KOPIO Technical Note TN095

KOPIO geometric acceptance

where do all the photons go ?

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Abstract

In this note I show the kinematical distributions of photons emitted in the decay $K_L^0 \rightarrow \pi^0 \nu \overline{\nu}$ followed by $\pi^0 \rightarrow 2\gamma$ and discuss how the geometric acceptance of the detection system may be optimized. The standard KOPIO beamline was assumed.

The KOPIO detector consists of photon and charged particle systems covering 4π sr solid angles. The photon systems not only detect photons from the decay of interest (the "signal") but also act as a veto system to suppress background with additional photons in particular from the decay $K \rightarrow 2\pi^0$. Presently fine-grained lead-scintillator sandwich (*Shashlyk*) detectors are considered for both tasks.

For full kinematic reconstruction of the signal events pre-radiator detectors are positioned in front of the Shashlyk detectors downstream of the decay region. The combined information from pre-radiator and Shashlyk calorimeter allows the reconstruction of both direction and energy of the two photons from signal events.

In this note I demonstrate that a gain in acceptance by a factor ≈ 2.5 can be achieved by a moderate increase in pre-radiator solid angle. Although I will sketch some modifications to the present design that would lead to this gain in acceptance no detailed analysis was made of the technical feasibility.

1 The full acceptance

The studies were made using FastMC [1] with the standard assumptions for the phase space of the kaon beam. Figure 1.1 shows space distributions of the decay point and the positions where the photons interact. The photon interacting closest to the beam exit is labeled

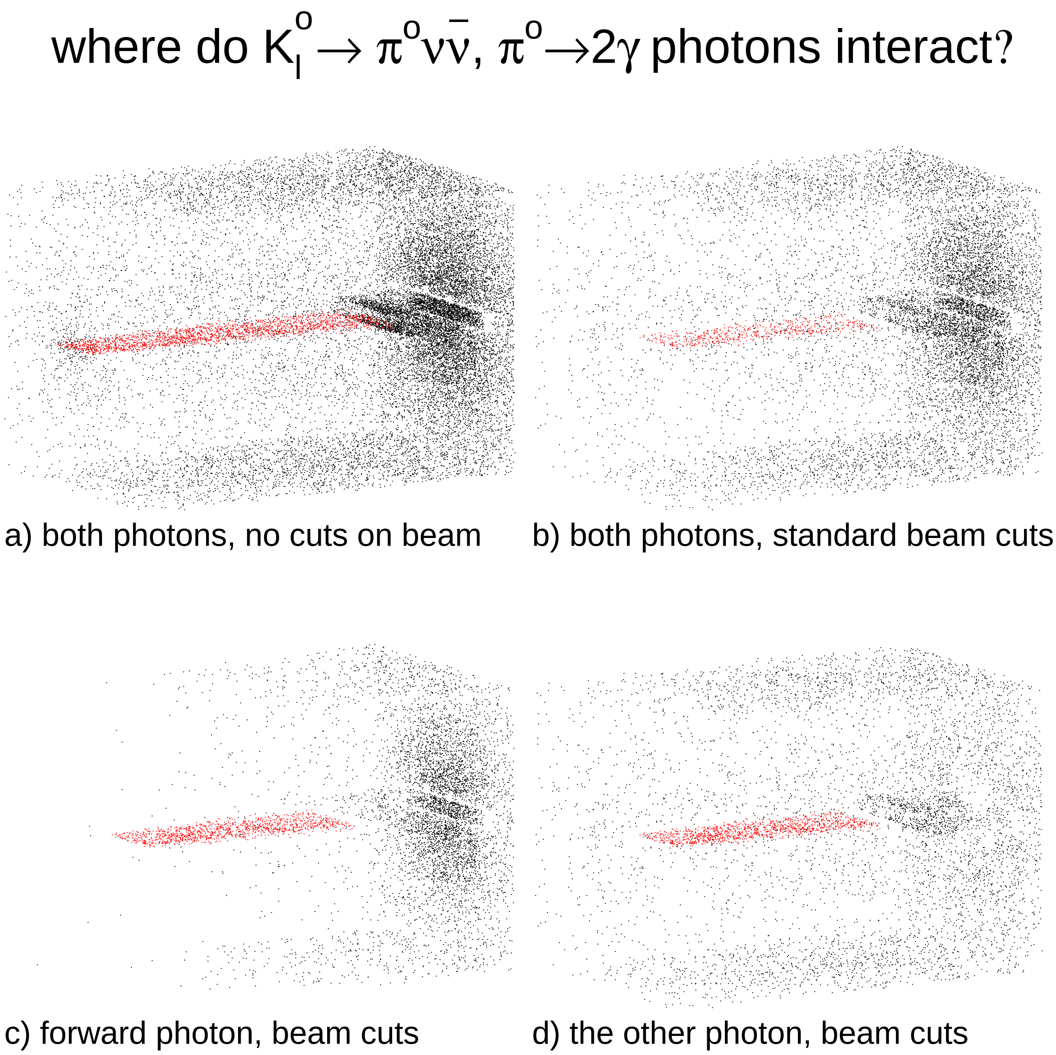

Figure 1.1: *Distributions of K decay points (red) and photon interaction points from signal events (black). Beam enters from the left. In 25% of the events at least one photon interacts with or leaves through the downstream beampipe.* **Standard beam cuts** *refer to kaon momentum in the range 400-1400 MeV/c and fiducial decay region of 275 cm along the beam.*

forward. Most forward photons reach the downstream detector wall and thus fall in the acceptance of the present KOPIO detector. As will be seen below in only one out of four events both photons interact there.

A more quantitative picture of the photon interaction points is given in Fig. 1.2. Here the xy distributions of the interaction points of both photons are shown for four different regions along the beam direction.

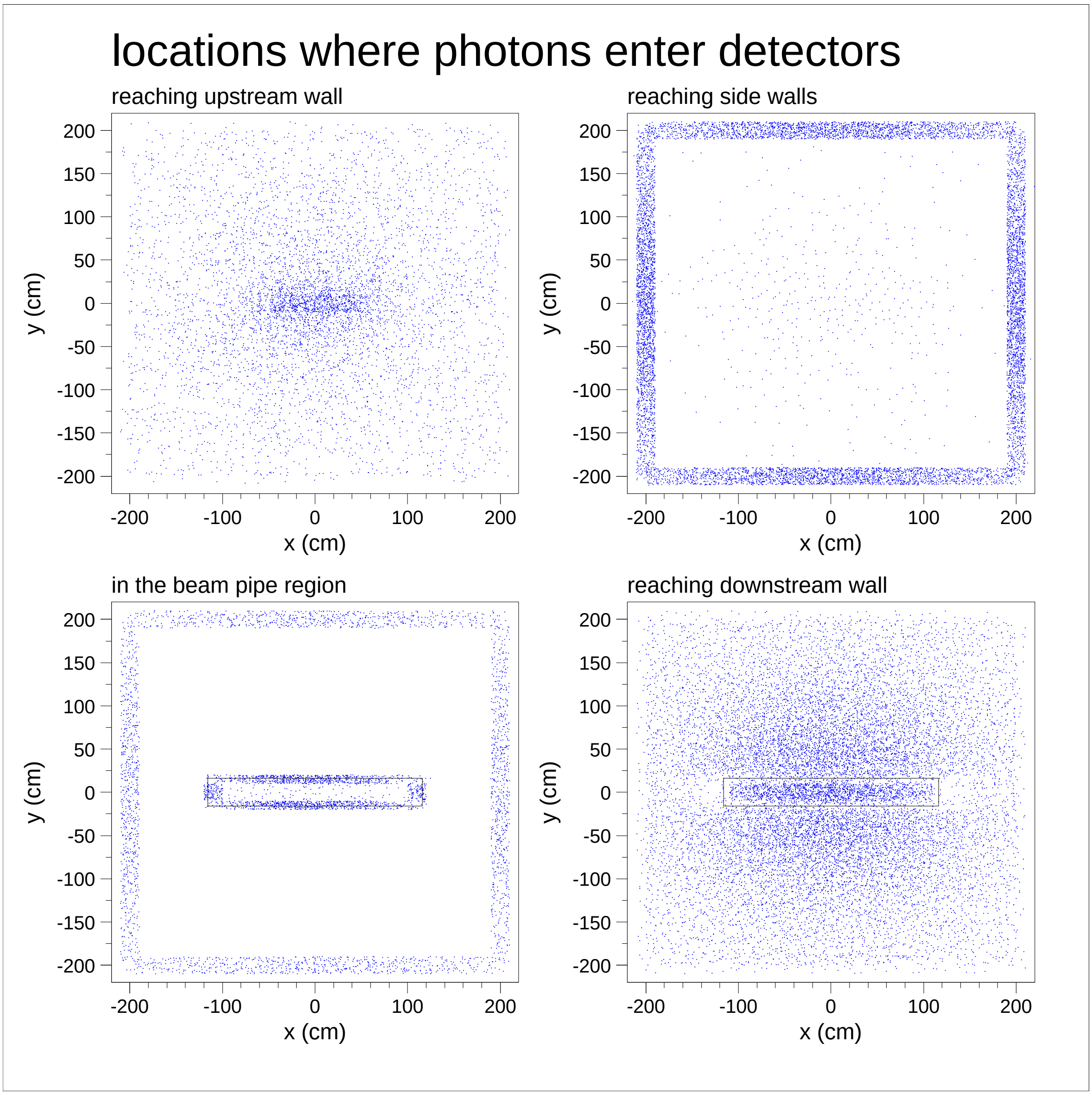

Figure 1.2: *xy-Distributions of the photon interaction points for four slices in z direction. No cuts made here.*

2 Distributions after removal of events with a photon leaving through the beam exit.

For the following discussion it is convenient to distinguish the two photons according to their interaction points. The photon interacting closest to the beam exit is called *forward* or *most downstream*. As can be seen from the distributions of Fig. 2.3 forward photons mostly reach

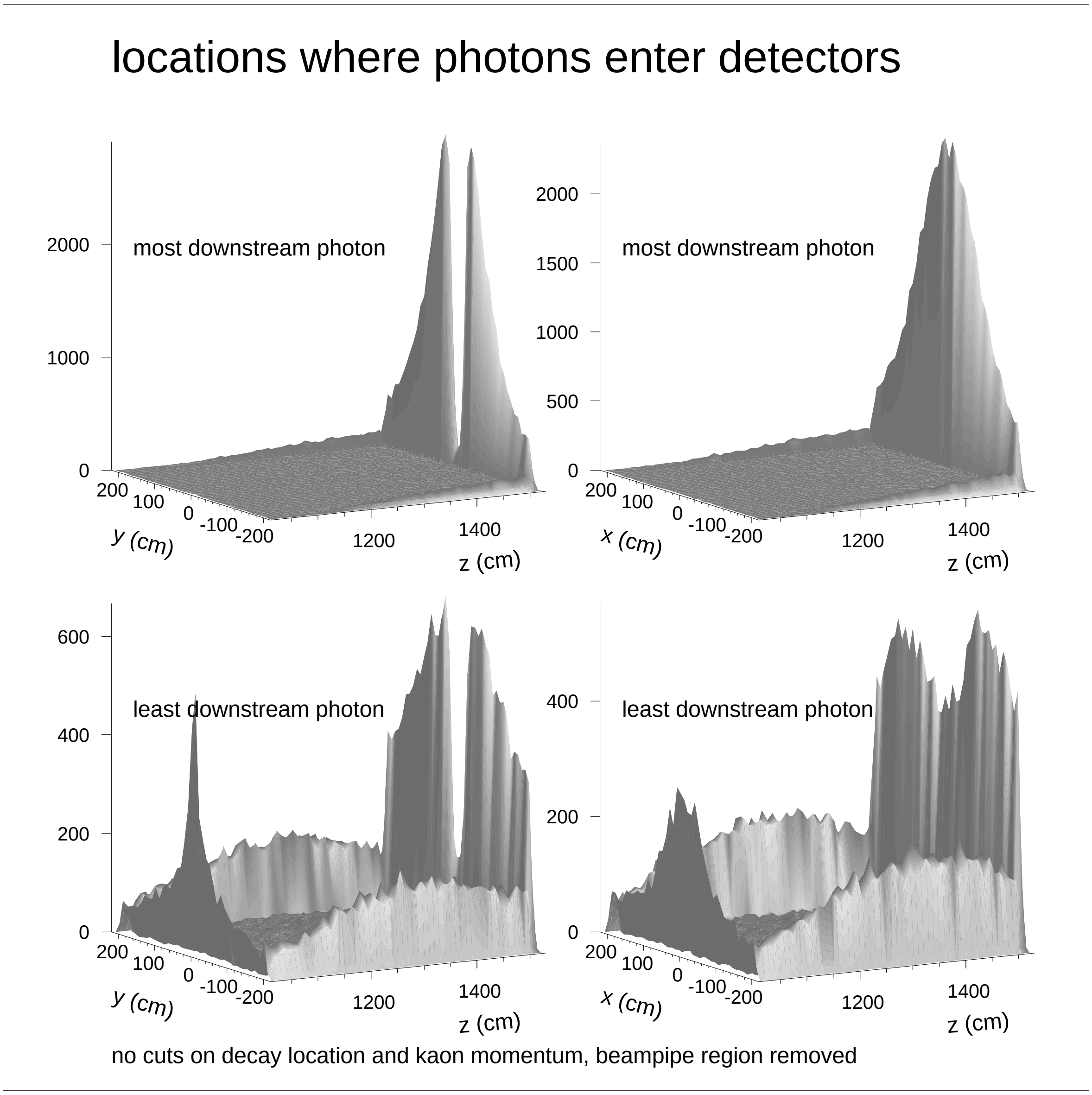

Figure 2.3: *yz- and xz-Distributions of photon interaction points after removal of* $\approx 25\%$ *events reaching the downstream beampipe. In most cases at least one photon goes to a side wall. Those events are not accepted at present. See Fig. 2.4 for a more quantitative picture.*

the downstream wall, so they fall in the present KOPIO acceptance. The second photon, however, has a large probability to reach one of the four side walls. When interpreting these distributions one should not forget that signifi cant numbers of events are situated in the continuum between the peaks. For a better idea of the fraction going to the side walls Fig. 2.4 shows the distributions of $\max(|x|, |y|)$ which peaks at 200 cm for all events with a photon reaching any of the four side walls.

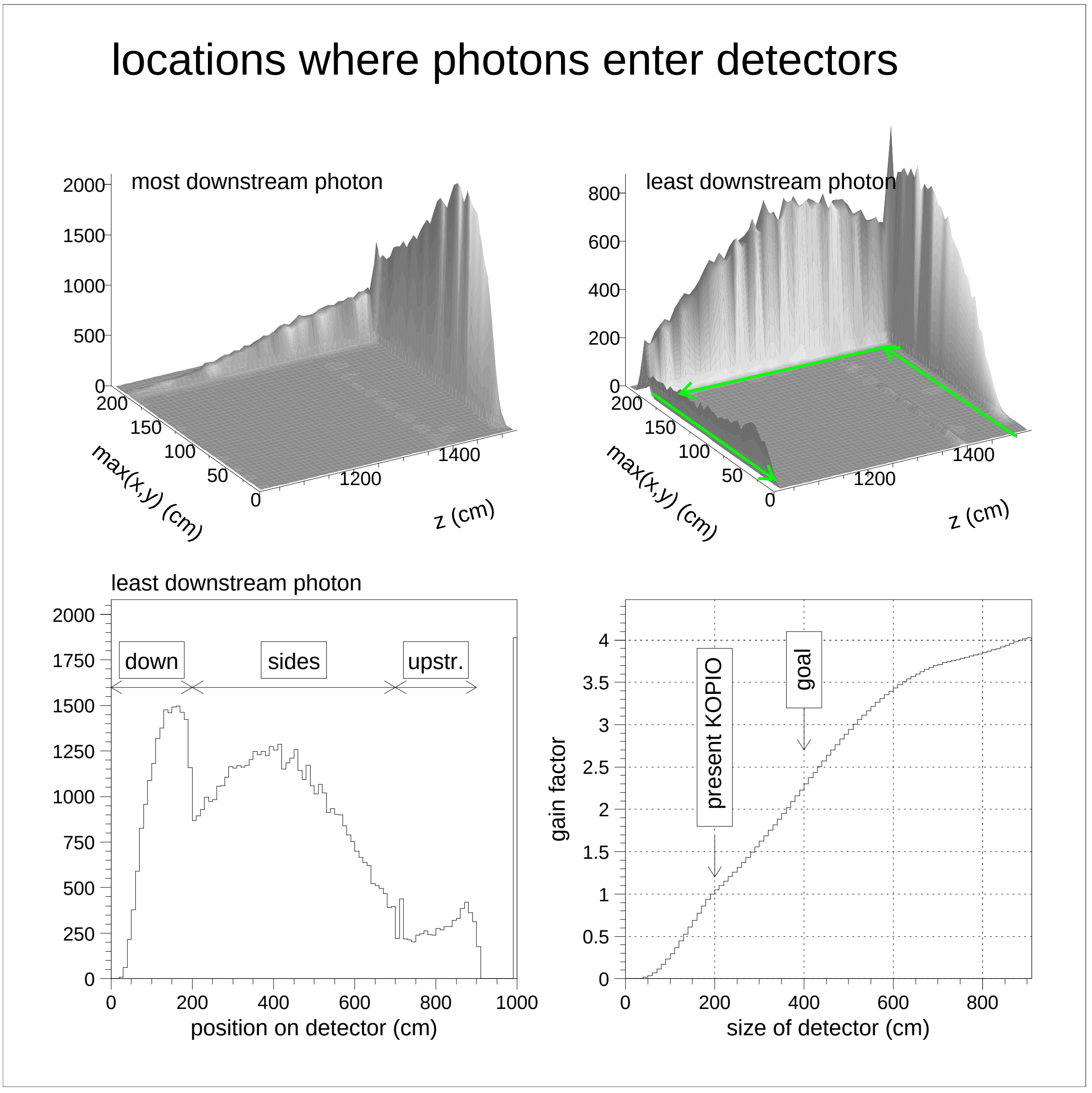

Figure 2.4: *One last figure with photon interaction points. This time all side walls hits appear in the back. The green arrows in the top-right distribution explain the definition of* **position on detector**, *i.e. 0 cm on the beam axis at exit, 200 cm at the corners where the downstream wall meets the sides and >700 cm for impacts on the upstream wall. For setups defined by an upper limit on this quantity events fall in the acceptance when the* **least downstream photon** *does. The acceptance can thus be deduced by integration of the position distribution of this photon. The integration limit is called* **size of detector**. *The result shown on the bottom right has been normalized to the present detector. The present setup accepts one quarter of all events surviving the beampipe cuts.*

Let us see what happens if we would increase the detector acceptance by including regions on the side walls closest to the downstream end. For the following discussion it is convenient to introduce a quantity **position on detector** as defined in Fig. 2.4. All interaction points on the downstream wall have positions below 200 cm. The positions on the side walls run from 200 cm (closest to the downstream wall) to 700 cm (closest to the upstream wall). The maximum value is 900 cm for photons moving against the beam.

As is shown in Fig. 2.4 only 25% of the *least downstream photons* reaches the downstream wall. This value rises a factor 2.5 for a detector size of 400 cm, i.e. a detector which includes 200 cm along the side walls at the downstream end.

3 Distributions after the standard beam cuts.

For reasons of background suppression cuts are made on kaon time of flight (or momentum) and position of the decay vertex along the beam. As is demonstrated in Fig. 3.5 the distribution of the gain factor v.s. detector size doesn't change much after these cuts are applied.

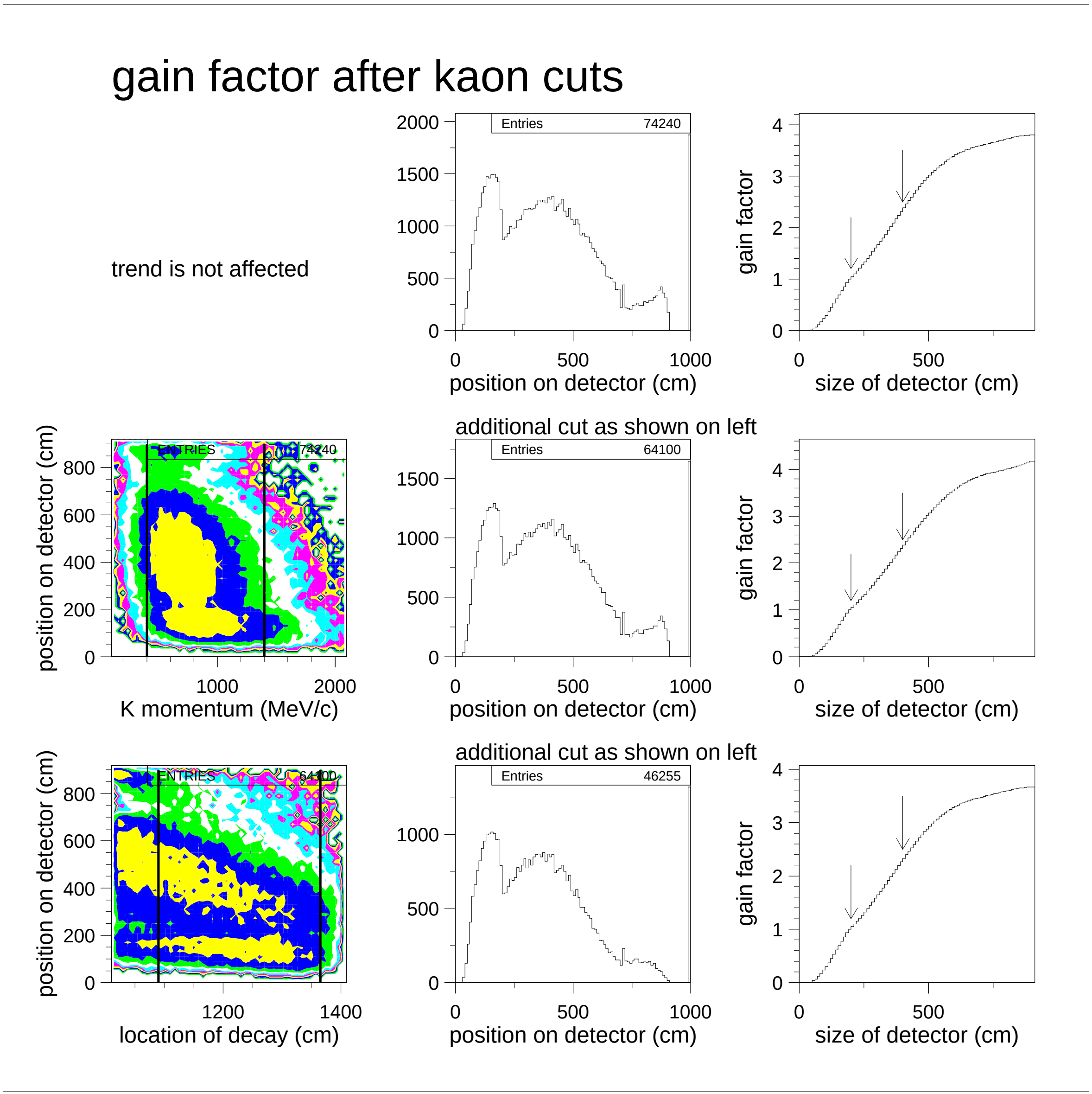

Figure 3.5: *Distributions of* **position on detector** *and* **size of detector** *with/without the standard cuts on kaon momentum and decay position along the beam. The gain factor distribution is only weakly dependent.*

4 Are these extra events any good ?

Since it is not obvious that these additional events can be reconstructed with similar resolutions in the kaon CMS system I studied the dependence of various kinematic quantities on **position on detector**. As can be seen in the distributions of Fig. 4.6 the events with photons reaching the side walls can be associated with π^0's with lower longitudinal momenta. Their

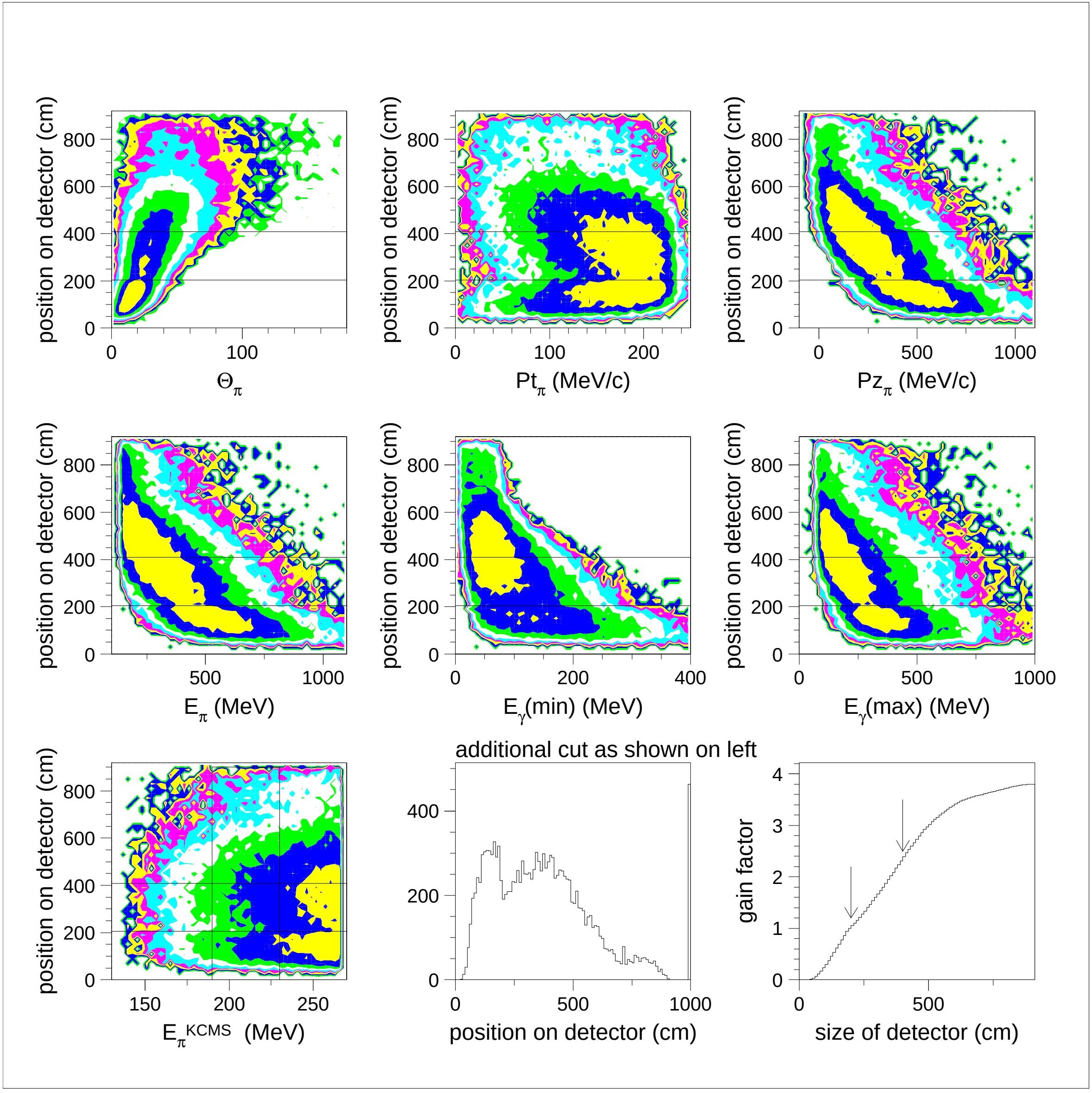

Figure 4.6: π^0 *and* γ *kinematic distributions v.s.* **position on detector**. *A detector with a size of 400 cm would still observe only pions moving downstream. Photon energies in the extra phase space are typically half of what they are in the present detector. On the bottom of the figure the distribution of pion energy in the kaon C.M.S. is shown. This is the main observable used to discriminate against the two-body mode* $K \rightarrow 2\pi^0$. *After applying the canonical window 190-230 MeV the gain factor at a size of 400 cm remains 2.5.*

energies are typically 300 MeV rather than 600 MeV so the photon energies are a factor two lower as well. At present there seems to be no reason why these events wouldn't have similar S/B ratios as the forward events.

Also shown in Fig. 4.6 is the effect of a cut on the π^0 energy in the kaon C.M.S. necessary to suppress $K \rightarrow 2\pi^0$ decays. Again the gain factor remains ≈ 2.5 after the cut.

5 How could a detector look?

The main purpose of this note is a discussion of the kinematic distributions to see how much gain a larger photon solid angle could bring. Additional gain could of course be achieved when a larger decay volume (compared to the present 275 cm) could be observed.

Without worrying too much yet about the technical feasibility a detector with size 400 cm as defined above probably shouldn't be the present detector with preradiator detectors added although it could. One possible alternative is shown in Fig. 5.7. The detector would be a Shashlyk box with inner dimensions typically (300 cm)^3 which would result in a decay region of ≈ 400 cm. When the vacuum walls could be integrated in the detectors a fiducial decay region of 275 cm could be achieved again.

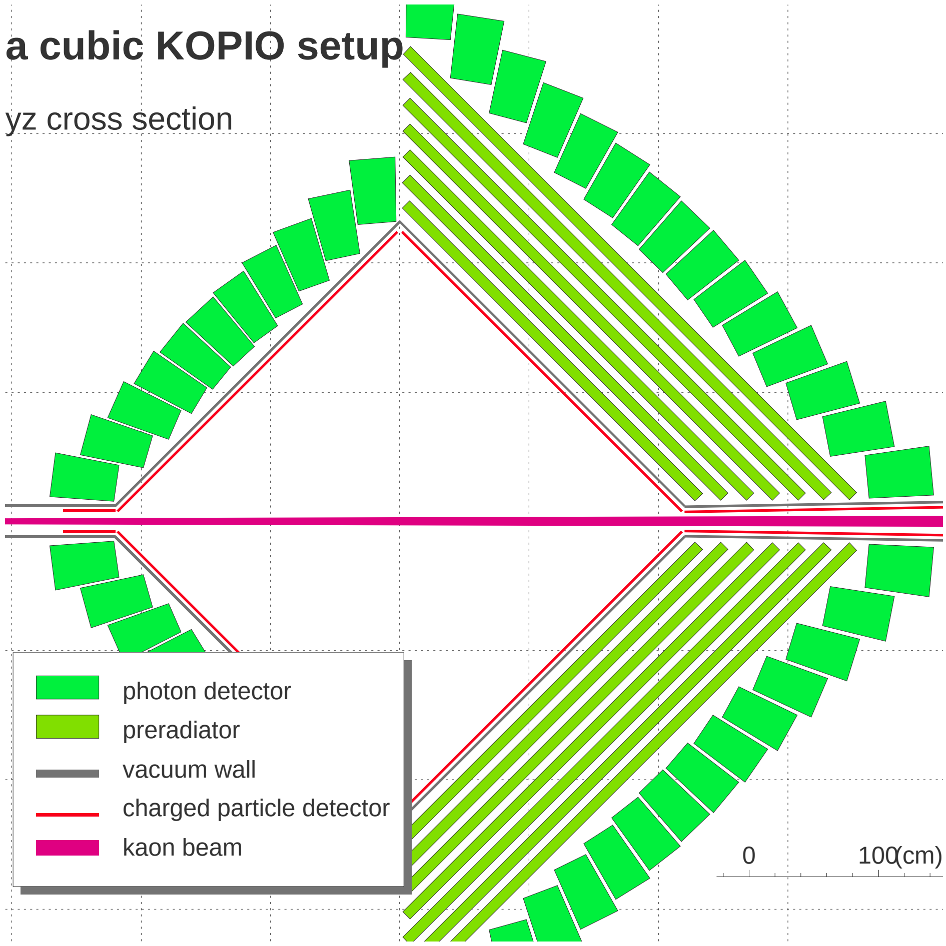

Figure 5.7: *A possible setup.*

References:

[1] David E. Jaffe, *FastMC User Manual*, KOPIO TN089v2