1 $K_L^0 \to \pi^0\pi^0$ background

1.1 General

$B = 9.36 \times 10^{-4}$
This background is known from the previous calculation to be the biggest one. So, perhaps, it's the most addressed and carefully checked background.

The signature of this decay is four photons coming from one common vertex. Two photons have to be missed in order this reaction to mimic the signal one. Consideration of mechanisms for producing background naturally falls into two classes: *even* background, when photons from the same π^0 are missed (or detected) and *odd* background — two photons from different pions are missed (detected).

Apparently the most powerful tool to suppress this background is a hermetic photon veto (PV). The proposal (TN000) gives the following figures for even (odd) background suppression with PV when it is applied after some other cuts (some of which guarantee its efficiency as described below): 8.3×10^{-8} (2.9×10^{-8}).

Since this reaction is the two body decay there is also a powerful kinematic tool to suppress the even background: region of $E^*_{\gamma\gamma} \simeq 249$ MeV ($E^*_{\gamma\gamma} = E^*_{\pi^0}$ is the energy of the pion in the kaon rest reference frame) should be avoided. Actually the signal region is chosen below this monochromatic energy peak. According to the proposal the suppression coming from this cut is 0.016.

Since odd background photons come from different pion decays they normally fail to give a pion mass as their effective mass. Requirement $m_{\gamma\gamma} = m_{\pi^0}$ is the most powerful kinematic Al tools for this background. According to the proposal only 0.09 can pass through.

So far we achieved (very roughly) the following level of suppression (expressed in terms of "effective branching ratio"):

$$B_{eff} = B \times (2 \cdot 0.016 \cdot 8.3 \times 10^{-8} + 4 \cdot 0.3 \cdot 0.09 \cdot 2.9 \times 10^{-8}) \sim 5 \times 10^{-12}$$

which brings it under control (the signal branching ration is predicted to be $\sim 3 \times 10^{-11}$). Here factors 2 and 4 account for possible pair combinations for even and odd backgrounds, 0.3 in the second term in round brackets accounts for suppression for odd background coming from $E^*_{\pi^0}$ cut.

1.2 Specially addressed issues

The following issues were considered specially and the corresponding backgrounds were shown (at some level of confidence) to be under control.

1.2.1 Photon veto issues

Low energy photon inefficiency. Led-scintillator type of PV is known to have principal limitation on efficiency of detection of low energy photon ($E_\gamma \leq 20$ MeV), but this region can be avoided by applying kinematic requirements. One of them is M_{miss} is greater than some threshold. Indeed, in a lab reference frame $M^2_{miss} = (P^{miss}_{\gamma_1} + P^{miss}_{\gamma_1})^2 = 2E^{miss}_{\gamma_1}E^{miss}_{\gamma_2}(1 -$

$\cos\alpha$), so a lower limit on M_{miss} prevent both $E^{miss}_{\gamma_1}$, $E^{miss}_{\gamma_2}$ from dropping to low values. There is a relation $E^*_{\pi^0} = \frac{m_K^2 + m_{\pi^0}^2 - M^2_{miss}}{2m_K}$. So the requirement on missing mass is taken care about implicitly when $E^*_{\pi^0}$ cut is applied.

Another useful cut in this respect for apparent reasons is missing energy cut: $E_K - E_{\gamma_1} - E_{\gamma_2}$.

Beam holes. Upstream and downstream. Some photons apparently escapes through upstream and downstream beam holes. This issue was specially addressed with $1 \cdot 10^8$ event fastmc study. This type of background was found to be dominated by odd pairing case with energies above 300 MeV escaping through the downstream hole. It's taken care by having 99% efficient beam catcher as a part of PV system.

Overlapping showers. Photons can hide in other (detected) photons showers. The following calculations/speculations show that this background can be suppressed to desired level:
(a) if the distance between photons is from 20 to 50 cm (2.5–6 Moliere radii) – few per cent of events – comparing the shower center of gravity in the electromagnetic calorimeter to the expected position from the preradiator helps to suppress this by another factor of 10^{-3} bringing the inefficiency due to overlapping photons to $\sim 10^{-5}$.
(b) if the distance is less than 20 cm – less than 1% of events – overlapping photons can not be resolved and an additional energy in such a cluster brings $E^*_{\pi^0}$ up (even background is targeted) and missing energy and mass down (both even and odd are targeted) so event will have additional suppression from kinematic cuts. The total suppression was shown to be brought to $\sim 10^{-5}$.

1.2.2 "Wrap-around" background

Stands for the following mechanism: photon(s) are produced by the slow kaon from the "previous" bunch while calculations assumes kaon to come from the "current" bunch. So the kaon momentum is miscalculated and subsequent cuts using it might be fooled. It was shown that calculating $E^*_{\pi^0}$ at assumption of kaon coming from the previous bunch and cutting of a monochromatic π^0 peak is enough to suppress this background to the desired level.

1.2.3 Interbunch background

This is almost the same mechanism as described above except the kaon comes from Interbunch interval. This issue is addressed in TN052-A. The conclusion was that it's under control if Interbunch extinction is kept at the level $< 10^{-2}$/ns.

1.3 Other background mechanisms ?

1.3.1 Bunchwidths

Following the logic of the two previous sections one might expect that not knowing an exact kaon time because of the finite widths of the bunch can confuse kaon momentum calculation hence kinematic cuts. Although normally its gaussian part should just contribute

to resolution effects and non-gaussian tails are somewhat accounted by putting requirement on interbunch extinction level it might worth to address this issue directly.