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COMPARISONS of EM CALORIMETRY for GEM

S. Manly, D. Dong, and C. Baltay
Physics Department, Yale University
260 Whitney Avenue
New Haven, CT 06511

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Abstract:
In this note we attempt to make an electromagnetic calorimetry comparison for the process $H^0 \rightarrow \gamma\gamma$ that is independent of concerns about cuts and backgrounds.

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Comparisons of EM Calorimetry for GEM

S.Manly, D.Dong, and C.Baltay

Yale University

The GEM collaboration must narrow down the list of possible choices for electromagnetic calorimetry in the near future. This decision should be based on a cost vs. performance comparison of the various proposed calorimetry types. In the past, discussions of the performance issue have revolved around studies of the process $H^\circ \rightarrow \gamma\gamma$. This is an important process in its own right. It is a promising avenue of discovery for the H° in the 80 to 120 GeV mass range where other methods of discovery fail. It is also thought of as a representative process for types of physics which demand the most of the electromagnetic calorimetry. One problem with the discussions of performance based on this process is that they often degenerate into discussions of cuts and backgrounds. The real issue of the performance comparison seems to get lost. In this note we attempt to make an electromagnetic calorimetry comparison for this process that is independent of concerns about cuts and backgrounds.

To first order the comparison between the various calorimetries listed in Table 1 is easy. At low energies the first term in the expression for the energy resolution is dominant. However, as the energy of the process increases the constant term increases in relative importance. The overall comparison depends on the energy spectrum of the process under consideration. In addition the contributions of finite spatial resolution and overlap events to the final mass resolution are not obvious. In this study $H^\circ \rightarrow \gamma\gamma$ events were generated by a Monte Carlo program and examined. The inherent energy resolution of each type of calorimetry as well as the spatial resolution and effects due to overlap events were taken into account. Once the shape of the reconstructed Higgs mass peak was determined for each type of calorimetry, the minimum signal-to-background (total signal in events to background in events/GeV) in order to observe a 5-σ effect was calculated (assuming a flat background). The relative values of the minimum required signal-to-background constitute the basis of comparison for the various calorimetries. The signal-to-background is allowed to vary because of the general uncertainty in the exact level of background that will be present at the SSC for this process. The background is not expected to be flat over a large mass region. However it is flat to a good approximation over the narrow Higgs mass peak widths discussed in this paper.

Three thousand $H^\circ \rightarrow \gamma\gamma$ events were generated by the ISAJET Monte Carlo package

(version 6.34). The energy of each of the two photons coming from the H° was smeared in the form of a gaussian with the half-width given by the expressions in Table 1. The original 4-vector of each photon was extrapolated to the calorimeter, i.e., until it intersected the surface of a cylinder (1m in radius) or one of the end of the cylinder ($\pm$2m). In order to simulate the spatial resolution of the calorimeter, the endpoint of the extrapolated photon vector was smeared in the form of two-dimensional gaussian with the half-width given in Table 1. Each photon 4-vector was redefined in order to be consistent with the new smeared values of the energy and the calorimeter position. The invariant mass of the two photon pair was calculated and saved. The mean number of overlapping events was calculated (depending on the luminosity and the speed of the readout). The extreme cases were all the 'light' readout calorimetries at $10^{33}cm^{-2}s^{-1}$ with 1.6 overlap events on the average and Pb-LAr at $10^{34}cm^{-2}s^{-1}$ with 64 overlap events on the average. For each $H^\circ \rightarrow \gamma\gamma$ event the number of overlapping events was chosen randomly from a Poisson distribution with the appropriate mean value. This number of events was randomly distributed flat along a distance of $\pm$5cm of the origin. The true region of proton-proton interactions will be $\pm$7cm at the SSC. However the probability of interaction is not flat due to the crossing angle of the beams; so a flat probability along $\pm$5cm was chosen as a simple approximation to the truth. Any event falling within $\pm$1cm of the origin, i.e., $\pm$1cm of the true event, was considered an overlapping event. The origin of the smeared 4-vector for each of the photons was redefined to be the vertex of each of the overlapping events and the two-photon invariant mass calculated and saved. The smeared photon-photon invariant mass for the photons from the true Higgs event along with the combinatoric background from the overlap events (one entry per overlap event, same photons with the overlap event vertex as the origin) for each types of calorimetry was plotted. The width of Higgs mass peaks for each of the types of calorimetry was calculated (assuming the peak to be gaussian). The results are given in Table 2. This information was sufficient to calculate the minimum required signal-to-background for a 5σ effect. A cut was made at $\pm 2\sigma$ about the Higgs mass in calculating the signal-to-background. It was assumed that the background is flat in the narrow region about the Higgs mass peak.

It is important to state clearly what is meant by 'signal' and 'background' in this note. This is best done by example. For the ultra-high precision calorimetry at a luminosity of $10^{33}cm^{-2}s^{-1}$ a gaussian fit to the smeared invariant mass distribution (including overlap events) yields a σ of 0.48 GeV. A $\pm 2\sigma$ cut is used in determining the significance of the signal. At $\pm 2\sigma$ the signal contains $\sim$95% of the events. Using the product $\sigma(pp \rightarrow H^\circ)$=100pb x $B(H^\circ \rightarrow \gamma\gamma)=10^{-3}$, we anticipate 1000 events produced per year; of these, 950 events will be within $\pm 2\sigma$ of the central value of 80 GeV. The maximum tolerable background, B, for a 5σ effect is 3.6×10^4 events given by $950 = 5\sqrt{B}$. It is necessary to factor out the dependence of the background number on the peak width. This is done by dividing the number of background events by the width of the peak used in the background

determination, i.e., $\pm 2\sigma$. Thus the tolerable background level for this particular example is 1.9×10^4 events/GeV. The minimum signal-to-background necessary to observe a 5σ effect in one year of running is taken to be 1000 events/1.9×10^4 events/GeV = 5.2%.

The minimal signal-to-background numbers were plotted as a function of time in Figures 1-4. The assumed SSC luminosity is given in the x-axis label on each figure. The reconstruction efficiency for $H^\circ \rightarrow \gamma\gamma$ was assumed to be 100%. Any deviation from this value (as in real life) is manifested as a slip in the timescale by the inverse of the efficiency (assumed to be the same for each type of calorimetry). The errors shown on the data points (10%) reflect the statistical errors for the numbers of events used in these calculations. The lines are present to guide the eye.

A number of conclusions can be drawn from this study. A comparison of the performance of the Pb-scint calorimetry and the Pb-LAr calorimetry in the first two plots (or in Table 2) shows that they are very similar. The effect of overlap events is not important if the pointing accuracy for the photons is around 1cm or less (larger values have not been studied carefully). Consequently the results at a luminosity of $10^{34}\text{cm}^{-2}\text{s}^{-1}$ (Fig. 3) are similar to the results at a luminosity of $10^{33}\text{cm}^{-2}\text{s}^{-1}$ (Figs. 1 and 2) except that the minimum signal-to-background that can be tolerated is a factor of ten smaller.

The dominant error in each of the plots is the energy-dependent term in the expression for the energy resolution. This term decreases in relative importance compared to the constant term as the energy of the process increases. It is often stated that the relative performance of Pb-scint or Pb-LAr calorimetry compared to the homogeneous calorimetries should improve toward the upper end of the 80-120 GeV Higgs mass window due to this. Figure 4 shows the variation of the minimal signal-to-background vs. time for Pb-LAr and a homogeneous calorimetry for the reconstruction of a 120 GeV Higgs. This plot and Figure 1 show that the relative performance between the two types of calorimetry is not strongly dependent on M_H as the Higgs mass goes from 80 to 120 GeV. The change in the energy spectrum of the photons is simply not enough to significantly increase the importance of the constant term relative to the energy-dependent term. The background level does fall as the region of interest increases from 80 to 120 GeV (the Higgs production cross section does not vary much). So, it should be noted that the relevant signal-to-background is different for the M_H=120 GeV plot and the M_H=80 GeV plot.

These figures can be used conveniently to compare different calorimetries in terms of the required time it takes to establish a 5σ effect. At $10^{33}\text{cm}^{-2}\text{s}^{-1}$ and a signal-to-background of 8%, a 5σ effect can be observed in $\sim$0.68 SSC years with the ultra-high precision calorimetry and in $\sim$0.94 SSC years with the Pb-scint or Pb-LAr calorimetry (1.4 times longer). This factor of 1.4 is fairly constant throughout the signal-to-background range in these figures. Therefore arguements about the exact level of background are irrelevant for this decision. Within the context of this study the cost of going with the Pb-LAr calorimetry as opposed

to the BaF calorimetry (just to choose concrete examples) is a factor of 1.4 in time. At any given time there is a small window of additional reach in signal-to-background for the BaF calorimetry as compared to the Pb-LAr. For example, after 1.5 years of running at $10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ it is possible to claim a 5σ effect with a signal-to-background as low as 3.5% with the BaF calorimetry. If the signal-to-background is 5.1% the Pb-LAr calorimetry is sufficient to see the effect. If the signal-to-background is below 5.1% the effect cannot be seen by either type of calorimetry (at 5σ).

Table 1: Parameters used to study proposed electromagnetic calorimetry for GEM.

type of EM calorimetry	energy resolution ($\frac{\sigma}{E}$)	spatial resolution	readout time in SSC pulses
BaF or LXe	$\frac{1.5\%}{\sqrt{E}} \oplus 0.5\%$	1mm	1
Pb-scint	$\frac{7.5\%}{\sqrt{E}} \oplus 0.5\%$	1mm	1
Pb-LAr	$\frac{7.5\%}{\sqrt{E}} \oplus 0.5\%$	1mm	4
Pb-scint	$\frac{15\%}{\sqrt{E}} \oplus 1\%$	2mm	1
Pb-LAr	$\frac{15\%}{\sqrt{E}} \oplus 1\%$	2mm	4

Table 2: Table of energy resolutions (in GeV) determined in this study.

type of EM calorimetry	M_H = 80 GeV L = 10^{33} cm^{-2}s^{-1}	M_H =120 GeV L=10^{33}cm^{-2}s^{-1}	M_H=80 GeV L=10^{34}cm^{-2}s^{-1}
BaF or LXe	0.48*	0.60	0.50
Pb-Scint(7.5%)	0.69	—	—
Pb-LAr(7.5%)	0.69	0.91	0.72
Pb-Scint(15%)	1.2	—	1.3
Pb-LAr(15%)	—	—	1.3

* Each value has approximately an 8% statistical error.

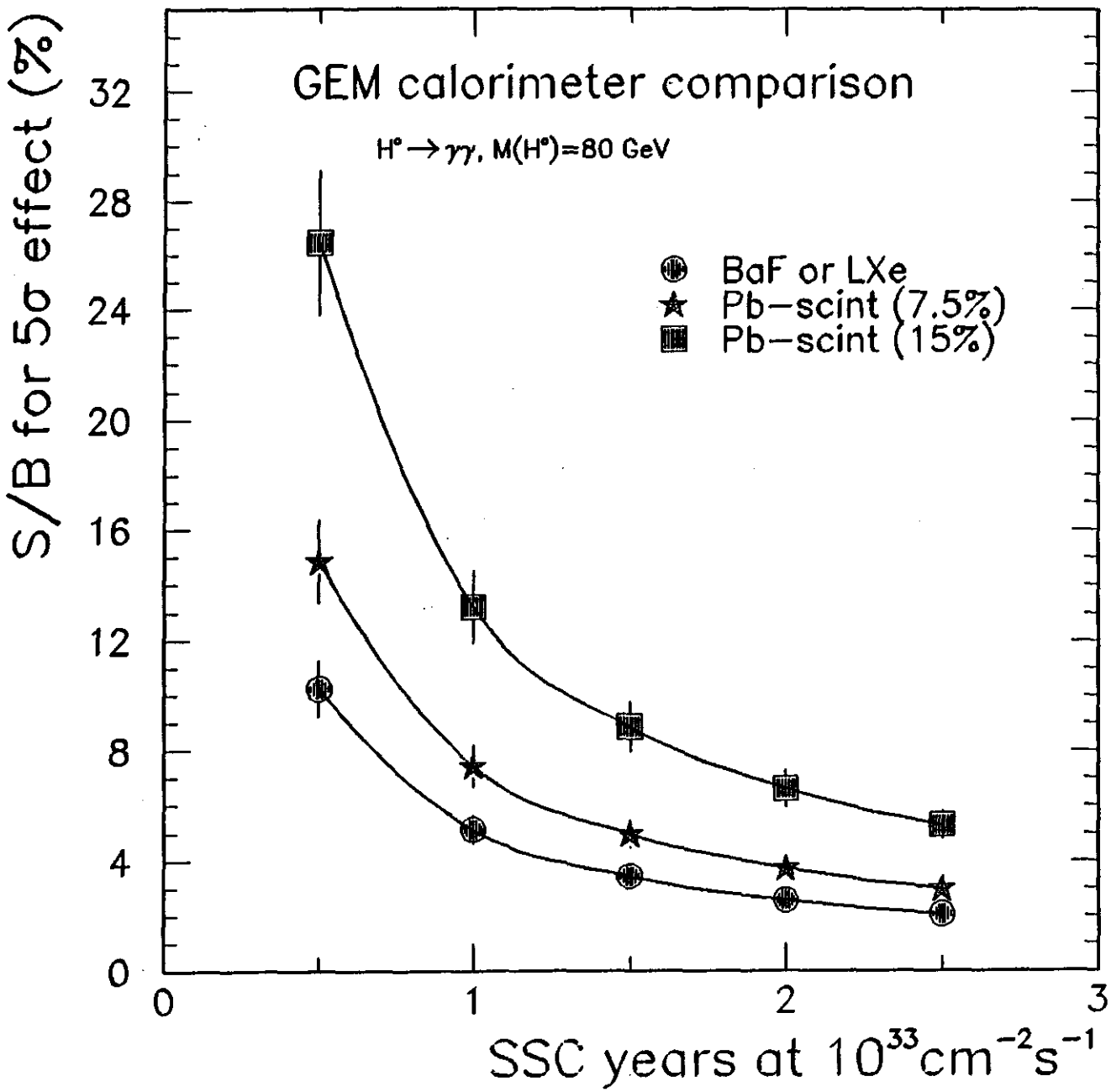
GEM calorimeter comparison
H° → γγ, M(H°)=80 GeV
BaF or LXe
Pb−scint (7.5%)
Pb−scint (15%)
S/B for 5σ effect (%)
0
4
8
12
16
20
24
28
32
0
1
2
3
SSC years at 10^33 cm^−2 s^−1

Figure 1.

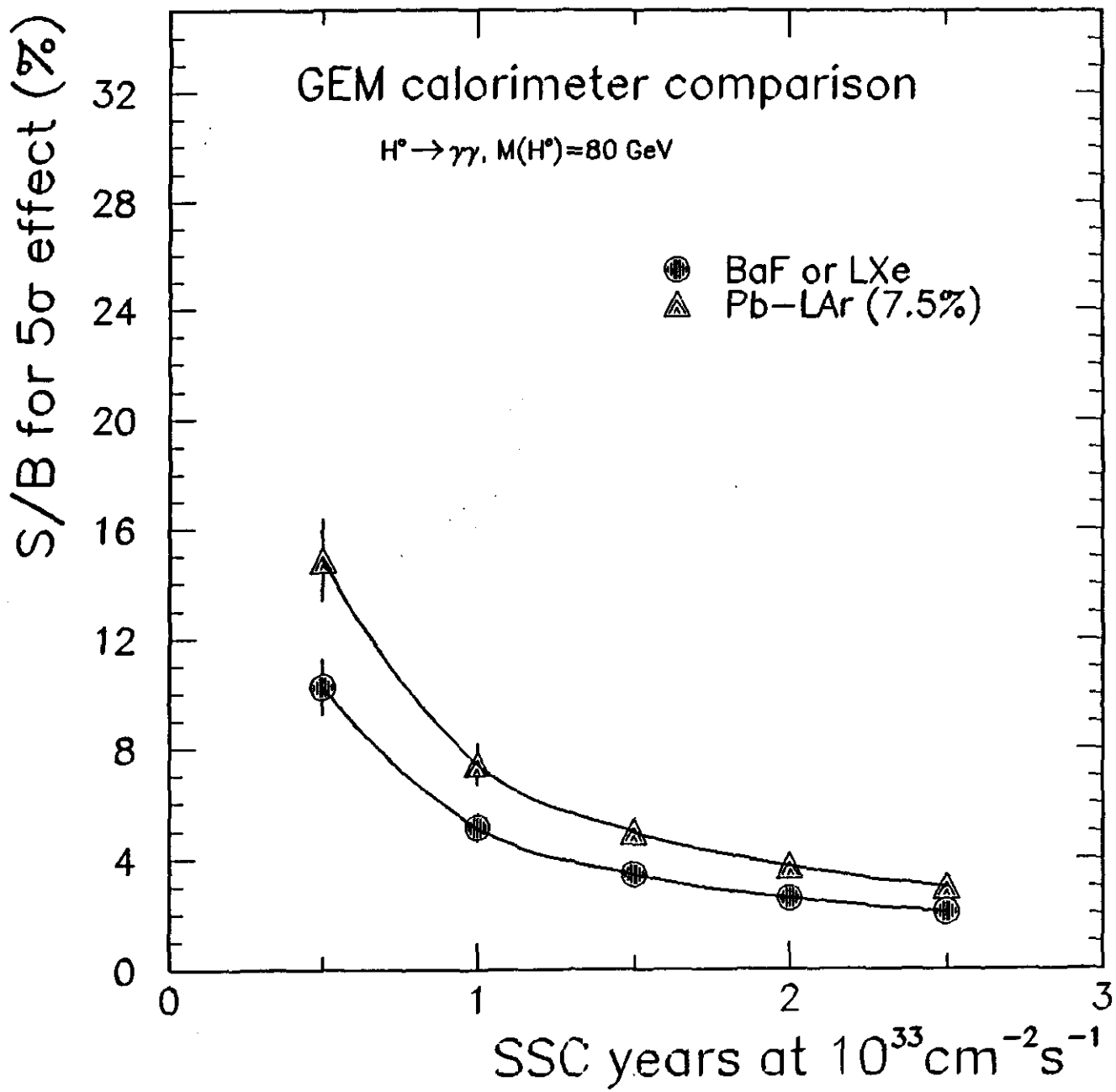
GEM calorimeter comparison
H° → γγ, M(H°)=80 GeV
BaF or LXe
Pb−LAr (7.5%)
S/B for 5σ effect (%)
0
4
8
12
16
20
24
28
32
0
1
2
3
SSC years at $10^{33}cm^{-2}s^{-1}$

Figure 2.

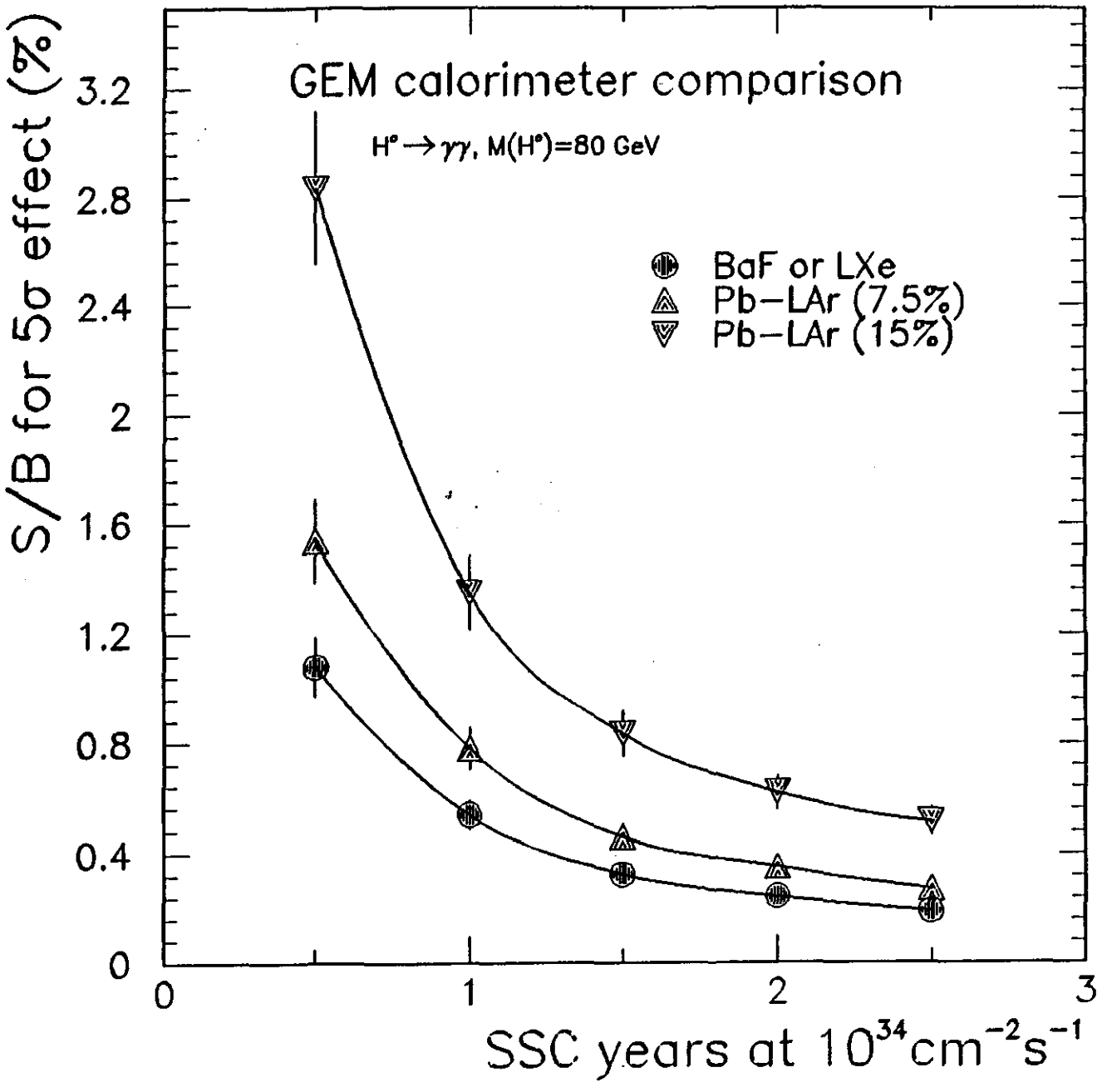
GEM calorimeter comparison
H° → γγ, M(H°)=80 GeV
BaF or LXe
Pb−LAr (7.5%)
Pb−LAr (15%)
S/B for 5σ effect (%)
SSC years at 10^34 cm^-2 s^-1
0
0.4
0.8
1.2
1.6
2
2.4
2.8
3.2
0
1
2
3

Figure 3.

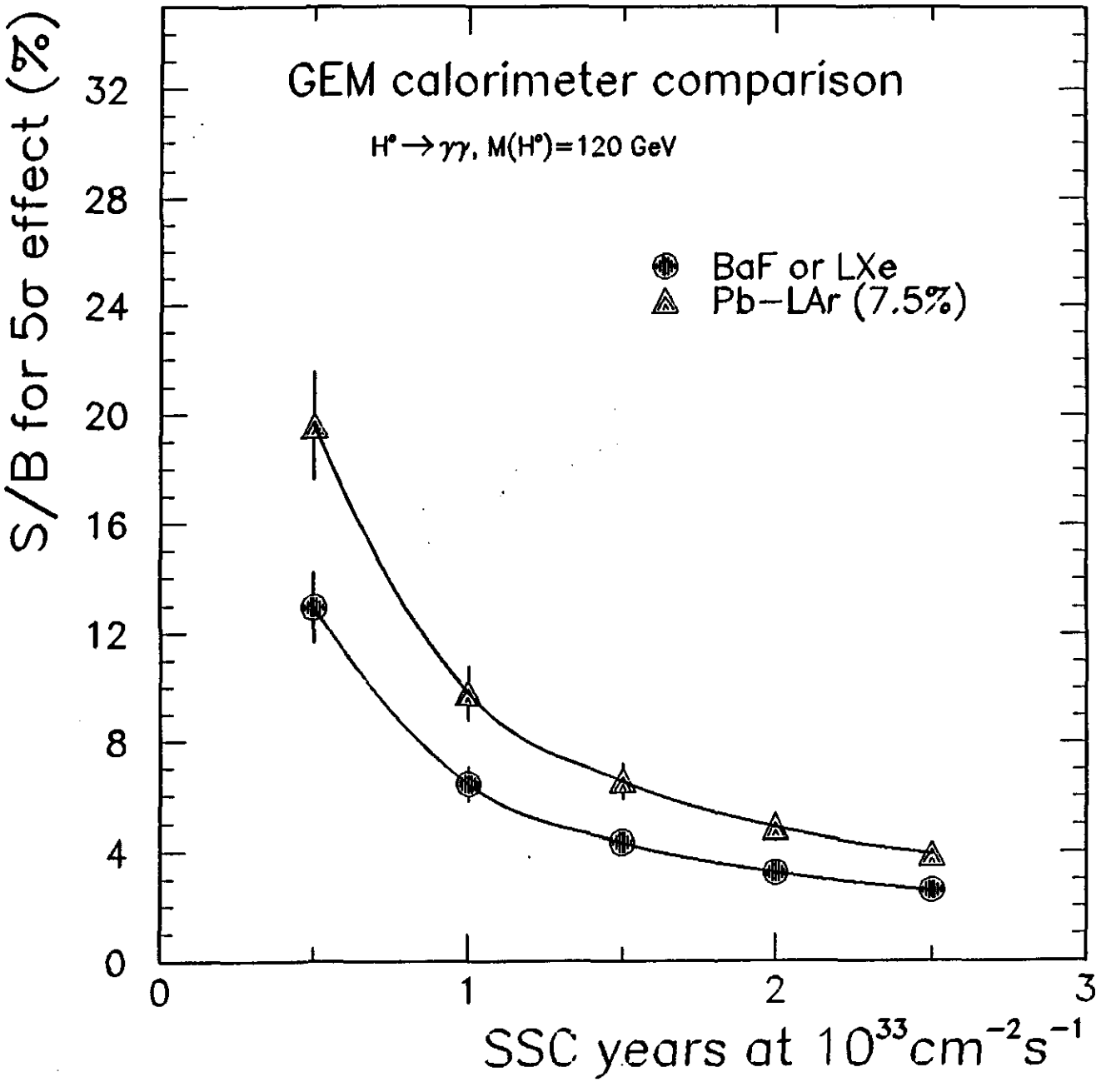
GEM calorimeter comparison
H° → γγ, M(H°)=120 GeV
BaF or LXe
Pb−LAr (7.5%)
S/B for 5σ effect (%)
SSC years at 10^33 cm^-2 s^-1
0
4
8
12
16
20
24
28
32
0
1
2
3

Figure 4.