ANALYSIS OF $B \to D^{(*)}\overline{\nu}(\tau \to l\overline{\nu}\nu)$ IN EFFECTIVE FIELD THEORY

Prospects and challenges for semi-tauonic decays at LHCb

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New Physics: The way down

$$\log\left[\int D\varphi\, e^{iS(\phi,\varphi)}\right] = iS_{eff}(\phi)$$

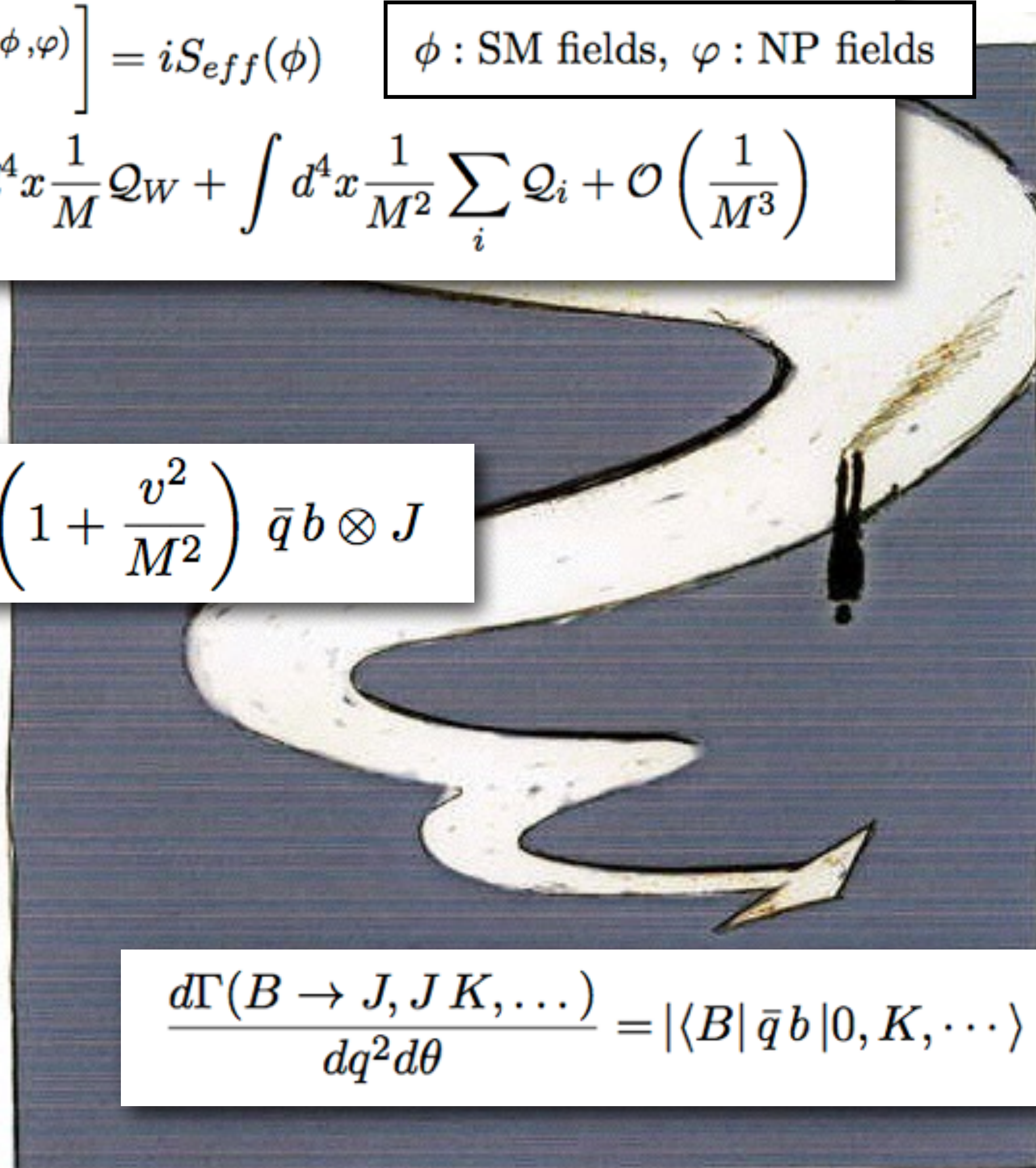
ϕ : SM fields, φ : NP fields

$$= iS_{SM} + \int d^4x \frac{1}{M}\mathcal{Q}_W + \int d^4x \frac{1}{M^2}\sum_i \mathcal{Q}_i + \mathcal{O}\left(\frac{1}{M^3}\right)$$

For recent studies, see:

Henning, Lu, Murayama

Drozd, Ellis, Quevillon, You



$$\mathcal{H}_{elem.} = G_F\left(1 + \frac{v^2}{M^2}\right)\bar{q}\, b \otimes J$$

$$\frac{d\Gamma(B \to J, J\,K, \dots)}{dq^2 d\theta} = |\langle B|\,\bar{q}\, b\,|0, K, \cdots\rangle\,\langle J\rangle|^2 \left(1 + \frac{v^2}{M^2}\right)^2$$

$E = m_B$

Effective Lagrangian for B Decay

i) Built with the fields at hand $b\,,c\,,s\,,u\,,d\,,l\,,\nu\,,F_{\mu\nu}$

ii) Respecting the (manifest) symmetries:
Lorentz, QCD, E-M $SU(3)_c \times U(1)_{em}$

e.g.

$$\frac{1}{\Lambda^2}\bar{l}\gamma_\mu P_L \nu_l\, \bar{c}\,\gamma^\mu P_L b$$

Effective Lagrangian of the SM

$\Lambda \geq E \geq v$

i) Built with the fields at hand $q_L^i\,, u_R^i\,, d_R^i\,, \ell_L^i\,, l_R^i\,, H\,, W_{\mu\nu}\,, B_{\mu\nu}$

ii) Respecting the (manifest) symmetries:
Lorentz, QCD, Weak Isospin & Hypercharge

$$SU(3)_c \times SU(2)_L \times U(1)_Y$$

e.g.

(2499 Ops)

Buchmuller & Wyler
Grzadkowski, Iskrzynski, Misiak and Rosiek

(anomalous dimension in:)

Trott Manohar Jenkins (I, II)
Trott Manohar Jenkins, Alonso, (III and Hol.)
Elias-Miro, Espinosa, Masso, Pomarol

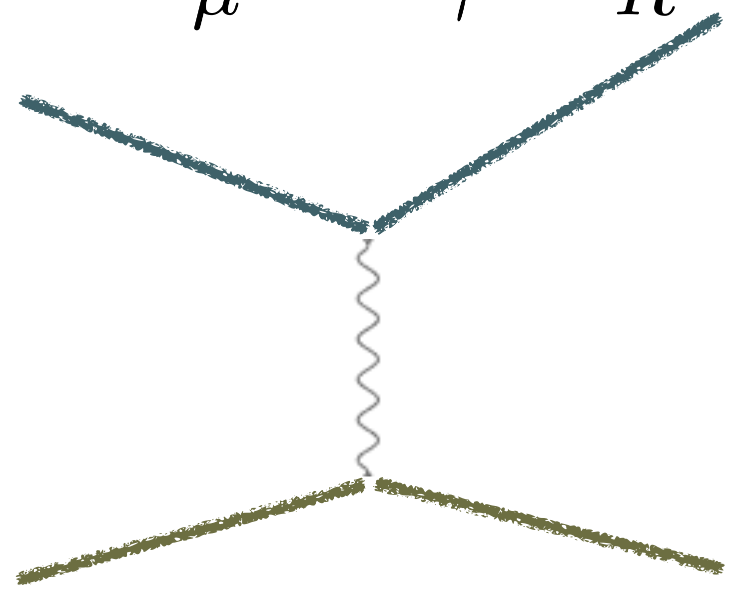
$\Lambda \geq E \geq v$

Effective Lagrangian of the SM

$$SU(3)_c \times SU(2)_L \times U(1)_Y$$

Consequences:

$$\frac{1}{\Lambda^2}\tilde{H}^\dagger D_\mu H\, \bar{c}\,\gamma^\mu P_R b$$



$$\frac{\epsilon_{\cancel{l}}}{\Lambda^2}\bar{l}\gamma_\mu P_L \nu_l\, \bar{c}\,\gamma^\mu P_R b \longleftarrow$$

$$g\bar{l}\gamma_\mu P_L \nu W^{-,\mu}$$

Lepton Flavor Universal

Cirigliano, Jenkins, Gonzalez-Alonso

In the Neutral Current Lag.

Alonso, Camalich, Grinstein

Charged Current Lagrangian for B Decay

$$\mathcal{L}_{\rm eff} = -\frac{G_F^{(0)} V_{cb}}{\sqrt{2}} \eta_{\rm EW} \sum_{\ell=e,\mu,\tau} \Big[\Big(1+\epsilon_L^\ell\Big) \bar{\ell}\gamma_\mu(1-\gamma_5)\nu_\ell \cdot \bar{c}\gamma^\mu(1-\gamma_5)b$$

$$+ \epsilon_R \, \bar{\ell}\gamma_\mu(1-\gamma_5)\nu_\ell \, \bar{c}\gamma^\mu(1+\gamma_5)b$$

$$+ \; \bar{\ell}(1-\gamma_5)\nu_\ell \cdot \bar{c}\Big[\epsilon_S^\ell - \epsilon_P^\ell\gamma_5\Big]b + \epsilon_T^\ell \, \bar{\ell}\sigma_{\mu\nu}(1-\gamma_5)\nu_\ell \cdot \bar{c}\sigma^{\mu\nu}(1-\gamma_5)b \Big] + \text{h.c.},$$

....

5 parameters encoding new physics contributions

But ϵ_R is flavor universal !

Case Study: differential decay rate of

$B \to D^{(*)}\tau\nu$

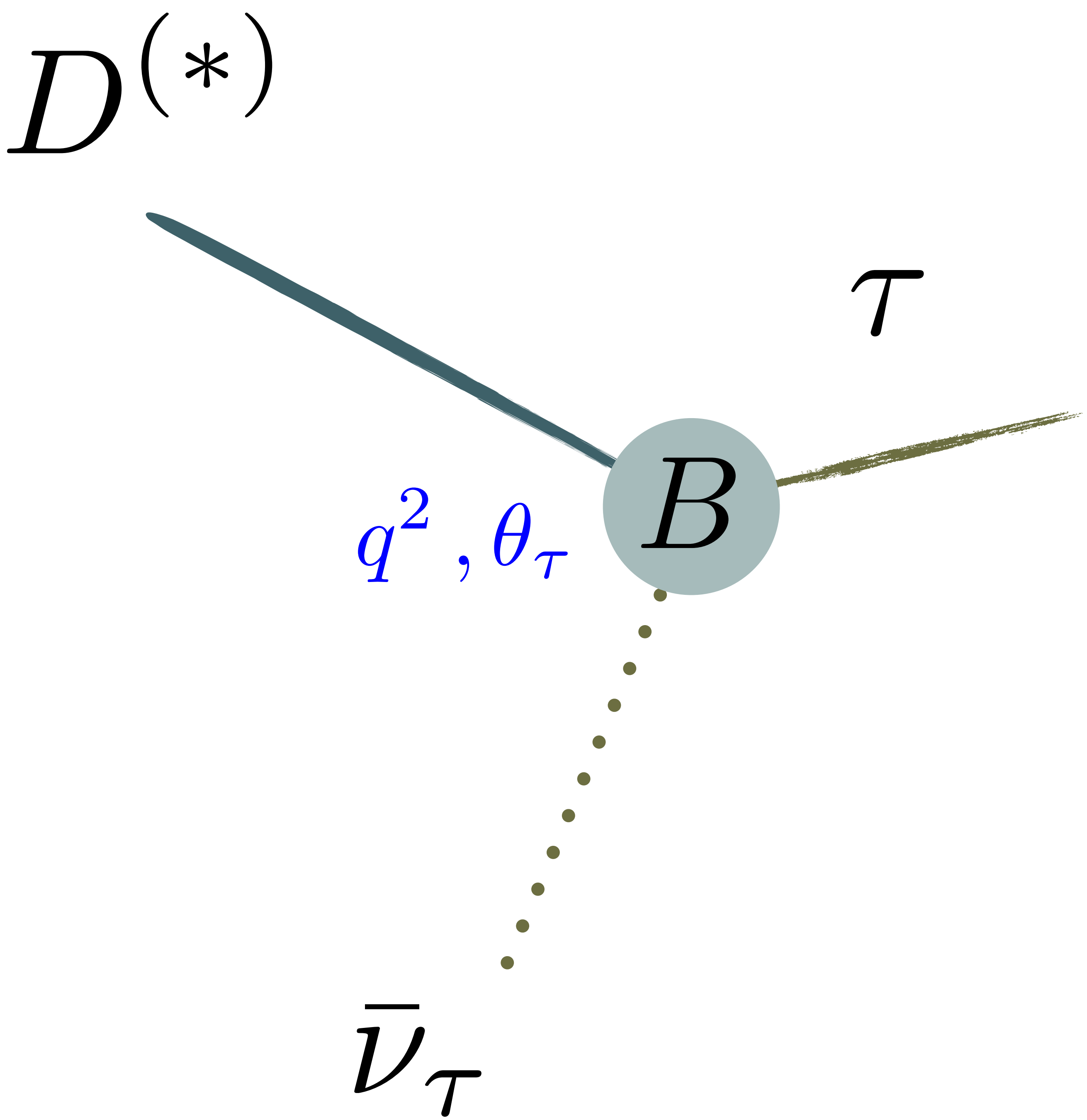
See also:

Freytsis et al. PRD92('15)

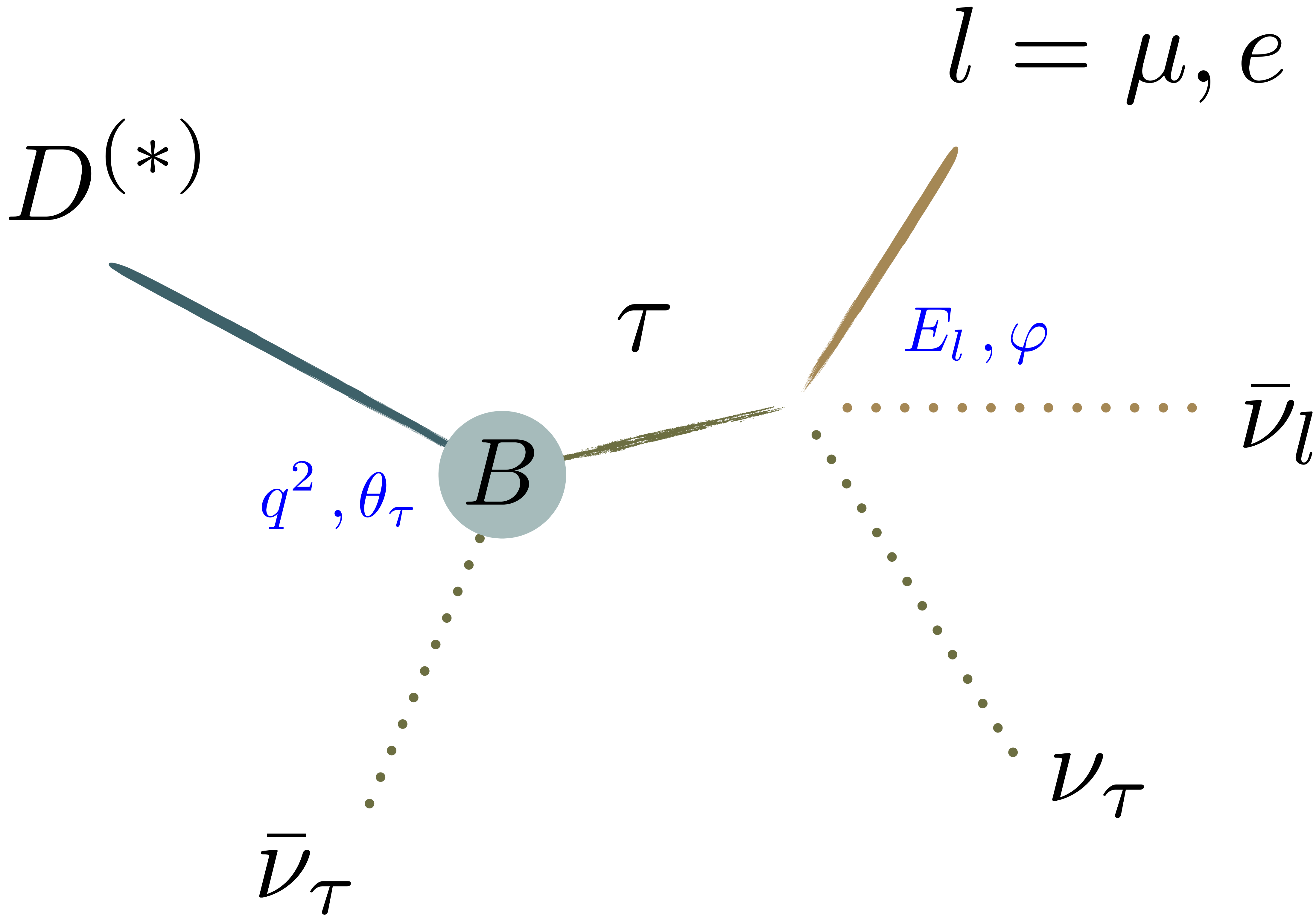
Becirevic, Fajfer, Nisandzic, Tayduganov '16

Bordone, Van Dyk, Isidori '16

UC San Diego



But, how do we reconstruct the τ *?*



$l = \mu, e$
$D^{(*)}$
τ
$E_l\ ,\varphi$
$\bar{\nu}_l$
B
$q^2\ ,\theta_\tau$
ν_τ
$\bar{\nu}_\tau$

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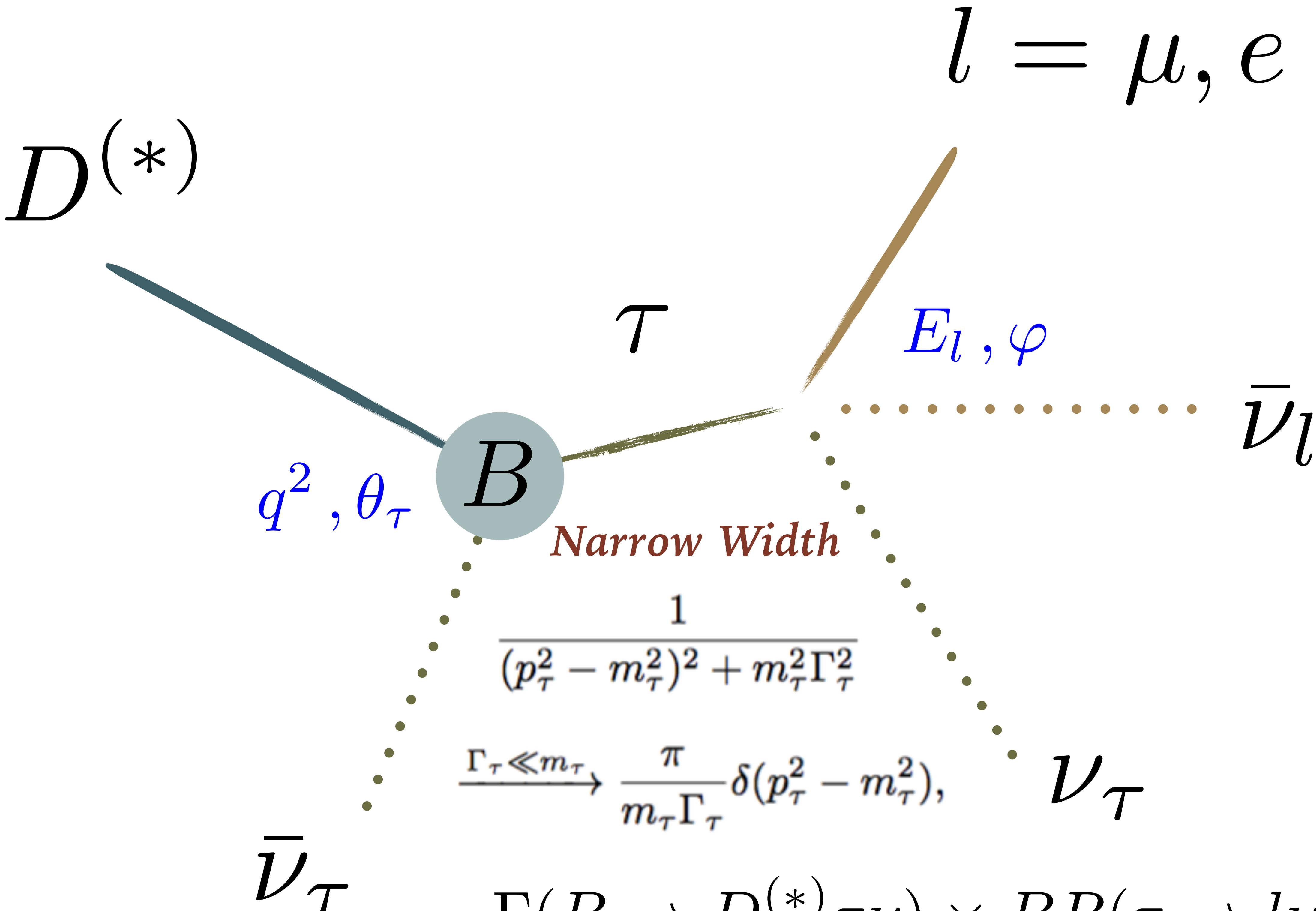
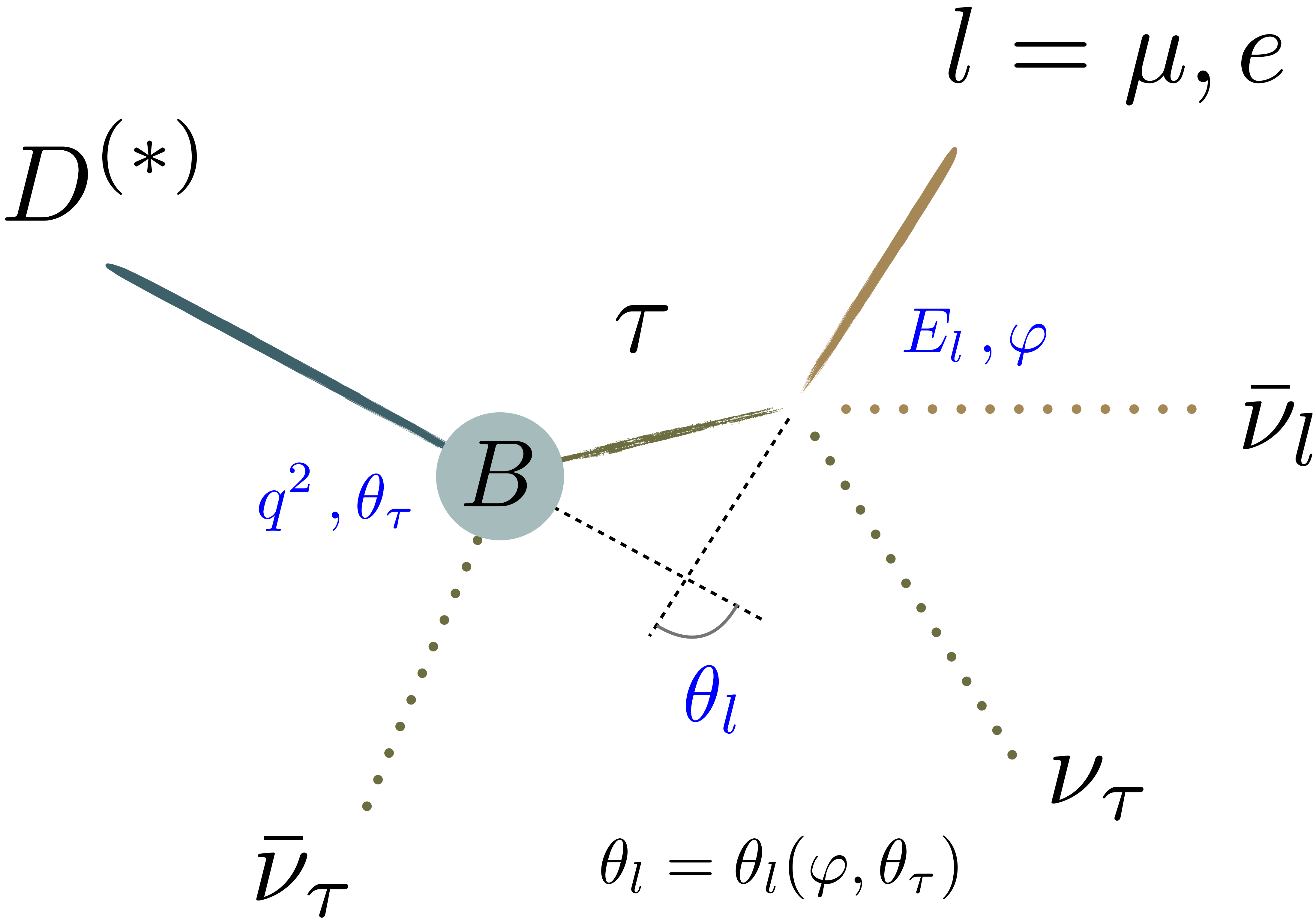
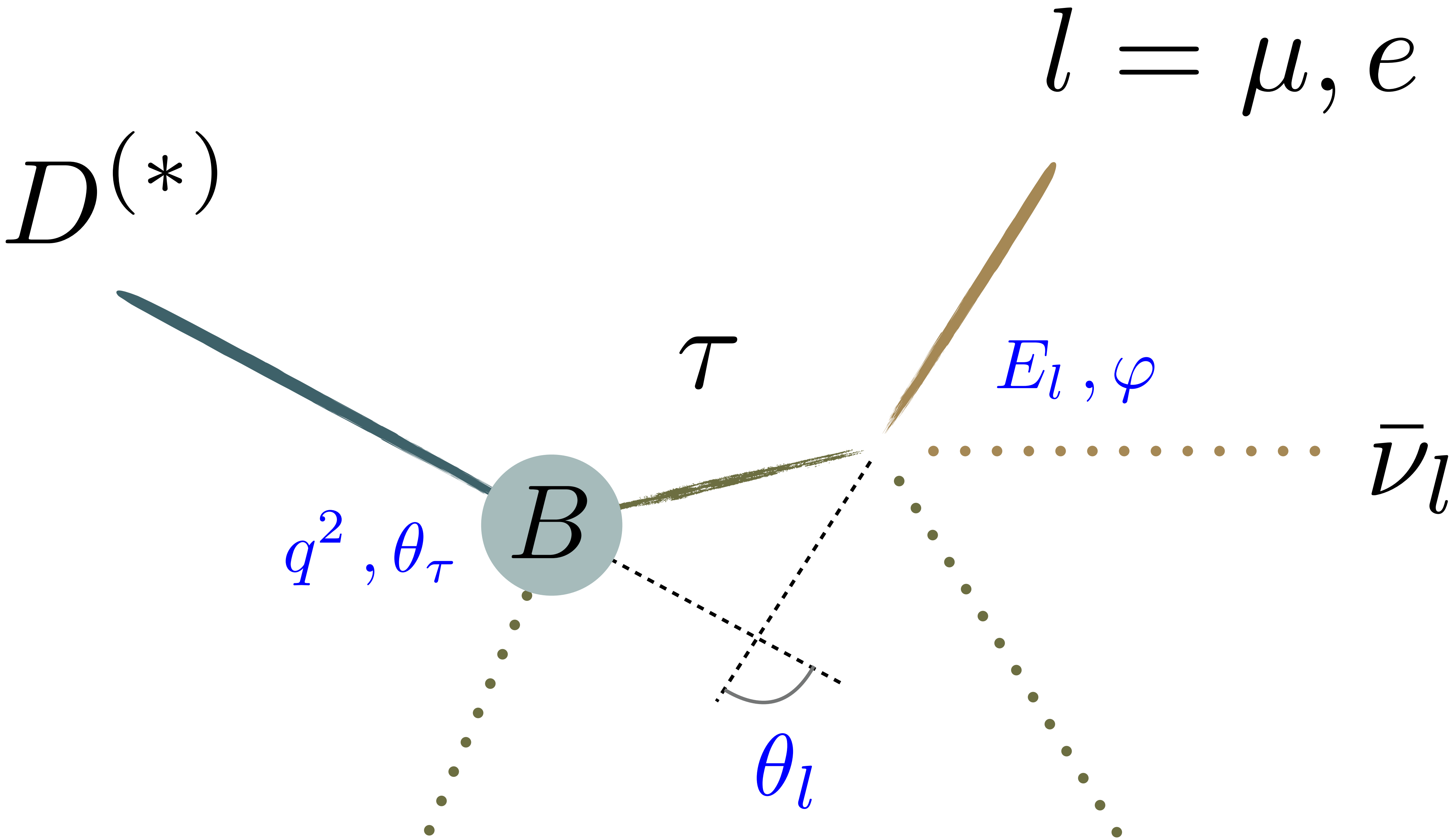


$$\frac{1}{(p_\tau^2 - m_\tau^2)^2 + m_\tau^2 \Gamma_\tau^2}$$

$$\xrightarrow{\Gamma_\tau \ll m_\tau} \frac{\pi}{m_\tau \Gamma_\tau} \delta(p_\tau^2 - m_\tau^2),$$

$$\Gamma(B \to D^{(*)} \tau \nu) \times BR(\tau \to l \nu \bar{\nu})$$


$l = \mu, e$
$D^{(*)}$
τ
$E_l \ , \varphi$
$\bar{\nu}_l$
$q^2 \ , \theta_\tau$
B
θ_l
ν_τ
$\bar{\nu}_\tau$
$\theta_l = \theta_l(\varphi, \theta_\tau)$



$$\theta_\tau = \theta_\tau(\varphi, \theta_l) \rightarrow \Gamma(B \to D^{(*)}\tau\nu) \times BR(\tau \to l\nu\bar{\nu})$$

'Convolution' that makes the final decay encode the primary angular distribution

Finally: Differential Decay Rate

$$\frac{d\Gamma(B \to D^{(*)}\tau(\to l\bar{\nu}_l\nu_\tau)\bar{\nu}_\tau)}{dq^2 dE_l d(\cos\theta_l)} =$$

$$\mathcal{B}[\tau_\ell]\,\frac{G_F^2|V_{cb}|^2\eta_{\mathrm{EW}}^2}{32\pi^3}\,\frac{|\vec{k}|}{m_B^2}\left(1-\frac{m_\tau^2}{q^2}\right)^2$$

$$\times\frac{E_\ell^2}{m_\tau^3}\times\left[I_0(q^2,E_\ell)+I_1(q^2,E_\ell)\cos\theta_\ell+I_2(q^2,E_\ell)\cos\theta_\ell^2\right],$$

Alonso, Camalich, Kobach

(Angle and energy defined in the q-rest frame)

Angular Coefficients

$$x^2 = \frac{q^2}{m_\tau^2}\,, \qquad y = \frac{E_\ell}{m_\tau}\,,$$

Alonso, Camalich, Kobach

$$I_0 = -\frac{2\left(2x^2+1\right)\left(4xy-3\right)}{3x}\Gamma_-^{(0)} + \frac{2\left(x^2+2\right)\left(3x-4y\right)}{3x^2}\Gamma_+^{(0)} + \frac{2}{15}\left(-12x^2y+10x+\frac{5}{x}-8y\right)\Gamma_-^{(2)} + \frac{\left(10x\left(x^2+2\right)-8\left(2x^2+3\right)y\right)}{15x^2}\Gamma_+^{(2)}\,,$$

$$I_1 = \frac{\left(8x^3y-4x^2+2\right)}{3x}\Gamma_-^{(1)} - \frac{2\left(x^3-2x+4y\right)}{3x^2}\Gamma_+^{(1)}\,,$$

$$I_2 = \frac{8\left(x^2-1\right)y}{15x^2}\Gamma_+^{(2)} - \frac{8}{15}\left(x^2-1\right)y\Gamma_-^{(2)}\,,$$

q^2, ϵ_i

$$\frac{d\Gamma(B\to D^{(*)}\tau\bar{\nu})}{dq^2\,d\cos\theta_\tau} = \cdots + \Gamma_+^{(1)}\cos\theta + \cdots$$

Forward-Backward Asymmetry

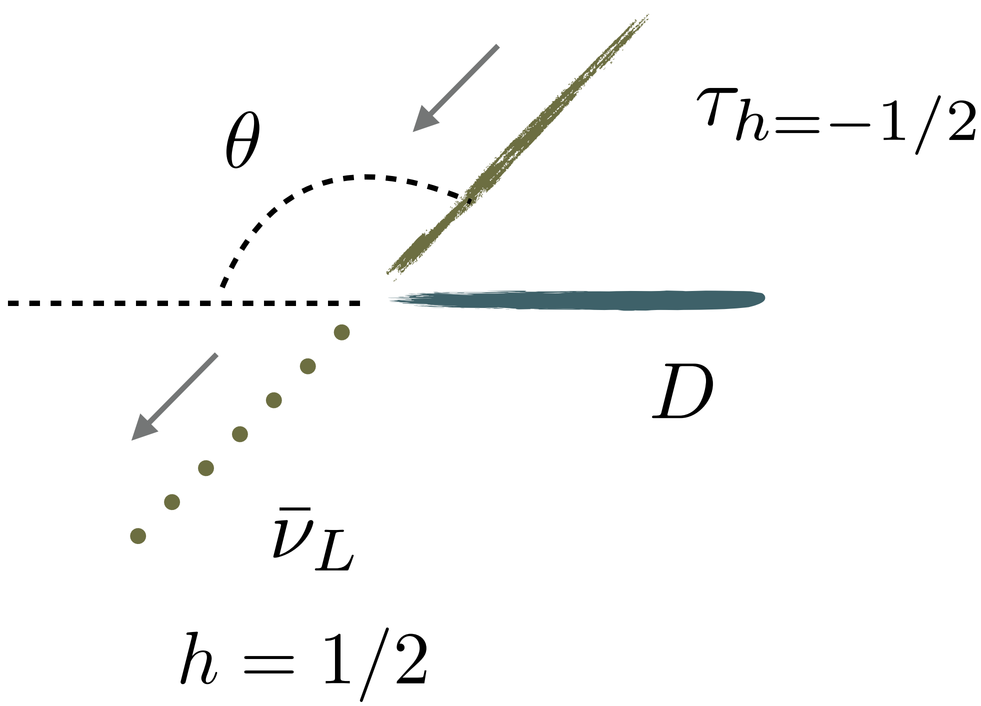
Differential

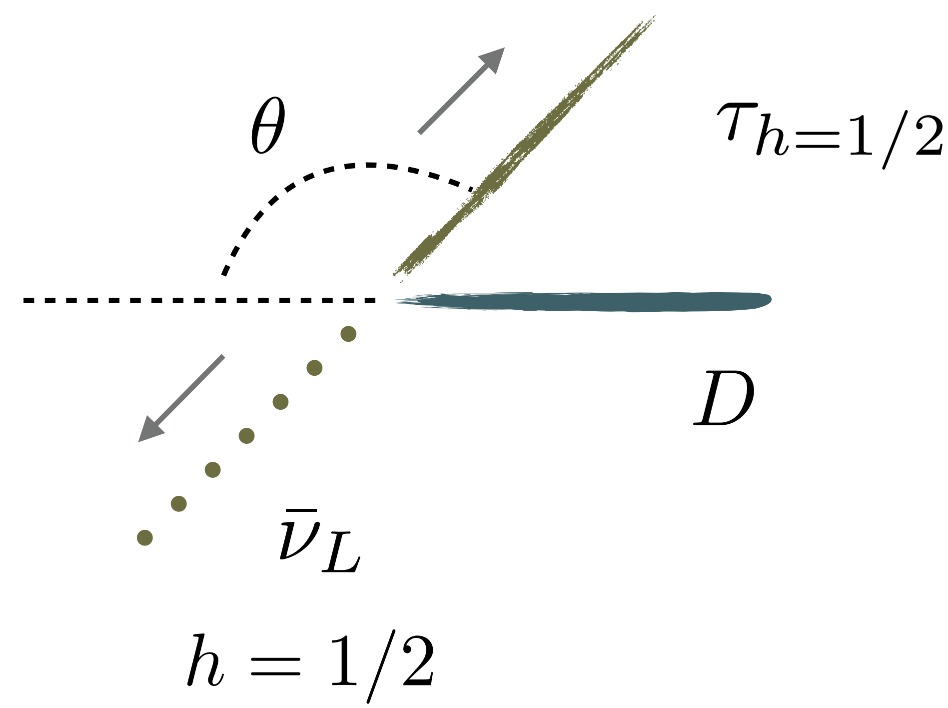
$$\frac{d^2 A_{FB}(q^2, E_\ell)}{dq^2 dE_\ell} = \left(\int_0^1 d(\cos\theta_\ell) - \int_{-1}^0 d(\cos\theta_\ell) \right) \frac{d^3\Gamma_5}{dq^2 dE_\ell d(\cos\theta_\ell)}.$$

Integrated

$$R_{FB}^{(*)} = \frac{1}{\mathcal{B}[\tau_\ell]} \frac{1}{\Gamma_{\text{norm.}}} A_{FB},$$

FB ASYMMETRY; WHERE DOES IT COME FROM?





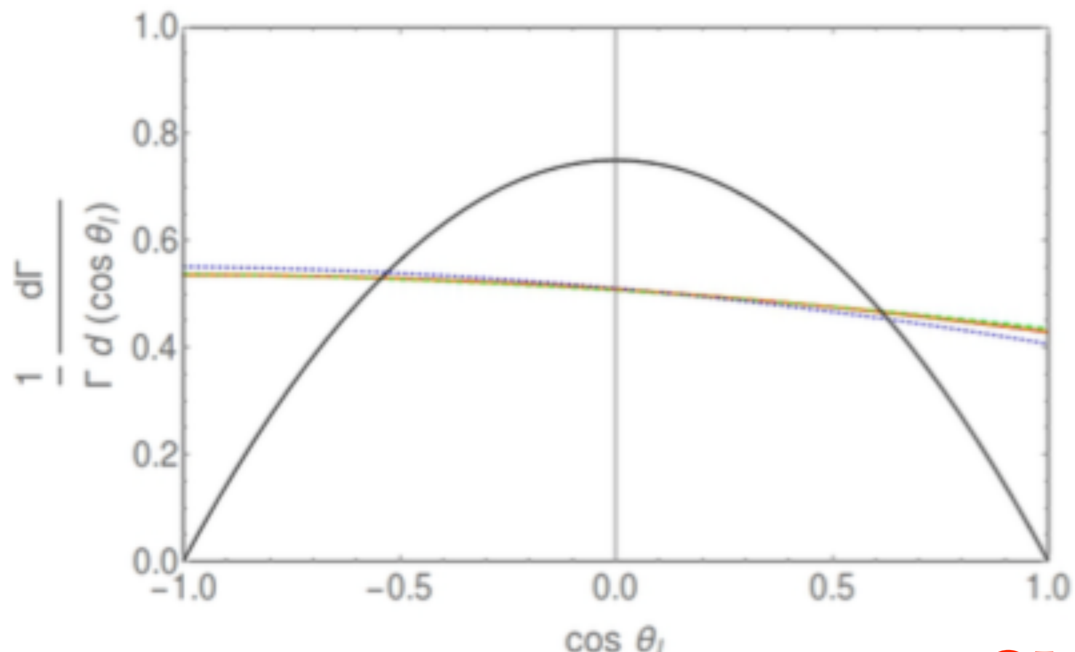
$$\langle L = 0 | L = 1, m_\theta = 1 \rangle \sim \sin\theta$$

$$\langle L = 0 | L = 0 \rangle \sim const.$$
$$+ \langle L = 0 | L = 1, m_\theta = 0 \rangle \sim \cos\theta$$

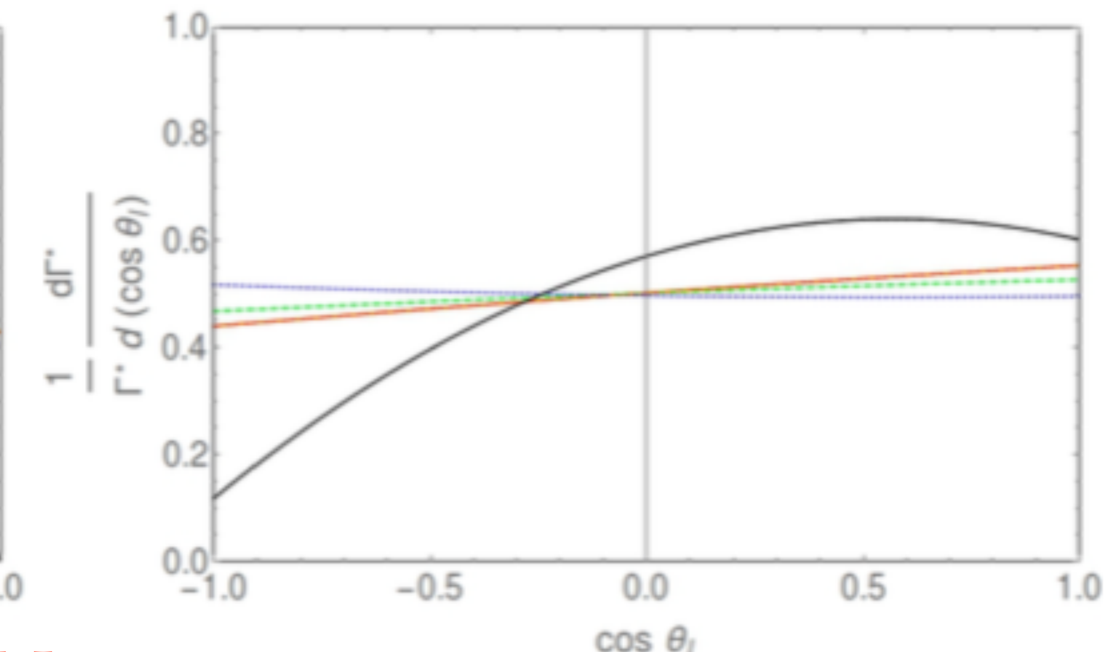
→ *Testing the positive helicity* τ

Angular Dependence

D



D^*



SM

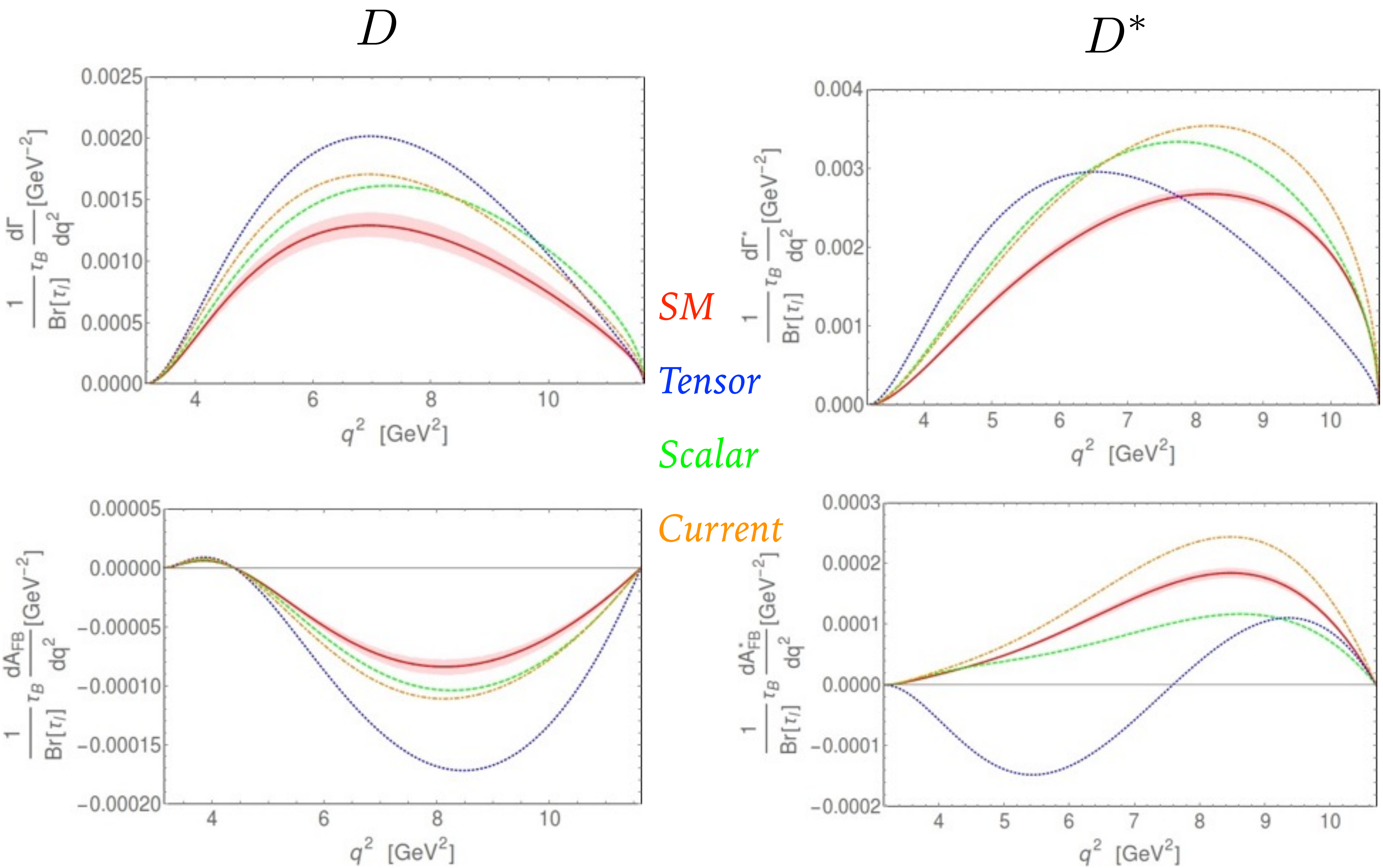
Tensor $\epsilon_T = 0.40\,,$

Scalar $\epsilon_{S_L} = 0.80\,, \epsilon_{S_R} = -0.65$

Current $\epsilon_L = 0.15$

Normalization

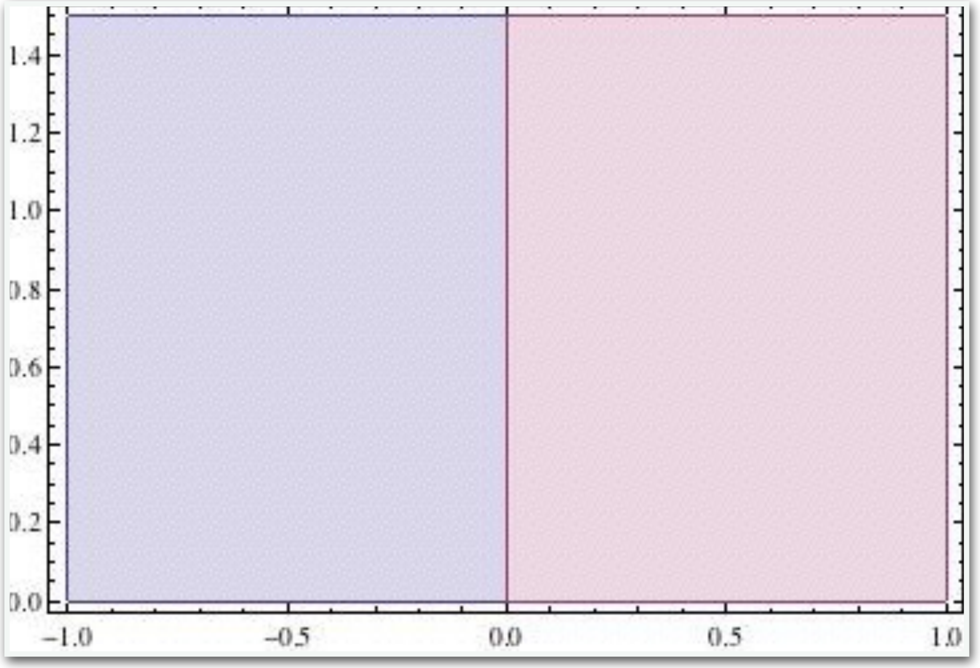
Forward Backward Asymmetry



FB Asymmetry at LHCb

(PRELIMINARY)

E_l, θ_l



$E_l\,(\mathrm{GeV})$

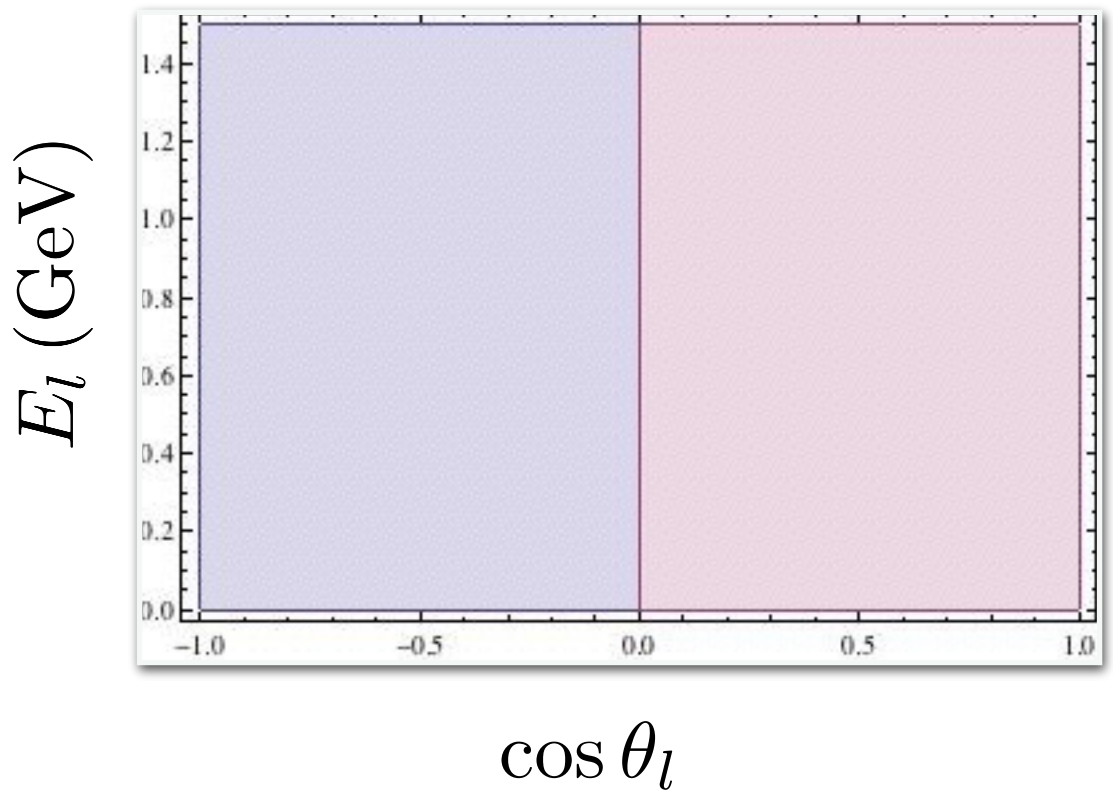
$\cos\theta_l$

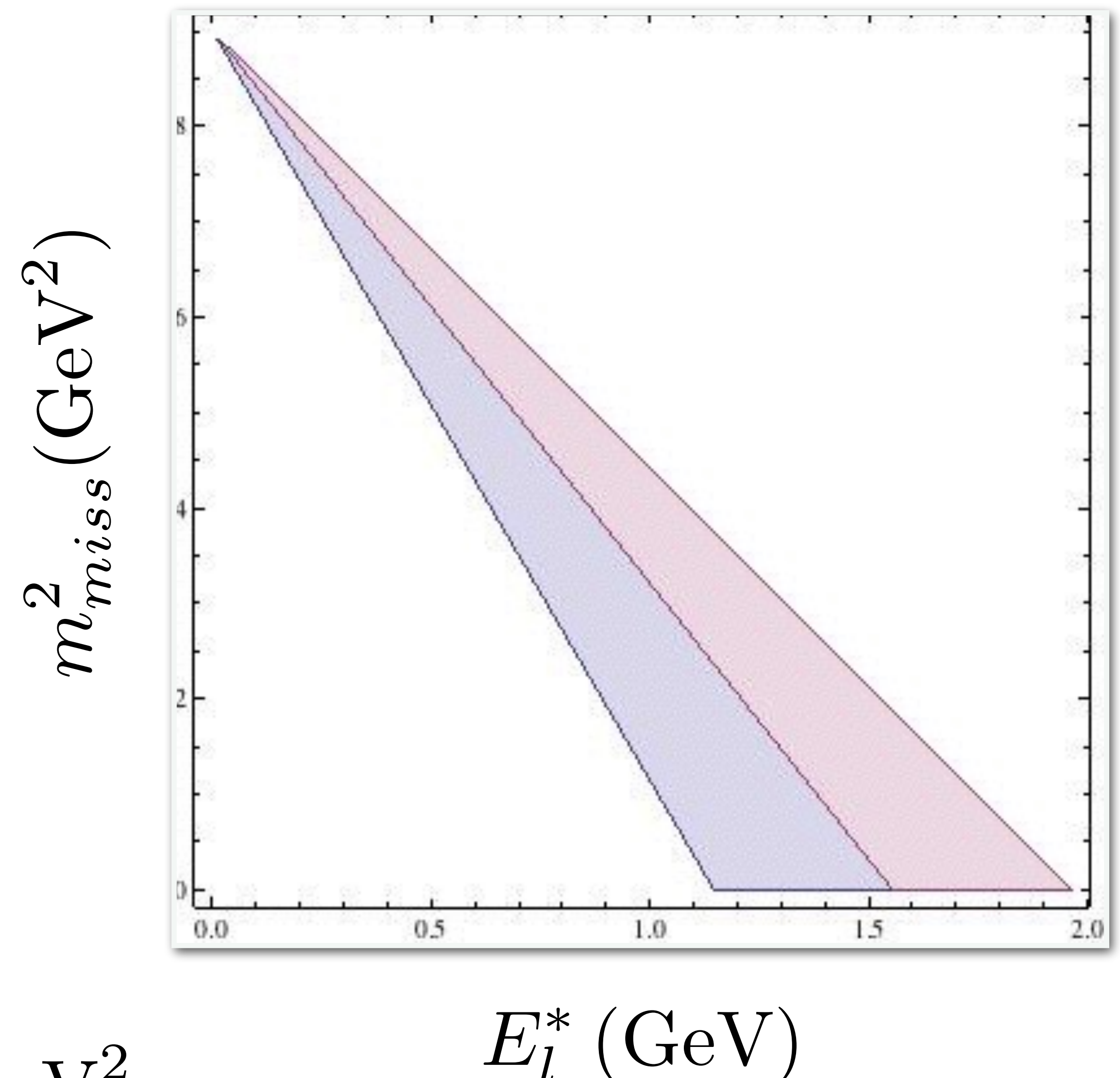
$q^2 = 9\mathrm{GeV}^2$

FB Asymmetry at LHCb

(PRELIMINARY)

$E_l, \theta_l \longrightarrow m^2_{miss}, E^*_l$





$q^2 = 9\mathrm{GeV}^2$

Forward-Backward Asymmetry

Integrated

$$R_{FB}^{(*)} = \frac{1}{\mathcal{B}[\tau_\ell]} \frac{1}{\Gamma_{\text{norm.}}} A_{FB},$$

	R_D	R_{FB}	R_{D^*}	R^*_{FB}
SM	0.310(19)	−0.0166(9)	0.252(4)	0.0143(5)
Current	0.410	−0.0219	0.333	0.0189
Scalar	0.400	−0.0205	0.315	0.0093
Tensor	0.467	−0.0315	0.346	−0.0030
Expt.	0.391(41)(28)	–	0.322(18)(12)	–

Forward-Backward Asymmetry

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Thank you for your attention