

# QUARKS

The  $u$ -,  $d$ -, and  $s$ -quark masses are the  $\overline{MS}$  masses at the scale  $\mu = 2$  GeV. The  $c$ - and  $b$ -quark masses are the  $\overline{MS}$  masses renormalized at the  $\overline{MS}$  mass, i.e.  $\overline{m} = \overline{m}(\mu = \overline{m})$ . The  $t$ -quark mass is extracted from event kinematics (see the review "The Top Quark").

**u**

$$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$$

$$m_u = 2.16^{+0.49}_{-0.26} \text{ MeV} \quad \text{Charge} = \frac{2}{3} e \quad I_z = +\frac{1}{2}$$

$$m_u/m_d = 0.474^{+0.056}_{-0.074}$$

**d**

$$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$$

$$m_d = 4.67^{+0.48}_{-0.17} \text{ MeV} \quad \text{Charge} = -\frac{1}{3} e \quad I_z = -\frac{1}{2}$$

$$m_s/m_d = 17-22$$

$$\overline{m} = (m_u + m_d)/2 = 3.45^{+0.35}_{-0.15} \text{ MeV}$$

**s**

$$I(J^P) = 0(\frac{1}{2}^+)$$

$$m_s = 93.4^{+8.6}_{-3.4} \text{ MeV} \quad \text{Charge} = -\frac{1}{3} e \quad \text{Strangeness} = -1$$

$$m_s / ((m_u + m_d)/2) = 27.33^{+0.67}_{-0.77}$$

**c**

$$I(J^P) = 0(\frac{1}{2}^+)$$

$$m_c = 1.27 \pm 0.02 \text{ GeV} \quad \text{Charge} = \frac{2}{3} e \quad \text{Charm} = +1$$

$$m_c/m_s = 11.76^{+0.05}_{-0.10}$$

$$m_b/m_c = 4.58 \pm 0.01$$

$$m_b - m_c = 3.45 \pm 0.05 \text{ GeV}$$

**b**

$$I(J^P) = 0(\frac{1}{2}^+)$$

$$m_b = 4.18^{+0.03}_{-0.02} \text{ GeV} \quad \text{Charge} = -\frac{1}{3} e \quad \text{Bottom} = -1$$

**t**

$$I(J^P) = 0(\frac{1}{2}^+)$$

$$\text{Charge} = \frac{2}{3} e \quad \text{Top} = +1$$

Mass (direct measurements)  $m = 172.69 \pm 0.30 \text{ GeV}^{[a,b]}$  (S = 1.3)

Mass (from cross-section measurements)  $m = 162.5^{+2.1}_{-1.5} \text{ GeV}^{[a]}$

Mass (Pole from cross-section measurements)  $m = 172.5 \pm 0.7 \text{ GeV}$

$m_t - m_{\bar{t}} = -0.15 \pm 0.20 \text{ GeV}$  (S = 1.1)

Full width  $\Gamma = 1.42^{+0.19}_{-0.15} \text{ GeV}$  (S = 1.4)

$\Gamma(Wb)/\Gamma(Wq(q = b, s, d)) = 0.957 \pm 0.034$  (S = 1.5)

### t-quark EW Couplings

$$F_0 = 0.693 \pm 0.013$$

$$F_- = 0.315 \pm 0.010$$

$$F_+ = -0.005 \pm 0.007$$

$$F_{V+A} < 0.29, \text{ CL} = 95\%$$

t DECAY MODES	Fraction ( $\Gamma_i/\Gamma$ )	Confidence level	$\frac{p}{\text{MeV}/c}$
$Wq(q = b, s, d)$			—
$Wb$			—
$e\nu_e b$	(11.10 ± 0.30) %		—
$\mu\nu_\mu b$	(11.40 ± 0.20) %		—
$\tau\nu_\tau b$	(10.7 ± 0.5) %		—
$q\bar{q}b$	(66.5 ± 1.4) %		—
$\gamma q(q=u,c)$	[c] < 1.8	$\times 10^{-4}$	95%
<b><math>\Delta T = 1</math> weak neutral current (T1) modes</b>			
$Zq(q=u,c)$	T1 [d] < 5	$\times 10^{-4}$	95%
$Hu$	T1 < 1.2	$\times 10^{-3}$	95%
$Hc$	T1 < 1.1	$\times 10^{-3}$	95%
$\ell^+ \bar{q}q'(q=d,s,b; q'=u,c)$	T1 < 1.6	$\times 10^{-3}$	95%

### **$b'$ (4<sup>th</sup> Generation) Quark, Searches for**

Mass  $m > 190 \text{ GeV}$ , CL = 95% ( $p\bar{p}$ , quasi-stable  $b'$ )

Mass  $m > 1390 \text{ GeV}$ , CL = 95% ( $B(b' \rightarrow Zb) = 1$ )

Mass  $m > 1350 \text{ GeV}$ , CL = 95% ( $B(b' \rightarrow Wt) = 1$ )

Mass  $m > 1570 \text{ GeV}$ , CL = 95% ( $B(b' \rightarrow Hb) = 1$ )

Mass  $m > 46.0 \text{ GeV}$ , CL = 95% ( $e^+e^-$ , all decays)

## **$t'$ (4<sup>th</sup> Generation) Quark, Searches for**

$$\begin{aligned}
 m(t'(2/3)) &> 1280 \text{ GeV, CL} = 95\% && (\text{B}(t' \rightarrow Z t) = 1) \\
 m(t'(2/3)) &> 1295 \text{ GeV, CL} = 95\% && (\text{B}(t' \rightarrow W b) = 1) \\
 m(t'(2/3)) &> 1310 \text{ GeV, CL} = 95\% && (\text{singlet } t') \\
 m(t'(2/3)) &> 1350 \text{ GeV, CL} = 95\% && (t' \text{ in a weak isospin doublet } (t', b')) \\
 m(t'(5/3)) &> 1.350 \times 10^3 \text{ GeV, CL} = 95\% && (t'(5/3) \rightarrow t W^+)
 \end{aligned}$$

## **Free Quark Searches**

All searches since 1977 have had negative results.

### NOTES

- [a] A discussion of the definition of the top quark mass in these measurements can be found in the review “The Top Quark.”
- [b] Based on published top mass measurements using data from Tevatron Run-I and Run-II and LHC at  $\sqrt{s} = 7$  TeV. Including the most recent unpublished results from Tevatron Run-II, the Tevatron Electroweak Working Group reports a top mass of  $173.2 \pm 0.9$  GeV. See the note “The Top Quark” in the Quark Particle Listings of this *Review*.
- [c] This limit is for  $\Gamma(t \rightarrow \gamma q)/\Gamma(t \rightarrow W b)$ .
- [d] This limit is for  $\Gamma(t \rightarrow Z q)/\Gamma(t \rightarrow W b)$ .