# A Straw-Man Particle ID System for Hall D

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## Abstract

We discuss simple considerations for particle identification in the Hall D detector, based on the reaction $\gamma p \rightarrow K^{\star}\bar{K}^{\star}p$ at 8 GeV/$c$. The main issue here is $K/\pi$ separation for momenta up to around 5 GeV/$c$. We argue that the correct approach for Phase I is a threshold, heavy gas Čerenkov detector, augmented by a time-of-flight hodoscope wall, just upstream of the LGD. The HERMES system of a dual radiator (aerogel plus gas) and imaging optics is also discussed.

The early physics goals in Hall D will likely involve reactions exciting various forms of strangeonium. These reactions will lead to multiparticle final states which mix $K^{\pm}$ with $\pi^{\pm}$. However, a large part of the cross section will lead to similar multiparticle states but with all pions. We focus, therefore, on particle identification (PID) that concentrates on $K/\pi$ separation.

SLAC Experiment E135, a.k.a. LASS [1], used time-of-flight (TOF) and two gas Čerenkov detectors, but also relied heavily on kinematic fitting for PID. For example, see their measurements of the reactions $K^{-}p \rightarrow \Lambda K^{\star}\bar{K}^{\star} \rightarrow \Lambda K^{+}K^{-}\pi^{+}\pi^{-}$ [2] and $K^{-}p \rightarrow \Lambda\pi^{+}\pi^{-}\pi^{+}\pi^{-}$ [3].

We expect to use the LASS solenoid as the primary magnetic field for our Phase I detector. A sketch of the current thinking of the apparatus (Fig. 1) is available online.[1]

To get some idea of the problem, we generated $10^{4}$ events of the type $\gamma p \rightarrow K^{\star}\bar{K}^{\star}p$ using the program gener8, at a photon beam energy of 8 GeV/$c$. The $p$, $K^{\pm}$, and $\pi^{\pm}$ momentum distributions are shown in Fig. 2 for all events and for particles which emerge at angles less than 14.5° with respect to the beam direction. The cross section for four charged pion production is substantial, proceeding through high mass vector resonance production [4], so it is reasonable to expect a significant pion contamination in the four prong event sample.

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[1] See http://dustbunny.physics.indiana.edu/ dzierba/PropDraft/Apparatus/Overview.html.

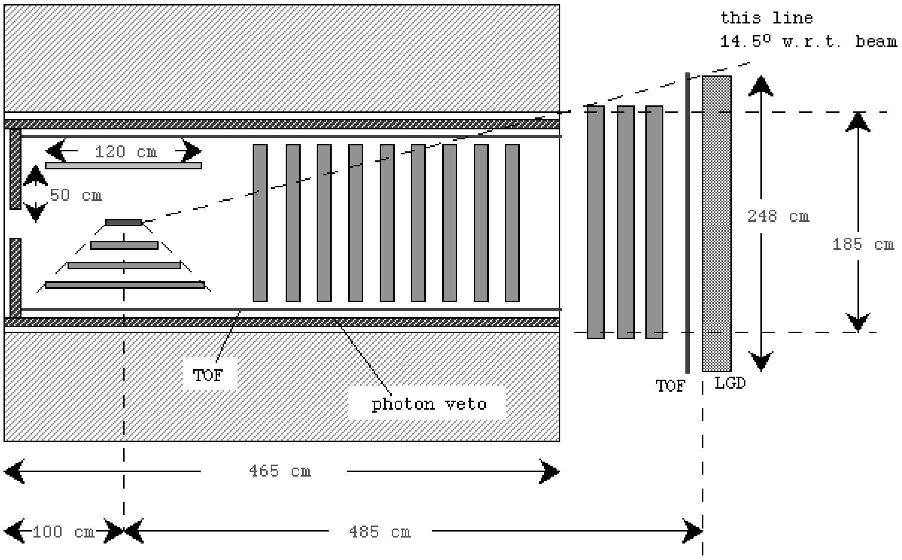

Figure 1: Schematic of the Phase I detector for Hall D. This was drawn on May 15, 1998, by A. Dzierba and J. Manak. *This figure is outdated! A more recent design concept will be presented and discussed at the workshop.*

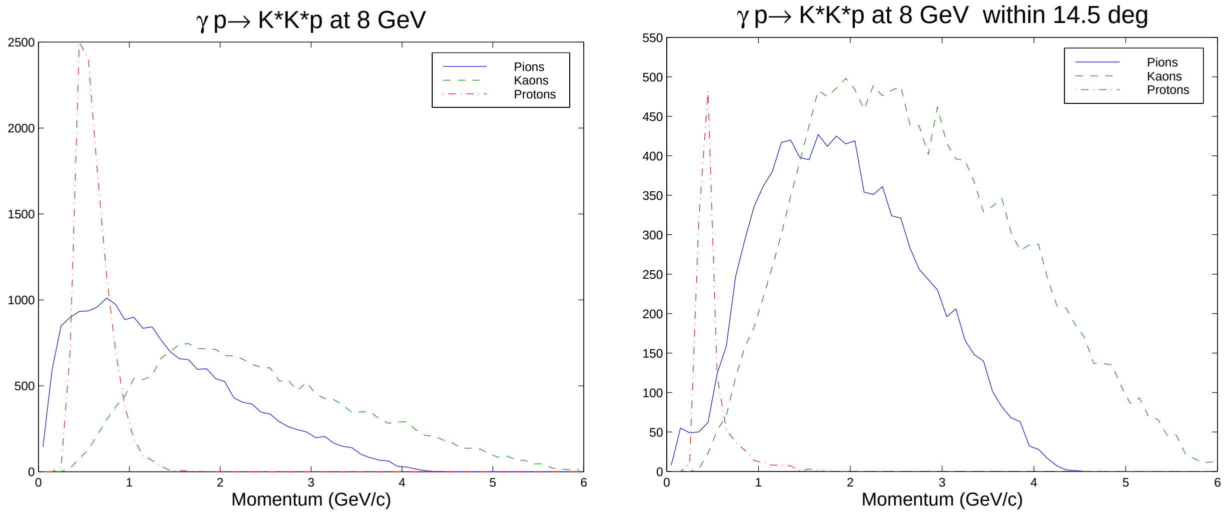

Figure 2: Momentum distributions for particles produced in the reaction $\gamma p \longrightarrow K^{\star}\bar{K}^{\star}p$ at 8 GeV/$c$. Particles within 14.5° will emerge from the downstream end of the solenoid.

We have not swum the particles through the magnetic field, but for this simple analysis we can neglect the bending. In PDG notation, the radius of curvature $R$ in a magnetic field $B$ is related to the momentum $p$ as $p\cos\lambda = 0.3BR$ where $\lambda$ is the "pitch" angle and $R$, $B$, and $p$ are measured in meters, tesla, and GeV/$c$ respectively. In our geometry, $p\cos\lambda = p_\perp$. We can estimate the effect of bending by calculating the fraction of one circular orbit executed during the time the particle spends in the solenoid. The time for one circular orbit is $2\pi R/c\cos\lambda$ and the transit time through the solenoid is $L/c\sin\lambda$ where $L \approx 3.5$ m. With $p = 4$, and $B = 2$, this fraction works out to be

$$\frac{L/v\sin\lambda}{2\pi R/v\cos\lambda} = \frac{L/\sin\lambda}{2\pi p/0.3B} \approx 0.1$$

for particles which emerge at small enough angles to exit the solenoid (i.e. $\lambda$ near 90°). This gives us some feel for the aberrations in particle trajectory exiting the magnet. We can neglect them for flight path estimates, but they will likely introduce important effects for calculating the effect on Čerenkov light direction.

The maximum radius of curvature that will be contained inside the magnet is the value of $R$ that equals one quarter of the bore diameter of 185 cm. Therefore only particles with $p_\perp \leq 280$ MeV/$c$ will be able to execute more than half a revolution before hitting the inside of the solenoid. Thus, if a particle is produced at an angle greater than 14.5° with respect to the beam, it will not exit the solenoid unless its momentum is less than about 1 GeV/$c$. These would have to be identified either with apparatus lining the inside of the solenoid, or possibly using $dE/dx$ information from the drift chambers. We preclude, at this point, the idea of including more detector components within the barrel so we can keep the number of radiation lengths to a minimum.

## PID for forward particles ($\theta \leq 14.5°$)

Time-of-flight (TOF) has been suggested as a possibility for PID in the forward region, for Phase I. It will be difficult, however, to cleanly separate $\pi$'s and $K$'s this way over much of the momentum range. Assuming a five meter flight path, the time difference between $\pi^\pm$ and $K^\pm$ works out to be the following:

| $p$ (GeV/$c$) | $t_K - t_\pi$ (ps ) |
|---:|---:|
| 2 | 463 |
| 3 | 207 |
| 4 | 117 |
| 5 | 75 |

For TOF scintillators that are ~ 2 m long, RMS time resolutions on the order of 100-120 ps are typically achievable using well established techniques [5]. With improvements in photomultiplier (PMT) design, however, one can achieve 50 ps RMS for detectors with long,

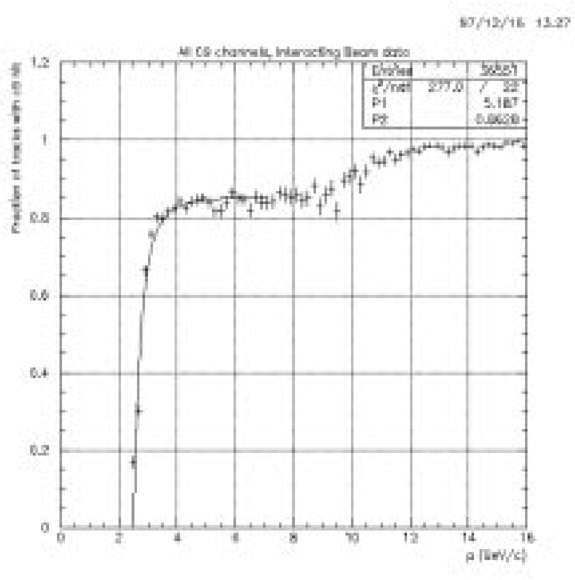

Figure 3: Performance of a heavy gas Čerenkov detector to $\pi^{\pm}$ and $K^{\pm}$.

narrow geometry. For example, Ref. [6] describes 2 m long detectors, with $2.5 \times 2.5$ cm$^2$ cross section and a 12-stage bialkali PMT on each end, which do this well. Of course, it would be important to control temperature and many other factors to routinely get 50 ps resolution on a large bank of counters.

It is our opinion that TOF should therefore be sufficient for momenta up to 2 or 3 GeV/$c$, but it would be unwise to rely on it for the necessary upper end of the momentum spectrum.

Of course, this is typically the region where heavy gas atmospheric Čerenkov detectors become useful for pion detection. One such detector, for example, has been used to identify individual particles in a multiparticle spectrometer setup not too dissimilar to ours [7]. Figure 3 shows some data taken recently as part of experiment E852 at BNL, where the detector was used to require that at least one $K^{\pm}$ be identified in $\pi^{-}p$ interactions at 18 GeV/$c$. The figure shows the fraction of *tracks* which produce a signal in the detector. It is filled with Freon-114 ($C_2Cl_2F_4$), with $n - 1 = 1.53 \times 10^{-3}$ for $\pi$ ($K$) momentum threshold of 2.51 GeV/$c$ (8.95 GeV/$c$). The breaks at these momentum thresholds are obvious and the detector would appear to be nearly fully efficient, based on the highest momentum $K^{\pm}$. (Fluoro-chlorocarbons are not longer produced, but a similar gas, $C_4F_{10}$ is available and has $n - 1 = 1.4 \times 10^{-3}$ [8].)

These results suggest a $C_4F_{10}$ filled Čerenkov detector followed immediately by a TOF system, just upstream of the LGD. (A preliminary optics design has been drawn up by P. Stoler.) This of course means that some of the present configuration, which includes drift chambers between the magnet and the LGD, will have to be modified.

An interesting variation of this theme has been built by the HERMES collaboration [8] and is presently being commissioned. This is a dual-radiator Čerenkov system, using $C_4F_{10}$

and aerogel with $n = 1.03$. The optics of the detector allow "rings" to be reconstructed with an array of small diameter PMT's. The size of the ring (5 cm radius for the gas, 25 cm for the aerogel) allows one to determine which radiator gave rise to the Čerenkov photons. The $K^{\pm}$ threshold in the aerogel is very close to the $\pi^{\pm}$ in the gas. Consequently, one obtains $K/\pi$ separation down to very low momenta in one detector and set of electronics. We should consider this possibility as well, although there is considerably greater expense in the photodetectors.

Finally, a pipeline readout system has been proposed for this detector. It has been pointed out that TOF techniques are not amenable to this form of data processing, but we may consider staging the TOF system against the pipeline readout and a dual-radiator Čerenkov detector.

### PID for particles within the solenoid ($\theta \geq 14.5^{\circ}$)

The particle momentum distributions have not been studied in any great detail, but it is clear from Fig. 2 that most particles with momenta greater than 2 GeV/$c$ will leave through the downstream end of the solenoid. Lower momentum particles produced at small enough angles so that they also exit the solenoid should be relatively easy to identify with TOF, although a good simulation needs to be carried out to study their trajectories outside the magnetic field. Higher momentum particles produced at large angles so that they intersect the inside of the solenoid will be difficult to identify.

In any case, there are not many options. As seen in Fig. 1, the present idea is to line the inside of the solenoid with TOF counters. There is also space needed for a detector which would serve as a veto for photons which miss the LGD.

Another possible option is to use $dE/dx$ techniques to separate at least the low momentum particles within the solenoid. This in fact was used rather successfuly by the LASS collaboration [1] to identify the recoil protons, which we also need to face. For E135, the cylindrical wire chamber package around the target separated protons from $\pi^{+}$ up to around 500 MeV/$c$. This subject has in fact been recently reviewed [9, 10] but we have not yet looked into the possibilities.

## References

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