Hadronization Spin and Lifetimes

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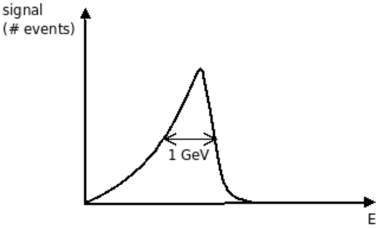
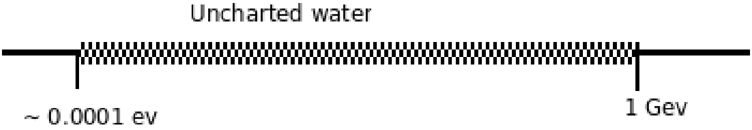
LIFETIME DETERMINATION

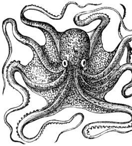
- Experimentally, if $\Gamma \gtrsim 1\,\mathrm{GeV}$, one can measure its decay width directly:



- For long lifetimes: Reconstruct momentum + mass $\Rightarrow$ Find the velocity + measure displaced vertexes $\Rightarrow$ find τ.
  We will use a figure of merit: $\tau \gtrsim 1\,\mathrm{ps}$, which is $\Gamma \lesssim 10^{-4}\,\mathrm{eV}$.

THE PROBLEM



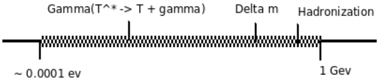


- For a very large window,

$$10^9 \text{ eV} \gtrsim \Gamma \gtrsim 10^{-4} \text{ eV},$$

  decay widths cannot be extracted.
- This is an experimental problem. It is safe to assume that narrowing the window with better equipment would not make so many orders of magnitude go away.

QCD INTRODUCING SOME NEW SCALES



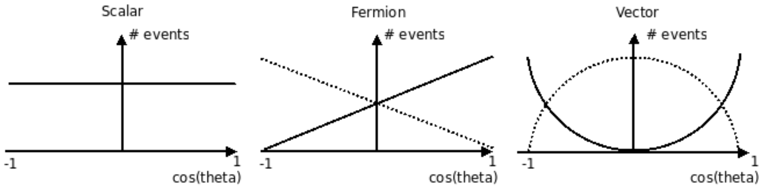
- Take a regular heavy quark as an example. Call it the "t" quark.
- $\Lambda_{\mathrm{QCD}} \sim 100\,\mathrm{MeV}$ - The quark hadronizes to meson or a "T" baryon. Spin is preserved to order $\mathcal{O}\left(\Lambda_{\mathrm{QCD}}/M_t\right)$
  $\Rightarrow |T_u(\tau_{had})\rangle = \frac{1}{\sqrt{2}}\left(|t:\uparrow, u:\uparrow\rangle + e^{i\phi}|t:\uparrow, u:\downarrow\rangle\right)$
- The vector and scalar mesons mass splitting: Δm protected at $\mathcal{O}\left(\Lambda^2_{QCD}/m_t\right)$. **A. F. Falk and M. E. Peskin, Phys. Rev. D 49, 3320 (1994), hep-ph/9308241.**

$$|T\rangle \propto \frac{1}{\sqrt{2}}\left(e^{im^* t}|J=1, m=1\rangle + \frac{e^{i\phi}}{\sqrt{2}}\left(e^{im^* t}|1,0\rangle + e^{imt}|0,0\rangle\right)\right)$$

- Finally the vector mesons decays to a singlet and a photon at Γ_γ.
- HQET gives us Δm and Γ_γ , e.g for m_t: $\Delta m \sim 1\,\mathrm{MeV}$, $\Gamma_\gamma \sim 1\,\mathrm{eV}$.

SPIN MEASUREMENT (A DIFFERENT TOPIC)

- Generally one can tell the spin of a mother or an intermediate particle by looking at the angular correlation of outgoing particles:

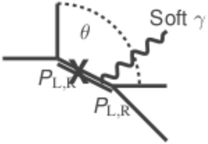


L. T. Wang and I. Yavin, JHEP 0704, 032 (2007), hep-ph/0605296

- However this can be washed out (Massive out going particles, Decay vertexes without explicit helicity, experimental bg, and combinatorics).

$$(1 \pm \cos\theta) \rightarrow (1 \pm r\cos\theta) \qquad r < 1$$

Spin in hadronized tops



- "Top" hadronization doesn't flip it's spin to $\mathcal{O}\left(\Lambda_{QCD}/M_r\right)$.
- If $\Gamma \ll \Delta m$ then half the spin information is lost to oscillation, $1 \pm \cos\theta \to 1 \pm \frac{1}{2}\cos\theta$:

$$|T\rangle \ni e^{im^* t}\,|J=1, m=0\rangle + e^{imt}\,|J=0, m=0\rangle$$

- If $\Gamma \ll \Gamma_\gamma$, then the vector part decays to photon scalar meson. Since (very soft). Thus a collider detector will not find it $\Rightarrow$ Spin information lost. (This happens for the B meson.)

GROUNDING THIS IN A FEW EQUATIONS

- The time dependent spin of the top is given by

$$\langle s_{\hat{p}} \rangle = \frac{1}{2} \left(\langle \uparrow | T(t) \rangle - \langle \downarrow | T(t) \rangle \right)$$

- Plugging in our state (and considering $\Delta m \gg \Gamma_\gamma$):

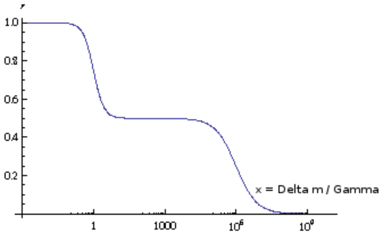
$$\frac{\langle s_{\hat{p}} \rangle (t)}{\langle s_{\hat{p}} \rangle_0} = \frac{1}{2} \left(\cos(\Delta m t) + e^{-\Gamma_\gamma t} \right)$$

- The final result really depends on the time-integrated spin measurement:

$$r \equiv \frac{\int dt \exp(-\Gamma t) \langle s_{\hat{p}} \rangle (t)}{\int dt \exp(-\Gamma t) \langle s_{\hat{p}} \rangle^{\text{free}}}$$
$$= \frac{1}{2} \left(\frac{1}{1+x^2} + \frac{1}{1+y} \right) \qquad x \equiv \frac{\Gamma}{\Delta m}, \; y \equiv \frac{\Gamma}{\Gamma_\gamma}$$

THE FINAL PICTURE

So finally we will get $(1 \pm \cos(\theta)) \rightarrow (1 \pm r\cos(\theta))$:



In this graph we take $\Delta m / \Gamma_\gamma \sim 10^6$ for a long lived t quark.

By measuring r one can find where Γ is relative to the other scales. (If we are lucky and Γ is comparable to one of the scales we can make more precise measurements.)

COMPLICATIONS

- We need to know a lot in order to make this measurement:
  - The spin of the heavy particle, its mass and the color representation of the particle to use HQET.
  - We need to know the chirality structure of the vertexes and the mass of the daughter particles in order to factor it in the "washing out" of the spin information.
  - We need to know about experimental backgrounds that could also washing out of spin information.
- We also can't use it for any particle:
  - For spin 0 particles or if not QCD charged, we would not get HF splitting at all.
  - HQET is also measured only for D and B system, i.e. for heavy quarks (QCD fundamental fermions). To be able to make predictions we first have to measure H?ET for one system of a heavy particle in the new representation.
  - Could create a hadron with two spectators, then they will form a spin 0 combination. (They have no Λ^2_{QCD}/M mass protection.) Thus no splitting.