LIMITS ON NEUTRAL LIGHT SCALAR AND PSEUDOSCALAR PARTICLES IN A PROTON BEAM DUMP EXPERIMENT

BERLIN - BUDAPEST - DUBNA - SERPUKHOV - COLLAB.

J. BLÜMLEIN
ZEUTHEN

1. INTRODUCTION
2. P & S - PRODUCTION
3. DECAY RATES
4. DATA & BACKGROUND
5. EXCLUSION LIMITS
6. DISCUSSION

INTRODUCTION

GOAL: SEARCH FOR ISOLATED ELECTROMAGNETIC SHOWERS

$$A^0, H^0 \longrightarrow \begin{cases} e^+e^- \\ \gamma\gamma \end{cases}$$

FROM THE DECAY OF LIGHT (PSEUDO) SCALARS.

- HIGGS-MASS WINDOW $10 \lesssim M_H \lesssim 200\,\text{keV}$
  (SM)
  MSSM, AXION-LIKE PARTICLES

BEAM-DUMP EXPERIMENT

$$pA \rightarrow B\,X$$

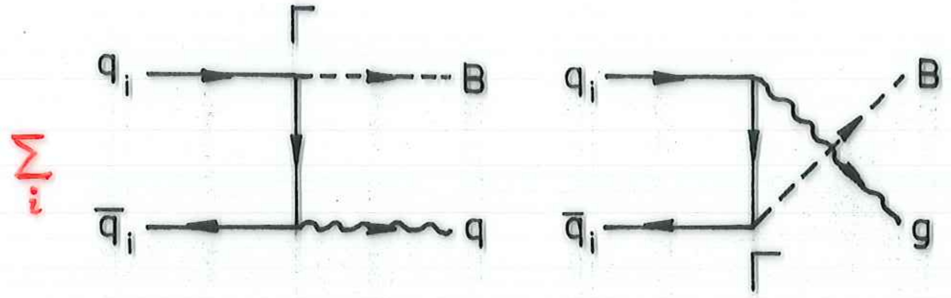
- QCD-BASED σ^{PROD}

$\longrightarrow$ FURTHER SOURCES: $\begin{cases} pA \rightarrow H \text{ elastic} \\ K, \pi \rightarrow B \\ \eta, \eta' \rightarrow B \end{cases}$ (H-A-coupling)

(NOT INCLUDED, BECAUSE OF THEOR. UNCERTAINTIES)

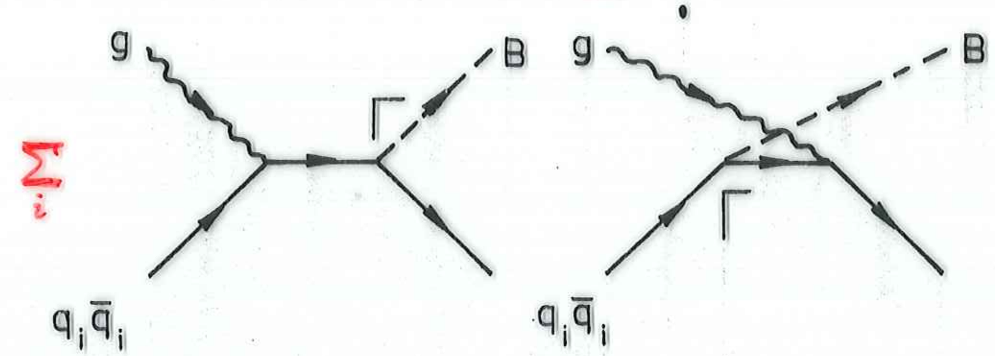
- DERIVE MASS & LIFETIME LIMITS.

B - PRODUCTION



ANNIHILATION

$$\Gamma = 1, \gamma_5$$



COMPTON

$$\frac{d\hat{\sigma}_{Ci}}{d\hat{t}} = \frac{1}{6}\,\frac{\alpha_s(\hat{s})}{4}\, g_H^2\, \lambda^{-1}(\hat{s}, m_i^2, 0) \cdot$$

$$\left\{ -\frac{\hat{u}-m_i^2}{\hat{s}-m_i^2} - \frac{\hat{s}-m_i^2}{\hat{u}-m_i^2} - 2 \right.$$

$$+ a_1 \cdot \left[\frac{1}{\hat{s}-m_i^2} + \frac{1}{\hat{u}-m_i^2} \right] + a_2 \frac{1}{(\hat{s}-m_i^2)(\hat{u}-m_i^2)}$$

$$\left. + a_3 \left[\frac{1}{(s-m_i^2)^2} + \frac{1}{(\hat{u}-m_i^2)^2} \right] \right\}$$

$$\frac{d\hat{\sigma}_{Ai}}{d\hat{t}} = -\frac{4}{9} \cdot 6 \left[\frac{\lambda(\hat{s}, m_i^2, 0)}{\lambda(\hat{s}, m_i^2, m_i^2)}\, \frac{d\hat{\sigma}_{Ci}}{d\hat{t}} \frac{1}{\alpha_s} \right] (\hat{t} \leftrightarrow \hat{s})\ \alpha_s(\hat{s})$$

$$a_i = a_i\left({S \atop P}, m_B^2, m_i^2 \right)$$

$$\frac{d\sigma}{dx_1 dx_2 d\hat{t}} = \sum_i \left\{ \left[f_{i1} \bar{f}_{i2} + f_{i2} \bar{f}_{i1} \right] \frac{d\sigma_{Ai}}{d\hat{t}} \right.$$

$$\left. + \left[G_1 (f_{i2} + \bar{f}_{i2}) + G_2 (f_{i1} + \bar{f}_{i1}) \right] \frac{d\sigma_{Ci}}{d\hat{t}} \right\}$$

$$f_{ij}, G_i = f_{ij}(x, \hat{s}), G_i(x, \hat{s})$$

$$\frac{d}{d\hat{t}} \sigma_{A,C_i} = \frac{d}{d\hat{t}} \sigma_{A,C_i} (\hat{s}, \hat{t})$$

$$\hat{s} = x_1 x_2 (S - 2M_N^2) + m_1^2 + m_2^2$$

↑ initial partons.

f_i, G - DO 1 (similar for EHLQ 1)

$m_u = 4.2$ MeV
$m_d = 7.5$ MeV
$m_s = 150$ MeV
$m_c = 1200$ MeV

- α_s^1 - CALCULATION
- SET $\alpha_s(\hat{s}) = \alpha_s(Q_0^2 = 4\,\text{GeV}^2)$ for $\hat{s} \leq Q_0^2$
(CONSERVATIVE CHOICE ; FOR LOWER $\hat{s}$ HO TERMS ARE NEEDED.)
- NO ACCOUNT FOR WEE - PARTONS $\hat{s} \lesssim 1\,\text{GeV}^2$
(BJORKEN - WEISBERG ENHANCEMENT).

	SCALAR	PSEUDOSCALAR
a_1	$+2m_B^2 - 8m_i^2$	$+2m_B^2$
a_2	$-2m_B^4 - 16m_i^4 + 12m_B^2 m_i^2$	$-2m_B^4 + 4m_B^2 m_i^2$
a_3	$-8m_i^4 + 2m_B^2 m_i^2$	$2m_B^2 m_i^2$

$$\lim_{m_i \to 0} a_j(P) = \lim_{m_i \to 0} a_j(S)$$

(γ_5 CAN BE ROTATED AWAY.)

ANALYTIC $\hat{t}$- INTEGRATION: $\longrightarrow \frac{dN}{dE_B^{lab}}$

$$F_{q_i(g)/P} = F_{q_i(g)/P}(x, \hat{S} = Q^2)$$

$$\alpha_s = \alpha_s(\hat{S})$$

$$\hat{t}_{min,max} = \hat{t}_{min,max}(E_B^{lab}, \theta_{max}^{lab})$$

$$x_1 x_2 \geq (m_B^2 + 2m_B m_i)/(S - 2m_N^2) \qquad \text{COMPTON}$$

$$x_1 x_2 \geq \max\{2m_i^2, m_B^2 - 2m_i^2\}/(S - 2m_N^2) \qquad \text{ANNIHILATION}$$

USE: $\hat{s} + \hat{u} + \hat{t} = 2m_i^2 + m_B^2$

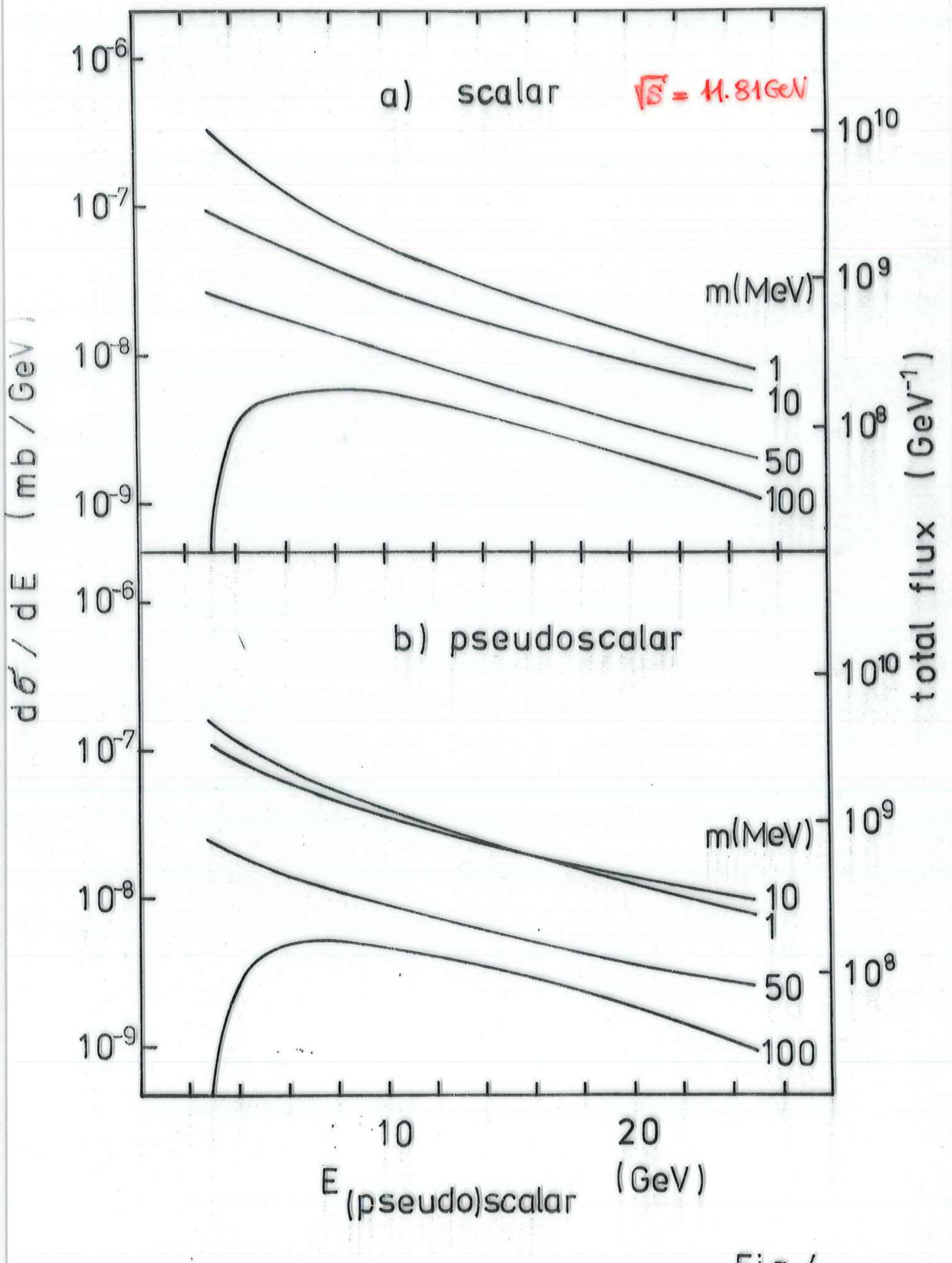
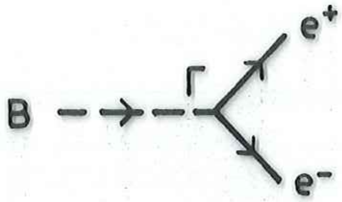
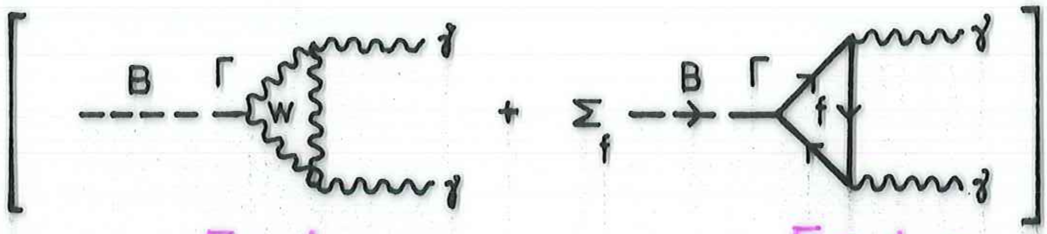

a) scalar
√s = 11.81 GeV
b) pseudoscalar
m(MeV)
1
10
50
100
dσ / dE (mb / GeV)
total flux (GeV⁻¹)
10⁻⁶
10⁻⁷
10⁻⁸
10⁻⁹
10⁸
10⁹
10¹⁰
10
20
E (pseudo)scalar (GeV)

Fig. 4

B-DECAY



$\Gamma = 1, \gamma_5$



$\Gamma = 1$ $\qquad\qquad$ $\Gamma = 1, \gamma_5$

$$\lambda(H \to \gamma\gamma) = \frac{64\pi^3}{\alpha^2 \sqrt{2} G_F m_H^3} \left| \frac{7}{2} s_W - \frac{2}{3} \sum_f Q_f^2 C_f I_h\left(\frac{m_f^2}{m_H^2}\right) s_f \right|^{-2}$$

$$\lambda(A \to \gamma\gamma) = \frac{64\pi^3}{\alpha^2 \sqrt{2} G_F m_A^3} \left| \sum_f Q_f^2 C_f I_A\left(\frac{m_f^2}{m_A^2}\right) p_f \right|^{-2}$$

$$\lambda(H \to e^+e^-) = \frac{8\pi}{\sqrt{2} G_F m_H m_e^2} \frac{1}{s_e^2} \left[1 - 4m_e^2/m_H^2\right]^{-3/2}$$

$$\lambda(A \to e^+e^-) = \frac{8\pi}{\sqrt{2} G_F m_A m_e^2} \frac{1}{p_e^2} \left[1 - 4m_e^2/m_A^2\right]^{-1/2}$$

$$I_H(g) = 3\int_0^1 dx \int_0^{1-x} dy \, \frac{1-4xy}{1-xy/g}$$

$$I_A(g) = 2\int_0^1 dx \int_0^{1-x} dy \, \frac{1}{1-xy/g}$$

$$\lim_{g\to\infty} I_H(g) = \lim_{g\to\infty} I_A(g) = 1.$$

DECAY PROBABILITY IN THE DETECTOR:

$$W(E, m_B) = \exp\left[-\frac{z\, m_B}{\lambda(m_B) E}\right]\left\{1 - \exp\left[-\frac{l\, m_B}{\lambda(m_B) E}\right]\right\}$$

z - DISTANCE OF THE DETECTOR TO THE BEAM DUMP

l - LENGTH OF THE DECAY VOLUME

NUMBER OF EXPECTED EVENTS:

$$\frac{dN(E, m_B)}{dE} = \phi(E, m_B)\, W(E, m_B)\, N_p\, \varepsilon(E)$$

ϕ : B- FLUX $\qquad \phi = \frac{1}{\sigma_{tot}(pN)} \cdot \frac{d\sigma}{dE}(pN \to BX)$

N_p : NUMBER OF PROTONS ON TARGET

$\varepsilon(E)$: RECONSTRUCTION EFFICIENCY $\approx 70\%$

DATA & BACKGROUND

DUMP : 2 TARGETS
70 GeV p ON IRON

μ SHIELD : 64 m

DETECTOR :
- CH_2 - Liqu.*Al - DC (x,y) - SANDWICH
- MAGNETIC FRAMES
- IRON TOROIDS + DC (x,y)

} μ - DETECTION

SEARCH FOR: ISOLATED ELECTROMAGNETIC SHOWERS (e^+e^-, $\gamma\gamma$) AT LOW ANGLES.

$$H^0, A^0 \longrightarrow \begin{cases} e^+e^- \\ \gamma\gamma \end{cases}$$

BACKGROUNDS:

$\overset{(-)}{\nu}_e N \to e^{(\pm)} X$ (DIS, quasielastic, resonant)

$\nu N \to \nu X \pi^0$'s

$\nu e \to \nu e$

$\nu A \to \nu \pi^0 A$

- MONTE CARLO SIMULATION OF ALL POSSIBLE BACKGROUNDS USING THE CALCULATED $\overset{(-)}{\nu}_e, \nu_e, \overset{(-)}{\nu}_\mu, \nu_\mu$ SPECTRA FOR THE BEAM DUMP. (CONSISTENCY WITH THE μ-MONITOR (μ-SHIELD)).

EVENT SELECTION:

3880 reconstructed events (GEOMETRY PROGRAM)

1771 no muon candidate

106 have an electromagnetic shower : $E_{em} \geq 3$ GeV.

$\delta E_{had} = 1.5$ GeV

23 $E_{had} \leq 1.5$ GeV.

9 $\theta_{em} < 0.1$ rad DATA. ; EFFICIENCY: 70%

MC: SELECTION:

10.7 (SAME CUTS) :

8.3 $\overset{(-)}{\nu}_e N \rightarrow e^{(\pm)} X$

0.8 $\overset{(-)}{\nu}_\mu N \rightarrow \pi^0 \overset{(-)}{\nu}_\mu X$

1.5 $\overset{(-)}{\nu} A \rightarrow \overset{(-)}{\nu} A \pi^0$

0.1 $\overset{(-)}{\nu} e \rightarrow \overset{(-)}{\nu} e$

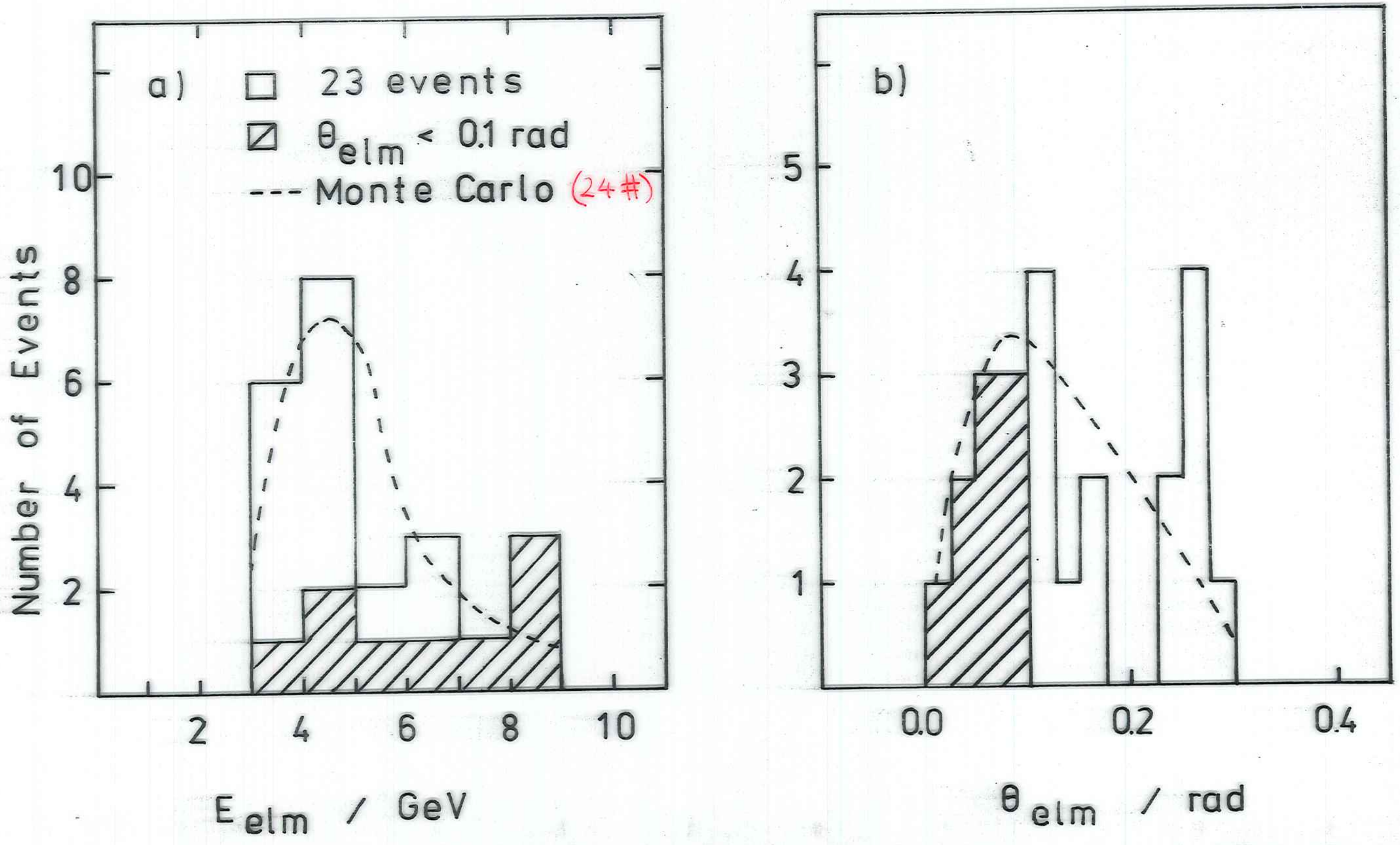

a)
23 events
θ_{elm} < 0.1 rad
--- Monte Carlo (24#)
Number of Events
2
4
6
8
10
E_{elm} / GeV
b)
1
2
3
4
5
0.0
0.2
0.4
θ_{elm} / rad

Fig. 3

EXCLUSION LIMITS

USE: χ^2 - METHOD : FIT SIGNAL TO DATA - BG.
95% CL's.

i) SM - HIGGS:

$1.1 \leq m_H \leq 102$ MeV

ii) MSSM - SCALARS, PSEUDOSCALAR:

$m - x$ & $m - \tau$ - DEPENDENCE FIGS

$m_{sc} < 150$ MeV at $\tau_{sc} = 10^{-10}$ sec

$m_{ps} < 100$ MeV at $\tau_{sc} = 2 \cdot 10^{-11}$ sec

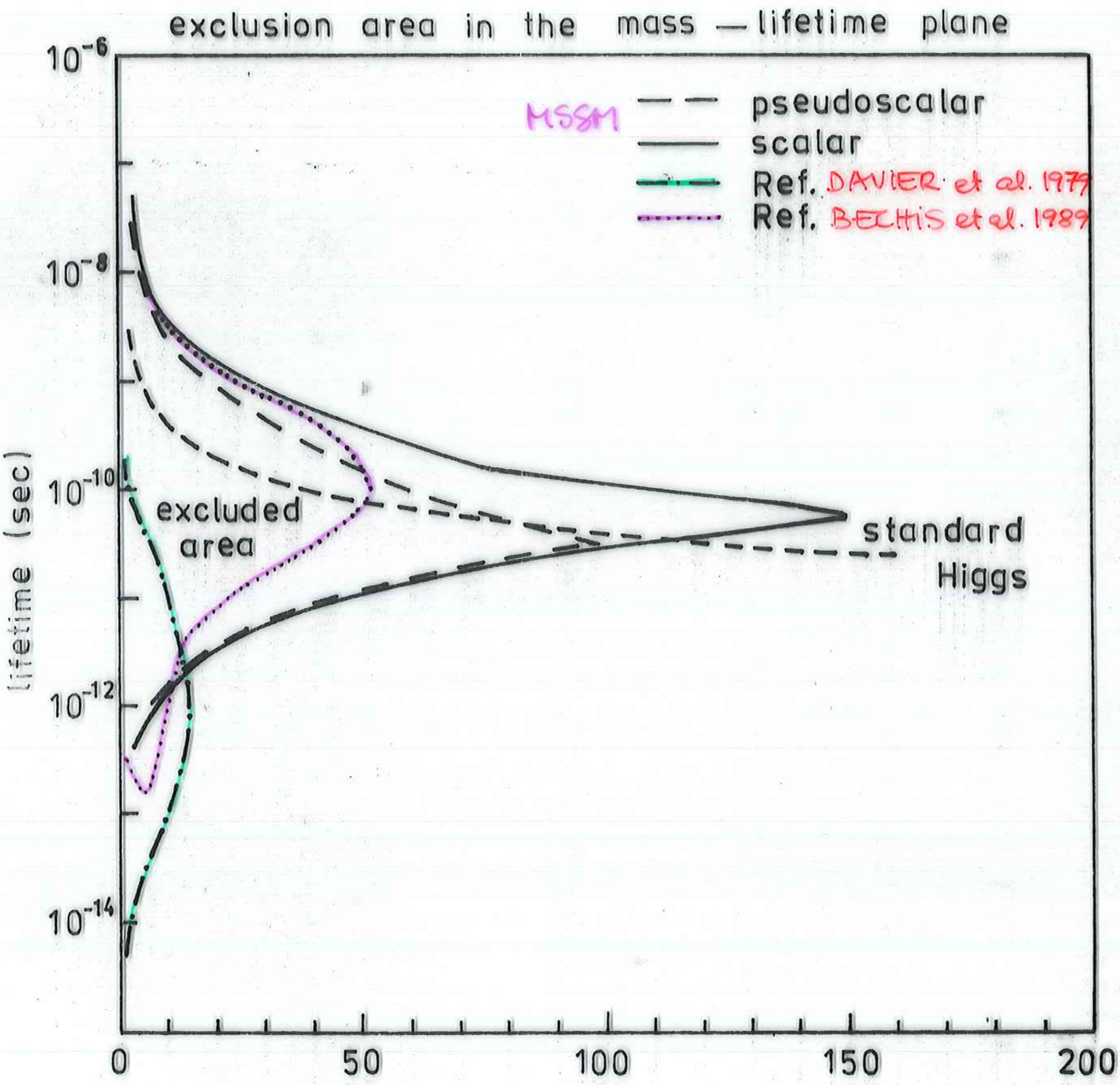
iii) PECCEI - QUINN axions:

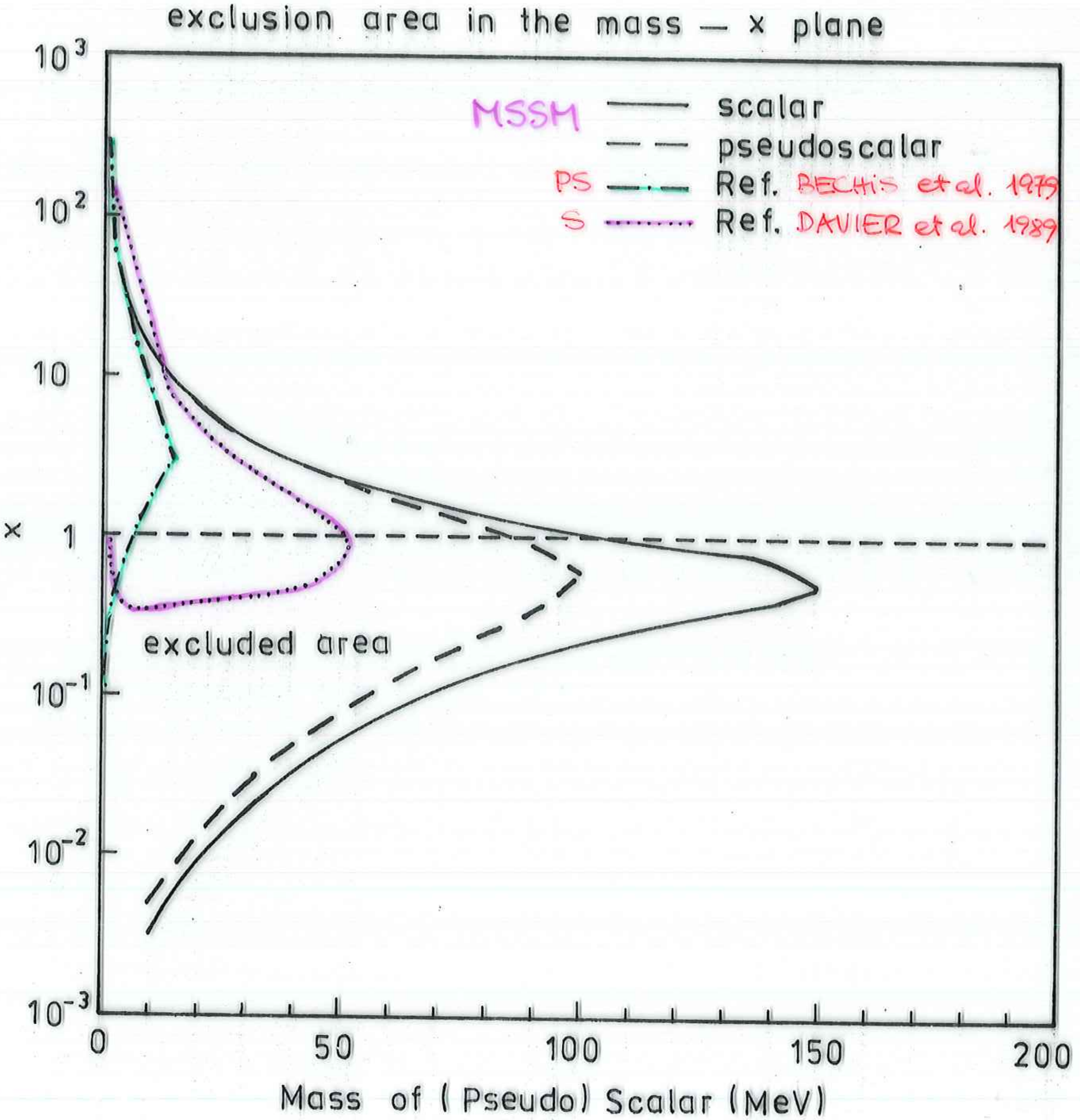
$x > 1$ $0.3 < m_A < 18$ MeV

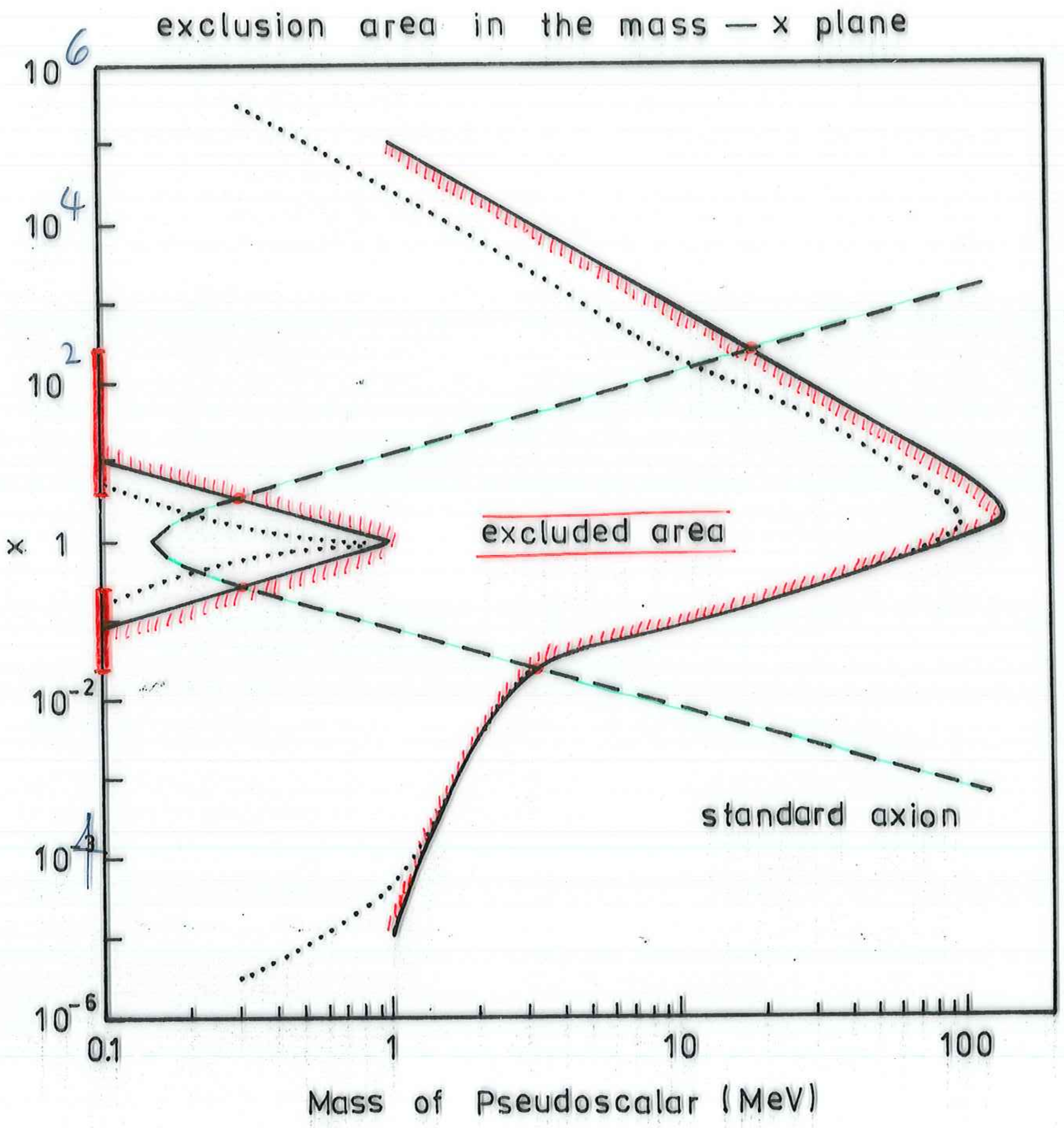
$x < 1$ $0.3 < m_A < 3.2$ MeV

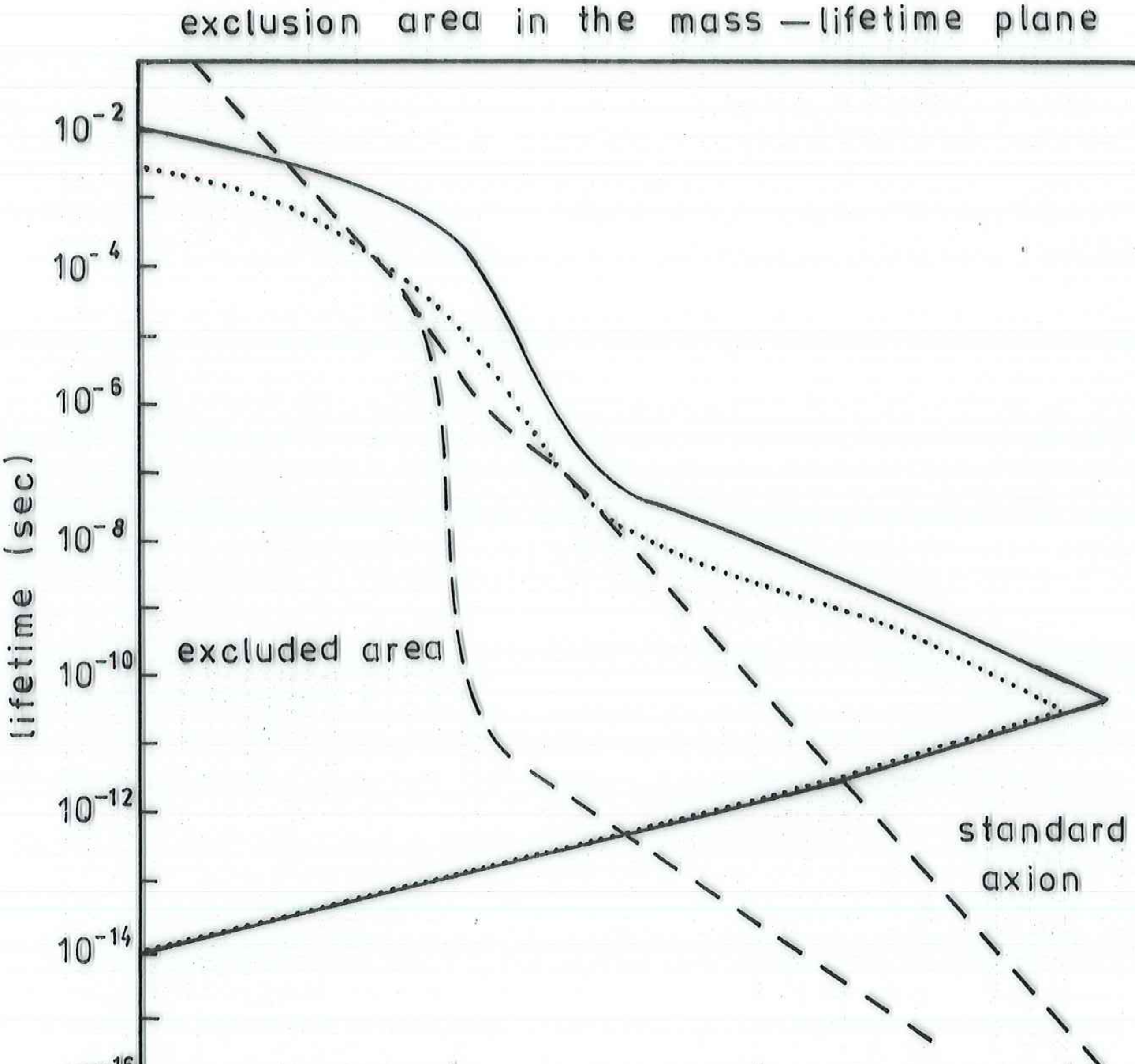
↪ $4 < x < 240$

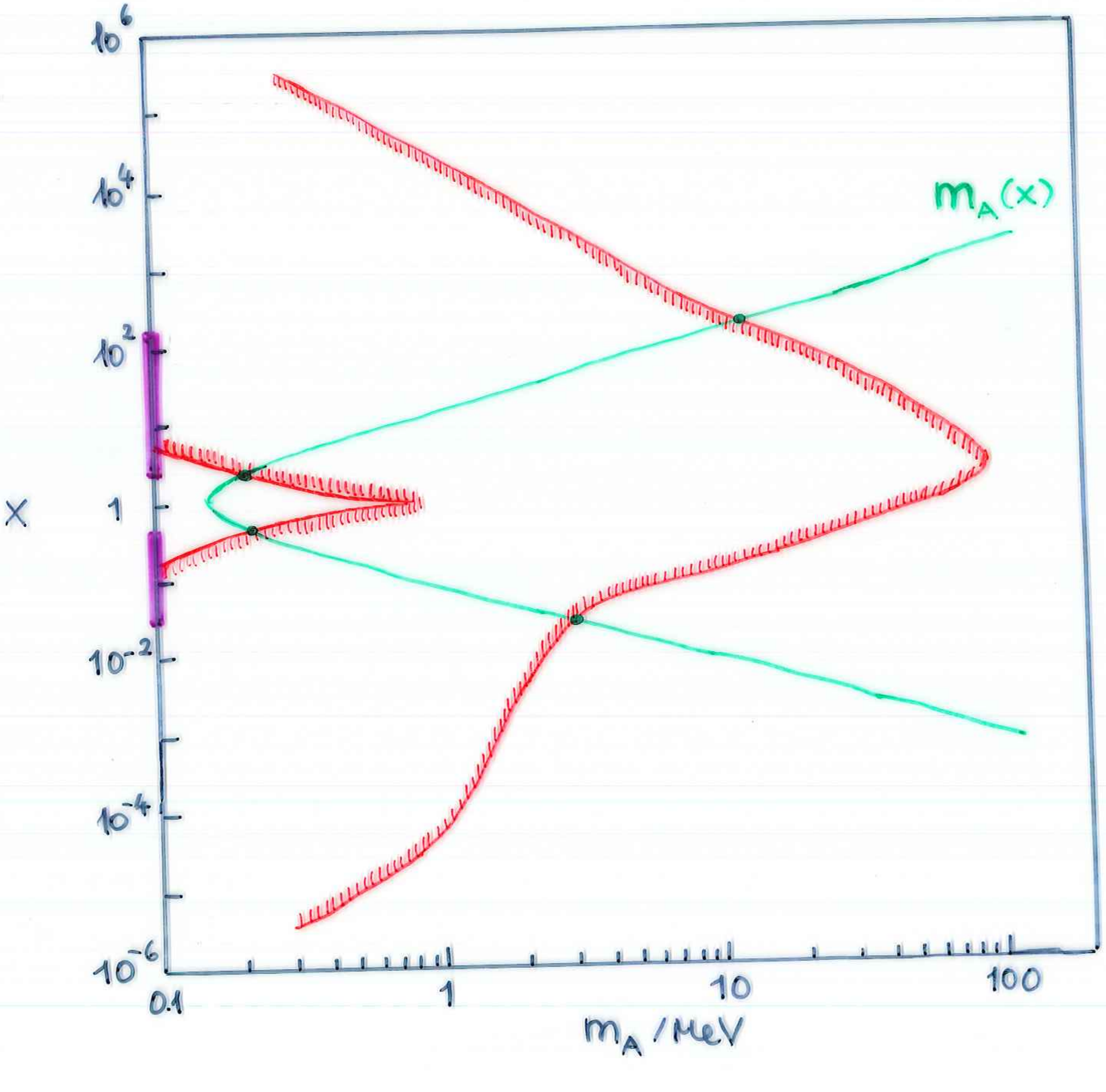
$0.023 < x < 0.25$


exclusion area in the mass — lifetime plane
MSSM
pseudoscalar
scalar
Ref. DAVIER et al. 1979
Ref. BECHIS et al. 1989
excluded area
standard Higgs
lifetime (sec)
10^{-6}
10^{-8}
10^{-10}
10^{-12}
10^{-14}
0
50
100
150
200
Mass of (Pseudo) Scalar (MeV)


exclusion area in the mass — x plane
MSSM
scalar
pseudoscalar
PS Ref. BECHIS et al. 1979
S Ref. DAVIER et al. 1989
excluded area
x
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
0
50
100
150
200
Mass of (Pseudo) Scalar (MeV)


exclusion area in the mass — x plane
10^6
10^4
10^2
x 1
10^{-2}
10^{-4}
10^{-6}
0.1
1
10
100
excluded area
standard axion
Mass of Pseudoscalar (MeV)


exclusion area in the mass — lifetime plane
lifetime (sec)
10^-2
10^-4
10^-6
10^-8
10^-10
10^-12
10^-14
10^-16
excluded area
standard axion
0.1
1
10
100
Mass of Pseudoscalar (MeV)



m_A(x)
X
10^6
10^4
10^2
1
10^-2
10^-4
10^-6
0.1
1
10
100
m_A / MeV

DISCUSSION

- COMPARISON WITH RESULTS FROM OTHER EXPERIMENTS:

→ SENSITIVE TO CONTRIBUTE TO CLOSE THE FORMER HIGGS WINDOW

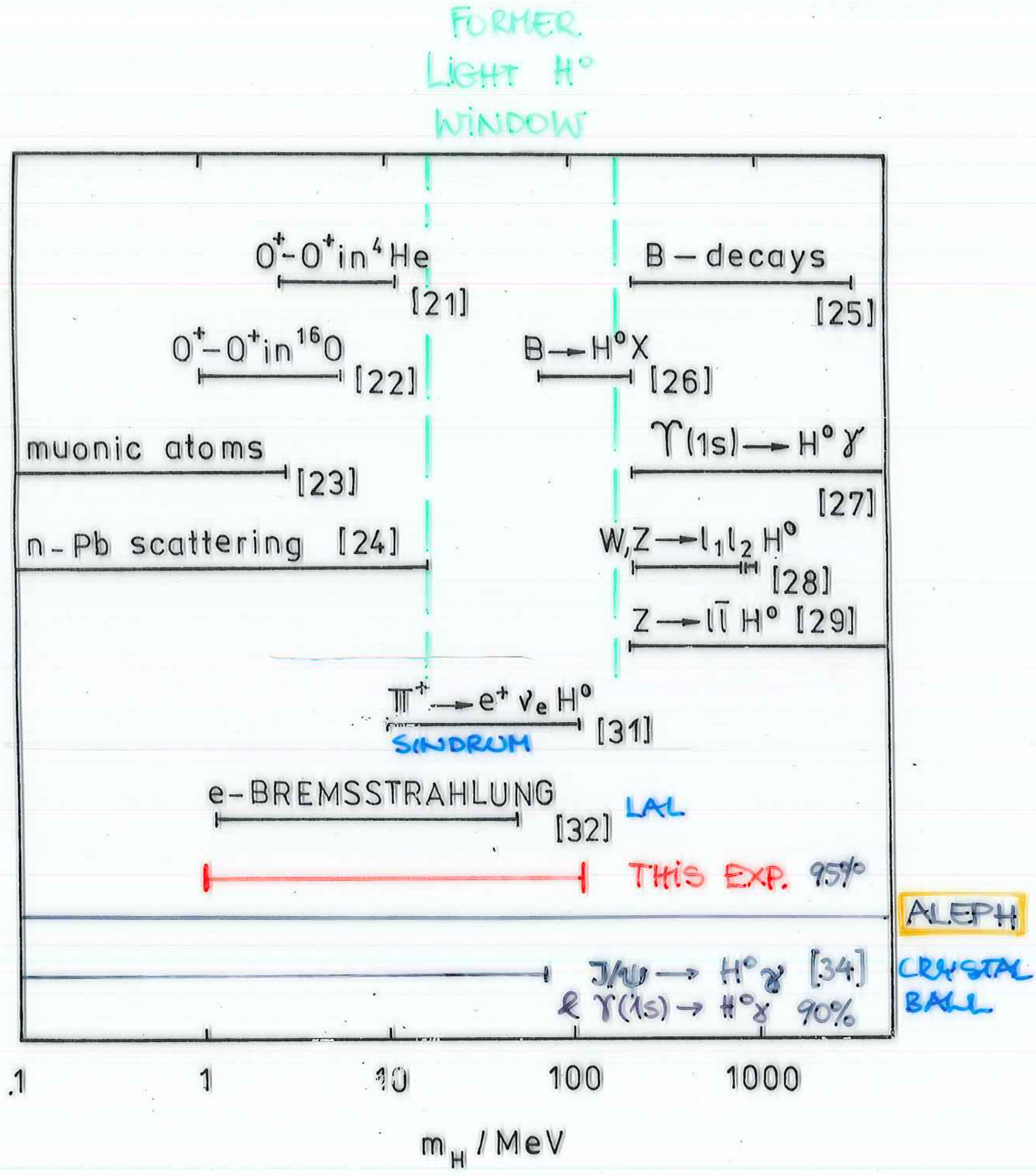
OTHER EXPERIMENTS: SINDRUM
LAL
CRYSTAL BALL
ALEPH, OPAL

Fig.

→ MSSM: EXTENSION OF THE RESULTS BY DAVIER et al. (LAL)

↦ ALEPH GAVE A STILL MORE COMPLETE EXCLUSION.

→ AXION: EXTENSION OF THE EXCLUDED RANGE BY BECHIS ET AL.


FORMER
LIGHT H°
WINDOW
0⁺-0⁺ in ⁴He [21]
B – decays [25]
0⁺-0⁺ in ¹⁶O [22]
B → H°X [26]
muonic atoms [23]
ϒ(1s) → H° γ [27]
n-Pb scattering [24]
W,Z → l₁l₂ H° [28]
Z → ll̄ H° [29]
π⁺ → e⁺ νₑ H° [31]
SINDRUM
e-BREMSSTRAHLUNG [32]
LAL
THIS EXP. 95%
ALEPH
J/ψ → H°γ [34]
& ϒ(1s) → H°γ 90%
CRYSTAL BALL
.1
1
10
100
1000
m_H / MeV