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INVESTIGATION OF SOFT PHOTON PRODUCTION IN HADRONIC COLLISIONS USING THE OMEGA SPECTROMETER

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ABSTRACT

A short exposure of the Omega Spectrometer, with a hydrogen target and the electromagnetic calorimeters, is proposed to investigate the anomalous production of soft gammas in hadronic collisions. The experiment is exploratory and aimed at confirming an observation made in BEBC: the yield of soft gammas (70% of the gammas have c.m. energies in the range ($20 < E(\gamma) < 60$ Mev)) exceeds the QED prediction of hadronic bremsstrahlung by a factor of 3. This effect may be related to the anomalous production of low mass lepton pairs (virtual gammas) observed in several hadronic experiments.

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2. PHYSICS INTEREST

A recent BEBC experiment [1] gives evidence for the production of soft photons in K^+p collisions at 70 GeV/c, in excess of those expected from the radiative decay of known hadrons. In the region of phase-space defined by $-0.001 < x < 0.008$, $p_T < 60$ MeV, the cross section $\sigma = (4.4 \pm 0.9)$mb exceeds the QED soft bremsstrahlung $\sigma = 1.1$ mb, indicating the presence of other source(s) of soft photons. This observation is probably related to the excess of low mass lepton pairs (virtual photons) observed in several experiments [2].

The BEBC result was limited by statistics. As the radiation length in hydrogen is long as compared to the chamber dimensions, the probability for the conversion of the emitted gammas into observed e^+e^- pairs was low. The large majority of emitted γ's only gave rise to one e^+e^- pair. The soft gamma signal appeared as a spike over a large background in the Feynman x spectrum, and also as a enhancement at low p_T values (fig. 1).

Models have been proposed to explain an excess of photons (real and virtual): annihilation of slow $q\bar{q}$ pairs [3], production of a transient quark-gluon plasma in hadron-hadron collisions [4], radiative decay of a low mass, large width hadronic state [5], multiple scattering of quarks in the colour field filling the hadron bags [6] etc. The available experimental evidence is still by far too scarse to allow a discrimination.

Additional interest for the soft photon spectrum in hadronic collisions comes from the possibility to study the formation of a quark-gluon plasma in collisions of heavy ions with heavy nuclei. Indeed, the measurement of this spectrum would allow to determine the plasma temperature [7]. This determination may be obscured by the production of photons arising from other, unknown sources.

These arguments appear in the Letter of Intent CERN/SPSC 84-60 Rev.; SPSC/I 156 (August 1984).

3. METHOD

The Omega will be used in the configuration already in operation for experiment WA70 (fig .2), with the addition of the inner electromagnetic calorimeter designed, build and tested by P. Sonderegger et al. [8]. It covers an area of 42 * 42 cm^2, which corresponds to the central hole of the outer electromagnetic calorimeter built by WA70 [9]. The inner calorimeter uses the novel technique of embedding scintillating fibers in a heavy metal matrix. Its design and preliminary test indicate the following characteristics:

- Spatial resolution = 1 cm.
- Energy resolution $\frac{\sigma(E)}{E} = 10\%/\sqrt{E} + 1\%$.
- Number of photoelectrons for $E(\gamma)$ = 1 GeV: 1200
- Energy deposited by a minimum ionizing charged particle: equivalent of a .25 GeV γ.

The prototype tested in the course of the 1984 data taking period of WA69 does not quite reach these design values, but a preliminary analysis [10] shows an ability to reconstruct π^0 decays with a resolution in invariant mass entirely adequate for the purpose of the present experiment.

Using an interaction trigger, the experiment will record the charged tracks detected by the Omega spectrometer and the gammas observed in the two e.m. calorimeters. As shown below (fig. 4(f)), the expected signal occurs mostly in the central part of the inner calorimeter. Data will be taken with pions of 280 GeV/c of both polarities. The Cedar in the beam will tag the incoming kaons. After geometrical reconstruction, the gammas arising from hadronic decays will be identified. As the detection probability, for gammas of more than 0.5 GeV occurring inside the geometrical acceptance of the detector is near 100%, hadronic decays (particularly of the overhelming π^0's) are readily reconstructed and subtracted event per event. The remaining sample of gammas will contain the QED soft bremsstrahlung as well as the possible additional gammas from unknown sources ("signal") and remaining bachelor gammas from uncompletely identified hadronic decays (mostly unsuccessful pairings of gammas from π^0 decay), arising because of finite resolution, errors in the reconstruction etc. ("noise"). The "signal to noise ratio" r, estimated by simulation (see below) will be about hundred times better than in the BEBC experiment. The signal will be compared to the hadronic bremsstrahlung computed from the charged track data of each event. The excess, if confirmed, will be studied as function of the quark content of the incident particle, and of the properties of the event: charged and neutral multiplicity, rapidity distribution etc.

The marked improvements of the proposed experiment with respect to the BEBC measurement are due mainly to the following:

- To the detection of practically all gammas, allowing for the subtraction of the large majority of gammas arising from hadronic decays on an event by event basis. In BEBC, the gamma detection probability was 12%, all the hadronic decays had to be subtracted globally on a statistical basis.

- To the expected larger statistics, allowing for the selection of a region of phase space (defined in the next section) where the signal is large and the noise is minimal.

4. SIMULATION

The Lund Monte-Carlo program [11] was used to generate π^+p interactions at 300 GeV/c. For each event, the probability of the emission of photons with $E(\gamma)_{LAB} > 500$ MeV by QED hadronic bremsstrahlung was computed. According to this probability, a number of bremsstrahlung photons were added to the event. The cut on $E(\gamma)$ corresponds to a conservative lower bound of the sensitivity of the inner calorimeter (600 photoelectrons). The cut, imposed by experimental contingencies, removes the theoretical divergence of the QED bremsstrahlung.

A typical event, as expected to be detected and reconstructed in the Omega spectrometer, is shown in fig 3.

In the following, the "signal" refers to the bremsstrahlung photons, although, if the BEBC result is correct, the anomalous gammas should appear in addition and an appreciably stronger signal of soft gammas should be observed.

The spectra of photons are shown on fig. 4, separately for bremsstrahlung photons and for photons arising from hadronic decays. The bremsstrahlung photons are observed to concentrate at low values of x and p_T, which correspond in the laboratory system, to low energies and small angles with respect to the direction of the incident beam. The calorimeter measures the position of impact of the gamma, hence its angle θ with the beam direction. It also measures its energy $E(\gamma)$. For small angles, $p_T = \theta * E(\gamma)$ and $x = E(\gamma)/E_i$, where E_i is the incident beam energy. The spectra of fig. 4 (c,f) suggest the following selection to enhance r, the signal to noise ratio:

$$\theta < 2° \tag{1}$$

with this selection, fig. 4(b,e) show that a further selection

$$0.5 \text{ GeV} < E(\gamma) < 1.5 \text{ GeV} \tag{2}$$

will keep most of the signal, while rejecting the major part of the decay photons. These selections will require, of course, optimization with real data.

Next, the photons were followed to the entrance surface of the inner calorimeter. For the purpose of the simulation, the acceptance of the experiment was limited to the inner calorimeter and was computed accordingly.

If two photons occurred at less than 1 cm distance, they were lumped together (merging) to simulate the effect of the finite resolution of the detector. The choice of 1 cm may need further investigation after tests of the detector.

An algorithm was then used to compute the effective mass of all pairs of photons, to select pairs occuring at the π^o mass (within limits defined by the expected resolution) and to remove them from the sample. This algorithm, its optimisation, and the computation of r were conducted on a sample of Monte-Carlo events where the radiative decays of hadrons other than π^o's were switched off, reducing by about 8% the total yield of decay gammas. The subtraction of the non π^o's hadronic decays was made in the BEBC experiment, and can be repeated here mutatis mutandis. Dalitz decays occur in about 5% of the events, their contribution to the single gamma spectra can also be readily taken into account.

In addition to r, a "figure of merit" f was computed, which accounts for the statistical weight of the data. It is defined in terms of the total number of detected gammas n

$$f = r * \sqrt{n}$$

The behaviour of r and f in the successive steps of analysis is summarized in fig. 5. It is seen in particular that the BEBC value $r = 0.05$ becomes here $r = 0.33$, after taking into account the effects of acceptance, merging, and removal of gamma pairs. This number could be slightly improved by using also the outer calorimeter. The optimisation shows that it is relatively insensitive to the distance target-calorimeter for a range extending from 10 to 25 m. The signal to noise ratio r improves to $r = 6.7$ using the selections (1,2) whereas the figure of merit f, normalized to $f = 1$ for all gammas with $E(\gamma) > 0.5$ GeV, reaches a value of 10.

Conversion of gammas in the target, in the chambers and in the air remove ~ 9% of the gammas from their total flux, but 1/4 of these can be reconstructed as e^+e^- pairs in the Omega spectrometer.

5. EXPOSURE

As about 20% of all events contain a bremsstrahlung gamma, an interaction trigger is adequate for the experiment. Using the data acquisition rate of the Omega system (80 events per pulse), and taking into account the various inefficiencies, one may expect to collect 100 k good events of each beam polarity (π^+, π^-) in two days of run, plus one day of setting up.

The data analysis will require the equivalent of 10 h of CDC 7600 CPU time, to be shared between the participating laboratories.

The WA70 Collaboration has kindly agreed to let us use the data to be taken, for its purposes, with an interaction trigger and with both calorimeters during its forthcoming data taking period. The setup of WA70, in these circumstances, closely resembles that needed here. These data will thus provide a valuable preliminary test for the proposed experiment.

Acknowledgements

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FIGURE CAPTIONS

Fig. 1 BEBC results:

(a,b) The data points represent the experimental results for the single gamma spectra, after subtraction of the non-π^0 radiative hadronic decays (lower curves). They are fitted (dotted line) by the single gammas resulting from π^0 decays, using the parent-daughter relationship. Excesses are noticed at low x and at low p_T.

(c,d) Single gamma spectra after subtraction of all hadronic radiative decays. The experimental points ($\sigma = (4.5 \pm 0.9)$mb) are seen to exceed the computed hadronic bremsstrahlung ($\sigma = 1.1$ mb) shown by the solid curves.

Fig. 2 Layout of the Omega spectrometer.

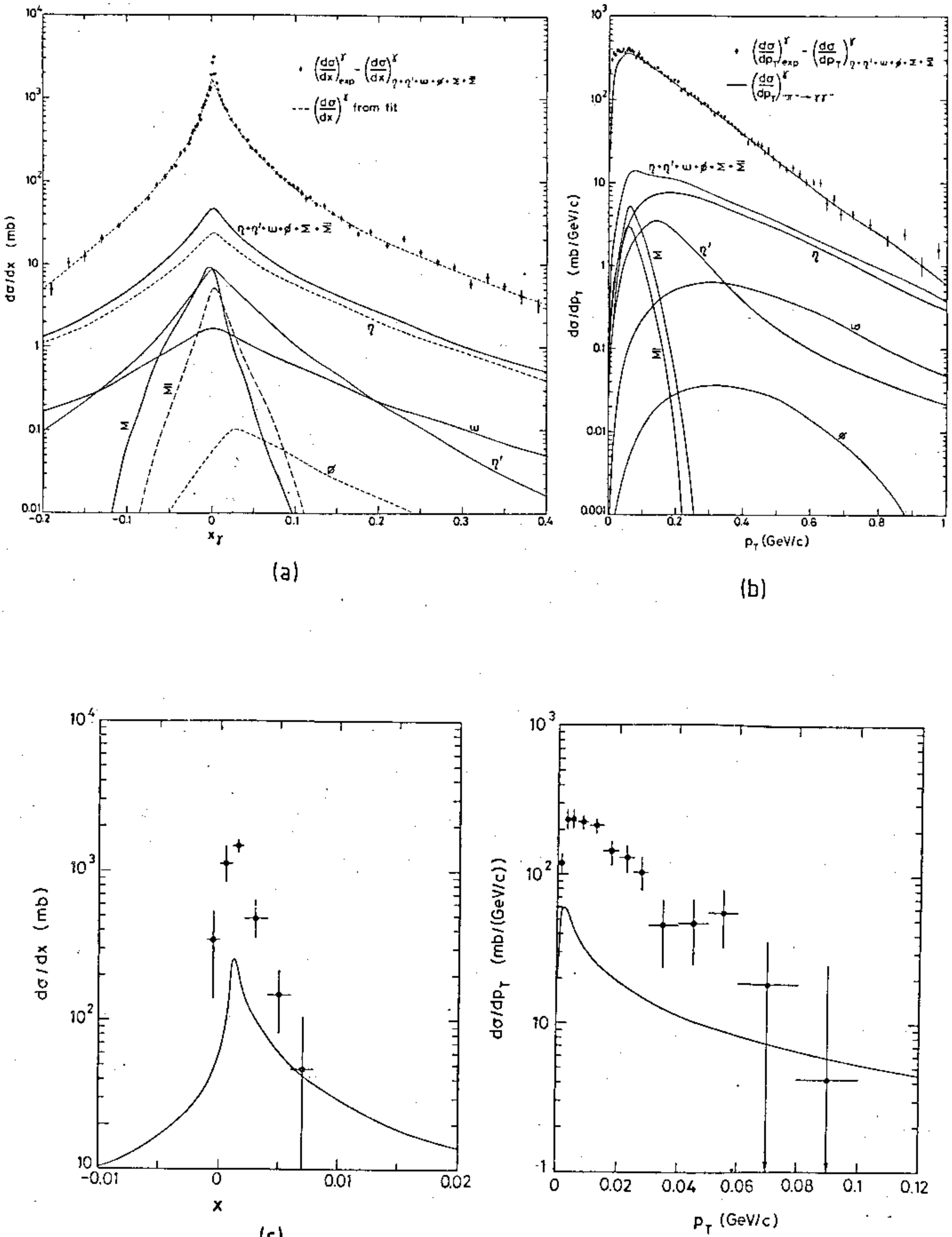
Fig. 3 Typical event: π^+p interaction at 300 GeV/c generated by the Lund Monte-Carlo, with added QED hadronic bremsstrahlung photons, as seen in the Omega spectrometer. Electron-positron pairs resulting from conversion of the gammas in the spectrometer are shown as dotted lines. Hits in the calorimeter are shown:

- inner cal. brems.	%	(soft-in)
- inner cal. decay	#	(hard-in)
- outer cal. brems.	&	(soft-out)
- outer cal. decay	x	(hard-out)

The numbers printed near the track indicate their dip angles in degrees.

Fig. 4 Spectra of gammas arising from:
Hadronic decays (a,b,c)
QED bremsstrahlung: (d,e,f)
(b,e): Feynman x
(a,d): p_T
(c,f): laboratory angle for $0.5 < E(\gamma) < 1.5$ GeV.

Fig. 5 Summary of the effects of the succesive steps of the simulation.


$(\frac{d\sigma}{dx})^{\gamma}_{exp} - (\frac{d\sigma}{dx})^{\gamma}_{\eta+\eta'+\omega+\phi+\Sigma+\bar{\Sigma}}$
$(\frac{d\sigma}{dx})^{\gamma}$ from fit
$\eta+\eta'+\omega+\phi+\Sigma+\bar{\Sigma}$
η
ω
η'
ϕ
Σ
Σ̄
dσ/dx (mb)
x_γ
$(\frac{d\sigma}{dp_T})^{\gamma}_{exp} - (\frac{d\sigma}{dp_T})^{\gamma}_{\eta+\eta'+\omega+\phi+\Sigma+\bar{\Sigma}}$
$(\frac{d\sigma}{dp_T})^{\gamma}_{\pi^0\to\gamma\gamma}$
$\eta+\eta'+\omega+\phi+\Sigma+\bar{\Sigma}$
η'
η
ω
ϕ
$d\sigma/dp_T$ (mb/(GeV/c))
p_T (GeV/c)
dσ/dx (mb)
x
$d\sigma/dp_T$ (mb/(GeV/c))
p_T (GeV/c)

(a)

(b)

(c)

(d)

Fig. 1

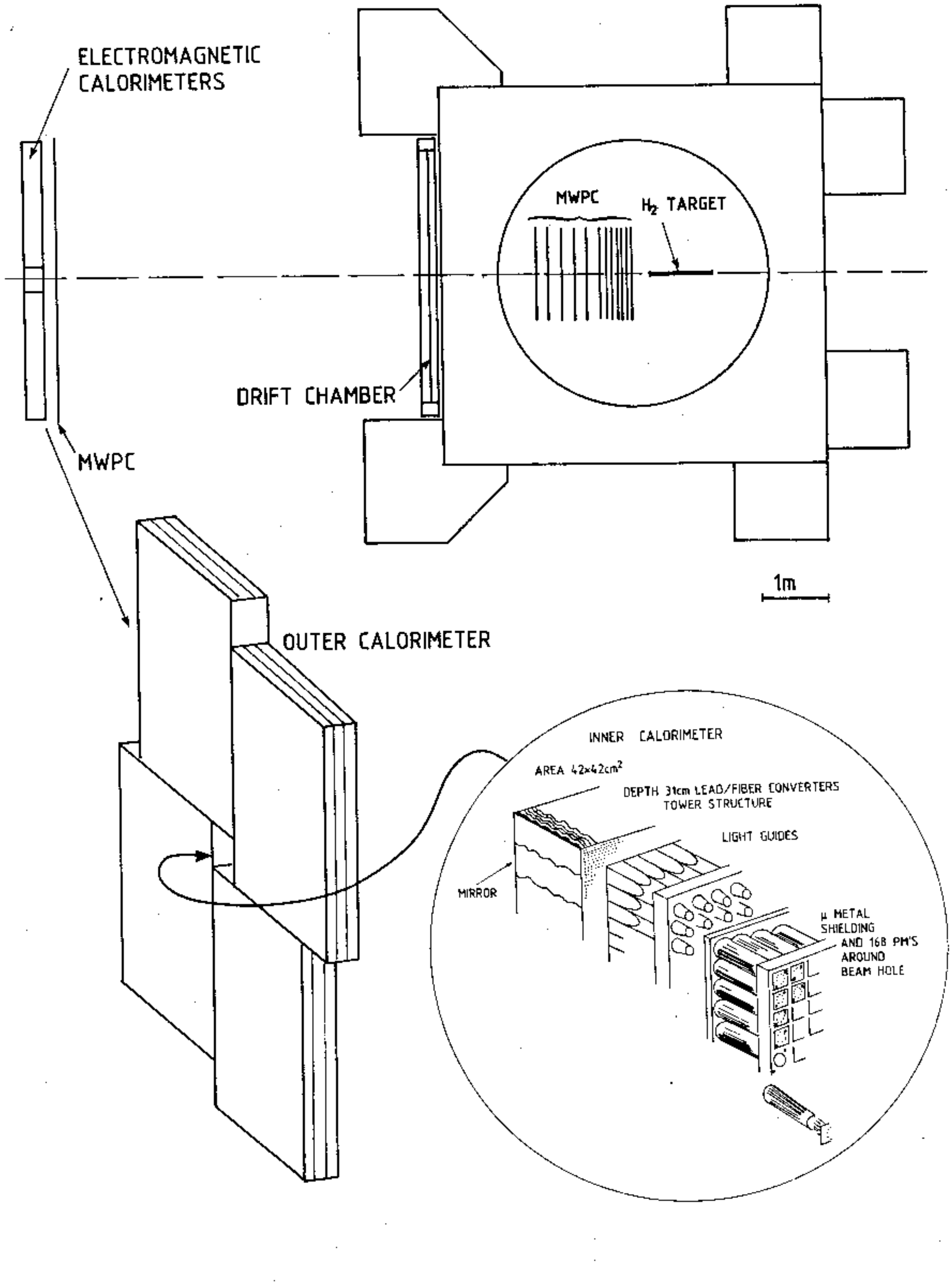

ELECTROMAGNETIC CALORIMETERS
MWPC
H2 TARGET
MWPC
DRIFT CHAMBER
1m
OUTER CALORIMETER
INNER CALORIMETER
AREA 42x42cm²
DEPTH 31cm LEAD/FIBER CONVERTERS TOWER STRUCTURE
LIGHT GUIDES
MIRROR
µ METAL SHIELDING AND 168 PM'S AROUND BEAM HOLE

Fig. 2

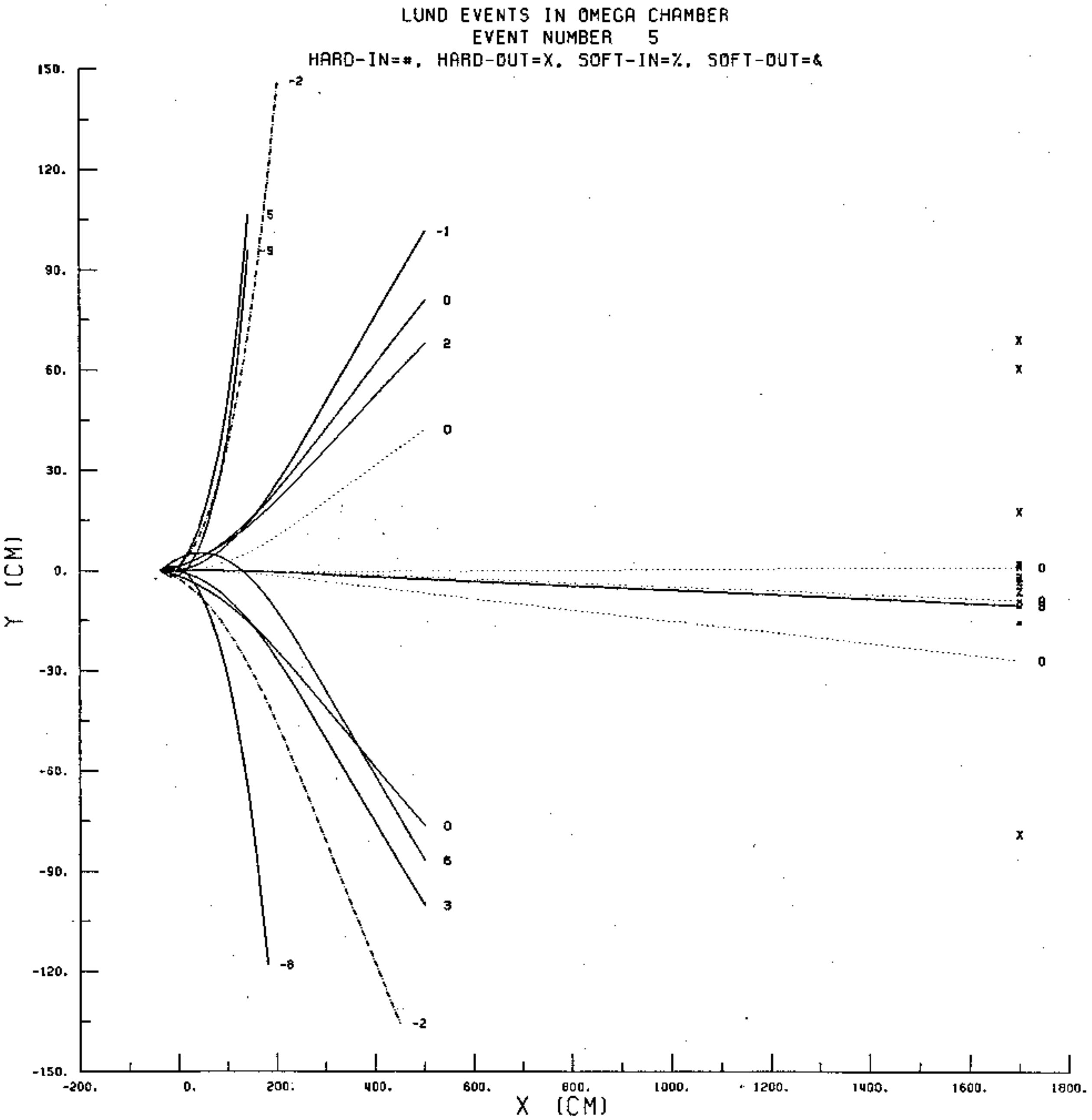

LUND EVENTS IN OMEGA CHAMBER
EVENT NUMBER 5
HARD-IN=#, HARD-OUT=X, SOFT-IN=%, SOFT-OUT=&
Y (CM)
X (CM)
150.
120.
90.
60.
30.
0.
-30.
-60.
-90.
-120.
-150.
-200.
0.
200.
400.
600.
800.
1000.
1200.
1400.
1600.
1800.
-2
5
-9
-1
0
2
0
X
X
X
0
8
0
X
0
6
3
-8
-2

Fig. 3

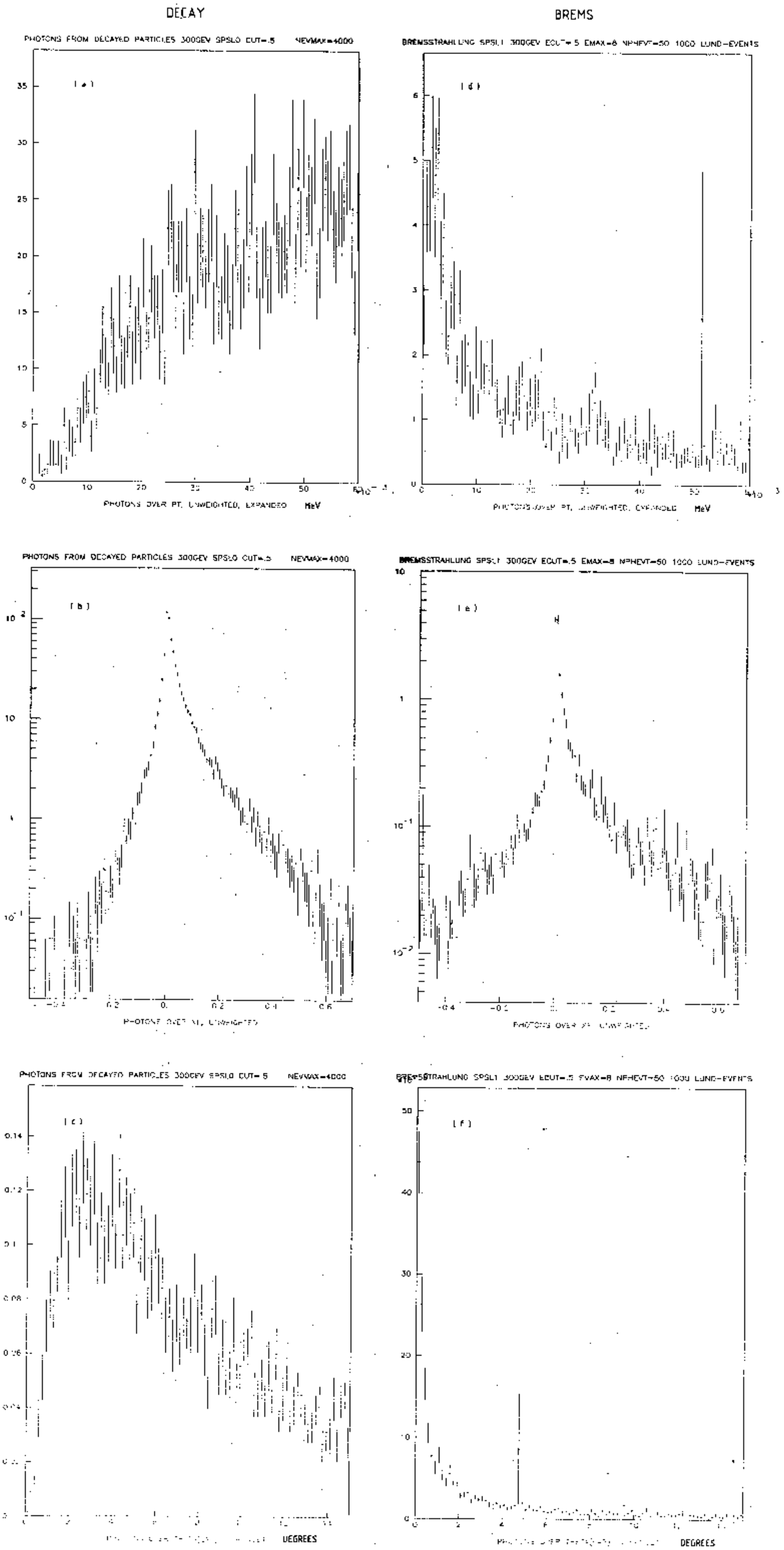

DECAY
BREMS
PHOTONS FROM DECAYED PARTICLES 300GEV SPSLO CUT=.5 NEVMAX=4000
(a)
PHOTONS OVER PT, UNWEIGHTED, EXPANDED MeV
BREMSSTRAHLUNG SPSL1 300GEV ECUT=.5 EMAX=8 NPHEVT=50 1000 LUND-EVENTS
(d)
PHOTONS OVER PT, UNWEIGHTED, EXPANDED MeV
PHOTONS FROM DECAYED PARTICLES 300GEV SPSLO CUT=.5 NEVMAX=4000
(b)
PHOTONS OVER XF, UNWEIGHTED
BREMSSTRAHLUNG SPSL1 300GEV ECUT=.5 EMAX=8 NPHEVT=50 1000 LUND-EVENTS
(e)
PHOTONS OVER XF, UNWEIGHTED
PHOTONS FROM DECAYED PARTICLES 300GEV SPSLO CUT=.5 NEVMAX=4000
(c)
DEGREES
BREMSSTRAHLUNG SPSL1 300GEV ECUT=.5 EMAX=8 NPHEVT=50 1000 LUND-EVENTS
(f)
DEGREES

Fig. 4

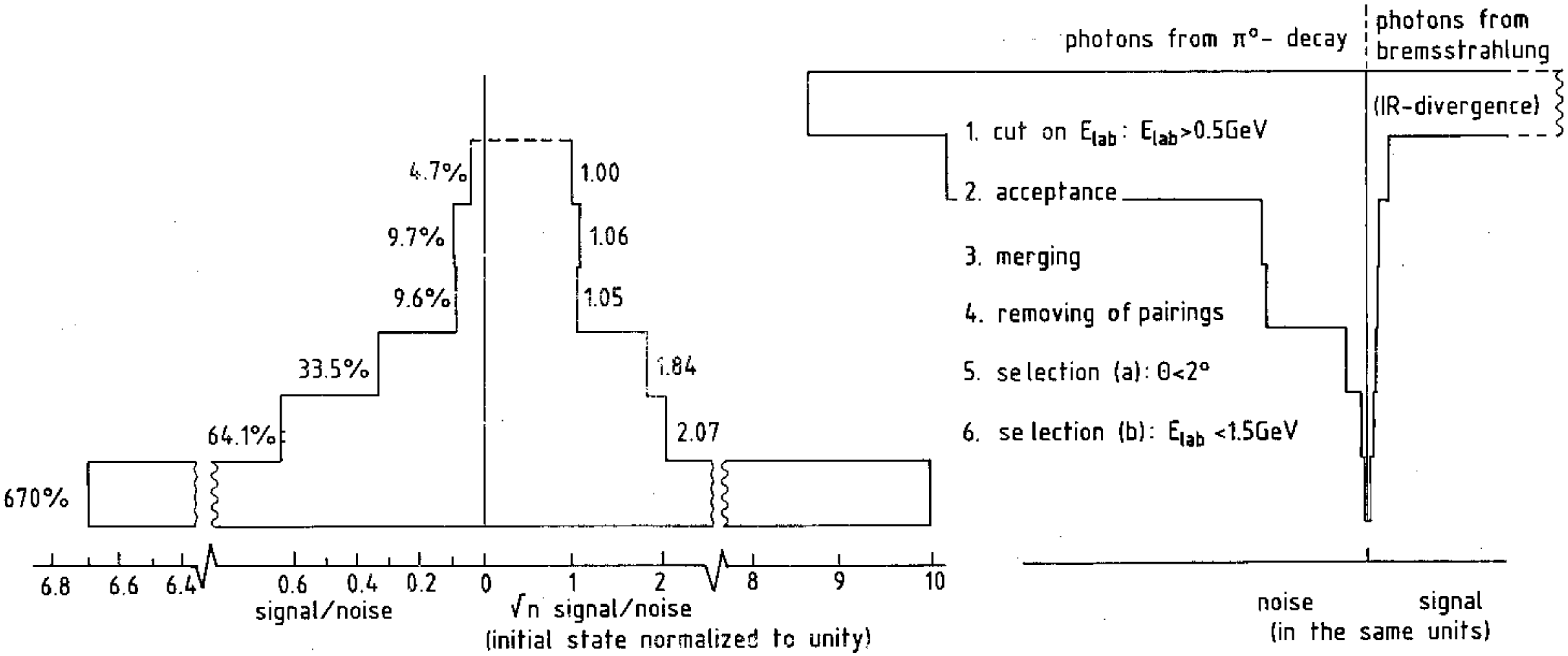

photons from π°- decay
photons from bremsstrahlung
(IR-divergence)
1. cut on E_{lab}: $E_{lab}>0.5$GeV
2. acceptance
3. merging
4. removing of pairings
5. selection (a): θ<2°
6. selection (b): E_{lab} <1.5GeV
noise
signal
(in the same units)
4.7%
9.7%
9.6%
33.5%
64.1%
670%
1.00
1.06
1.05
1.84
2.07
6.8
6.6
6.4
0.6
0.4
0.2
0
1
2
8
9
10
signal/noise
√n signal/noise
(initial state normalized to unity)

Fig. 5