Light Quarks (u, d, s)

OMITTED FROM SUMMARY TABLE

See the related review(s):

Quark Masses

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 2 and 3 in the "Quark masses" review.

$\overline{\text{MS}}$ *MASS* (MeV)	*CL%*	*DOCUMENT ID*		*TECN*
2.16 ±0.07 (CL = 90%) OUR EVALUATION See the ideogram below.				
2.6 ±0.4		[1] DOMINGUEZ	19	THEO
2.130±0.041		[2] BAZAVOV	18	LATT
2.27 ±0.06 ±0.06		[3] FODOR	16	LATT
2.36 ±0.24		[4] CARRASCO	14	LATT
2.24 ±0.10 ±0.34		[5] BLUM	10	LATT
2.01 ±0.14		[6] MCNEILE	10	LATT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
2.57 ±0.26 ±0.07		[7] AOKI	12	LATT
2.15 ±0.03 ±0.10		[8] DURR	11	LATT
1.9 ±0.2		[9] BAZAVOV	10	LATT
2.01 ±0.14		[6] DAVIES	10	LATT
2.9 ±0.2		[10] DOMINGUEZ	09	THEO
2.9 ±0.8		[11] DEANDREA	08	THEO
3.02 ±0.33		[12] BLUM	07	LATT
2.7 ±0.4		[13] JAMIN	06	THEO
1.9 ±0.2		[14] MASON	06	LATT
2.8 ±0.2		[15] NARISON	06	THEO
1.7 ±0.3		[16] AUBIN	04A	LATT

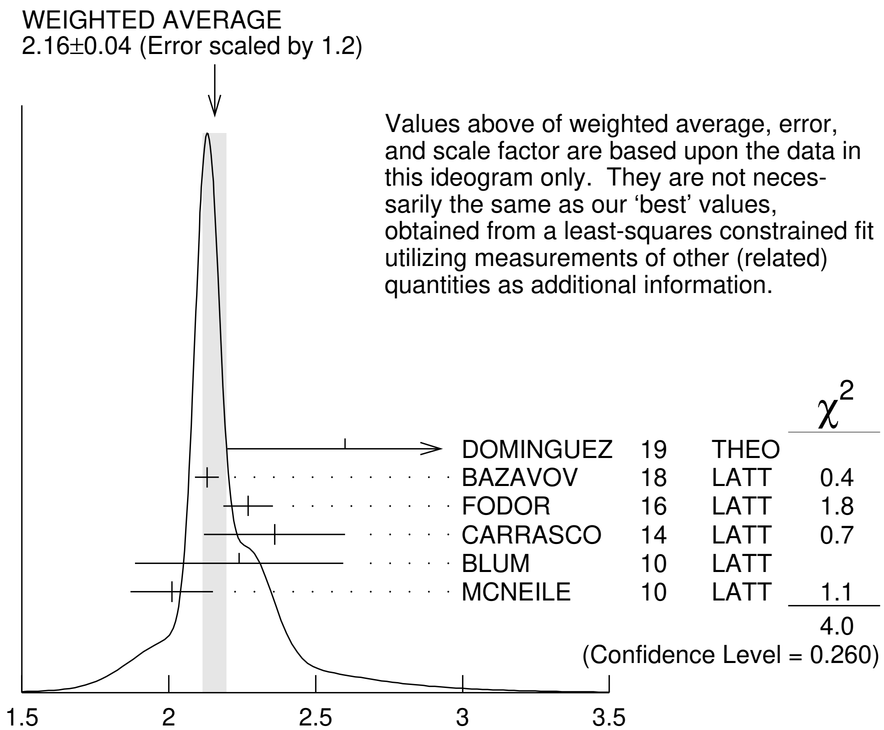
[1] DOMINGUEZ 19 determine the quark mass from a QCD finite energy sum rule for the divergence of the axial current.

[2] BAZAVOV 18 determine the quark masses using a lattice computation with staggered fermions and four active quark flavors.

[3] FODOR 16 is a lattice simulation with $n_f = 2 + 1$ dynamical flavors and includes partially quenched QED effects.

[4] CARRASCO 14 is a lattice QCD computation of light quark masses using $2 + 1 + 1$ dynamical quarks, with $m_u = m_d \neq m_s \neq m_c$. The u and d quark masses are

obtained separately by using the K meson mass splittings and lattice results for the electromagnetic contributions.



u-QUARK MASS (MeV)

[5] BLUM 10 determines light quark masses using a QCD plus QED lattice computation of the electromagnetic mass splittings of the low-lying hadrons. The lattice simulations use 2+1 dynamical quark flavors.

[6] DAVIES 10 and MCNEILE 10 determine $\overline{m}_c(\mu)/\overline{m}_s(\mu) = 11.85 \pm 0.16$ using a lattice computation with $n_f = 2 + 1$ dynamical fermions of the pseudoscalar meson masses. Mass m_u is obtained from this using the value of m_c from ALLISON 08 or MCNEILE 10 and the BAZAVOV 10 values for the light quark mass ratios, $m_s/\overline{m}$ and m_u/m_d.

[7] AOKI 12 is a lattice computation using $1 + 1 + 1$ dynamical quark flavors.

[8] DURR 11 determine quark mass from a lattice computation of the meson spectrum using $n_f = 2 + 1$ dynamical flavors. The lattice simulations were done at the physical quark mass, so that extrapolation in the quark mass was not needed. The individual m_u, m_d values are obtained using the lattice determination of the average mass m_{ud} and of the ratio m_s/m_{ud} and the value of $Q = (m_s^2 - m_{\text{ud}}^2) \ / \ (m_d^2 - m_u^2)$ as determined from $\eta \to 3\pi$ decays.

[9] BAZAVOV 10 is a lattice computation using 2+1 dynamical quark flavors.

[10] 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.

[11] 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.

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

[13] 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.

[14] 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.

[15] 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.

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

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d-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. The values of "Our Evaluation" were determined in part via Figures 2 and 3 in the "Quark masses" review.

$\overline{\text{MS}}$ *MASS* (MeV)	*CL%*	*DOCUMENT ID*		*TECN*
4.70 ±0.07 (CL = 90%) OUR EVALUATION See the ideogram below.				
5.3 ±0.4		[1] DOMINGUEZ	19	THEO
4.675±0.056		[2] BAZAVOV	18	LATT
4.67 ±0.06 ±0.06		[3] FODOR	16	LATT
5.03 ±0.26		[4] CARRASCO	14	LATT
4.65 ±0.15 ±0.32		[5] BLUM	10	LATT
4.77 ±0.15		[6] MCNEILE	10	LATT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
3.68 ±0.29 ±0.10		[7] AOKI	12	LATT
4.79 ±0.07 ±0.12		[8] DURR	11	LATT
4.6 ±0.3		[9] BAZAVOV	10	LATT
4.79 ±0.16		[6] DAVIES	10	LATT
5.3 ±0.4		[10] DOMINGUEZ	09	THEO
4.7 ±0.8		[11] DEANDREA	08	THEO
5.49 ±0.39		[12] BLUM	07	LATT
4.8 ±0.5		[13] JAMIN	06	THEO
4.4 ±0.3		[14] MASON	06	LATT
5.1 ±0.4		[15] NARISON	06	THEO
3.9 ±0.5		[16] AUBIN	04A	LATT

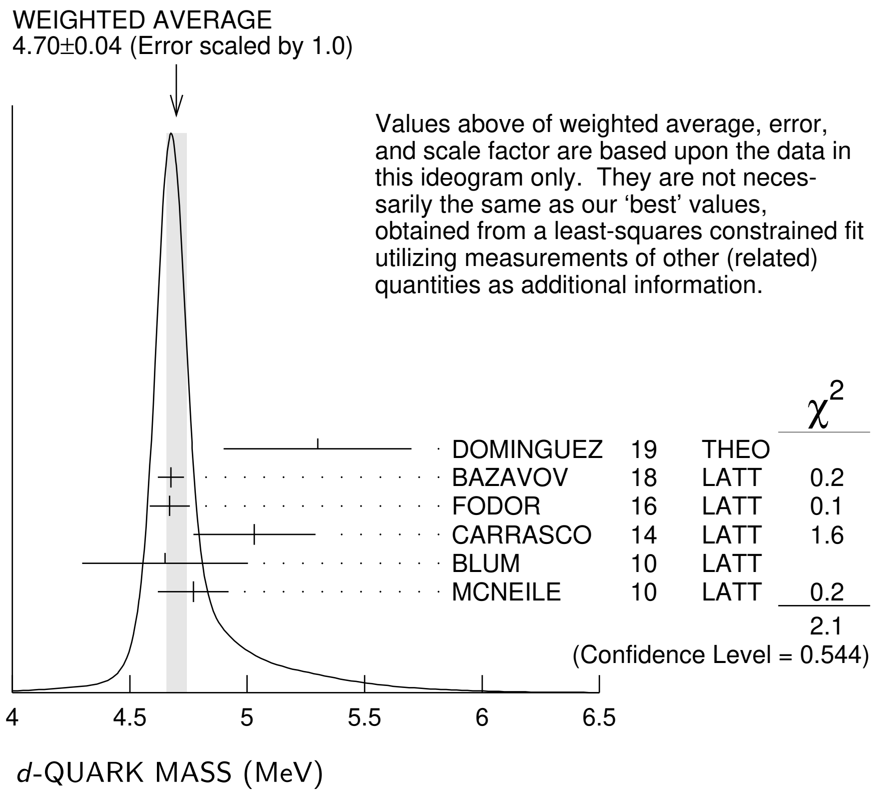
[1] DOMINGUEZ 19 determine the quark mass from a QCD finite energy sum rule for the divergence of the axial current.

[2] BAZAVOV 18 determine the quark masses using a lattice computation with staggered fermions and four active quark flavors.

[3] FODOR 16 is a lattice simulation with $n_f = 2+1$ dynamical flavors and includes partially quenched QED effects.

[4] CARRASCO 14 is a lattice QCD computation of light quark masses using 2 + 1 + 1 dynamical quarks, with $m_u = m_d \neq m_s \neq m_c$. The u and d quark masses are

obtained separately by using the K meson mass splittings and lattice results for the electromagnetic contributions.



[5] BLUM 10 determines light quark masses using a QCD plus QED lattice computation of the electromagnetic mass splittings of the low-lying hadrons. The lattice simulations use 2+1 dynamical quark flavors.

[6] DAVIES 10 and MCNEILE 10 determine $\overline{m}_c(\mu)/\overline{m}_s(\mu) = 11.85 \pm 0.16$ using a lattice computation with $n_f = 2 + 1$ dynamical fermions of the pseudoscalar meson masses. Mass m_d is obtained from this using the value of m_c from ALLISON 08 or MCNEILE 10 and the BAZAVOV 10 values for the light quark mass ratios, $m_s/\overline{m}$ and m_u/m_d.

[7] AOKI 12 is a lattice computation using 1 + 1 + 1 dynamical quark flavors.

[8] DURR 11 determine quark mass from a lattice computation of the meson spectrum using $n_f = 2 + 1$ dynamical flavors. The lattice simulations were done at the physical quark mass, so that extrapolation in the quark mass was not needed. The individual m_u, m_d values are obtained using the lattice determination of the average mass $m_{\rm ud}$ and of the ratio $m_s/m_{\rm ud}$ and the value of $Q = (m_s^2 - m_{\rm ud}^2) / (m_d^2 - m_u^2)$ as determined from $\eta \rightarrow 3\pi$ decays.

[9] BAZAVOV 10 is a lattice computation using 2+1 dynamical quark flavors.

[10] 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.

[11] 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.

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

[13] 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.

[14] 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.

[15] 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.

[16] 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.

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

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 2 and 3 in the "Quark masses" review.

$\overline{\text{MS}}$ MASS (MeV)	CL%	DOCUMENT ID		TECN
3.49 ±0.07 (CL = 90%) OUR EVALUATION		See the ideogram below.		
$3.636 \pm 0.066 {}^{+0.060}_{-0.057}$		[1] ALEXANDROU	21	LATT
$3.54 \pm 0.12 \pm 0.09$		[2] BRUNO	20	LATT
3.9 ± 0.3		[3] DOMINGUEZ	19	THEO
$4.7 {}^{+0.8}_{-0.7}$		[4] YUAN	17	THEO
3.70 ± 0.17		[5] CARRASCO	14	LATT
3.45 ± 0.12		[6] ARTHUR	13	LATT
$3.469 \pm 0.047 \pm 0.048$		[7] DURR	11	LATT
3.6 ± 0.2		[8] BLOSSIER	10	LATT
3.39 ± 0.06		[9] MCNEILE	10	LATT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
3.59 ± 0.21		[10] AOKI	11A	LATT
3.40 ± 0.07		[9] DAVIES	10	LATT
4.1 ± 0.2		[11] DOMINGUEZ	09	THEO
3.72 ± 0.41		[12] ALLTON	08	LATT
$3.85 \pm 0.12 \pm 0.4$		[13] BLOSSIER	08	LATT
$\geq 4.85 \pm 0.20$		[14] DOMINGUEZ...	08B	THEO
$3.55 {}^{+0.65}_{-0.28}$		[15] ISHIKAWA	08	LATT
4.026 ± 0.048		[16] NAKAMURA	08	LATT
4.25 ± 0.35		[17] BLUM	07	LATT
$4.08 \pm 0.25 \pm 0.42$		[18] GOCKELER	06	LATT
$4.7 \pm 0.2 \pm 0.3$		[19] GOCKELER	06A	LATT
3.2 ± 0.3		[20] MASON	06	LATT

3.95	±0.3		[21] NARISON	06	THEO
2.8	±0.3		[22] AUBIN	04	LATT
4.29	±0.14	±0.65	[23] AOKI	03	LATT
3.223	±0.3		[24] AOKI	03B	LATT
4.4	±0.1	±0.4	[25] BECIREVIC	03	LATT
4.1	±0.3	±1.0	[26] CHIU	03	LATT

[1] ALEXANDROU 21 determines the quark mass using a lattice calculation of the meson and baryon masses with a twisted mass fermion action. The simulations are carried out using 2+1+1 dynamical quarks with $m_u = m_d \neq m_s \neq m_c$, including gauge ensembles close to the physical pion point.

[2] BRUNO 20 determines the light quark mass using a lattice calculation with $n_f = 2+1$ flavors of Wilson fermions. The scale has been set from f_π and f_K. The tuning was done using the masses of the lightest (π) and strange (K) pseudoscalar mesons.

[3] DOMINGUEZ 19 determine the quark mass from a QCD finite energy sum rule for the divergence of the axial current.

[4] YUAN 17 determine $\overline{m}$ using QCD sum rules in the isospin I=0 scalar channel. At the end of the "Numerical Results" section of YUAN 17 the authors discuss the significance of their larger value of the light quark mass compared to previous determinations.

[5] CARRASCO 14 is a lattice QCD computation of light quark masses using 2 + 1 + 1 dynamical quarks, with $m_u = m_d \neq m_s \neq m_c$. The u and d quark masses are obtained separately by using the K meson mass splittings and lattice results for the electromagnetic contributions.

[6] ARTHUR 13 is a lattice computation using 2+1 dynamical domain wall fermions. Masses at $\mu = 3$ GeV have been converted to $\mu = 2$ GeV using conversion factors given in their paper.

[7] DURR 11 determine quark mass from a lattice computation of the meson spectrum using $n_f = 2 + 1$ dynamical flavors. The lattice simulations were done at the physical quark mass, so that extrapolation in the quark mass was not needed.

[8] BLOSSIER 10 determines quark masses from a computation of the hadron spectrum using n_f=2 dynamical twisted-mass Wilson fermions.

[9] DAVIES 10 and MCNEILE 10 determine $\overline{m}_c(\mu)/\overline{m}_s(\mu) = 11.85 \pm 0.16$ using a lattice computation with $n_f = 2 + 1$ dynamical fermions of the pseudoscalar meson masses. Mass $\overline{m}$ is obtained from this using the value of m_c from ALLISON 08 or MCNEILE 10 and the BAZAVOV 10 values for the light quark mass ratio, $m_s/\overline{m}$.

[10] AOKI 11A determine quark masses from a lattice computation of the hadron spectrum using $n_f = 2 + 1$ dynamical flavors of domain wall fermions.

[11] 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.

[12] 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.

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

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

[15] 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.

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

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

[18] 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.

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

[20] 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.

[21] 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.

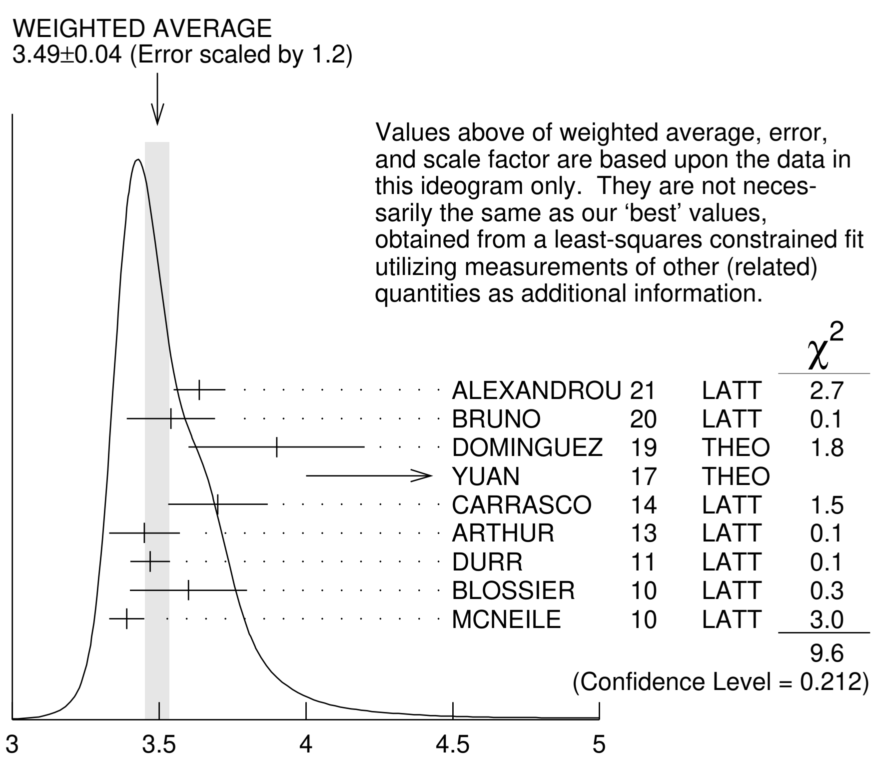
[22] AUBIN 04 perform three flavor dynamical lattice calculation of pseudoscalar meson masses, with one-loop perturbative renormalization constant.

[23] 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.

[24] 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.

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

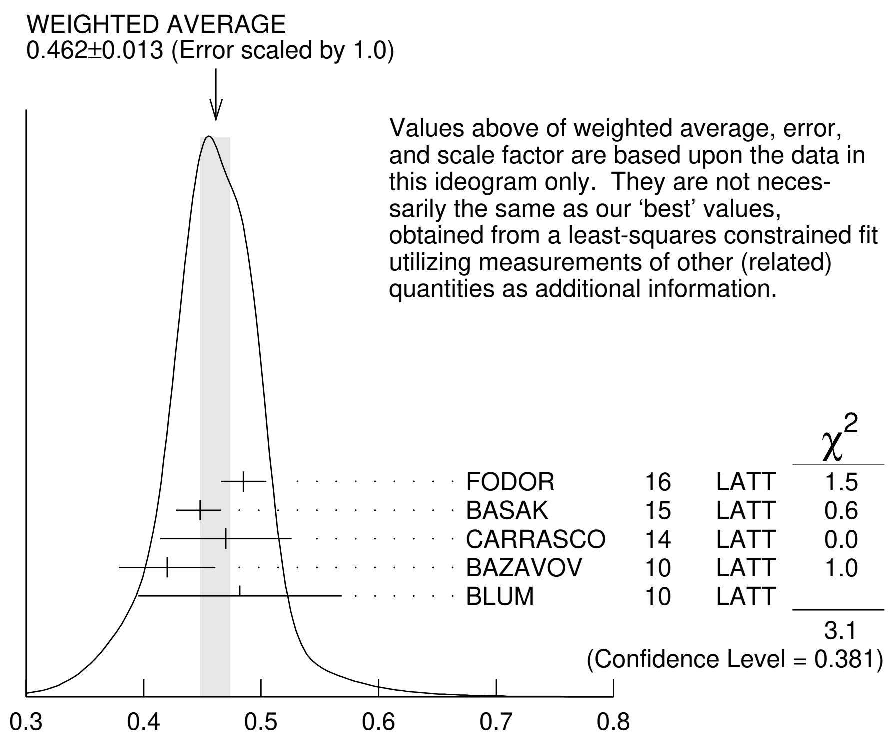
[26] CHIU 03 determines quark masses from the pion and kaon masses using a lattice simulation with a chiral fermion action in quenched approximation.



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

m_u/m_d MASS RATIO

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
0.462 ±0.020 (CL = 90%) OUR EVALUATION					See the ideogram below.
0.485 ±0.011 ±0.016		[1] FODOR	16	LATT	
$0.4482^{+0.0173}_{-0.0206}$		[2] BASAK	15	LATT	
0.470 ±0.056		[3] CARRASCO	14	LATT	
0.42 ±0.01 ±0.04		[4] BAZAVOV	10	LATT	
0.4818±0.0096±0.0860		[5] BLUM	10	LATT	
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.698 ±0.051		[6] AOKI	12	LATT	
0.550 ±0.031		[7] BLUM	07	LATT	
0.43 ±0.08		[8] AUBIN	04A	LATT	
0.410 ±0.036		[9] NELSON	03	LATT	
0.553 ±0.043		[10] LEUTWYLER	96	THEO	Compilation



m_u/m_d MASS RATIO

[1] FODOR 16 is a lattice simulation with $n_f = 2 + 1$ dynamical flavors and includes partially quenched QED effects.

[2] BASAK 15 is a lattice computation using 2+1 dynamical quark flavors.

[3] CARRASCO 14 is a lattice QCD computation of light quark masses using 2 + 1 + 1 dynamical quarks, with $m_u = m_d \neq m_s \neq m_c$. The u and d quark masses are obtained separately by using the K meson mass splittings and lattice results for the electromagnetic contributions.

[4] BAZAVOV 10 is a lattice computation using 2+1 dynamical quark flavors.

[5] BLUM 10 is a lattice computation using 2+1 dynamical quark flavors.

[6] AOKI 12 is a lattice computation using 1 + 1 + 1 dynamical quark flavors.

[7] BLUM 07 determine quark masses from the pseudoscalar meson masses using a QED plus QCD lattice computation with two dynamical quark flavors.
[8] AUBIN 04A perform three flavor dynamical lattice calculation of pseudoscalar meson masses, with continuum estimate of electromagnetic effects in the kaon masses.
[9] 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.
[10] 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.

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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.

$\overline{\text{MS}}$ *MASS* (MeV)	*CL%*	*DOCUMENT ID*		*TECN*
93.5 ± 0.8 (CL = 90%) OUR EVALUATION See the ideogram below.				
98.7 ± 2.4 $^{+4.0}_{-3.2}$		[1] ALEXANDROU	21	LATT
95.7 ± 2.5 ± 2.4		[2] BRUNO	20	LATT
92.47 ± 0.69		[3] BAZAVOV	18	LATT
93.85 ± 0.75		[4] LYTLE	18	LATT
87.6 ± 6.0		[5] ANANTHANA...	16	THEO
99.6 ± 4.3		[6] CARRASCO	14	LATT
94.4 ± 2.3		[7] ARTHUR	13	LATT
94 ± 9		[8] BODENSTEIN	13	THEO
95.5 ± 1.1 ± 1.5		[9] DURR	11	LATT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
93.6 ± 0.8		[10] CHAKRABOR...	15	LATT
102 ± 3 ± 1		[11] FRITZSCH	12	LATT
96.2 ± 2.7		[12] AOKI	11A	LATT
95 ± 6		[13] BLOSSIER	10	LATT
97.6 ± 2.9 ± 5.5		[14] BLUM	10	LATT
92.4 ± 1.5		[15] DAVIES	10	LATT
92.2 ± 1.3		[15] MCNEILE	10	LATT
107.3 ± 11.7		[16] ALLTON	08	LATT
105 ± 3 ± 9		[17] BLOSSIER	08	LATT
102 ± 8		[18] DOMINGUEZ	08A	THEO
90.1 $^{+17.2}_{-6.1}$		[19] ISHIKAWA	08	LATT
105.6 ± 1.2		[20] NAKAMURA	08	LATT
119.5 ± 9.3		[21] BLUM	07	LATT
105 ± 6 ± 7		[22] CHETYRKIN	06	THEO
111 ± 6 ± 10		[23] GOCKELER	06	LATT
119 ± 5 ± 8		[24] GOCKELER	06A	LATT
92 ± 9		[25] JAMIN	06	THEO
87 ± 6		[26] MASON	06	LATT
104 ± 15		[27] NARISON	06	THEO
$\geq 71 \pm 4$, $\leq 151 \pm 14$		[28] NARISON	06	THEO

96	$^{+5}_{-3}$	$^{+16}_{-18}$	[29] BAIKOV	05	THEO
81	±22		[30] GAMIZ	05	THEO
125	±28		[31] GORBUNOV	05	THEO
93	±32		[32] NARISON	05	THEO
76	± 8		[33] AUBIN	04	LATT
116	± 6	± 0.65	[34] AOKI	03	LATT
84.5	$^{+12}_{-1.7}$		[35] AOKI	03B	LATT
106	± 2	± 8	[36] BECIREVIC	03	LATT
92	± 9	±16	[37] CHIU	03	LATT
117	±17		[38] GAMIZ	03	THEO
103	±17		[39] GAMIZ	03	THEO

[1] ALEXANDROU 21 determines the quark mass using a lattice calculation of the meson and baryon masses with a twisted mass fermion action. The simulations are carried out using 2+1+1 dynamical quarks with $m_u = m_d \neq m_s \neq m_c$, including gauge ensembles close to the physical pion point.

[2] BRUNO 20 determines the light quark mass using a lattice calculation with n_f = 2+1 flavors of Wilson fermions. The scale has been set from f_π and f_K. The tuning was done using the masses of the lightest (π) and strange (K) pseudoscalar mesons.

[3] BAZAVOV 18 determine the quark masses using a lattice computation with staggered fermions and four active quark flavors.

[4] LYTLE 18 combined with CHAKRABORTY 2015 determine $\overline{m}_s$(3 GeV) = 84.78 ± 0.65 MeV from a lattice simulation with n_f = 2+1+1 flavors. They also determine the quoted value $\overline{m}_s$(2 GeV) for n_f = 4 dynamical flavors.

[5] ANANTHANARAYAN 16 determine $\overline{m}_s$(2 GeV) = 106.70 ± 9.36 MeV and 74.47 ± 7.77 MeV from fits to ALEPH and OPAL τ decay data, respectively. We have used the weighted average of the two.

[6] CARRASCO 14 is a lattice QCD computation of light quark masses using 2 + 1 + 1 dynamical quarks, with $m_u = m_d \neq m_s \neq m_c$. The u and d quark masses are obtained separately by using the K meson mass splittings and lattice results for the electromagnetic contributions.

[7] ARTHUR 13 is a lattice computation using 2+1 dynamical domain wall fermions. Masses at μ = 3 GeV have been converted to μ = 2 GeV using conversion factors given in their paper.

[8] BODENSTEIN 13 determines m_s from QCD finite energy sum rules, and the perturbative computation of the pseudoscalar correlator to five-loop order.

[9] DURR 11 determine quark mass from a lattice computation of the meson spectrum using n_f = 2 + 1 dynamical flavors. The lattice simulations were done at the physical quark mass, so that extrapolation in the quark mass was not needed.

[10] CHAKRABORTY 15 is a lattice QCD computation that determines m_c and m_c/m_s using pseudoscalar mesons masses tuned on gluon field configurations with 2+1+1 dynamical flavors of HISQ quarks with u/d masses down to the physical value.

[11] FRITZSCH 12 determine m_s using a lattice computation with n_f = 2 dynamical flavors.

[12] AOKI 11A determine quark masses from a lattice computation of the hadron spectrum using n_f = 2 + 1 dynamical flavors of domain wall fermions.

[13] BLOSSIER 10 determines quark masses from a computation of the hadron spectrum using n_f=2 dynamical twisted-mass Wilson fermions.

[14] BLUM 10 determines light quark masses using a QCD plus QED lattice computation of the electromagnetic mass splittings of the low-lying hadrons. The lattice simulations use 2+1 dynamical quark flavors.

[15] DAVIES 10 and MCNEILE 10 determine $\overline{m}_c(\mu)/\overline{m}_s(\mu)$ = 11.85 ± 0.16 using a lattice computation with n_f = 2 + 1 dynamical fermions of the pseudoscalar meson masses. Mass m_s is obtained from this using the value of m_c from ALLISON 08 or MCNEILE 10.

[16] 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.

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

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

[19] 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.

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

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

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

[23] 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.

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

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

[26] 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.

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

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

[29] 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.

[30] 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.

[31] GORBUNOV 05 use hadronic tau decays to N3LO, including power corrections.

[32] 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.

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

[34] 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.

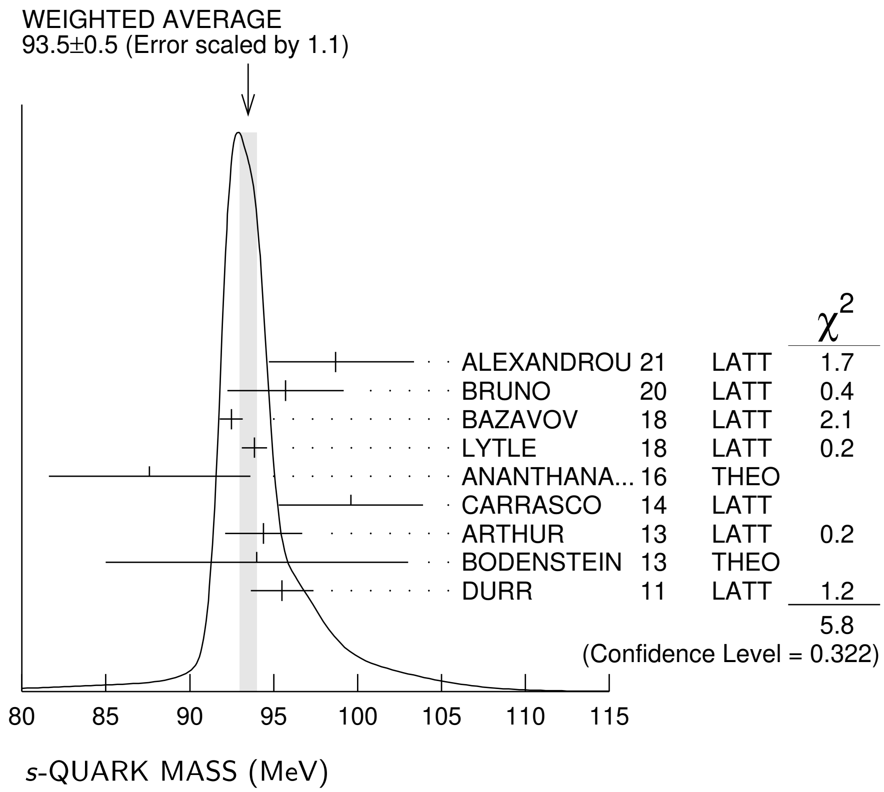
[35] AOKI 03B uses lattice simulation of the meson and baryon masses with two dynamical light quarks. Simulations are performed using the $\mathcal{O}(a)$ improved Wilson action.

[36] 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 $\overline{m}/m_s$=$24.3 \pm 0.2 \pm 0.6$.

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

[38] 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.

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



OTHER LIGHT QUARK MASS RATIOS

m_s/m_d MASS RATIO

VALUE	DOCUMENT ID		TECN	COMMENT
17–22 OUR EVALUATION				
20.0	[1] GAO	97	THEO	
18.9±0.8	[2] LEUTWYLER	96	THEO	Compilation
21	[3] DONOGHUE	92	THEO	
18	[4] GERARD	90	THEO	
18 to 23	[5] LEUTWYLER	90B	THEO	

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

[2] 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.

[3] 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 $(\psi(2S) \rightarrow J/\psi(1S)\pi)/(\psi(2S) \rightarrow J/\psi(1S)\eta)$.

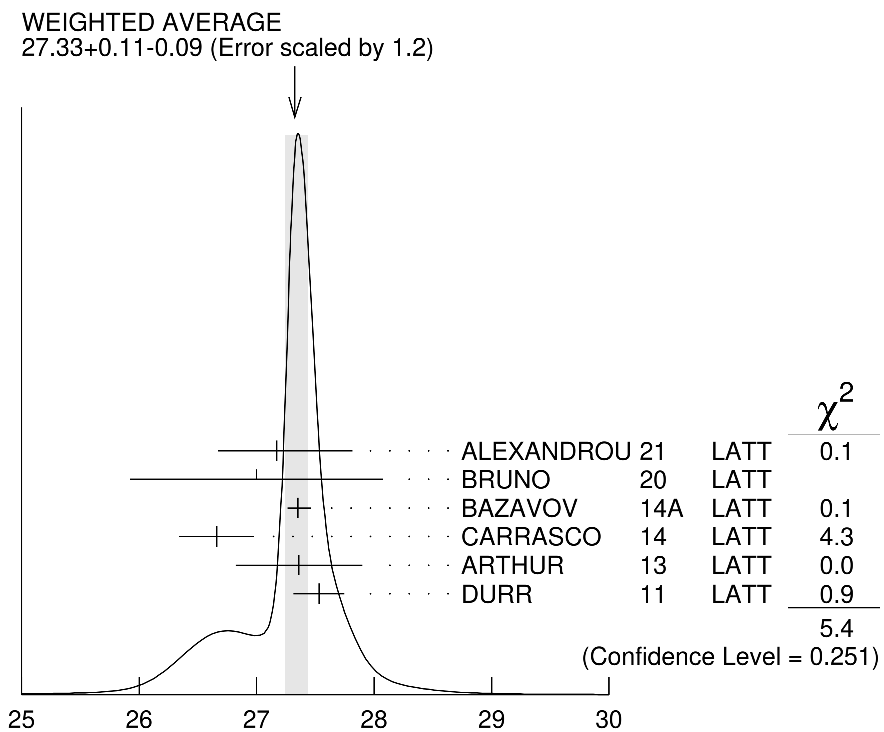
[4] GERARD 90 uses large N and η-η' mixing.

[5] 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	CL%	DOCUMENT ID		TECN
$27.33^{+0.18}_{-0.14}$ (CL = 90%) OUR EVALUATION		See the ideogram below.		
$27.17 \pm 0.32 {}^{+0.56}_{-0.38}$		[1] ALEXANDROU	21	LATT
$27.0 \pm 1.0 \pm 0.4$		[2] BRUNO	20	LATT
$27.35 \pm 0.05 {}^{+0.10}_{-0.07}$		[3] BAZAVOV	14A	LATT
26.66 ± 0.32		[4] CARRASCO	14	LATT
27.36 ± 0.54		[5] ARTHUR	13	LATT
$27.53 \pm 0.20 \pm 0.08$		[6] DURR	11	LATT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
26.8 ± 1.4		[7] AOKI	11A	LATT
27.3 ± 0.9		[8] BLOSSIER	10	LATT
28.8 ± 1.65		[9] ALLTON	08	LATT
$27.3 \pm 0.3 \pm 1.2$		[10] BLOSSIER	08	LATT
23.5 ± 1.5		[11] OLLER	07A	THEO
27.4 ± 0.4		[12] AUBIN	04	LATT



$m_s/\overline{m}$ MASS RATIO

[1] ALEXANDROU 21 determines the quark mass using a lattice calculation of the meson and baryon masses with a twisted mass fermion action. The simulations are carried out using 2+1+1 dynamical quarks with $m_u = m_d \neq m_s \neq m_c$, including gauge ensembles close to the physical pion point.

[2] BRUNO 20 determines the light quark mass using a lattice calculation with $n_f = 2+1$ flavors of Wilson fermions. The scale has been set from f_π and f_K. The tuning was done using the masses of the lightest (π) and strange (K) pseudoscalar mesons.

[3] BAZAVOV 14A is a lattice computation using 4 dynamical flavors of HISQ fermions.
[4] CARRASCO 14 is a lattice QCD computation of light quark masses using 2 + 1 + 1 dynamical quarks, with $m_u = m_d \neq m_s \neq m_c$. The u and d quark masses are obtained separately by using the K meson mass splittings and lattice results for the electromagnetic contributions.
[5] ARTHUR 13 is a lattice computation using 2+1 dynamical domain wall fermions.
[6] DURR 11 determine quark mass from a lattice computation of the meson spectrum using $n_f = 2 + 1$ dynamical flavors. The lattice simulations were done at the physical quark mass, so that extrapolation in the quark mass was not needed.
[7] AOKI 11A determine quark masses from a lattice computation of the hadron spectrum using $n_f = 2 + 1$ dynamical flavors of domain wall fermions.
[8] BLOSSIER 10 determines quark masses from a computation of the hadron spectrum using n_f=2 dynamical twisted-mass Wilson fermions.
[9] 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.
[10] BLOSSIER 08 use a lattice computation of pseudoscalar meson masses and decay constants with 2 dynamical flavors and non-perturbative renormalization.
[11] OLLER 07A use unitarized chiral perturbation theory to order p^4.
[12] Three flavor dynamical lattice calculation of pseudoscalar meson masses.

Q MASS RATIO

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

VALUE	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits, limits, etc. • • •			
22.1±0.7	[1] COLANGELO	18	THEO
22.0±0.7	[2] COLANGELO	17	THEO
21.6±1.1	[3] GUO	17	THEO
23.4±0.4±0.5	[4] FODOR	16	LATT
21.4±0.4	[5] GUO	15F	THEO
22.8±0.4	[6] MARTEMYA...	05	THEO
22.7±0.8	[7] ANISOVICH	96	THEO

[1] COLANGELO 18 obtain Q from a dispersive analysis of $\eta \rightarrow 3\pi$ decay.
[2] COLANGELO 17 obtain Q from a dispersive analysis of KLOE collaboration data on $\eta \rightarrow \pi^+\pi^-\pi^0$ decays and chiral perturbation theory input.
[3] GUO 17 determine Q from a dispersive model fit to KLOE and WASA-at-COSY data on $\eta \rightarrow \pi^+\pi^-\pi^0$ decay and matching to chiral perturbation theory.
[4] FODOR 16 is a lattice simulation with $n_f = 2 + 1$ dynamical flavors and includes partially quenched QED effects.
[5] GUO 15F determine Q from a Khuri-Treiman analysis of $\eta \rightarrow 3\pi$ decays.
[6] MARTEMYANOV 05 determine Q from $\eta \rightarrow 3\pi$ decay.
[7] 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

ALEXANDROU	21	PR D104 074515	C. Alexandrou *et al.*	(ETM Collab.)
BRUNO	20	EPJ C80 169	M. Bruno *et al.*	(ALPHA Collab.)
DOMINGUEZ	19	JHEP 1902 057	C.A. Dominguez, A. Mes, K. Schilcher	(CAPE, MAINZ)
BAZAVOV	18	PR D98 054517	A. Bazavov *et al.*	(Fermilab Lattice, MILC, TUMQCD)
COLANGELO	18	EPJ C78 947	G. Colangelo *et al.*	
LYTLE	18	PR D98 014513	A.T. Lytle *et al.*	(HPQCD Collab.)
COLANGELO	17	PRL 118 022001	G. Colangelo *et al.*	(BERN, IND, JLAB)
GUO	17	PL B771 497	P. Guo *et al.*	
YUAN	17	PR D96 014034	J.-M. Yuan *et al.*	
ANANTHANA...	16	PR D94 116014	B. Ananthanarayan, D. Das	(BANG, AHMED)
FODOR	16	PRL 117 082001	Z. Fodor *et al.*	(BMW Collab.)
BASAK	15	JPCS 640 012052	S. Basak *et al.*	(MILC Collab.)
CHAKRABOR...	15	PR D91 054508	B. Chakraborty *et al.*	(HPQCD Collab.)
GUO	15F	PR D92 054016	P. Guo *et al.*	
BAZAVOV	14A	PR D90 074509	A. Bazavov *et al.*	(Fermi-LAT and MILC Collabs.)
CARRASCO	14	NP B887 19	N. Carrasco *et al.*	(European Twisted Mass Collab.)
ARTHUR	13	PR D87 094514	R. Arthur *et al.*	(RBC and UKQCD Collabs.)
BODENSTEIN	13	JHEP 1307 138	S. Bodenstein, C.A. Dominguez, K. Schilcher	
AOKI	12	PR D86 034507	S. Aoki *et al.*	(PACS-CS Collab.)
FRITZSCH	12	NP B865 397	P. Fritzsch *et al.*	(ALPHA Collab.)
AOKI	11A	PR D83 074508	Y. Aoki *et al.*	(RBC-UKQCD Collab.)
DURR	11	PL B701 265	S. Durr *et al.*	(BMW Collab.)
BAZAVOV	10	RMP 82 1349	A. Bazavov *et al.*	(MILC Collab.)
BLOSSIER	10	PR D82 114513	B. Blossier *et al.*	(ETM Collab.)
BLUM	10	PR D82 094508	T. Blum *et al.*	
DAVIES	10	PRL 104 132003	C.T.H. Davies *et al.*	(HPQCD Collab.)
MCNEILE	10	PR D82 034512	C. McNeile *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 Collabs.)
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 011502	T. Ishikawa *et al.*	(CP-PACS and JLQCD Collabs.)
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 and UKQCD Collabs)
GOCKELER	06A	PL B639 307	M. Gockeler *et al.*	(QCDSF and 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	JP G33 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 031504	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	
GAO	97	PR D56 4115	D.-N. Gao, B.A. Li, M.-L. Yan	
ANISOVICH	96	PL B375 335	A.V. Anisovich, H. Leutwyler	
LEUTWYLER	96	PL B378 313	H. Leutwyler	
DONOGHUE	92	PRL 69 3444	J.F. Donoghue, B.R. Holstein, D. Wyler	(MASA+)
GERARD	90	MPL A5 391	J.M. Gerard	(MPIM)
LEUTWYLER	90B	NP B337 108	H. Leutwyler	(BERN)