2.24 Simulation Study of K_L Beam: K_L Rates and Background

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Abstract

We report our simulation results for K_L-beam and neutron background production, estimated rates for certain run conditions and resolution for K_L-beam momentum.

1. K_L **Beam Line**

   Our calculations have been performed for Jefferson Lab Hall D setup geometry. Primary K_L-production target has been placed in Hall D collimator cave. For the target material, we selected beryllium as for thick targets K_L-yield roughly proportional to the radiation length and density, which gives beryllium as the best candidate. Beam plug and sweeping magnet are placed right after the target. For our calculations we took a simple beam plug: 15 cm thick piece of lead. Sweeping magnet is cleaning up charged component and has a field integral 2 Tesla . meter, which is enough to remove all charged background coming out of the beam plug. Vacuum beam pipe has 7 cm diameter and preventing neutron rescattering in air. Where are two collimators: one placed before the wall between collimator cave and experimental hall, another - in front of the Hall D detector. Distance between primary Be target and liquid hydrogen (LH_2) target (located inside Hall D detector) has been taken 16 m in our calculations, it can be increased upto 20 m.

2. K_L **Production**

   We simulated K_L-production in photon bremstruhlung beam produced by 12 GeV electron beam in Hall D tagger amorphous radiator. We analyzed K_L-production via ϕ-meson photoproduction in detail. This is one of the main mechanisms of K_L-production at our energy range. It gives the same number of K^0 and $\bar{K}^0$. Another mechanism is hyperon photoproduction (which gives only K^0) was not studied in our simulations separately. Instead, we have taken as an alternative model Pythia generator [1], which includes hyperon production. ϕ-meson photoproduction total and differential cross sections on proton and complex nuclei (coherent and incoherent) were taken from Refs. [2,3]. Angular distributions for $\phi \to K_L K_S$ decay, we used are from Ref. [2,4,5]. These calculations show that ϕ decay in its rest frame is going mostly perpendicular to the axis of ϕ momentum. Since K_Ls need to stay on original photon beam direction to get LH_2 target, this condition requires that ϕ production and decay angles in laboratory frame should be about the same. That means we will have in the LH_2 only K_Ls from ϕ-mesons produced at relatively high t. It suppresses the number of "useful" K_Ls by factor of $\sim$3 or more (in comparison with the case if K_L and K_S momenta are parallel to ϕ momentum). K_L absorption used in our calculations was studied in Ref. [6] very well. About 80% of produced K_Ls will be absorbed in Be target itself and beam plug. This value of absorbed K_Ls can be reduced by optimizing beam plug setup.

3. K_L **Beam Parameters**

One of the main K_L-beam parameters is momentum distribution. Momentum spectrum is a function of the distance and angle. We are giving here resulting spectra for K_L reaching LH_2 target. Results of our simulations for K_L momentum spectrum is shown on Fig. 1. The spectrum first has increasing shape since ϕ decay cone angle decreasing at higher γ-beam and K_L momentum. This selecting lower ϕ production t values, which are more favorable according to ϕ differential cross section. At certain point highest possible γ-beam momentum is reached and K_L momentum spectrum is dying out pretty fast. For comparison, we selected part of K_L spectrum from Pythia generator originated only from ϕ decays and showed it on the same plot (red histogram).

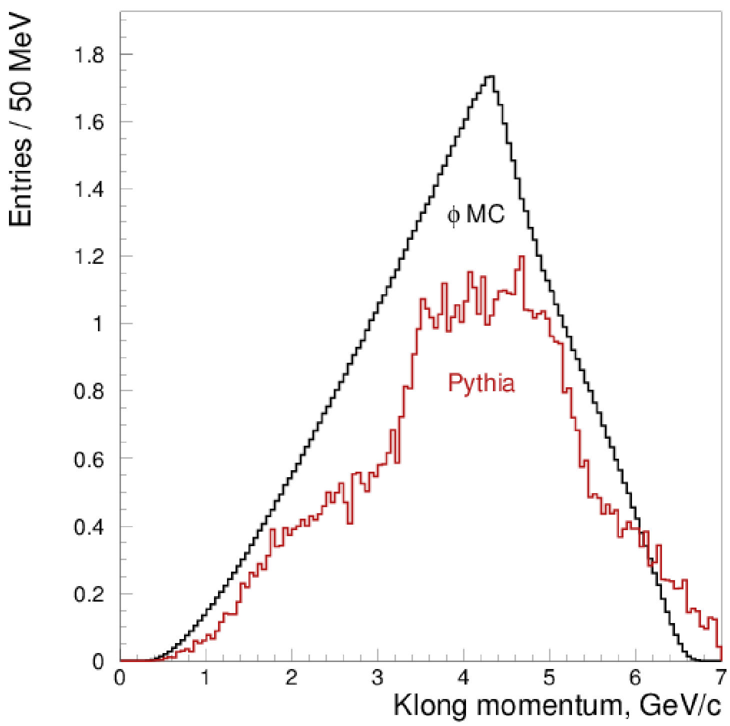

Figure 1: K_L momentum spectra originated from ϕ decays: black histogram - our simulation using GEANT [7], red - Pythia generator result [1].

Pythia shows, that ϕ decays give about 30% of K_Ls. Number of K^0 exceeds number of $\bar{K}^0$ by 30% according to this generator for our conditions. Their momentum spectra are shown on Fig. 2 separetly.

To estimate expected rate of K_L at LH_2 target we used the following conditions: electron beam current is 3.2 μA, tagger radiator thickness is 1% of radiation length, Be target thickness is 40 cm, distance Be to LH_2 target is 16 m, radius of LH_2 target is 2 cm. Our calculations are related to the K_L flux at that distance and solid angle. For K_L-beam intensity under the above condition, we got 100 K_Ls per second for our ϕ photoproduction simulation and

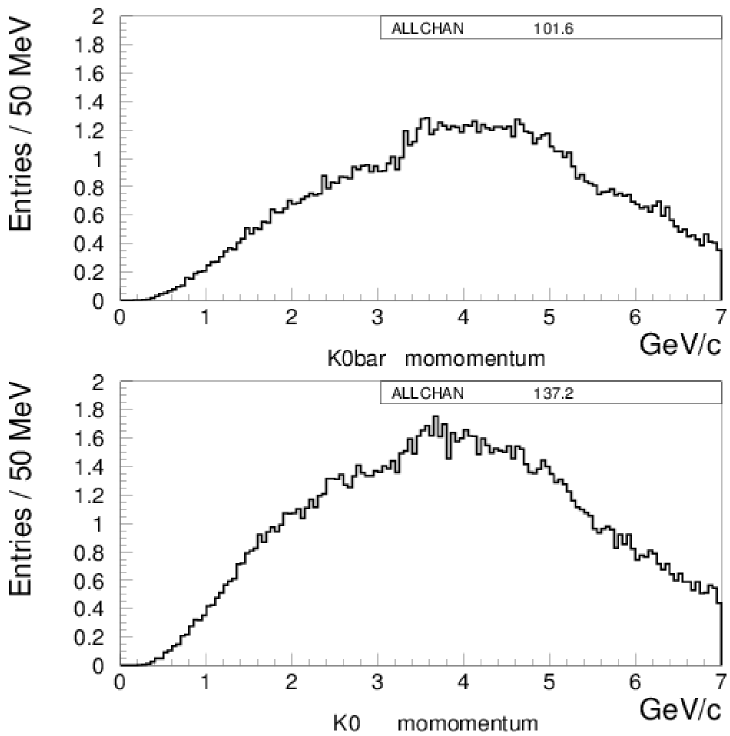

Figure 2: $\bar{K}^0$ (top plot) and K^0 (bottom plot) momentum spectra from Pythia generator.

240 K_Ls per second from all sources from Pythia. There are ways to increase the K_L-beam intensity by increasing tagger radiator thickness, electron beam current and other parameters. Increasing LH_2 target radius will increase number of K_Ls reaching it proportionally to the solid angle. For example for LH_2 target radius 4 cm, electron beam current 5 μA, 5% rad. length radiator and increased Be target sizes we shall be able to obtain beam rate about 7,000 K_Ls per second from all production mechanisms at LH_2 target face. For comparison this value corresponds to $\sim$10 million of produced K_Ls in Be target per second.

4. K_L **Beam Resolution**

K_L-beam momentum can be measured using TOF - time between accelerator bunch and reaction in LH_2 target detected by start counter. Hall D tagger timing can not be used at such high intensity conditions. Thus TOF resolution is a quadratic sum of accelerator time and start counter time resolutions. Since accelerator signal has very good time resolution ($\sim$0.1 ns or better), TOF resolution will be defined by start counter. Hall D start counter has resolution $\sim$0.35 ns. This value can be hopefully improved with upgrading counter design and parameters. In our calculations we used an optimistic value of 0.25 ns start counter time resolution. Of course to get TOF information electron beam needs to have narrow bunch time structure with the distance between bunches at least 30 ns. At low (< 1 GeV/c) K_L momenta uncertainty in K_L production point position within Be target will also affect TOF calculation precision. Fig. 3 shows TOF and beam momentum resolution as a function of K_L beam momentum.

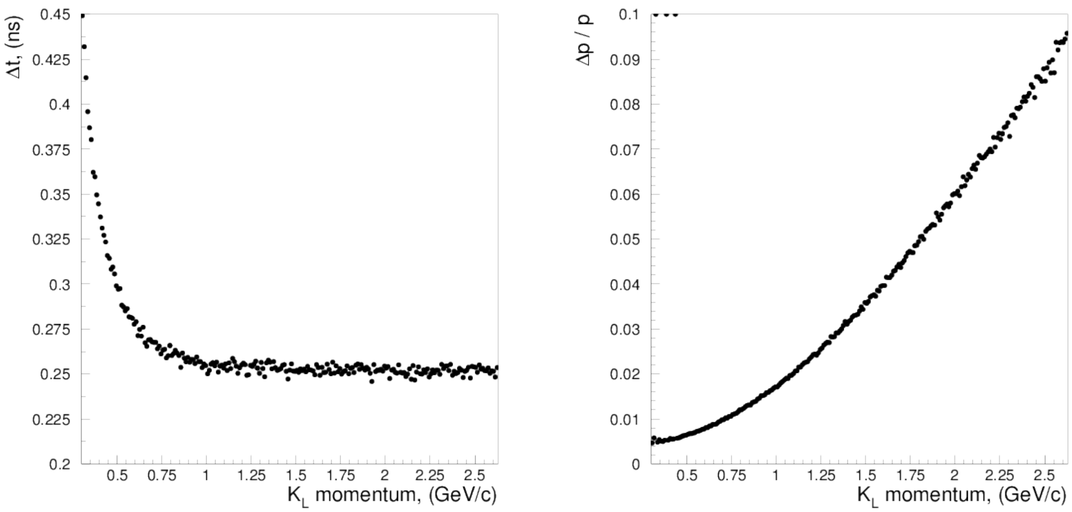

Figure 3: K_L-beam TOF (left plot) and momentum (right plot) resolution as a function of momentum.

TOF resolution is flat for momenta higher that 1 GeV/c. Momentum resolution is growing with momentum value, for 1 GeV/c it is $\sim$1.7%, for 2 GeV/c $\sim$6%.

5. K_L Beam Background

Background conditions is one of the most important parameter of the beam. After passing through 30 radiation length beam plug and swiping out charged background component, we will have some residual γ background and neutrons produced by electromagnetic showers. Momentum spectrum of residual γs shown on Fig. 4.

It decreases exponentially with increasing γ energy. For the rates we obtained $\sim$100,000 per second for γs with energy above 50 MeV and $\sim$1,000 per second for γs above 500 MeV.

The most important and unpleasant background for K_L-beam is neutron background. Special care needs to be taken to estimate and if possible to eliminate this kind of background. In our calculations to estimate neutron background we used two independent program packages: Pythia [1] and DINREG [8]. Both packages give the same order of magnitude neutron background level. At our condition it is $\sim$140 neutrons per second at LH_2 target for neutrons with momenta higher than 500 MeV/c. These spectra along with K_L momentum spectrum are shown on Fig. 5.

Additionally we calculated muon production level. Muon will be swiped out of the beam line thus they are not our background. But since their high penetration ability it might be important the for purposes of the shielding. We taken into account only Bethe-Heitler muon production process. Muons from pion decays and other production mechanisms will increase total muon yield only slightly. They were not included in our model. Number of produced

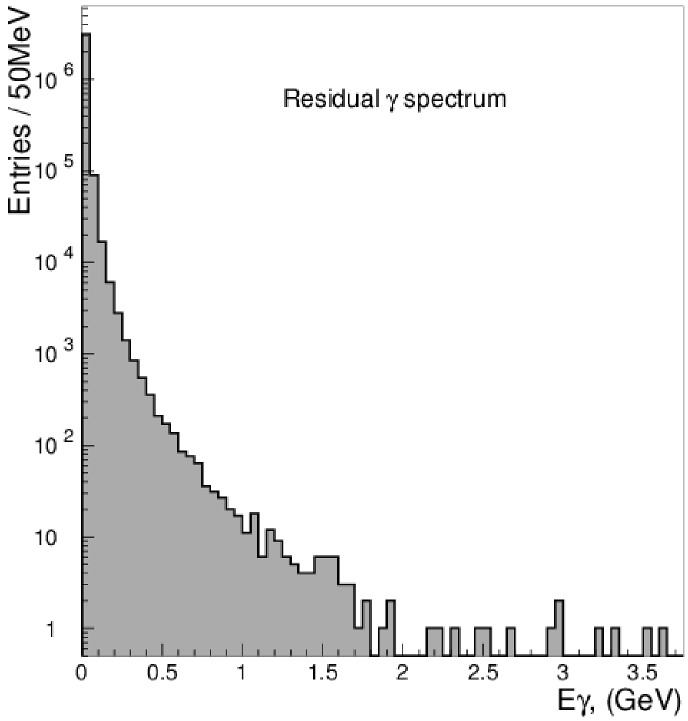

Figure 4: Momentum spectrum of residual γs.

muon in Be target and lead beam plug is about the same, lead originating muons have much softer momentum spectrum. Estimated number of produced muons $\sim$6 million per second. Their momentum spectrum is shown on Fig. 6.

Half of muons have momentum higher than 2 GeV/c, $\sim$10% of muons have momentum higher than 6 GeV/c and $\sim$1% of muons - momentum above 10 GeV/c.

6. **Summary**

In the summary part, we want to emphasize that K_L-beam facility opens horizons for new rich physics. Jefferson Lab GlueX spectrometer has very good acceptance and resolution parameters [9], which perfectly fit K_L-beam facility requirements. Expected rates for K_L-beam with increased γ-beam luminosity will allow to collect statistics order of magnitude higher than other facilities can provide. One of the main advantage of such facility is that K_L-beam is produced by γ-beam which provides low neutron background level comparing with hadron produced K_L-beam. To get more precise K_L-beam rates and neutron background estimations as well as radiation levels induced, it is important to conduct a few days measurements on low intensity test beam.

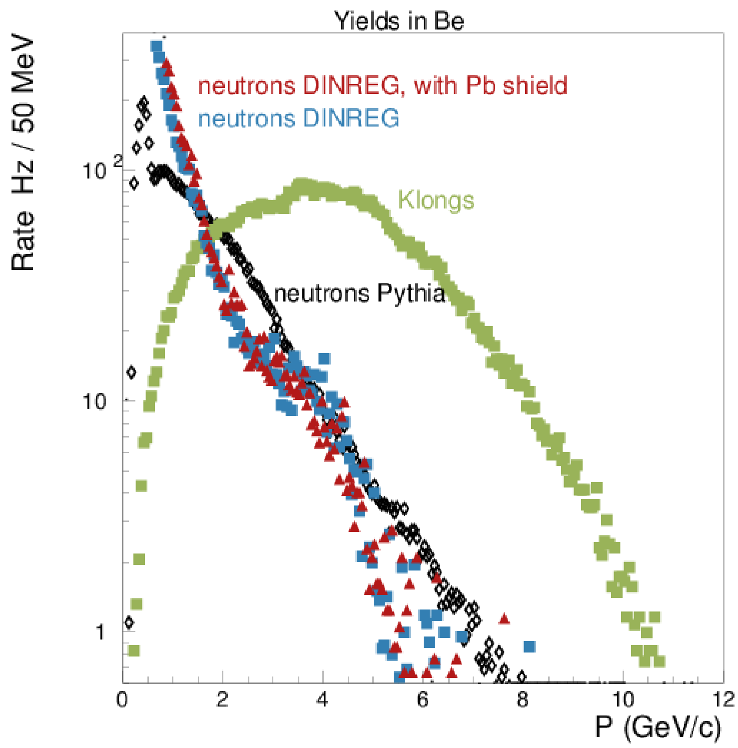

Figure 5: K_L and neutron momentum spectra obtained with different packages.

7. **Acknowledgments**

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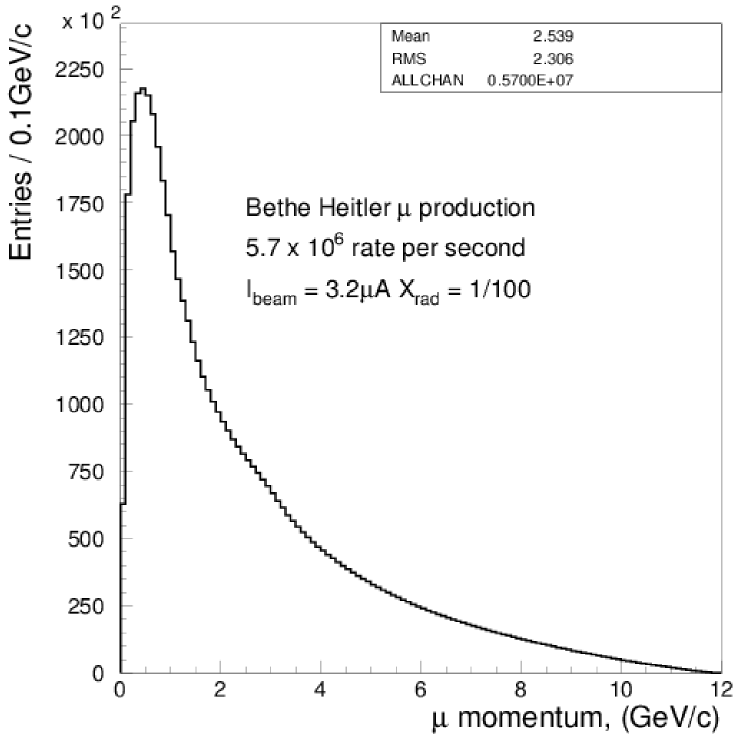

Figure 6: Muon momentum spectrum for Bethe-Heitler production.

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