



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

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

### c-QUARK MASS

The  $c$ -quark mass corresponds to the “running” mass  $m_c(\mu = m_c)$  in the  $\overline{\text{MS}}$  scheme. We have converted masses in other schemes to the  $\overline{\text{MS}}$  scheme using two-loop QCD perturbation theory with  $\alpha_s(\mu=m_c) = 0.38 \pm 0.03$ . The value  $1.27 \pm 0.02$  GeV for the  $\overline{\text{MS}}$  mass corresponds to  $1.67 \pm 0.07$  GeV for the pole mass (see the “Note on Quark Masses”).

$\overline{\text{MS}}$ MASS (GeV)	DOCUMENT ID	TECN
<b>1.27 ±0.02 OUR EVALUATION</b>	See the ideogram below.	
1.266 ±0.006	1 NARISON	20 THEO
1.290 <sup>+0.077</sup> <sub>-0.053</sub>	2 ABRAMOWICZ18	HERA
1.273 ±0.010	3 BAZAVOV	18 LATT
1.2737±0.0077	4 LYTLE	18 LATT
1.223 ±0.033	5 PESET	18 THEO
1.279 ±0.008	6 CHETYRKIN	17 THEO
1.272 ±0.008	7 ERLER	17 THEO
1.246 ±0.023	8 KIYO	16 THEO
1.288 ±0.020	9 DEHNADI	15 THEO
1.348 ±0.046	10 CARRASCO	14 LATT
1.24 ±0.03 <sup>+0.03</sup> <sub>-0.07</sub>	11 ALEKHIN	13 THEO
1.159 ±0.075	12 SAMOYLOV	13 NOMD
1.278 ±0.009	13 BODENSTEIN	11 THEO
1.28 <sup>+0.07</sup> <sub>-0.06</sub>	14 LASCHKA	11 THEO
1.196 ±0.059 ±0.050	15 AUBERT	10A BABR
1.25 ±0.04	16 SIGNER	09 THEO
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●		
1.263 ±0.014	17 NARISON	18A THEO
1.264 ±0.006	18 NARISON	18B THEO
1.335 ±0.043 <sup>+0.040</sup> <sub>-0.011</sub>	19 BERTONE	16 THEO
1.2715±0.0095	20 CHAKRABOR..15	LATT
1.26 ±0.05 ±0.04	21 ABRAMOWICZ13C	COMB
1.282 ±0.011 ±0.022	22 DEHNADI	13 THEO
1.286 ±0.066	23 NARISON	13 THEO
1.36 ±0.04 ±0.10	24 ALEKHIN	12 THEO
1.261 ±0.016	25 NARISON	12A THEO
1.01 ±0.09 ±0.03	26 ALEKHIN	11 THEO
1.28 ±0.04	27 BLOSSIER	10 LATT
1.299 ±0.026	28 BODENSTEIN	10 THEO
1.273 ±0.006	29 MCNEILE	10 LATT
1.261 ±0.018	30 NARISON	10 THEO
1.279 ±0.013	31 CHETYRKIN	09 THEO
1.268 ±0.009	32 ALLISON	08 LATT

1.286 ± 0.013	33	KUHN	07	THEO
1.295 ± 0.015	34	BOUGHEZAL	06	THEO
1.24 ± 0.09	35	BUCHMUEL...	06	THEO
1.224 ± 0.017 ± 0.054	36	HOANG	06	THEO
1.33 ± 0.10	37	AUBERT	04X	THEO
1.29 ± 0.07	38	HOANG	04	THEO
1.319 ± 0.028	39	DEDIVITIIS	03	LATT
1.19 ± 0.11	40	EIDEMULLER	03	THEO
1.289 ± 0.043	41	ERLER	03	THEO
1.26 ± 0.02	42	ZYABLYUK	03	THEO

<sup>1</sup> NARISON 20 determines the quark mass using QCD Laplace sum rules from the  $B_c$  mass, combined with previous determinations of the QCD condensates and  $c$  and  $b$  masses.

<sup>2</sup> ABRAMOWICZ 18 determine  $\overline{m}_c(\overline{m}_c) = 1.290^{+0.046+0.062+0.003}_{-0.041-0.014-0.031}$  from the production of  $c$  quarks in  $ep$  collisions at HERA using combined H1 and ZEUS data. The experimental/fitting errors, and those from modeling and parameterization have been combined in quadrature.

<sup>3</sup> BAZAVOV 18 determine the quark masses using a lattice computation with staggered fermions and four active quark flavors.

<sup>4</sup> LYTLE 18 combined with CHAKRABORTY 15 determine  $\overline{m}_c(3 \text{ GeV}) = 0.9874(48) \text{ GeV}$  from a lattice simulation with  $n_f = 2+1+1$  flavors. They also determine the quoted value  $\overline{m}_c(\overline{m}_c)$  for  $n_f = 4$  dynamical flavors.

<sup>5</sup> PESET 18 determine  $\overline{m}_c(\overline{m}_c)$  and  $\overline{m}_b(\overline{m}_b)$  using an N3LO calculation of the  $\eta_c$ ,  $\eta_b$  and  $B_c$  masses.

<sup>6</sup> CHETYRKIN 17 determine  $\overline{m}_c(\mu = 3 \text{ GeV}) = 0.993 \pm 0.008 \text{ GeV}$  and  $\overline{m}_c(\overline{m}_c)$  from a four-loop sum-rule computation of the cross-section for  $e^+e^- \rightarrow$  hadrons in the charm threshold region.

<sup>7</sup> ERLER 17 determine  $\overline{m}_c(\overline{m}_c) = 1.272 \pm 0.008 \text{ GeV}$  from a three-loop QCD sum-rule computation of the vector current correlator. This result is for fixed  $\alpha_s(M_Z) = 0.1182$ . Including an  $\alpha_s$  uncertainty of  $\pm 0.0016$ , the charm mass error increases from 8 to 9 MeV.

<sup>8</sup> KIYO 16 determine  $\overline{m}_c(\overline{m}_c)$  from the  $J/\psi(1S)$  mass at order  $\alpha_s^3$  (N3LO).

<sup>9</sup> DEHNADI 15 determine  $\overline{m}_c(\overline{m}_c)$  using sum rules for  $e^+e^- \rightarrow$  hadrons at order  $\alpha_s^3$  (N3LO), and fitting to both experimental data and lattice results.

<sup>10</sup> 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.

<sup>11</sup> ALEKHIN 13 determines  $m_c$  from charm production in deep inelastic scattering at HERA using approximate NNLO QCD.

<sup>12</sup> SAMOYLOV 13 determines  $m_c$  from a study of charm dimuon production in neutrino-iron scattering using the NLO QCD result for the charm quark production cross section.

<sup>13</sup> BODENSTEIN 11 determine  $\overline{m}_c(3 \text{ GeV}) = 0.987 \pm 0.009 \text{ GeV}$  and  $\overline{m}_c(\overline{m}_c) = 1.278 \pm 0.009 \text{ GeV}$  using QCD sum rules for the charm quark vector current correlator.

<sup>14</sup> LASCHKA 11 determine the  $c$  mass from the charmonium spectrum. The theoretical computation uses the heavy  $Q\overline{Q}$  potential to order  $1/m_Q$  obtained by matching the short-distance perturbative result onto lattice QCD result at larger scales.

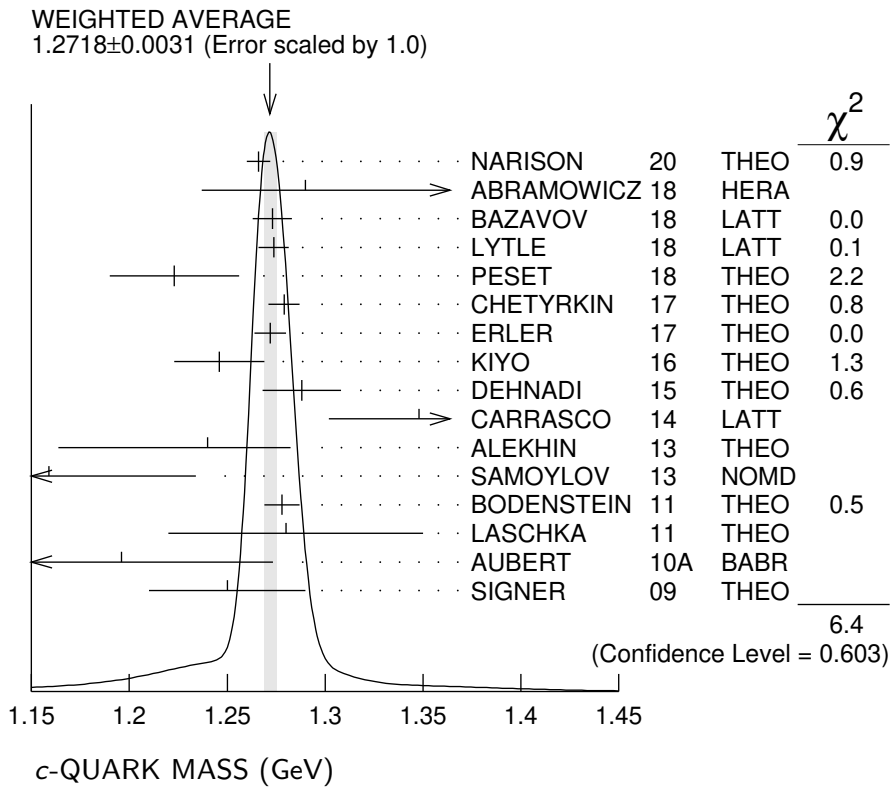
<sup>15</sup> AUBERT 10A determine the  $b$ - and  $c$ -quark masses from a fit to the inclusive decay spectra in semileptonic  $B$  decays in the kinetic scheme (and convert it to the  $\overline{MS}$  scheme).

<sup>16</sup> SIGNER 09 determines the  $c$ -quark mass using non-relativistic sum rules to analyze the  $e^+e^- \rightarrow c\overline{c}$  cross-section near threshold. Also determine the PS mass  $m_{PS}(\mu_F = 0.7 \text{ GeV}) = 1.50 \pm 0.04 \text{ GeV}$ .

<sup>17</sup> NARISON 18A determines simultaneously  $\overline{m}_c(\overline{m}_c)$  and the 4-dimension gluon condensate using QCD exponential sum rules and their ratios evaluated at the optimal scale

- $\mu = 2.85$  GeV at N2LO-N3LO of perturbative QCD and including condensates up to dimension 6–8 in the (axial-)vector and (pseudo-)scalar charmonium channels.
- 18 NARISON 18B determines  $\overline{m}_c(\overline{m}_c)$  using QCD vector moment sum rules and their ratios at N2LO-N3LO of perturbative QCD and including condensates up to dimension 8.
  - 19 BERTONE 16 determine  $\overline{m}_c(\overline{m}_c)$  from HERA deep inelastic scattering data using the FONLL scheme. Also determine  $\overline{m}_c(\overline{m}_c) = 1.318 \pm 0.054^{+0.490}_{-0.022}$  using the fixed flavor number scheme.
  - 20 CHAKRABORTY 15 is a lattice QCD computation using 2+1+1 dynamical flavors. Moments of pseudoscalar current-current correlators are matched to  $\alpha_s^3$ -accurate QCD perturbation theory with the  $\eta_c$  meson mass tuned to experiment.
  - 21 ABRAMOWICZ 13C determines  $m_c$  from charm production in deep inelastic  $e p$  scattering, using the QCD prediction at NLO order. The uncertainties from model and parameterization assumptions, and the value of  $\alpha_s$ , of  $\pm 0.03$ ,  $\pm 0.02$ , and  $\pm 0.02$  respectively, have been combined in quadrature.
  - 22 DEHNADI 13 determines  $m_c$  using QCD sum rules for the charmonium spectrum and charm continuum to order  $\alpha_s^3$  (N3LO). The statistical and systematic experimental errors of  $\pm 0.006$  and  $\pm 0.009$  have been combined in quadrature. The theoretical uncertainties  $\pm 0.019$  from truncation of the perturbation series,  $\pm 0.010$  from  $\alpha_s$ , and  $\pm 0.002$  from the gluon condensate have been combined in quadrature.
  - 23 NARISON 13 determines  $m_c$  using QCD spectral sum rules to order  $\alpha_s^2$  (NNLO) and including condensates up to dimension 6.
  - 24 ALEKHIN 12 determines  $m_c$  from heavy quark production in deep inelastic scattering at HERA using approximate NNLO QCD.
  - 25 NARISON 12A determines  $m_c$  using sum rules for the vector current correlator to order  $\alpha_s^3$ , including the effect of gluon condensates up to dimension eight.
  - 26 ALEKHIN 11 determines  $m_c$  from heavy quark production in deep inelastic scattering using fixed target and HERA data, and approximate NNLO QCD.
  - 27 BLOSSIER 10 determines quark masses from a computation of the hadron spectrum using  $N_f=2$  dynamical twisted-mass Wilson fermions.
  - 28 BODENSTEIN 10 determines  $\overline{m}_c(3 \text{ GeV}) = 1.008 \pm 0.026$  GeV using finite energy sum rules for the vector current correlator. The authors have converted this to  $\overline{m}_c(\overline{m}_c)$  using  $\alpha_s(M_Z) = 0.1189 \pm 0.0020$ .
  - 29 MCNEILE 10 determines  $m_c$  by comparing the order  $\alpha_s^3$  perturbative results for the pseudo-scalar current to lattice simulations with  $N_f = 2+1$  sea-quarks by the HPQCD collaboration.
  - 30 NARISON 10 determines  $m_c$  from ratios of moments of vector current correlators computed to order  $\alpha_s^3$  and including the dimension-six gluon condensate.
  - 31 CHETYRKIN 09 determine  $m_c$  and  $m_b$  from the  $e^+ e^- \rightarrow Q \overline{Q}$  cross-section and sum rules, using an order  $\alpha_s^3$  computation of the heavy quark vacuum polarization. They also determine  $m_c(3 \text{ GeV}) = 0.986 \pm 0.013$  GeV.
  - 32 ALLISON 08 determine  $m_c$  by comparing four-loop perturbative results for the pseudo-scalar current correlator to lattice simulations by the HPQCD collaboration. The result has been updated in MCNEILE 10.
  - 33 KUHN 07 determine  $\overline{m}_c(\mu = 3 \text{ GeV}) = 0.986 \pm 0.013$  GeV and  $\overline{m}_c(\overline{m}_c)$  from a four-loop sum-rule computation of the cross-section for  $e^+ e^- \rightarrow$  hadrons in the charm threshold region.
  - 34 BOUGHEZAL 06 result comes from the first moment of the hadronic production cross-section to order  $\alpha_s^3$ .
  - 35 BUCHMUELLER 06 determine  $m_b$  and  $m_c$  by a global fit to inclusive  $B$  decay spectra.

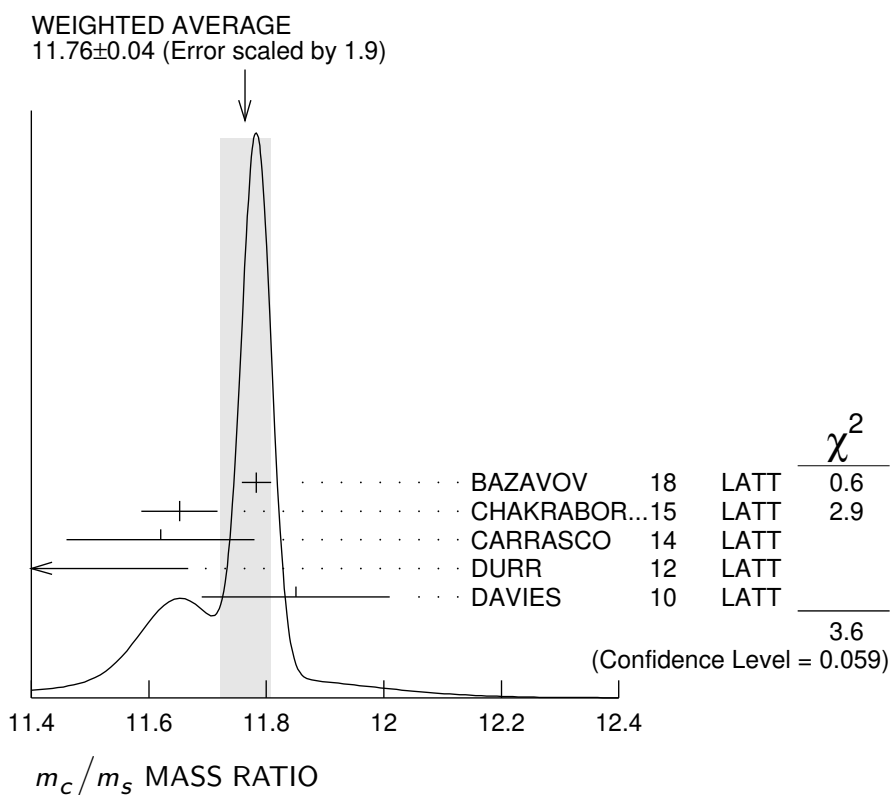
- 36 HOANG 06 determines  $\overline{m}_c(\overline{m}_c)$  from a global fit to inclusive  $B$  decay data. The  $B$  decay distributions were computed to order  $\alpha_s^2\beta_0$ , and the conversion between different  $m_c$  mass schemes to order  $\alpha_s^3$ .
- 37 AUBERT 04X obtain  $m_c$  from a fit to the hadron mass and lepton energy distributions in semileptonic  $B$  decay. The paper quotes values in the kinetic scheme. The  $\overline{MS}$  value has been provided by the BABAR collaboration.
- 38 HOANG 04 determines  $\overline{m}_c(\overline{m}_c)$  from moments at order  $\alpha_s^2$  of the charm production cross-section in  $e^+e^-$  annihilation.
- 39 DEDIVITIIS 03 use a quenched lattice computation of heavy-heavy and heavy-light meson masses.
- 40 EIDEMULLER 03 determines  $m_b$  and  $m_c$  using QCD sum rules.
- 41 ERLER 03 determines  $m_b$  and  $m_c$  using QCD sum rules. Includes recent BES data.
- 42 ZYABLYUK 03 determines  $m_c$  by using QCD sum rules in the pseudoscalar channel and comparing with the  $\eta_c$  mass.



### $m_c/m_s$ MASS RATIO

<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
<b>11.72 ± 0.25 OUR EVALUATION</b>	See the ideogram below.	
11.783 ± 0.025	1 BAZAVOV 18	LATT
11.652 ± 0.065	2 CHAKRABOR..15	LATT
11.62 ± 0.16	3 CARRASCO 14	LATT
11.27 ± 0.30 ± 0.26	4 DURR 12	LATT
11.85 ± 0.16	5 DAVIES 10	LATT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●		
11.747 ± 0.019 <sup>+0.059</sup> <sub>-0.043</sub>	6 BAZAVOV 14A	LATT
12.0 ± 0.3	7 BLOSSIER 10	LATT

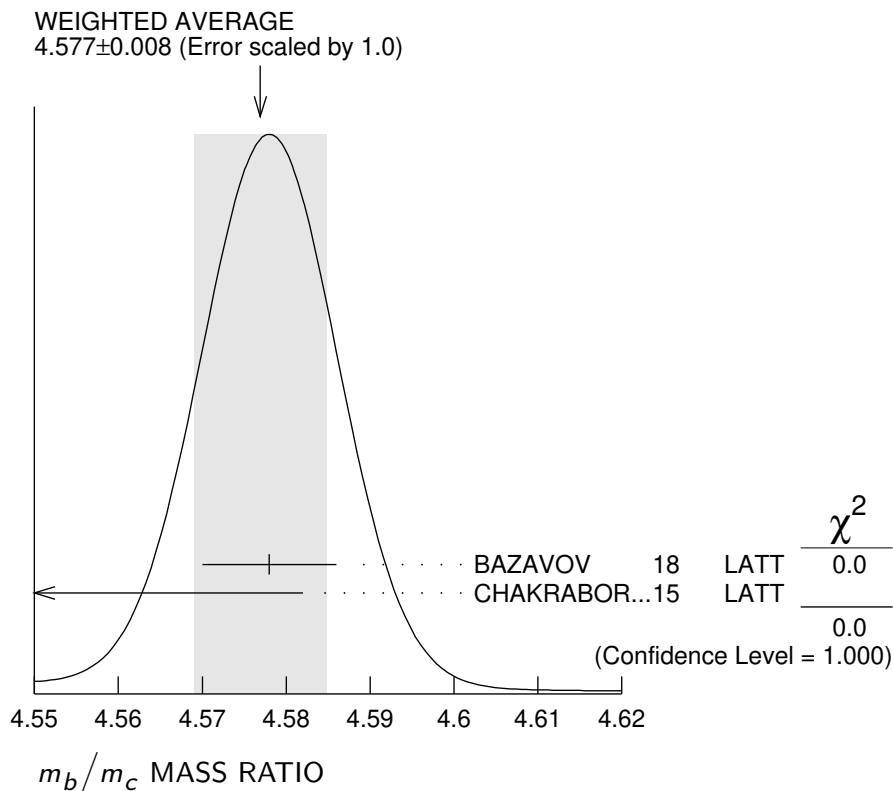
- <sup>1</sup>BAZAVOV 18 determine the quark masses using a lattice computation with staggered fermions and four active quark flavors.
- <sup>2</sup>CHAKRABORTY 15 is a lattice QCD computation on gluon field configurations with 2+1+1 dynamical flavors of HISQ quarks with  $u/d$  masses down to the physical value.  $m_c$  and  $m_s$  are tuned from pseudoscalar meson masses.
- <sup>3</sup>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.
- <sup>4</sup>DURR 12 determine  $m_c/m_s$  using a lattice computation with  $N_f = 2$  dynamical fermions. The result is combined with other determinations of  $m_c$  to obtain  $m_s(2 \text{ GeV}) = 97.0 \pm 2.6 \pm 2.5 \text{ MeV}$ .
- <sup>5</sup>DAVIES 10 determine  $m_c/m_s$  from meson masses calculated on gluon fields including  $u$ ,  $d$ , and  $s$  sea quarks with lattice spacing down to 0.045 fm. The Highly Improved Staggered quark formalism is used for the valence quarks.
- <sup>6</sup>BAZAVOV 14A is a lattice computation using 4 dynamical flavors of HISQ fermions.
- <sup>7</sup>BLOSSIER 10 determine  $m_c/m_s$  from a computation of the hadron spectrum using  $N_f = 2$  dynamical twisted-mass Wilson fermions.



### $m_b/m_c$ MASS RATIO

VALUE	DOCUMENT ID	TECN
<b>4.577±0.008 OUR AVERAGE</b>	See the ideogram below.	
4.578±0.008	<sup>1</sup> BAZAVOV 18	LATT
4.528±0.054	<sup>2</sup> CHAKRABOR..15	LATT

- <sup>1</sup>BAZAVOV 18 determine the quark masses using a lattice computation with staggered fermions and four active quark flavors for the  $u$ ,  $d$ ,  $s$ ,  $c$  quarks and five active flavors for the  $b$  quark.
- <sup>2</sup>CHAKRABORTY 15 is a lattice computation using 4 dynamical quark flavors.



### $m_b - m_c$ QUARK MASS DIFFERENCE

VALUE (GeV)                      DOCUMENT ID                      TECN

#### **$3.45 \pm 0.05$ OUR EVALUATION**

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

$3.472 \pm 0.032$	<sup>1</sup> AUBERT	10A	BABR
$3.42 \pm 0.06$	<sup>2</sup> ABDALLAH	06B	DLPH
$3.44 \pm 0.03$	<sup>3</sup> AUBERT	04X	BABR
$3.41 \pm 0.01$	<sup>3</sup> BAUER	04	THEO

<sup>1</sup> AUBERT 10A determine the  $b$ - and  $c$ -quark masses from a fit to the inclusive decay spectra in semileptonic  $B$  decays in the kinetic scheme.

<sup>2</sup> ABDALLAH 06B determine  $m_b - m_c$  from moments of the hadron invariant mass and lepton energy spectra in semileptonic inclusive  $B$  decays.

<sup>3</sup> Determine  $m_b - m_c$  from a global fit to inclusive  $B$  decay spectra.

### $c$ -QUARK REFERENCES

NARISON	20	PL B802 135221	S. Narison	(MONP)
ABRAMOWICZ	18	EPJ C78 473	H. Abramowicz <i>et al.</i>	(H1 and ZEUS Collabs.)
BAZAVOV	18	PR D98 054517	A. Bazavov <i>et al.</i>	(Fermilab Lattice, MILC, TUMQCD)
LYTLE	18	PR D98 014513	A.T. Lytle <i>et al.</i>	(HPQCD Collab.)
NARISON	18A	IJMP A33 1850045	S. Narison	(MONP)
NARISON	18B	PL B784 261	S. Narison	(MONP)
PESET	18	JHEP 1809 167	C. Peset, A. Pineda, J. Segovia	(BARC, TUM)
CHETYRKIN	17	PR D96 116007	K.G. Chetyrkin <i>et al.</i>	
ERLER	17	EPJ C77 99	J. Erler, P. Masjuan, H. Spiesberger	
BERTONE	16	JHEP 1608 050	V. Bertone <i>et al.</i>	(xFitter Developers)
KIYO	16	PL B752 122	Y. Kiyo, G. Mishima, Y. Sumino	
CHAKRABOR...	15	PR D91 054508	B. Chakraborty <i>et al.</i>	(HPQCD Collab.)
DEHNADI	15	JHEP 1508 155	B. Dehnadi, A.H. Hoang, V. Mateu	
BAZAVOV	14A	PR D90 074509	A. Bazavov <i>et al.</i>	(Fermi-LAT and MILC Collabs.)
CARRASCO	14	NP B887 19	N. Carrasco <i>et al.</i>	(European Twisted Mass Collab.)

ABRAMOWICZ	13C	EPJ C73 2311	H. Abramowicz <i>et al.</i>	(H1 and Zeus Collabs.)
ALEKHIN	13	PL B720 172	S. Alekhin <i>et al.</i>	(SERP, DESYZ, WUPP+)
DEHNADI	13	JHEP 1309 103	B. Dehnadi <i>et al.</i>	(SHRZ, VIEN, MPIM+)
NARISON	13	PL B718 1321	S. Narison	(MONP)
SAMOYLOV	13	NP B876 339	O. Samoylov <i>et al.</i>	(NOMAD Collab.)
ALEKHIN	12	PL B718 550	S. Alekhin <i>et al.</i>	(SERP, WUPP, DESY+)
DURR	12	PRL 108 122003	S. Durr, G. Koutsou	(WUPP, JULI, CYPR)
NARISON	12A	PL B706 412	S. Narison	(MONP)
ALEKHIN	11	PL B699 345	S. Alekhin, S. Moch	(DESY, SERP)
BODENSTEIN	11	PR D83 074014	S. Bodenstein <i>et al.</i>	
LASCHKA	11	PR D83 094002	A. Laschka, N. Kaiser, W. Weise	
AUBERT	10A	PR D81 032003	B. Aubert <i>et al.</i>	(BABAR Collab.)
BLOSSIER	10	PR D82 114513	B. Blossier <i>et al.</i>	(ETM Collab.)
BODENSTEIN	10	PR D82 114013	S. Bodenstein <i>et al.</i>	
DAVIES	10	PRL 104 132003	C.T.H. Davies <i>et al.</i>	(HPQCD Collab.)
MCNEILE	10	PR D82 034512	C. McNeile <i>et al.</i>	(HPQCD Collab.)
NARISON	10	PL B693 559	S. Narison	(MONP)
Also		PL B705 544 (errat.)	S. Narison	(MONP)
CHETYRKIN	09	PR D80 074010	K.G. Chetyrkin <i>et al.</i>	(KARL, BNL)
SIGNER	09	PL B672 333	A. Signer	(DURH)
ALLISON	08	PR D78 054513	I. Allison <i>et al.</i>	(HPQCD Collab.)
KUHN	07	NP B778 192	J.H. Kuhn, M. Steinhauser, C. Sturm	
ABDALLAH	06B	EPJ C45 35	J. Abdallah <i>et al.</i>	(DELPHI Collab.)
BOUGHEZAL	06	PR D74 074006	R. Boughezal, M. Czakon, T. Schutzmeier	
BUCHMUEL...	06	PR D73 073008	O.L. Buchmueller, H.U. Flacher	(RHBL)
HOANG	06	PL B633 526	A.H. Hoang, A.V. Manohar	
AUBERT	04X	PRL 93 011803	B. Aubert <i>et al.</i>	(BABAR Collab.)
BAUER	04	PR D70 094017	C. Bauer <i>et al.</i>	
HOANG	04	PL B594 127	A.H. Hoang, M. Jamin	
DEDIVITIIS	03	NP B675 309	G.M. de Divitiis <i>et al.</i>	
EIDEMULLER	03	PR D67 113002	M. Eidemuller	
ERLER	03	PL B558 125	J. Erler, M. Luo	
ZYABLYUK	03	JHEP 0301 081	K.N. Zybalyuk	(ITEP)