b' (4^{th} Generation) Quark, Searches for

NODE=Q008

MASS LIMITS for b' (4^{th} Generation) Quark or Hadron in $p\overline{p}$ Collisions

NODE=Q008BPP
NODE=Q008BPP;CHECK LIMITS

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
>268	95	[1] AALTONEN	07C	CDF	B($b' \to bZ$) = 1 assumed
>190	95	[2] ACOSTA	03	CDF	quasi-stable b'
>128	95	[3] ABACHI	95F	D0	$\ell\ell$ + jets, ℓ + jets
• • • We do not use the following data for averages, fits, limits, etc. • • •					
>199	95	[4] AFFOLDER	00	CDF	NC: $b' \to bZ$
>148	95	[5] ABE	98N	CDF	NC: $b' \to bZ$ +decay vertex
> 96	95	[6] ABACHI	97D	D0	NC: $b' \to b\gamma$
> 75	95	[7] MUKHOPAD...	93	RVUE	NC: $b' \to b\ell\ell$
> 85	95	[8] ABE	92	CDF	CC: $\ell\ell$
> 72	95	[9] ABE	90B	CDF	CC: $e + \mu$
> 54	95	[10] AKESSON	90	UA2	CC: e + jets + missing E_T
> 43	95	[11] ALBAJAR	90B	UA1	CC: μ + jets
> 34	95	[12] ALBAJAR	88	UA1	CC: e or μ + jets

[1] Result is based on 1.06 fb^{-1} of data. No excess from the SM Z+jet events is found when Z decays into ee or $\mu\mu$. The $m_{b'}$ bound is found by comparing the resulting upper bound on $\sigma(b'\overline{b}')$ [1-(1-B($b' \to bZ$))^2] and the LO estimate of the b' pair production cross section shown in Fig. 38 of the article.

NODE=Q008BPP;LINKAGE=AL

[2] ACOSTA 03 looked for long-lived fourth generation quarks in the data sample of 90 pb^{-1} of $\sqrt{s}$=1.8 TeV $p\overline{p}$ collisions by using the muon-like penetration and anomalously high ionization energy loss signature. The corresponding lower mass bound for the charge (2/3)e quark (t') is 220 GeV. The t' bound is higher than the b' bound because t' is more likely to produce charged hadrons than b'. The 95% CL upper bounds for the production cross sections are given in their Fig. 3.

NODE=Q008BPP;LINKAGE=CS

[3] ABACHI 95F bound on the top-quark also applies to b' and t' quarks that decay predominantly into W. See FROGGATT 97.

NODE=Q008BPP;LINKAGE=1K

[4] AFFOLDER 00 looked for b' that decays in to b+Z. The signal searched for is $bbZZ$ events where one Z decays into e^+e^- or $\mu^+\mu^-$ and the other Z decays hadronically. The bound assumes B($b' \to bZ$)= 100%. Between 100 GeV and 199 GeV, the 95%CL upper bound on $\sigma(b' \to \overline{b}')\times$B^2($b' \to bZ$) is also given (see their Fig. 2).

NODE=Q008BPP;LINKAGE=EB

[5] ABE 98N looked for $Z \to e^+e^-$ decays with displaced vertices. Quoted limit assumes B($b' \to bZ$)=1 and $c\tau_{b'}$=1 cm. The limit is lower than m_Z+m_b ($\sim$ 96 GeV) if $c\tau$> 22 cm or $c\tau$< 0.009 cm. See their Fig. 4.

NODE=Q008BPP;LINKAGE=AN

[6] ABACHI 97D searched for b' that decays mainly via FCNC. They obtained 95%CL upper bounds on B($b'\overline{b}' \to \gamma$+ 3 jets) and B($b'\overline{b}' \to 2\gamma$+ 2 jets), which can be interpreted as the lower mass bound $m_{b'}$ >m_Z+m_b.

NODE=Q008BPP;LINKAGE=K2

[7] MUKHOPADHYAYA 93 analyze CDF dilepton data of ABE 92G in terms of a new quark decaying via flavor-changing neutral current. The above limit assumes B($b' \to b\ell^+\ell^-$)=1%. For an exotic quark decaying only via virtual Z [B($b\ell^+\ell^-$) = 3%], the limit is 85 GeV.

NODE=Q008BPP;LINKAGE=C

[8] ABE 92 dilepton analysis limit of >85 GeV at CL=95% also applies to b' quarks, as discussed in ABE 90B.

NODE=Q008BPP;LINKAGE=U

[9] ABE 90B exclude the region 28–72 GeV.

NODE=Q008BPP;LINKAGE=AB

[10] AKESSON 90 searched for events having an electron with p_T > 12 GeV, missing momentum > 15 GeV, and a jet with E_T > 10 GeV, $|\eta|$ < 2.2, and excluded $m_{b'}$ between 30 and 69 GeV.

NODE=Q008BPP;LINKAGE=F

[11] For the reduction of the limit due to non-charged-current decay modes, see Fig. 19 of ALBAJAR 90B.

NODE=Q008BPP;LINKAGE=A

[12] ALBAJAR 88 study events at E_{cm} = 546 and 630 GeV with a muon or isolated electron, accompanied by one or more jets and find agreement with Monte Carlo predictions for the production of charm and bottom, without the need for a new quark. The lower mass limit is obtained by using a conservative estimate for the $b'\overline{b}'$ production cross section and by assuming that it cannot be produced in W decays. The value quoted here is revised using the full $O(\alpha_s^3)$ cross section of ALTARELLI 88.

NODE=Q008BPP;LINKAGE=D

MASS LIMITS for b' (4^{th} Generation) Quark or Hadron in e^+e^- Collisions

NODE=Q008BPE

Search for hadrons containing a fourth-generation $-1/3$ quark denoted b'.

NODE=Q008BPE

The last column specifies the assumption for the decay mode (CC denotes the conventional charged-current decay) and the event signature which is looked for.

NODE=Q008BPE

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
>46.0	95	[13] DECAMP	90F	ALEP	any decay

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

none 96–103	95	[14] ABDALLAH	07	DLPH	$b' \to bZ$, cW	
		[15] ADRIANI	93G	L3	Quarkonium	
>44.7	95	ADRIANI	93M	L3	$\Gamma(Z)$	
>45	95	ABREU	91F	DLPH	$\Gamma(Z)$	
none 19.4–28.2	95	ABE	90D	VNS	Any decay; event shape	
>45.0	95	ABREU	90D	DLPH	B(CC) = 1; event shape	
>44.5	95	[16] ABREU	90D	DLPH	$b' \to cH^-$, $H^- \to \overline{c}s$, $\tau^-\nu$	OCCUR=2
>40.5	95	[17] ABREU	90D	DLPH	$\Gamma(Z \to$ hadrons)	OCCUR=3
>28.3	95	ADACHI	90	TOPZ	B(FCNC)=100%; isol. γ or 4 jets	
>41.4	95	[18] AKRAWY	90B	OPAL	Any decay; acoplanarity	
>45.2	95	[18] AKRAWY	90B	OPAL	B(CC) = 1; acoplanarity	OCCUR=2
>46	95	[19] AKRAWY	90J	OPAL	$b' \to \gamma +$ any	
>27.5	95	[20] ABE	89E	VNS	B(CC) =1; μ, e	
none 11.4–27.3	95	[21] ABE	89G	VNS	B($b' \to b\gamma$) > 10%; isolated γ	
>44.7	95	[22] ABRAMS	89C	MRK2	B(CC)= 100%; isol. track	
>42.7	95	[22] ABRAMS	89C	MRK2	B(bg)= 100%; event shape	OCCUR=2
>42.0	95	[22] ABRAMS	89C	MRK2	Any decay; event shape	OCCUR=3
>28.4	95	[23,24] ADACHI	89C	TOPZ	B(CC) =1; μ	
>28.8	95	[25] ENO	89	AMY	B(CC) $\gtrsim$ 90%; μ, e	
>27.2	95	[25,26] ENO	89	AMY	any decay; event shape	OCCUR=2
>29.0	95	[25] ENO	89	AMY	B($b' \to bg$) $\gtrsim$ 85%; event shape	OCCUR=3
>24.4	95	[27] IGARASHI	88	AMY	μ,e	
>23.8	95	[28] SAGAWA	88	AMY	event shape	
>22.7	95	[29] ADEVA	86	MRKJ	μ	
>21		[30] ALTHOFF	84C	TASS	R, event shape	
>19		[31] ALTHOFF	84I	TASS	Aplanarity	

[13] DECAMP 90F looked for isolated charged particles, for isolated photons, and for four-jet final states. The modes $b' \to bg$ for B($b' \to bg$) > 65% $b' \to b\gamma$ for B($b' \to b\gamma$) > 5% are excluded. Charged Higgs decay were not discussed. NODE=Q008BPE;LINKAGE=DC

[14] ABDALLAH 07 searched for b' pair production at $E_{\rm cm}$=196–209 GeV, with 420 pb^{-1}. No signal leads to the 95% CL upper limits on B($b' \to bZ$) and B($b' \to cW$) for $m_{b'}$ = 96 to 103 GeV. NODE=Q008BPE;LINKAGE=DA

[15] ADRIANI 93G search for vector quarkonium states near Z and give limit on quarkonium-Z mixing parameter δm^2 <(10–30) GeV^2 (95%CL) for the mass 88–94.5 GeV. Using Richardson potential, a 1S ($b'\overline{b}'$) state is excluded for the mass range 87.7–94.7 GeV. This range depends on the potential choice. NODE=Q008BPE;LINKAGE=TB

[16] ABREU 90D assumed $m_{H^-} < m_{b'} - 3$ GeV. NODE=Q008BPE;LINKAGE=AB

[17] Superseded by ABREU 91F. NODE=Q008BPE;LINKAGE=AF

[18] AKRAWY 90B search was restricted to data near the Z peak at $E_{\rm cm}$ = 91.26 GeV at LEP. The excluded region is between 23.6 and 41.4 GeV if no H^+ decays exist. For charged Higgs decays the excluded regions are between (m_{H^+} + 1.5 GeV) and 45.5 GeV. NODE=Q008BPE;LINKAGE=AK

[19] AKRAWY 90J search for isolated photons in hadronic Z decay and derive B($Z \to b'\overline{b}'$)·B($b' \to \gamma$X)/B($Z \to$ hadrons) < 2.2×10^{-3}. Mass limit assumes B($b' \to \gamma$X) > 10%. NODE=Q008BPE;LINKAGE=T

[20] ABE 89E search at $E_{\rm cm}$ = 56–57 GeV at TRISTAN for multihadron events with a spherical shape (using thrust and acoplanarity) or containing isolated leptons. NODE=Q008BPE;LINKAGE=A

[21] ABE 89G search was at $E_{\rm cm}$ = 55–60.8 GeV at TRISTAN. NODE=Q008BPE;LINKAGE=B

[22] If the photonic decay mode is large (B($b' \to b\gamma$) > 25%), the ABRAMS 89C limit is 45.4 GeV. The limit for for Higgs decay ($b' \to cH^-$, $H^- \to \overline{c}s$) is 45.2 GeV. NODE=Q008BPE;LINKAGE=G

[23] ADACHI 89C search was at $E_{\rm cm}$ = 56.5–60.8 GeV at TRISTAN using multi-hadron events accompanying muons. NODE=Q008BPE;LINKAGE=C

[24] ADACHI 89C also gives limits for any mixture of CC and bg decays. NODE=Q008BPE;LINKAGE=F

[25] ENO 89 search at $E_{\rm cm}$ = 50–60.8 at TRISTAN. NODE=Q008BPE;LINKAGE=D

[26] ENO 89 considers arbitrary mixture of the charged current, bg, and $b\gamma$ decays. NODE=Q008BPE;LINKAGE=E

[27] IGARASHI 88 searches for leptons in low-thrust events and gives $\Delta R(b')$ < 0.26 (95% CL) assuming charged current decay, which translates to $m_{b'}$ > 24.4 GeV. NODE=Q008BPE;LINKAGE=S

[28] SAGAWA 88 set limit σ(top) < 6.1 pb at CL=95% for top-flavored hadron production from event shape analyses at $E_{\rm cm}$ = 52 GeV. By using the quark parton model cross-section formula near threshold, the above limit leads to lower mass bounds of 23.8 GeV for charge $-1/3$ quarks. NODE=Q008BPE;LINKAGE=Q

[29] ADEVA 86 give 95%CL upper bound on an excess of the normalized cross section, ΔR, as a function of the minimum c.m. energy (see their figure 3). Production of a pair of 1/3 charge quarks is excluded up to E_{cm} = 45.4 GeV. NODE=Q008BPE;LINKAGE=J

[30] ALTHOFF 84C narrow state search sets limit $\Gamma(e^+ e^-)$B(hadrons) <2.4 keV CL = 95% and heavy charge 1/3 quark pair production m >21 GeV, CL = 95%. NODE=Q008BPE;LINKAGE=K

[31] ALTHOFF 84I exclude heavy quark pair production for 7 < m <19 GeV (1/3 charge) using aplanarity distributions (CL = 95%). NODE=Q008BPE;LINKAGE=L

REFERENCES FOR Searches for (Fourth Generation) b' Quark

NODE=Q008

AALTONEN	07C	PR D76 072006	T. Aaltonen *et al.*	(CDF Collab.)	REFID=51994
ABDALLAH	07	EPJ C50 507	J. Abdallah *et al.*	(DELPHI Collab.)	REFID=51764
ACOSTA	03	PRL 90 131801	D. Acosta *et al.*	(CDF Collab.)	REFID=49298
AFFOLDER	00	PRL 84 835	A. Affolder *et al.*	(CDF Collab.)	REFID=47308
ABE	98N	PR D58 051102	F. Abe *et al.*	(CDF Collab.)	REFID=46140
ABACHI	97D	PRL 78 3818	S. Abachi *et al.*	(D0 Collab.)	REFID=45459
FROGGATT	97	ZPHY C73 333	C.D. Froggatt, D.J. Smith, H.B. Nielsen	(GLAS+)	REFID=45376
ABACHI	95F	PR D52 4877	S. Abachi *et al.*	(D0 Collab.)	REFID=44482
ADRIANI	93G	PL B313 326	O. Adriani *et al.*	(L3 Collab.)	REFID=43472
ADRIANI	93M	PRPL 236 1	O. Adriani *et al.*	(L3 Collab.)	REFID=43644
MUKHOPAD...	93	PR D48 2105	B. Mukhopadhyaya, D.P. Roy	(TATA)	REFID=43481
ABE	92	PRL 68 447	F. Abe *et al.*	(CDF Collab.)	REFID=41874
Also		PR D45 3921	F. Abe *et al.*	(CDF Collab.)	REFID=42068
ABE	92G	PR D45 3921	F. Abe *et al.*	(CDF Collab.)	REFID=42068
ABREU	91F	NP B367 511	P. Abreu *et al.*	(DELPHI Collab.)	REFID=41840
ABE	90B	PRL 64 147	F. Abe *et al.*	(CDF Collab.)	REFID=40986
ABE	90D	PL B234 382	K. Abe *et al.*	(VENUS Collab.)	REFID=41105
ABREU	90D	PL B242 536	P. Abreu *et al.*	(DELPHI Collab.)	REFID=41317
ADACHI	90	PL B234 197	I. Adachi *et al.*	(TOPAZ Collab.)	REFID=41106
AKESSON	90	ZPHY C46 179	T. Akesson *et al.*	(UA2 Collab.)	REFID=41051
AKRAWY	90B	PL B236 364	M.Z. Akrawy *et al.*	(OPAL Collab.)	REFID=40987
AKRAWY	90J	PL B246 285	M.Z. Akrawy *et al.*	(OPAL Collab.)	REFID=41336
ALBAJAR	90B	ZPHY C48 1	C. Albajar *et al.*	(UA1 Collab.)	REFID=41312
DECAMP	90F	PL B236 511	D. Decamp *et al.*	(ALEPH Collab.)	REFID=41035
ABE	89E	PR D39 3524	K. Abe *et al.*	(VENUS Collab.)	REFID=40844
ABE	89G	PRL 63 1776	K. Abe *et al.*	(VENUS Collab.)	REFID=40951
ABRAMS	89C	PRL 63 2447	G.S. Abrams *et al.*	(Mark II Collab.)	REFID=40966
ADACHI	89C	PL B229 427	I. Adachi *et al.*	(TOPAZ Collab.)	REFID=40952
ENO	89	PRL 63 1910	S. Eno *et al.*	(AMY Collab.)	REFID=40953
ALBAJAR	88	ZPHY C37 505	C. Albajar *et al.*	(UA1 Collab.)	REFID=40464
ALTARELLI	88	NP B308 724	G. Altarelli *et al.*	(CERN, ROMA, ETH)	REFID=40899
IGARASHI	88	PRL 60 2359	S. Igarashi *et al.*	(AMY Collab.)	REFID=40606
SAGAWA	88	PRL 60 93	H. Sagawa *et al.*	(AMY Collab.)	REFID=40453
ADEVA	86	PR D34 681	B. Adeva *et al.*	(Mark-J Collab.)	REFID=40171
ALTHOFF	84C	PL 138B 441	M. Althoff *et al.*	(TASSO Collab.)	REFID=12195
ALTHOFF	84I	ZPHY C22 307	M. Althoff *et al.*	(TASSO Collab.)	REFID=12196