[75] The limit is for the branching fraction of $^{16}O^*$(6.05 MeV, 0^+) $\rightarrow$ $^{16}O X^0$, $X^0 \rightarrow e^+e^-$ against internal pair conversion for m_{X^0} = 1.7 MeV and $\tau_{X^0} < 10^{-11}$ s. Similar limits are obtained for m_{X^0} = 1.3–3.2 MeV. The spin parity of X^0 must be either 0^+ or 1^-. The limit at 1.7 MeV is translated into a limit for the X^0-nucleon coupling constant: $g^2_{X^0 NN}/4\pi < 2.3 \times 10^{-9}$.

[76] The DOEHNER 88 limit is for m_{A^0} = 1.7 MeV, $\tau(A^0) < 10^{-10}$ s. Limits less than 10^{-4} are obtained for m_{A^0} = 1.2–2.2 MeV.

[77] SAVAGE 88 looked for A^0 that decays into e^+e^- in the decay of the 9.17 MeV $J^P = 2^+$ state in ^{14}N, 17.64 MeV state $J^P = 1^+$ in ^{8}Be, and the 18.15 MeV state $J^P = 1^+$ in ^{8}Be. This experiment constrains the isovector coupling of A^0 to hadrons, if m_{A^0} = (1.1 $\rightarrow$ 2.2) MeV and the isoscalar coupling of A^0 to hadrons, if m_{A^0} = (1.1 $\rightarrow$ 2.6) MeV. Both limits are valid only if $\tau(A^0) \lesssim 1 \times 10^{-11}$ s.

[78] Limits are for $\Gamma(A^0(1.8 \text{ MeV}))/\Gamma(\pi M1)$; i.e., for 1.8 MeV axion emission normalized to the rate for internal emission of e^+e^- pairs. Valid for $\tau_{A^0} < 2 \times 10^{-11}$s. ^{6}Li isovector decay data strongly disfavor PECCEI 86 model I, whereas the ^{10}B and ^{14}N isoscalar decay data strongly reject PECCEI 86 model II and III.

[79] SAVAGE 86B looked for A^0 that decays into e^+e^- in the decay of the 9.17 MeV $J^P = 2^+$ state in ^{14}N. Limit on the branching fraction is valid if $\tau_{A^0} \lesssim 1. \times 10^{-11}$s for m_{A^0} = (1.1–1.7) MeV. This experiment constrains the iso-vector coupling of A^0 to hadrons.

[80] ANANEV 85 with IBR-2 pulsed reactor exclude standard A^0 at CL = 95% masses below 470 keV (Li* decay) and below $2m_e$ for deuteron* decay.

[81] CAVAIGNAC 83 at Bugey reactor exclude axion at any $m_{^{97}\text{Nb}^*\text{decay}}$ and axion with m_{A^0} between 275 and 288 keV (deuteron* decay).

[82] ALEKSEEV 82 with IBR-2 pulsed reactor exclude standard A^0 at CL = 95% mass-ranges m_{A^0} <400 keV (Li* decay) and 330 keV $< m_{A^0}$ <2.2 MeV. (deuteron* decay).

[83] LEHMANN 82 obtained $A^0 \rightarrow 2\gamma$ rate $< 6.2 \times 10^{-5}$/s (CL = 95%) excluding m_{A^0} between 100 and 1000 keV.

[84] ZEHNDER 82 used Goesgen 2.8GW light-water reactor to check A^0 production. No 2γ peak in Li*, Nb* decay (both single p transition) nor in n capture (combined with previous Ba* negative result) rules out standard A^0. Set limit m_{A^0} <60 keV for any A^0.

[85] ZEHNDER 81 looked for Ba* $\rightarrow$ A^0Ba transition with $A^0 \rightarrow 2\gamma$. Obtained 2γ coincidence rate $< 2.2 \times 10^{-5}$/s (CL = 95%) excluding m_{A^0} >160 keV (or 200 keV depending on Higgs mixing). However, see BARROSO 81.

[86] CALAPRICE 79 saw no axion emission from excited states of carbon. Sensitive to axion mass between 1 and 15 MeV.

A^0 (Axion) Limits from Its Electron Coupling

Limits are for $\tau(A^0 \rightarrow e^+e^-)$.

VALUE (s)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •					
none 4×10^{-16}–4.5×10^{-12}	90	[87] BROSS	91	BDMP	$eN \rightarrow eA^0N$ ($A^0 \rightarrow ee$)
		[88] GUO	90	BDMP	$eN \rightarrow eA^0N$ ($A^0 \rightarrow ee$)
		[89] BJORKEN	88	CALO	$A \rightarrow e^+e^-$ or 2γ
		[90] BLINOV	88	MD1	$ee \rightarrow eeA^0$ ($A^0 \rightarrow ee$)
none 1×10^{-14}–1×10^{-10}	90	[91] RIORDAN	87	BDMP	$eN \rightarrow eA^0N$ ($A^0 \rightarrow ee$)
none 1×10^{-14}–1×10^{-11}	90	[92] BROWN	86	BDMP	$eN \rightarrow eA^0N$ ($A^0 \rightarrow ee$)
none 6×10^{-14}–9×10^{-11}	95	[93] DAVIER	86	BDMP	$eN \rightarrow eA^0N$ ($A^0 \rightarrow ee$)
none 3×10^{-13}–1×10^{-7}	90	[94] KONAKA	86	BDMP	$eN \rightarrow eA^0N$ ($A^0 \rightarrow ee$)

[87] The listed BROSS 91 limit is for m_{A^0} = 1.14 MeV. B($A^0 \rightarrow e^+e^-$) = 1 assumed. Excluded domain in the τ_{A^0}–m_{A^0} plane extends up to $m_{A^0} \approx$ 7 MeV (see Fig. 5). Combining with electron $g-2$ constraint, axions coupling only to e^+e^- ruled out for m_{A^0} < 4.8 MeV (90%CL).

[88] GUO 90 use the same apparatus as BROWN 86 and improve the previous limit in the shorter lifetime region. Combined with $g-2$ constraint, axions coupling only to e^+e^- are ruled out for m_{A^0} < 2.7 MeV (90% CL).

[89] BJORKEN 88 reports limits on axion parameters (f_A, m_A, τ_A) for m_{A^0} < 200 MeV from electron beam-dump experiment with production via Primakoff photoproduction, bremsstrahlung from electrons, and resonant annihilation of positrons on atomic electrons.

[90] BLINOV 88 assume zero spin, m = 1.8 MeV and lifetime < 5×10^{-12} s and find $\Gamma(A^0 \rightarrow \gamma\gamma)$B($A^0 \rightarrow e^+e^-$) < 2 eV (CL=90%).

[91] Assumes $A^0\gamma\gamma$ coupling is small and hence Primakoff production is small. Their figure 2 shows limits on axions for m_{A^0} < 15 MeV.

[92] Uses electrons in hadronic showers from an incident 800 GeV proton beam. Limits for m_{A^0} < 15 MeV are shown in their figure 3.

[93] m_{A^0} = 1.8 MeV assumed. The excluded domain in the τ_{A^0}–m_{A^0} plane extends up to $m_{A^0} \approx$ 14 MeV, see their figure 4.

[94] The limits are obtained from their figure 3. Also given is the limit on the $A^0\gamma\gamma$–$A^0e^+e^-$ coupling plane by assuming Primakoff production.

Search for A^0 (Axion) Resonance in Bhabha Scattering

The limit is for $\Gamma(A^0)[\text{B}(A^0 \rightarrow e^+e^-)]^2$.

VALUE (10^{-3} eV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •					
< 1.3	97	[95] HALLIN	92	CNTR	m_{A^0} = 1.75–1.88 MeV
none 0.0016–0.47	90	[96] HENDERSON	92C	CNTR	m_{A^0}= 1.5–1.86 MeV
< 2.0	90	[97] WU	92	CNTR	m_{A^0}= 1.56–1.86 MeV
< 0.013	95	TSERTOS	91	CNTR	m_{A^0} = 1.832 MeV
none 0.19–3.3	95	[98] WIDMANN	91	CNTR	m_{A^0}= 1.78–1.92 MeV
< 5	97	BAUER	90	CNTR	m_{A^0} = 1.832 MeV
none 0.09–1.5	95	[99] JUDGE	90	CNTR	m_{A^0} = 1.832 MeV, elastic
< 1.9	97	[100] TSERTOS	89	CNTR	m_{A^0} = 1.82 MeV
<(10–40)	97	[100] TSERTOS	89	CNTR	m_{A^0} = 1.51–1.65 MeV
<(1–2.5)	97	[100] TSERTOS	89	CNTR	m_{A^0} = 1.80–1.86 MeV
< 31	95	LORENZ	88	CNTR	m_{A^0} = 1.646 MeV
< 94	95	LORENZ	88	CNTR	m_{A^0} = 1.726 MeV
< 23	95	LORENZ	88	CNTR	m_{A^0} = 1.782 MeV
< 19	95	LORENZ	88	CNTR	m_{A^0} = 1.837 MeV
< 3.8	97	[101] TSERTOS	88	CNTR	m_{A^0} = 1.832 MeV
		[102] VANKLINKEN	88	CNTR	
		[103] MAIER	87	CNTR	
<2500	90	MILLS	87	CNTR	m_{A^0} = 1.8 MeV
		[104] VONWIMMER.	87	CNTR	

[95] HALLIN 92 quote limits on lifetime, 8×10^{-14} – 5×10^{-13} sec depending on mass, assuming B($A^0 \rightarrow e^+e^-$) = 100%. They say that TSERTOS 91 overstated their sensitivity by a factor of 3.

[96] HENDERSON 92C exclude axion with lifetime τ_{A^0}=1.4 × 10^{-12} – 4.0 × 10^{-10} s, assuming B($A^0 \rightarrow e^+e^-$)=100%. HENDERSON 92C also exclude a vector boson with τ=1.4 × 10^{-12} – 6.0 × 10^{-10} s.

[97] WU 92 quote limits on lifetime > 3.3 × 10^{-13} s assuming B($A^0 \rightarrow e^+e^-$)=100%. They say that TSERTOS 89 overestimate the limit by a factor of $\pi/2$. WU 92 also quote a bound for vector boson, τ > 8.2 × 10^{-13} s.

[98] WIDMANN 91 bound applies exclusively to the case B($A^0 \rightarrow e^+e^-$)=1, since the detection efficiency varies substantially as $\Gamma(A^0)_{\text{total}}$ changes. See their Fig. 6.

[99] JUDGE 90 excludes an elastic pseudoscalar e^+e^- resonance for 4.5 × 10^{-13} s < $\tau(A^0)$ < 7.5 × 10^{-12} s (95% CL) at m_{A^0} = 1.832 MeV. Comparable limits can be set for m_{A^0} = 1.776–1.856 MeV.

[100] See also TSERTOS 88B in references.

[101] The upper limit listed in TSERTOS 88 is too large by a factor of 4. See TSERTOS 88B, footnote 3.

[102] VANKLINKEN 88 looked for relatively long-lived resonance (τ = 10^{-10}–10^{-12} s). The sensitivity is not sufficient to exclude such a narrow resonance.

[103] MAIER 87 obtained limits $R\Gamma \lesssim$ 60 eV (100 eV) at $m_{A^0} \simeq$ 1.64 MeV (1.83 MeV) for energy resolution $\Delta E_{\text{cm}} \simeq$ 3 keV, where R is the resonance cross section normalized to that of Bhabha scattering, and $\Gamma = \Gamma^2_{ee}/\Gamma_{\text{total}}$. For a discussion implying that $\Delta E_{\text{cm}} \simeq$ 10 keV, see TSERTOS 89.

[104] VONWIMMERSPERG 87 measured Bhabha scattering for E_{cm} = 1.37–1.86 MeV and found a possible peak at 1.73 with $\int \sigma dE_{\text{cm}}$ = 14.5 ± 6.8 keV·b. For a comment and a reply, see VANKLINKEN 88B and VONWIMMERSPERG 88. Also see CONNELL 88.

Search for A^0 (Axion) Resonance in $e^+e^- \rightarrow \gamma\gamma$

The limit is for $\Gamma(A^0 \rightarrow e^+e^-)\cdot\Gamma(A^0 \rightarrow \gamma\gamma)/\Gamma_{\text{total}}$

VALUE (10^{-3} eV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •					
< 6.6	95	[105] TRZASKA	91	CNTR	m_{A^0} = 1.8 MeV
< 4.4	95	WIDMANN	91	CNTR	m_{A^0}= 1.78–1.92 MeV
		[106] FOX	89	CNTR	
< 0.11	95	[107] MINOWA	89	CNTR	m_{A^0} = 1.062 MeV
<33	97	CONNELL	88	CNTR	m_{A^0} = 1.580 MeV
<42	97	CONNELL	88	CNTR	m_{A^0} = 1.642 MeV
<73	97	CONNELL	88	CNTR	m_{A^0} = 1.782 MeV
<79	97	CONNELL	88	CNTR	m_{A^0} = 1.832 MeV

[105] TRZASKA 91 also give limits in the range (6.6–30) × 10^{-3} eV (95%CL) for m_{A^0} = 1.6–2.0 MeV.

[106] FOX 89 measured positron annihilation with an electron in the source material into two photons and found no signal at 1.062 MeV (< 9 × 10^{-5} of two-photon annihilation at rest).

[107] Similar limits are obtained for m_{A^0} = 1.045–1.085 MeV.

Search for X^0 (Light Boson) Resonance in $e^+e^- \rightarrow \gamma\gamma$

The limit is for $\Gamma(X^0 \rightarrow e^+e^-)\cdot\Gamma(X^0 \rightarrow \gamma\gamma)/\Gamma_{\text{total}}$. C invariance forbids spin-0 X^0 coupling to both e^+e^- and $\gamma\gamma$.

VALUE (10^{-3} eV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<3.8	95	[108] SKALSEY	92	CNTR	m_{X^0}= 1.5 MeV

[108] SKALSEY 92 also give limits 4.3 for m_{X^0} = 1.54 and 7.5 for 1.64 MeV. The spin of X^0 is assumed to be one.