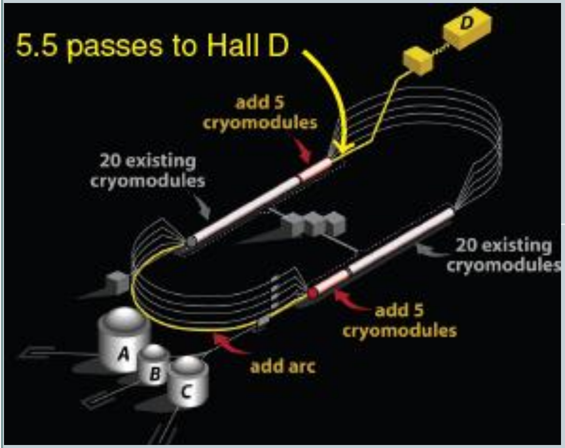
Simulation study of K_L-beam: K_L rates and background

I. LARIN

outline

- K_L beamline
- Simulation of K_L production
- Beam momentum resolution
- Expected K_L and background rates

Hall D


5.5 passes to Hall D
D
add 5
cryomodules
20 existing
cryomodules
20 existing
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add 5
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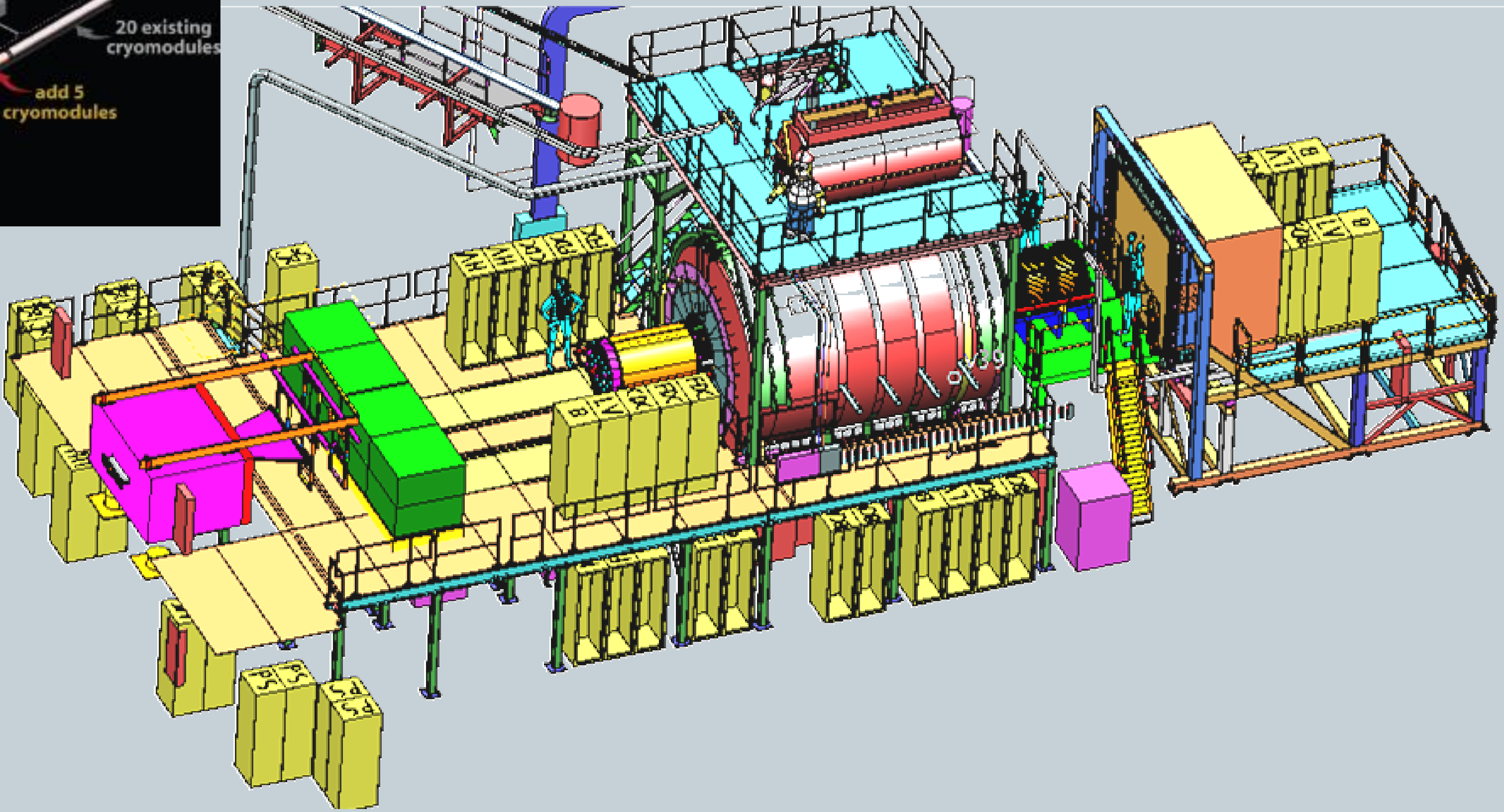
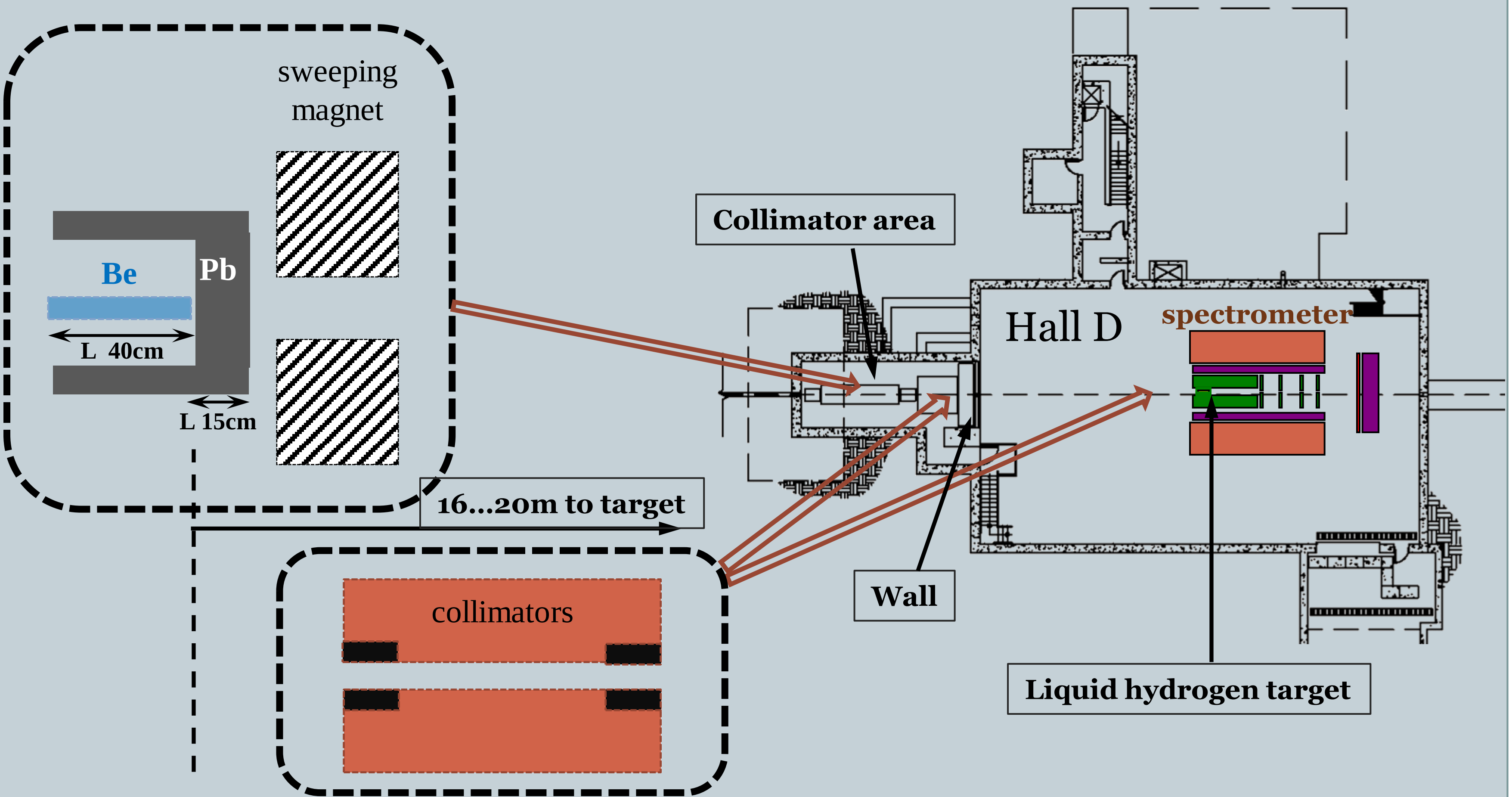
A
B
C



K_L-beam line


sweeping
magnet
Be
Pb
L 40cm
L 15cm
16…20m to target
collimators
Collimator area
Hall D
spectrometer
Wall
Liquid hydrogen target

K_L-production and propagation: simulation details

- K_L production mechanisms
- K_L absorption
- K_L beam momentum spectrum
- Comparison with Pythia
- Expected rates

K_L production:

- One of the main K_L production mechanisms at our momentum range is φ photoproduction. It gives same number of K^0 and $\overline{K^0}$ in the beam. This mechanism was studied in our simulations in details
- For thick production target K_L yield in first approximation is proportional to material rad. length and density, i.e. r.l. expressed in [g/cm^2]. It determines beryllium, boron and carbon as most preferable K_L production targets. We performed detailed simulation studies for beryllium, which is "traditional" K_L production target
- We compared our simulation results with what Pythia is giving us

φ photoproduction: cross section

Total photoproduction cross section as a function of beam energy

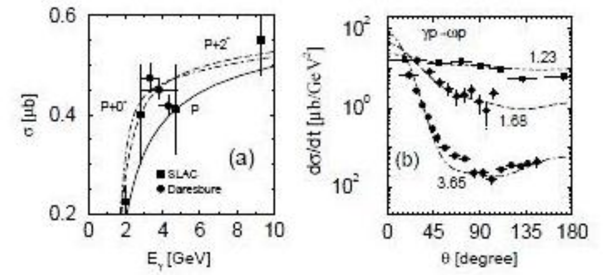


FIG. 3. (a) The total cross section of $\gamma p \to \phi p$ reaction as a function of the photon energy E_γ for models I–III indicated by dashed, long-dashed, and dot-dashed curves, respectively. Data are taken from Refs. [57,58]. (b) The total cross section for the hybrid model.

data taken from *"Spin effects and baryon resonance dynamics in φ-meson photoproduction at few GeV", A. Titov and T.-S. Lee, Phys. Rev. C **67** 065205 (2003)*

Differential cross section ($\frac{d\sigma}{dt}$) as a function of $\boldsymbol{t}_\perp$

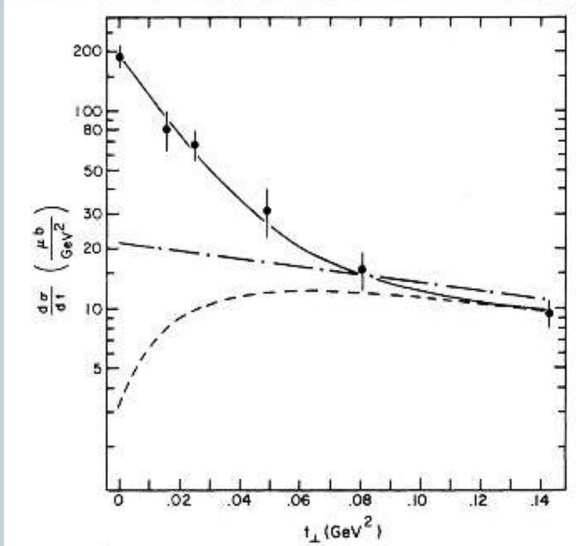


FIG. 3. The t dependence from carbon, $\langle E_\varphi \rangle = 6.4$ GeV. The solid curve is a fit using the equation given in the text. The dashed curve is the incoherent contribution to this expression. The dot-dashed straight line is a calculation of the incoherent cross section following Kolbig and Margolis (Ref. 12) normalized to the elastic contribution at $t = 0$, shown for comparison.

Coherent and incoherent mechanisms, data taken from *"Photoproduction of phi mesons from hydrogen, deuterium and complex nuclei", G. McClellan, et al, PRL 1971* ***V26***

K_L production via φ decay: angular distributions

$$\frac{d\,\sigma}{d\,cos\theta^*}$$

Gottfried – Jackson frame

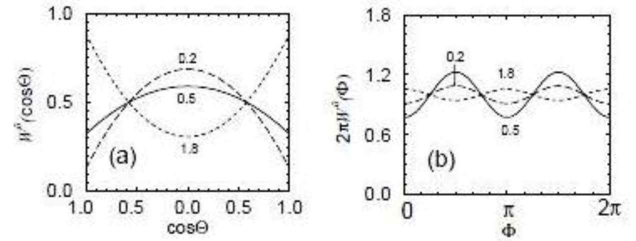


FIG. 7. The angular distribution of the ϕ-meson decay in the reaction $\gamma p \to \phi p$ with unpolarized photon beam at $E_\gamma = 2.2$ GeV and $|t| = 0.2$, 0.5, and 1.8 GeV^2. (a) The dependence on $\cos\Theta$ (integrated over the azimuthal angle Φ); (b) the dependence on Φ (integrated over $\cos\Theta$).

data from *"Spin effects and baryon resonance dynamics in φ-meson photoproduction at few GeV", A. Titov and T.-S. Lee, Phys. Rev. C **67** 065205 (2003)*

helicity frame

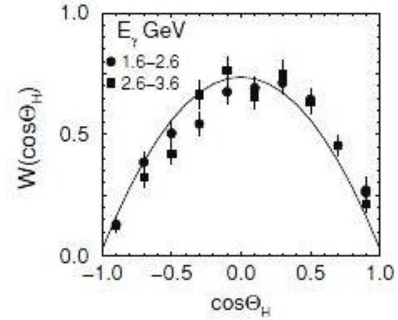
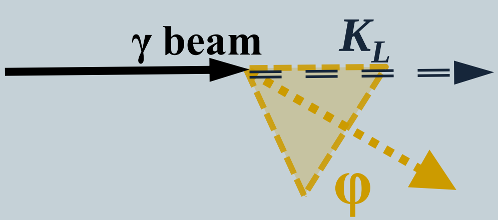


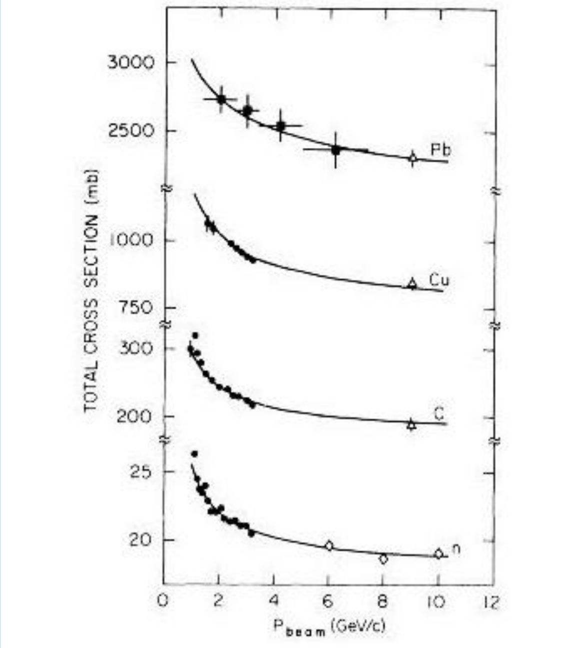
FIG. 13. Angular distribution $W(\cos\Theta)$ for the $\gamma D \to \phi D \to K^+K^-D$ reaction in the helicity frame at $E_\gamma = 3.1$ GeV and $-t_0 = 0.3$ GeV^2. Experimental data for two energy intervals and $|t| = 0.35$–0.8 GeV^2 are taken from Ref. [16].

data from *"Photoproduction of the φ-meson off the deuteron near threshold", A. Titov and B. Kampfer, Phys. Rev. C **76** 035202 (2007) and "Measurement of coherent φ -meson photoproduction from the deuteron at low energies," T. Mibe et al. (CLAS Collaboration), Phys. Rev. C**76**, 052202 (2007)*



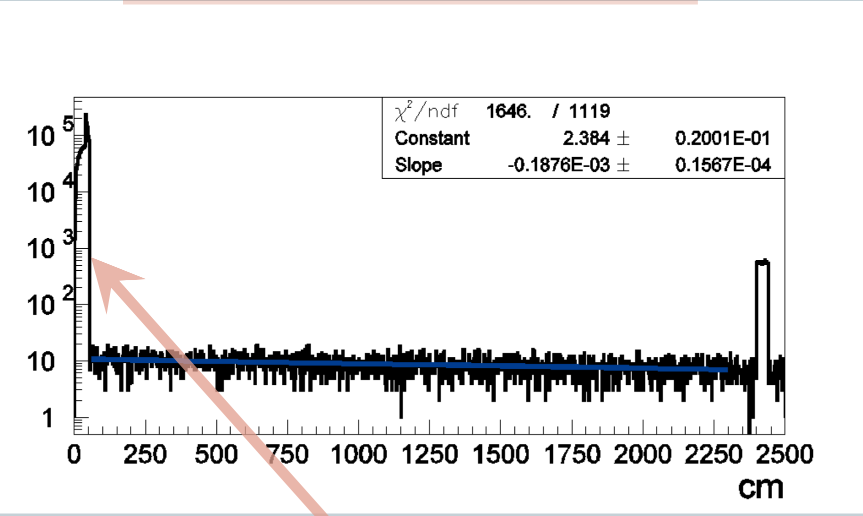
K_L absorption on the way: in beryllium (primary target) and lead (beam shutter)

total absorption cross – section as a function of K_L momentum



data from *"Production of K_L mesons and neutrons from Electrons on Beryllium Above 10GeV", G.W. Brandenburg, Phys. Rev. D 7 (1973)*

Number of absorbed Kaons per unit of distance

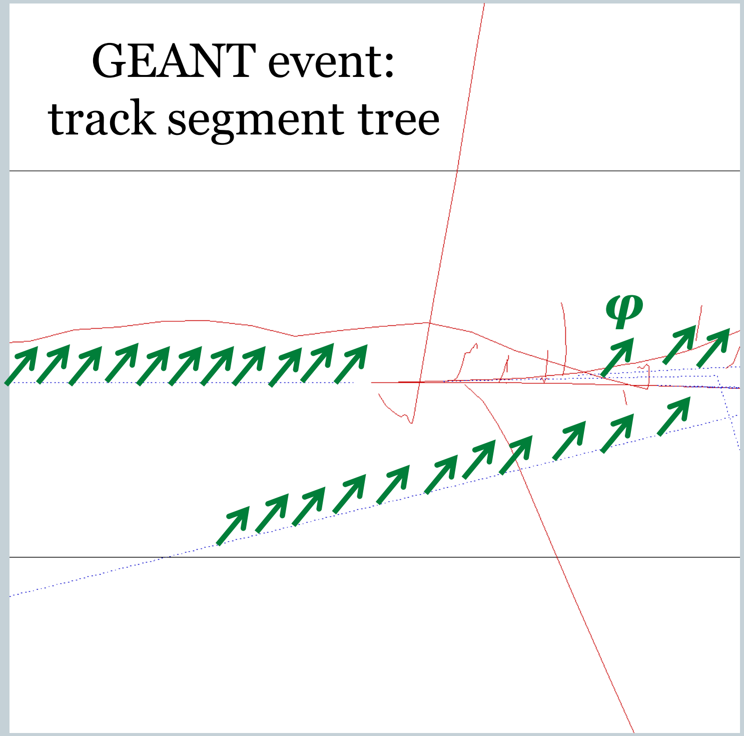


- *~80% of Kaons will be absorbed in Be and lead*
- *Elastic Kaon scattering does not decrease K_L flux on target*

K_L from φ decays simulations

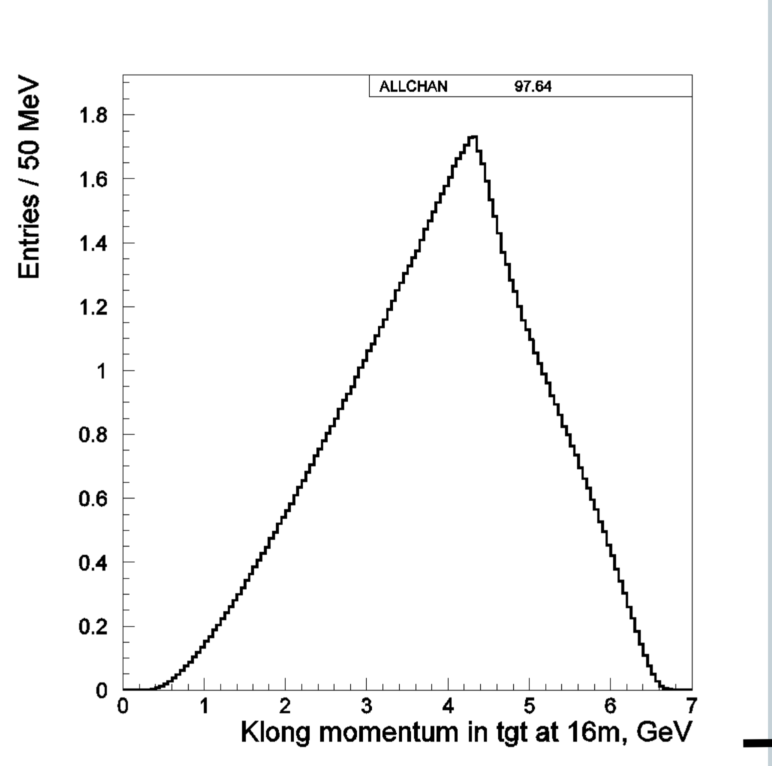
- K_L yield via φ photoproduction was simulated in GEANT program
- Roughly, only over billion photons gives K_L at target face – simulation of 1M statistics at target would require generation of $\sim 10^{15}$ events

- Possible solution:
  - generate φ photoproduction on each tiny photon track segment
  - Assign weight which equals to photoproduction probability in case if product K_L reaches the target



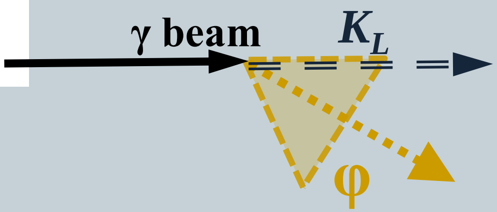
K_L momentum spectrum from φ decays

Simulation result for K_L momenta at 16m downstream primary target



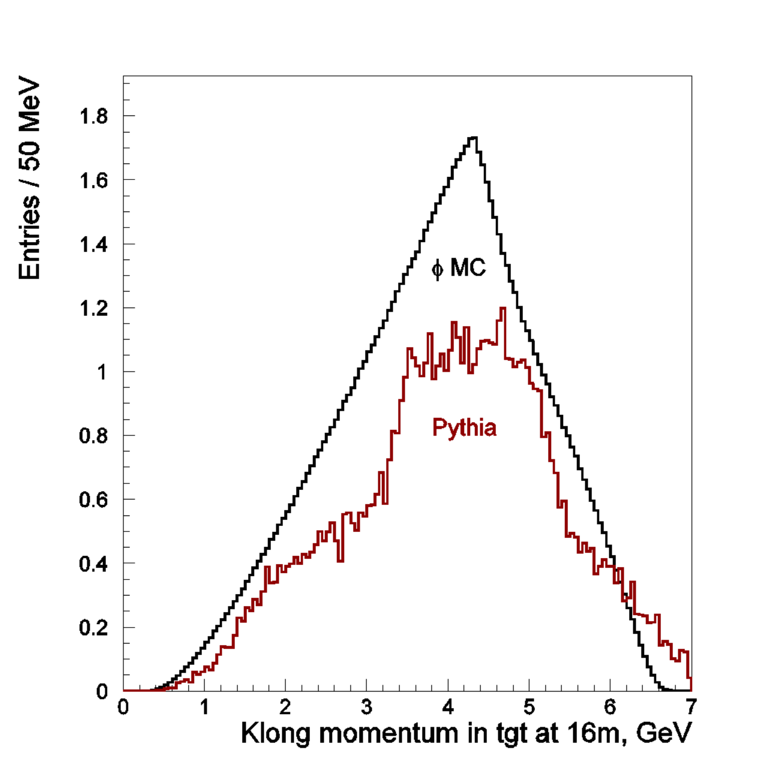
<u>growing part of kaon spectrum:</u>
φ decay cone angle in lab frame decreases, which requires smaller φ production ***t*** values (*φ* production angle should be close to *φ* decay cone angle for our geometry)

<u>second part of spectrum is dropping down:</u>
due to limited γ-beam energies (effect of bremsstrahlung spectrum edge)



K_L momentum spectrum (φ decay only): comparing with Pythia

Simulation result for K_L momenta at 16m downstream primary target



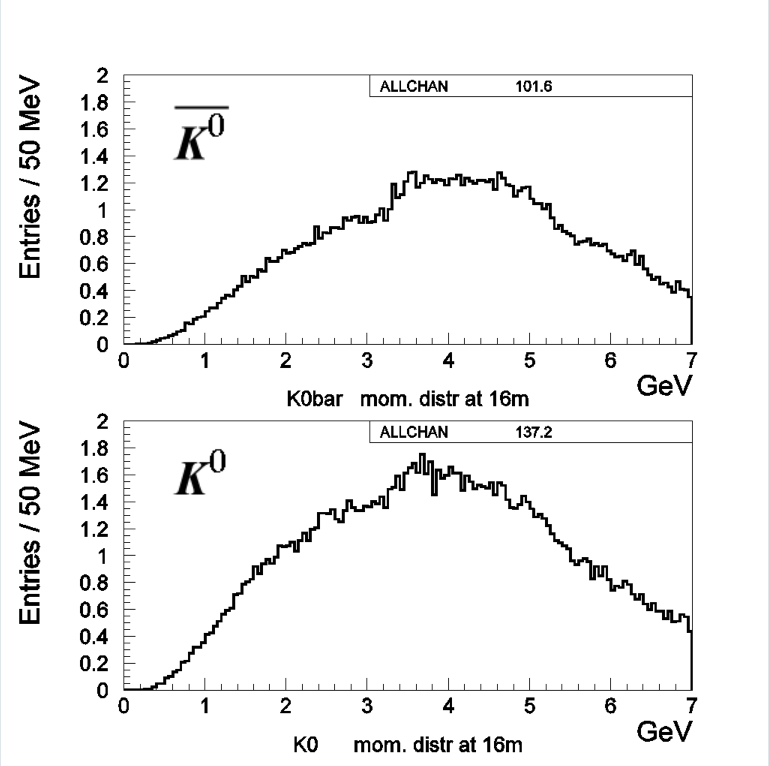
1) Shapes of K_L momentum spectra are close and have maximum at ~4 GeV

2) Number of K_L produced only via φ production mechanism in Pythia 30% smaller than in our Monte-Carlo

3) Total number of K_L given by Pythia was ~ 2.5 times higher than our Monte-Carlo

K_L momentum spectrum (total): Pythia

Simulation result for K_L momenta at 16m downstream primary target



1) K_L momentum spectrum has maximum at 4 GeV (same as we see for φ production mechanism)

2) Number of produced K^0 exceeds number of $\overline{K^0}$ by ~30% (due to hyperon photoproduction)

3) φ photoproduction mechanism in Pythia gives ~30% of total number of K_L

K_L-beam rates and run conditions

Calculated rates are given for

- Electron beam current I_{beam} = 3.2μA
- Tagger radiator thickness X_{rad} = 1%(rad. len.)
- Beryllium target: thickness L_{be} = 40cm, radius R_{Be} = 2cm
- Distance from primary target (Be) to production target (liquid H_2) z = 16m
- Production target (liquid H_2) radius R_{tgt} = 2cm
- The part of the whole beam integrated over solid angle of production target

K_L-beam rates and run conditions

Calculated rates for given beam parameters, for survived K_L (no decay or absorption) observed at forward production target plane:

- K_L via φ photoproduction (50% K^0 and 50% $\overline{K^0}$, our simulations) **~100 per sec**
- K_L via all production mechanisms (~55% K^0 and ~45% $\overline{K^0}$, Pythia) ~**240 per sec**

Possible ways to increase K_L beam rate:

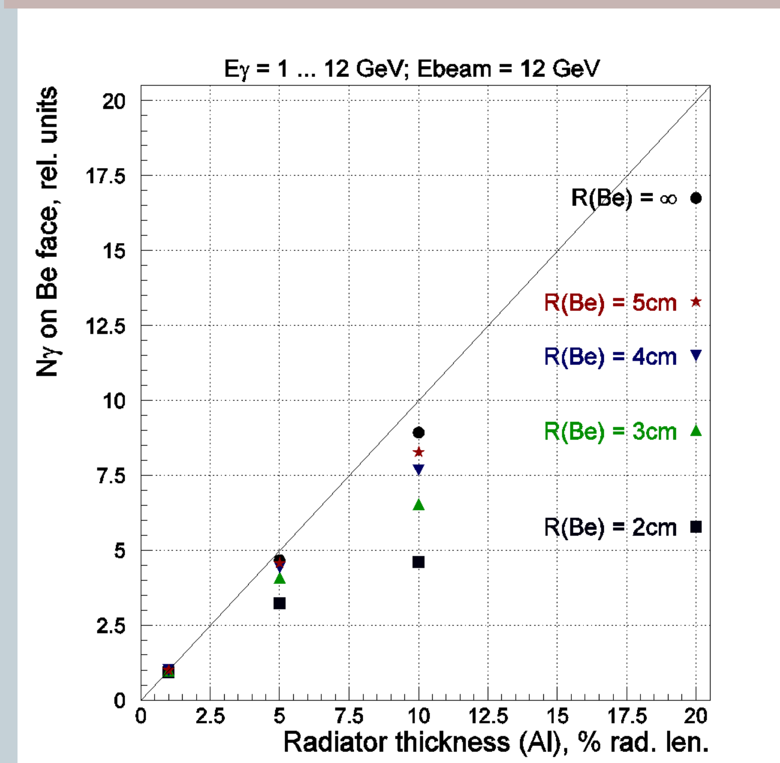
- Increase production (liquid H_2) target radius (wider solid angle) from 2cm to 3…4cm
- Increase Be target thickness to 50…55cm
- Increase beam current and tagger radiator thickness

For production target radius R = 4cm, 5μA beam current, 5% rad. len. radiator thickness, Be target radius R_{Be} = 4cm and thickness L_{Be} = 50cm we estimate:

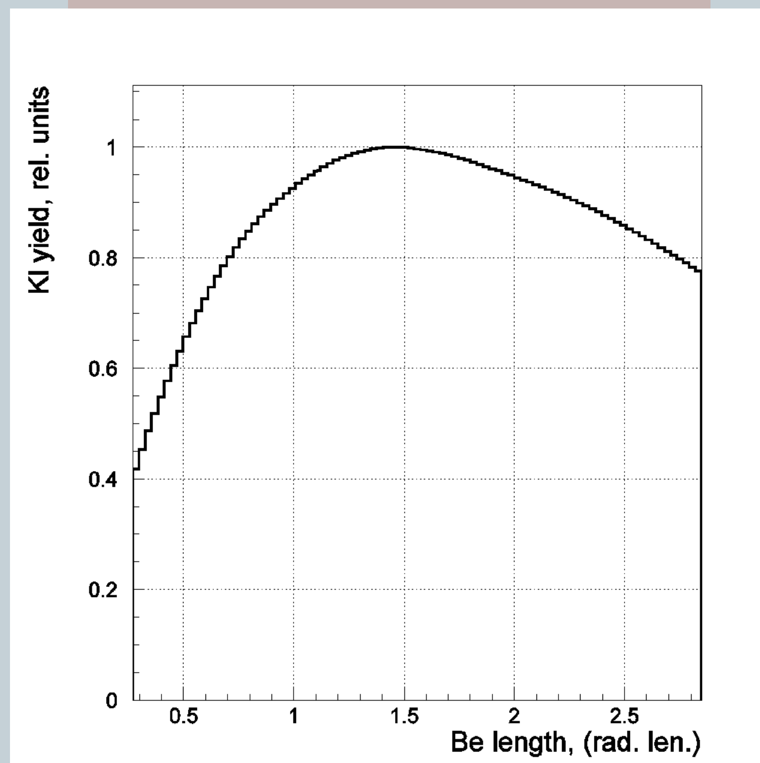
- K_L via **all** production mechanisms **7k per sec** (at liquid H_2 target face)
- K_L production rate in Be target at this conditions ~**10M per sec**

Yields vs radiator thickness and Be target size

γ–beam yield on Be-target face vs radiator thickness for different Be radii



K_L yield vs Be-target thickness

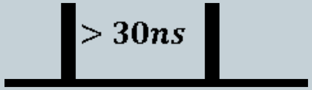


K_L-beam resolution

- Time resolution
- Momentum resolution
- W resolution
- Angular resolution

beam time, momentum and $\sqrt{s}$ resolutions

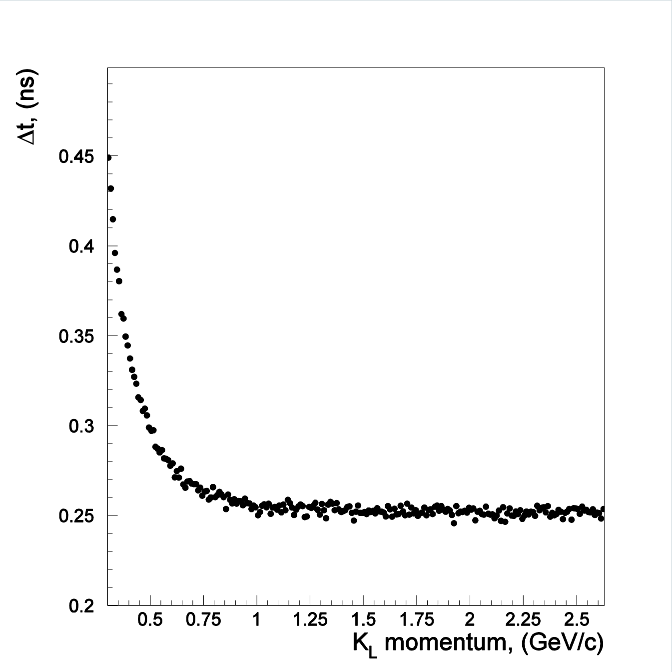
- *Input parameters:*
- $\boldsymbol{K_L}$ path from production point to target: 20m
- $\boldsymbol{K_L}$ production primary Be target length: 40cm
- Start counter vs RF time resolution: 0.25ns
- Beam RF structure is essential for TOF analysis:



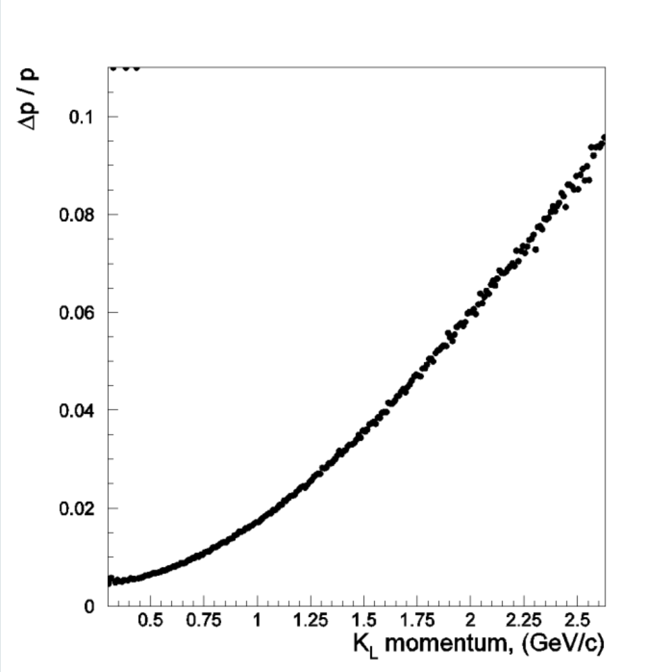
Simulation results:

- SC time resolution defines TOF resolution starting at 1 GeV/c
- Beam momentum and $\boldsymbol{W}$ ($\boldsymbol{K_L+p}$ system) resolutions defined by TOF resolution

time and momentum resolution

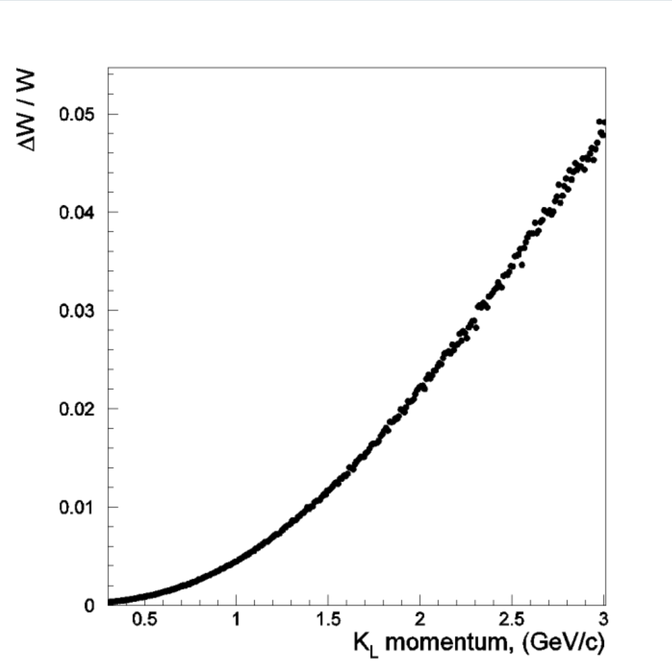


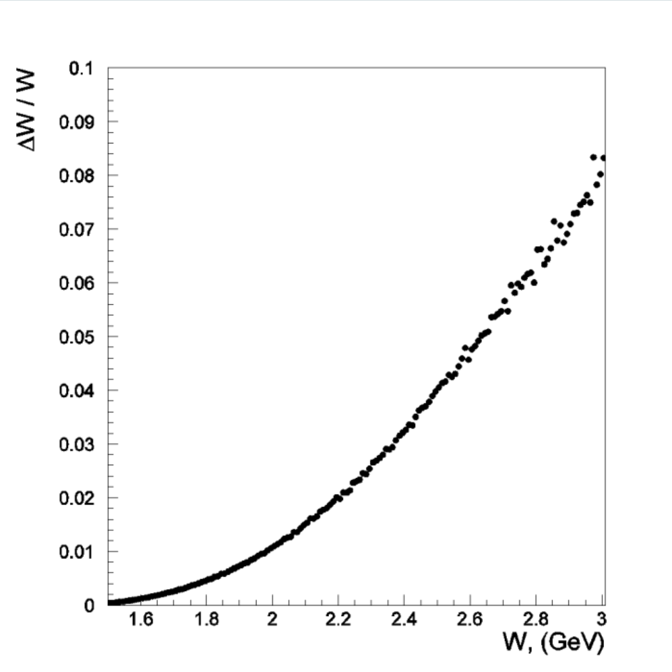
Time resolution is flat from 1GeV K_L momenta and defined by start counter time



Momentum resolution ~1.7% at 1GeV/c and ~6% at 2GeV/c K_L momentum

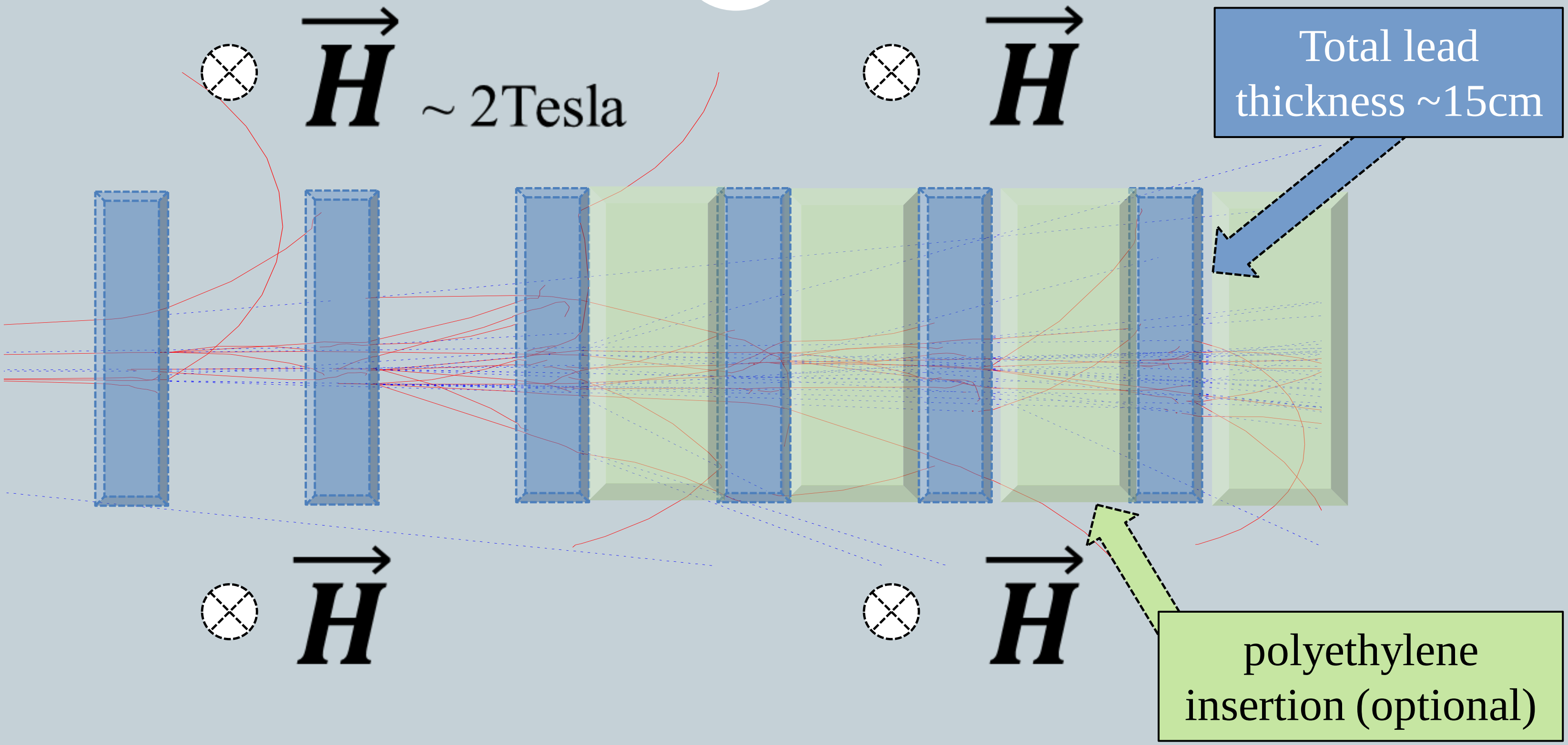
W and angle resolution





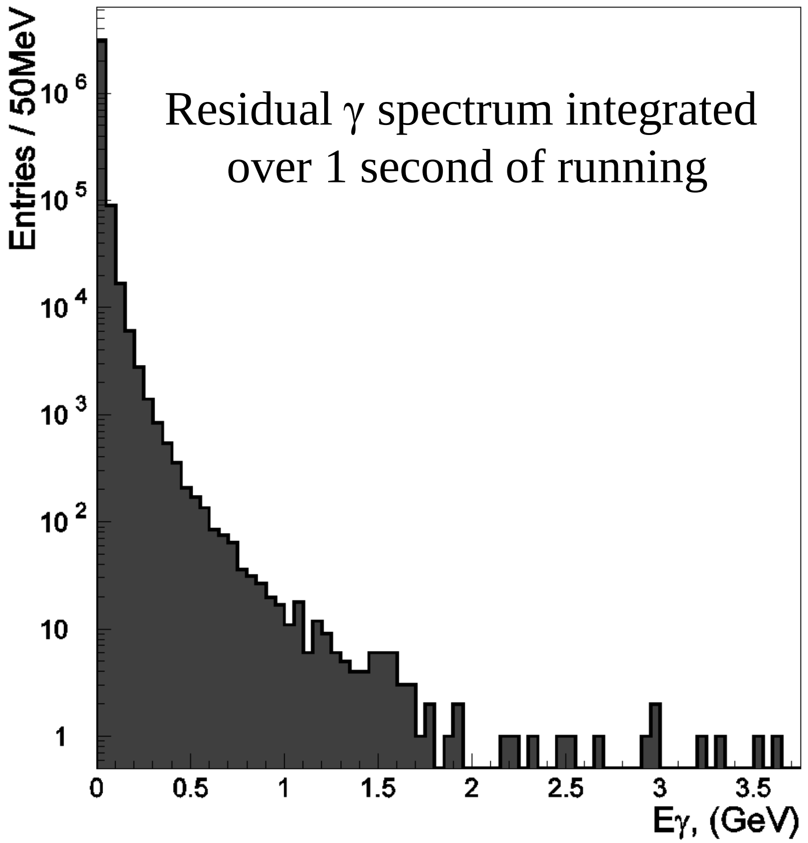
W resolution better than 1% up to 1.4GeV/c and within 2% up to 1.9GeV/c K_L momentum
Angular resolution defined by setup geometry and within 3mrad

Beam shutter



Multilayers shield with magnetic field additionally suppresses residual γ / n background by ~20 % in comparison with the same thickness solid block

γ residual background



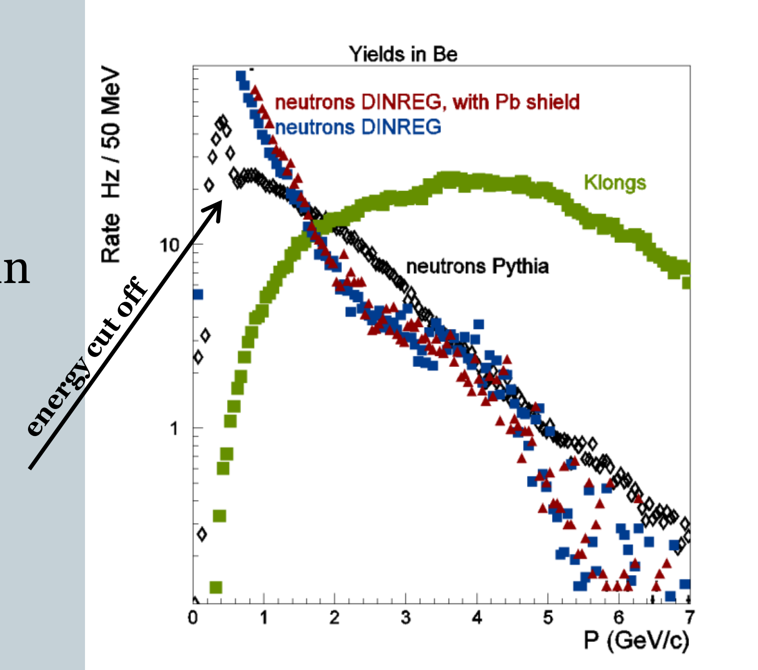
After 15 cm of lead shield residual γ background rate on hydrogen target (passing through collimator hole):

$E_\gamma >$ 10MeV $\rightarrow \approx$ 3M/sec
$E_\gamma >$ 50MeV $\rightarrow \approx$ 100k/sec
$E_\gamma >$ 100MeV $\rightarrow \approx$ 30k/sec
$E_\gamma >$ 500MeV $\rightarrow \approx$ < 1k/sec

Neutron background

- Neutron rate was estimated by two independent ways: Pythia generator (photoproduction on energies greater than 3GeV (thanks to Sasha Somov) and DINREG package (courtesy of Pavel Degtiarenko).
- Both packages give same order number of neutrons and K_L starting from energies 1GeV (**140** neutrons per second for Pythia).
- For low momenta energies number of neutrons in DINREG packages increases faster
- Inclusion of magnetic field, (non-magnetic) iron and polyethylene spacers in beam shutter will reduce neutron background significantly
- Placing Be target in magnetic field can reduce number of produced neutrons up to 25%

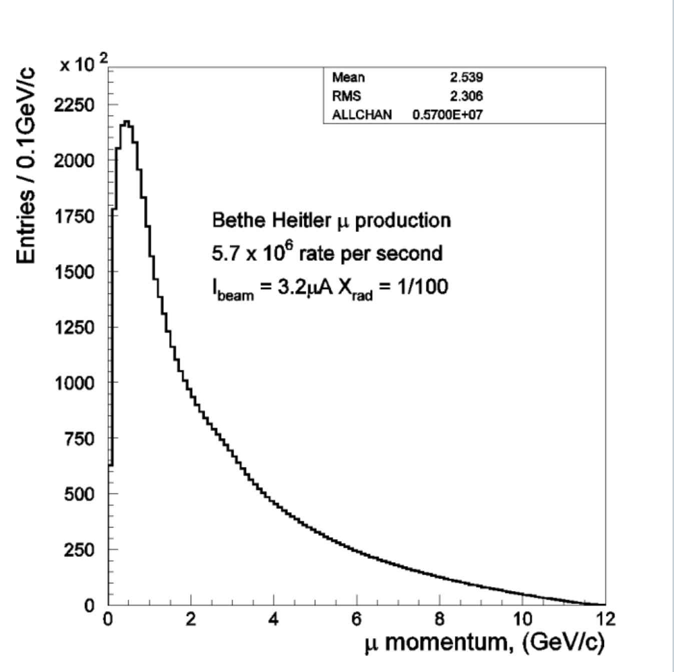
Neutron vs K_L momentum spectrum



Muon rates

- Muons will be removed by swiping magnet after beam shutter. Nevertheless special attention is needed for muon protection.
- Muon pair production via Bethe-Heitler process has been simulated in GEANT to estimate μ production rate
- Additional muons expected from pions decay (less energetic though)
- Be target and lead beam shutter give roughly the same amount of muons, muons produced in lead are softer
- About half of muons have momentum higher than 2GeV/c; 10% of muons with momentum above 6GeV and ~ 1% of muons with momentum above 10GeV
- Number of produced muons of both signs for 3.2µA beam current and 1% radiator ~ 6M/sec

Bethe-Heitler muons momentum spectrum



Summary

- K_L beam facility at 12 GeV opens horizons for new physics. We expect a lot of new ideas and original proposals.
- Hall D setup and spectrometer perfectly fit K_L beam facility needs.
- High intensity γ-beam is needed to provide measurements in K_L beam with order of magnitude higher statistics than other beam facilities can provide
- Big advantage of γ-beam is that it provides low neutron contamination K_L-beam
- Neutron background is comparable with K_L-beam intensity. It is seen, that there are ways for further background reduction
- Estimated K_L and background rates need to be verified with existing measurements, such as ***NINA*** experiment data
- K_L and background rates need to be measured experimentally during few days of low intensity test beam running. It will also give us more precise estimation of radiation levels caused by K_L beam production