Phenomenological analysis of $D_s^+ \to \pi^+ \mu^- \mu^+$ decay

MARXIL SÁNCHEZ GARCÍA

In collaboration with: Genaro Toledo (IF-UNAM) and Iván Heredia (CINVESTAV)

Based on: **Phys. Rev. D 106, 073002 (2022)**

XVIII MEXICAN WORKSHOP ON PARTICLES AND FIELDS
21-25 NOVEMBER 2022
EDIFICIO CAROLINO, BUAP

Instituto de Física
UNAM

OUTLINE

- $D_s^+ \to \pi^+ \mu^- \mu^+$: Role of the parameters involved in the resonance region.
- δρϕ parameter bound from LHCb data.
- Observables insensitive to δρϕ.
- Forward-backward observable in some general scenarios.

MOTIVATION

- Precise measurements in the charm sector will allow to test new physics scenarios in an intermediate energy. Mod. Phys. Lett. A 36, 2130002 (2021)

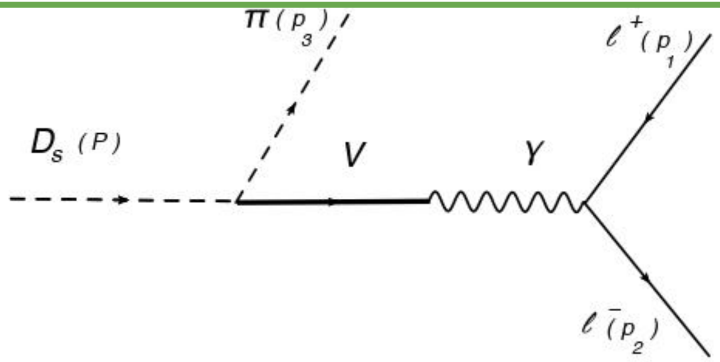
- $D_s^+ \to \pi^+\ell^-\ell^+$ decay has been used as a reference channel in the understanding of suppressed modes (FCNC).

- Knowing the full aspects of non-FCNC processes would help to identify the truly FCNC contribution features.

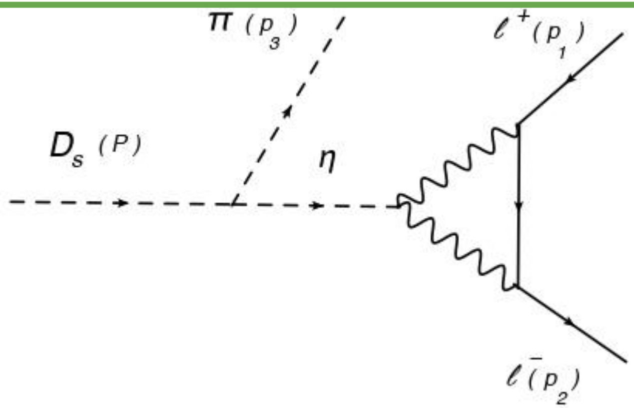
- New physics prospects (charm sector) are expected to be tested in the so-called off-resonance region, (below η and above ϕ).

THE $D_s^+ \to \pi^+ \ell^- \ell^+$ DECAY

$$\mathcal{M}_{LD} = ie^2 a_\phi e^{i\delta_\phi} \left(\frac{a_{\rho\phi} e^{i\delta_{\rho\phi}}}{k^2 - m_\rho^2 + i m_\rho \Gamma_\rho} + \frac{a_{\omega\phi} e^{i\delta_{\omega\phi}}}{k^2 - m_\omega^2 + i m_\omega \Gamma_\omega} + \frac{1}{k^2 - m_\phi^2 + i m_\phi \Gamma_\phi} \right) (P + p_3)_\nu l^\nu$$



(a)



(b)

$$a_{V\phi} \equiv \left| \frac{G_{D_s \pi V}}{g_V} \Big/ \frac{G_{D_s \pi \phi}}{g_\phi} \right|$$

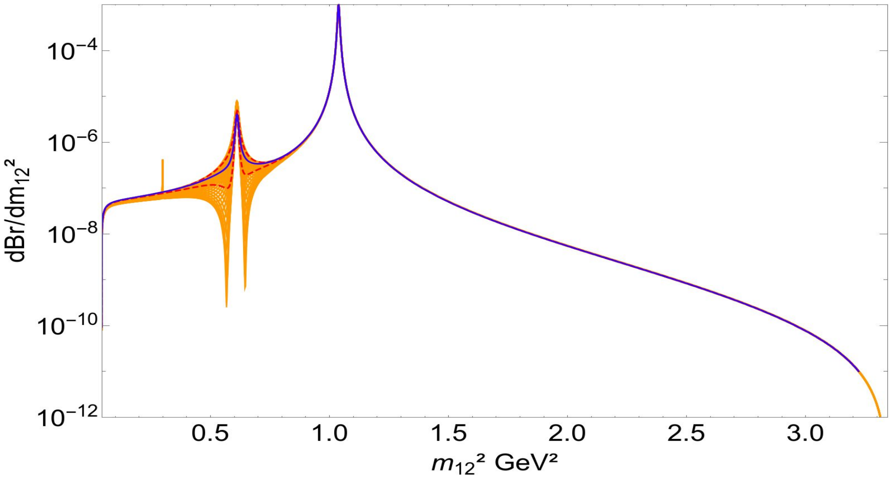
$$a_\phi e^{i\delta_\phi} \equiv \frac{G_{D_s \pi \phi}}{g_\phi}$$

$$a_\eta = g_{D_s \pi \eta} g_{\eta\mu\mu}$$

$a_{\rho\phi} = 0.11$ $\quad a_\phi = 7.63 \times 10^{-8}$

$g_{\eta\mu\mu} = 1.94 \times 10^{-5}$ $\quad g_{D_s \pi \eta} = 1.54 \times 10^{-6}$

DI-MUON INVARIANT MASS $m_{\mu\mu}^2$



χ^2 fit (LHCb data) in the region between the ρ and the φ resonances. Phys. Lett. B 724, 203 (2013)

$\delta_{\rho\varphi} = (0.44 \pm 0.21)\pi$
(fitting uncertainty and 10% data extraction)

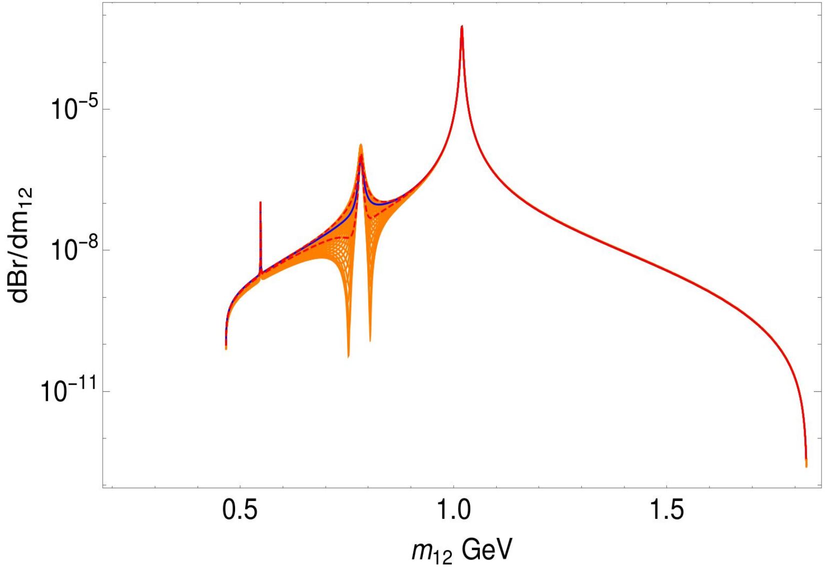
TABLE III. Branching ratio ($\mathcal{B}$) contributions in the three mass regions as defined in the text.

$\mathcal{B}$	$[m_\phi - 4\Gamma_\phi, m_\phi + 4\Gamma_\phi]$	$[2m_\mu, m_\phi - 4\Gamma_\phi]$	$[m_\phi + 4\Gamma_\phi, m_{D_s} - m_\pi]$	Total
$\mathrm{LD}_{\mathrm{full}\delta_{\rho\phi}}$	$[1.2371, 1.2384] \times 10^{-5}$	$[7.97, 8.08] \times 10^{-7}$	$[4.46, 4.52] \times 10^{-7}$	$[1.36, 0.003] \times 10^{-5}$
$\mathrm{LD}_{\mathrm{fit}\delta_{\rho\phi}}$	$(1.2378 \pm 0.0004) \times 10^{-5}$	$(8.05 \pm 0.04) \times 10^{-7}$	$(4.46 \pm 0.02) \times 10^{-7}$	$(1.362 \pm 0.001) \times 10^{-5}$
SD	8.726×10^{-17}	2.0×10^{-15}	8.084×10^{-16}	2.896×10^{-15}
LD-SD	5.706×10^{-13}	6.31×10^{-11}	2.4×10^{-11}	3.961×10^{-11}

ANGULAR OBSERVABLES

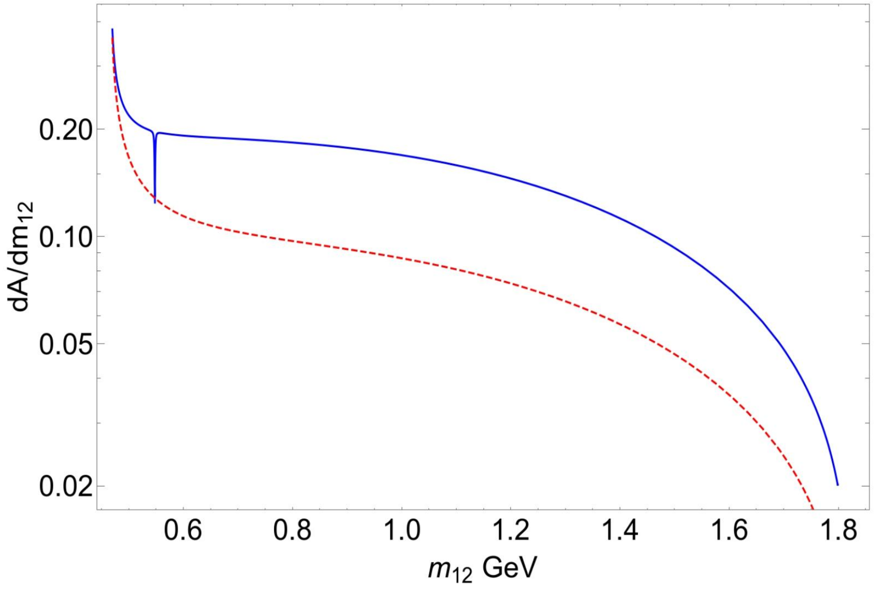
$$\frac{d\Gamma}{dM_{inv}\, d\cos\theta} = \int \frac{|\mathcal{M}|^2 \delta(M_{D_s} - E_1 - E_{l_1} - E_{l_2})}{8M_{D_s}^2 (2\pi)^3} \frac{|\mathbf{p}_1||\mathbf{l}_1||M_{inv}|}{E_{l_2}} dE_{l_1}$$

$$E_{l_2} = \sqrt{m_l^2 + \mathbf{p}_1^2 + \mathbf{l}_1^2 + 2|\mathbf{p}_1||\mathbf{l}_1|\cos\theta}, \;\; E_1 = (M_{D_s}^2 + m_\pi^2 - M_{inv}^2)/2M_{D_s}$$



Di-muon invariant mass distribution at $\cos\theta = 0.1$ (denoted by $dBr/dm_{12} \equiv \frac{1}{\Gamma_{D_s}} d\Gamma/dm_{\mu\mu}$) obtained from LD contributions.

FORWARD-BACKWARD DISTRIBUTION.



$$A_{FB}|_{\cos\theta} = \frac{\frac{d\Gamma}{dM_{inv}d\cos\theta}|_{\cos\theta} - \frac{d\Gamma}{dM_{inv}d\cos\theta}|_{-\cos\theta}}{\frac{d\Gamma}{dM_{inv}d\cos\theta}|_{\cos\theta} + \frac{d\Gamma}{dM_{inv}d\cos\theta}|_{-\cos\theta}}$$

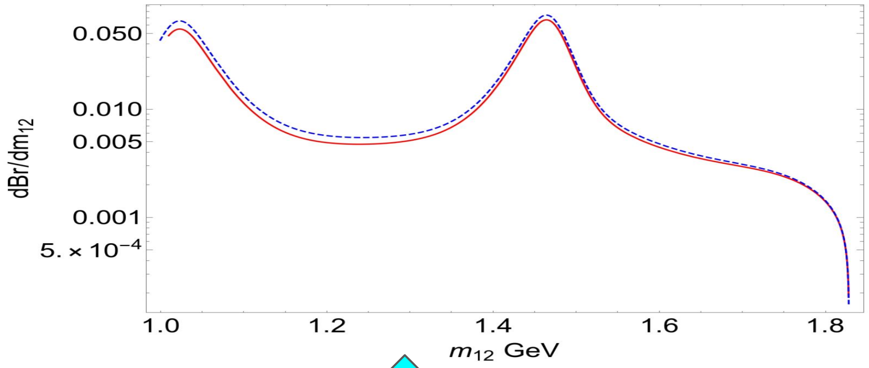
$dA/m_{12} = A_{FB}|_{cos\theta}$ distribution (LD) for $\cos\theta = 0.1$ (solid line). Pure phase space estimation (dashed line).

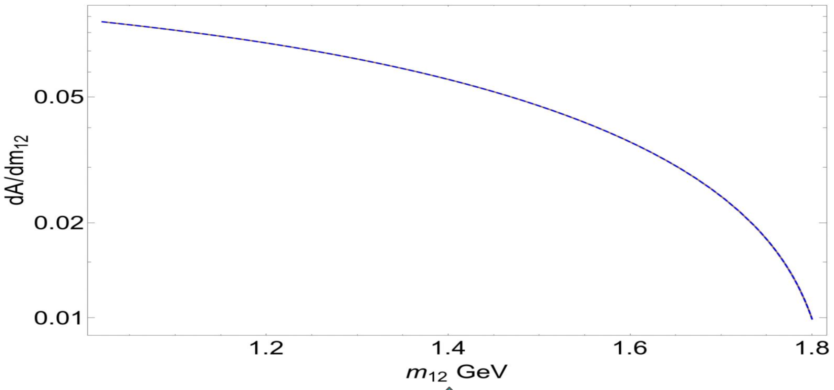
$$A_{FB}^{(PS)}|_{\cos\theta}/A_{FB}|_{\cos\theta} = 0.1024/0.1863 = 0.55$$

BACKGROUND: $D_s \to \pi\pi\pi$ DECAY.

FOCUS collaboration Phys. Lett. B 585, 200 (2004)

$$f_0(980),\ f_0(1300),\ f_0(1200-1600),\ f_0(1500),\ f_0(1750)$$

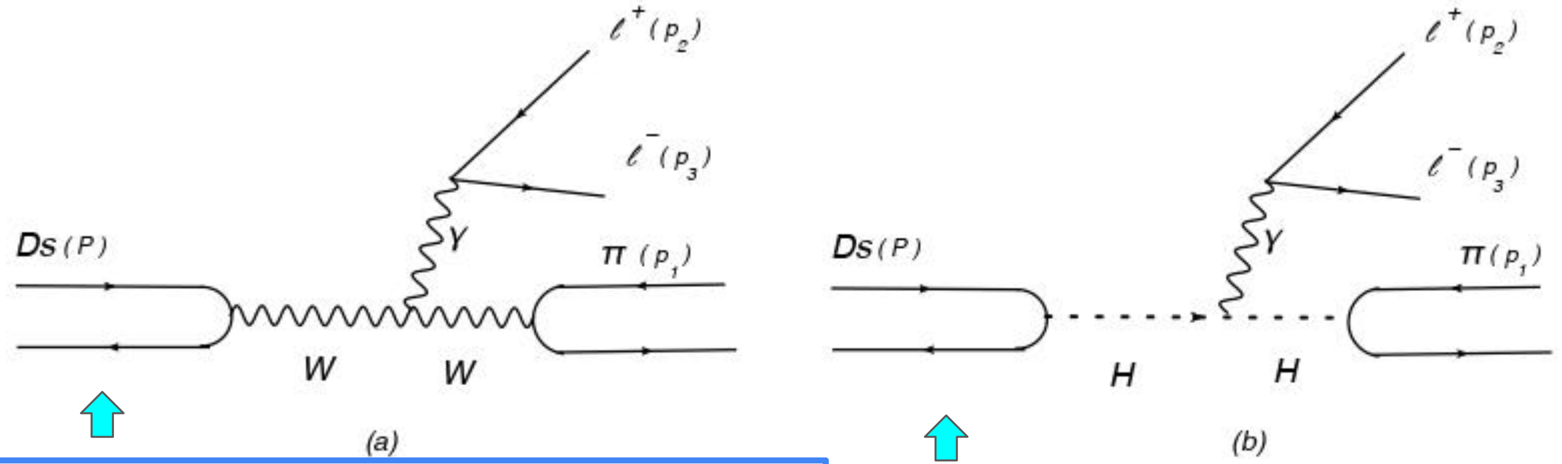




Di-pion invariant mass distributions at given angles, $\cos\theta$ =0.1(solid line) and -0.1 (dashed line).

$A_{FB}|_{\cos\theta}$ distribution at $\cos\theta = 0.1$

SM AND NO-SM SHORT DISTANCE CONTRIBUTION



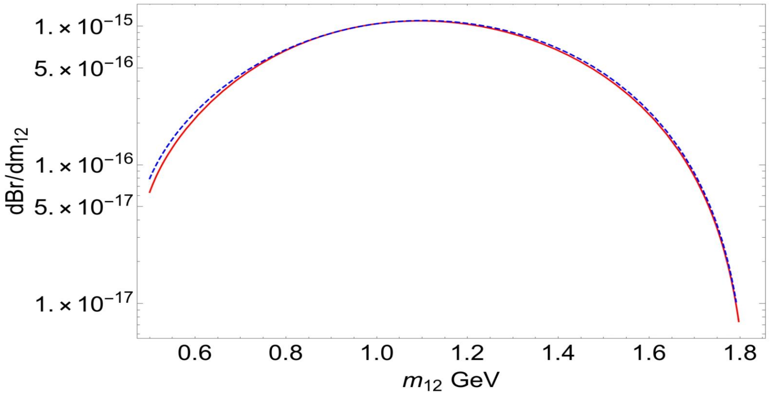
$$\mathcal{M}_{SD} = -i\frac{G_F V_{cs}^* V_{ud} f_{D_s} f_\pi e^2}{\sqrt{2} M_W^2 k^2} P^\rho p_1^\theta l^\alpha \Gamma_{\alpha\rho\theta}$$

$$\Gamma_{\alpha\rho\theta} = g_{\alpha\rho}(-k - P)_\theta + g_{\theta\alpha}(k - p_1)_\rho + g_{\rho\theta}(P + p_1)_\alpha$$

$$\mathcal{M}_H = \frac{ie^2 G_F}{\sqrt{2}} V_{ud} V_{cs}^* f_\pi f_{D_s} m_\pi^2 m_{D_s}^2 \frac{1}{\tan^2\beta} \frac{1}{k^2 m_H^4} P_\mu l^\mu$$

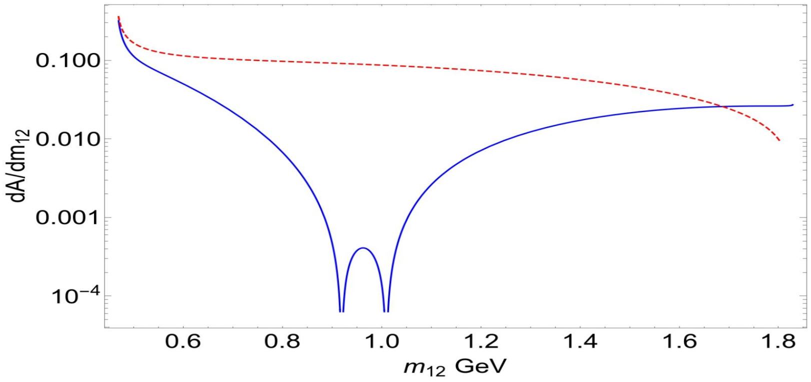
$$\frac{-\sqrt{2} V_{ud}}{v} (m_u \cot\beta P_L + m_d \tan\beta P_R) d H^+$$

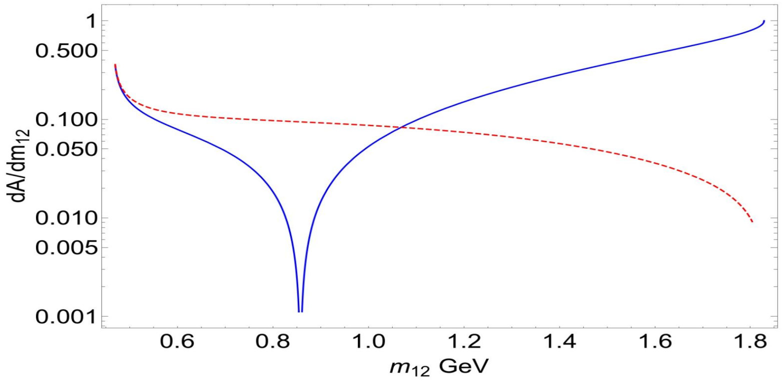
$f_\pi = 0.13$ GeV $f_{D_s} = 0.249$ GeV
$m_H = 600\mathrm{GeV} \quad \tan\beta = 10$



Di-muon invariant mass: $\cos\theta = 0.1$ (solid line) and -0.1 (dashed line)

$A_{FB}|_{\cos\theta}$ distribution for the SD and 2HDM-II at $\cos\theta = 0.1$(solid line), compared to the pure phase space estimation (dashed line).





DISCUSSION

- We explored the role of the dominant source of uncertainty (between the ρ and the ϕ mesons).
- Analysis of the LHCb data provides a first approach to the relative strong phase: $\delta_{\rho\phi} = (0.44 \pm 0.24)\pi$
- Observables insensitive to the $\delta_{\rho\phi}$ phase would be also useful to keep the hadronic contributions under control.
- Forward-backward distribution exhibits no dependence on $\delta_{\rho\phi}$ phase.
- SD contribution in SM, and the 2HDM-II exhibit distinguishable features among themselves, which might be useful in the understanding of the different contributions.
- Belle II may be capable of providing precise measurements of the proposed observable, with reduced systematic uncertainties given the low background environment in e^+e^- collisions, almost unbiased selections, and excellent particle identification