LIGHT QUARKS (*u*, *d*, *s*)

OMITTED FROM SUMMARY TABLE

u-QUARK MASS

The *u*-, *d*-, and *s*-quark masses are estimates of so-called "current-quark masses," in a mass- independent subtraction scheme such as $\overline{\text{MS}}$. The ratios m_u/m_d and m_s/m_d are extracted from pion and kaon masses using chiral symmetry. The estimates of *d* and *u* masses are not without controversy and remain under active investigation. Within the literature there are even suggestions that the *u* quark could be essentially massless. The *s*-quark mass is estimated from SU(3) splittings in hadron masses.

We have normalized the $\overline{\text{MS}}$ masses at a renormalization scale of $\mu = 2$ GeV. Results quoted in the literature at $\mu = 1$ GeV have been rescaled by dividing by 1.35. The values of "Our Evaluation" were determined in part via Figures 1 and 2.

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
$\mathbf{2.49^{+0.81}_{-0.79}}$ **(1.7–3.3) OUR EVALUATION**	See the ideogram below.			
2.01 ± 0.14	[1] DAVIES	10	LATT	$\overline{\text{MS}}$ scheme
2.9 ± 0.2	[2] DOMINGUEZ	09	THEO	$\overline{\text{MS}}$ scheme
2.9 ± 0.8	[3] DEANDREA	08	THEO	$\overline{\text{MS}}$ scheme
3.02 ± 0.33	[4] BLUM	07	LATT	$\overline{\text{MS}}$ scheme
2.7 ± 0.4	[5] JAMIN	06	THEO	$\overline{\text{MS}}$ scheme
1.9 ± 0.2	[6] MASON	06	LATT	$\overline{\text{MS}}$ scheme
2.8 ± 0.2	[7] NARISON	06	THEO	$\overline{\text{MS}}$ scheme
1.7 ± 0.3	[8] AUBIN	04A	LATT	$\overline{\text{MS}}$ scheme
• • • We do not use the following data for averages, fits, limits, etc. • • •				
2.9 ± 0.6	[9] JAMIN	02	THEO	$\overline{\text{MS}}$ scheme
2.3 ± 0.4	[10] NARISON	99	THEO	$\overline{\text{MS}}$ scheme
3.9 ± 1.1	[11] JAMIN	95	THEO	$\overline{\text{MS}}$ scheme
3.0 ± 0.7	[12] NARISON	95C	THEO	$\overline{\text{MS}}$ scheme

[1] DAVIES 10 determine $\overline{m}_c(\mu)/\overline{m}_s(\mu) = 11.85 \pm 0.16$ using a lattice computation with dynamical fermions of the pseudoscalar meson masses. Mass m_u is obtained from this using the value of m_c from ALLISON 08 and the BAZAVOV 10 values for the light quark mass ratios, $m_s/\overline{m}$ and m_u/m_d.

[2] DOMINGUEZ 09 use QCD finite energy sum rules for the two-point function of the divergence of the axial vector current computed to order α_s^4.

[3] DEANDREA 08 determine $m_u - m_d$ from $\eta \rightarrow 3\pi^0$, and combine with the PDG 06 lattice average value of $m_u + m_d = 7.6 \pm 1.6$ to determine m_u and m_d.

[4] BLUM 07 determine quark mass using a QED plus QCD lattice computation with two dynamical flavors of the pseudoscalar meson masses.

[5] JAMIN 06 determine m_u(2 GeV) by combining the value of m_s obtained from the spectral function for the scalar $K\pi$ form factor with other determinations of the quark mass ratios.

[6] MASON 06 extract light quark masses from a lattice simulation using staggered fermions with an improved action, and three dynamical light quark flavors with degenerate u and d quarks. Perturbative corrections were included at NNLO order. The quark masses m_u and m_d were determined from their $(m_u+m_d)/2$ measurement and AUBIN 04A m_u/m_d value.

[7] NARISON 06 uses sum rules for $e^+ e^- \rightarrow$ hadrons to order α_s^3 to determine m_s combined with other determinations of the quark mass ratios.

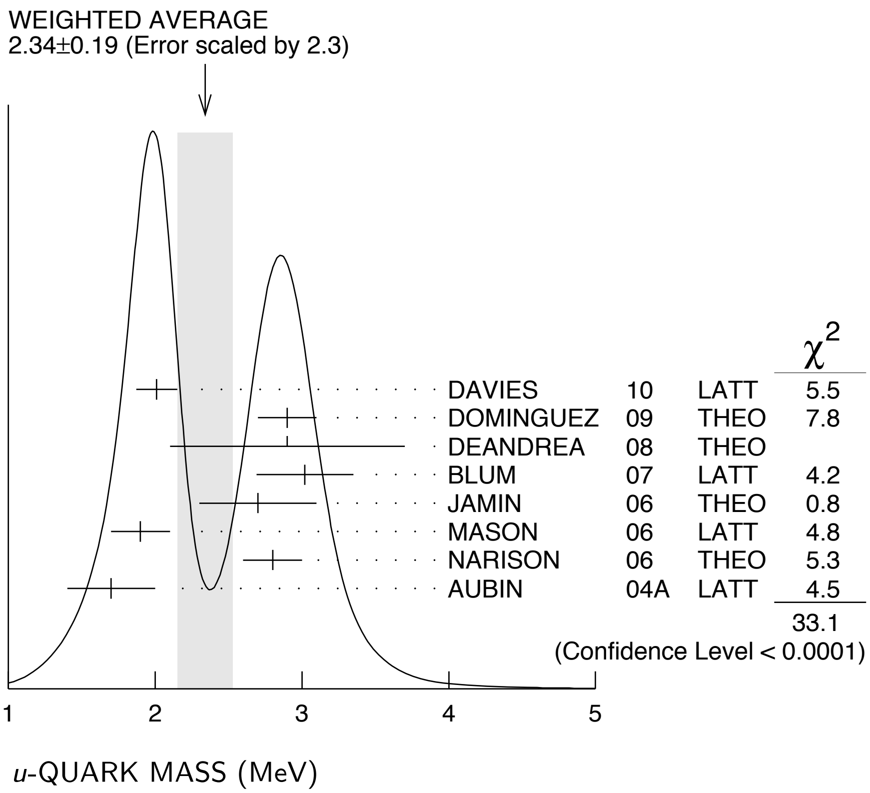
[8] AUBIN 04A employ a partially quenched lattice calculation of the pseudoscalar meson masses.

[9] JAMIN 02 first calculates the strange quark mass from QCD sum rules using the scalar channel, and then combines with the quark mass ratios obtained from chiral perturbation theory to obtain m_u.

[10] NARISON 99 uses sum rules to order α_s^3 for ϕ meson decays to get m_s, and finds m_u by combining with sum rule estimates of m_u+m_d and Dashen's formula.

[11] JAMIN 95 uses QCD sum rules at next-to-leading order. We have rescaled m_u(1 GeV) = 5.3 ± 1.5 to μ = 2 GeV.

[12] For NARISON 95C, we have rescaled m_u(1 GeV) = 4 ± 1 to μ = 2 GeV.



d-QUARK MASS

See the comment for the u quark above.

We have normalized the $\overline{\text{MS}}$ masses at a renormalization scale of μ = 2 GeV. Results quoted in the literature at μ = 1 GeV have been rescaled by dividing by 1.35. The values of "Our Evaluation" were determined in part via Figures 1 and 2.

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
$\mathbf{5.05^{+0.75}_{-0.95}}$ **(4.1–5.8) OUR EVALUATION** See the ideogram below.				
4.79±0.16	[13] DAVIES	10	LATT	$\overline{\text{MS}}$ scheme
5.3 ±0.4	[14] DOMINGUEZ	09	THEO	$\overline{\text{MS}}$ scheme
4.7 ±0.8	[15] DEANDREA	08	THEO	$\overline{\text{MS}}$ scheme
5.49±0.39	[16] BLUM	07	LATT	$\overline{\text{MS}}$ scheme
4.8 ±0.5	[17] JAMIN	06	THEO	$\overline{\text{MS}}$ scheme
4.4 ±0.3	[18] MASON	06	LATT	$\overline{\text{MS}}$ scheme
5.1 ±0.4	[19] NARISON	06	THEO	$\overline{\text{MS}}$ scheme
3.9 ±0.5	[20] AUBIN	04A	LATT	$\overline{\text{MS}}$ scheme
• • • We do not use the following data for averages, fits, limits, etc. • • •				
5.2 ±0.9	[21] JAMIN	02	THEO	$\overline{\text{MS}}$ scheme
6.4 ±1.1	[22] NARISON	99	THEO	$\overline{\text{MS}}$ scheme
7.0 ±1.1	[23] JAMIN	95	THEO	$\overline{\text{MS}}$ scheme
7.4 ±0.7	[24] NARISON	95C	THEO	$\overline{\text{MS}}$ scheme

[13] DAVIES 10 determine $\overline{m}_c(\mu)/\overline{m}_s(\mu) = 11.85 \pm 0.16$ using a lattice computation with dynamical fermions of the pseudoscalar meson masses. Mass m_d is obtained from this using the value of m_c from ALLISON 08 and the BAZAVOV 10 values for the light quark mass ratios, $m_s/\overline{m}$ and m_u/m_d.

[14] DOMINGUEZ 09 use QCD finite energy sum rules for the two-point function of the divergence of the axial vector current computed to order α_s^4.

[15] DEANDREA 08 determine $m_u - m_d$ from $\eta \to 3\pi^0$, and combine with the PDG 06 lattice average value of $m_u + m_d = 7.6 \pm 1.6$ to determine m_u and m_d.

[16] BLUM 07 determine quark mass using a QED plus QCD lattice computation with two dynamical flavors of the pseudoscalar meson masses.

[17] JAMIN 06 determine m_d(2 GeV) by combining the value of m_s obtained from the spectral function for the scalar $K\pi$ form factor with other determinations of the quark mass ratios.

[18] MASON 06 extract light quark masses from a lattice simulation using staggered fermions with an improved action, and three dynamical light quark flavors with degenerate u and d quarks. Perturbative corrections were included at NNLO order. The quark masses m_u and m_d were determined from their $(m_u + m_d)/2$ measurement and AUBIN 04A m_u/m_d value.

[19] NARISON 06 uses sum rules for $e^+ e^- \to$ hadrons to order α_s^3 to determine m_s combined with other determinations of the quark mass ratios.

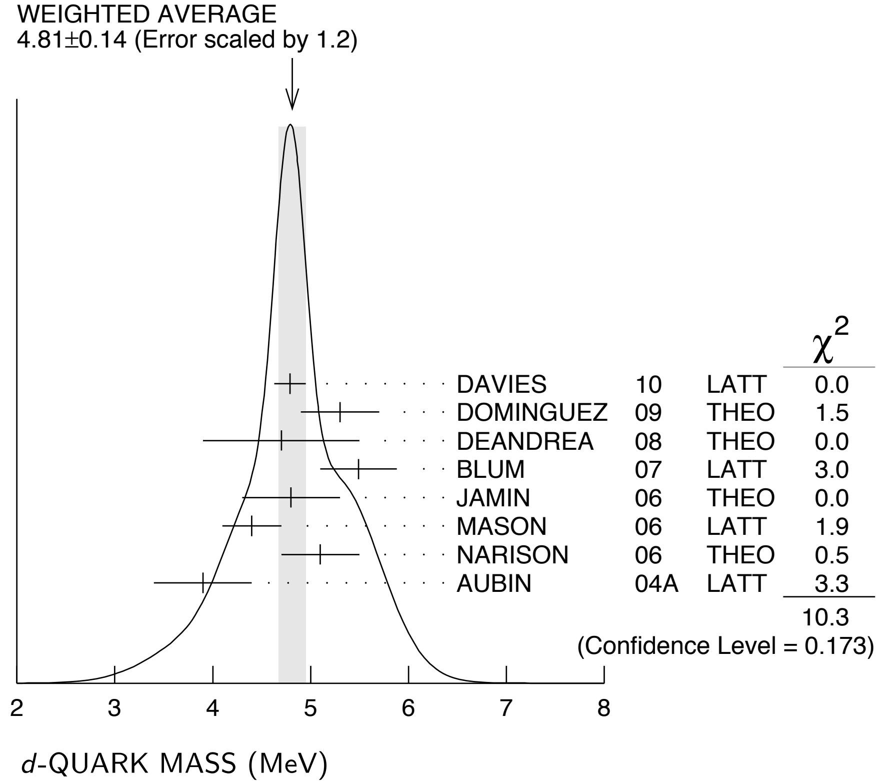
[20] AUBIN 04A perform three flavor dynamical lattice calculation of pseudoscalar meson masses, with continuum estimate of electromagnetic effects in the kaon masses, and one-loop perturbative renormalization constant.

[21] JAMIN 02 first calculates the strange quark mass from QCD sum rules using the scalar channel, and then combines with the quark mass ratios obtained from chiral perturbation theory to obtain m_d.

[22] NARISON 99 uses sum rules to order α_s^3 for ϕ meson decays to get m_s, and finds m_d by combining with sum rule estimates of $m_u + m_d$ and Dashen's formula.

[23] JAMIN 95 uses QCD sum rules at next-to-leading order. We have rescaled m_d(1 GeV) $= 9.4 \pm 1.5$ to $\mu = 2$ GeV.

[24] For NARISON 95C, we have rescaled m_d(1 GeV) $= 10 \pm 1$ to $\mu = 2$ GeV.



$\overline{m} = (m_u + m_d)/2$

See the comments for the *u* quark above.

We have normalized the $\overline{\text{MS}}$ masses at a renormalization scale of $\mu = 2$ GeV. Results quoted in the literature at $\mu = 1$ GeV have been rescaled by dividing by 1.35. The values of "Our Evaluation" were determined in part via Figures 1 and 2.

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
$3.77^{+1.03}_{-0.77}$ (3.0–4.8) OUR EVALUATION	See the ideogram below.			
3.40 ±0.07	[25] DAVIES	10	LATT	$\overline{\text{MS}}$ scheme
4.1 ±0.2	[26] DOMINGUEZ	09	THEO	$\overline{\text{MS}}$ scheme
3.72 ±0.41	[27] ALLTON	08	LATT	$\overline{\text{MS}}$ scheme
3.85 ±0.12 ±0.4	[28] BLOSSIER	08	LATT	$\overline{\text{MS}}$ scheme
$3.55^{+0.65}_{-0.28}$	[29] ISHIKAWA	08	LATT	$\overline{\text{MS}}$ scheme
4.026±0.048	[30] NAKAMURA	08	LATT	$\overline{\text{MS}}$ scheme
4.25 ±0.35	[31] BLUM	07	LATT	$\overline{\text{MS}}$ scheme
4.08 ±0.25 ±0.42	[32] GOCKELER	06	LATT	$\overline{\text{MS}}$ scheme
4.7 ±0.2 ±0.3	[33] GOCKELER	06A	LATT	$\overline{\text{MS}}$ scheme
3.2 ±0.3	[34] MASON	06	LATT	$\overline{\text{MS}}$ scheme
3.95 ±0.3	[35] NARISON	06	THEO	$\overline{\text{MS}}$ scheme
2.8 ±0.3	[36] AUBIN	04	LATT	$\overline{\text{MS}}$ scheme
4.29 ±0.14 ±0.65	[37] AOKI	03	LATT	$\overline{\text{MS}}$ scheme
3.223±0.3	[38] AOKI	03B	LATT	$\overline{\text{MS}}$ scheme
4.4 ±0.1 ±0.4	[39] BECIREVIC	03	LATT	$\overline{\text{MS}}$ scheme
4.1 ±0.3 ±1.0	[40] CHIU	03	LATT	$\overline{\text{MS}}$ scheme

• • • We do not use the following data for averages, fits, limits, etc. • • •

$\geq$ 4.85	$\pm$0.20		[41] DOMINGUEZ...	08B	THEO	$\overline{\text{MS}}$ scheme
3.45	$^{+0.14}_{-0.20}$		[42] ALIKHAN	02	LATT	$\overline{\text{MS}}$ scheme
5.3	$\pm$0.3		[43] CHIU	02	LATT	$\overline{\text{MS}}$ scheme
3.9	$\pm$0.6		[44] MALTMAN	02	THEO	$\overline{\text{MS}}$ scheme
3.9	$\pm$0.6		[45] MALTMAN	01	THEO	$\overline{\text{MS}}$ scheme
4.57	$\pm$0.18		[46] AOKI	00	LATT	$\overline{\text{MS}}$ scheme
4.4	$\pm$2		[47] GOCKELER	00	LATT	$\overline{\text{MS}}$ scheme
4.23	$\pm$0.29		[48] AOKI	99	LATT	$\overline{\text{MS}}$ scheme
$\geq$ 2.1			[49] STEELE	99	THEO	$\overline{\text{MS}}$ scheme
4.5	$\pm$0.4		[50] BECIREVIC	98	LATT	$\overline{\text{MS}}$ scheme
4.6	$\pm$1.2		[51] DOSCH	98	THEO	$\overline{\text{MS}}$ scheme
4.7	$\pm$0.9		[52] PRADES	98	THEO	$\overline{\text{MS}}$ scheme
2.7	$\pm$0.2		[53] EICKER	97	LATT	$\overline{\text{MS}}$ scheme
3.6	$\pm$0.6		[54] GOUGH	97	LATT	$\overline{\text{MS}}$ scheme
3.4	$\pm$0.4	$\pm$0.3	[55] GUPTA	97	LATT	$\overline{\text{MS}}$ scheme
>3.8			[56] LELLOUCH	97	THEO	$\overline{\text{MS}}$ scheme
4.5	$\pm$1.0		[57] BIJNENS	95	THEO	$\overline{\text{MS}}$ scheme

[25] DAVIES 10 determine $\overline{m}_c(\mu)/\overline{m}_s(\mu) = 11.85 \pm 0.16$ using a lattice computation with dynamical fermions of the pseudoscalar meson masses. Mass $\overline{m}$ is obtained from this using the value of m_c from ALLISON 08 and the BAZAVOV 10 values for the light quark mass ratio, $m_s/\overline{m}$.

[26] DOMINGUEZ 09 use QCD finite energy sum rules for the two-point function of the divergence of the axial vector current computed to order α_s^4.

[27] ALLTON 08 use a lattice computation of the π, K, and Ω masses with 2+1 dynamical flavors of domain wall quarks, and non-perturbative renormalization.

[28] BLOSSIER 08 use a lattice computation of pseudoscalar meson masses and decay constants with 2 dynamical flavors and non-perturbative renormalization.

[29] ISHIKAWA 08 use a lattice computation of the light meson spectrum with 2+1 dynamical flavors of $\mathcal{O}(a)$ improved Wilson quarks, and one-loop perturbative renormalization.

[30] NAKAMURA 08 do a lattice computation using quenched domain wall fermions and non-perturbative renormalization.

[31] BLUM 07 determine quark mass using a QED plus QCD lattice computation with two dynamical flavors of the pseudoscalar meson masses.

[32] GOCKELER 06 use an unquenched lattice computation of the axial Ward Identity with $N_f = 2$ dynamical light quark flavors, and non-perturbative renormalization, to obtain $\overline{m}(2\text{ GeV}) = 4.08 \pm 0.25 \pm 0.19 \pm 0.23$ MeV, where the first error is statistical, the second and third are systematic due to the fit range and force scale uncertainties, respectively. We have combined the systematic errors linearly.

[33] GOCKELER 06A use an unquenched lattice computation of the pseudoscalar meson masses with $N_f = 2$ dynamical light quark flavors, and non-perturbative renormalization.

[34] MASON 06 extract light quark masses from a lattice simulation using staggered fermions with an improved action, and three dynamical light quark flavors with degenerate u and d quarks. Perturbative corrections were included at NNLO order.

[35] NARISON 06 uses sum rules for $e^+ e^- \to$ hadrons to order α_s^3 to determine m_s combined with other determinations of the quark mass ratios.

[36] AUBIN 04 perform three flavor dynamical lattice calculation of pseudoscalar meson masses, with one-loop perturbative renormalization constant.

[37] AOKI 03 uses quenched lattice simulation of the meson and baryon masses with degenerate light quarks. The extrapolations are done using quenched chiral perturbation theory.

[38] The errors given in AOKI 03B were $^{+0.046}_{-0.069}$. We changed them to ± 0.3 for calculating the overall best values. AOKI 03B uses lattice simulation of the meson and baryon masses with two dynamical light quarks. Simulations are performed using the $\mathcal{O}(a)$ improved Wilson action.

[39] BECIREVIC 03 perform quenched lattice computation using the vector and axial Ward identities. Uses $\mathcal{O}(a)$ improved Wilson action and nonperturbative renormalization.

[40] CHIU 03 determines quark masses from the pion and kaon masses using a lattice simulation with a chiral fermion action in quenched approximation.

[41] DOMINGUEZ-CLARIMON 08B obtain an inequality from sum rules for the scalar two-point correlator.

[42] ALIKHAN 02 uses lattice simulation of the meson and baryon masses with two dynamical flavors and degenerate light quarks.

[43] CHIU 02 extracts the average light quark mass from quenched lattice simulations using quenched chiral perturbation theory.

[44] MALTMAN 02 uses finite energy sum rules in the $u d$ and $u s$ pseudoscalar channels. Other mass values are also obtained by similar methods.

[45] MALTMAN 01 uses Borel transformed and finite energy sum rules.

[46] AOKI 00 obtain the light quark masses from a quenched lattice simulation of the meson and baryon spectrum with the Wilson quark action.

[47] GOCKELER 00 obtained from a quenched lattice computation of the pseudoscalar meson masses using $\mathcal{O}(a)$ improved Wilson fermions and nonperturbative renormalization.

[48] AOKI 99 obtain the light quark masses from a quenched lattice simulation of the meson spectrum with the staggered quark action employing the regularization independent scheme.

[49] STEELE 99 obtain a bound on the light quark masses by applying the Holder inequality to a sum rule. We have converted their bound of $(m_u+m_d)/2 \geq 3$ MeV at μ=1 GeV to μ=2 GeV.

[50] BECIREVIC 98 compute the quark mass using the Alpha action in the quenched approximation. The conversion from the regularization independent scheme to the $\overline{\text{MS}}$ scheme is at NNLO.

[51] DOSCH 98 use sum rule determinations of the quark condensate and chiral perturbation theory to obtain $9.4 \leq (m_u+m_d)(1\,\text{GeV}) \leq 15.7$ MeV. We have converted to result to μ=2 GeV.

[52] PRADES 98 uses finite energy sum rules for the axial current correlator.

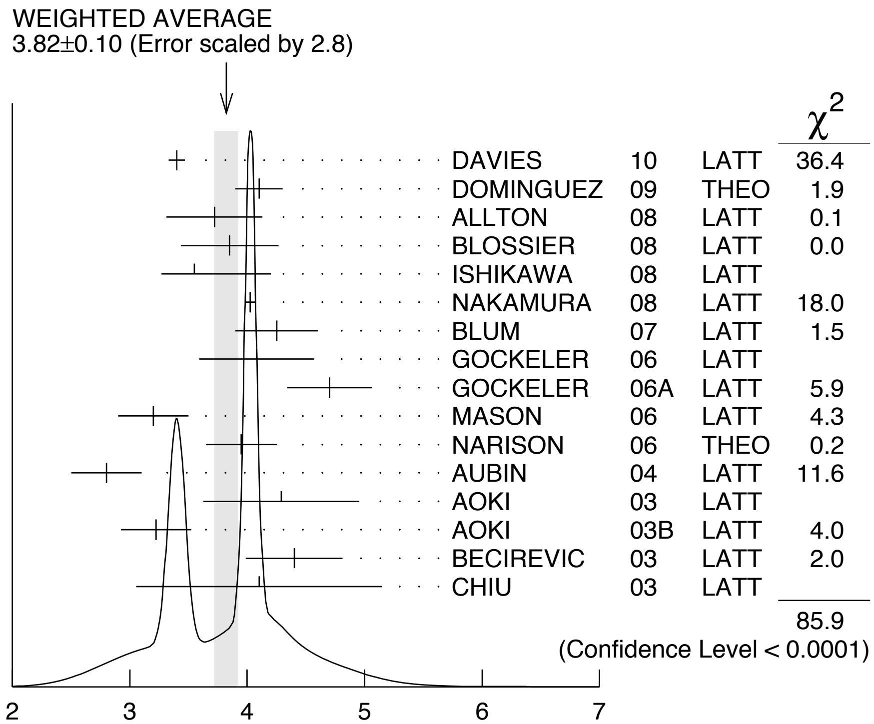
[53] EICKER 97 use lattice gauge computations with two dynamical light flavors.

[54] GOUGH 97 use lattice gauge computations in the quenched approximation. Correcting for quenching gives $2.1 < \overline{m} < 3.5$ MeV at μ=2 GeV.

[55] GUPTA 97 use Lattice Monte Carlo computations in the quenched approximation. The value for two light dynamic flavors at $\mu = 2$ GeV is $2.7 \pm 0.3 \pm 0.3$ MeV.

[56] LELLOUCH 97 obtain lower bounds on quark masses using hadronic spectral functions.

[57] BIJNENS 95 determines m_u+m_d (1 GeV) $= 12 \pm 2.5$ MeV using finite energy sum rules. We have rescaled this to 2 GeV.



$\overline{m} = (m_u+m_d)/2$ (MeV)

m_u/m_d MASS RATIO

VALUE	DOCUMENT ID		TECN	COMMENT
$0.494^{+0.106}_{-0.144}$ (0.35–0.60) OUR EVALUATION See the ideogram below.				
0.550±0.031	[58] BLUM	07	LATT	$\overline{\rm MS}$ scheme
0.43 ±0.08	[59] AUBIN	04A	LATT	$\overline{\rm MS}$ scheme
0.410±0.036	[60] NELSON	03	LATT	$\overline{\rm MS}$ scheme
0.553±0.043	[61] LEUTWYLER	96	THEO	Compilation
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.44	[62] GAO	97	THEO	$\overline{\rm MS}$ scheme
<0.3	[63] CHOI	92	THEO	
0.26	[64] DONOGHUE	92	THEO	
0.30 ±0.07	[65] DONOGHUE	92B	THEO	
0.66	[66] GERARD	90	THEO	
0.4 to 0.65	[67] LEUTWYLER	90B	THEO	
0.05 to 0.78	[68] MALTMAN	90	THEO	

[58] BLUM 07 determine quark mass using a QED plus QCD lattice computation with two dynamical flavors of the pseudoscalar meson masses.

[59] AUBIN 04A perform three flavor dynamical lattice calculation of pseudoscalar meson masses, with continuum estimate of electromagnetic effects in the kaon masses.

[60] NELSON 03 computes coefficients in the order p^4 chiral Lagrangian using a lattice calculation with three dynamical flavors. The ratio m_u/m_d is obtained by combining this with the chiral perturbation theory computation of the meson masses to order p^4.

[61] LEUTWYLER 96 uses a combined fit to $\eta \rightarrow 3\pi$ and $\psi' \rightarrow J/\psi$ (π,η) decay rates, and the electromagnetic mass differences of the π and K.

[62] GAO 97 uses electromagnetic mass splittings of light mesons.

[63] CHOI 92 result obtained from the decays $\psi(2S) \to J/\psi(1S)\pi$ and $\psi(2S) \to J/\psi(1S)\eta$, and a dilute instanton gas estimate of some unknown matrix elements.

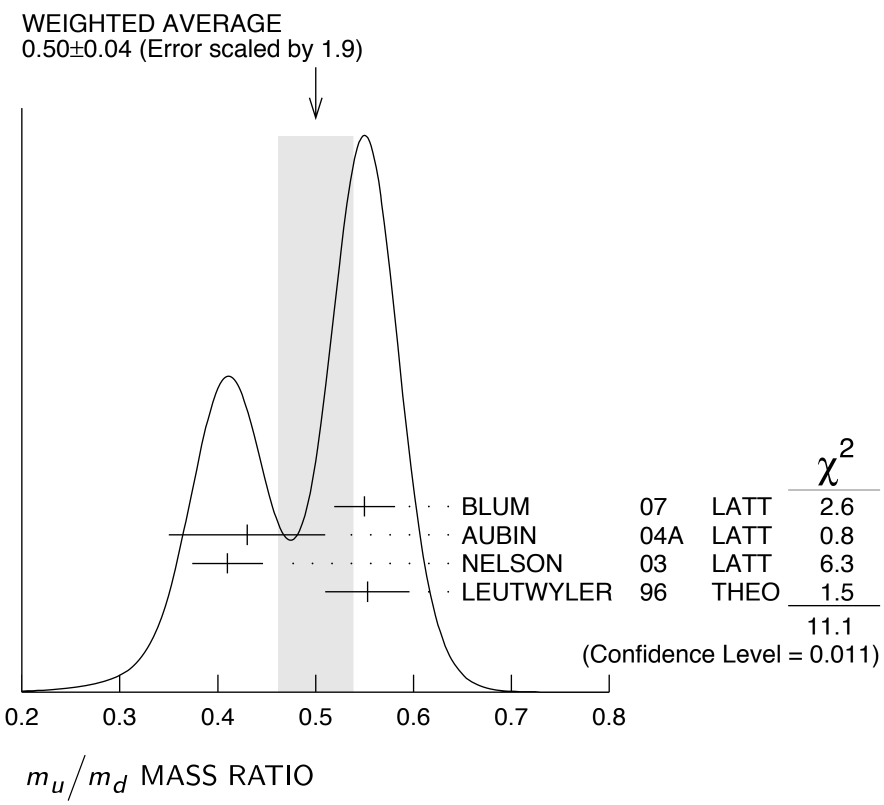
[64] DONOGHUE 92 result is from a combined analysis of meson masses, $\eta \to 3\pi$ using second-order chiral perturbation theory including nonanalytic terms, and $(\psi(2S) \to J/\psi(1S)\pi)/(\psi(2S) \to J/\psi(1S)\eta)$.

[65] DONOGHUE 92B computes quark mass ratios using $(\psi(2S) \to J/\psi(1S)\pi)/(\psi(2S) \to J/\psi(1S)\eta)$, and an estimate of L_{14} using Weinberg sum rules.

[66] GERARD 90 uses large N and η-η' mixing.

[67] LEUTWYLER 90B determines quark mass ratios using second-order chiral perturbation theory for the meson and baryon masses, including nonanalytic corrections. Also uses Weinberg sum rules to determine L_7.

[68] MALTMAN 90 uses second-order chiral perturbation theory including nonanalytic terms for the meson masses. Uses a criterion of "maximum reasonableness" that certain coefficients which are expected to be of order one are ≤ 3.



s-QUARK MASS

See the comment for the u quark above.

We have normalized the $\overline{\text{MS}}$ masses at a renormalization scale of $\mu = 2$ GeV. Results quoted in the literature at $\mu = 1$ GeV have been rescaled by dividing by 1.35.

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
101^{+29}_{-21} (80–130) OUR EVALUATION	See the ideogram below.			
92.4 ± 1.5	[69] DAVIES	10	LATT	$\overline{\text{MS}}$ scheme

107.3 ± 11.7	[70] ALLTON	08	LATT	$\overline{\rm MS}$ scheme
$105 \pm 3 \pm 9$	[71] BLOSSIER	08	LATT	$\overline{\rm MS}$ scheme
102 ± 8	[72] DOMINGUEZ	08A	THEO	$\overline{\rm MS}$ scheme
$90.1^{+17.2}_{-6.1}$	[73] ISHIKAWA	08	LATT	$\overline{\rm MS}$ scheme
105.6 ± 1.2	[74] NAKAMURA	08	LATT	$\overline{\rm MS}$ scheme
119.5 ± 9.3	[75] BLUM	07	LATT	$\overline{\rm MS}$ scheme
$105 \pm 6 \pm 7$	[76] CHETYRKIN	06	THEO	$\overline{\rm MS}$ scheme
$111 \pm 6 \pm 10$	[77] GOCKELER	06	LATT	$\overline{\rm MS}$ scheme
$119 \pm 5 \pm 8$	[78] GOCKELER	06A	LATT	$\overline{\rm MS}$ scheme
92 ± 9	[79] JAMIN	06	THEO	$\overline{\rm MS}$ scheme
87 ± 6	[80] MASON	06	LATT	$\overline{\rm MS}$ scheme
104 ± 15	[81] NARISON	06	THEO	$\overline{\rm MS}$ scheme
$\geq 71 \pm 4, \leq 151 \pm 14$	[82] NARISON	06	THEO	$\overline{\rm MS}$ scheme
$96^{+5}_{-3}{}^{+16}_{-18}$	[83] BAIKOV	05	THEO	$\overline{\rm MS}$ scheme
81 ± 22	[84] GAMIZ	05	THEO	$\overline{\rm MS}$ scheme
125 ± 28	[85] GORBUNOV	05	THEO	$\overline{\rm MS}$ scheme
93 ± 32	[86] NARISON	05	THEO	$\overline{\rm MS}$ scheme
76 ± 8	[87] AUBIN	04	LATT	$\overline{\rm MS}$ scheme
$116 \pm 6 \pm 0.65$	[88] AOKI	03	LATT	$\overline{\rm MS}$ scheme
$84.5^{+12}_{-1.7}$	[89] AOKI	03B	LATT	$\overline{\rm MS}$ scheme
$106 \pm 2 \pm 8$	[90] BECIREVIC	03	LATT	$\overline{\rm MS}$ scheme
$92 \pm 9 \pm 16$	[91] CHIU	03	LATT	$\overline{\rm MS}$ scheme
117 ± 17	[92] GAMIZ	03	THEO	$\overline{\rm MS}$ scheme
103 ± 17	[93] GAMIZ	03	THEO	$\overline{\rm MS}$ scheme

• • • We do not use the following data for averages, fits, limits, etc. • • •

88^{+3}_{-6}	[94] ALIKHAN	02	LATT	$\overline{\rm MS}$ scheme
115 ± 8	[95] CHIU	02	LATT	$\overline{\rm MS}$ scheme
99 ± 16	[96] JAMIN	02	THEO	$\overline{\rm MS}$ scheme
100 ± 12	[97] MALTMAN	02	THEO	$\overline{\rm MS}$ scheme
116^{+20}_{-25}	[98] CHEN	01B	THEO	$\overline{\rm MS}$ scheme
125 ± 27	[99] KOERNER	01	THEO	$\overline{\rm MS}$ scheme
130 ± 15	[100] AOKI	00	LATT	$\overline{\rm MS}$ scheme
97 ± 4	[101] GARDEN	00	LATT	$\overline{\rm MS}$ scheme
105 ± 4	[102] GOCKELER	00	LATT	$\overline{\rm MS}$ scheme
118 ± 14	[103] AOKI	99	LATT	$\overline{\rm MS}$ scheme
170^{+44}_{-55}	[104] BARATE	99R	ALEP	$\overline{\rm MS}$ scheme
115 ± 8	[105] MALTMAN	99	THEO	$\overline{\rm MS}$ scheme
129 ± 24	[106] NARISON	99	THEO	$\overline{\rm MS}$ scheme
114 ± 23	[107] PICH	99	THEO	$\overline{\rm MS}$ scheme
111 ± 12	[108] BECIREVIC	98	LATT	$\overline{\rm MS}$ scheme
148 ± 48	[109] CHETYRKIN	98	THEO	$\overline{\rm MS}$ scheme
103 ± 10	[110] CUCCHIERI	98	LATT	$\overline{\rm MS}$ scheme
115 ± 19	[111] DOMINGUEZ	98	THEO	$\overline{\rm MS}$ scheme
152.4 ± 14.1	[112] CHETYRKIN	97	THEO	$\overline{\rm MS}$ scheme
≥ 89	[113] COLANGELO	97	THEO	$\overline{\rm MS}$ scheme

140	±20		[114] EICKER	97	LATT	$\overline{\rm MS}$ scheme
95	±16		[115] GOUGH	97	LATT	$\overline{\rm MS}$ scheme
100	±21	±10	[116] GUPTA	97	LATT	$\overline{\rm MS}$ scheme
>100			[117] LELLOUCH	97	THEO	$\overline{\rm MS}$ scheme
140	±24		[118] JAMIN	95	THEO	$\overline{\rm MS}$ scheme

[69] DAVIES 10 determine $\overline{m}_c(\mu)/\overline{m}_s(\mu) = 11.85 \pm 0.16$ using a lattice computation with dynamical fermions of the pseudoscalar meson masses. Mass m_s is obtained from this using the value of m_c from ALLISON 08.

[70] ALLTON 08 use a lattice computation of the π, K, and Ω masses with 2+1 dynamical flavors of domain wall quarks, and non-perturbative renormalization.

[71] BLOSSIER 08 use a lattice computation of pseudoscalar meson masses and decay constants with 2 dynamical flavors and non-perturbative renormalization.

[72] DOMINGUEZ 08A make determination from QCD finite energy sum rules for the pseudoscalar two-point function computed to order α_s^4.

[73] ISHIKAWA 08 use a lattice computation of the light meson spectrum with 2+1 dynamical flavors of $\mathcal{O}(a)$ improved Wilson quarks, and one-loop perturbative renormalization.

[74] NAKAMURA 08 do a lattice computation using quenched domain wall fermions and non-perturbative renormalization.

[75] BLUM 07 determine quark mass using a QED plus QCD lattice computation with two dynamical flavors of the pseudoscalar meson masses.

[76] CHETYRKIN 06 use QCD sum rules in the pseudoscalar channel to order α_s^4.

[77] GOCKELER 06 use an unquenched lattice computation of the axial Ward Identity with $N_f = 2$ dynamical light quark flavors, and non-perturbative renormalization, to obtain $\overline{m}_s(2\ \text{GeV}) = 111 \pm 6 \pm 4 \pm 6$ MeV, where the first error is statistical, the second and third are systematic due to the fit range and force scale uncertainties, respectively. We have combined the systematic errors linearly.

[78] GOCKELER 06A use an unquenched lattice computation of the pseudoscalar meson masses with $N_f = 2$ dynamical light quark flavors, and non-perturbative renormalization.

[79] JAMIN 06 determine $\overline{m}_s(2\ \text{GeV})$ from the spectral function for the scalar $K\pi$ form factor.

[80] MASON 06 extract light quark masses from a lattice simulation using staggered fermions with an improved action, and three dynamical light quark flavors with degenerate u and d quarks. Perturbative corrections were included at NNLO order.

[81] NARISON 06 uses sum rules for $e^+e^- \rightarrow$ hadrons to order α_s^3.

[82] NARISON 06 obtains the quoted range from positivity of the spectral functions.

[83] BAIKOV 05 determines $\overline{m}_s(M_\tau) = 100^{+5}_{-3}{}^{+17}_{-19}$ from sum rules using the strange spectral function in τ decay. The computations were done to order α_s^3, with an estimate of the α_s^4 terms. We have converted the result to $\mu = 2$ GeV.

[84] GAMIZ 05 determines $\overline{m}_s(2\ \text{GeV})$ from sum rules using the strange spectral function in τ decay. The computations were done to order α_s^2, with an estimate of the α_s^3 terms.

[85] GORBUNOV 05 use hadronic tau decays to N^{3}LO, including power corrections.

[86] NARISON 05 determines $\overline{m}_s(2\ \text{GeV})$ from sum rules using the strange spectral function in τ decay. The computations were done to order α_s^3.

[87] AUBIN 04 perform three flavor dynamical lattice calculation of pseudoscalar meson masses, with one-loop perturbative renormalization constant.

[88] AOKI 03 uses quenched lattice simulation of the meson and baryon masses with degenerate light quarks. The extrapolations are done using quenched chiral perturbation theory. Determines $m_s = 113.8 \pm 2.3^{+5.8}_{-2.9}$ using K mass as input and $m_s = 142.3 \pm 5.8^{+22}_{-0}$ using ϕ mass as input. We have performed a weighted average of these values.

[89] AOKI 03B uses lattice simulation of the meson and baryon masses with two dynamical light quarks. Simulations are performed using the $\mathcal{O}(a)$ improved Wilson action.

[90] BECIREVIC 03 perform quenched lattice computation using the vector and axial Ward identities. Uses $\mathcal{O}(a)$ improved Wilson action and nonperturbative renormalization. They also quote $\overline{m}/m_s$=24.3 ± 0.2 ± 0.6.

[91] CHIU 03 determines quark masses from the pion and kaon masses using a lattice simulation with a chiral fermion action in quenched approximation.

[92] GAMIZ 03 determines m_s from SU(3) breaking in the τ hadronic width. The value of V_{us} is chosen to satisfy CKM unitarity.

[93] GAMIZ 03 determines m_s from SU(3) breaking in the τ hadronic width. The value of V_{us} is taken from the PDG.

[94] ALIKHAN 02 uses lattice simulation of the meson and baryon masses with two dynamical flavors and degenerate light quarks. The above value uses the K-meson mass to determine m_s. If the ϕ meson is used, the number changes to $90^{+\ 5}_{-10}$.

[95] CHIU 02 extracts the strange quark mass from quenched lattice simulations using quenched chiral perturbation theory.

[96] JAMIN 02 calculates the strange quark mass from QCD sum rules using the scalar channel.

[97] MALTMAN 02 uses finite energy sum rules in the ud and us pseudoscalar channels. Other mass values are also obtained by similar methods.

[98] CHEN 01B uses an analysis of the hadronic spectral function in τ decay.

[99] KOERNER 01 obtain the s quark mass of $m_s(m_\tau) = 130 \pm 27$(exp) ± 9(thy) MeV from an analysis of Cabibbo suppressed τ decays. We have converted this to $\mu = 2$ GeV.

[100] AOKI 00 obtain the light quark masses from a quenched lattice simulation of the meson and baryon spectrum with the Wilson quark action. We have averaged their results of m_s= 115.6 ± 2.3 and m_s= 143.7 ± 5.8 obtained using m_K and m_ϕ, respectively, to normalize the spectrum.

[101] GARDEN 00 use a quenched lattice computation of the hadron spectrum.

[102] GOCKELER 00 obtained from a quenched lattice computation of the pseudoscalar meson masses using $\mathcal{O}(a)$ improved Wilson fermions and nonperturbative renormalization.

[103] AOKI 99 obtain the light quark masses from a quenched lattice simulation of the meson spectrum with the Staggered quark action employing the regularization independent scheme. We have averaged their results of m_s=106.0 ± 7.1 and m_s=129 ± 12 obtained using m_K and m_ϕ, respectively, to normalize the spectrum.

[104] BARATE 99R obtain the strange quark mass from an analysis of the observed mass spectra in τ decay. We have converted their value of $m_s(m_\tau)$= 176^{+46}_{-57} MeV to μ=2 GeV.

[105] MALTMAN 99 determines the strange quark mass using finite energy sum rules.

[106] NARISON 99 uses sum rules to order α_s^3 for ϕ meson decays.

[107] PICH 99 obtain the s-quark mass from an analysis of the moments of the invariant mass distribution in τ decays.

[108] BECIREVIC 98 compute the quark mass using the Alpha action in the quenched approximation. The conversion from the regularization independent scheme to the $\overline{\text{MS}}$ scheme is at NNLO.

[109] CHETYRKIN 98 uses spectral moments of hadronic τ decays to determine m_s(1 GeV)=200 ± 70 MeV. We have rescaled the result to μ=2 GeV.

[110] CUCCHIERI 98 obtains the quark mass using a quenched lattice computation of the hadronic spectrum.

[111] DOMINGUEZ 98 uses hadronic spectral function sum rules (to four loops, and including dimension six operators) to determine m_s(1 GeV)< 155 ± 25 MeV. We have rescaled the result to μ=2 GeV.

[112] CHETYRKIN 97 obtains 205.5 ± 19.1 MeV at μ=1 GeV from QCD sum rules including fourth-order QCD corrections. We have rescaled the result to 2 GeV.

[113] COLANGELO 97 is QCD sum rule computation. We have rescaled m_s(1 GeV) > 120 to μ = 2 GeV.

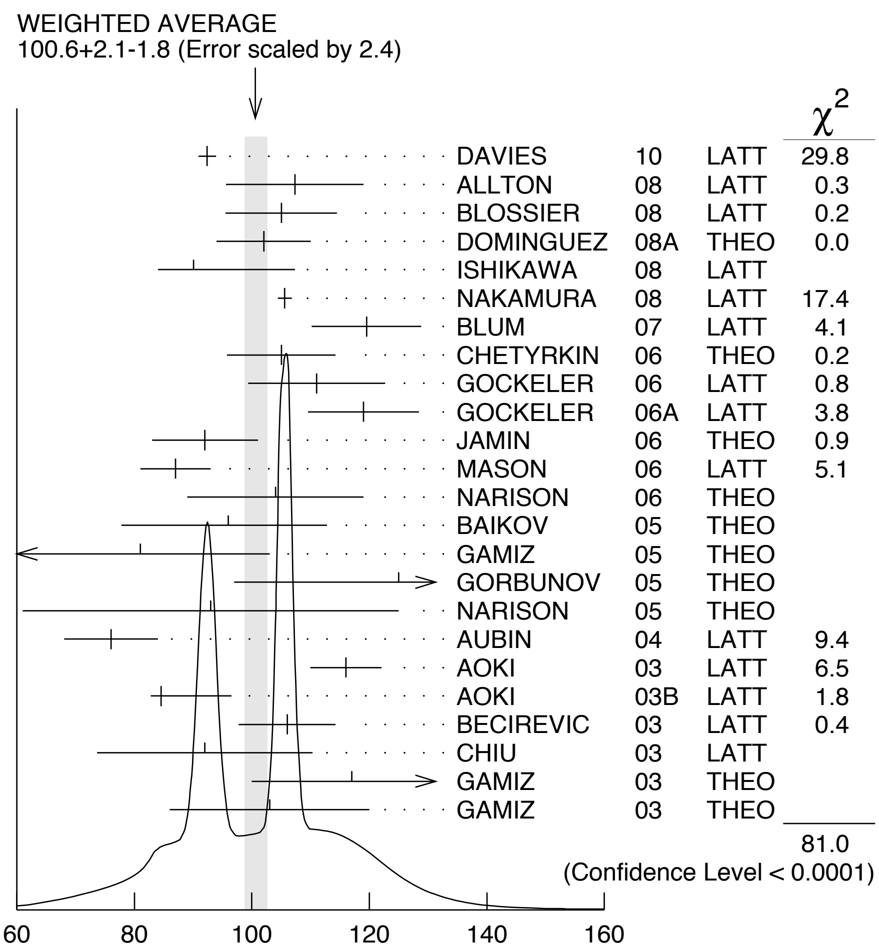
[114] EICKER 97 use lattice gauge computations with two dynamical light flavors.

[115] GOUGH 97 use lattice gauge computations in the quenched approximation. Correcting for quenching gives 54 $< m_s <$ 92 MeV at μ=2 GeV.

[116] GUPTA 97 use Lattice Monte Carlo computations in the quenched approximation. The value for two light dynamical flavors at μ = 2 GeV is 68 $\pm$ 12 $\pm$ 7 MeV.

[117] LELLOUCH 97 obtain lower bounds on quark masses using hadronic spectral functions.

[118] JAMIN 95 uses QCD sum rules at next-to-leading order. We have rescaled m_s(1 GeV) = 189 $\pm$ 32 to μ = 2 GeV.



s-QUARK MASS (MeV)

OTHER LIGHT QUARK MASS RATIOS

m_s/m_d MASS RATIO

VALUE	DOCUMENT ID		TECN	COMMENT
17 to 22 OUR EVALUATION				
• • • We do not use the following data for averages, fits, limits, etc. • • •				
20.0	[119] GAO	97	THEO	$\overline{\text{MS}}$ scheme
18.9±0.8	[120] LEUTWYLER	96	THEO	Compilation
21	[121] DONOGHUE	92	THEO	
18	[122] GERARD	90	THEO	
18 to 23	[123] LEUTWYLER	90B	THEO	

[119] GAO 97 uses electromagnetic mass splittings of light mesons.
[120] LEUTWYLER 96 uses a combined fit to $\eta \rightarrow 3\pi$ and $\psi' \rightarrow J/\psi\ (\pi,\eta)$ decay rates, and the electromagnetic mass differences of the π and K.
[121] DONOGHUE 92 result is from a combined analysis of meson masses, $\eta \rightarrow 3\pi$ using second-order chiral perturbation theory including nonanalytic terms, and $(\psi(2S) \rightarrow J/\psi(1S)\pi)/(\psi(2S) \rightarrow J/\psi(1S)\eta)$.
[122] GERARD 90 uses large N and η-η' mixing.
[123] LEUTWYLER 90B determines quark mass ratios using second-order chiral perturbation theory for the meson and baryon masses, including nonanalytic corrections. Also uses Weinberg sum rules to determine L_7.

$m_s/\overline{m}$ MASS RATIO

$\overline{m} \equiv (m_u + m_d)/2$

VALUE	DOCUMENT ID		TECN	COMMENT
22 to 30 OUR EVALUATION				
• • • We do not use the following data for averages, fits, limits, etc. • • •				
28.8±1.65	[124] ALLTON	08	LATT	$\overline{\rm MS}$ scheme
27.3±0.3 ±1.2	[125] BLOSSIER	08	LATT	$\overline{\rm MS}$ scheme
23.5±1.5	[126] OLLER	07A	THEO	
27.4±0.4	[127] AUBIN	04	LATT	

[124] ALLTON 08 use a lattice computation of the π, K, and Ω masses with 2+1 dynamical flavors of domain wall quarks, and non-perturbative renormalization.
[125] BLOSSIER 08 use a lattice computation of pseudoscalar meson masses and decay constants with 2 dynamical flavors and non-perturbative renormalization.
[126] OLLER 07A use unitarized chiral perturbation theory to order p^4.
[127] Three flavor dynamical lattice calculation of pseudoscalar meson masses.

Q MASS RATIO

$Q \equiv \sqrt{(m^2{}_s - \overline{m}^2)/(m^2{}_d - m^2{}_u)}$; $\quad \overline{m} \equiv (m_u + m_d)/2$

VALUE	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits, limits, etc. • • •			
22.8±0.4	[128] MARTEMYA...	05	THEO
22.7±0.8	[129] ANISOVICH	96	THEO

[128] MARTEMYANOV 05 determine Q from $\eta \rightarrow 3\pi$ decay.
[129] ANISOVICH 96 find Q from $\eta \rightarrow \pi^+\pi^-\pi^0$ decay using dispersion relations and chiral perturbation theory.

LIGHT QUARKS (u, d, s) REFERENCES

BAZAVOV	10	arXiv:0903.3598	A. Bazavov et al.	(MILC Collab.)
DAVIES	10	PRL 104 132003	C.T.H. Davies et al.	(HPQCD Collab.)
DOMINGUEZ	09	PR D79 014009	C.A. Dominguez et al.	
ALLISON	08	PR D78 054513	I. Allison et al.	(HPQCD Collab.)
ALLTON	08	PR D78 114509	C. Allton et al.	(RBC and UKQCD Collab.)
BLOSSIER	08	JHEP 0804 020	B. Blossier et al.	(ETM Collab.)
DEANDREA	08	PR D78 034032	A. Deandrea, A. Nehme, P. Talavera	
DOMINGUEZ	08A	JHEP 0805 020	C.A. Dominguez et al.	
DOMINGUEZ...	08B	PL B660 49	A. Dominguez-Clarimon, E. de Rafael, J. Taron	
ISHIKAWA	08	PR D78 011502R	T. Ishikawa et al.	(CP-PACS and JLQCD Collab.)
NAKAMURA	08	PR D78 034502	Y. Nakamura et al.	(CP-PACS Collab.)
BLUM	07	PR D76 114508	T. Blum et al.	(RBC Collab.)
OLLER	07A	EPJ A34 371	J.A. Oller, L. Roca	
CHETYRKIN	06	EPJ C46 721	K.G. Chetyrkin, A. Khodjamirian	
GOCKELER	06	PR D73 054508	M. Gockeler et al.	(QCDSF, UKQCD Collabs)
GOCKELER	06A	PL B639 307	M. Gockeler et al.	(QCDSF, UKQCD Collabs)
JAMIN	06	PR D74 074009	M. Jamin, J.A. Oller, A. Pich	

MASON	06	PR D73 114501	Q. Mason *et al.*	(HPQCD Collab.)
NARISON	06	PR D74 034013	S. Narison	
PDG	06	JPG 33 1	W.-M. Yao *et al.*	(PDG Collab.)
BAIKOV	05	PRL 95 012003	P.A. Baikov, K.G. Chetyrkin, J.H. Kuhn	
GAMIZ	05	PRL 94 011803	E. Gamiz *et al.*	
GORBUNOV	05	PR D71 013002	D.S. Gorbunov, A.A. Pivovarov	
MARTEMYA...	05	PR D71 017501	B.V. Martemyanov, V.S. Sopov	
NARISON	05	PL B626 101	S. Narison	
AUBIN	04	PR D70 031504R	C. Aubin *et al.*	(HPQCD, MILC, UKQCD Collabs.)
AUBIN	04A	PR D70 114501	C. Aubin *et al.*	(MILC Collab.)
AOKI	03	PR D67 034503	S. Aoki *et al.*	(CP-PACS Collab.)
AOKI	03B	PR D68 054502	S. Aoki *et al.*	(CP-PACS Collab.)
BECIREVIC	03	PL B558 69	D. Becirevic, V. Lubicz, C. Tarantino	
CHIU	03	NP B673 217	T.-W. Chiu, T.-H. Hsieh	
GAMIZ	03	JHEP 0301 060	E. Gamiz *et al.*	
NELSON	03	PRL 90 021601	D. Nelson, G.T. Fleming, G.W. Kilcup	
ALIKHAN	02	PR D65 054505	A. Ali Khan *et al.*	(CP-PACS Collab.)
Also		PR D67 059901 (erratum)	A. Ali Khan *et al.*	(CP-PACS Collab.)
CHIU	02	PL B538 298	T.-W. Chiu, T.-H. Hsieh	
JAMIN	02	EPJ C24 237	M. Jamin, J.A. Oller, A. Pich	
MALTMAN	02	PR D65 074013	K. Maltman, J. Kambor	
CHEN	01B	EPJ C22 31	S. Chen *et al.*	
KOERNER	01	EPJ C20 259	J.G. Koerner, F. Krajewski, A.A. Pivovarov	
MALTMAN	01	PL B517 332	K. Maltman, J. Kambor	
AOKI	00	PRL 84 238	S. Aoki *et al.*	(CP-PACS Collab.)
GARDEN	00	NP B571 237	J. Garden *et al.*	(ALPHA, UKQCD Collabs)
GOCKELER	00	PR D62 054504	M. Gockeler *et al.*	
AOKI	99	PRL 82 4392	S. Aoki *et al.*	(JLQCD Collab.)
BARATE	99R	EPJ C11 599	R. Barate *et al.*	(ALEPH Collab.)
MALTMAN	99	PL B462 195	K. Maltman	
NARISON	99	PL B466 345	S. Narison	
PICH	99	JHEP 9910 004	A. Pich, J. Prades	
STEELE	99	PL B451 201	T.G. Steele, K. Kostuik, J. Kwan	
BECIREVIC	98	PL B444 401	D. Becirevic *et al.*	
CHETYRKIN	98	NP B533 473	K.G. Chetyrkin, J.H. Kuehn, A.A. Pivovarov	
CUCCHIERI	98	PL B422 212	A. Chucchieri *et al.*	
DOMINGUEZ	98	PL B425 193	C.A. Dominguez, L. Pirovano, K. Schilcher	
DOSCH	98	PL B417 173	H.G. Dosch, S. Narison	
PRADES	98	NPBPS 64 253	J. Prades	
CHETYRKIN	97	PL B404 337	K.G. Chetyrkin, D. Pirjol, K. Schilcher	
COLANGELO	97	PL B408 340	P. Colangelo *et al.*	
EICKER	97	PL B407 290	N. Eicker *et al.*	(SESAM Collab.)
GAO	97	PR D56 4115	D.-N. Gao, B.A. Li, M.-L. Yan	
GOUGH	97	PRL 79 1622	B. Gough *et al.*	
GUPTA	97	PR D55 7203	R. Gupta, T. Bhattacharya	
LELLOUCH	97	PL B414 195	L. Lellouch, E. de Rafael, J. Taron	
ANISOVICH	96	PL B375 335	A.V. Anisovich, H. Leutwyler	
LEUTWYLER	96	PL B378 313	H. Leutwyler	
BIJNENS	95	PL B348 226	J. Bijnens, J. Prades, E. de Rafael	(NORD, BOHR+)
JAMIN	95	ZPHY C66 633	M. Jamin, M. Munz	(HEIDT, MUNT)
NARISON	95C	PL B358 113	S. Narison	(MONP)
CHOI	92	PL B292 159	K.W. Choi	(UCSD)
DONOGHUE	92	PRL 69 3444	J.F. Donoghue, B.R. Holstein, D. Wyler	(MASA+)
DONOGHUE	92B	PR D45 892	J.F. Donoghue, D. Wyler	(MASA, ZURI, UCSBT)
GERARD	90	MPL A5 391	J.M. Gerard	(MPIM)
LEUTWYLER	90B	NP B337 108	H. Leutwyler	(BERN)
MALTMAN	90	PL B234 158	K. Maltman, T. Goldman, Stephenson Jr.	(YORKC+)