# Predictions for the Decays of $\overline{B}^0 \to \overline{K}^{*0} X(YZ)$ and $\overline{B}_s^0 \to \phi X(YZ)$ with $X(4160), Y(3940), Z(3930)$

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# Outline

- Introduction and motivation
- Formalism
- Results of the ratios
- Complementary test of the molecular nature of the *XYZ* states
- Summary

# ◆ Introduction and motivation

- **The nature of the XYZ resonaces is still unclear.**
- **Within the framework of the hidden gauge formalism:**

**Some XYZ states are dynamically generated from the V - V interaction, most motably the $D^*\bar{D}^*$ or $D_s^*\bar{D}_s^*$ states.**

| Energy [MeV] | $I^G[J^{PC}]$ | Strongest channel | Experimental state |
|---|---|---|---|
| $3943 - i7.4$ | $0^+[0^{++}]$ | $D^*\bar{D}^*$ | $Y(3940)$ [75] |
| $3945 - i0$ | $0^-[1^{+-}]$ | $D^*\bar{D}^*$ | ? $Y_P$ |
| $3922 - i26$ | $0^+[2^{++}]$ | $D^*\bar{D}^*$ | $Z(3930)$ [76] |
| $4169 - i66$ | $0^+[2^{++}]$ | $D_s^*\bar{D}_s^*$ | $X(4160)$ [77] |

**[ R. Molina and E. Oset, Y(3940),Z(3930) and the X(4160) as dynamically generated resonances form the vector-vector interaction, PRD80(2009)114013 ]**

**These XYZ states are predicted to be molecular states.**

# ◆ Introduction and motivation

## The aim of this work:

- **Study reactions where some *XYZ* states can be procuced;**

$$\bar{B}^0 \to \bar{K}^{*0} X(YZ),\ \ \bar{B}_s^0 \to \phi X(YZ)$$

with *XYZ* states generated dynamically from V-V interactions.

**[ R. Molina and E. Oset, PRD80(2009)114013 ]**

- **Evaluate ratios for different decay modes.**

- **Propose a test linked to the molecular nature of some *XYZ* resonances.**

# ◆ Formalism

$$\bar{B}_s^0 \to \phi R, \quad \bar{B}^0 \to \bar{K}^{*0} R. \qquad [R = X(4160),\ Y(3940),\ Z(3930)]$$

$$\begin{pmatrix} u \\ d \end{pmatrix} \begin{pmatrix} c \\ s \end{pmatrix} \begin{pmatrix} t \\ b \end{pmatrix} \qquad \text{Cabibbo favored transitions}: \begin{matrix} b \to c \\ c \to s \end{matrix}$$

- **The Cabibbo favored dominant mechanism:**

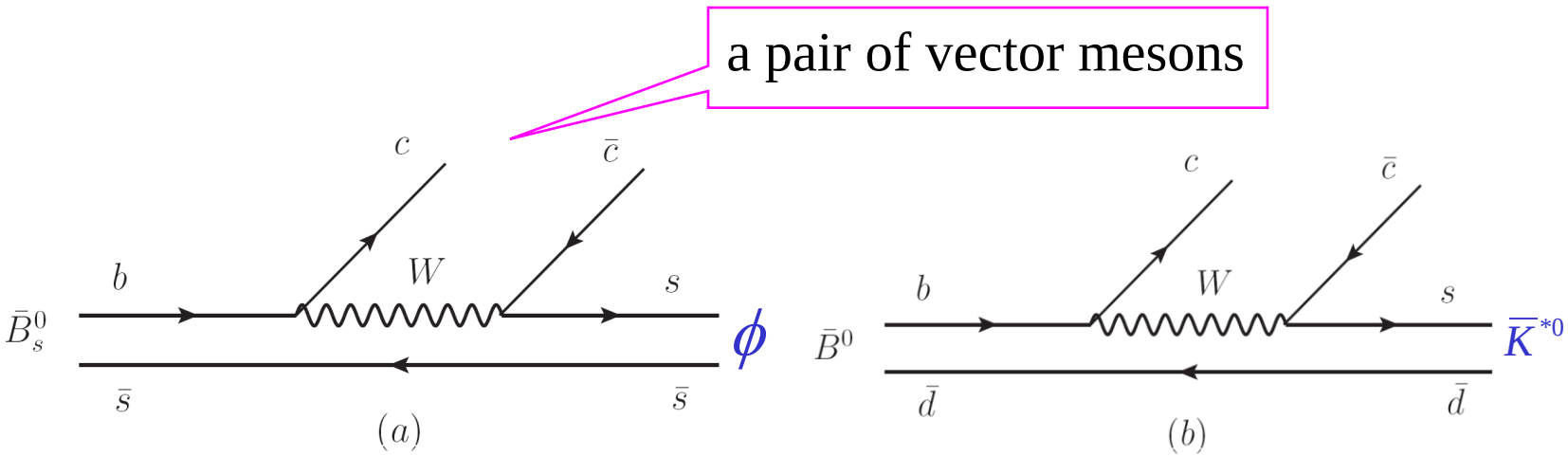


Fig. 1 $\bar{B}_s^0$ and $\bar{B}^0$ decays into $c\bar{c}$ and a $q\bar{q}$ pair.

# ◆ Formalism

- **Hadronization of ccbar:**

Adding an extra $q\bar{q}$ pair with the quantum numbers of the vacuum,

**a pair of vector mesons**

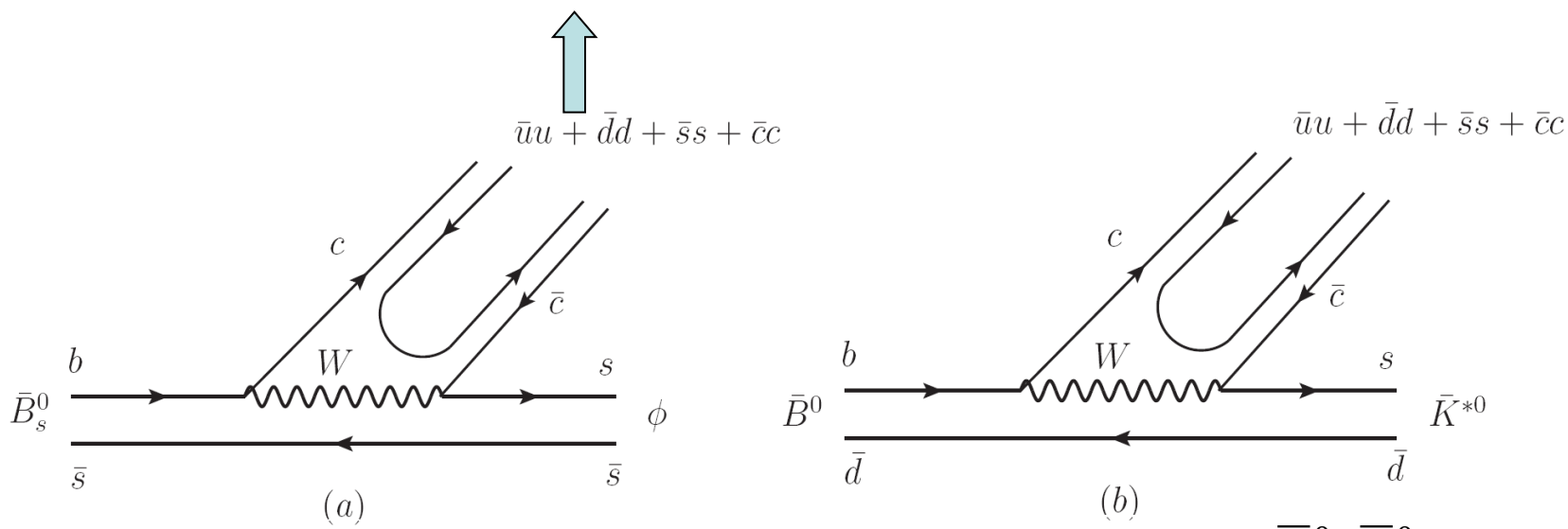


Fig. 2 Hadronizat ion of the $c\bar{c}$ pair into two vector mesons for $\bar{B}_s^0(\bar{B}^0)$ decay.

$c\bar{c}$ pair is in $I = 0$ ⟹ $V$-$V$ pair with $I$=0

# ◆ Formalism

**The $q\bar{q}$ matrix :**

$$M = \begin{pmatrix} u\bar{u} & u\bar{d} & u\bar{s} & u\bar{c} \\ d\bar{u} & d\bar{d} & d\bar{s} & d\bar{c} \\ s\bar{u} & s\bar{d} & s\bar{s} & s\bar{c} \\ c\bar{u} & c\bar{d} & c\bar{s} & c\bar{c} \end{pmatrix} = \begin{pmatrix} u \\ d \\ s \\ c \end{pmatrix} \begin{pmatrix} \bar{u} & \bar{d} & \bar{s} & \bar{c} \end{pmatrix}$$

with the property $M \cdot M = M(\bar{u}u + \bar{d}d + \bar{s}s + \bar{c}c)$.

The matrix *M* corresponds to the SU(4) vector matrix:

$$V = \begin{pmatrix} \frac{\rho^0}{\sqrt{2}} + \frac{\omega}{\sqrt{2}} & \rho^+ & K^{*+} & \bar{D}^{*0} \\ \rho^- & -\frac{\rho^0}{\sqrt{2}} + \frac{\omega}{\sqrt{2}} & K^{*0} & \bar{D}^{*-} \\ K^{*-} & \bar{K}^{*0} & \phi & \bar{D}_s^{*-} \\ D^{*0} & D^{*+} & D_s^{*+} & J/\psi \end{pmatrix}$$

# ◆ Formalism

$$c\bar{c}(\bar{u}u + \bar{d}d + \bar{s}s + \bar{c}c) \equiv (M \cdot M)_{44} \equiv (V \cdot V)_{44}$$

$$(V \cdot V)_{44} = D^{*0}\bar{D}^{*0} + D^{*+}D^{*-} + D_s^{*+}D_s^{*-} + \boxed{J/\psi J/\psi.}$$

neglected

$$\boxed{(V \cdot V)_{44} \to \sqrt{2}(D^*\bar{D}^*)^{I=0} + D_s^{*+}D_s^{*-}.}$$

After the hadronization of the $c\bar{c}$ pair,

only the $D^*\overline{D}^*$ and $D_s^*\overline{D}_s^*$ with $I = 0$ can be produced.

# ◆ Formalism

- **FSI of the vector-vector mesons:**

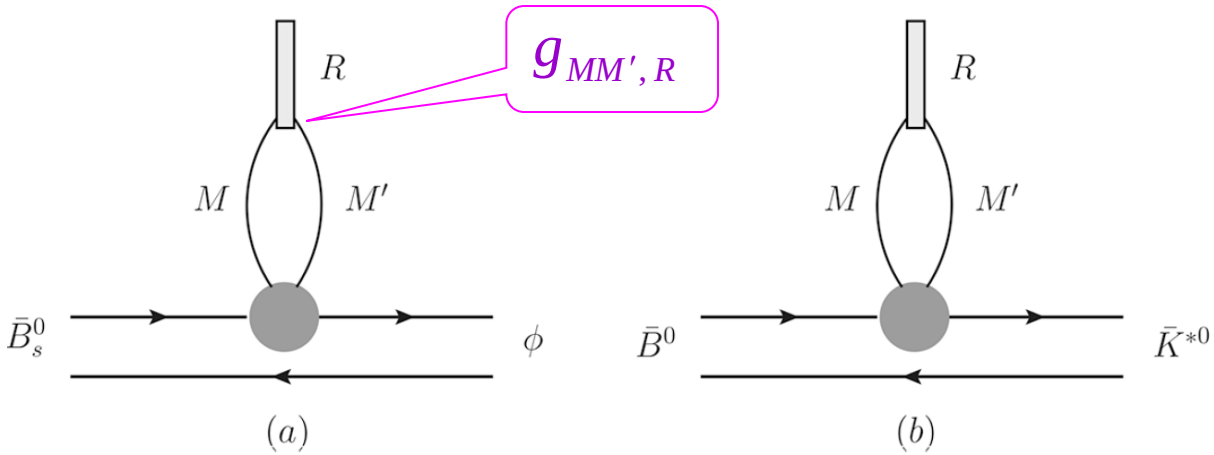


Fig. 3. Formation of $R(XYZ)$ through rescattering of $MM'(D^*\bar{D}^*$ or $D_s^*\bar{D}_s^*)$ and coupling to the resonance $R$.

Connect with the work of **[ R. Molina and E. Oset, PRD80(2009)114013 ],** where four $XYZ$ states with $I$=0 were dynamically generated from V-V interaction.

# ◆ Formalism

- **XYZ states generated from V-V interaction:**

| Energy [MeV] | $I^G[J^{PC}]$ | Strongest channel | Experimental state |
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**[ R. Molina and E. Oset, Y(3940),Z(3930) and the X(4160) as dynamically generated resonances form the vector-vector interaction, PRD80(2009)114013 ]**

**These XYZ states are predicted to be molecular states.**

# ◆ Formalism

- **Transition amplitude and the partial decay width:**

**Amplitude:**

$$t(\bar{B}_s^0 \to \phi R) = V_P(\sqrt{2} g_{D^*\bar{D}^*,R} G_{D^*\bar{D}^*} + g_{D_s^*\bar{D}_s^*,R} G_{D_s^*\bar{D}_s^*})$$

$V_P$ : Different unknown constants, summarizing the production amplitude at tree level;

$G_{MM'}$ : the loop function of two vector meson propagators.

$$G_i(s) = i \int \frac{d^4q}{(2\pi)^4} \frac{1}{(P-q)^2 - m_1^2 + i\varepsilon} \frac{1}{q^2 - m_2^2 + i\varepsilon}, \quad s = P^2$$

$g_{MM',R}$ : the coupling of the resonance $R$ to the $MM'$ meson pair, taken from **[ R. Molina and E. Oset, PRD80(2009)114013 ].**

**Similar farmalism for $\bar{B}^0 \to \bar{K}^{*0} R$.**

# ◆ Formalism

**Partial decay width:**

$$\Gamma_{R_i} = \frac{1}{8\pi}\frac{1}{m^2_{\bar{B}^0_i}}\left|t_{\bar{B}^0_i\to\phi(\bar{K}^{*0})R_i}\right|^2 P^{2L+1}_{\phi(\bar{K}^{*0})},$$

$$\text{angular momentum } L = \begin{cases} 0, & \text{for } J^P = 1^+; \\ 1, & \text{for } J^P = 0^+, 2^+. \end{cases}$$

- **The ratios:** (the unknown constants $V_P$ are canceled)

$$R_1 \equiv \frac{\Gamma_{\bar{B}^0_s\to\phi R^{J=0}}}{\Gamma_{\bar{B}^0\to K^{*0}R^{J=0}}}, \qquad R_2 \equiv \frac{\Gamma_{\bar{B}^0_s\to\phi R^{J=1}}}{\Gamma_{\bar{B}^0\to K^{*0}R^{J=1}}},$$

$$R_3 \equiv \frac{\Gamma_{\bar{B}^0_s\to\phi R_1^{J=2}}}{\Gamma_{\bar{B}^0\to K^{*0}R_1^{J=2}}}, \qquad R_4 \equiv \frac{\Gamma_{\bar{B}^0_s\to\phi R_2^{J=2}}}{\Gamma_{\bar{B}^0\to K^{*0}R_2^{J=2}}}, \qquad R_5 \equiv \frac{\Gamma_{\bar{B}^0_s\to\phi R_1^{J=2}}}{\Gamma_{\bar{B}^0_s\to\phi R_2^{J=2}}},$$

where $R^{J=0}$, $R^{J=1}$, $R_1^{J=2}$ and $R_2^{J=2}$ are the $Y(3940)$, $Y_P$, $Z(3930)$ and $X(4160)$, respectively.

# ◆ Results for the ratios

$$R_1 = 0.95, \qquad R_2 = 0.96,$$

$$R_3 = 0.95, \qquad R_4 = 0.83, \qquad R_5 = 0.84.$$

**( without free parameters! )**

- All the ratios are of the order of unity;

- The ratios $R_1 \sim R_4$ obtained are not determining the molecular nature of the resonances, but only on the fact that they are $c\bar{c}$ based.

- The ratios $R_5$ is not just a phase space ratio, providing more information, since it invoves two independent resonances.

If only phase space, $R_5 \approx 4$.

## ◆ Complementary test of the molecular nature of the *XYZ* states

**We study the decay $\bar{B}_s^0 \to \phi D^* \bar{D}^*$ or $\bar{B}_s^0 \to \phi D_s^* \bar{D}_s^*$ close to the $D^* \bar{D}^*$ and $D_s^* \bar{D}_s^*$ thresholds.**

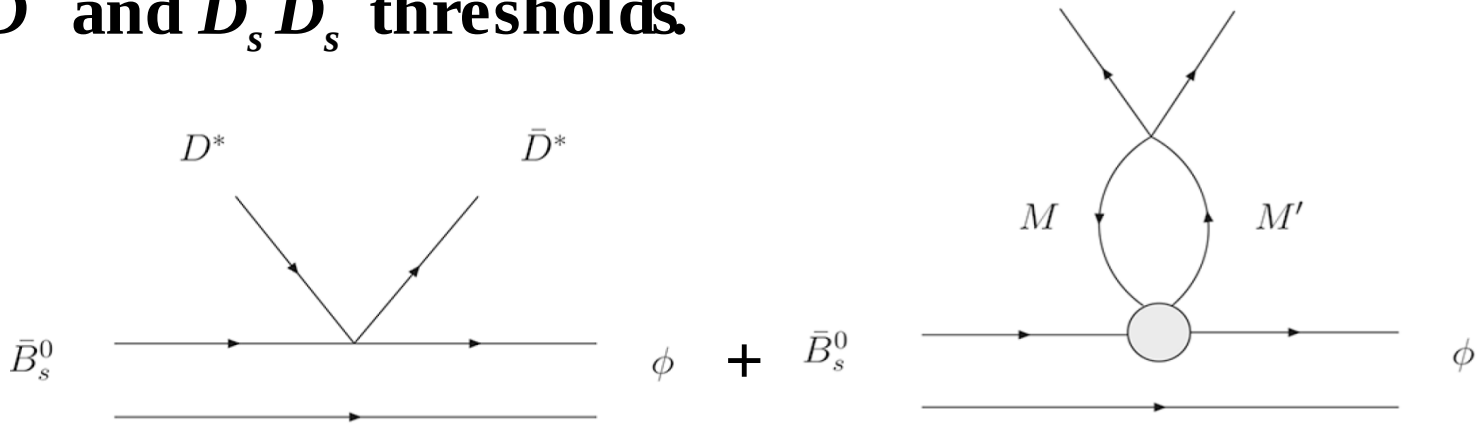



**Fig. 4.** Feynmann diagrams for the $D^* D^*$ production in $B_s^0$ decays.

$$t_{(\bar{B}_s^0 \to \phi D^* \bar{D}^*)} = V_P(\sqrt{2} + \sqrt{2}\, G_1\, t_{(1\to 1)} + G_2\, t_{(2\to 1)}),$$

$$t_{(\bar{B}_s^0 \to \phi D_s^* \bar{D}_s^*)} = V_P\left(1 + \sqrt{2}\, G_1\, t_{(1\to 2)} + G_2\, t_{(2\to 2)}\right)$$

**1: $D^* \bar{D}^*$; 2: $D_s^* \bar{D}_s^*$**

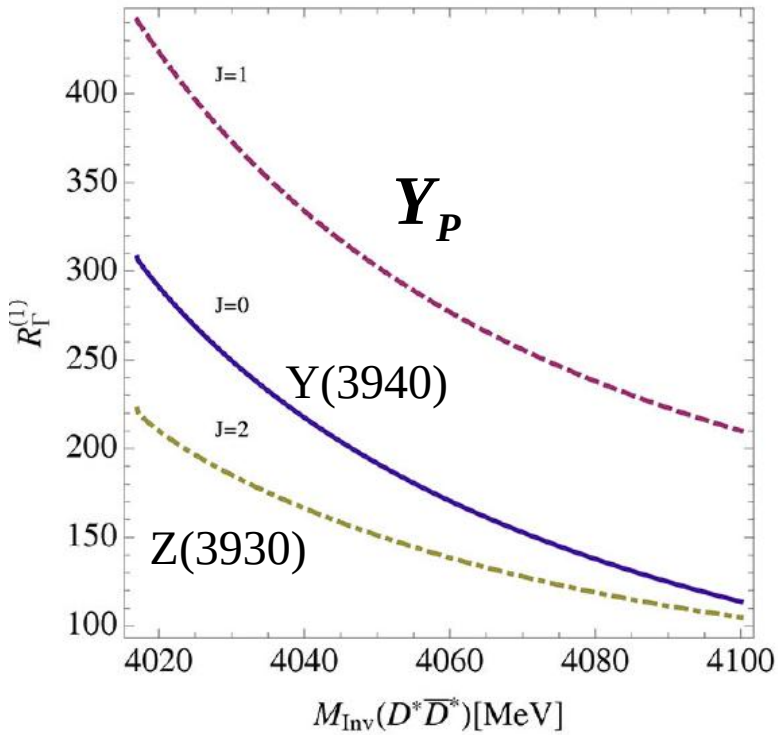
## ◆ Complementary test of the molecular nature of the *XYZ* states

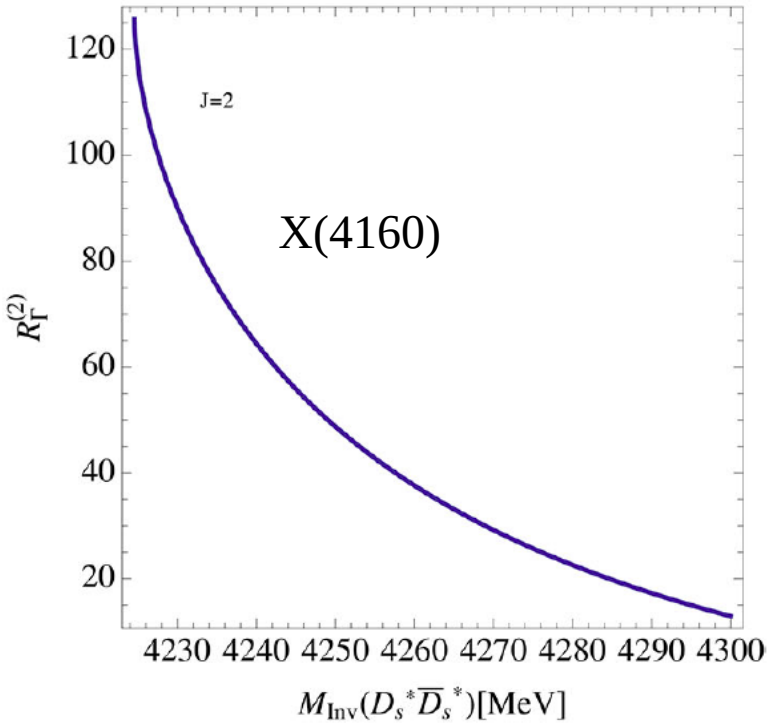
**The differential cross section for production:**

$$\frac{\mathrm{d}\Gamma}{\mathrm{d}M_{\mathrm{inv}}} = \frac{1}{32\,\pi^3 M^2_{\bar{B}^0_s}} p_\phi \tilde{p}_{D^*} \left| t_{(\bar{B}^0_s \to \phi D^* D^*)} \right|^2 p_\phi^{2L},$$

$$R_\Gamma = \frac{M_R^3}{p_\phi \tilde{p}_{D^*}} \frac{1}{\Gamma_R} \frac{\mathrm{d}\Gamma}{\mathrm{d}M_{\mathrm{inv}}}$$

$$= \frac{M_R^3}{4\pi^2} \frac{p_\phi^{2L}(M_{\mathrm{inv}})}{p_\phi^{2L+1}(M_R)} \left| \frac{t_{(\bar{B}^0_s \to \phi D^* \bar{D}^*)}}{t_{(\bar{B}^0 \to R\phi)}} \right|^2,$$




- The ratios are different for each case and have some structure;

- There is a fall down of the differential cross sections as a function of energy, as it would correspond to the tail of a resonance below threshold.

# ◆ Summary

- We have investigated the decays of $\overline{B}^0 \to \overline{K}^* R$ and $\overline{B}_s^0 \to \phi R$ with $R$ being the X(4160), Y(3940), Z(3930) and a pridicted $J = 1$ resonances.

- Using the chiral unitary theory, these states are dynamically generated from the V - V interaction, most motably the $D^* \overline{D}^*$ or $D_s^* \overline{D}_s^*$ states.

- We predict five ratios for the production of these XYZ states. Some ratios only tell us that the resonance is build from ccbar with or without extra hadronization.

- **In order to offer some extra test for the molecular composition of these states, we have evaluated the invariant mass distributions for the decays of $\overline{B}^0 \to \overline{K}^* D^* \overline{D}^*$ and $\overline{B}_s^0 \to \phi D_s^* \overline{D}_s^*$ close to threshold and have made pridictions for these magnitudes relative to the width for the production of the resonances.**

- **The experimental investigation of these decay modes, and comparison with the predictions made, would shed light on the nature of these XYZ states.**

# Thanks for your attention!