Intro to flavour tutorial

25 April 2022 10:46

https://home.cern/news/news/physics/mystery-beauty-baryon-lifetime-resolved

https://pdglive.lbl.gov/Viewer.action

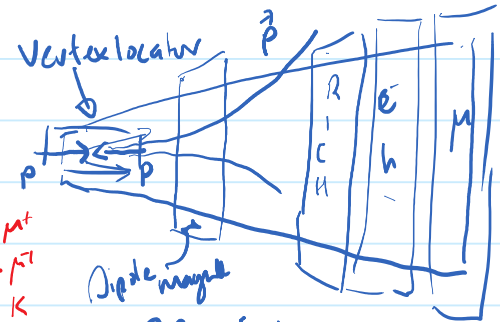
1) l = distance in lab $= |\vec{v}|\, t_{lab}$
$= \beta c\, \gamma \tau$
τ lifetime Λ_b

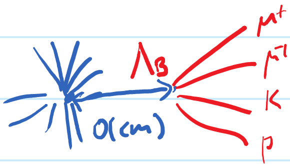
PDG: $\tau_\Lambda / \tau_{B^0} = 0.964$

$\tau_{B^0} = 1.52 \times 10^{-12}\,s$
$= 1.52\,ps$

$\Rightarrow l = 100 \times c\tau = 3.3\,cm$

$\beta\gamma = \frac{|\vec{p}|}{m}$

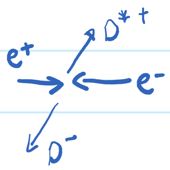




B^0 lifetime is compared to Λ_b
length scale
$\equiv$ time

2)

$D^+ = c\bar{d}$ $D^0 = c\bar{u}$



$\sqrt{s} = 4.03\,GeV$

$|\vec{p}_{D^*}|$

$p_{e^+} + p_{e^-} = p_{D^*} + p_D$ $(E, \vec{p}$ cons.$)$

$p_{e^+} + p_{e^-} = (\sqrt{s}, 0, 0, 0)$

$\Rightarrow p_D = p_{e^+} + p_{e^-} - p_{D^*}$

$\Rightarrow m_D^2 = s + m_{D^*}^2 - 2\, p_{D^*} \cdot (p_{e^+} + p_{e^-})$
$\hookrightarrow 2 E_{D^*} \sqrt{s}$

$\Rightarrow E_{D^*} = \frac{m_{D^*}^2 + s - m_D^2}{2\sqrt{s}}$
$= 2.083\,GeV$

$m_{D^+} = 1.869\,GeV$
$m_{D^{*-}} = 2.010\,GeV$

$|\vec{p}_{D^*}|^2 = \sqrt{E_{D^*}^2 - m_{D^*}^2} = 0.547\,GeV$

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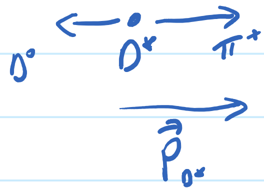
$D^{*+} \to D^0 \pi^+$
↑ maximum $|\vec{p}|$

In the rest frame of D^* : $E_D = \dfrac{m_D^2 + m_{D^*}^2 - m_\pi^2}{2 m_{D^*}}$

$|\vec{p}_D| = |\vec{p}_\pi| = 0.001\,\text{GeV}$

Maximum in Lab frame

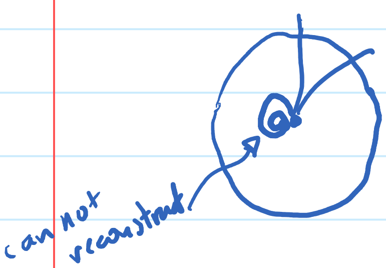


Boost of D^* in the lab

$\beta = \dfrac{p_{D^*}}{E_{D^*}} = 0.27$

$p_\pi^{Lab} = \gamma (p_\pi^{cm} + \beta E_\pi^{cm})$

$= 40\,\text{MeV}$ //



$D^{*+} \to D^0 \pi^+$ $\quad m_{D^*} - m_D = \Delta m$ to find D^*

$D^{*0} \to D^0 \gamma$ ← electromagnetic

$D^{*0} \to D^0 \pi^0$ $\quad m_{D^{*0}} > m_{D^0} + m_{\pi^0}$ ✓ kinematically allowed

$\not\to D^+ \pi^-$ $\quad m_{D^{*0}} < m_{D^+} + m_{\pi^-}$

—— // ——

3) Compare π momentum from $B^0 \to \pi^- l^+ \nu_l$ at Belle II and LHCb?
V_{ub}

Belle II

7 GeV e^- → ← e^+ 4 GeV

B mesons decay length is ~ 100 μm

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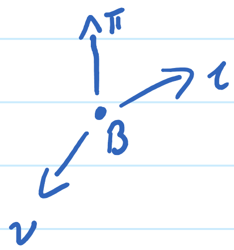
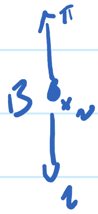
$E_B = \frac{M_{\Upsilon(4S)}}{2} = 5.29$ GeV $\qquad m_{B^0} = 5.279$ GeV

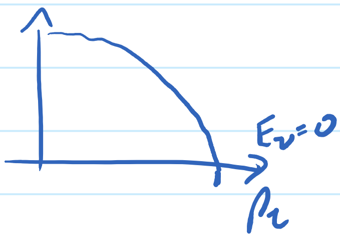
$p_B = 320$ MeV $\qquad$ C of M frame

$\beta = \frac{7-4}{7+4} = \frac{p_{TOT}}{E_{TOT}} = \frac{3}{11} = 0.273$

$\Rightarrow$ maximum B momentum $= 5.6$ MeV



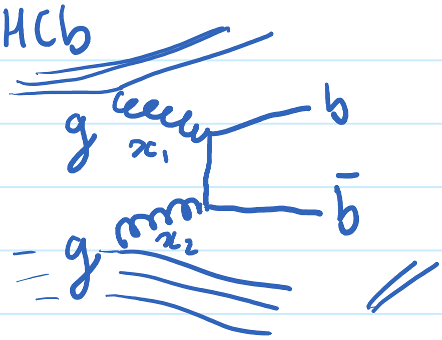


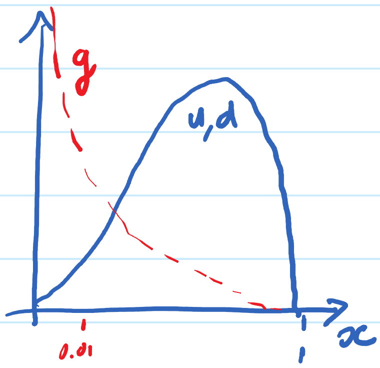


$B \to \pi \ell \qquad |\vec{p}^{\,*}_\pi| = 2.6$ GeV $\quad \Rightarrow \quad |\vec{p}_\pi| = 3.6$ GeV

Return to 2

LHCb





$\langle \vec{p}_B \rangle_{LHCb} = 80$ GeV $\qquad \beta_B = \frac{\langle p_B \rangle}{E_B} \approx 1 \qquad \gamma = \frac{\langle p_B \rangle}{m_B} \approx 16$

$\Rightarrow p_\pi^{LAB} = 83$ GeV

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4) $V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$ $\qquad V_{CKM}^{\dagger} V_{CKM} = \mathbb{I}$

unitarity condition

$$f = |V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1$$

$|V_{ud}| = 0.97370 \pm 0.00014$

$\Rightarrow |V_{us}| = 0.2245 \pm 0.0008$ $\qquad \Rightarrow 0.9979 \pm ?$

$|V_{ub}| = 0.0038 \pm 0.0002$

$$\sigma_f^2 = \left(\frac{\partial f}{\partial V_{ud}}\right)^2 \sigma_{V_{ud}}^2 + \left(\frac{\partial f}{\partial V_{us}}\right)^2 \sigma_{V_{us}}^2 + \left(\frac{\partial f}{\partial V_{ub}}\right)^2 \sigma_{V_{ub}}^2$$

$$= 4 |V_{ud}|^2 \sigma_{V_{ud}}^2 + \dots$$

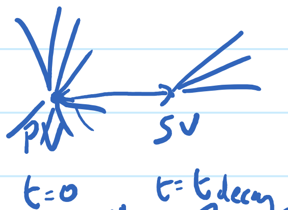
Cabibbo angle anomaly

$\Rightarrow \sigma_f = 5 \times 10^{-4}$ $\qquad 0.9979(5) \qquad \sim 4\sigma$

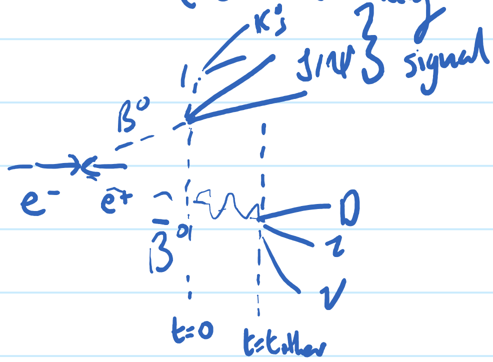
↑ uncertainty in last d.p

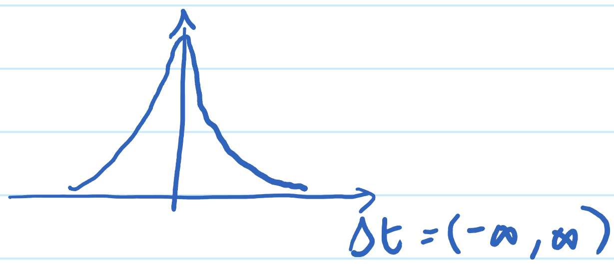
— x —

Aside



$t_{decay} = (0, \infty)$





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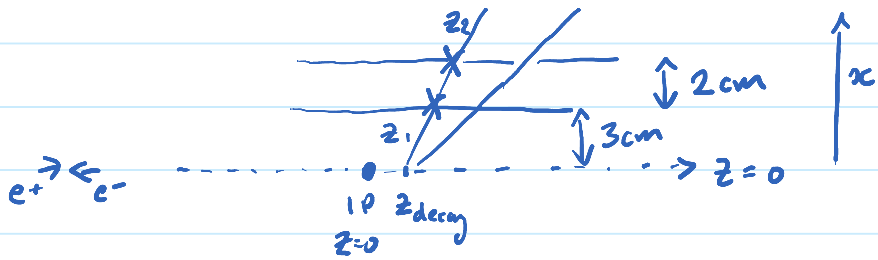
5) BABAR $\quad 9\,\text{GeV}\ e^-$ $\quad 3.1\,\text{GeV}\ e^+$ $\quad \Rightarrow \beta = 0.487$

$\langle l \rangle = \beta\gamma c\tau = 250\,\mu m$

c.f. (1)



$$z = mx + z_{decay}$$

$$\left.\begin{array}{l} z_1 = 3m + z_{decay} \\ z_2 = 5m + z_{decay} \end{array}\right\} \Rightarrow \frac{z_1 - z_d}{z_2 - z_d} = \frac{3}{5}$$

$$\Rightarrow z_d = \frac{5}{2}\left(z_1 - \frac{3}{5} z_2\right)$$

$$\sigma_{z_d}^2 = \left(\frac{5}{2}\right)^2 \sigma_{z_1}^2 + \left(\frac{3}{2}\right)^2 \sigma_{z_2}^2$$

$\sigma_{z_1} = \sigma_{z_2}$ $\quad \Rightarrow \sigma_{z_d} = 2.9\,\sigma_z \leftarrow \sigma_z = \sigma_{z_1} = \sigma_{z_2}$

$\sigma_{z_d} = 60\,\mu m$ $\quad \sigma_z = 20\,\mu m$ ← typical resolution of Si strip detector

Yes//

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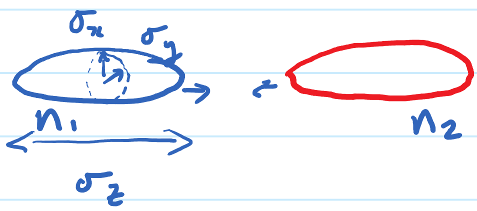
6 $$\mathcal{L} = \frac{f n_1 n_2}{4\pi \sigma_x \sigma_y}$$

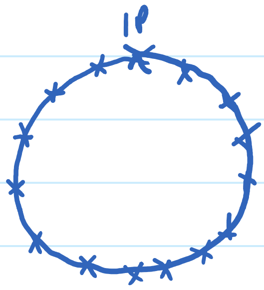
f ← frequency of collision

$n_1 n_2$ ← particles in each bunch

$\sigma_x \sigma_y$ ← transverse widths of the bunches



l = accelerator length ; n_b = number of bunches



$$f = \frac{c}{l} \times n_b$$

$\mathcal{L}_{BABAR-PEP} = 10^{33} \, cm^{-2} s^{-1}$

$\mathcal{L}_{KEKB} = 3 \times 10^{33} \, cm^{-2} s^{-1}$

$\mathcal{L}_{SUPERKEKB} = 3.8 \times 10^{34} \, cm^{-2} s^{-1}$ $(6 \times 10^{35} \, cm^{-2} s^{-1})$