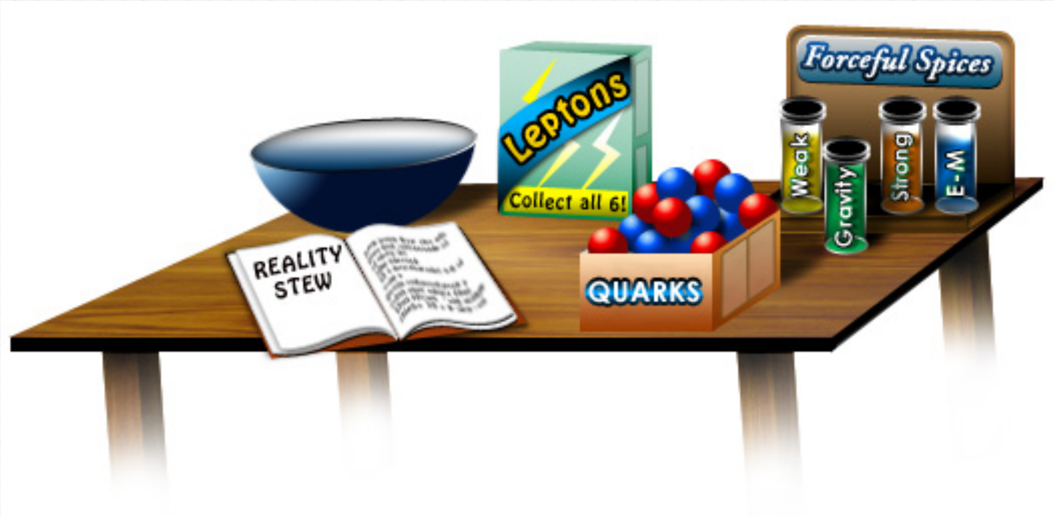
# Leptonic Decays

## Headaches with soft photons



* **Leptonic decays**: simplest probe to learn on flavor physics in and beyond the Standard Model

$$\Gamma(P \to \ell\nu) = \frac{G_F^2 m_P^3}{8\pi} |V_{UD}|^2 f_P^2 \left(\frac{m_\ell}{m_P}\right)^2 \left[1 - \left(\frac{m_\ell}{m_P}\right)^2\right]$$

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  **theory** (precision determination by LQCD)
  **experiment** (check on the systematics)

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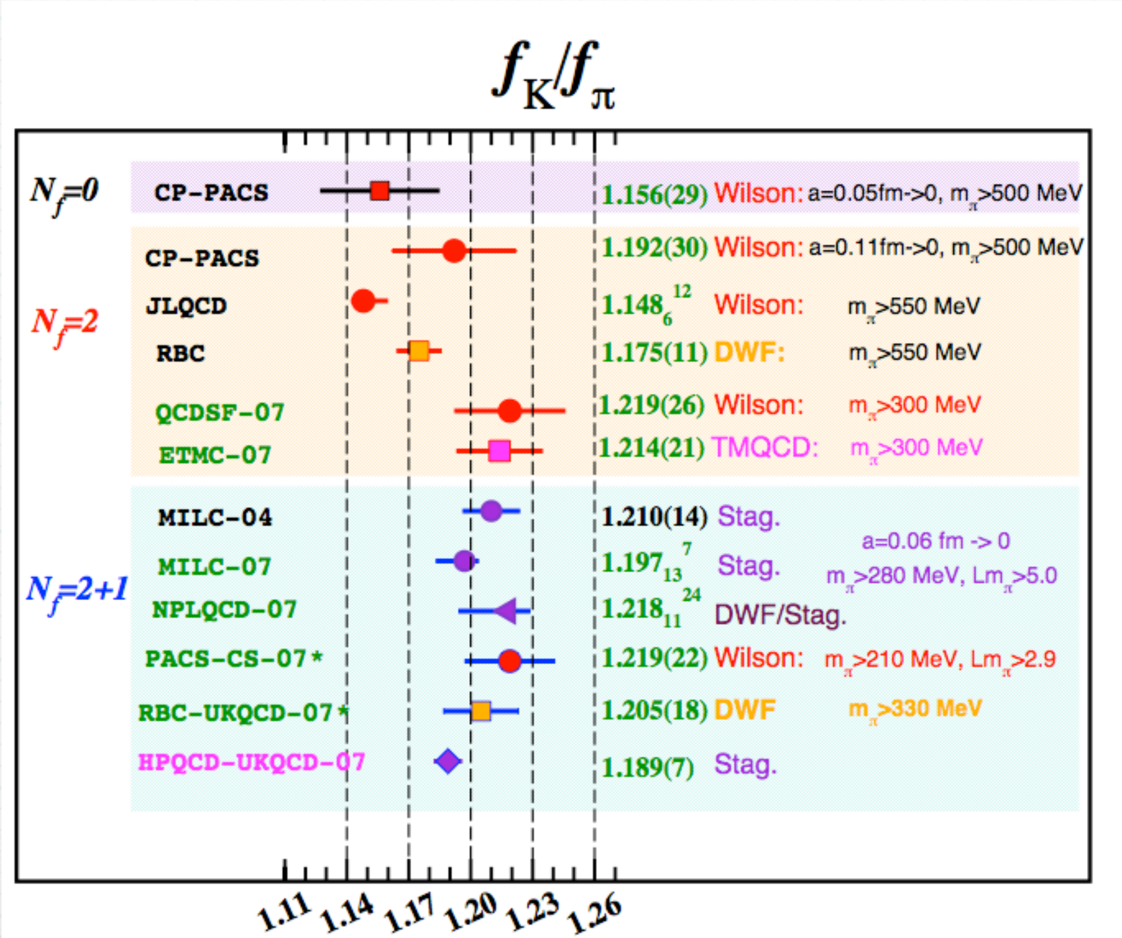

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* **Perspectives**:
  **theory** (precision determination by LQCD)
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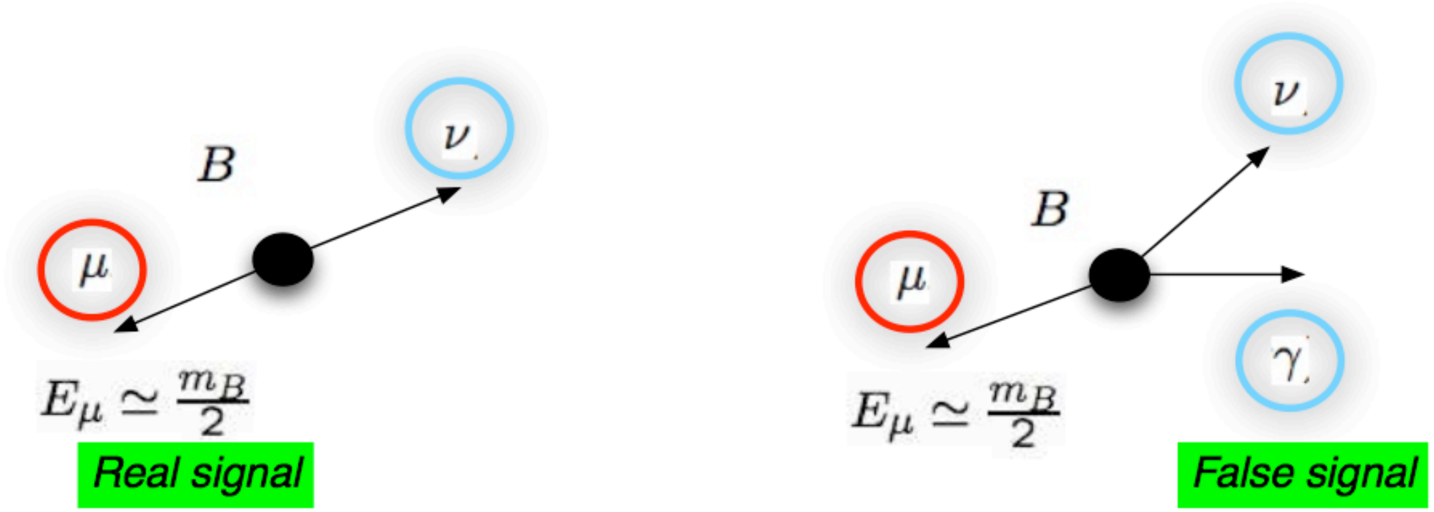
* **Errors**:
  **theory** (don't extrapolate the errors - once you touch the precision under 5%, many hidden skeletons come out of the cupboard)
  **experiment** (early 2000 - experts said - No way to see $B \to \tau\ \nu$ ; B-factories detected those events and now extrapolate to potentially visible $B \to \mu\ \nu$ ) Is systematics under control?

# Soft photons

Experimental event selection of $B \to \mu\nu$

$\mu$ with energy $\simeq m_B/2 \pm 200$ MeV in the $B$ rest frame




N.B. Photons with energy less than 500 MeV in B-factories are invisible! CLEO-c cuts about 300 MeV

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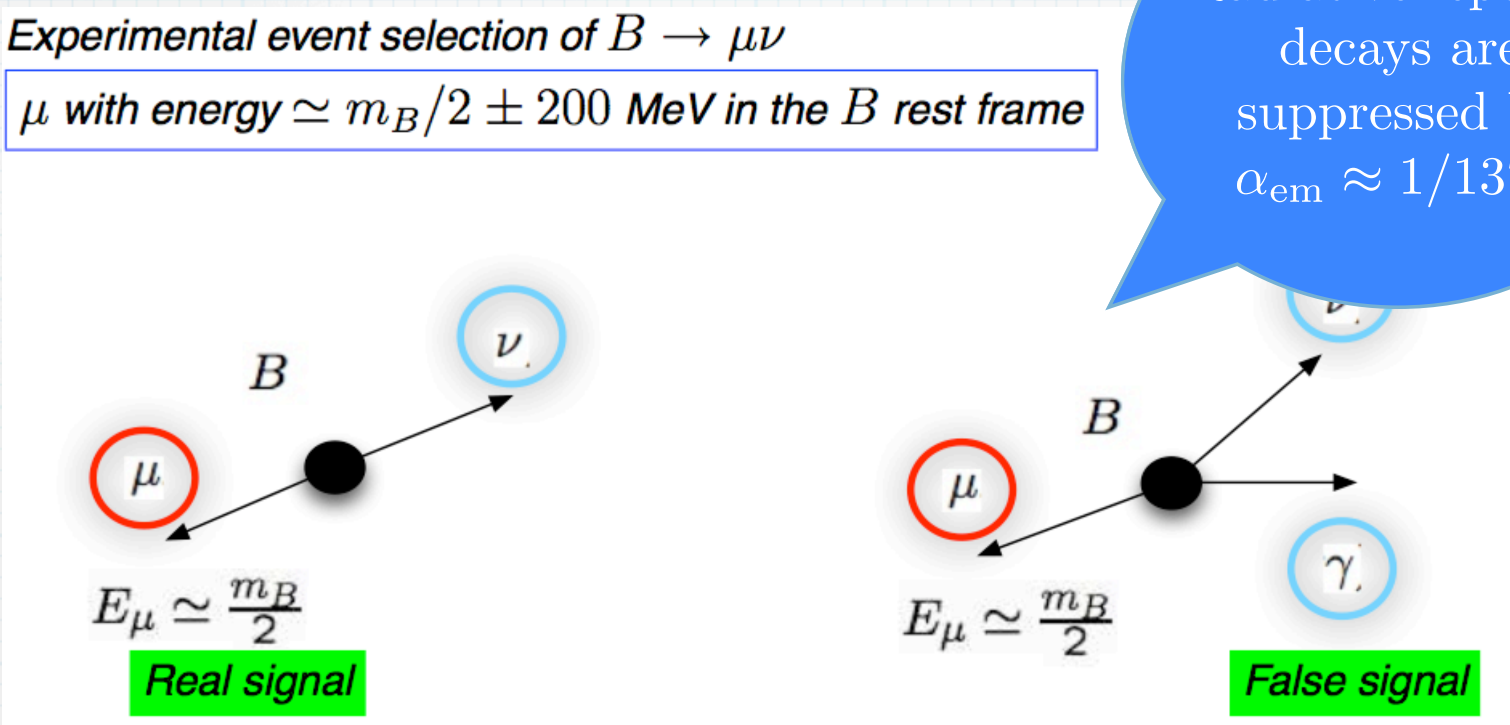


Radiative leptonic decays are suppressed by $\alpha_{\rm em} \approx 1/137$ !

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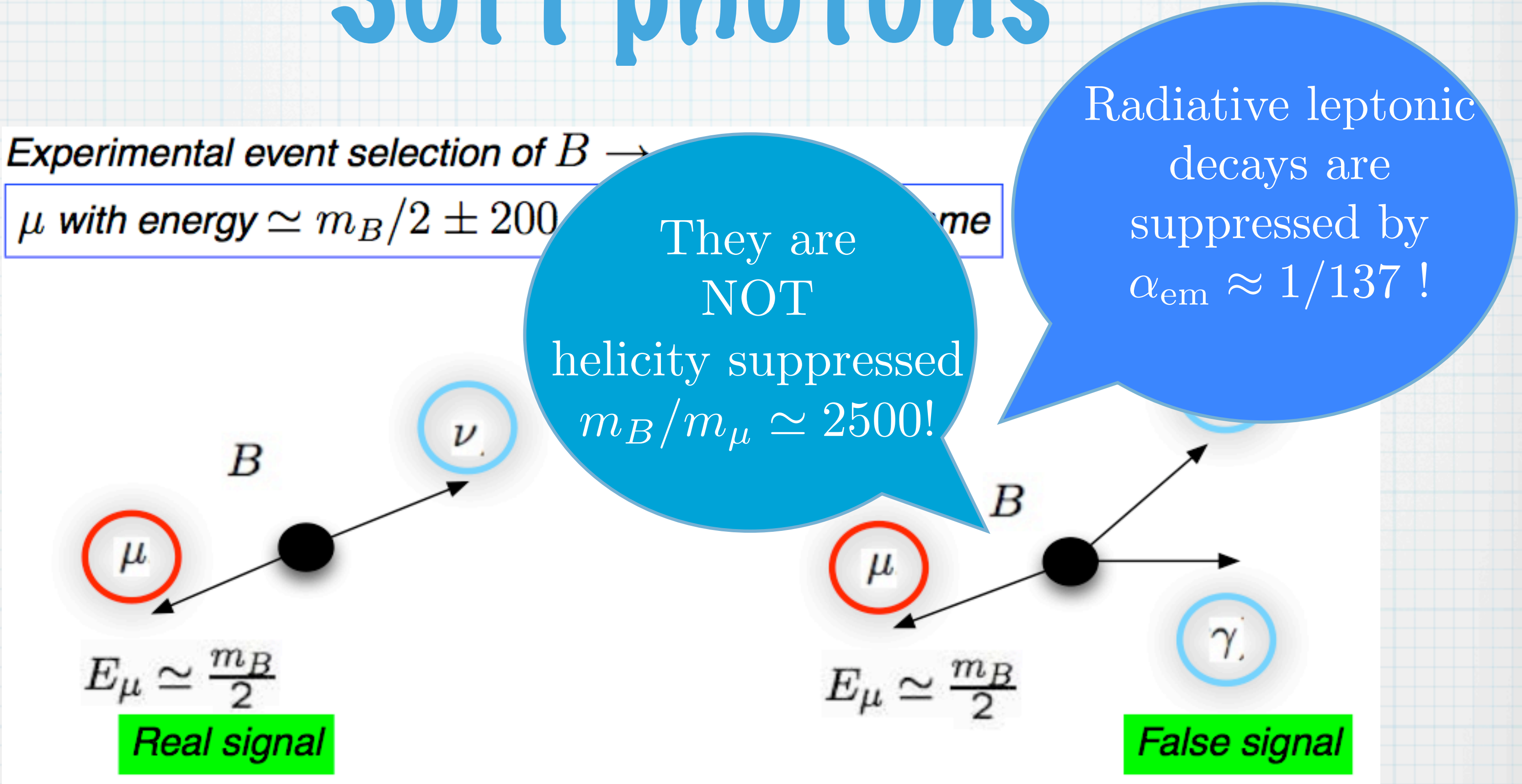


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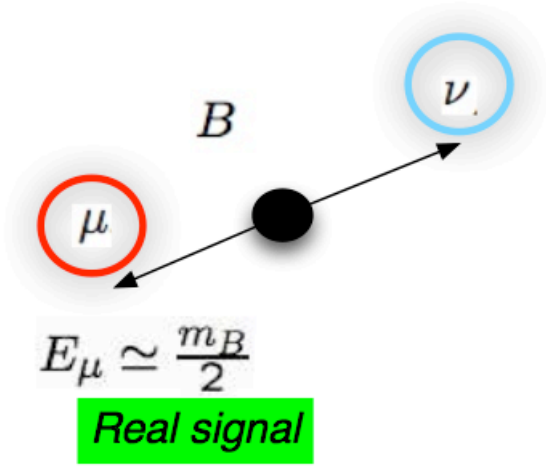
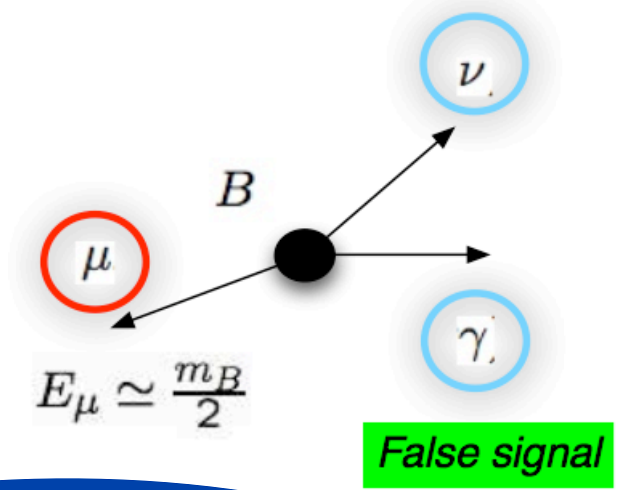



How many events in the sample are fake?

# Decay distribution

$$B^+(p) \to l^+(p_l)\nu_l(p_\nu)\gamma(k)$$

$$M(B^+ \to l^+\nu_l\gamma) = M_{IB} + M_{SD}$$

$$\begin{aligned} M_{IB} &= ie\frac{G_F}{\sqrt{2}}V_{ub}f_B m_l \epsilon^*_\mu L^\mu \\ M_{SD} &= -i\frac{G_F}{\sqrt{2}}V_{ub}f_B m_l \epsilon^*_\mu \tilde{H}^{\mu\nu} l_\nu \end{aligned}$$

$$\begin{aligned} L^\mu &= m_l \bar{u}(p_\nu)(1+\gamma_5)\left(\frac{2p^\mu}{2p\cdot k} - \frac{2p_l^\mu + \not{k}\gamma^\mu}{2p_l\cdot k}\right)v(p_l, s_l) \\ l^\mu &= \bar{u}(p_\nu)\gamma^\mu(1+\gamma_5)v(p_l, s_l) \\ \tilde{H}^{\mu\nu} &= iF_V(q^2)\epsilon^{\mu\nu\alpha\beta}k_\alpha p_\beta - F_A(q^2)(p\cdot k g^{\mu\nu} - p^\mu k^\nu) \end{aligned}$$

# Decay distribution

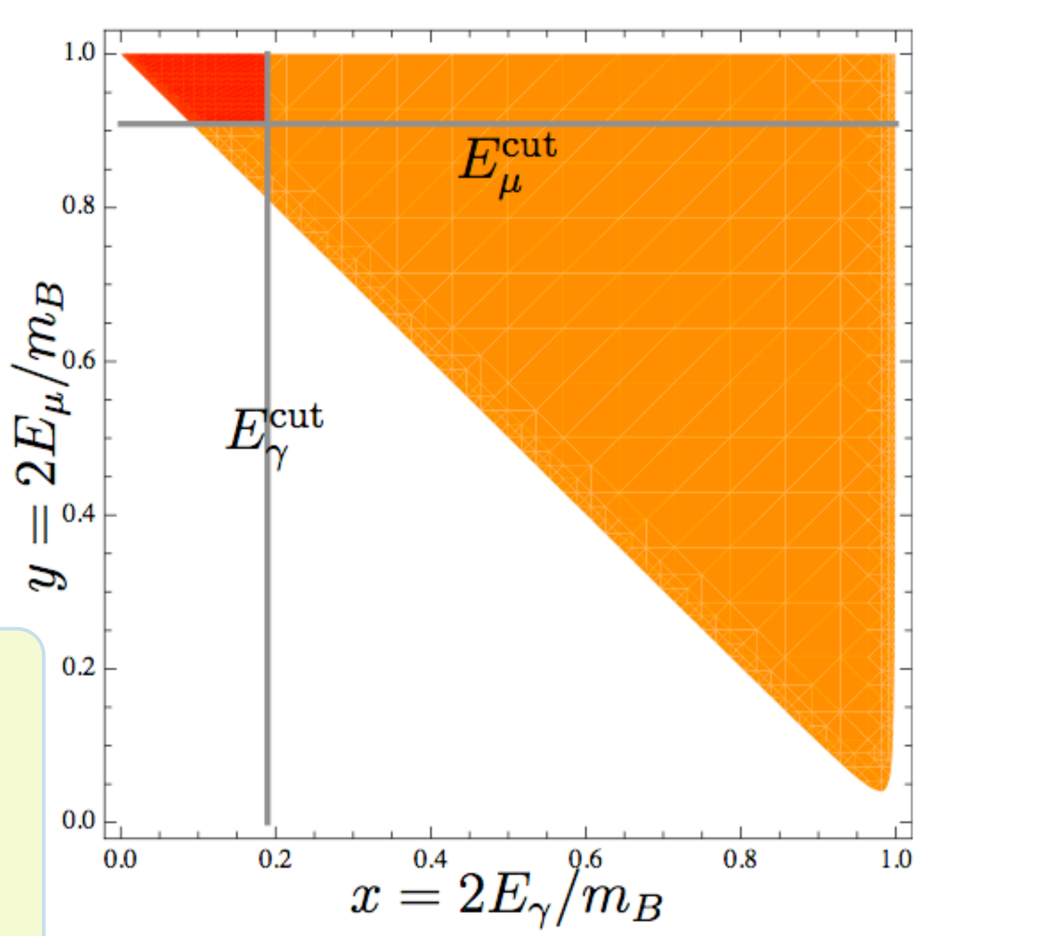
$$x = \frac{2p \cdot k}{M_B^2} = \frac{2E_\gamma}{M_B}$$

$$y = \frac{2p \cdot p_l}{M_B^2} = \frac{2E_l}{M_B}$$

$$0 \leq x \leq 1 - r_l$$

$$1 - x + \frac{r_l}{1-x} \leq y \leq 1 + r_l$$

$$r_l = \frac{m_l^2}{M_B^2}$$



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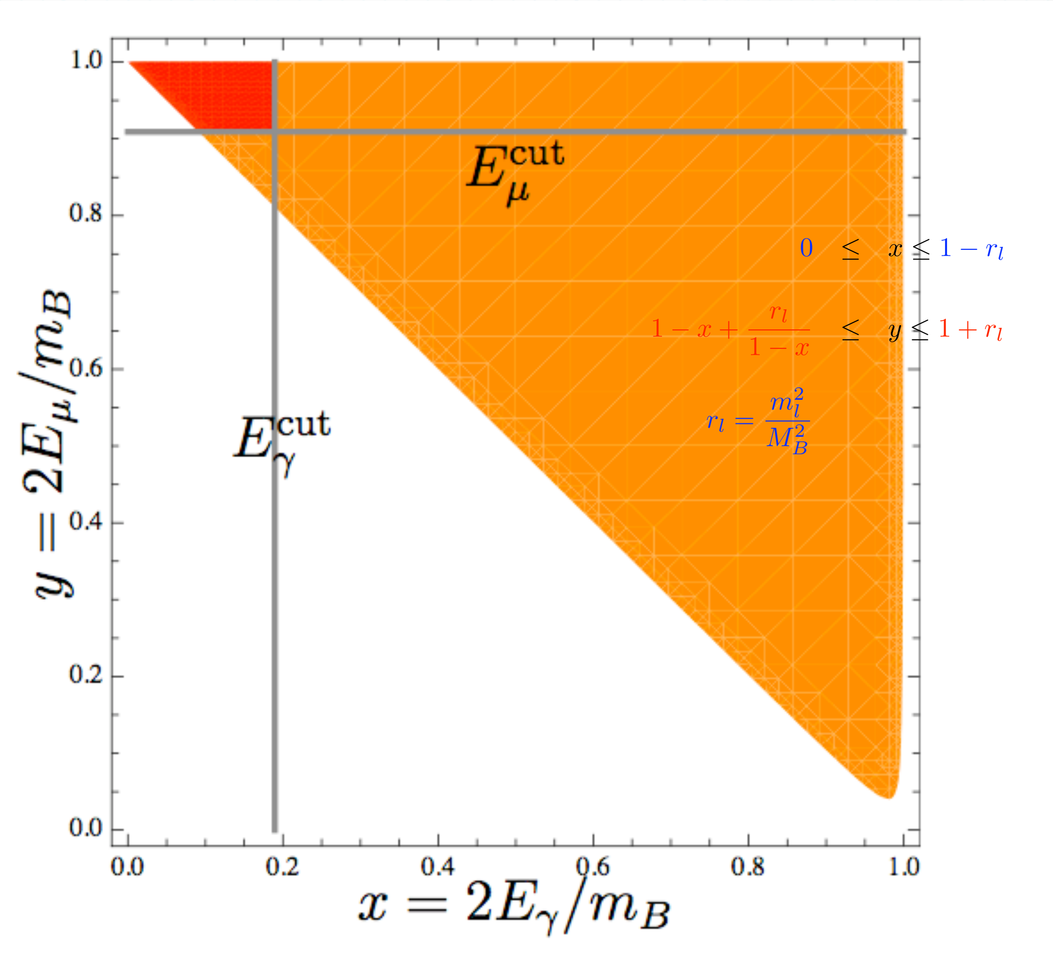


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# Structure dependent part

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$M(B^+ \to l^+\nu_l\gamma) = M_{IB} + M_{SD}$

Due to the nearness of $M_{B^*}$ wrt $M_B$
the form factor $F_V$ is dominant
and in the small $x$-region

$$F_V(x) \approx \left. \frac{f_{B^*} M_{B^*} g_{B^* B\gamma}}{M_{B^*}^2 - q^2} \right|_{q^2 = M_B^2(1-x)}$$

$$L^\mu = m_l \bar{u}(p_\nu)(1+\gamma_5)\left(\frac{2p^\mu}{2p\cdot k} - \frac{2p_l^\mu + \not{k}\gamma^\mu}{2p_l\cdot k}\right) v(p_l, s_l)$$

$$l^\mu = \bar{u}(p_\nu)\gamma^\mu(1+\gamma_5)v(p_l, s_l)$$

$$\tilde{H}^{\mu\nu} = iF_V(q^2)\epsilon^{\mu\nu\alpha\beta}k_\alpha p_\beta - F_A(q^2)(p\cdot k g^{\mu\nu} - p^\mu k^\nu)$$

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$$\langle \gamma(p_\gamma, \epsilon) B(p_B) | B^*(\eta) \rangle = -i\varepsilon_{\mu\nu\alpha\beta} p_\gamma^\mu \eta^\nu v^\alpha \epsilon^{*\beta} g_{B^* B\gamma}$$

$$g_{B^* B\gamma} = e M_B \left( \frac{Q_b}{m_b} + Q_q \beta \right)$$

light quark contribution to the magnetic moment of the vector meson

Various models $1.7 \leq |g_{B^* B^+ \gamma}| \leq 3.0$ [LCSR 2.7, Aliev et al, 2001]

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$$\left( \vec{\alpha} \cdot \vec{p} + m\beta + V(\vec{r}) - E \right) \Psi(\vec{r}) = 0$$

$$V(r) = -\frac{\kappa}{r} + \beta \ (ar + c)$$

*Dirac Model which was successfull in D*Dπ coupling*

$$\beta = \frac{2}{3} \int_0^\infty \left\{ f_{1/2}^{(-1)*} g_{1/2}^{(-1)} + g_{1/2}^{(-1)*} f_{1/2}^{(-1)} \right\} r^3 dr$$

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$$F_V^{\text{pole}}(x) = \frac{C_V^b}{x - 1 + \Delta_b}$$

$$C_V^b = \frac{f_{B^*} m_{B^*} g_{B^* B^- \gamma}}{m_B^2 \sqrt{4\pi\alpha_{\text{em}}}}, \qquad \Delta_b = \frac{m_{B^*}^2}{m_B^2}$$

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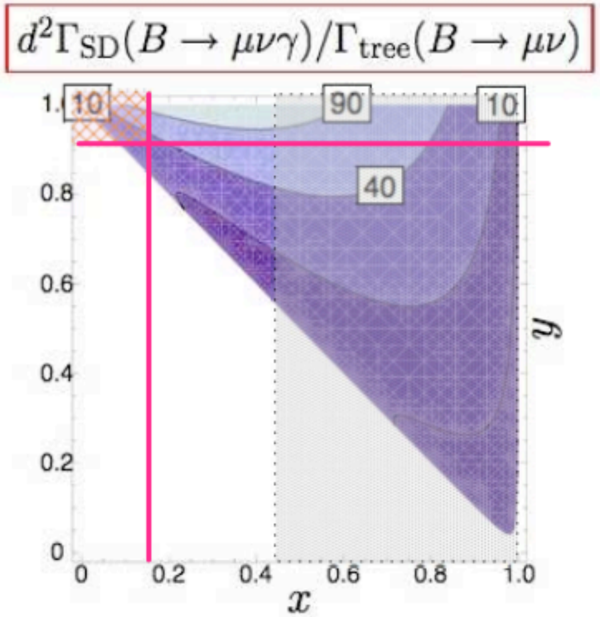
$$\beta = 1.5 \pm 0.2 \text{ GeV}^{-1}$$

# As a result...

$B^+(p) \to l^+(p_l)\nu_l(p_\nu)\gamma(k)$



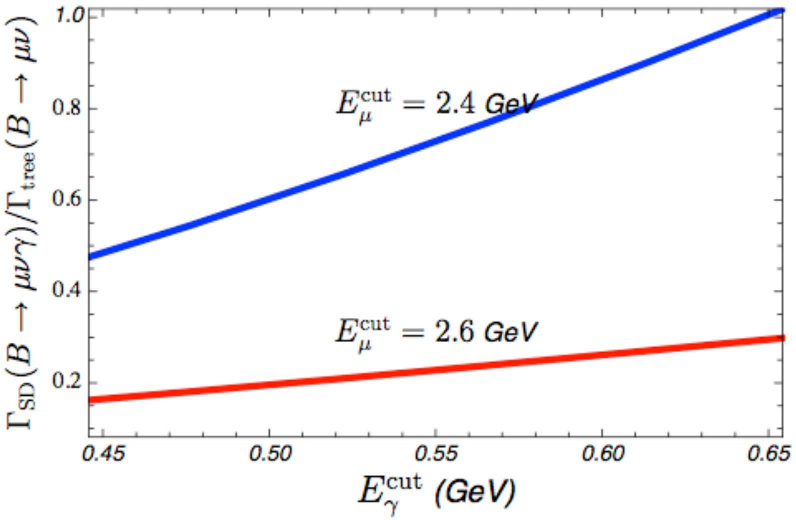

$$x = \frac{2E_\gamma}{M_B}, \quad y = \frac{2E_\mu}{M_B}$$

☞ $B \to \mu\nu$ signal region

$$E_\mu = E_{miss} = \frac{M_B}{2} \simeq 2.6 \text{ GeV}$$

☞ Cross-talk region (invisible photon)

$$E_\mu > 2.4\text{GeV}, \quad E_\gamma < 0.5\text{GeV}$$



* In the case of D-decays the effect is -of course- smaller: We just finished computing $D^*D\gamma$-coupling on the lattice (first ever!) ➡ D-leptonic decays will be under better control

* In the case of B-decays needs to have excellent photon resolution: computing $B^*B\gamma$-coupling on the lattice is difficult ➡ ideas to do it in the static limit

* Leptonic B-decay to τ (tau) is difficult but is theoretically cleaner
  What can be [really] done in Super-B?

- List of References and detailed discussion of what I just announced here will soon appear in our -Orsay- papers

- Discussion of the soft photon traps in B-leptonic decay : ➡ paper with B.Haas and E.Kou

- In the case of D-decays the effect is -of course- smaller: $D^*D\gamma$-coupling together with $D^*D\pi$ ➡ paper with B.Haas to appear

- D-meson decay constant (and Ds) with the discussion of the soft photons ➡ paper with B.Haas and E.Kou to appear

- Figuring out the way to compute $B^*B\gamma$ in the static limit ➡ with E.Chang