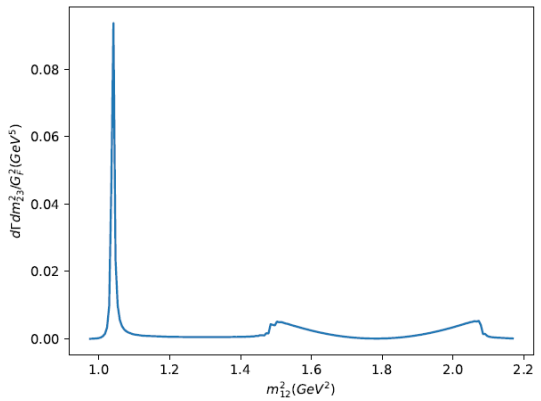




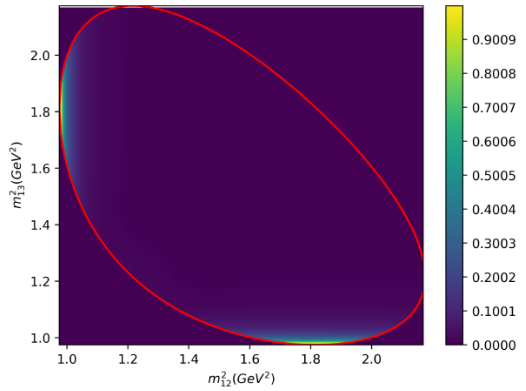
Main results

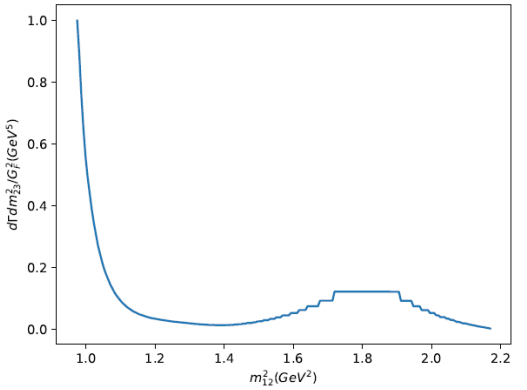
$[\phi]$



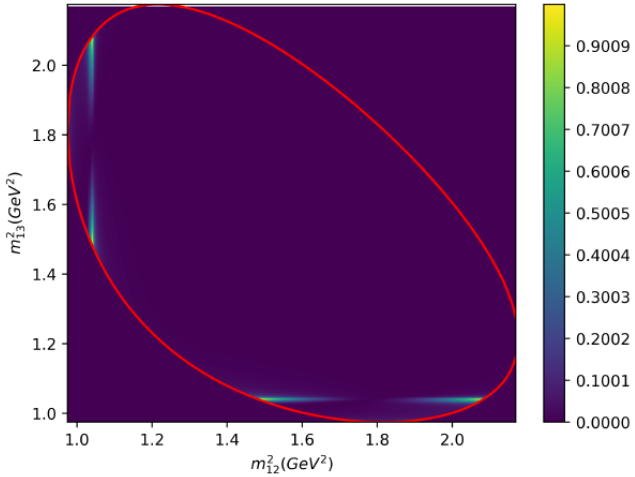


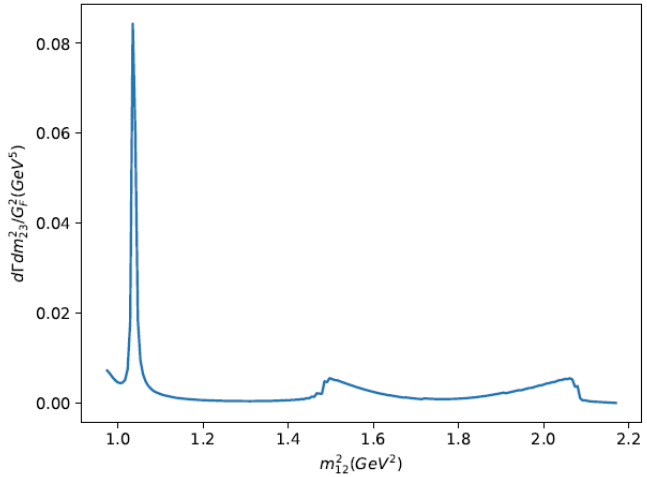
$[f_0]$





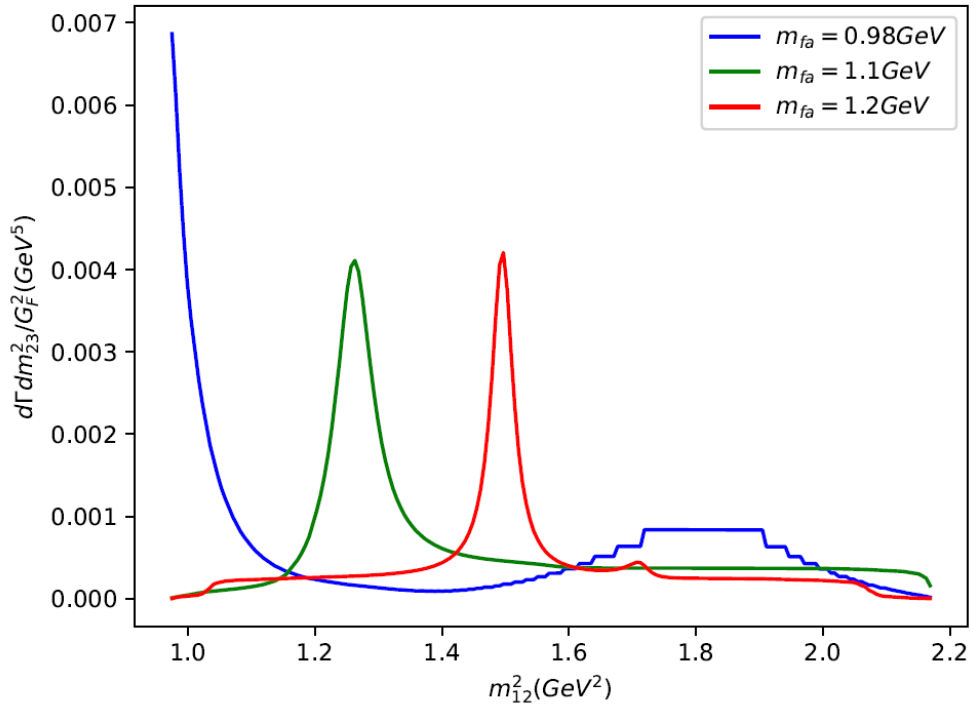
Combined



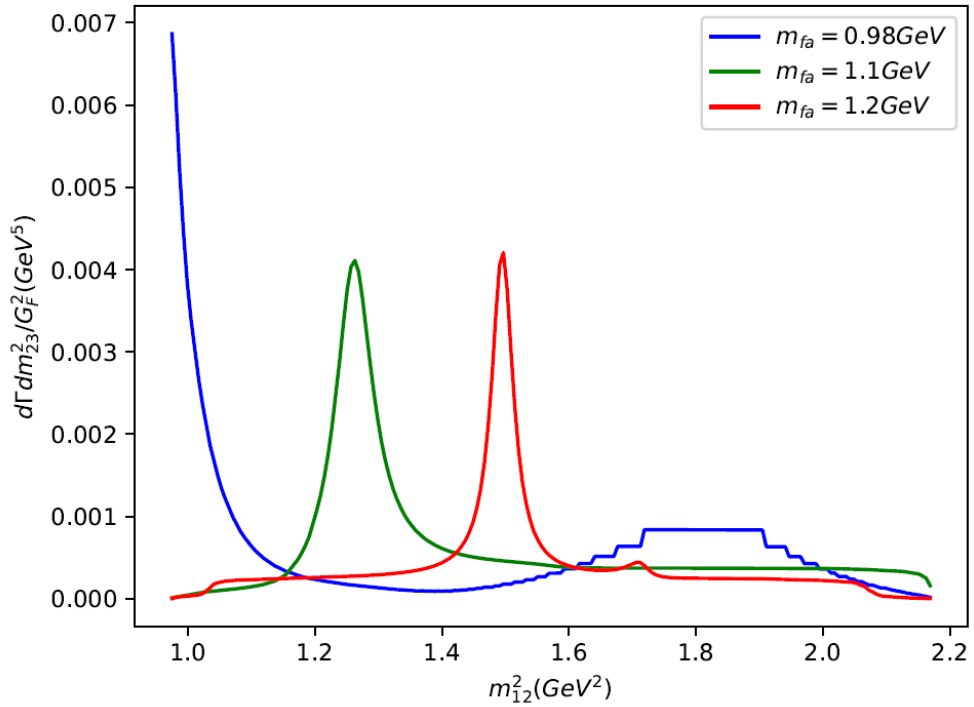


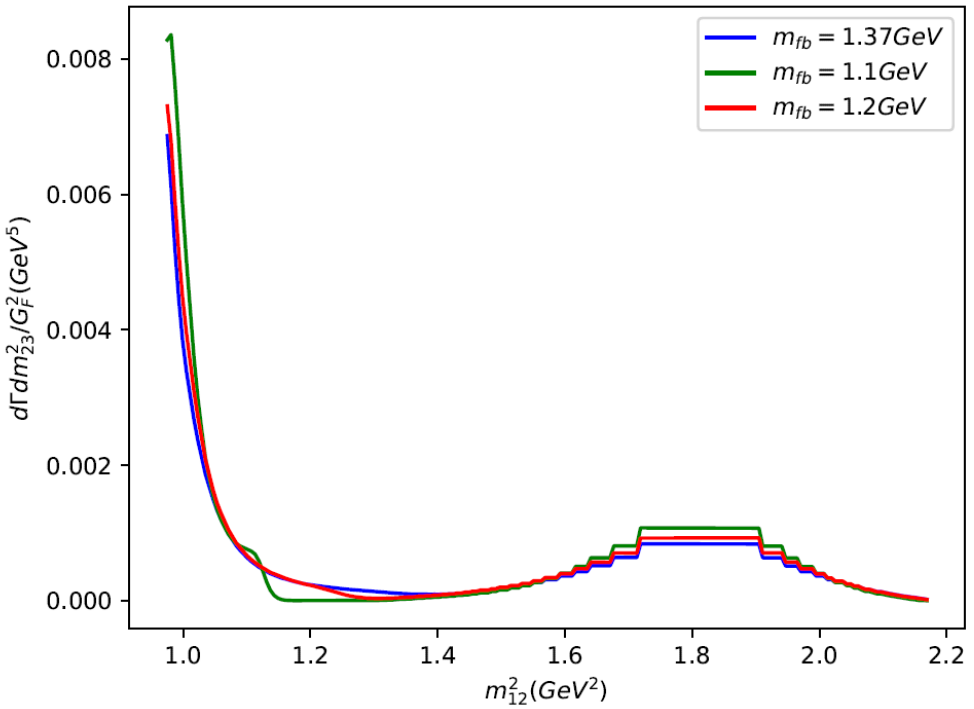
Parameters of the model

Parameters of the model



Parameters of the model





Gen—T

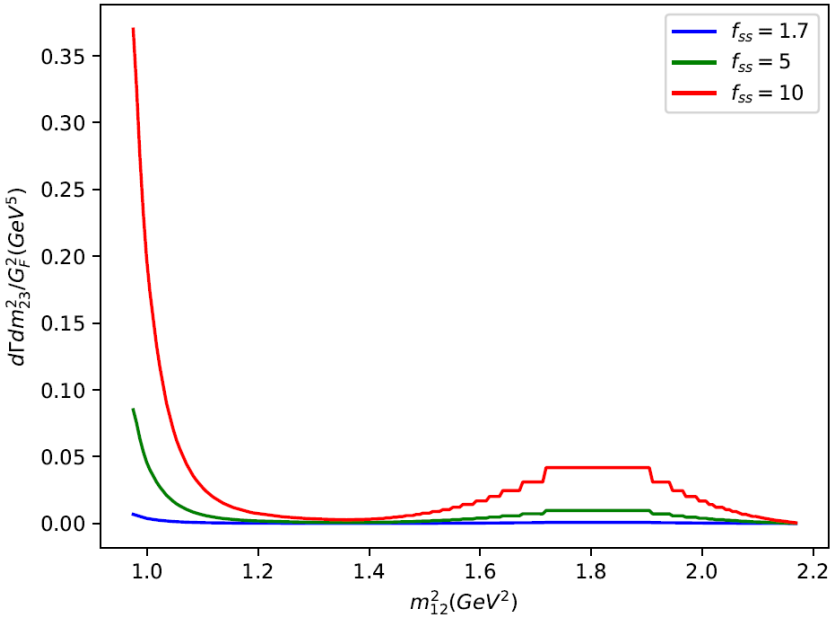
IFIC INSTITUT DE FÍSICA CORPUSCULAR

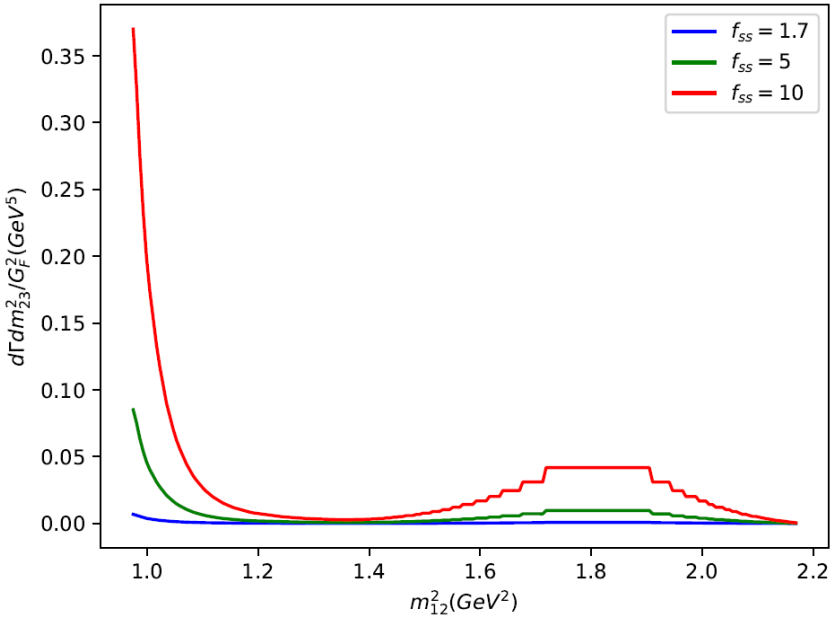
VNIVERSITAT DE VALÈNCIA

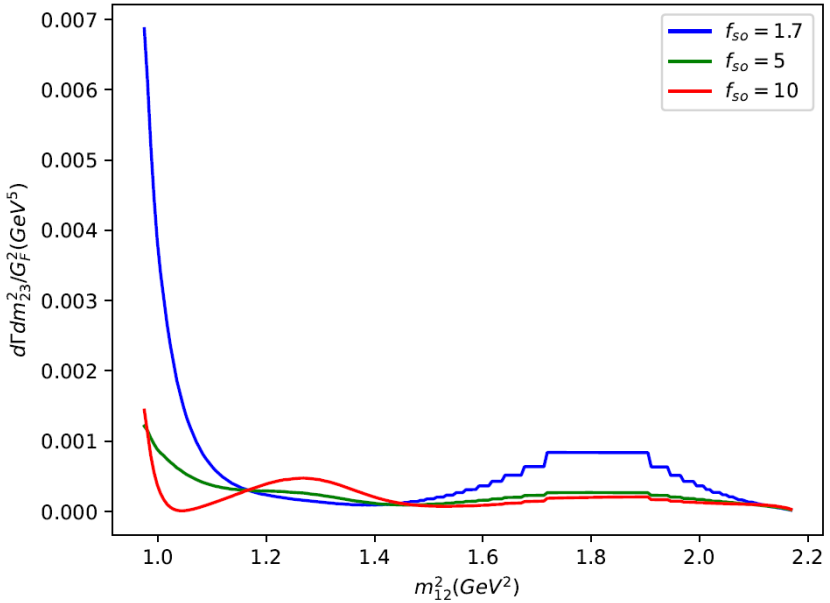
Gen—T

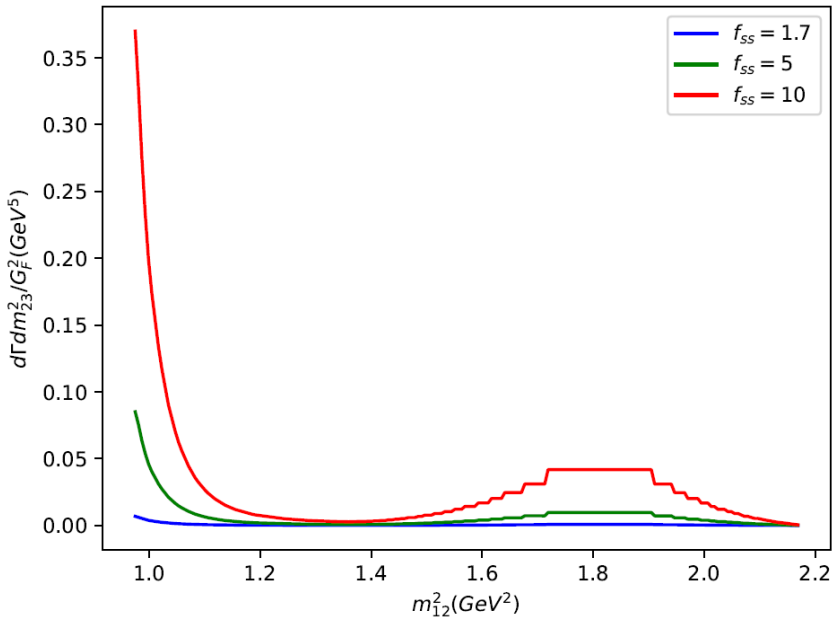
IFIC
INSTITUT DE FÍSICA CORPUSCULAR

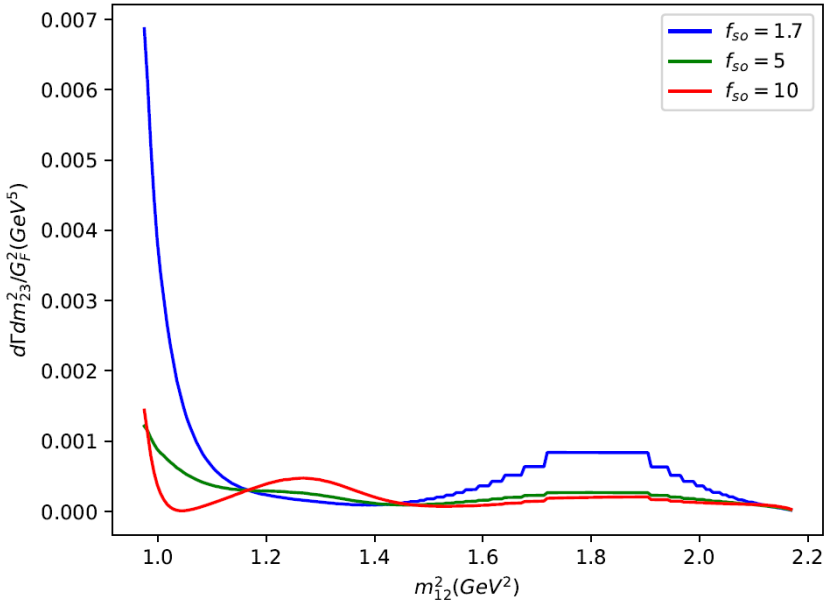
VNIVERSITAT DE VALÈNCIA

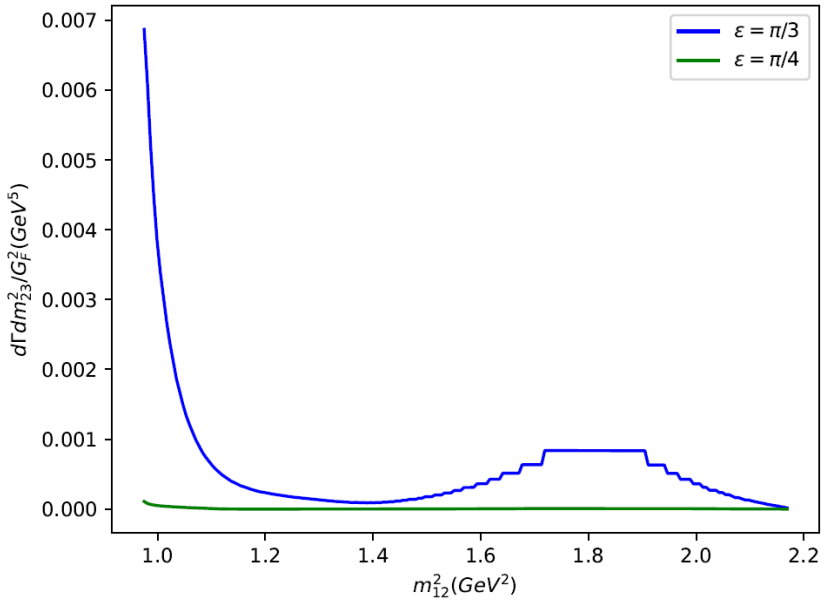

$f_{ss} = 1.7$
$f_{ss} = 5$
$f_{ss} = 10$
$d\Gamma dm_{23}^2/G_F^2(GeV^5)$
$m_{12}^2(GeV^2)$
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
1.0
1.2
1.4
1.6
1.8
2.0
2.2


$f_{ss} = 1.7$
$f_{ss} = 5$
$f_{ss} = 10$
$d\Gamma dm_{23}^2/G_F^2(GeV^5)$
$m_{12}^2(GeV^2)$


$f_{so} = 1.7$
$f_{so} = 5$
$f_{so} = 10$
$d\Gamma dm_{23}^2/G_F^2(GeV^5)$
$m_{12}^2(GeV^2)$







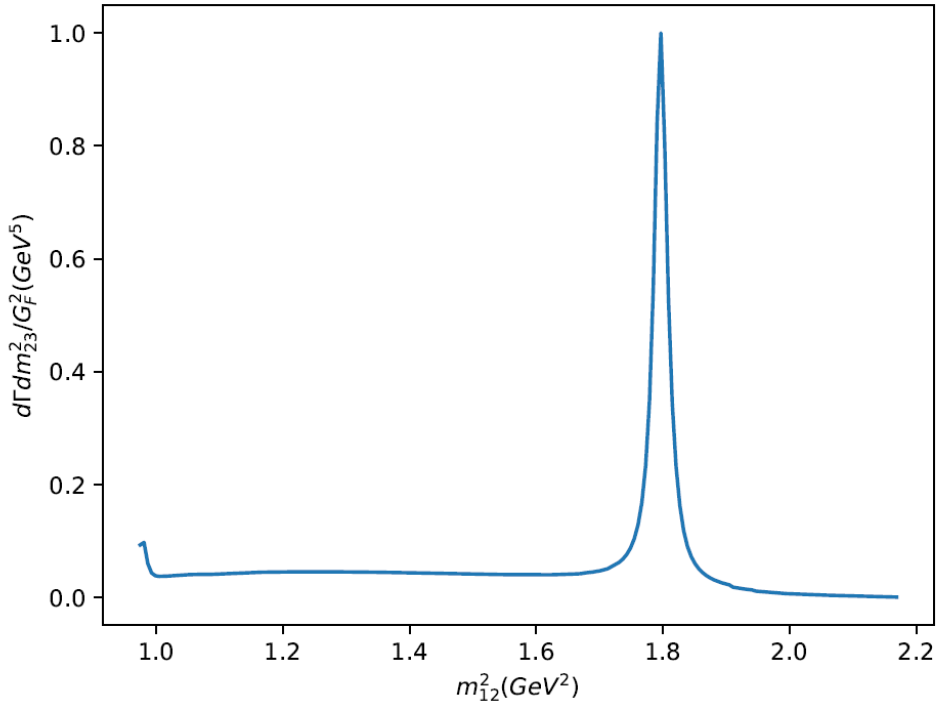
Gen—T

IFIC INSTITUT DE FÍSICA CORPUSCULAR

VNIVERSITAT DE VALÈNCIA

Model implemented with parameters taken from recent data analysis

Model implemented with parameters taken from recent data analysis



Parameters taken from: R. Aaij et al. Dalitz plot analysis of the $D^+ \to K^+K^-K^+$ decay, 2019.

Gen—T

IFIC INSTITUT DE FÍSICA CORPUSCULAR

VNIVERSITAT DE VALÈNCIA

1) Motivation

2) The $D_S^+ \to K^+K^-K^+$ decay

3) Conclusions and perspectives

1) Motivation

2) The $D_S^+ \to K^+K^-K^+$ decay

3) Conclusions and perspectives

Conclusions and perspectives

- For the $D_s^+ \to 3K$ decay a model to the external W-emission topology has been achieved.
- It is necessary to fit the $D_s^+ \to 3K$ decay model parameters not only using the external W-emission topology but also constraining them even more by the inclusion of the W-annihilation topology
- There is further work to be done: To include the real part of the loops, to parametrize the form factors, to implement dispersive relations.

References

- L. Chau. Quark Mixing in Weak Interactions, Phys. Rept., 95:1–94, 1983.
- R. T. Aude et al. Multimeson model for the $D^+ \to K^+K^-K^+$ decay amplitude Phys. Rev. D, 98(5):056021, 2018.
- P. C. Magalhães et al. Multibody decay analyses: A new phenomenological model for meson-meson subamplitudes. Phys. Rev. D, 102(7):076012, 2020.
- J. Gasser and H. Leutwyler. Chiral Perturbation Theory: Expansions in the Mass of the Strange Quark. Nucl. Phys. B, 250:465–516, 1985.
- G. Ecker et al. The Role of Resonances in Chiral Perturbation Theory. Nucl. Phys. B, 321:311–342, 1989.
- R. Aaij et al. Dalitz plot analysis of the $D^+ \to K^+K^-K^+$ decay, JHEP, 04:063, 2019.
- L. Roca and E.Oset. Scalar resonances in the $D^+ \to K^+K^-K^+$ decay, Phys.Rev.D 103 2020.

Gen—T

IFIC INSTITUT DE FÍSICA CORPUSCULAR

VNIVERSITAT DE VALÈNCIA