

UTHEP-92-0501

May 1992

Multiple photon effects in  $pp$  scattering at SSC energies \*

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*SLAC, Stanford University, Stanford, CA 94309, USA***ABSTRACT**

The Monte Carlo program SSCYFS2 is used in conjunction with available parton distribution functions to calculate the effects of multiple photon radiation on  $pp$  scattering at SSC energies. Effects relevant to precision SSC physics such as Higgs discovery and exploration are illustrated.

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\*Supported in part by the Texas National Research Laboratory Commission for the Superconducting Super Collider Laboratory via grant RCFY9201, by the US Department of Energy Contracts DE-FG05-91ER40627 and DE-AC03-76ER00515, and by the Polish Ministry of Education grants KBN 223729102 and KBN 203809101.

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Now that the SSC is under construction, it is important to prepare for the maximal exploration of its new energy frontier. Higher-order radiative corrections to its basic physics processes are then of large significance, for these corrections determine the precise level at which signals for new physics or Higgs physics can be separated from background as well as the precise level at which such signals can be measured. Accordingly, we have recently initiated [1] the development and implementation of the YFS Monte Carlo approach in Ref. [2] to higher-order radiative corrections to the SSC physics processes. In this Letter, we present our results for the multiple photon radiative effects in  $pp \rightarrow qq^{(\prime)} + n(\gamma) + X$  where  $q, q' = u, d, s$ , and we require that the  $pp$  c.m.s. production angle of  $q(q')$ ,  $\theta_{q(q')}$ , must satisfy the SDC acceptance cut (GEM would have a similar cut)  $|\eta| < 2.8$  for definiteness. (We recall for completeness that the development in Ref. [2] is based on the original work of Yennie, Frautschi and Suura in Ref. [3].)

Specifically, we use the Monte Carlo (MC) event generator SSCYFS2 which was developed in Ref. [1] for

$$q(\bar{q})' \rightarrow q(\bar{q})' + n(\gamma) \quad (1)$$

and the parton distributions of Refs. [4] to simulate, on an event-by-event basis, the multiple photon initial state radiative effects in

$$pp \rightarrow qq^{(\prime)} + n(\gamma) + X, \quad (2)$$

where  $q, q' = u, d, s$ .

The basic master formula for the cross-section is then the usual parton distribution convolution

$$\sigma = \sum_{q, q'} \int \mathcal{D}_q(x_1) \mathcal{D}_{q'}(x_2) \sigma_{\text{YFS}}(x_1 x_2 s) dx_1 dx_2 \quad (3)$$

where  $\mathcal{D}_q(x_1)$  is the usual parton distribution of quark  $q$  in  $p$  and  $\sigma_{\text{YFS}}$  is the YFS multiple-photon cross-section for (1) realized by MC methods in SSCYFS2 in Ref. [1]. We emphasize that the formula in (3) is new in that it combines the YFS amplitude based higher order QED corrections to the reduced hard subprocess with the QCD evolved parton distributions. The theoretical basis for this is the well-known factorization theorem for hard hadron-hadron collisions [5]. Equivalently, since the distributions are strictly defined in the leading-log approximation framework, each emission of a gluon or a photon from an incoming parton is independent

in that framework so that all gluon emissions may be factorized away from the photon emissions, as we imply in (3), for the hard subprocess case. Note that this implies that the QED corrections to the low energy data from which the  $\mathcal{D}_q$  are evolved have been done properly [6]. We emphasize that the entire cross-section in (3) is also now realized by MC methods by using such methods to choose  $x_1$  and  $x_2$  as well as to realize  $\sigma_{\text{YFS}}$ . The resulting program is called SSCYFSP and it will be described in detail elsewhere [7]. Here, we present results obtained with SSCYFSP and we comment on their implications for SSC physics objectives.

More precisely, our complete trigger cuts for our sample MC data are as follows:

$$E_\gamma > 3 \text{ GeV}, \quad E_{\text{particleout}} > 80 \text{ GeV}, \quad \theta > \pi/6 \quad (4)$$

so that we expect these data to be relevant to the GEM and the SDC acceptances. For this trigger, we show in turn in Figs. 1-5 the photon multiplicity, the total photon transverse momentum, the total photon mass, the final  $v$ -distribution of the outgoing  $qq^{(\prime)}$  system, and the outgoing parton energy fraction distribution in the  $pp$  cms system.

What we see in Fig.1 is that the mean value of  $n_\gamma$  is  $.133 \pm .369$ . Thus, multiple photon effects must be considered in detail in view of our cuts, where we require  $E_\gamma > 3 \text{ GeV}$ .

In Fig. 2, we show that the total photon transverse momentum has a mean value

$$\langle p_{\perp, \text{tot}} \rangle = 4.1 \pm 16.9 \text{ GeV}. \quad (5)$$

The key issue regarding background to  $H \rightarrow \gamma\gamma$  in the intermediate regime is how often we get  $40 \text{ GeV} \lesssim E_\gamma \lesssim 75 \text{ GeV}$  in the transverse directions. We see from Fig. 2 that, even allowing for realistic parton distributions, which clearly degrade substantially the energy available in the reduced collisions in (3) on the average, we still will have to deal with this question in detail. Such discussion will appear elsewhere.

In Fig. 3, we illustrate further the need to make a detailed study of the background from multiple photon effects to  $H \rightarrow \gamma\gamma$  via the total photon mass plot, where we find the mean value

$$\langle M_{n\gamma} \rangle = \langle ((\sum_i k_i)^2)^{\frac{1}{2}} \rangle = 37.2 \pm 6.9 \text{ GeV}. \quad (6)$$

Again, the value of  $M_{n\gamma}$  emphasizes that the issue of how many such  $n\gamma$  final states in (2) can fake  $H \rightarrow \gamma\gamma$  has to be studied in detail.[7]

The  $v \equiv (\hat{s} - \hat{s}')/\hat{s}$  distribution shown in Fig. 4 illustrates again that a substantial fraction of the available energy is radiated away. The mean value of  $v$  is

$$\langle v \rangle = .0179 \pm .0668. \quad (7)$$

Hence, even for heavy Higgs hunting at the SSC, a detailed assessment of the effect of this radiation will be required. Such an assessment will appear elsewhere.[7]

Our final Fig. 5 shows the effect of the interplay of the parton distributions and our SS-CYFSP multiple photon radiation in the final parton energy distribution. Our YFS radiation shifts the average value of the parton energy to lower values by a fraction  $\sim 0.5\langle v \rangle$  of  $\sqrt{s'}/2$  so that the final parton energy distribution is only slightly modified to softer values by our YFS radiation. As expected, since our reduced cross section scales like  $1/s'$ , our final parton energy distribution is indeed significantly softer than our input distribution: in our input distribution, we have

$$\langle E_q/(\sqrt{s}/2) \rangle \simeq .11 \quad (8)$$

whereas in Fig. 5 we have

$$\langle E'_q/(\sqrt{s'}/2) \rangle = .34 \pm .27. \quad (9)$$

This is consistent with (7) and it illustrates the effect of the reduced hard cross section on the YFS radiation—the preference for smaller values of  $s'$  weakens the YFS radiation effects relative to what we found in Ref. [1], as expected. This is a consistency check on our work. In all of our figures, our input distributions were those of Glück, Reya, and Vogt in Ref. [4]. We have checked that the use of the distributions of Duke and Owens in Ref.[4] does not make a significant change in our results. The trigger cross-section which we find,  $5.672 \pm .002$  nanobarns, is consistent with the results in Ref. [1] and references therein.

In summary, we have combined our SSCYFS2 MC event generator with the parton distributions in Ref. [4] to make for the first time a realistic simulation of  $pp \rightarrow qq^{(\prime)} + n(\gamma) + X$  at SSC energies on an event-by-event basis. We have found that the general character of the

SSCYFS2 results in Ref. [1] for  $q(\bar{q}) \rightarrow q(\bar{q}') + n(\gamma)$  still hold true for the  $pp$  case. Indeed, our results emphasize the need for detailed  $n(\gamma)$  background studies to  $H \rightarrow \gamma\gamma$  and  $n(\gamma)$  radiative studies in Higgs hunting analysis methods in general. Such work will appear elsewhere.[7]

## Acknowledgements

Two of the authors (S.J. and B.F.L.W.) are grateful to Prof. J. Ellis for the kind hospitality of the CERN TH Division, where part of this work was done.

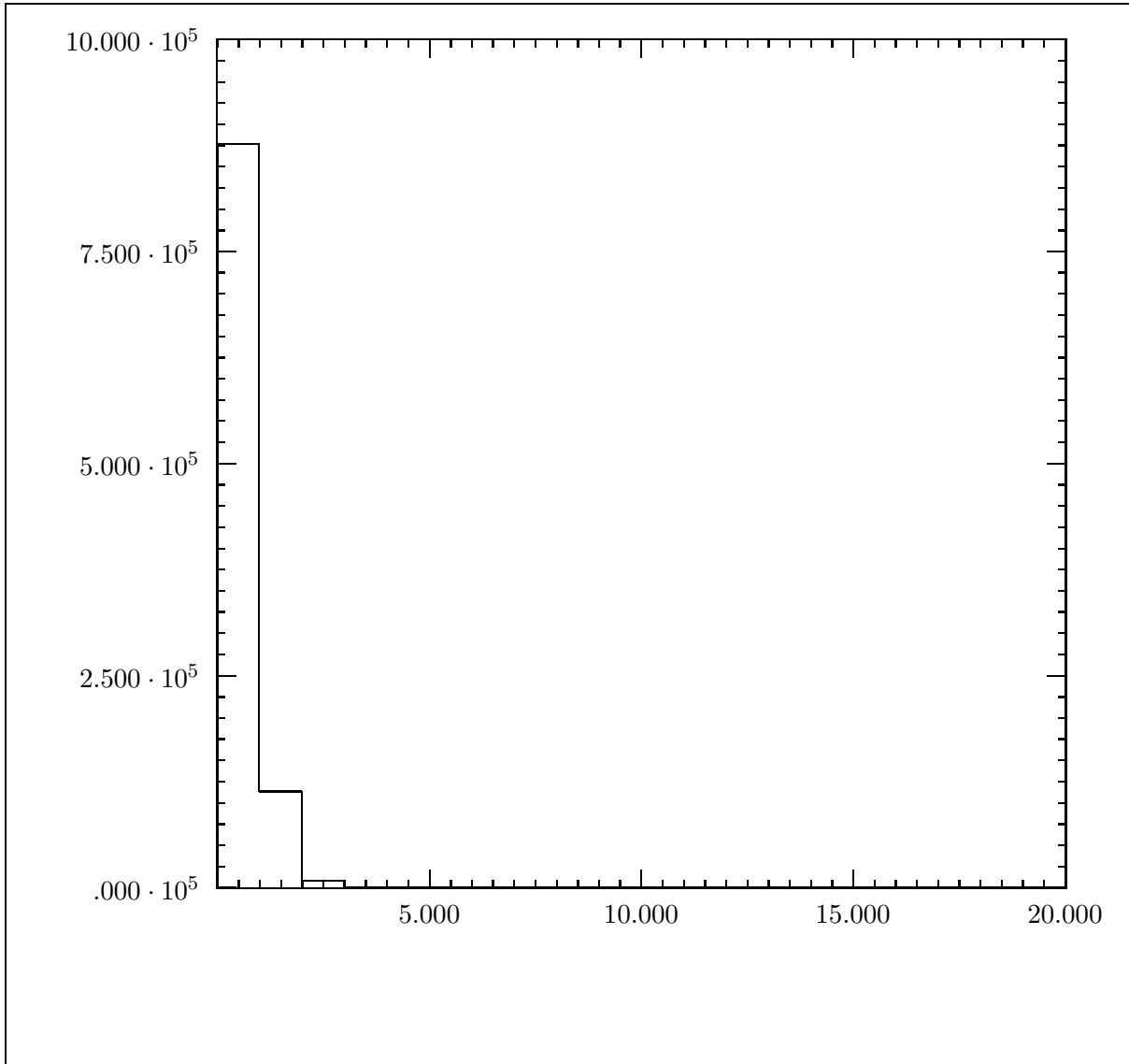
## Figure Captions

1. Photon multiplicity for  $E_\gamma > 3$  GeV in  $pp \rightarrow qq^{(\prime)} + n(\gamma) + X$ , with the trigger cuts in (4), for  $\sqrt{s} = 40$  TeV. (In each of our figures, we show histograms of the respective observable in units as indicated in the title thereof.)
2. Total photon transverse momentum in GeV units in the  $pp$  cms system for the trigger cuts in (4) for  $pp \rightarrow qq^{(\prime)} + n(\gamma) + X$  at  $\sqrt{s} = 40$  TeV.
3. Total photon squared mass in  $\text{GeV}^2$  in  $pp \rightarrow qq^{(\prime)} + n(\gamma) + X$  for the trigger cuts in (4) at  $\sqrt{s} = 40$  TeV.
4.  $v$ -distribution for  $pp \rightarrow qq^{(\prime)} + n(\gamma) + X$  at  $\sqrt{s} = 40$  TeV for the trigger cuts in (4).
5. Final parton energy fraction distribution for  $pp \rightarrow qq^{(\prime)} + n(\gamma) + X$  at  $\sqrt{s} = 40$  TeV for the trigger cuts in (4); here, the parton energy is measured in the subprocess cms system.

## References

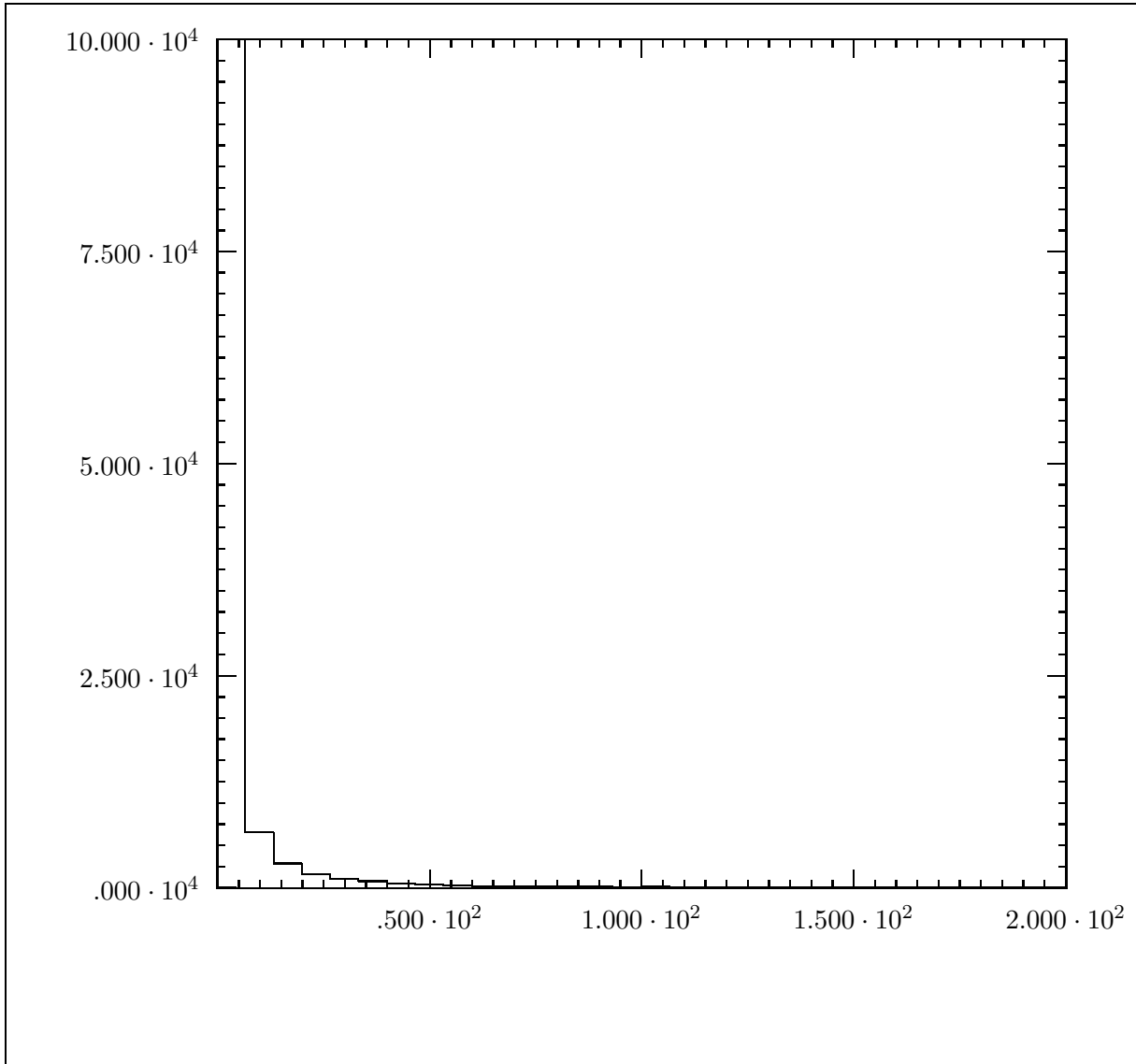
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# PHOTON MULTIPLICITY

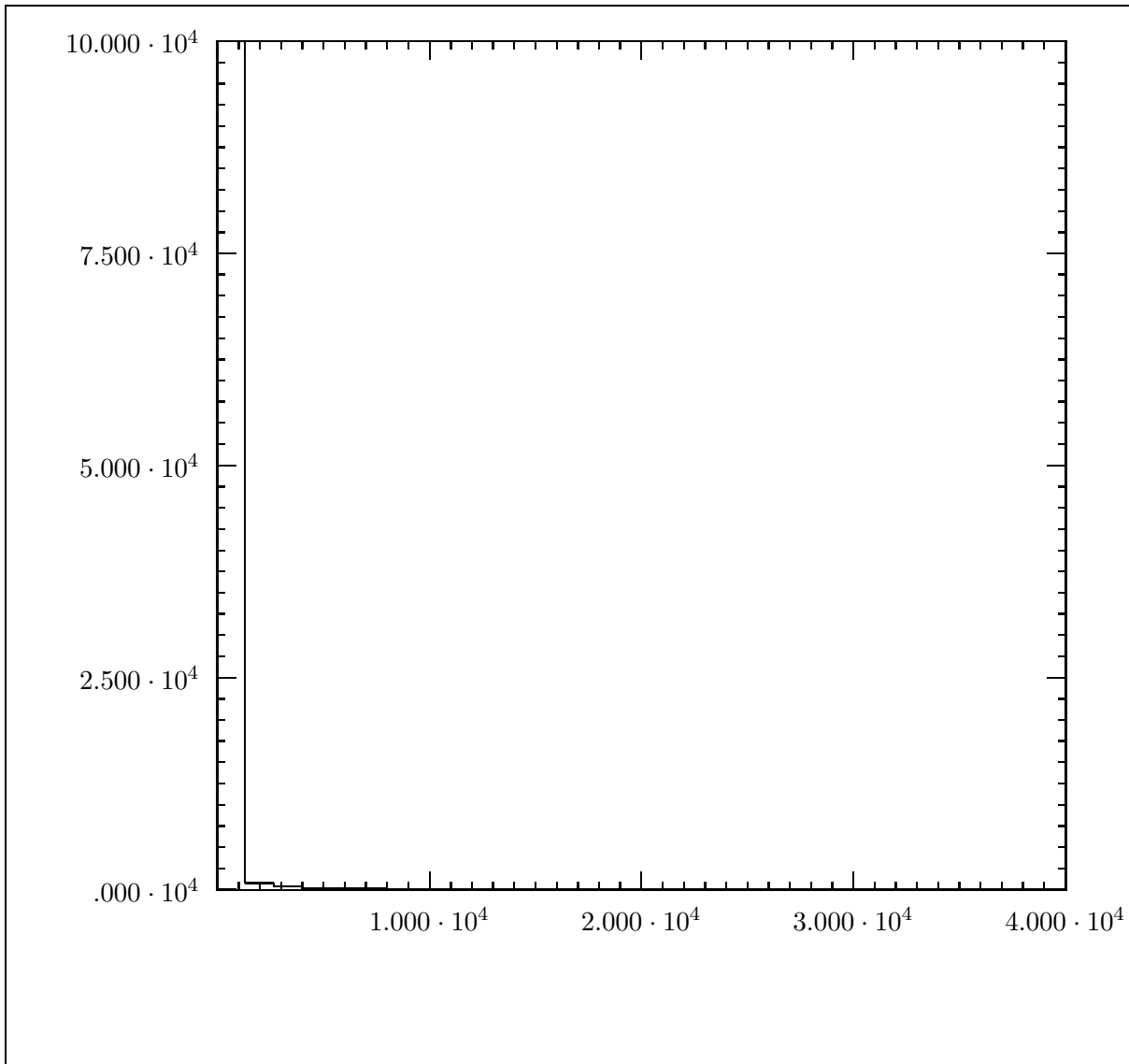




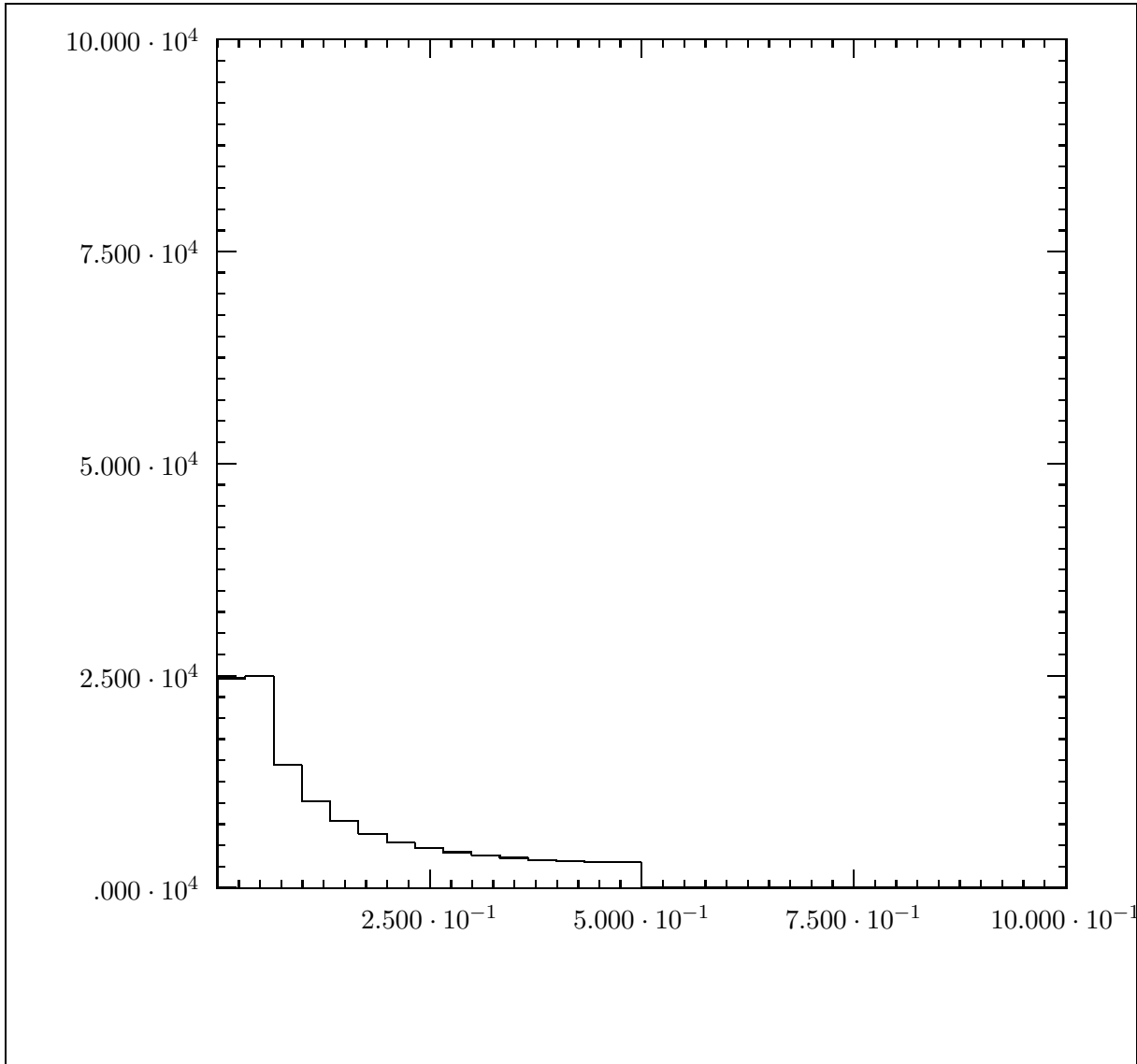
PHOTON SUM TRANSVERSE MOMENTUM (GeV)



PHOTON SUM MASS SQUARED ( $\text{GeV}^2$ )



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# PARTON ENERGY FRACTION

