Institute of Particle Physics, University of València, Spain.

Institute of Physics, University of São Paulo, Brazil.

Disclosing $D^*\bar{D}^*$ molecules in the $B_c^- \to \pi^- J/\psi \omega$ decay

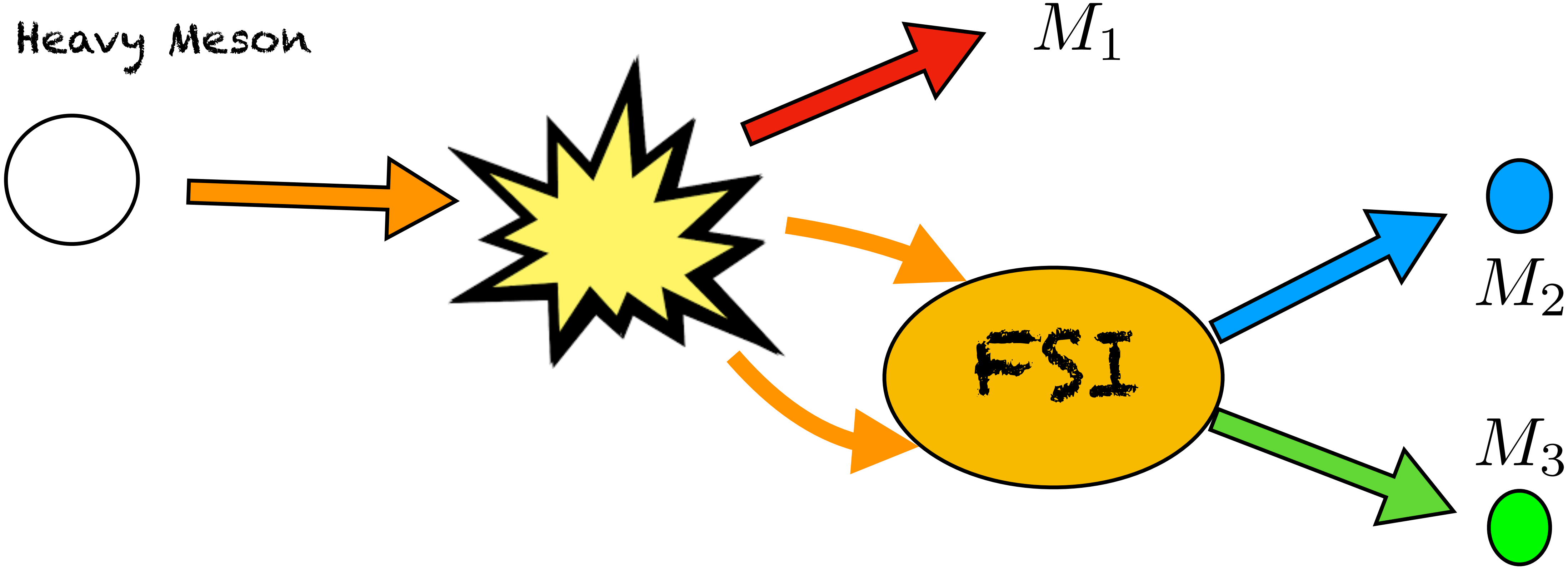
Jorgivan M. Dias

In collaboration with: E. Oset

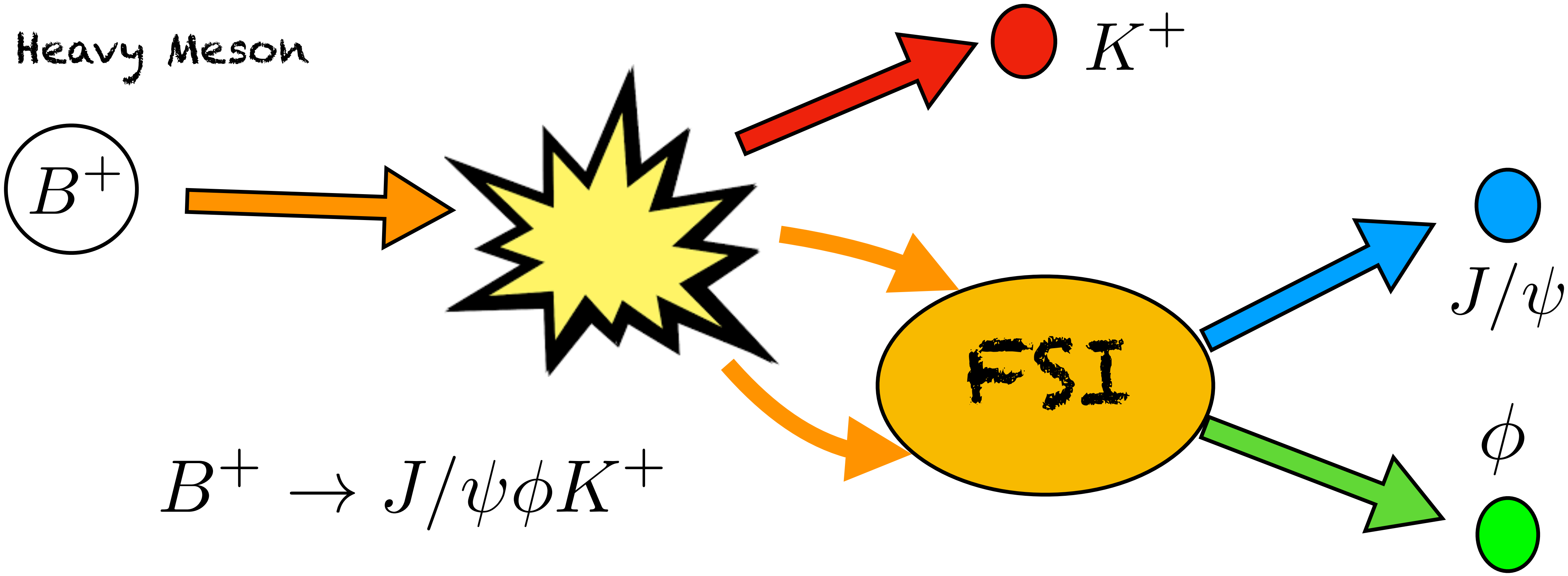
LiangRong Dai

São Paulo Research Foundation

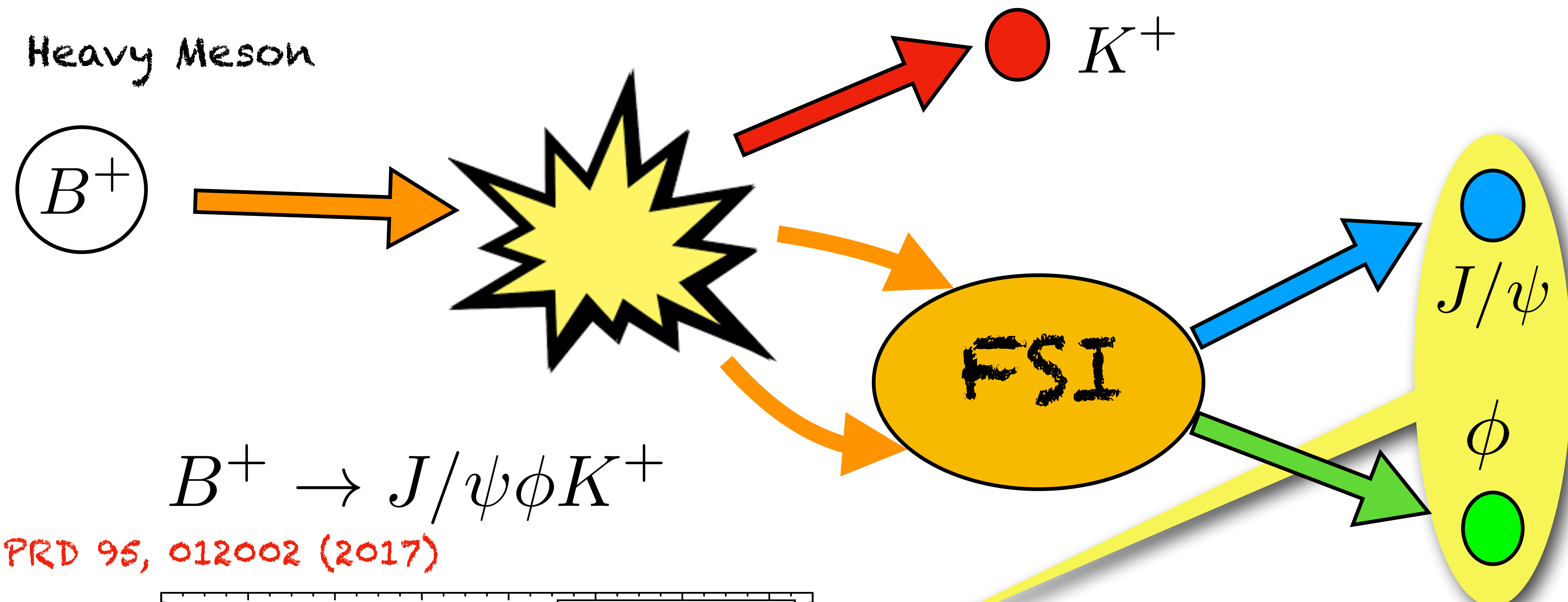
Heavy meson decays



Heavy meson decays

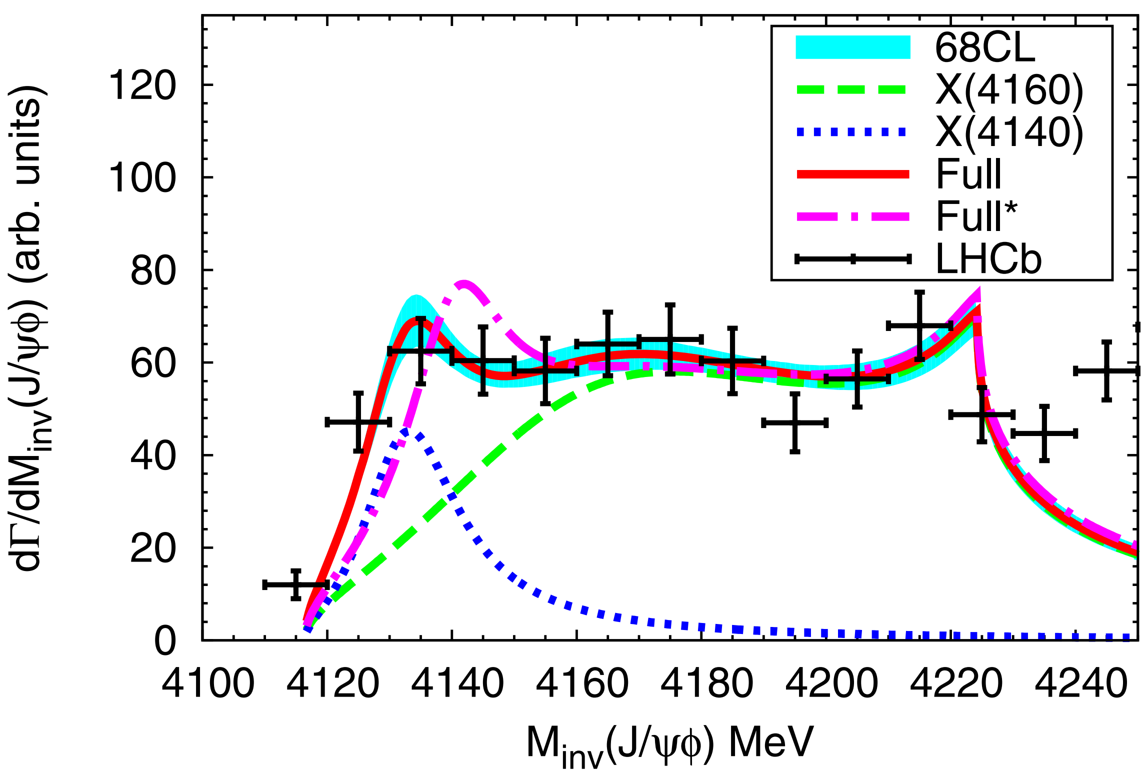


Heavy meson decays

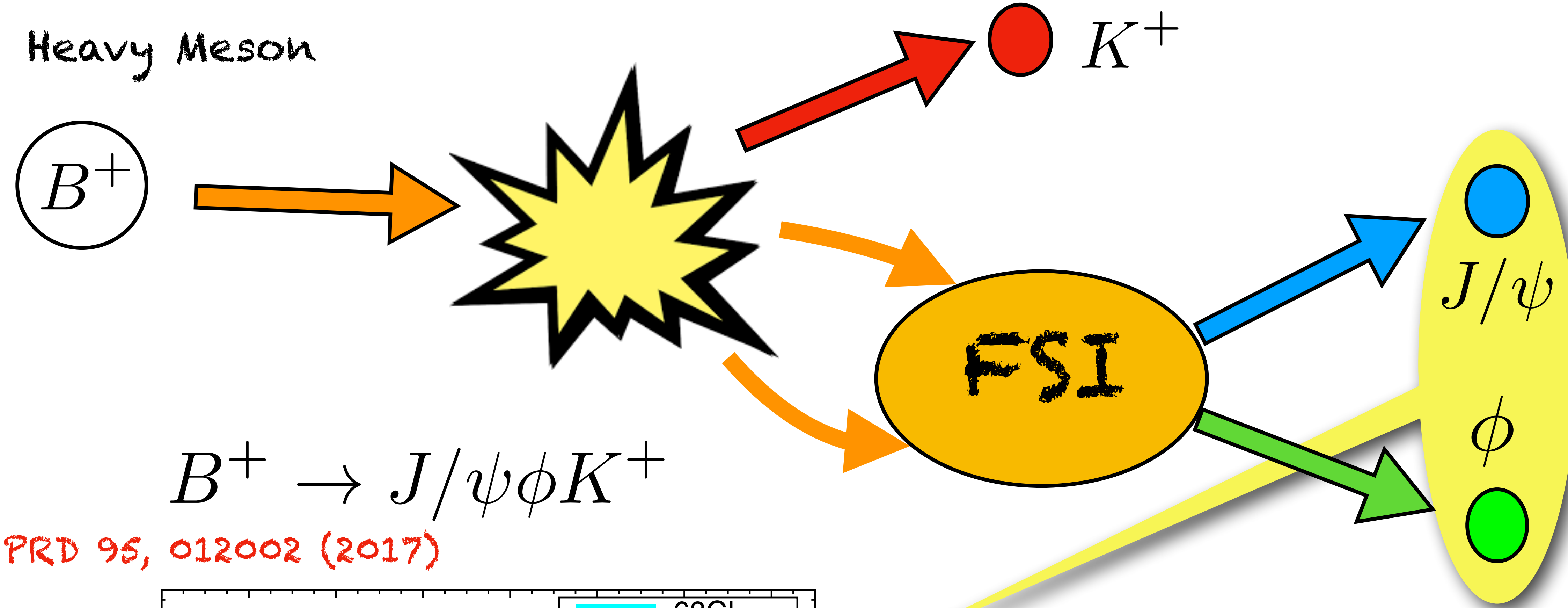


$$B^+ \to J/\psi \phi K^+$$

PRD 95, 012002 (2017)

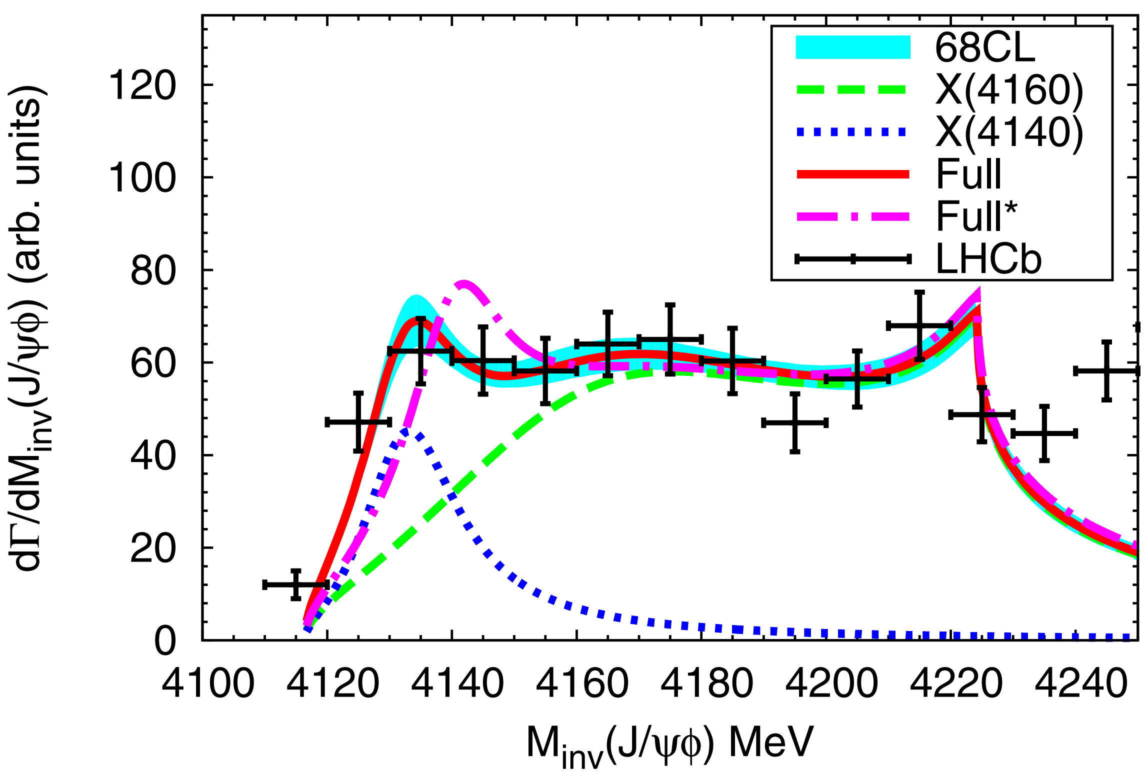


Heavy meson decays



$$B^+ \to J/\psi \phi K^+$$

PRD 95, 012002 (2017)



PRD 80, 114013 (2017)

$0^+(2^{++})$

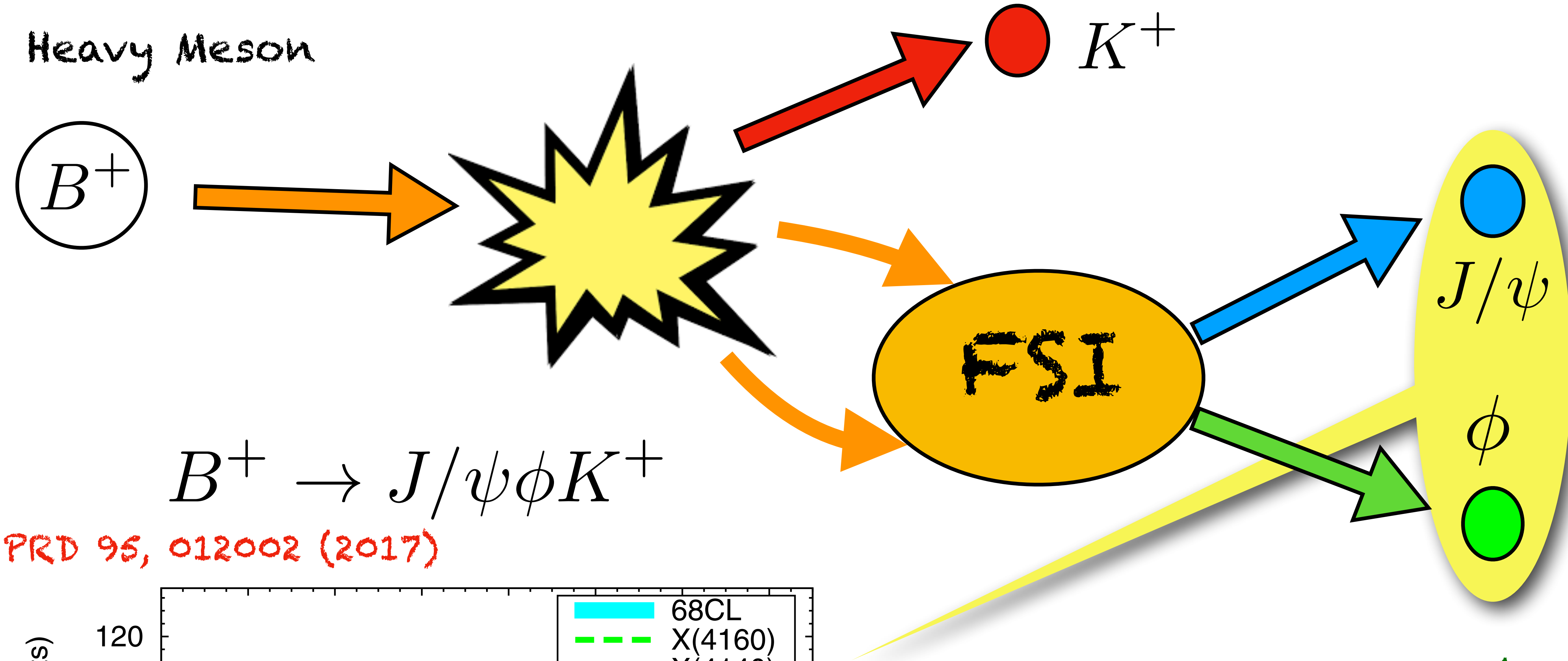
$D_s^* \bar{D}_s^*$

$J/\psi\phi$

⋮

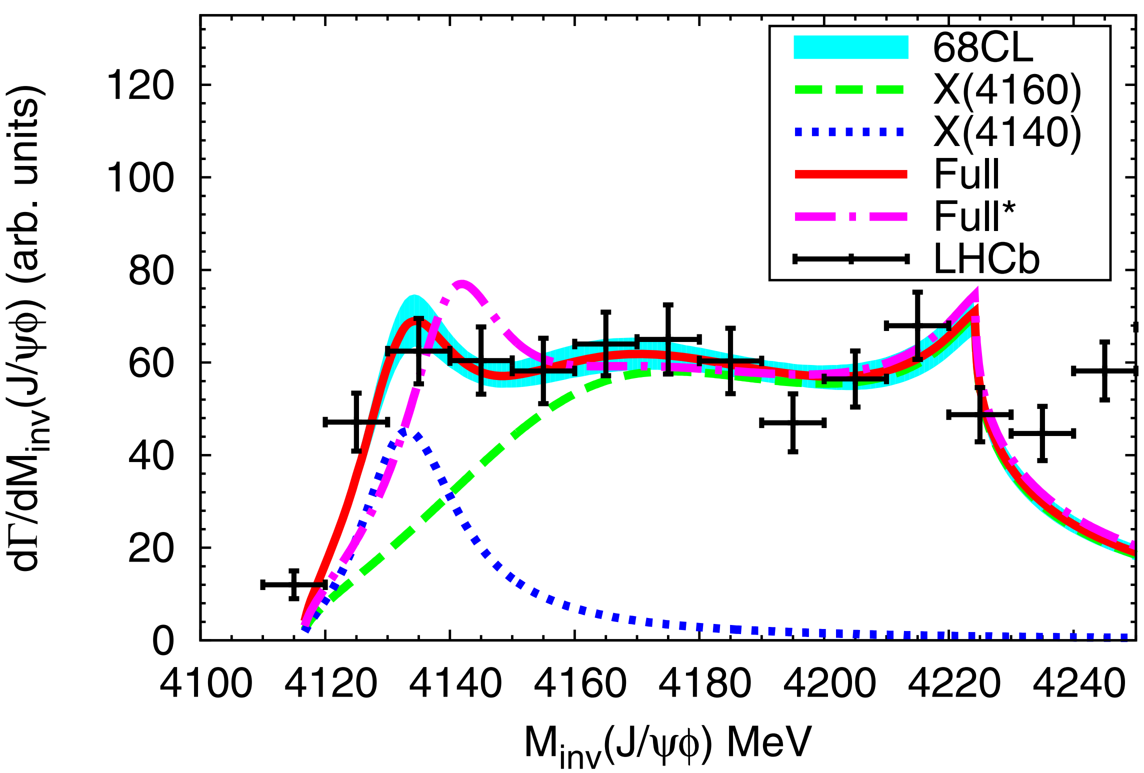
Heavy meson decays

Heavy Meson



$$B^+ \to J/\psi\phi K^+$$

PRD 95, 012002 (2017)



PRD 80, 114013 (2017)

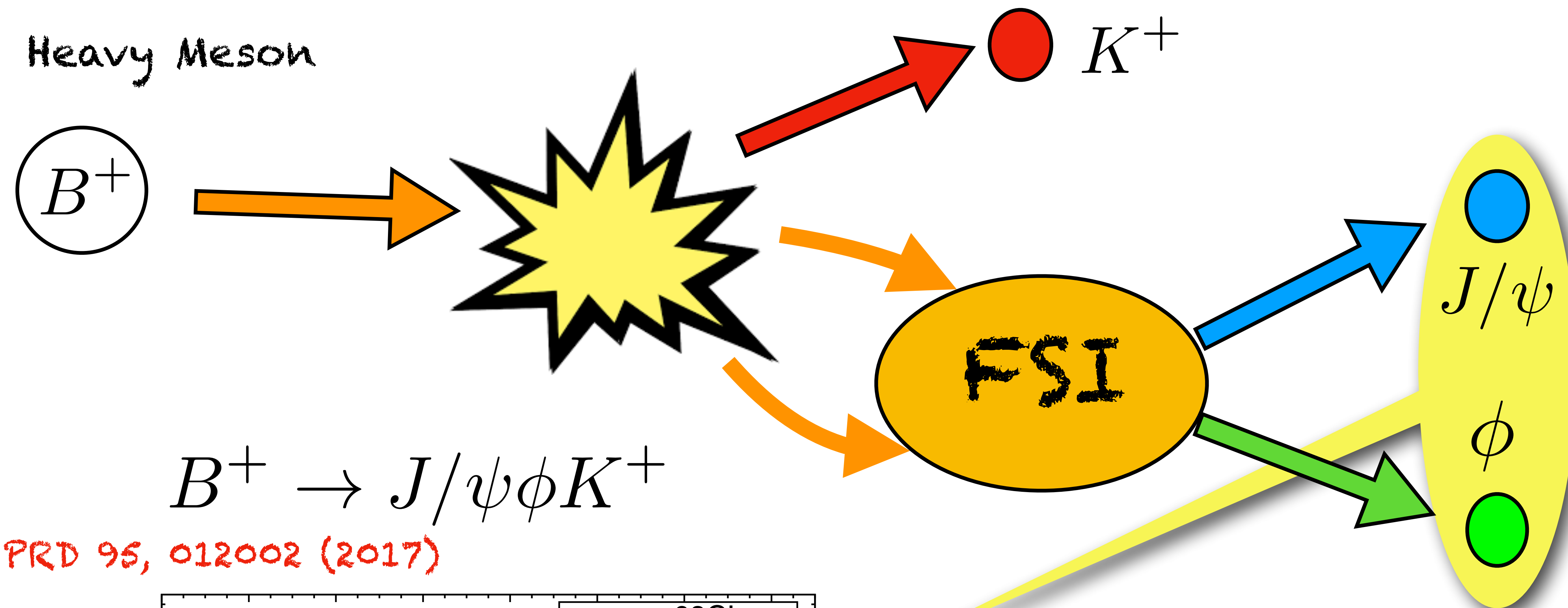
$X(4160)$ $\quad 0^+(2^{++})$

$D_s^* \bar{D}_s^*$

$J/\psi\phi$

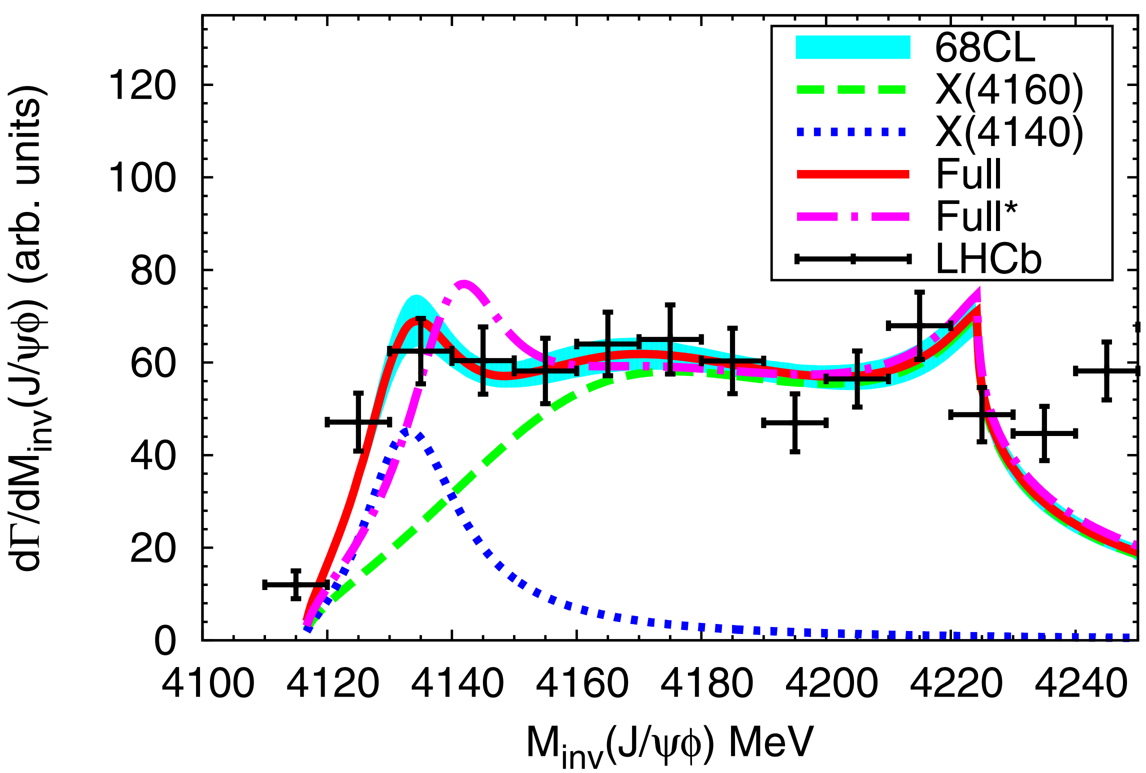
⋮

Heavy meson decays

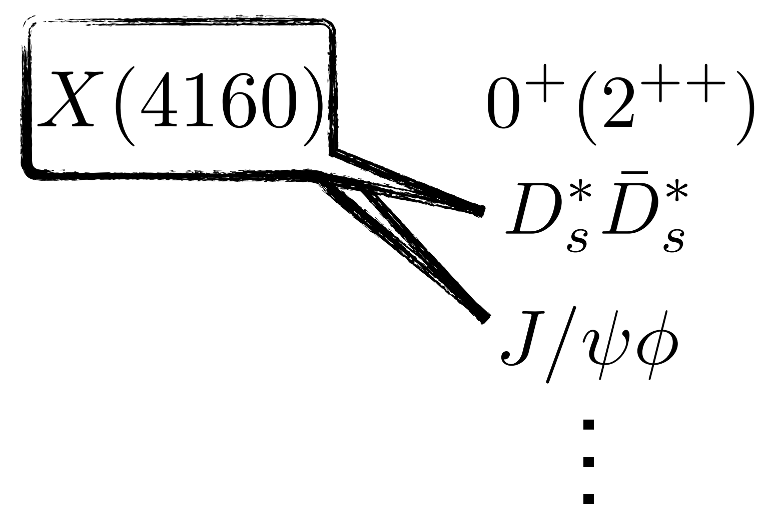


$$B^+ \to J/\psi \phi K^+$$

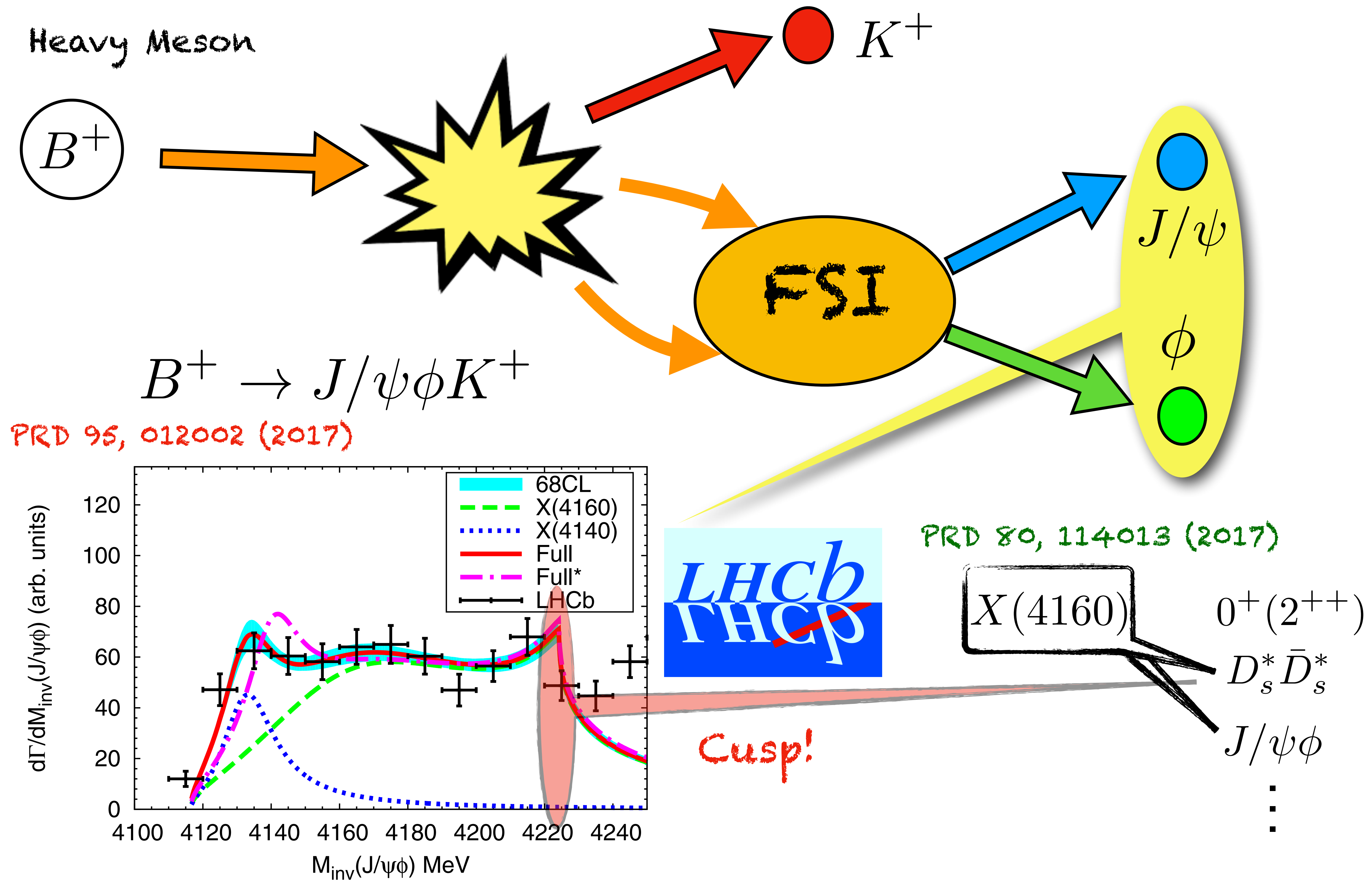
PRD 95, 012002 (2017)



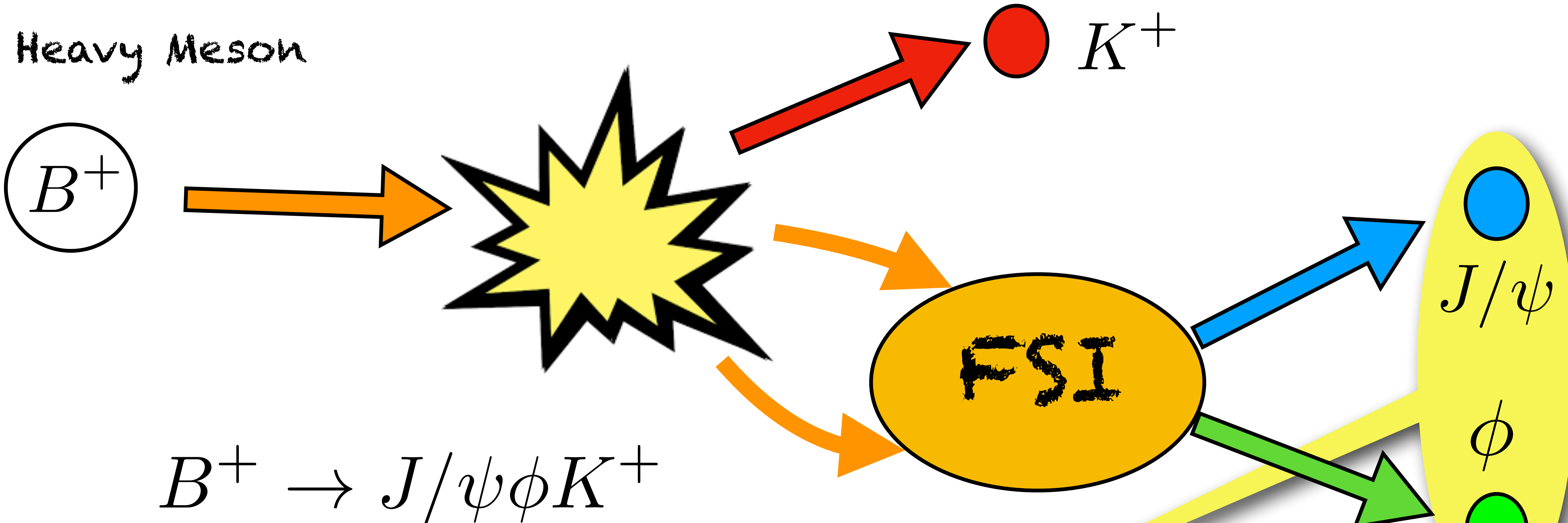
PRD 80, 114013 (2017)



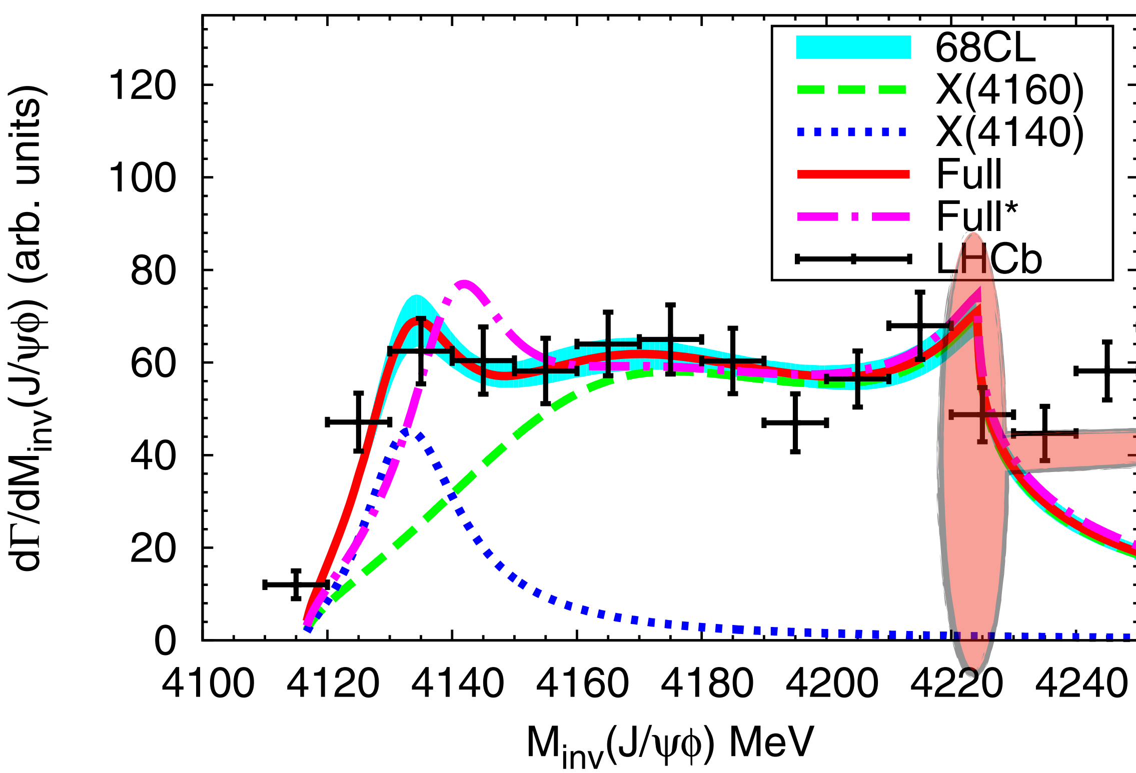
Heavy meson decays



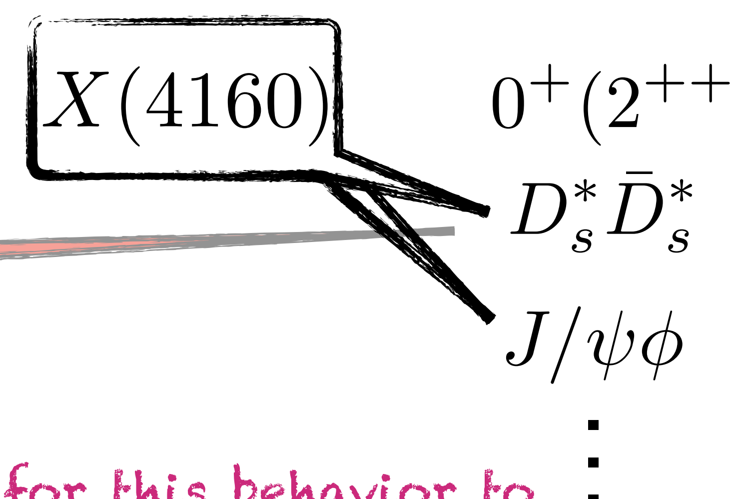
Heavy meson decays



PRD 95, 012002 (2017)



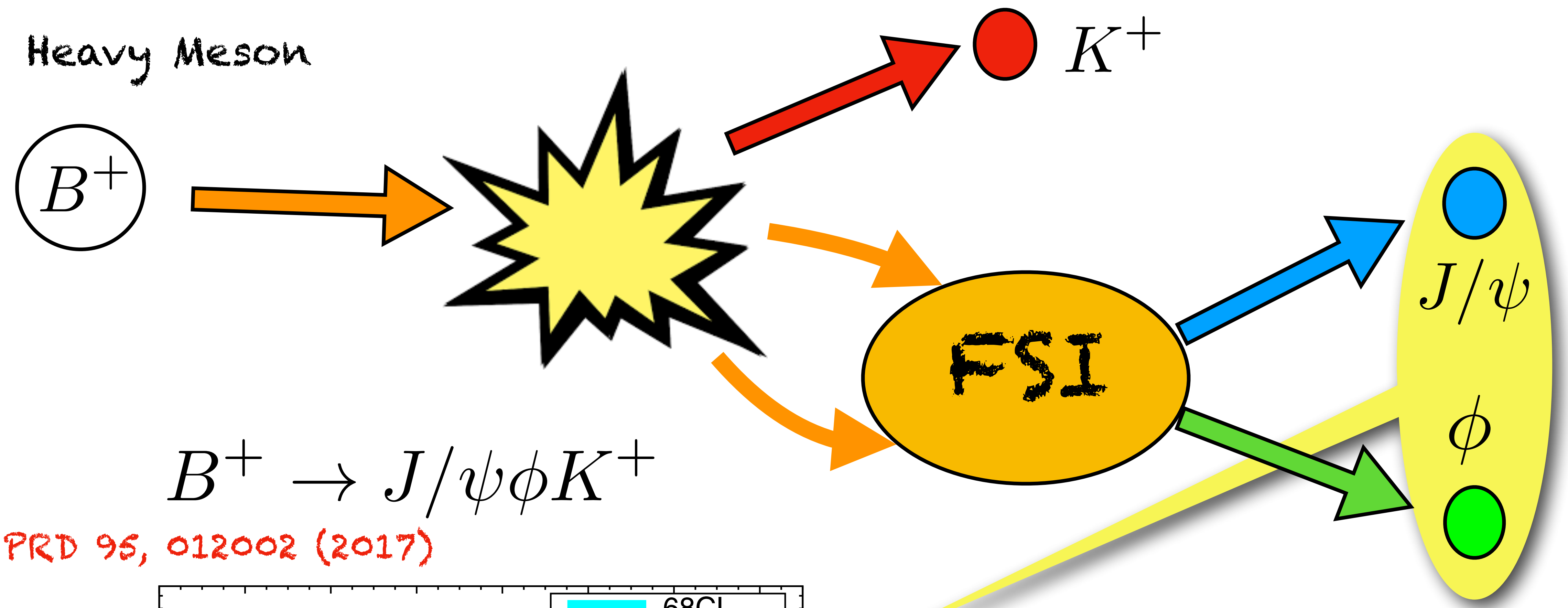
PRD 80, 114013 (2017)



Cusp!

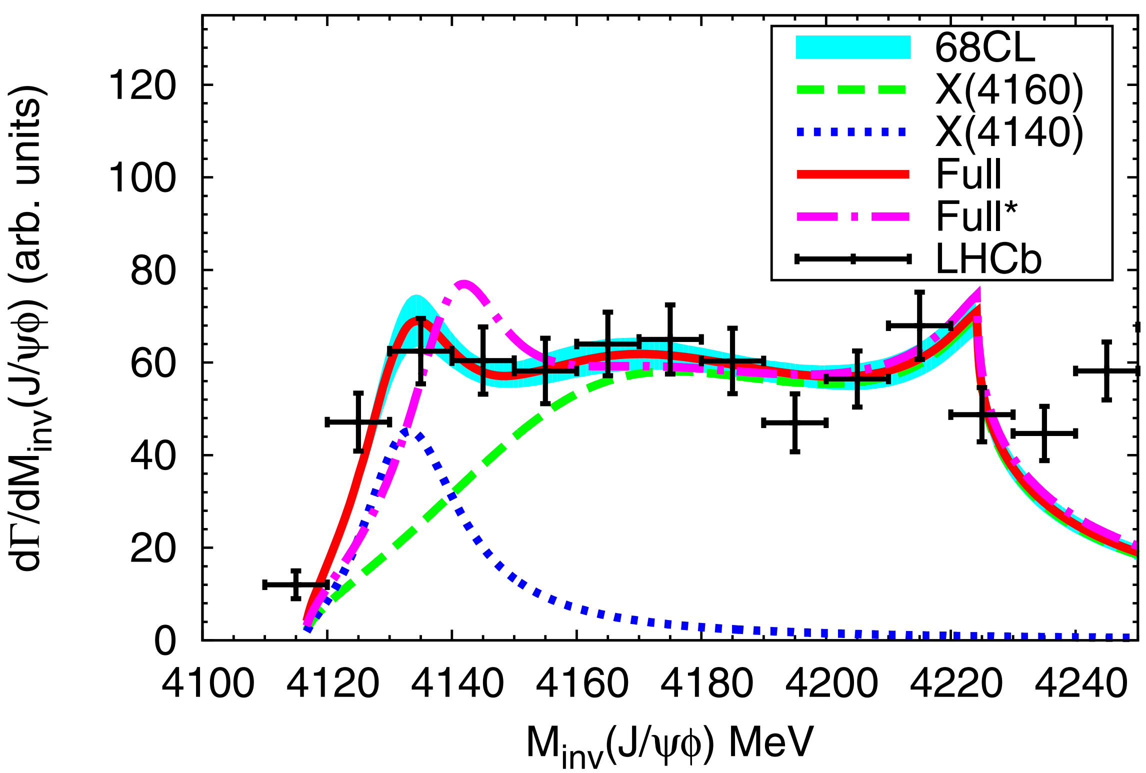
So, we can look for this behavior to test the molecular nature of some states!

Heavy meson decays

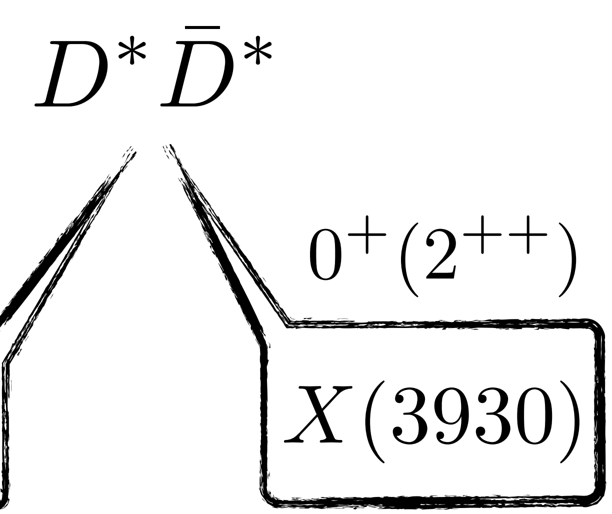


$B^+ \to J/\psi\phi K^+$

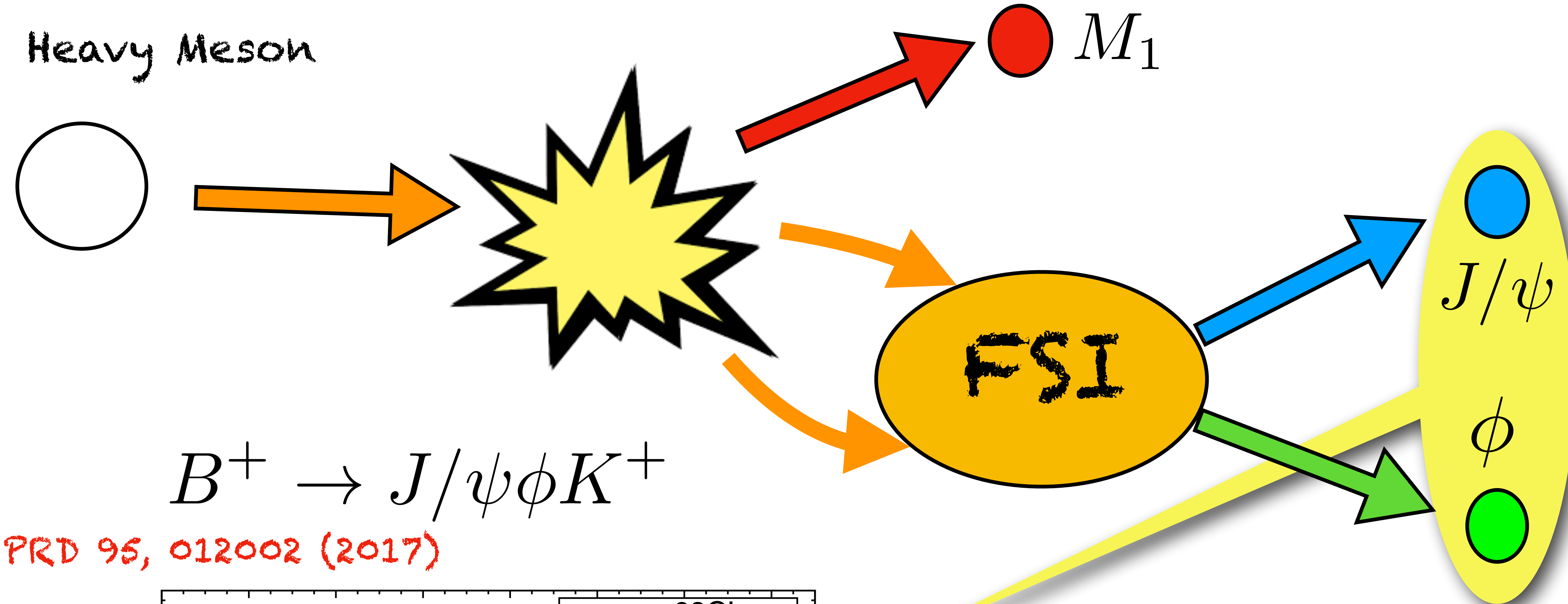
PRD 95, 012002 (2017)



PRD 80, 114013 (2017)

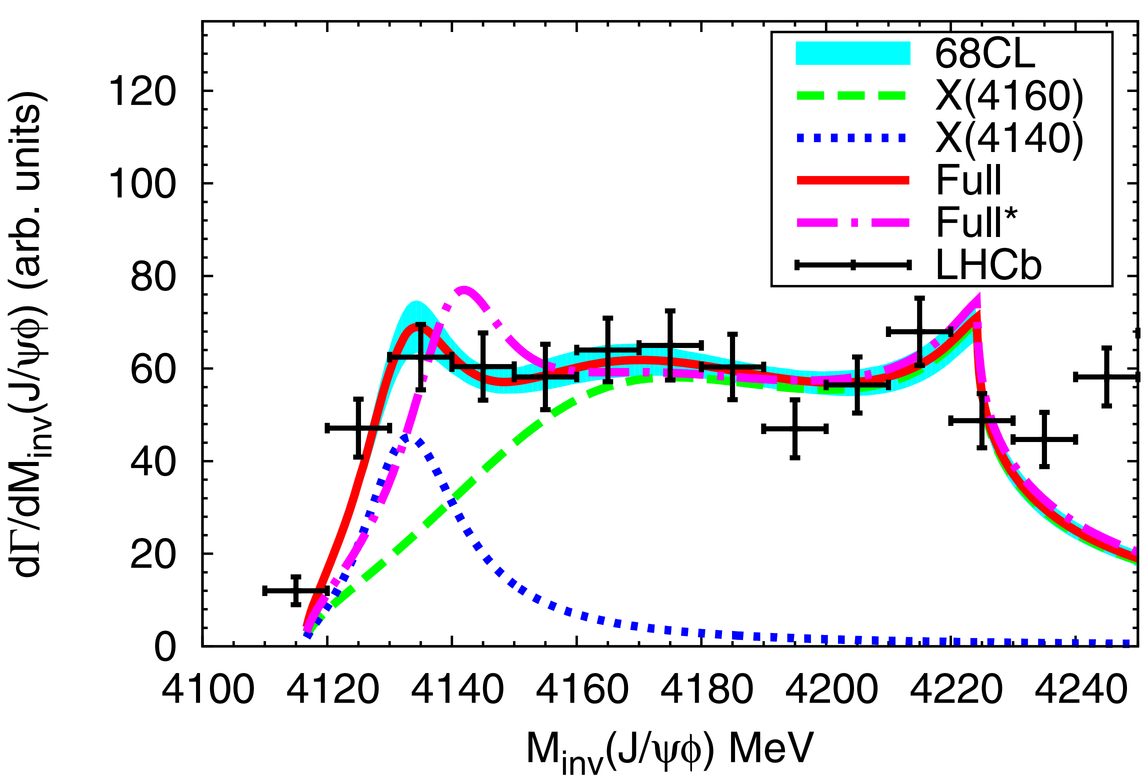


Heavy meson decays



$$B^+ \to J/\psi \phi K^+$$

PRD 95, 012002 (2017)



PRD 80, 114013 (2017)

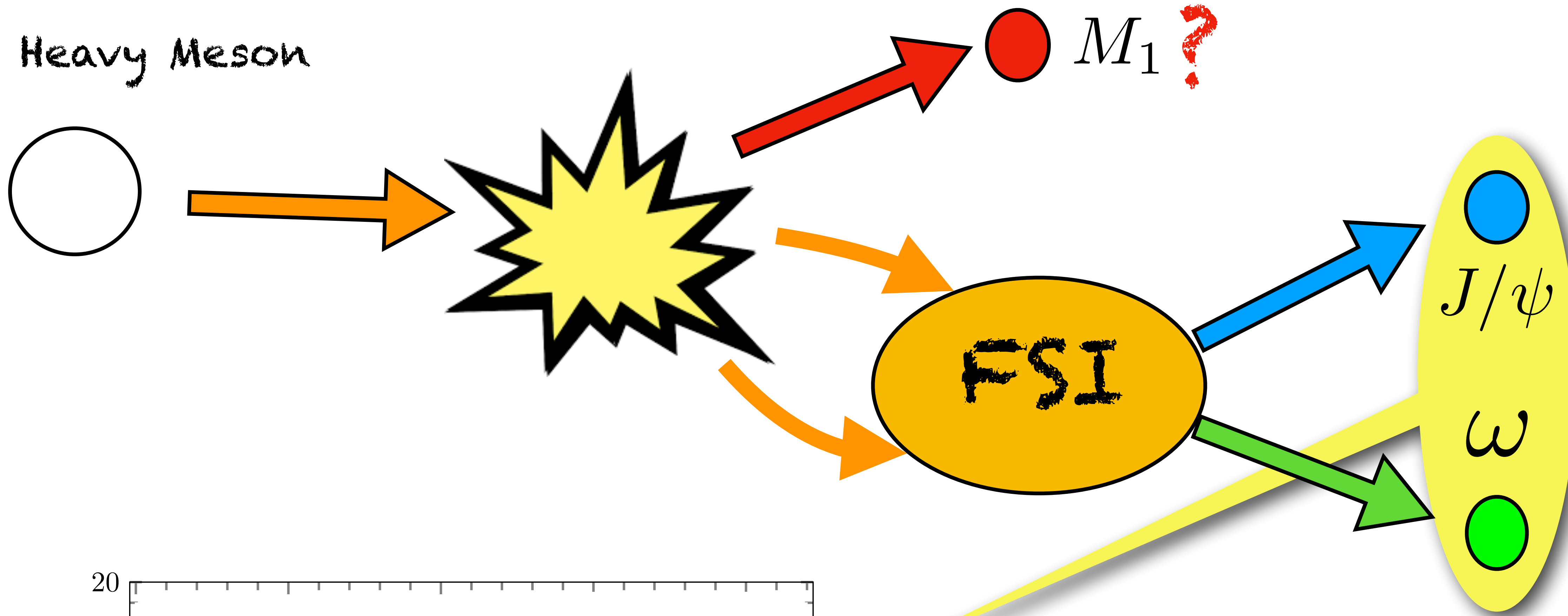
$D^* \bar{D}^*$ $J/\psi\,\omega$

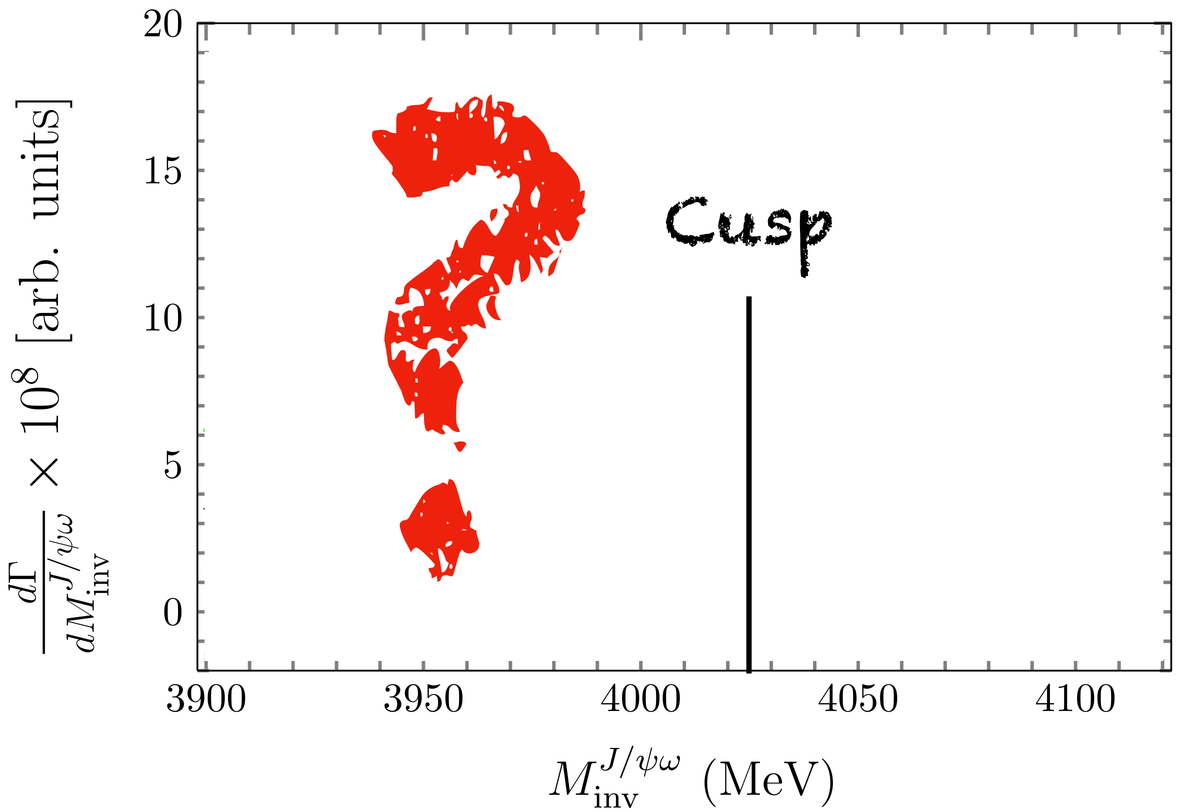
$0^+(0^{++})$ $X(3940)$

$0^+(2^{++})$ $X(3930)$

Both states also couple to $J/\psi\,\omega$

Heavy meson decays





LHCb

PRD 80, 114013 (2017)

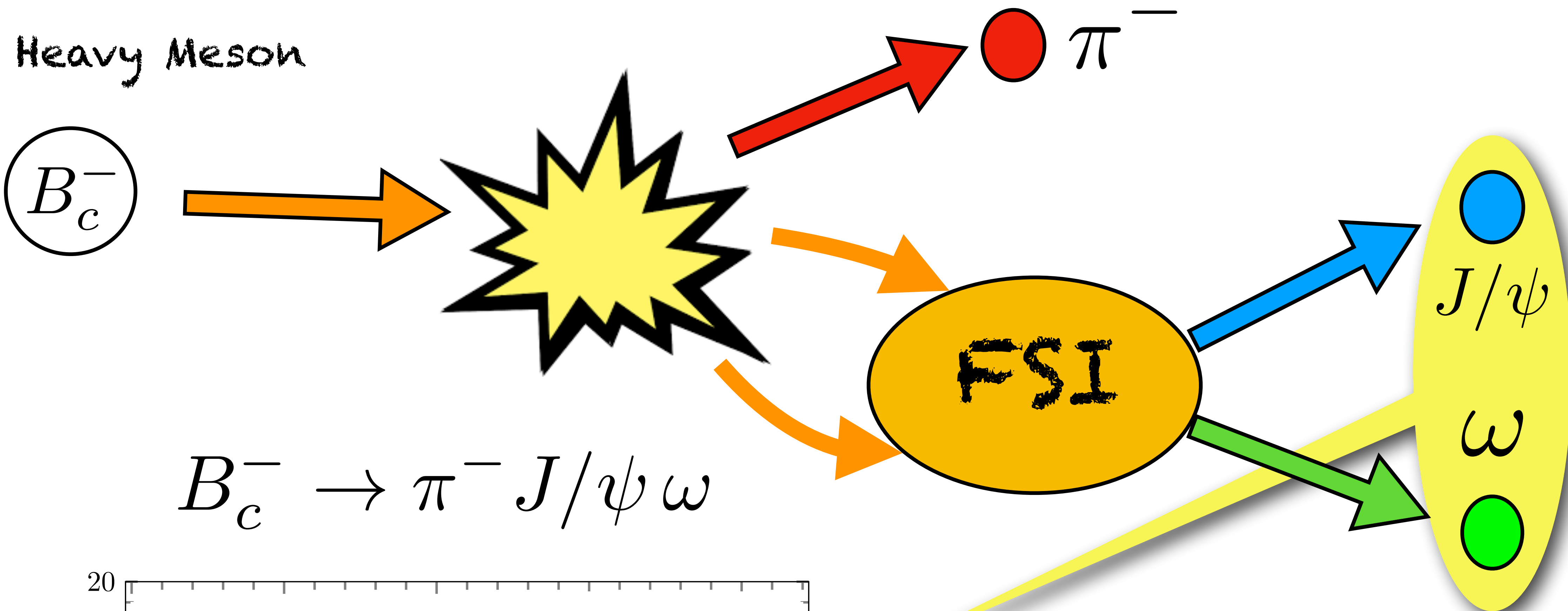
$D^*\bar{D}^*$ $J/\psi\,\omega$

$0^+(0^{++})$ $X(3940)$

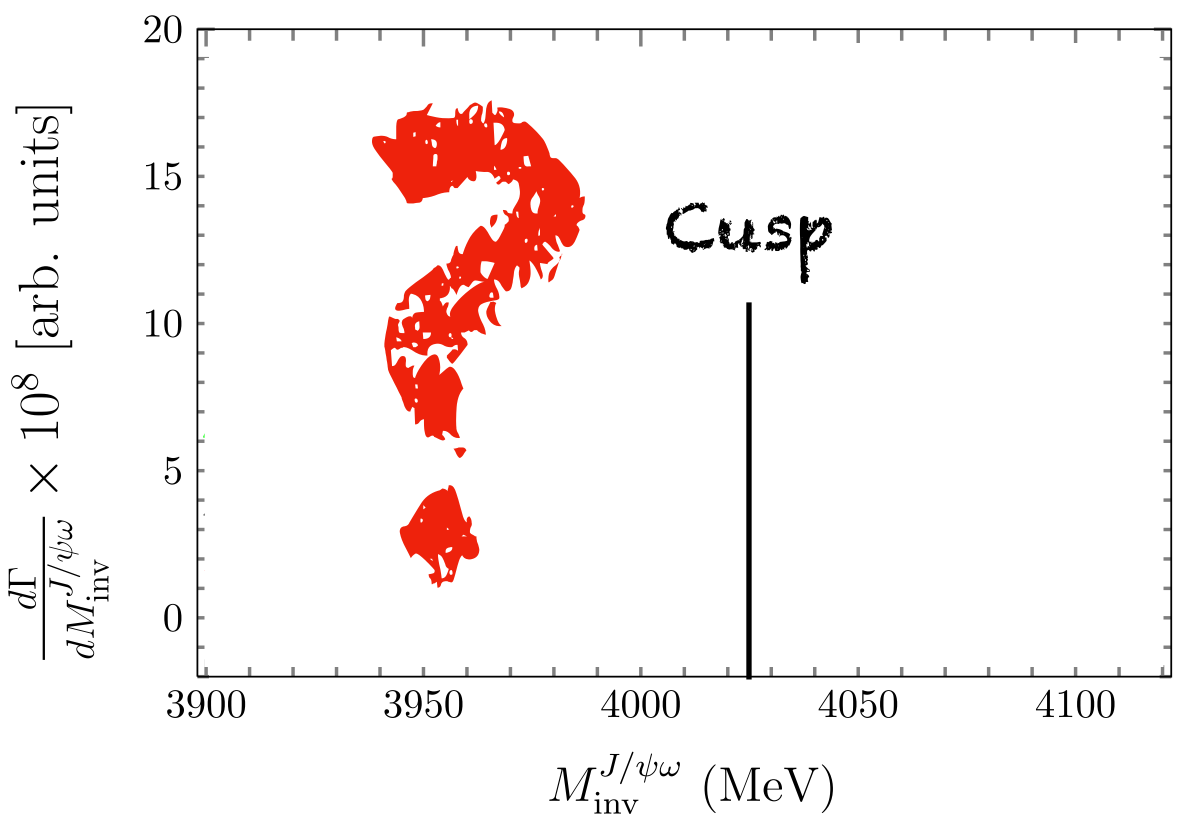
$0^+(2^{++})$ $X(3930)$

Both states also couple to $J/\psi\,\omega$

Heavy meson decays



$$B_c^- \to \pi^- J/\psi\, \omega$$



PRD 80, 114013 (2017)

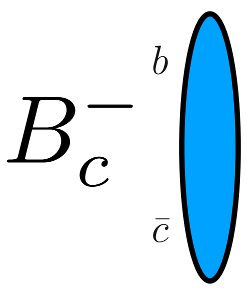
$D^*\bar{D}^*$ $J/\psi\,\omega$

$0^+(0^{++})$ $X(3940)$

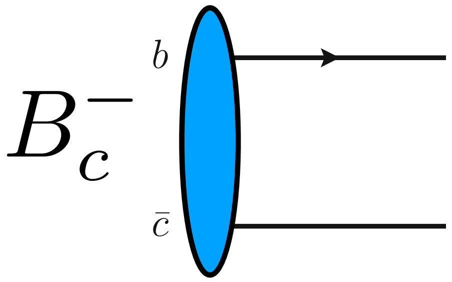
$0^+(2^{++})$ $X(3930)$

Both states also couple to $J/\psi\,\omega$

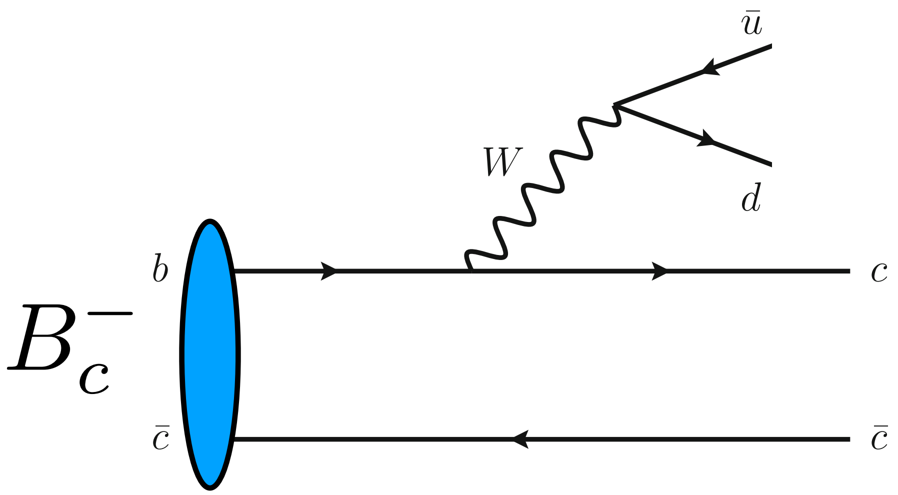
Formalism...



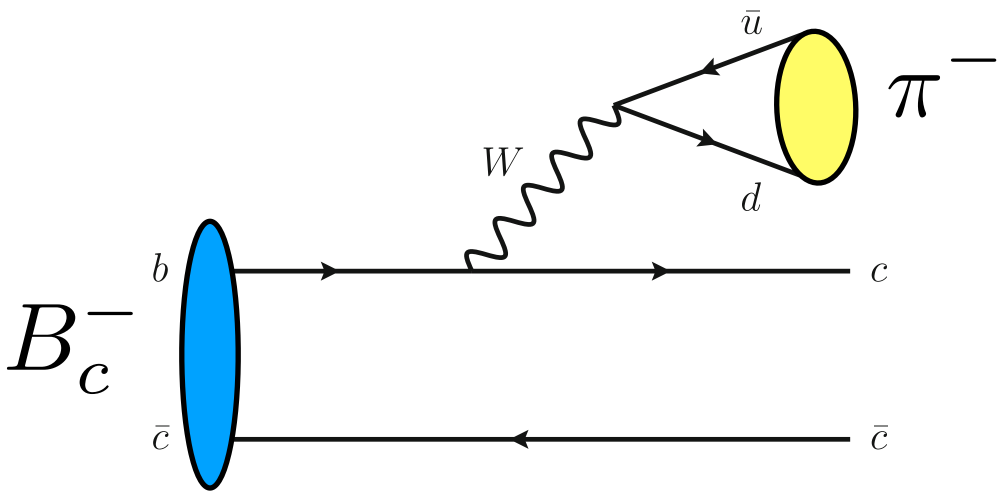
Formalism...



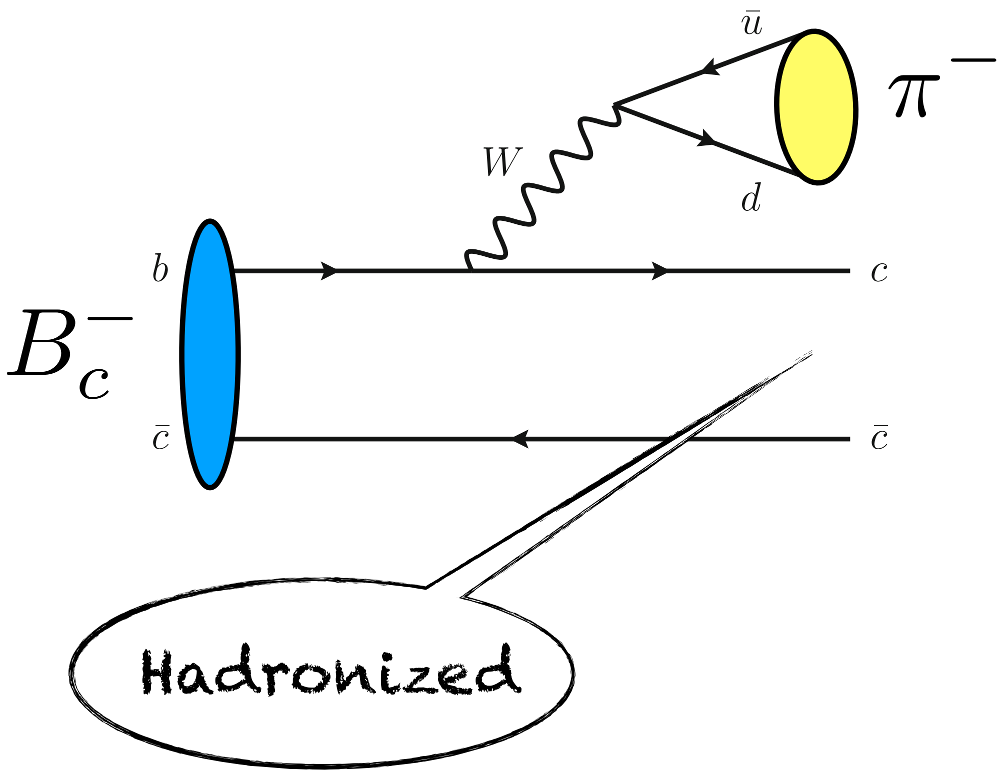
Formalism...



Formalism...

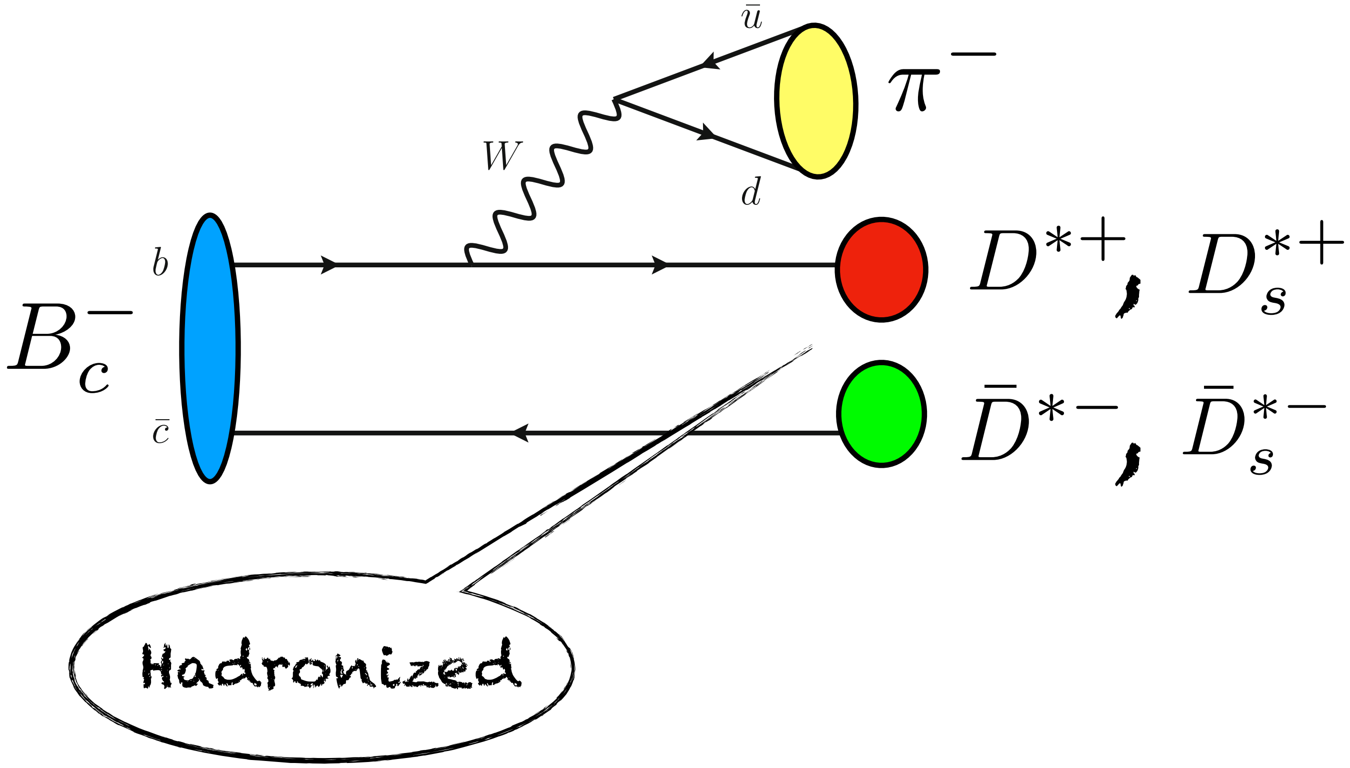


Formalism...



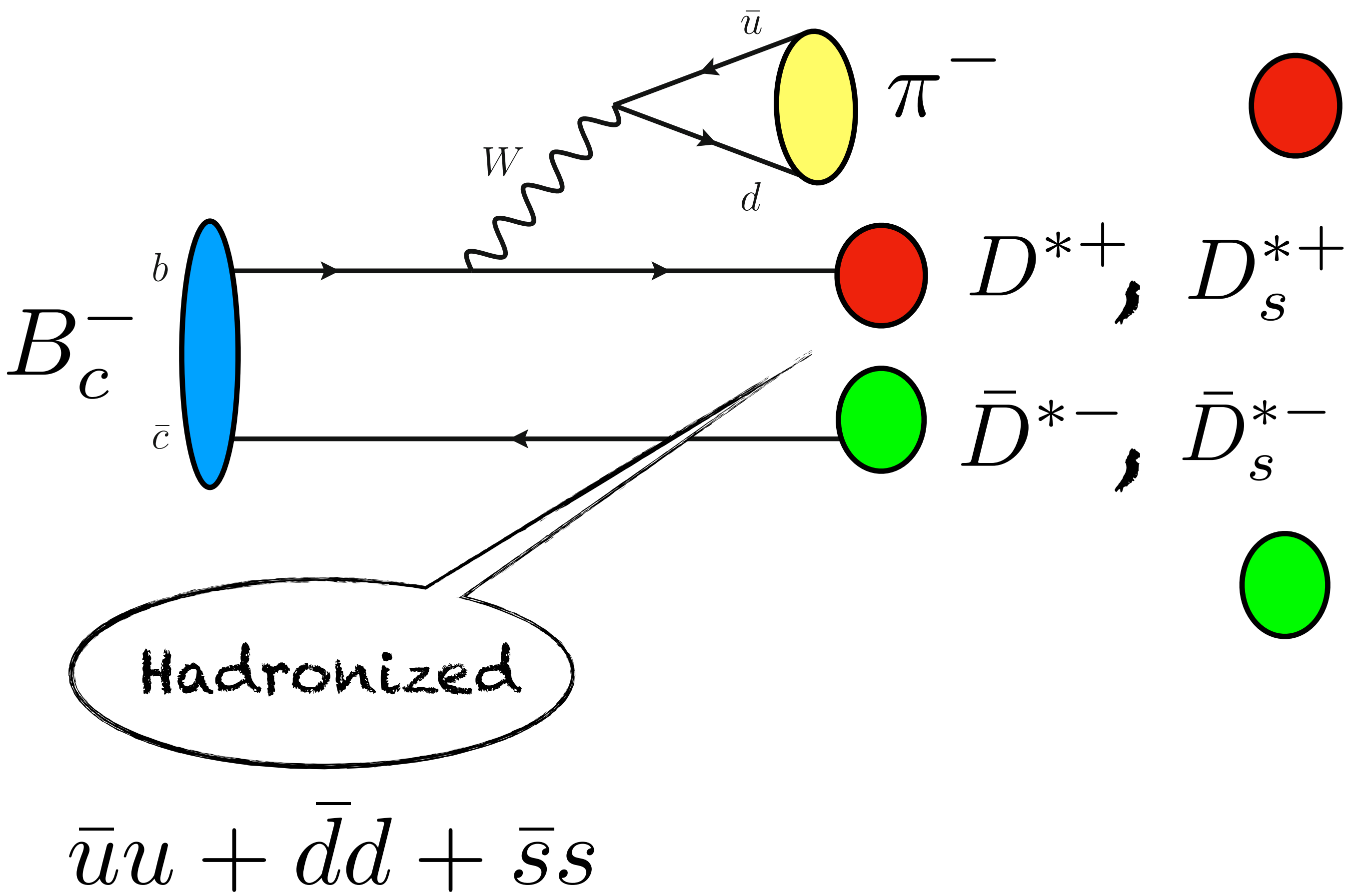
$$\bar{u}u + \bar{d}d + \bar{s}s$$

Formalism...

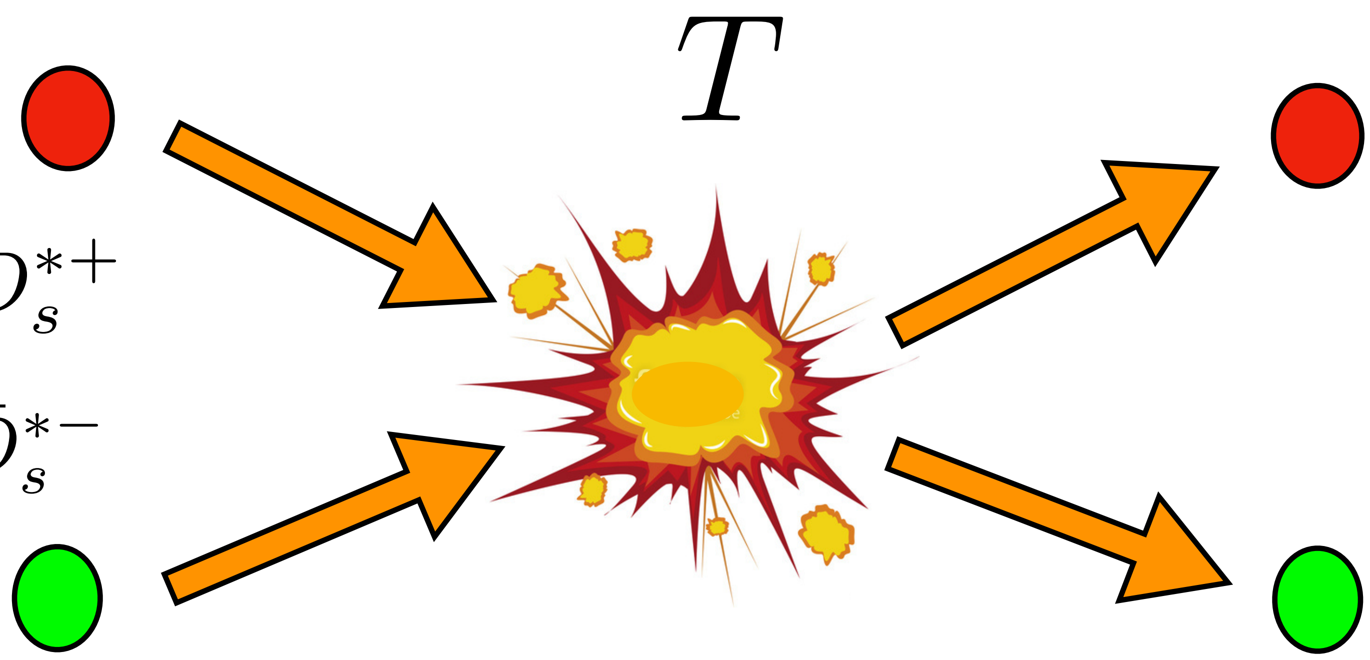


$$\bar{u}u + \bar{d}d + \bar{s}s$$

Formalism...

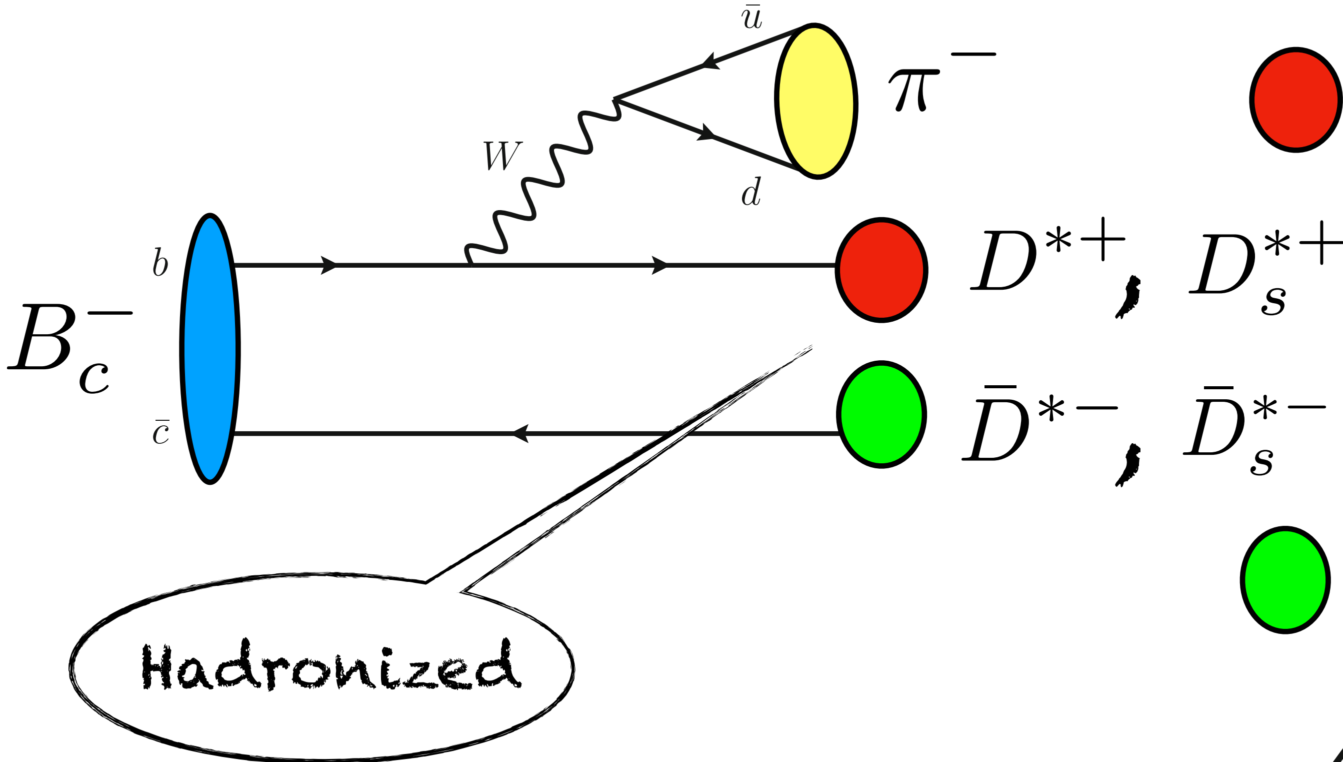


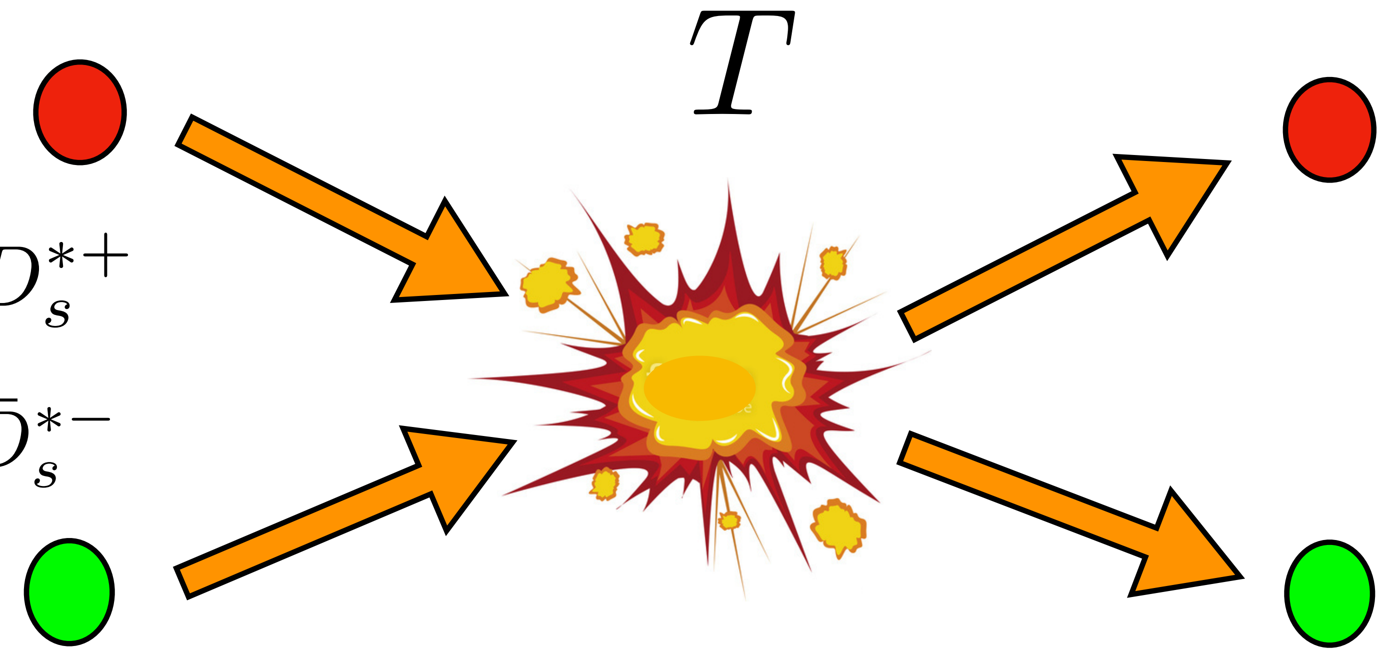
$\bar{u}$
π^-
W
d
b
B_c^-
D^{*+}, D_s^{*+}
$\bar{c}$
$\bar{D}^{*-}$, $\bar{D}_s^{*-}$
Hadronized
$\bar{u}u + \bar{d}d + \bar{s}s$



T

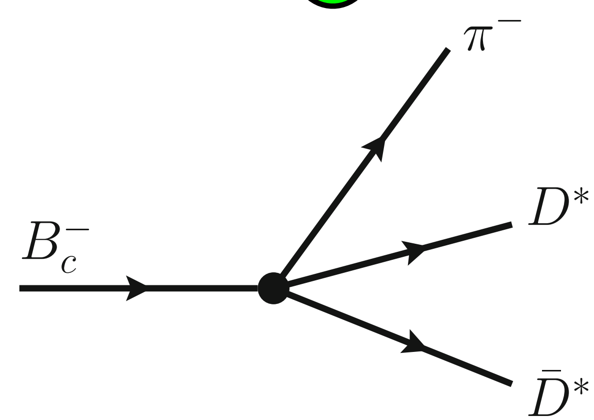
Formalism...



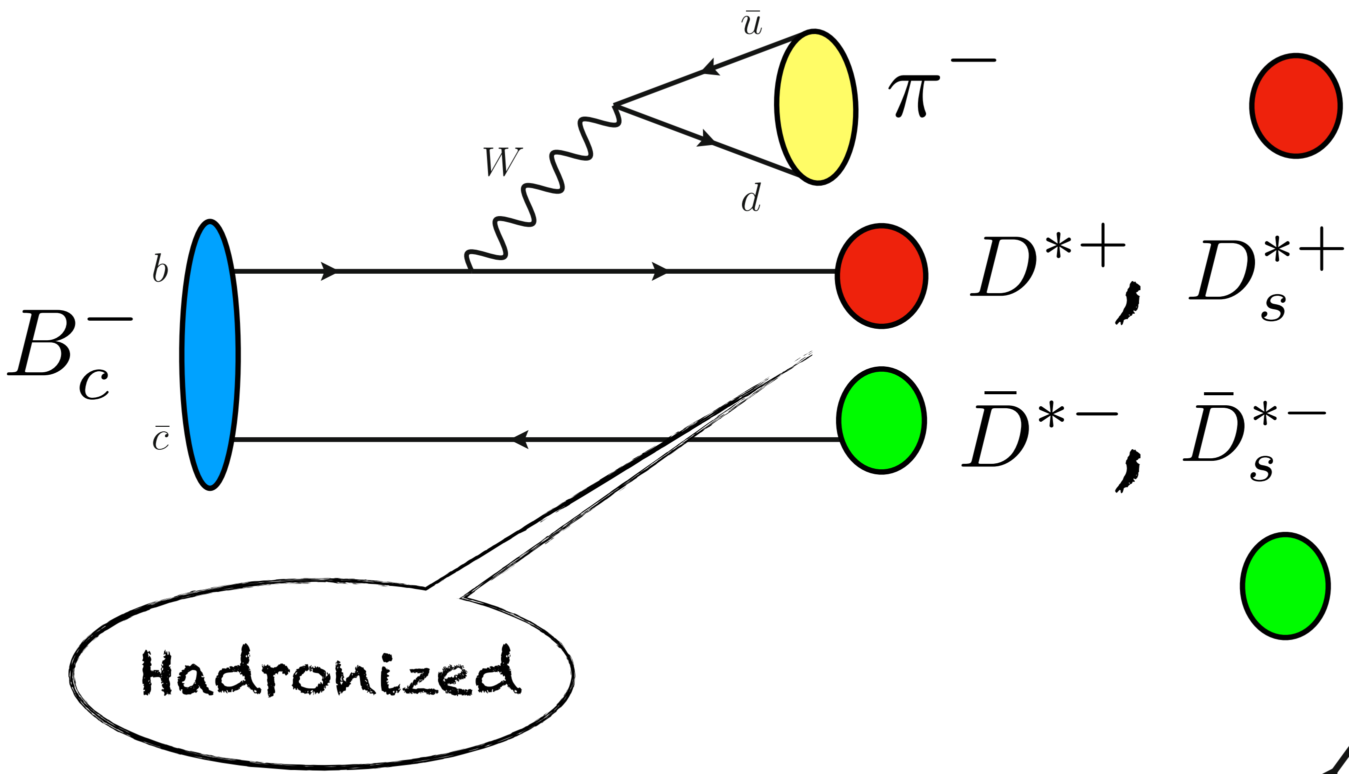


$$\bar{u}u + \bar{d}d + \bar{s}s$$

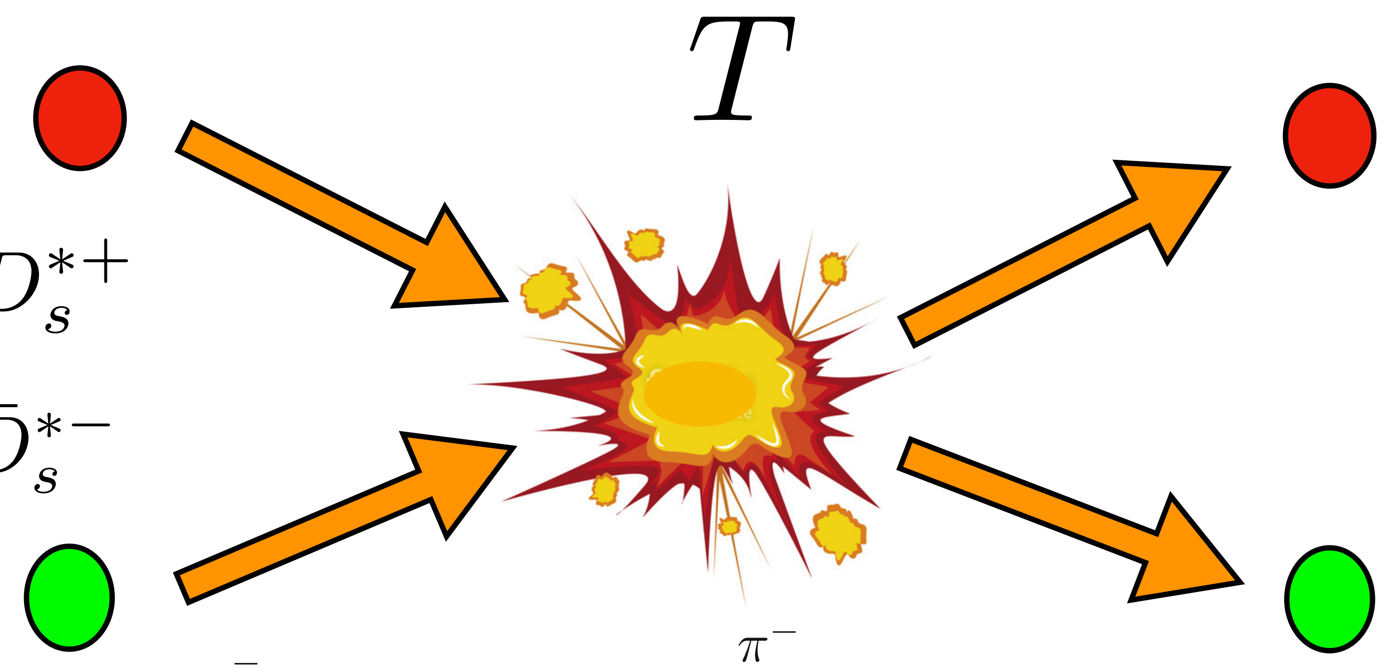
$T =$



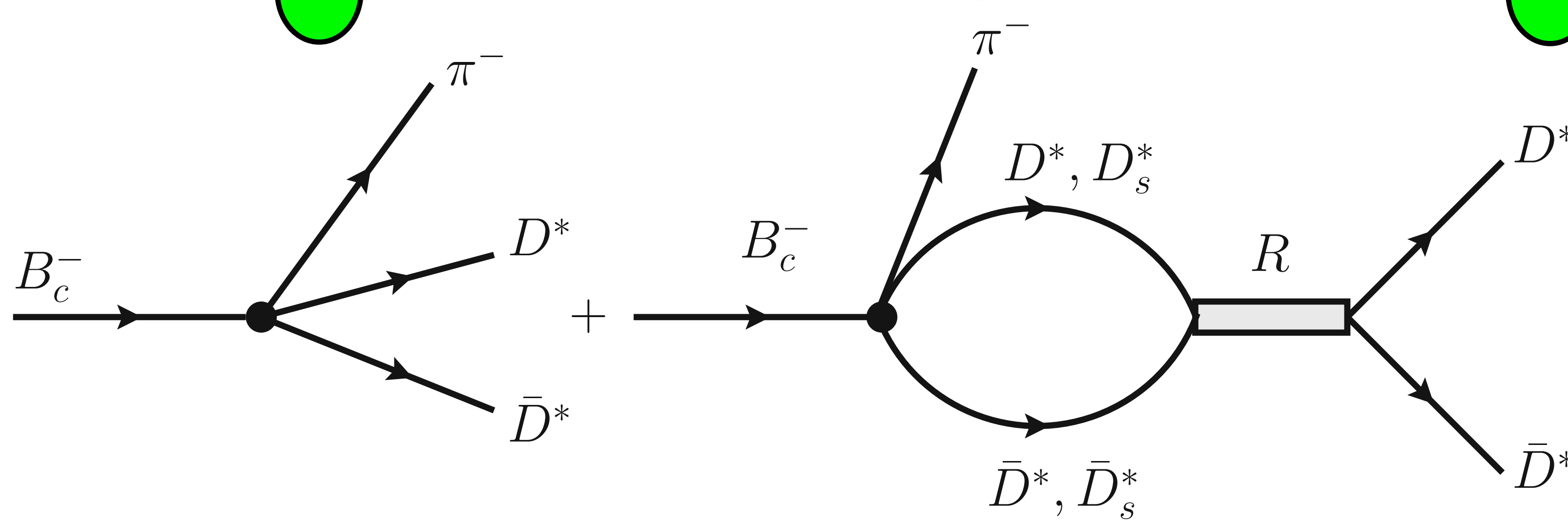
Formalism...



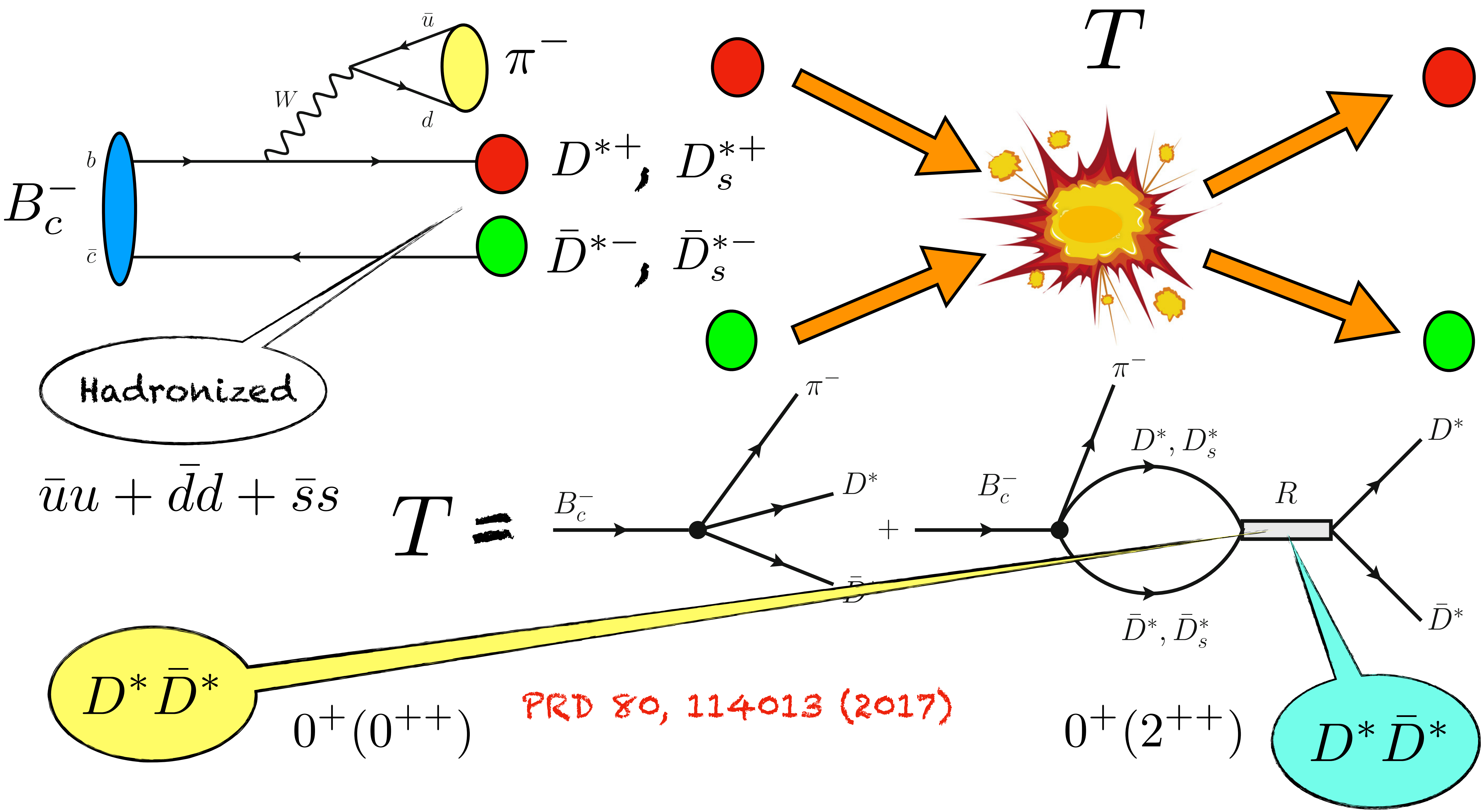
$$\bar{u}u + \bar{d}d + \bar{s}s$$



$T =$

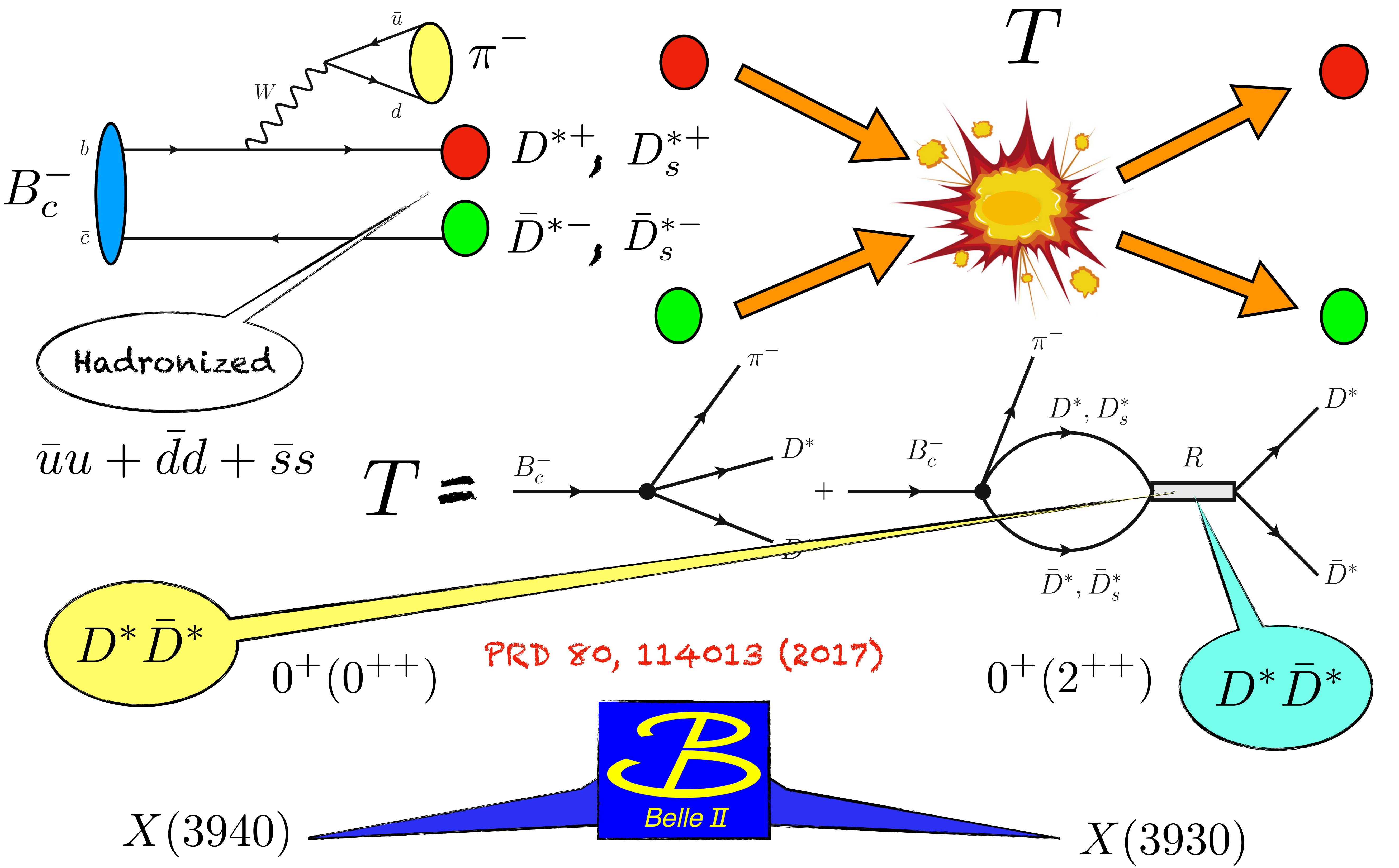


Formalism...



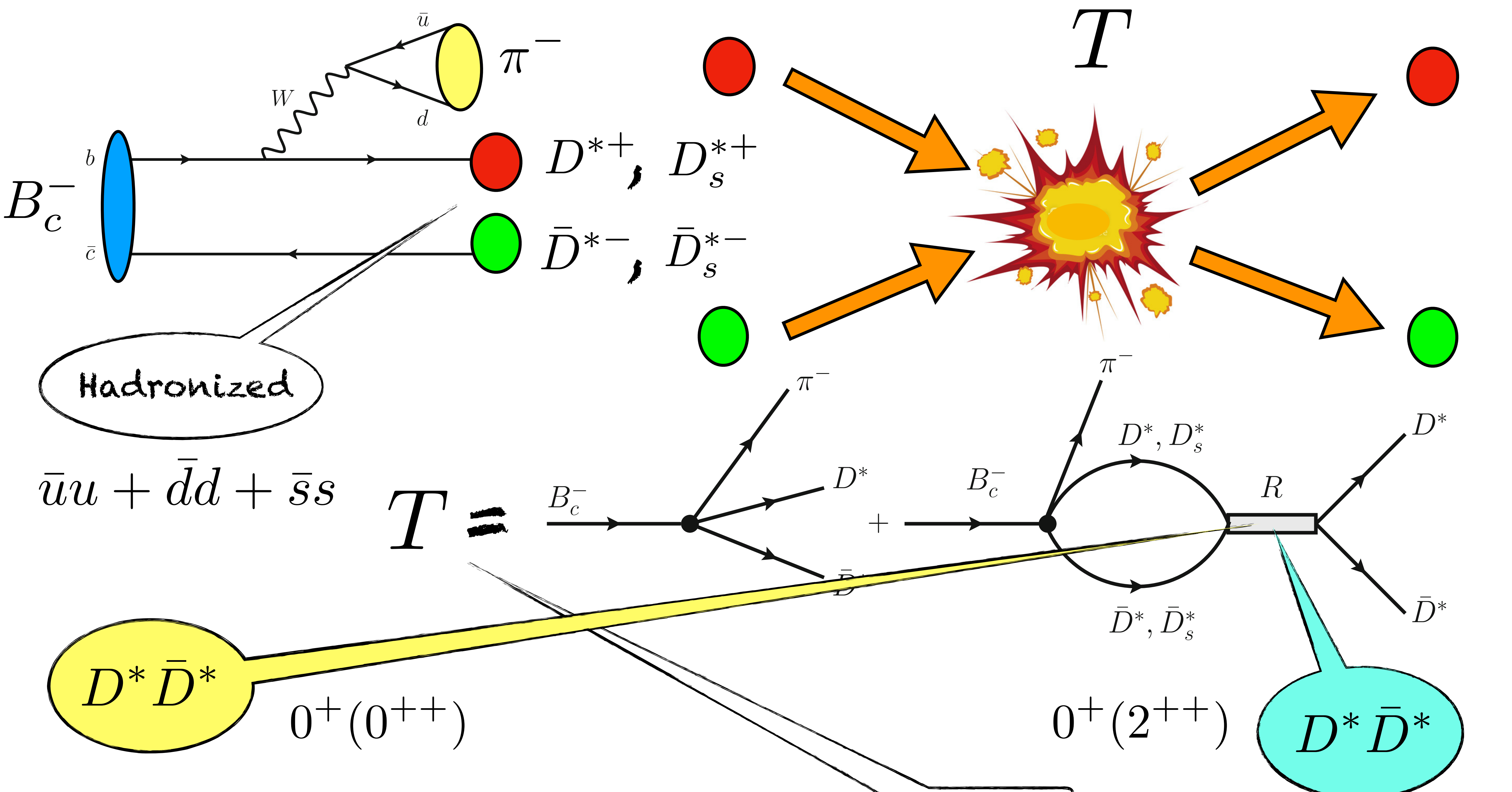
π^-
$\bar{u}$
d
W
b
$\bar{c}$
B_c^-
D^{*+}, D_s^{*+}
$\bar{D}^{*-}$, $\bar{D}_s^{*-}$
Hadronized
$\bar{u}u + \bar{d}d + \bar{s}s$
T
$T =$
B_c^-
π^-
D^*
$\bar{D}^*$
+
D^*, D_s^*
$\bar{D}^*, \bar{D}_s^*$
R
$D^*\bar{D}^*$
$0^+(0^{++})$
PRD 80, 114013 (2017)
$0^+(2^{++})$
$D^*\bar{D}^*$

Formalism...



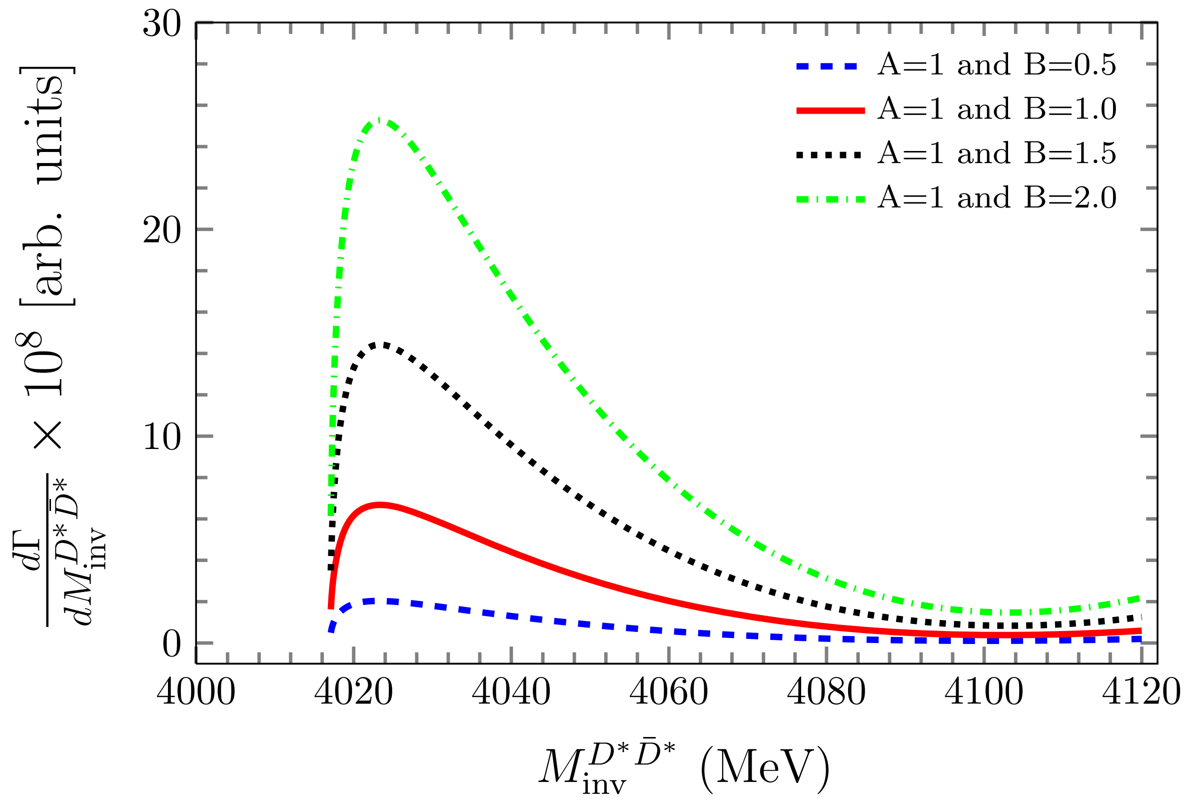
PRL 94, 182002 (2005) PRL 98, 082001 (2007) PRL 98, 082001 (2007)

Formalism...



$$\frac{d\Gamma}{dM_{inv}^{D^*\bar{D}^*}} = \frac{1}{(2\pi)^3}\frac{k' p_{D^*}}{4M_{B_c}^2}\boxed{|T|^2}$$

Results: $D^*\bar{D}^*$ distribution



$$T \sim A(\epsilon \cdot \epsilon')$$

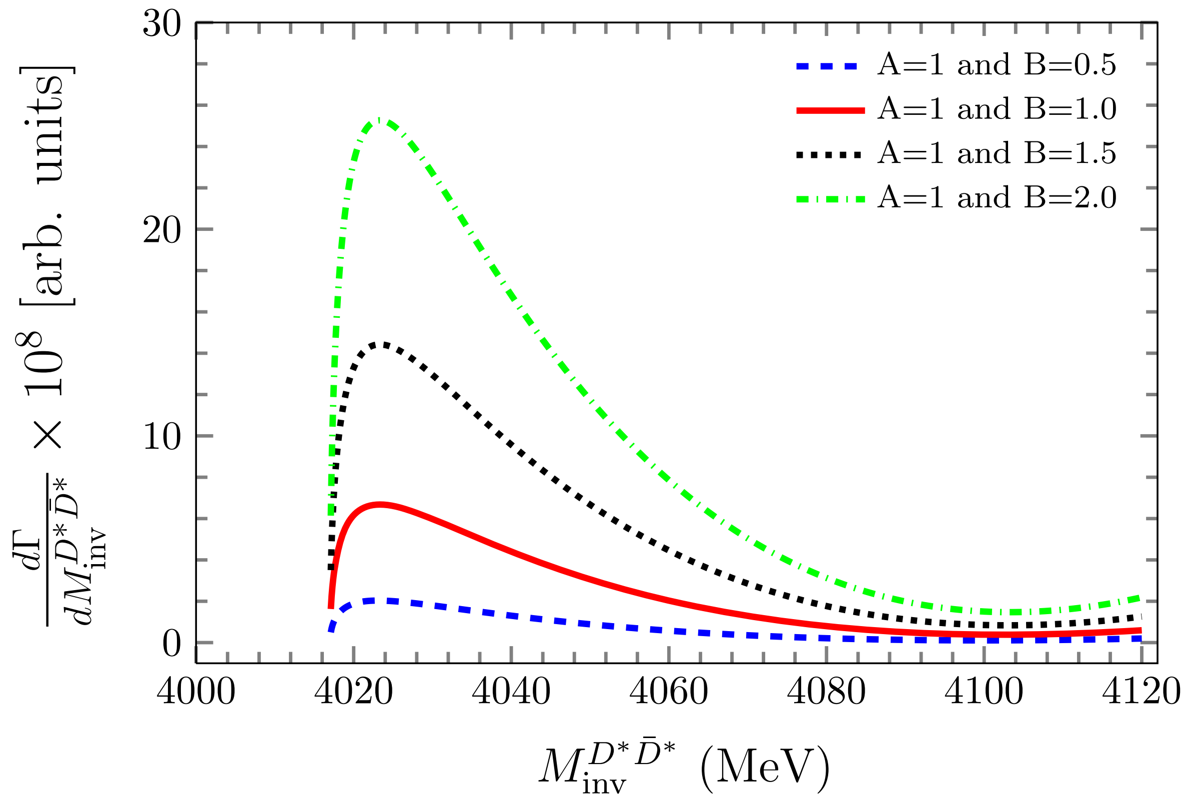
Production

$D^*\bar{D}^*$

$0^+(0^{++})$

$$\frac{d\Gamma}{dM_{inv}^{D^*\bar{D}^*}} = \frac{1}{(2\pi)^3}\frac{k' p_{D^*}}{4M_{B_c}^2}|T|^2$$

Results: $D^*\bar{D}^*$ distribution



$$T \sim A(\epsilon\cdot\epsilon') + B\left[(\epsilon\cdot\mathbf{k})(\epsilon'\cdot\mathbf{k}) - \frac{1}{3}|\mathbf{k}|^2(\epsilon\cdot\epsilon')\right]$$

Production

$D^*\bar{D}^*$

$0^+(0^{++})$

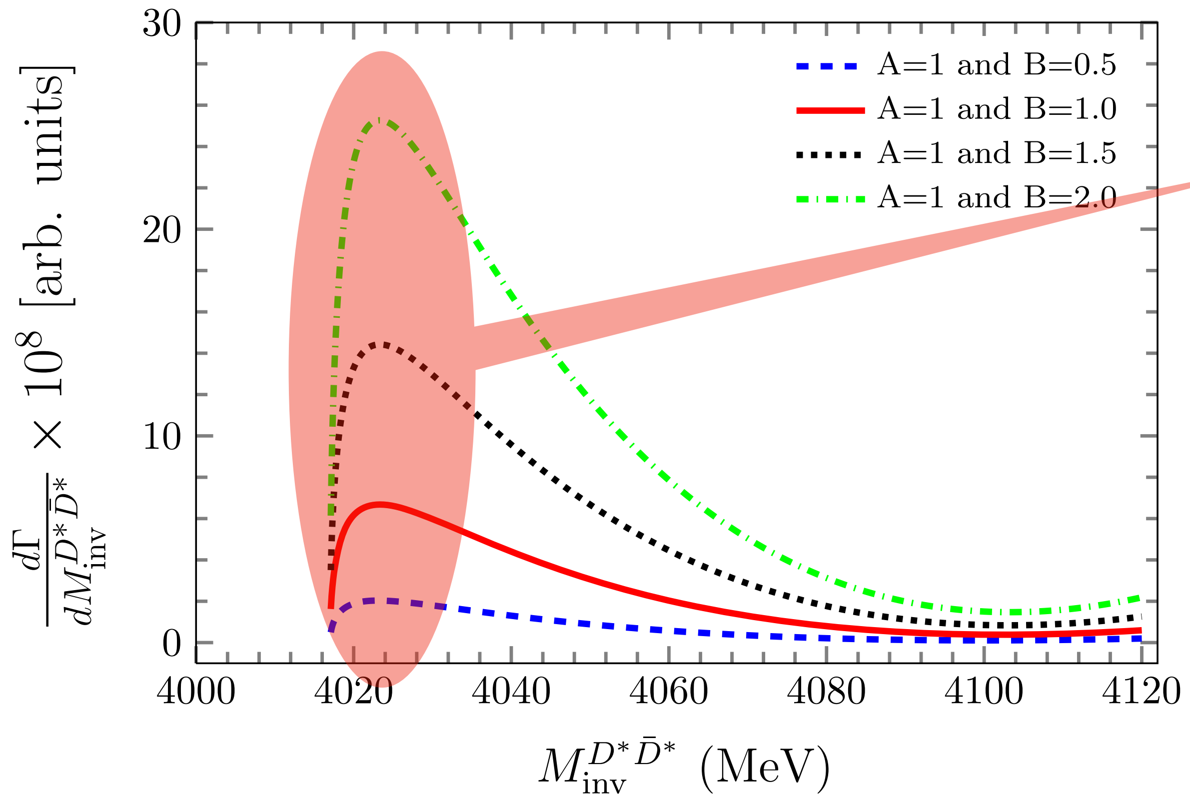
$0^+(2^{++})$

$D^*\bar{D}^*$

Production

$$\frac{d\Gamma}{dM_{inv}^{D^*\bar{D}^*}} = \frac{1}{(2\pi)^3}\frac{k' p_{D^*}}{4M_{B_c}^2}\boxed{|T|^2}$$

Results: $D^*\bar{D}^*$ distribution



- Indicates an influence by a resonance below threshold

$$T \sim A(\epsilon \cdot \epsilon') + B\left[(\epsilon \cdot \mathbf{k})(\epsilon' \cdot \mathbf{k}) - \frac{1}{3}|\mathbf{k}|^2(\epsilon \cdot \epsilon')\right]$$

Production

$D^*\bar{D}^*$

$0^+(0^{++})$

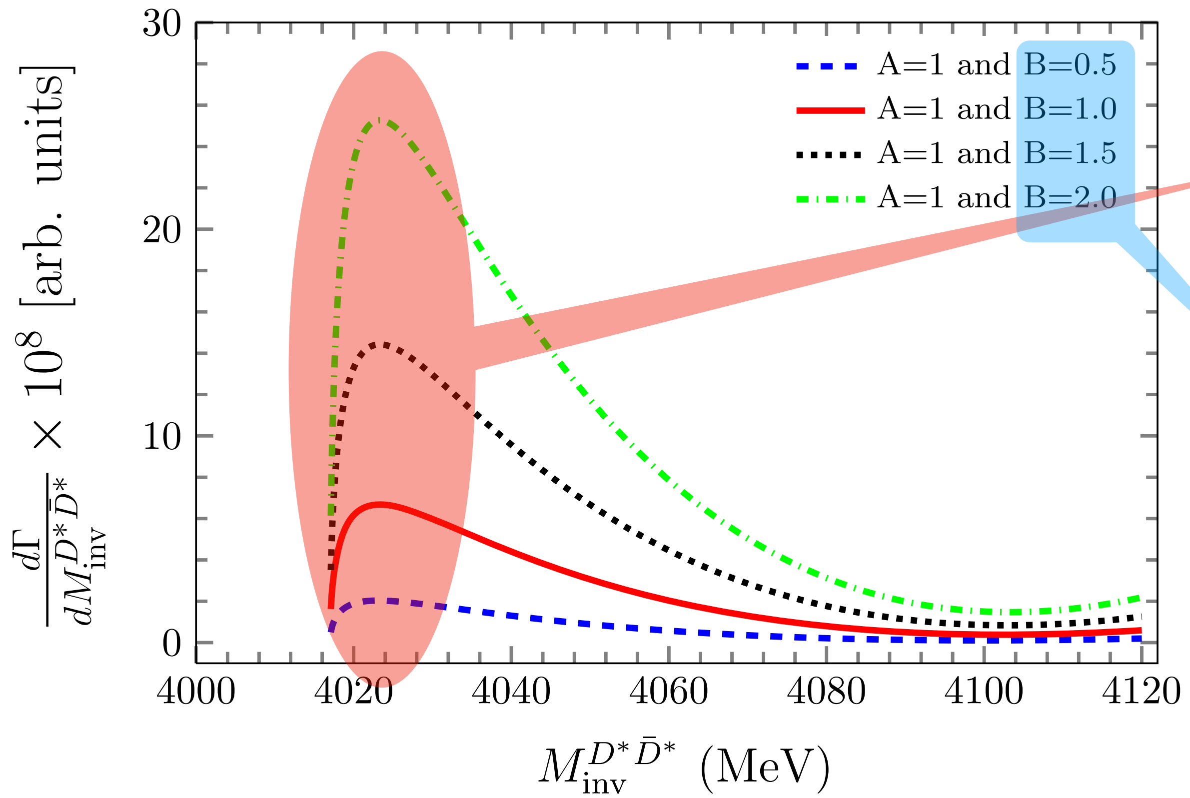
$0^+(2^{++})$

$D^*\bar{D}^*$

$$\frac{d\Gamma}{dM_{inv}^{D^*\bar{D}^*}} = \frac{1}{(2\pi)^3}\frac{k' p_{D^*}}{4M_{B_c}^2}|T|^2$$

Production

Results: $D^*\bar{D}^*$ distribution



- Indicates an influence by a resonance below threshold
- It is influenced by the tensor resonance

$$T \sim A(\epsilon \cdot \epsilon') + B\left[(\epsilon \cdot \mathbf{k})(\epsilon' \cdot \mathbf{k}) - \frac{1}{3}|\mathbf{k}|^2(\epsilon \cdot \epsilon')\right]$$

Production

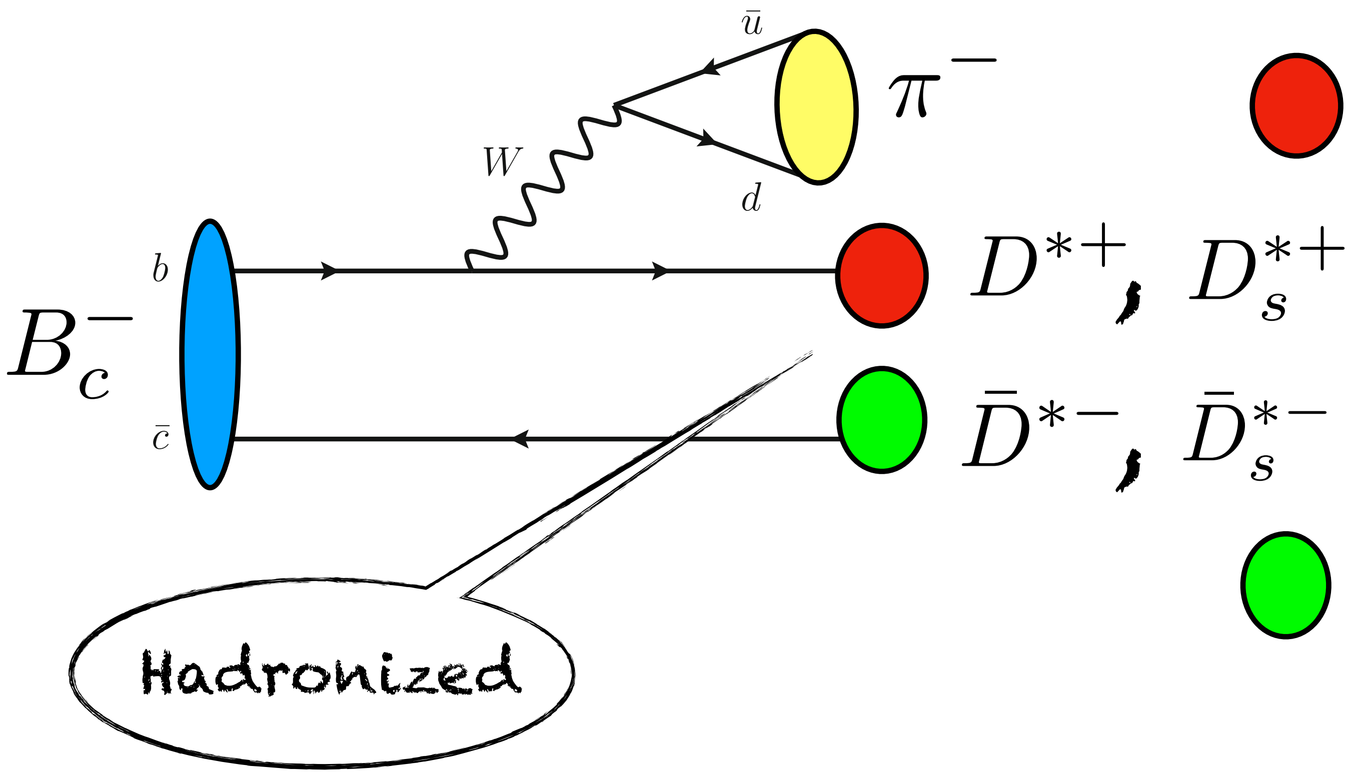
$D^*\bar{D}^*$ $0^+(0^{++})$

$0^+(2^{++})$ $D^*\bar{D}^*$

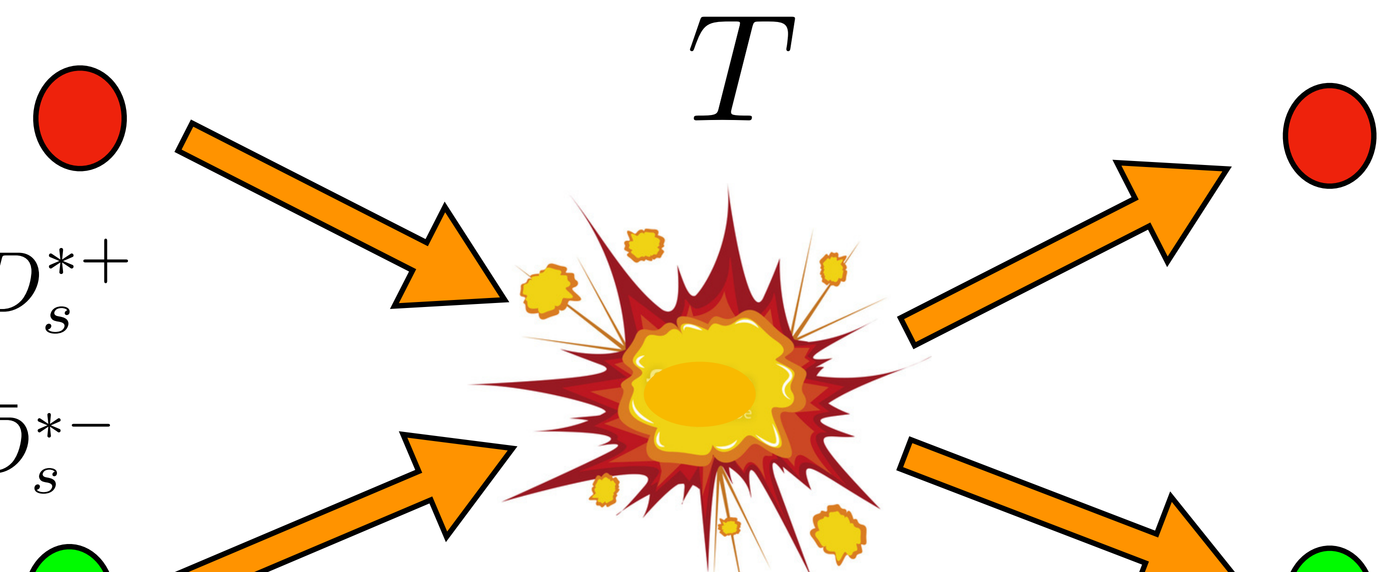
$$\frac{d\Gamma}{dM_{inv}^{D^*\bar{D}^*}} = \frac{1}{(2\pi)^3}\frac{k' p_{D^*}}{4M_{B_c}^2}|T|^2$$

Production

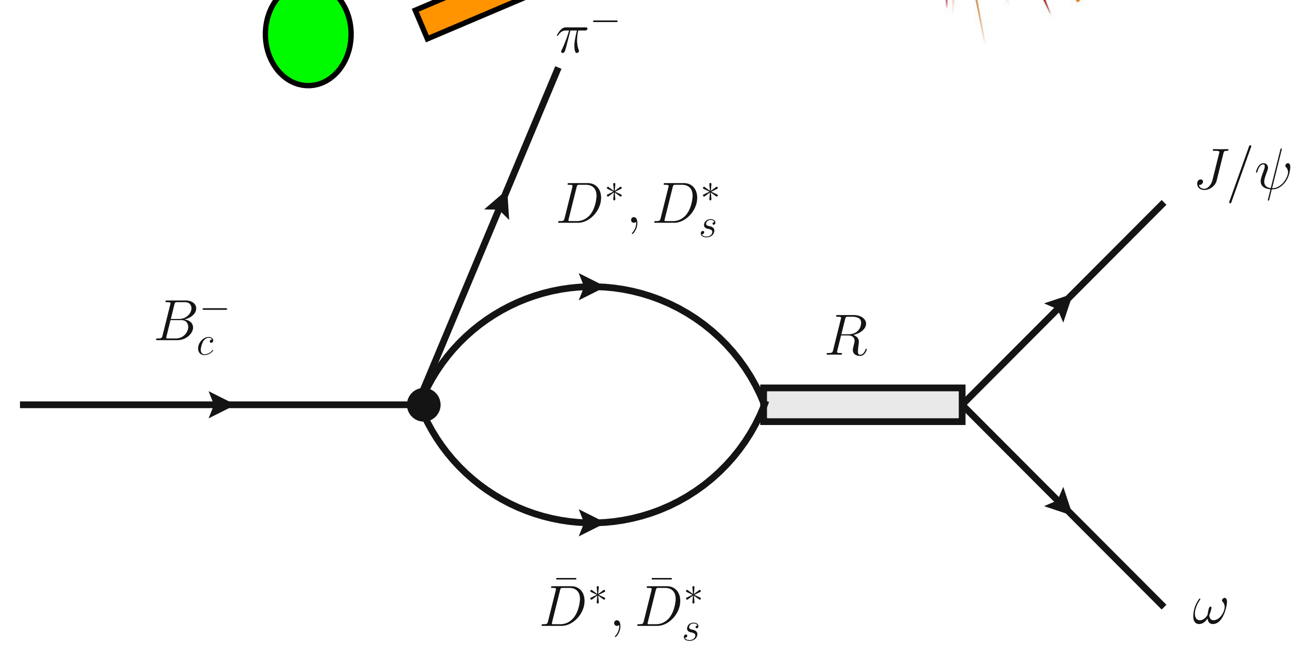
Formalism...



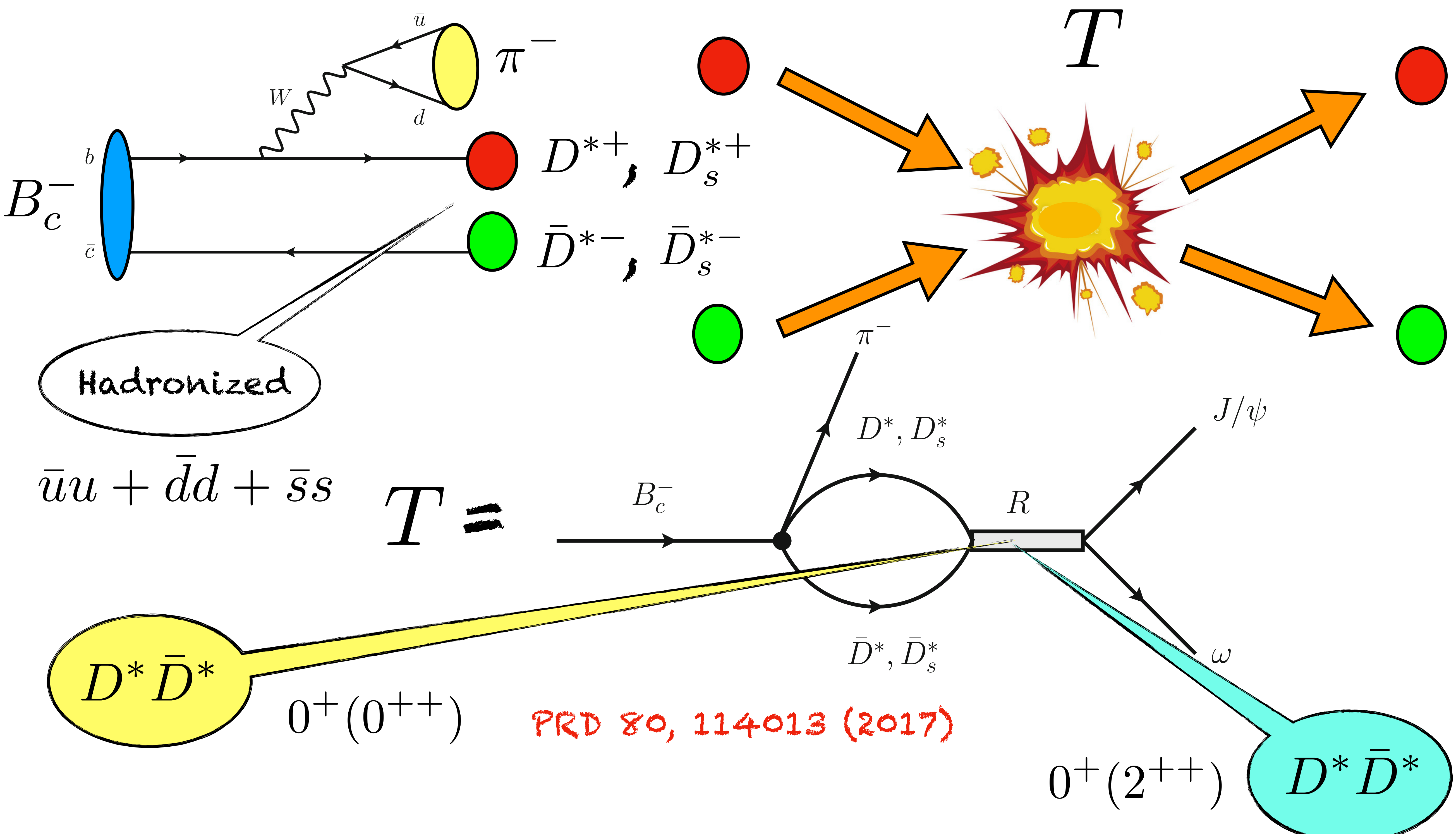
$$\bar{u}u + \bar{d}d + \bar{s}s$$



$T =$

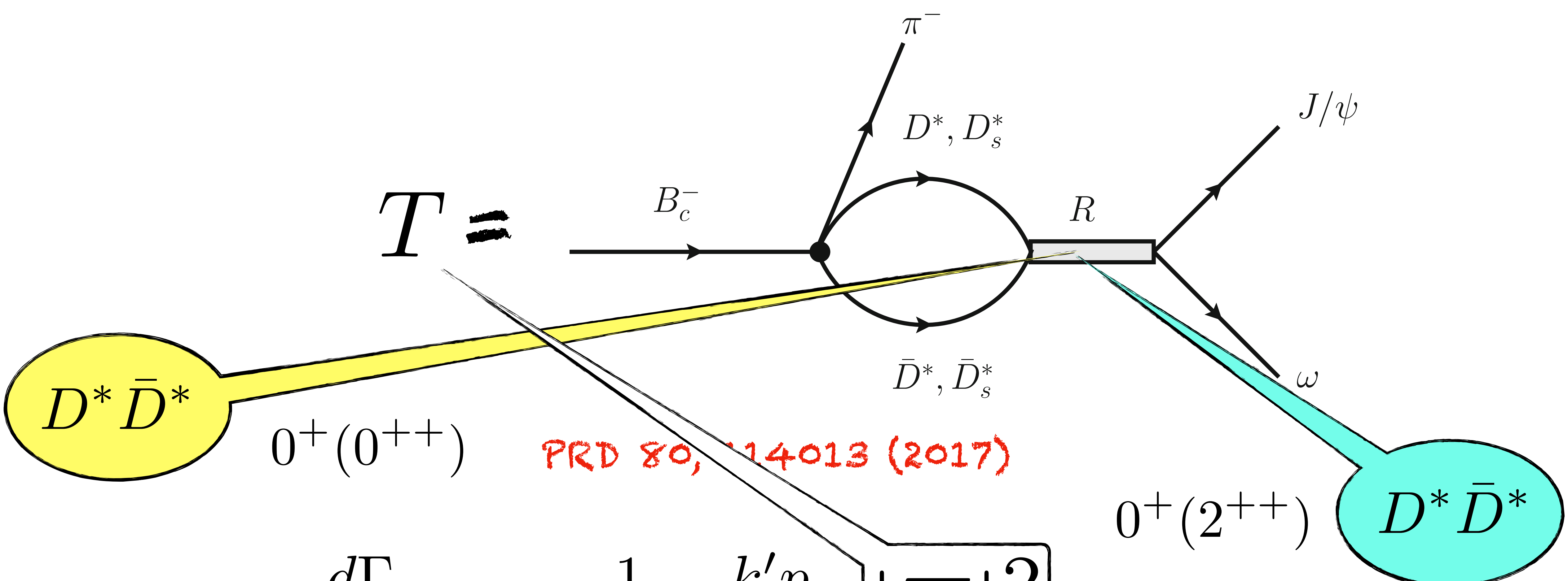


Formalism...



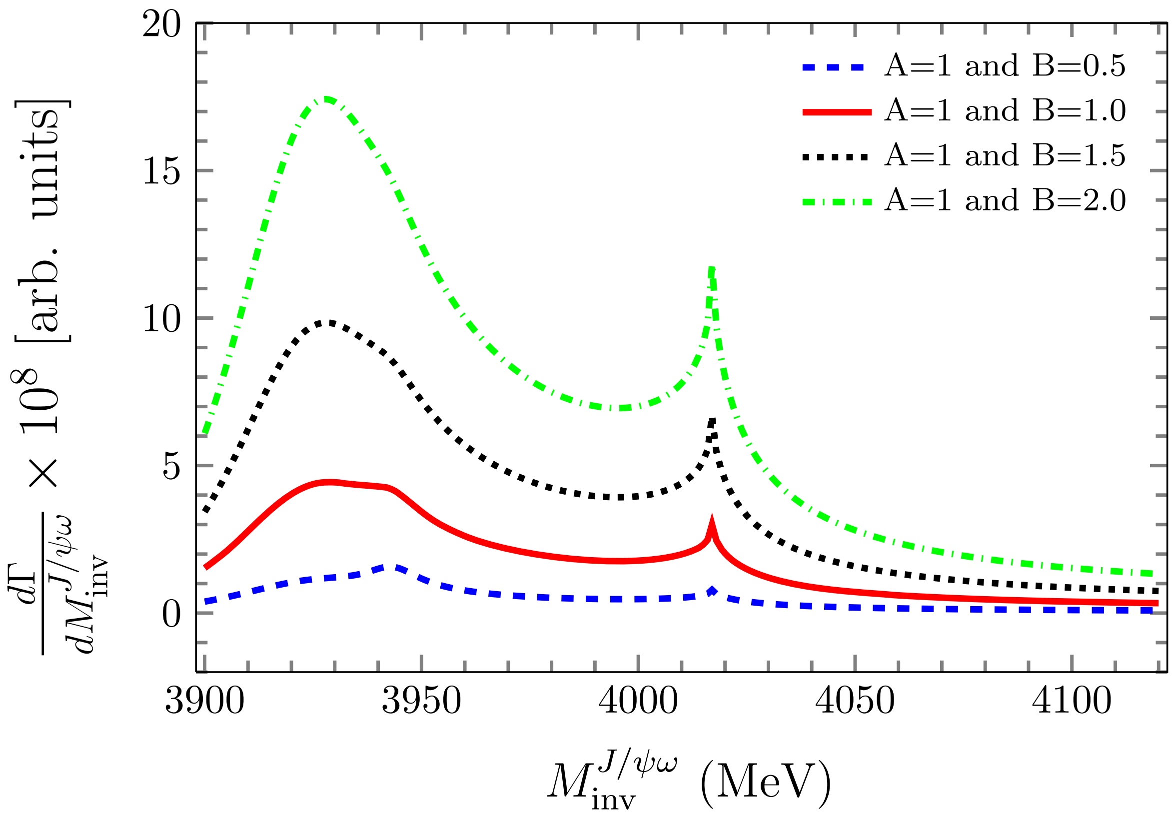
$\bar{u}$
π^-
W
d
b
B_c^-
$\bar{c}$
D^{*+}, D_s^{*+}
$\bar{D}^{*-}$, $\bar{D}_s^{*-}$
Hadronized
$\bar{u}u + \bar{d}d + \bar{s}s$
T
$T =$
π^-
D^*, D_s^*
J/ψ
B_c^-
R
$\bar{D}^*, \bar{D}_s^*$
ω
$D^*\bar{D}^*$
$0^+(0^{++})$
PRD 80, 114013 (2017)
$0^+(2^{++})$
$D^*\bar{D}^*$

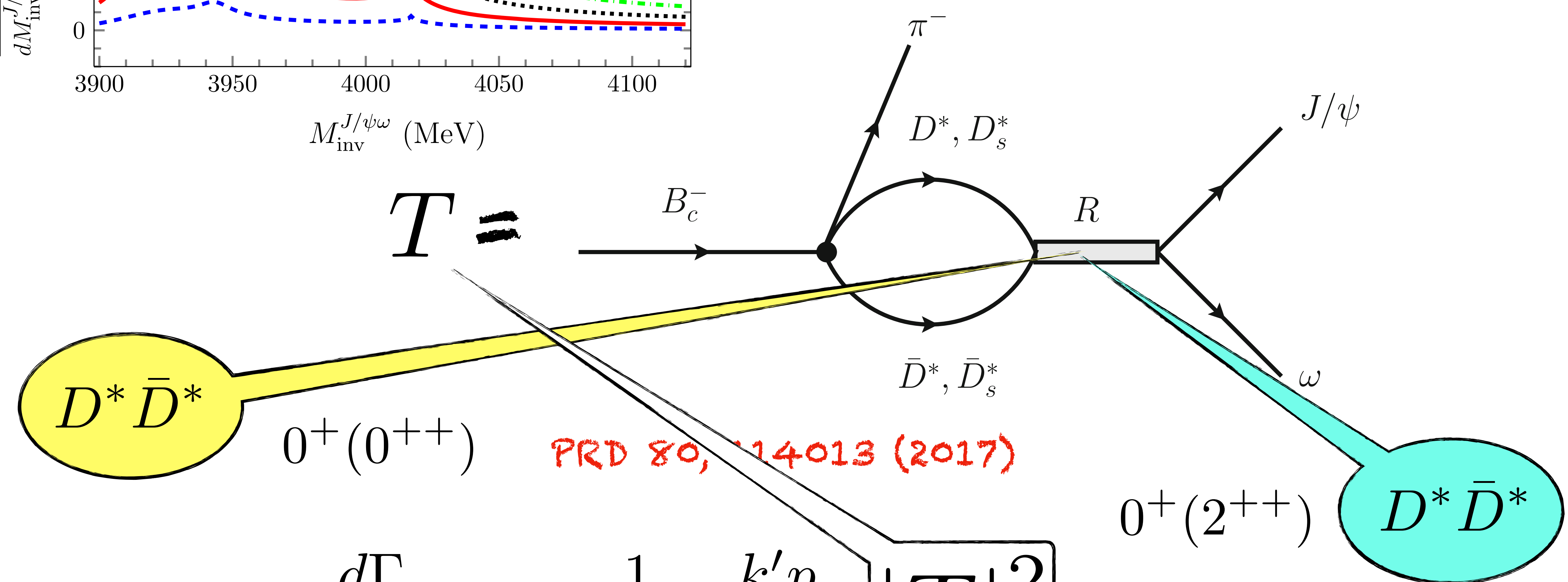
Results: $J/\psi\,\omega$ distribution



$$\frac{d\Gamma}{dM_{inv}^{J/\psi\omega}} = \frac{1}{(2\pi)^3}\frac{k' p_\omega}{4M_{B_c}^2}\boxed{|T|^2}$$

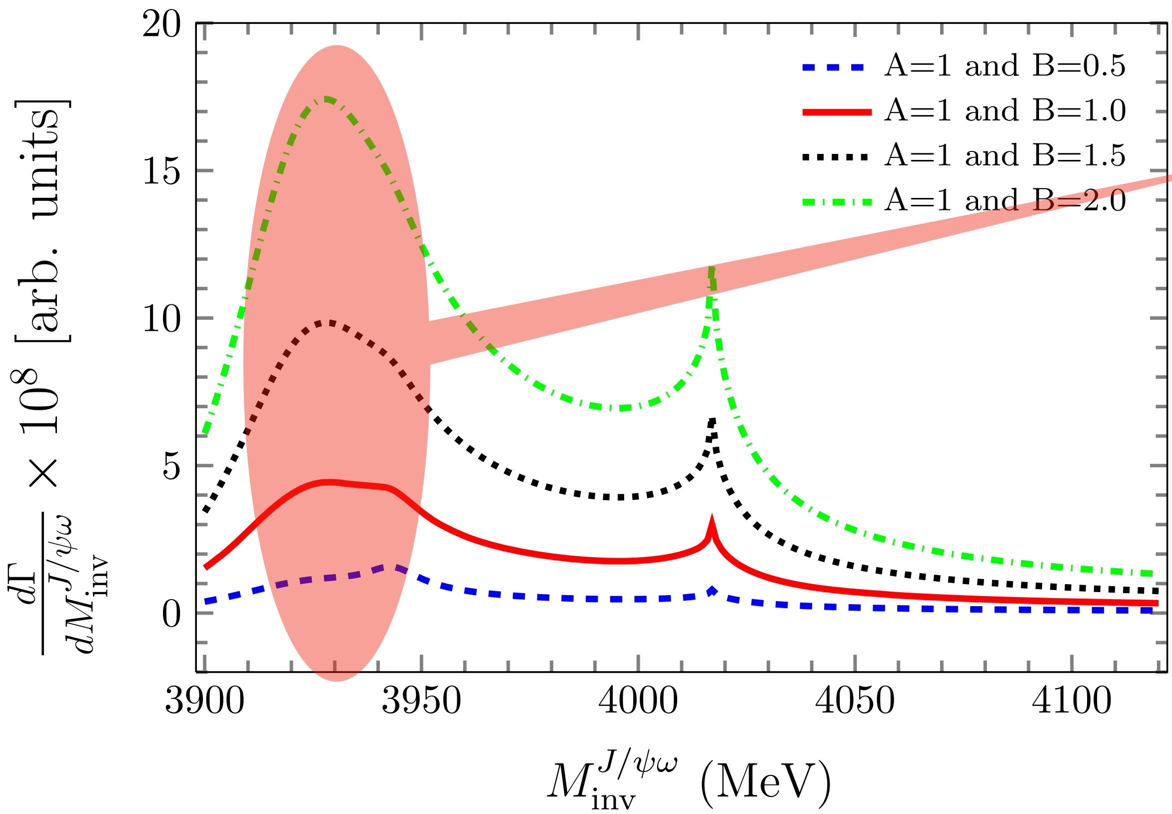
Results: $J/\psi\,\omega$ distribution





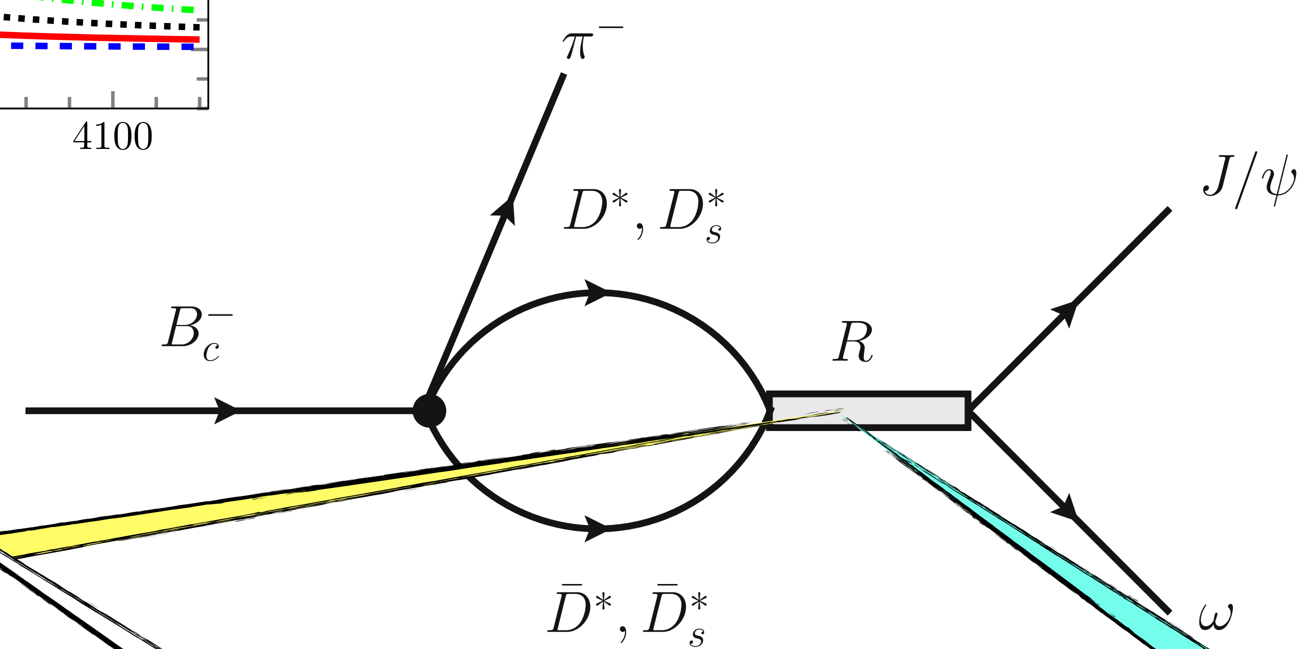
$$\frac{d\Gamma}{dM_{inv}^{J/\psi\omega}} = \frac{1}{(2\pi)^3}\frac{k' p_\omega}{4M_{B_c}^2}\left|T\right|^2$$

Results: $J/\psi\,\omega$ distribution



– The two resonances merge into a broader one

$T =$



$D^*\bar{D}^*$ $0^+(0^{++})$

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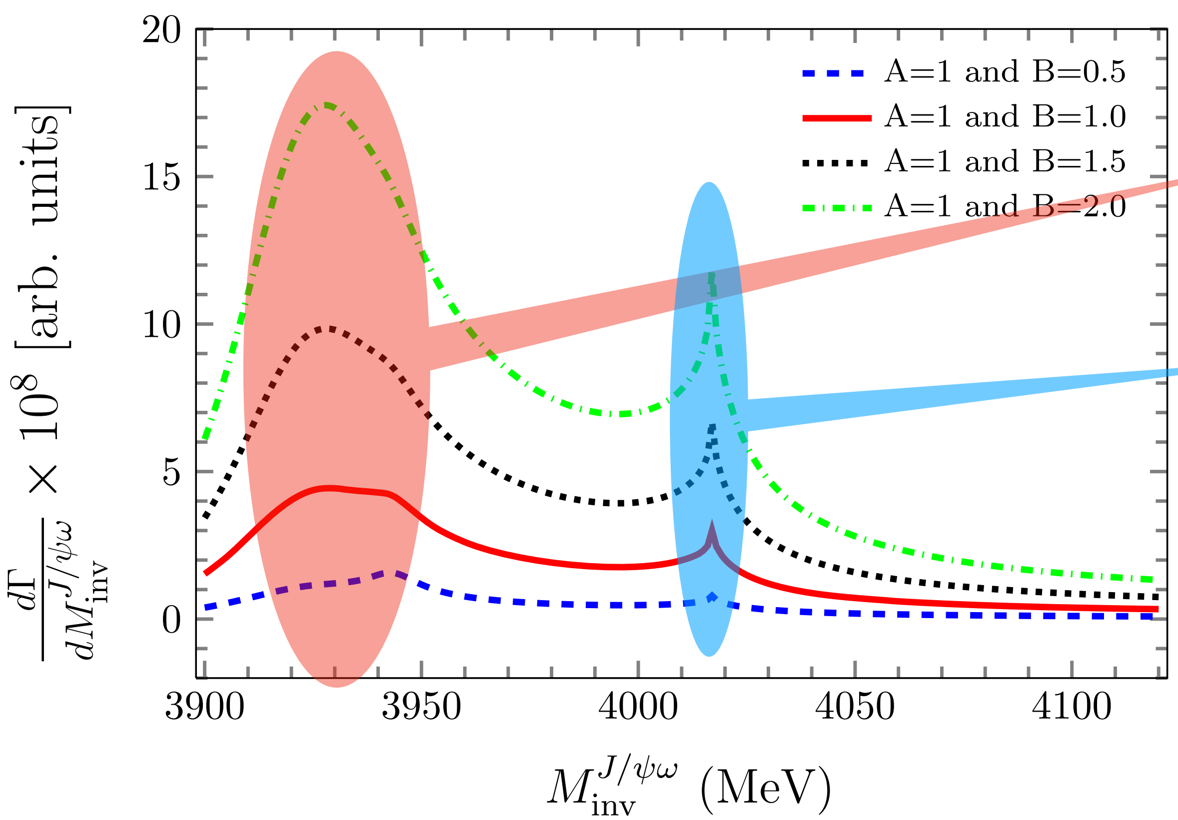
$0^+(2^{++})$ $D^*\bar{D}^*$

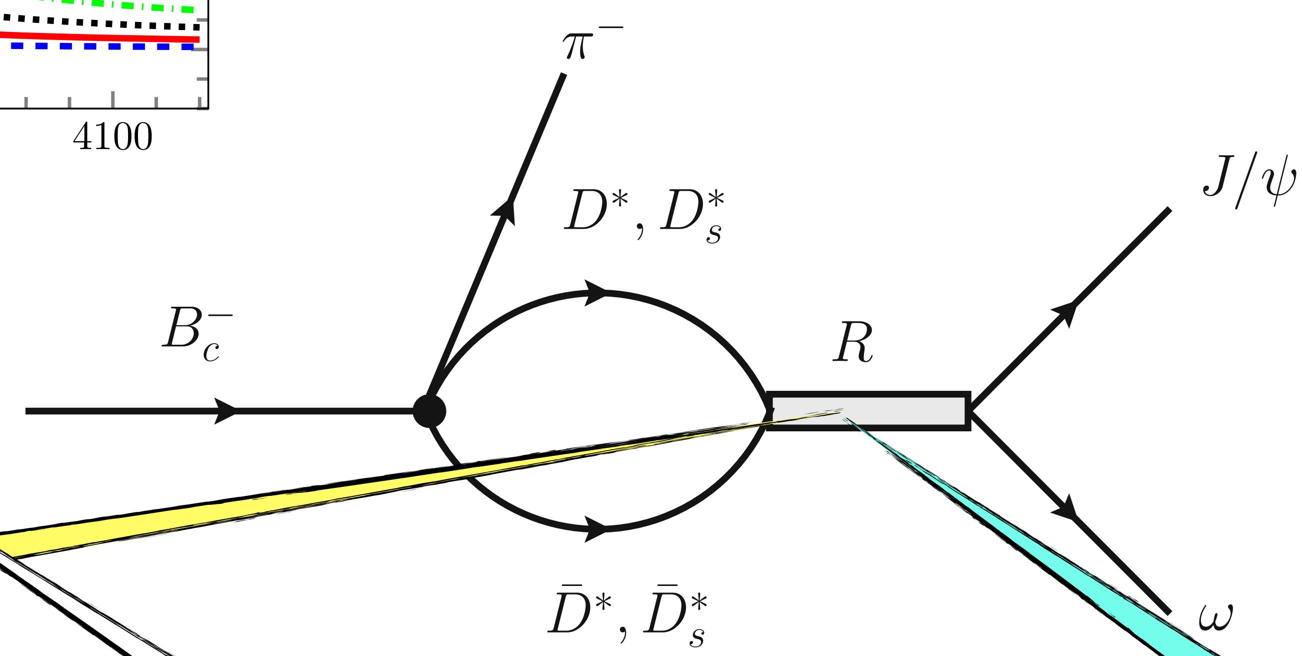
$$\frac{d\Gamma}{dM_{inv}^{J/\psi\omega}} = \frac{1}{(2\pi)^3}\frac{k' p_\omega}{4M_{B_c}^2}|T|^2$$

Results: $J/\psi\,\omega$ distribution



- The two resonances merge into a broader one
- Cusp at $D^*\bar{D}^*$ threshold
- Its strength is influenced by the tensor resonance

$T =$



$D^*\bar{D}^*$ $0^+(0^{++})$

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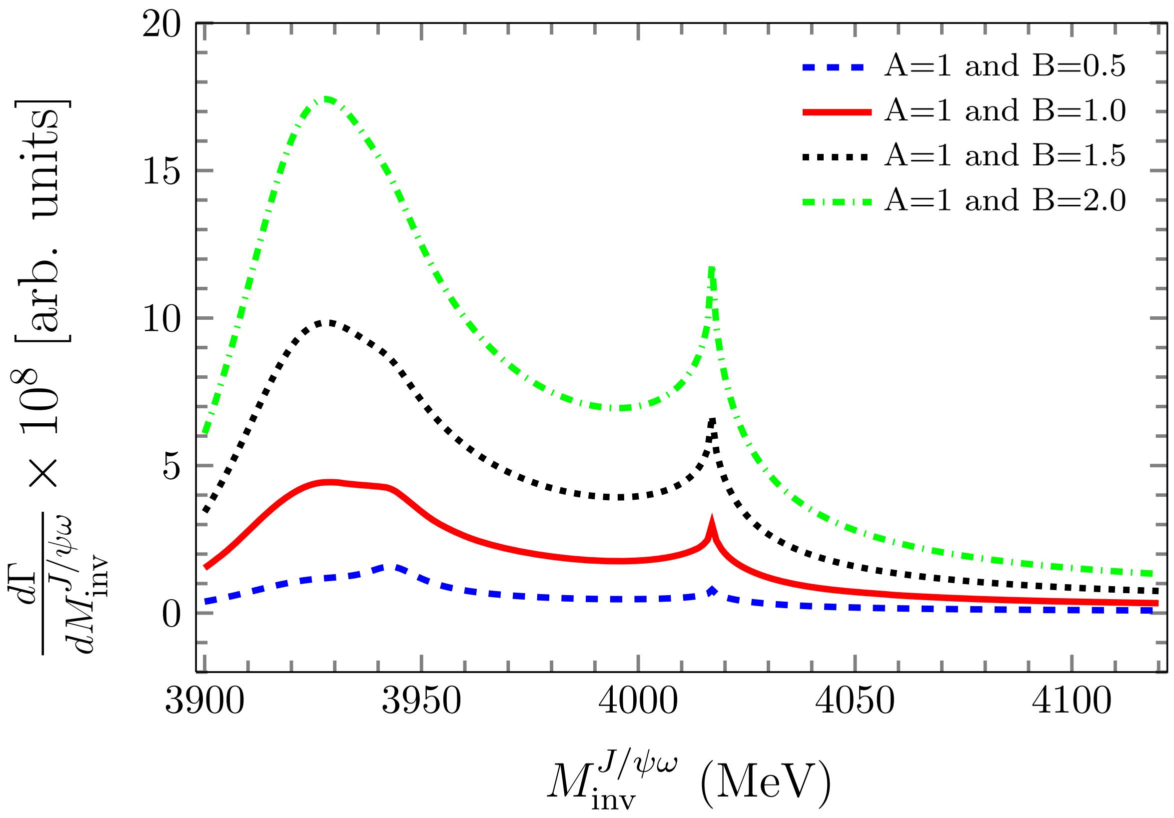
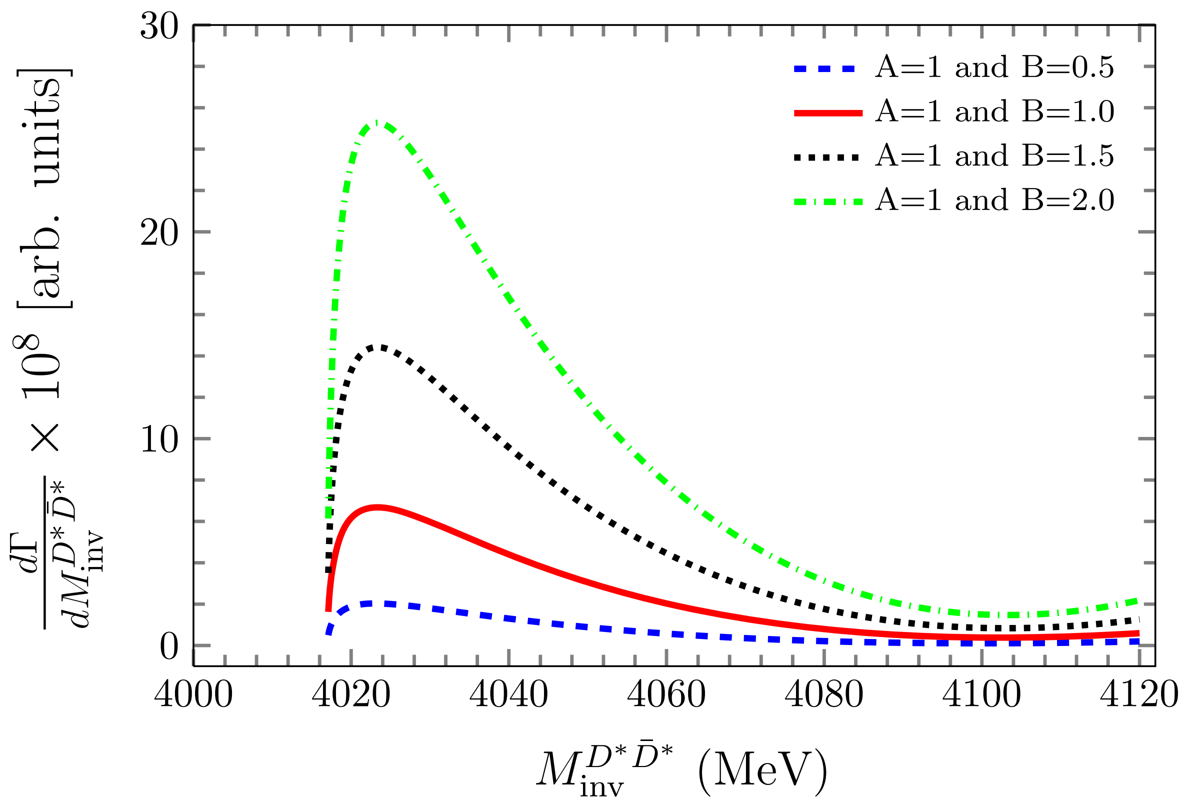
$D^*\bar{D}^*$ $0^+(2^{++})$

$$\frac{d\Gamma}{dM_{inv}^{J/\psi\omega}} = \frac{1}{(2\pi)^3}\frac{k' p_\omega}{4M_{B_c}^2}|T|^2$$

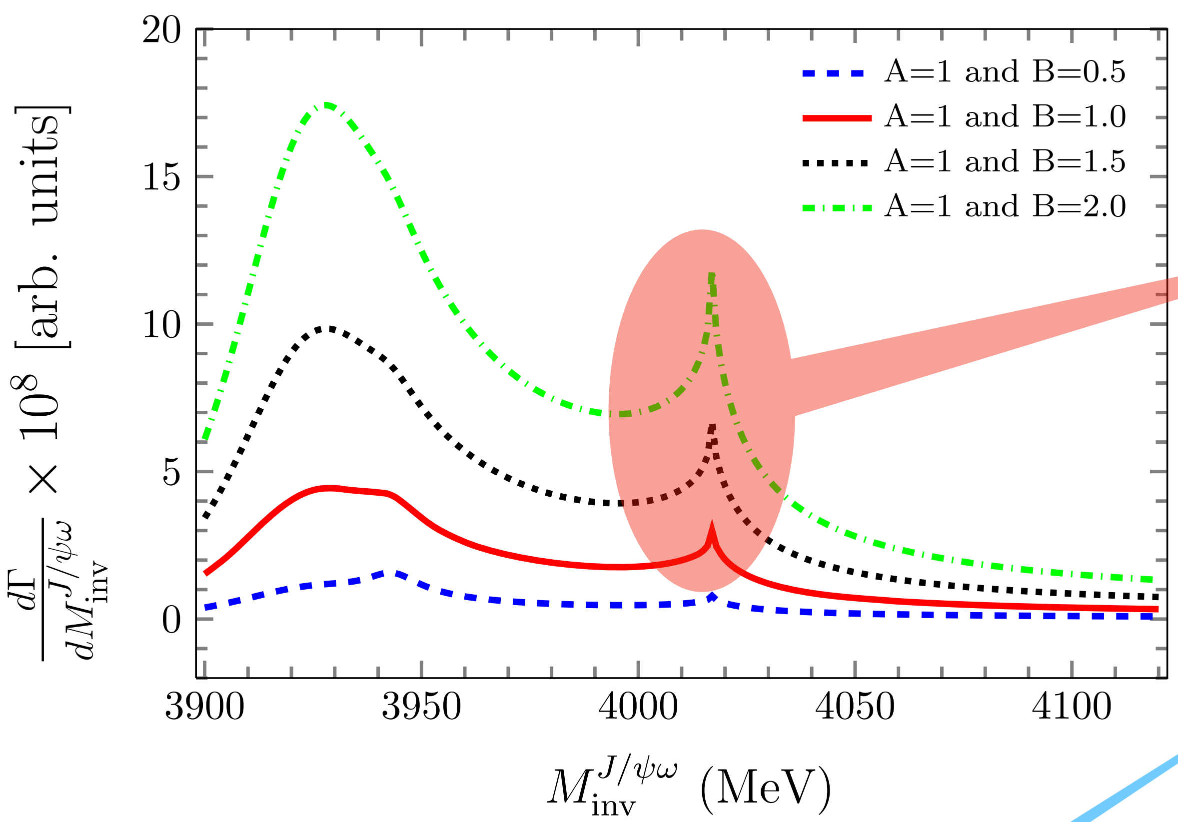
Results: Ratio between the distributions



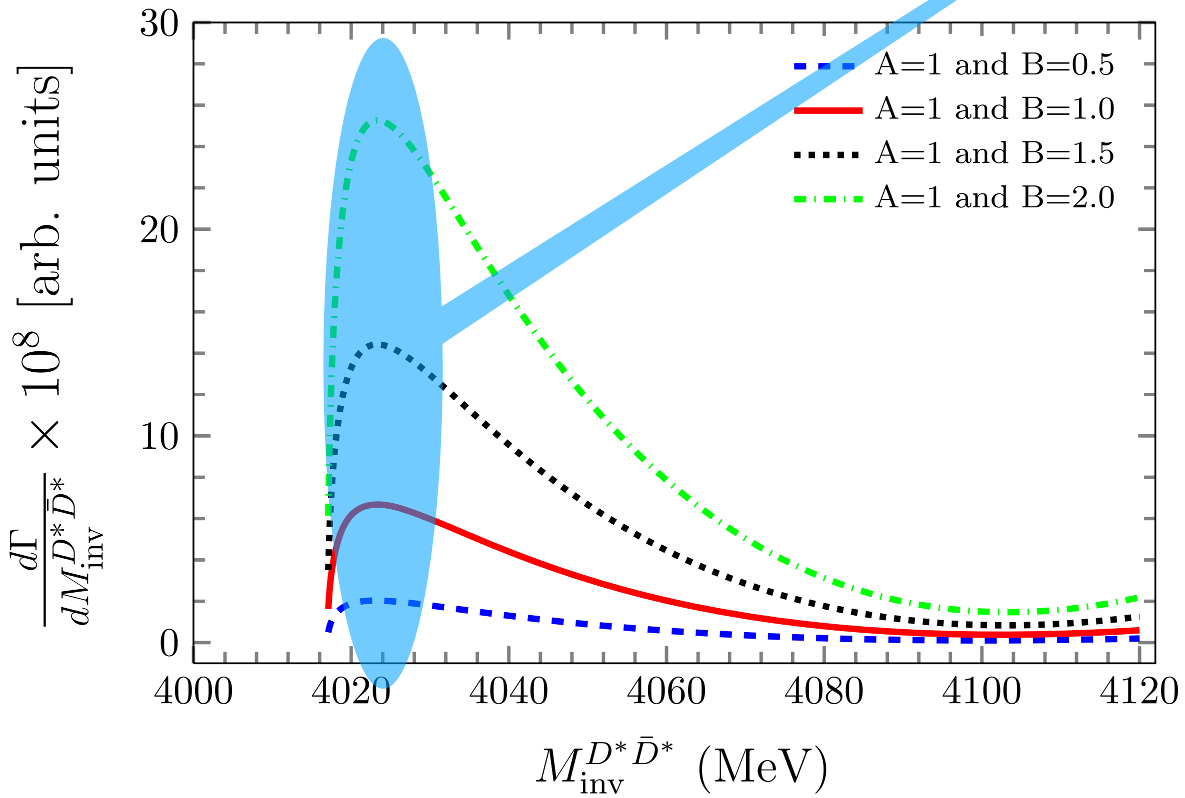
$$\frac{\frac{d\Gamma}{dM_{inv}^{J/\psi\omega}}(cusp)}{\frac{d\Gamma}{dM_{inv}^{D^*\bar{D}^*}}(peak)} = R$$



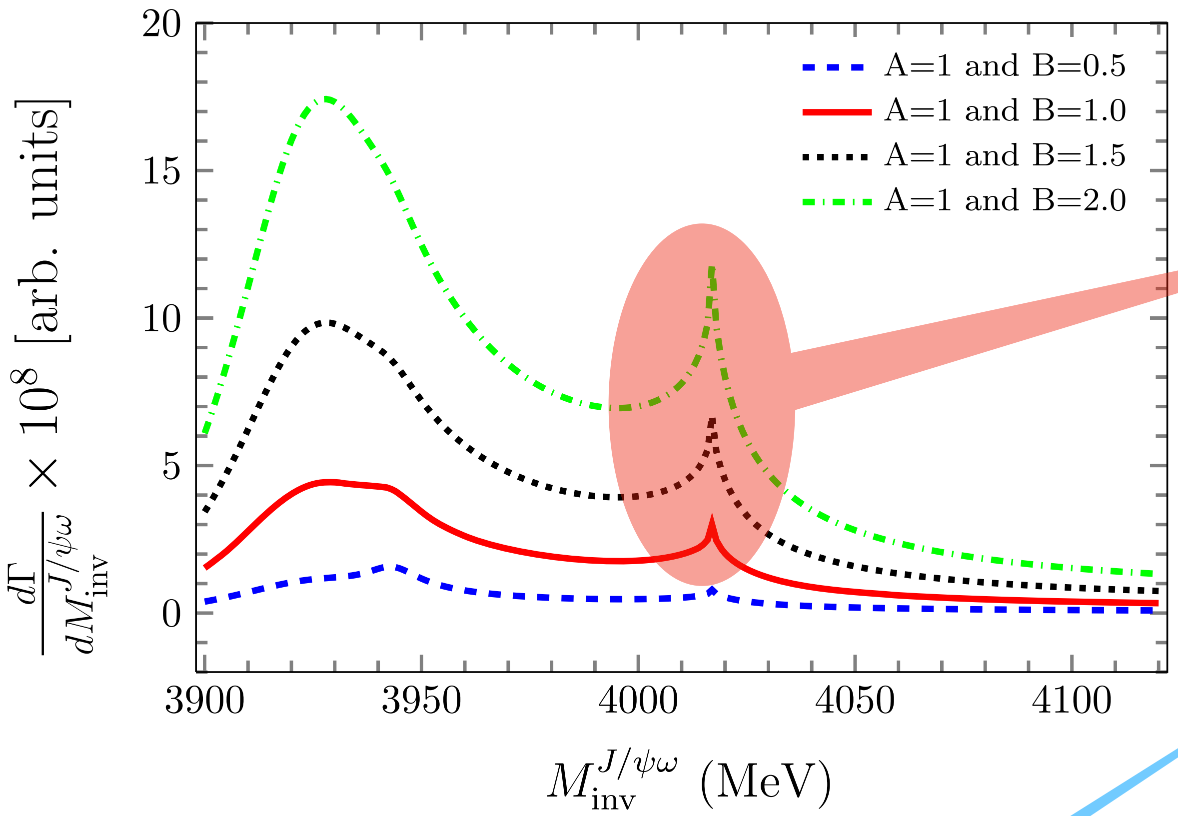
Results: Ratio between the distributions

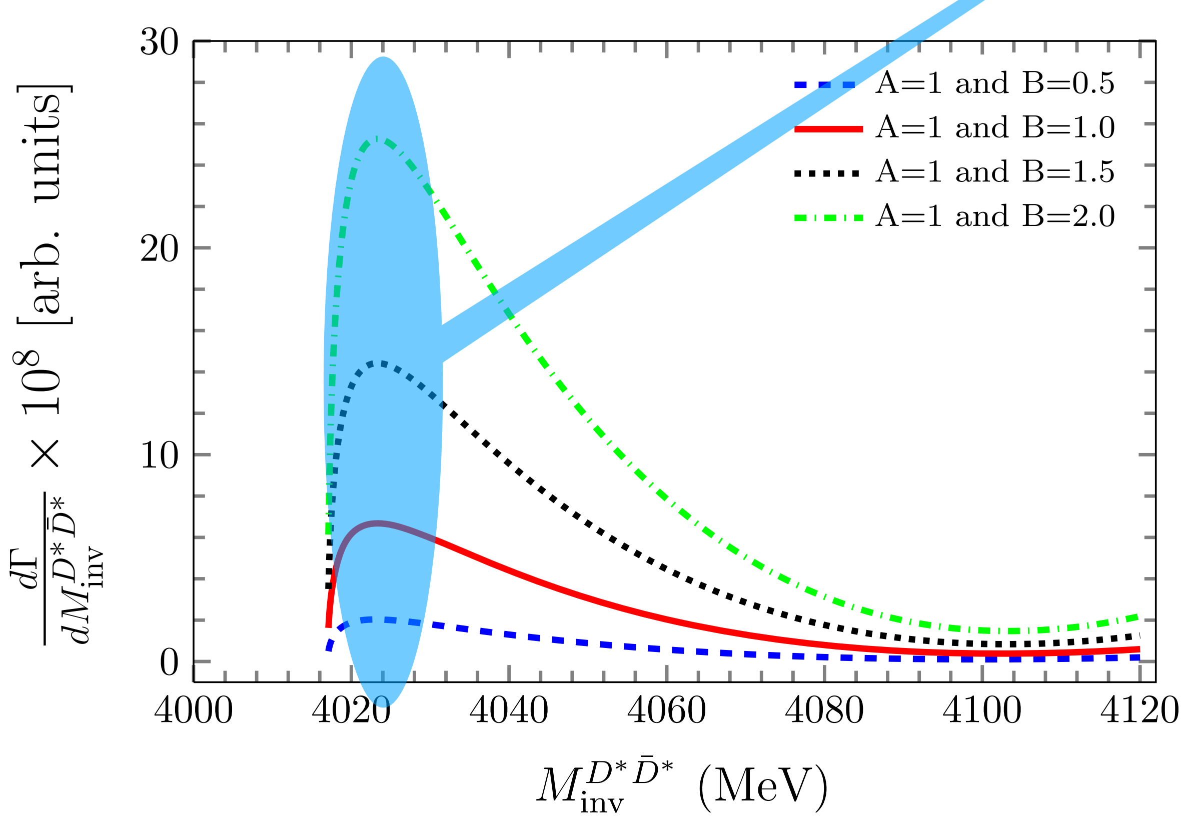


$$\frac{\dfrac{d\Gamma}{dM_{inv}^{J/\psi\omega}}(cusp)}{\dfrac{d\Gamma}{dM_{inv}^{D^*\bar{D}^*}}(peak)} = R$$



Results: Ratio between the distributions

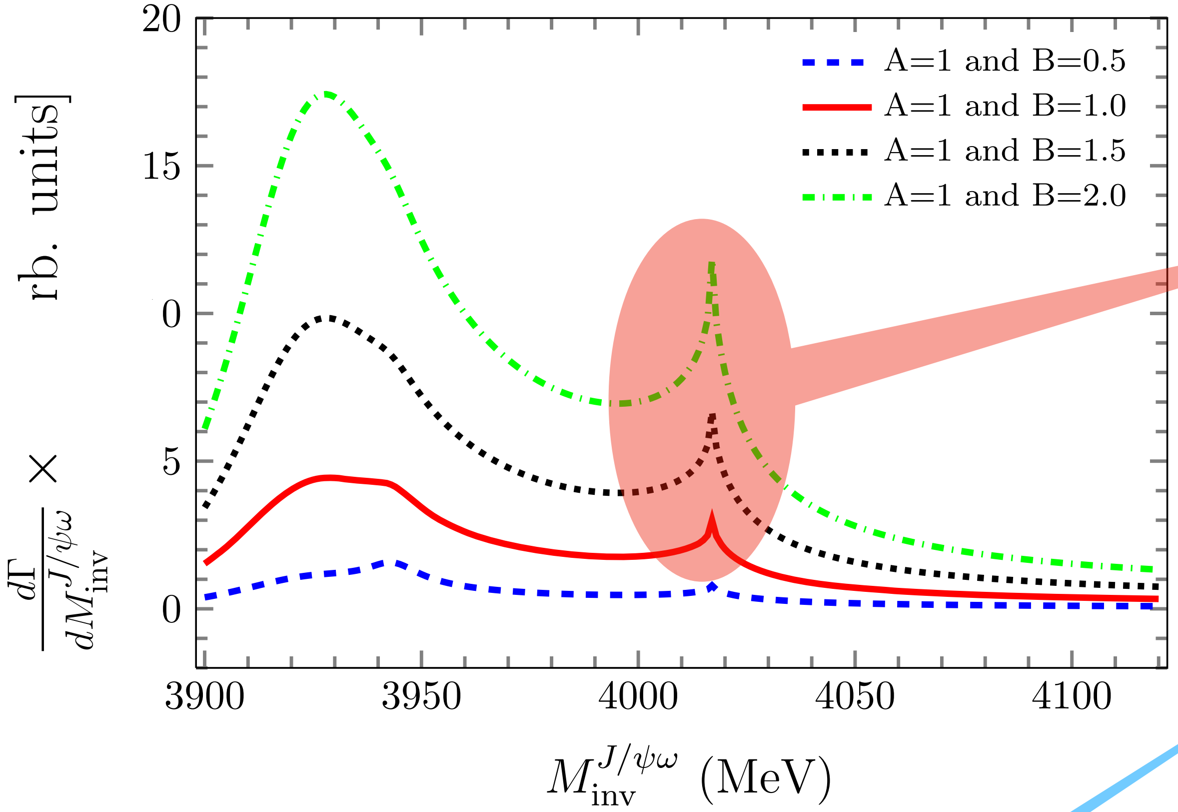




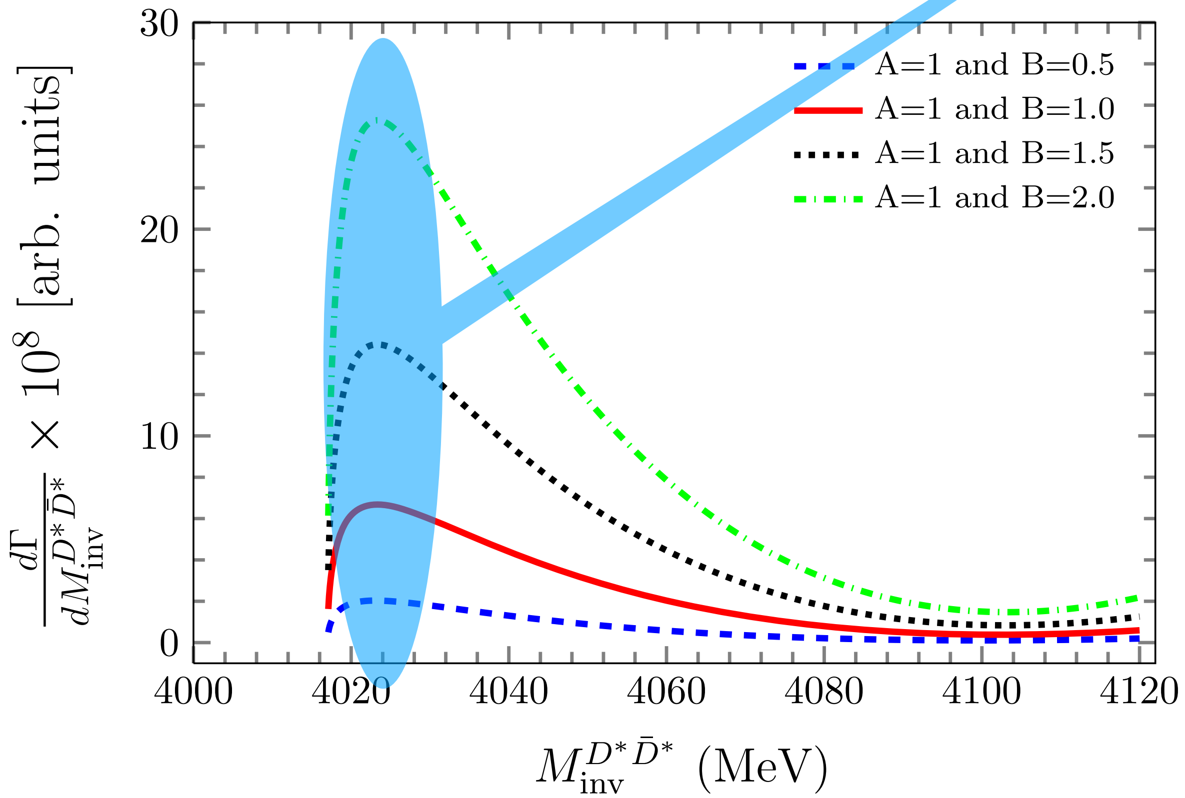
$$\frac{\dfrac{d\Gamma}{dM_{inv}^{J/\psi\omega}}(cusp)}{\dfrac{d\Gamma}{dM_{inv}^{D^*\bar{D}^*}}(peak)} = R$$

$A = 1.0$			
$B = 0.5$	$B = 1.0$	$B = 1.5$	$B = 2.0$
$R = 2.57$	$R = 2.22$	$R = 2.16$	$R = 2.13$

Results: Ratio between the distributions



$$\frac{\dfrac{d\Gamma}{dM_{inv}^{J/\psi\omega}}(cusp)}{\dfrac{d\Gamma}{dM_{inv}^{D^*\bar{D}^*}}(peak)} = R$$



$A = 1.0$			
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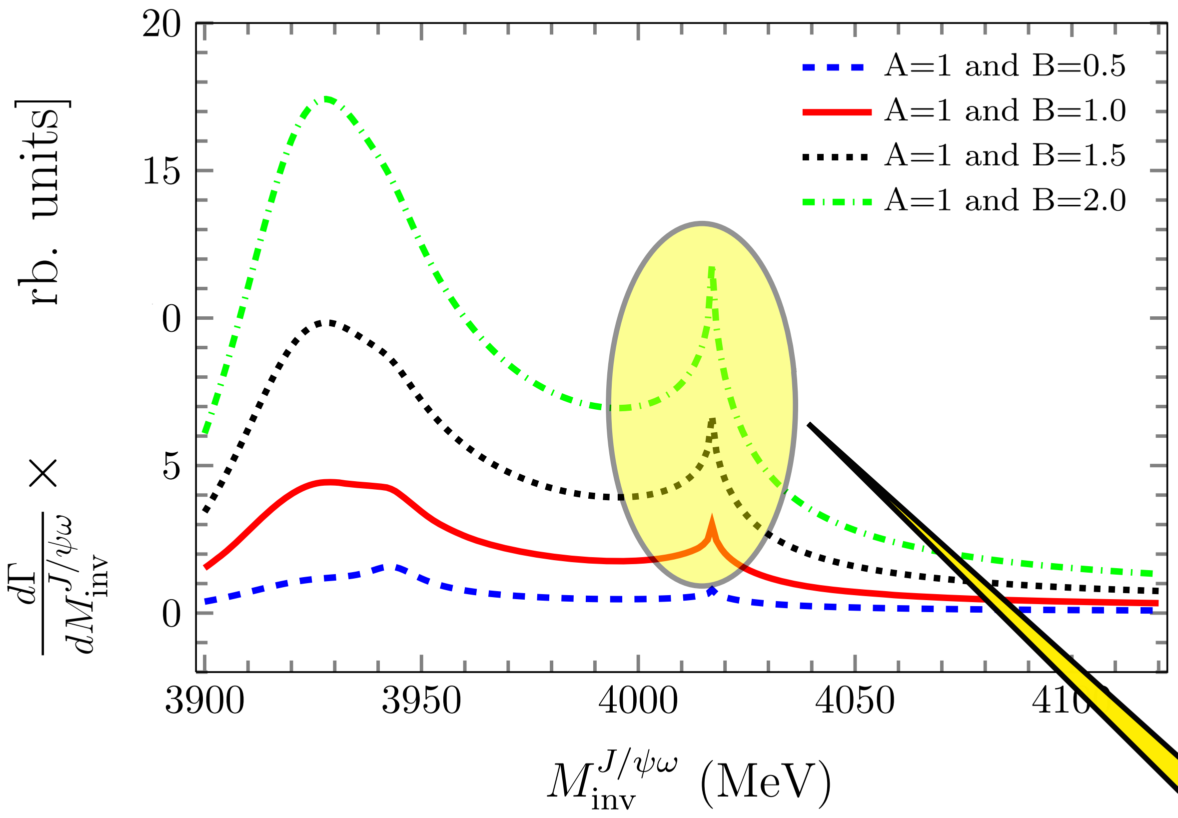
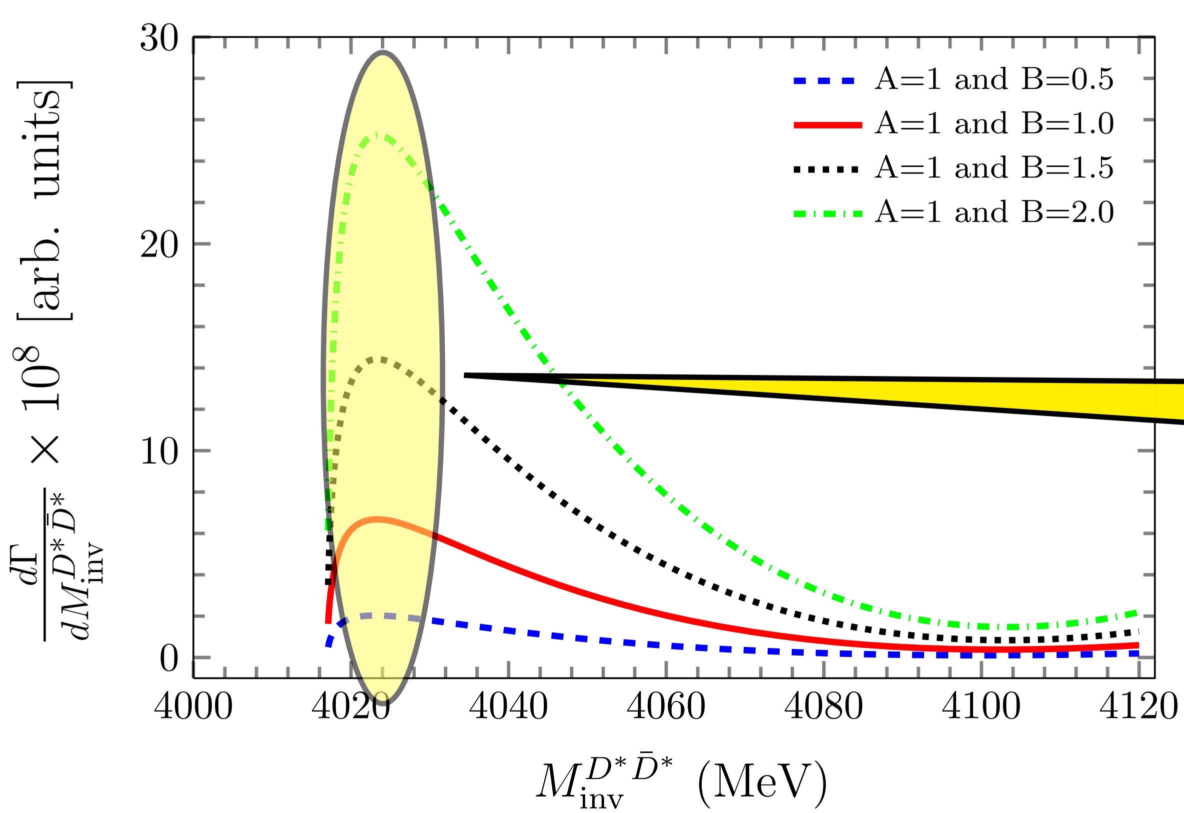
$R = 2.57$	$R = 2.22$	$R = 2.16$	$R = 2.13$

- The ratio is relatively stable

Results: Ratio between the distributions





$$\frac{\dfrac{d\Gamma}{dM_{inv}^{J/\psi\omega}}(cusp)}{\dfrac{d\Gamma}{dM_{inv}^{D^*\bar{D}^*}}(peak)} = R$$

$A = 1.0$			
$B = 0.5$	$B = 1.0$	$B = 1.5$	$B = 2.0$
$R = 2.57$	$R = 2.22$	$R = 2.16$	$R = 2.13$

- The ratio is relatively stable

Tensor state

Summary and conclusions

- We have looked at $B_c^- \to J/\psi\,\omega$ decay

$\frac{d\Gamma}{dM_{inv}^{J/\psi\omega}}$ is influenced by the X(3940) and X(3930) states

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$0^+(0^{++})$ $0^+(2^{++})$

- Both states couple mostly to $D^*\bar{D}^*$
- In order to find support for this nature of these states:

1) $J/\psi\,\omega$ is not the main channel, but $D^*\bar{D}^*$.

As consequence, a cusp appears!

2) The states influence the $D^*\bar{D}^*$ distribution

Thank you for your attention!