[13] ASANO 82 at KEK set limits for B($K^+ \to \pi^+ A^0$) for m_{A^0} <100 MeV as BR $< 4. \times 10^{-8}$ for $\tau(A^0 \to n\gamma\text{'s}) > 1. \times 10^{-9}$ s, BR $< 1.4 \times 10^{-6}$ for $\tau < 1. \times 10^{-9}$s.

[14] ASANO 81B is KEK experiment. Set B($K^+ \to \pi^+ A^0$) $< 3.8 \times 10^{-8}$ at CL = 90%.

[15] ZHITNITSKII 79 argue that a heavy axion predicted by YANG 78 (3 $< m <$40 MeV) contradicts experimental muon anomalous magnetic moments.

A^0 (Axion) Searches in Quarkonium Decays

Decay or transition of quarkonium. Limits are for branching ratio.

VALUE	CL%	EVTS	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<4.0 \times 10^{-5}$	90		ANTREASYAN 90C	CBAL	$\Upsilon(1S) \to A^0\gamma$
			[16] ANTREASYAN 90C	RVUE	
$<5 \times 10^{-5}$	90		[17] DRUZHININ 87	ND	$\phi \to \gamma A^0$ ($A^0 \to e^+e^-$)
$<2 \times 10^{-3}$	90		[18] DRUZHININ 87	ND	$\phi \to \gamma A^0$ ($A^0 \to \gamma\gamma$)
$<7 \times 10^{-6}$	90		[19] DRUZHININ 87	ND	$\phi \to \gamma A^0$ ($A^0 \to$ missing)
$<3.1 \times 10^{-4}$	90	0	[20] ALBRECHT 86D	ARG	$\Upsilon(1S) \to \gamma A^0$ ($A^0 \to e^+e^-$)
$<4 \times 10^{-4}$	90	0	[20] ALBRECHT 86D	ARG	$\Upsilon(1S) \to \gamma A^0$ ($A^0 \to \mu^+\mu^-$, $\pi^+\pi^-$, K^+K^-)
$<8 \times 10^{-4}$	90	1	[21] ALBRECHT 86D	ARG	$\Upsilon(1S) \to \gamma A^0$
$<1.3 \times 10^{-3}$	90	0	[22] ALBRECHT 86D	ARG	$\Upsilon(1S) \to \gamma A^0$ ($A^0 \to e^+e^-, \gamma\gamma$)
$<2. \times 10^{-3}$	90		[23] BOWCOCK 86	CLEO	$\Upsilon(2S) \to \Upsilon(1S) \to A^0$
$<5. \times 10^{-3}$	90		[24] MAGERAS 86	CUSB	$\Upsilon(1S) \to A^0\gamma$
$<3. \times 10^{-4}$	90		[25] ALAM 83	CLEO	$\Upsilon(1S) \to A^0\gamma$
$<9.1 \times 10^{-4}$	90		[26] NICZYPORUK 83	LENA	$\Upsilon(1S) \to A^0\gamma$
$<1.4 \times 10^{-5}$	90		[27] EDWARDS 82	CBAL	$J/\psi \to A^0\gamma$
$<3.5 \times 10^{-4}$	90		[28] SIVERTZ 82	CUSB	$\Upsilon(1S) \to A^0\gamma$
$<1.2 \times 10^{-4}$	90		[28] SIVERTZ 82	CUSB	$\Upsilon(3S) \to A^0\gamma$

[16] The combined limit of ANTREASYAN 90C and EDWARDS 82 excludes standard axion with $m_{A^0} < 2m_e$ at 90% CL as long as $C_\Upsilon C_{J/\psi} > 0.09$, where C_V ($V = \Upsilon$, J/ψ) is the reduction factor for $\Gamma(V \to A^0\gamma)$ due to QCD and/or relativistic corrections. The same data excludes $0.02 < x < 260$ (90% CL) if $C_\Upsilon = C_{J/\psi} = 0.5$, and further combining with ALBRECHT 86D result excludes $5 \times 10^{-5} < x < 260$. x is the ratio of the vacuum expectation values of the two Higgs fields. These limits use conventional assumption $\Gamma(A^0 \to ee) \propto x^{-2}$. The alternative assumption $\Gamma(A^0 \to ee) \propto x^2$ gives a somewhat different excluded region $0.00075 < x < 44$.

[17] The first DRUZHININ 87 limit is valid when $\tau_{A^0}/m_{A^0} < 3 \times 10^{-13}$ s/MeV and $m_{A^0} < 20$ MeV.

[18] The second DRUZHININ 87 limit is valid when $\tau_{A^0}/m_{A^0} < 5 \times 10^{-13}$ s/MeV and $m_{A^0} < 20$ MeV.

[19] The third DRUZHININ 87 limit is valid when $\tau_{A^0}/m_{A^0} > 7 \times 10^{-12}$ s/MeV and $m_{A^0} < 200$ MeV.

[20] $\tau_{A^0} < 1 \times 10^{-13}$s and $m_{A^0} < 1.5$ GeV. Applies for $A^0 \to \gamma\gamma$ when $m_{A^0} < 100$ MeV.

[21] $\tau_{A^0} > 1 \times 10^{-7}$s.

[22] Independent of τ_{A^0}.

[23] BOWCOCK 86 looked for A^0 that decays into e^+e^- in the cascade decay $\Upsilon(2S) \to \Upsilon(1S)\pi^+\pi^-$ followed by $\Upsilon(1S) \to A^0\gamma$. The limit for $B(\Upsilon(1S) \to A^0\gamma)B(A^0 \to e^+e^-)$ depends on m_{A^0} and τ_{A^0}. The quoted limit for m_{A^0}=1.8 MeV is at $\tau_{A^0} \sim 2. \times 10^{-12}$s, where the limit is the worst. The same limit $2. \times 10^{-3}$ applies for all lifetimes for masses $2m_e < m_{A^0} < 2m_\mu$ when the results of this experiment are combined with the results of ALAM 83.

[24] MAGERAS 86 looked for $\Upsilon(1S) \to \gamma A^0$ ($A^0 \to e^+e^-$). The quoted branching fraction limit is for m_{A^0} = 1.7 MeV, at $\tau(A^0) \sim 4. \times 10^{-13}$s where the limit is the worst.

[25] ALAM 83 is at CESR. This limit combined with limit for $B(J/\psi \to A^0\gamma)$ (EDWARDS 82) excludes standard axion.

[26] NICZYPORUK 83 is DESY-DORIS experiment. This limit together with lower limit 9.2×10^{-4} of $B(\Upsilon \to A^0\gamma)$ derived from $B(J/\psi(1S) \to A^0\gamma)$ limit (EDWARDS 82) excludes standard axion.

[27] EDWARDS 82 looked for $J/\psi \to \gamma A^0$ decays by looking for events with a single γ [of energy $\sim$ 1/2 the $J/\psi(1S)$ mass], plus nothing else in the detector. The limit is inconsistent with the axion interpretation of the FAISSNER 81B result.

[28] SIVERTZ 82 is CESR experiment. Looked for $\Upsilon \to \gamma A^0$, A^0 undetected. Limit for 1S (3S) is valid for m_{A^0} <7 GeV (4 GeV).

A^0 (Axion) Searches in Positronium Decays

Decay or transition of positronium. Limits are for branching ratio.

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$<2.8 \times 10^{-5}$	90	[29] AKOPYAN 91	CNTR	o-Ps $\to A^0\gamma$ ($A^0 \to \gamma\gamma$), $m_{A^0} < 30$ keV
$<1.1 \times 10^{-6}$	90	[30] ASAI 91	CNTR	o-Ps $\to A^0\gamma$, $m_{A^0} < 800$ keV
$<3.8 \times 10^{-4}$	90	GNINENKO 90	CNTR	o-Ps $\to A^0\gamma$, $m_{A^0} <$ 30 keV
$<(1–5) \times 10^{-4}$	95	[31] TSUCHIAKI 90	CNTR	o-Ps $\to A^0\gamma$, m_{A^0} = 300–900 keV
$<6.4 \times 10^{-5}$	90	[32] ORITO 89	CNTR	o-Ps $\to A^0\gamma$, $m_{A^0} < 30$ keV
		[33] AMALDI 85	CNTR	Ortho-positronium
		[34] CARBONI 83	CNTR	Ortho-positronium

[29] The AKOPYAN 91 limit applies for a short-lived A^0 with $\tau_{A^0} < 10^{-13}\, m_{A^0}$ [keV] s.

[30] ASAI 91 limit translates to $g^2_{A^0 e^+e^-}/4\pi < 1.1 \times 10^{-11}$ (90%CL) for $m_{A^0} < 800$ keV.

[31] The TSUCHIAKI 90 limit is based on inclusive photon spectrum and is independent of A^0 decay modes.

[32] ORITO 89 limit translates to $g^2_{A^0 ee}/4\pi < 6.2 \times 10^{-10}$. Somewhat more sensitive limits are obtained for larger m_{A^0}: $B < 7.6 \times 10^{-6}$ at 100 keV.

[33] AMALDI 85 set limits $B(A^0\gamma)$ / $B(\gamma\gamma\gamma) < (1–5) \times 10^{-6}$ for m_{A^0} = 900–100 keV which are about 1/10 of the CARBONI 83 limits.

[34] CARBONI 83 looked for orthopositronium $\to A^0\gamma$. Set limit for A^0 electron coupling squared, $g(eeA^0)^2/(4\pi) < 6. \times 10^{-10}$–$7. \times 10^{-9}$ for m_{A^0} from 150–900 keV (CL = 99.7%). This is about 1/10 of the bound from $g-2$ experiments.

A^0 (Axion) Search in Photoproduction

VALUE	DOCUMENT ID	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •		
	[35] BASSOMPIE... 93	m_{A^0}= 1.8 MeV

[35] BASSOMPIERRE 93 looked for a peak in invariant mass of e^+e^- at 1.8 MeV in photoproduction on an aligned Ge crystal. They quote a bound on the portion of possible resonance contribution of 10^{-3} for $\tau_{X^0} < 4 \times 10^{-13}$ s.

A^0 (Axion) Production in Hadron Collisions

Limits are for $\sigma(A^0)$ / $\sigma(\pi^0)$.

VALUE	CL%	EVTS	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
			[36] BLUEMLEIN 92	BDMP	$A^0 N_Z \to \ell^+\ell^- N_Z$
			[37] MEIJERDREES 92	SPEC	$\pi^- p \to nA^0$, $A^0 \to e^+e^-$
			[38] BLUEMLEIN 91	BDMP	$A^0 \to e^+e^-, 2\gamma$
			[39] FAISSNER 89	OSPK	Beam dump, $A^0 \to e^+e^-$
			[40] DEBOER 88	RVUE	$A^0 \to e^+e^-$
			[41] EL-NADI 88	EMUL	$A^0 \to e^+e^-$
			[42] FAISSNER 88	OSPK	Beam dump, $A^0 \to 2\gamma$
			[43] BADIER 86	BDMP	$A^0 \to e^+e^-$
$<2. \times 10^{-11}$	90	0	[44] BERGSMA 85	CHRM	CERN beam dump
$<1. \times 10^{-13}$	90	0	[44] BERGSMA 85	CHRM	CERN beam dump
		24	[45] FAISSNER 83	OSPK	Beam dump, $A^0 \to 2\gamma$
			[46] FAISSNER 83B	RVUE	LAMPF beam dump
			[47] FRANK 83B	RVUE	LAMPF beam dump
			[48] HOFFMAN 83	CNTR	$\pi p \to nA^0$ ($A^0 \to e^+e^-$)
			[49] FETSCHER 82	RVUE	See FAISSNER 81B
		12	[50] FAISSNER 81	OSPK	CERN PS ν wideband
		15	[51] FAISSNER 81B	OSPK	Beam dump, $A^0 \to 2\gamma$
		8	[52] KIM 81	OSPK	26 GeV $pN \to A^0 X$
		0	[53] FAISSNER 80	OSPK	Beam dump, $A^0 \to e^+e^-$
$<1. \times 10^{-8}$	90		[54] JACQUES 80	HLBC	28 GeV protons
$<1. \times 10^{-14}$	90		[54] JACQUES 80	HLBC	Beam dump
			[55] SOUKAS 80	CALO	28 GeV p beam dump
			[56] BECHIS 79	CNTR	
$<1. \times 10^{-8}$	90		[57] COTEUS 79	OSPK	Beam dump
$<1. \times 10^{-3}$	95		[58] DISHAW 79	CALO	400 GeV pp
$<1. \times 10^{-8}$	90		ALIBRAN 78	HYBR	Beam dump
$<6. \times 10^{-9}$	95		ASRATYAN 78B	CALO	Beam dump
$<1.5 \times 10^{-8}$	90		[59] BELLOTTI 78	HLBC	Beam dump
$<5.4 \times 10^{-14}$	90		[59] BELLOTTI 78	HLBC	m_{A^0}=1.5 MeV
$<4.1 \times 10^{-9}$	90		[59] BELLOTTI 78	HLBC	m_{A^0}=1 MeV
$<1. \times 10^{-8}$	90		[60] BOSETTI 78B	HYBR	Beam dump
			[61] DONNELLY 78		
$<0.5 \times 10^{-8}$	90		HANSL 78D	WIRE	Beam dump
			[62] MICELMAC... 78		
			[63] VYSOTSKII 78		