FORWARD ANGLE PHYSICS IN HALL A

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Abstract

There are a variety of physics reasons for getting to small scattering angles. An example is presented here for hypernuclear physics, where attaining high resolution at forward angles is crucial for such a program. Preliminary suggestions for one possible option using a septum and the Hall A HRS2 spectrometers is given. This note is the first step in proposing such a device for Hall A.

1 Forward Angle Physics

Because the Mott cross section peaks at forward angles, there are obvious advantages to going to the most forward angle. However when performing separations of the response functions, the backward angle dominates the time requirement. For a different class of experiments, wherein one is not looking at longitudinal and transverse (L/T) separations, there are other advantages. For example, some experiments look at small asymmetries in polarization observables. These experiments demand a large number of statistical counts and which can lead to large running times. Other experiments are trying to look at specific reactions which have very small cross sections. One example of this latter type is hypernuclear production, where reaching small scattering angles is essential.

This technical note will concentrate on hypernuclear physics, showing the feasibility of such an experimental program for Hall A in Section 2. Although I have chosen to concentrate primarily on a hypernuclear program, such a device would be useful for a variety of other experiments. Section 3 shows how such a small angle capability would enhance the experimental program for Hall A. A brief description of what such a device might look like is given in Section 4 (and in figures 2 and 3), and finally Section 5 gives a summary.

2 Hypernuclear Physics

The kaon was first discovered in the cloud chamber data of G. Rochester and C. Butler in 1946; the existence of the Λ was discovered in 1951 (also in cloud chamber data). Hypernuclei were discovered in emulsion photos in 1953 (M. Danyz, J. Pniewski).[1] In SU(3), the Λ, Σ, and Ξ are all members of the same baryon octet as the neutron and proton. Implications are that the hyperon (Y) has separate shell structure making it possible to embed the hyperon (deeply) within the nucleus, providing a probe of nuclear matter. However hypernuclear physics does not just give a minor twist.

Traditional nuclear physics looks at the properties of protons and neutrons bound in nuclei. The past several decades have been spent trying to understand "normal" nuclear matter – nuclear matter with the properties (temperature, density, volume) of infinite nuclei. More recently, efforts have been made to examine extreme nuclear matter. Hypernuclei, resulting from bound hyperons, offer new degrees of freedom.

Hypernuclear spectroscopy will measure the hypernuclear static properties (level spacings, magnetic moments, etc.) of a given nucleus. Measureing the spin-dependent ΛN and ΛNN splittings of the mean field central potential and the effective potential requires high missing mass resolution. Comparing various hypernuclei, there are indications of a smooth saturation of the binding energy; interesting because of the lack of shell dependence as well as the saturation. The collective motions of hypernuclei (vibrational frequency, the moment of inertia, etc.) just beginning to be explored offer dynamical symmetries that are forbidden in ordinary nuclei. Comparisons of Λ- to Σ-hypernuclei will explore the effects of meson exchange currents.

2.1 Kinematics and Rates

Hall A is limited to kaons with fairly high momenta; with the 28 meter flight path of the HRS, kaons with momenta less than about 2 GeV/c do not survive to reach the focal plane. This is shown in figure 1 which plots the kaon survival fraction versus drift distance for 1, 2, 3, and 4 GeV/c momenta kaons. A sample of one possible kinematics is listed here: a 4.0 GeV beam, a 2.0 GeV outgoing electron, $\theta_e = \theta_K = 6°$, and a kaon momenta of 1.8 GeV/c. The survival fraction is 15% and the kaons are detected along the direction of the virtual photon. TURTLE and TRANSPORT calculations show that the solid angle of the HRS spectrometers is reduced by a factor of 3, to 2.5 msr. The target is 100 mg of ^{12}C, and a beam current of 100μA is assumed for the rates. The cross section is taken from reference [2] for the $^{12}C(e,e'K)^{12}_{\Lambda}B(1^{-}g.s.)$; several other authors have also computed hypernuclear cross sections.[3] The rate is comparable to the zero-degree experiment in Hall C of [4] because the target thickness is $\times 10$ higher, and the current is $\times 100$ higher, since

Table 1: **A(e,e′K)$_Y$X Kinematics**

e GeV	e′ GeV	θ_e deg	θ_K deg	p_K GeV/c	$\frac{d\sigma}{d\Omega_e d\Omega_k d\omega}$ nb/sr^2/GeV	Rate Hz
4.0	2.0	6	6	1.8	2.7	0.0015

Rates assume a 100 mg target, 100 μA beam and the HRS acceptances

Table 2: **Missing Mass Resolution**
assuming a mometnum dispersed beam

Source		error
primary beam	(2×10^{-5} of 4 GeV)	80 keV
outgoing electron	(10^{-4} of 2.0 GeV)	200 keV
outgoing kaon	(10^{-4} of 1.8 GeV)	180 keV
kaon straggling	(1.7 MeV/gm-cm$^2\times$ 100 cm^2	170 kev
total:		330 keV

the present proposal is not singles rate limited. However the missing mass resolution with the HRS2 spectrometers is significantly better.

As an example of the missing mass resolution that might be achieved, a simple estimate is presented in Table 2. As has been suggested,[5]-[4] there are a number of further tricks which can be used to give small improvements. The target can be segmented to correct for straggling, as well as constrained transversely (i.e., a vertical wire) to further reduce the uncertainty in the horizontal scattering angle and get rid of beam spot size effects. It is worth repeating that the purpose of these experiments is hypernuclear spectroscopy. The most important quality of a hypernuclear setup is the missing mass resolution. Recently it has been suggested that a modification of the Hall C SOS spectrometer would give a missing mass resolution of 500 keV for that experiment[6]-[7]; the setup proposed here would do substantially better (300-400 keV missing mass resolution).

2.2 Backgrounds

The K^+ single arm rate is difficult to estimate. There is little reliable electroproduction data in this energy range to compare to, and most estimates compute the product of the virtual photon flux multiplied by a fit to the photoproduction cross section: $\frac{d\sigma}{d\Omega_K dp_K} = \Gamma \cdot \frac{d\sigma}{d\Omega_K}$,[8] meaning that photons over a wide energy range can contribute, as well as a variety of production mechanisms (*i.e.*, the decay of Φ mesons). However, using this ansatz and following the prescription in [5] gives approximately 5 nb/sr-MeV per nucleon. This would correspond to a singles rate of 520 Hz over the full acceptance or 1.3 Kaons/sec per 500 keV bin. The π^+ pion rates (1.8 KHz over the full acceptance or 5.2 Hz per 500 keV bin) and the proton rates (22.5 KHz over the full acceptance or 62.5 Hz per 500 KeV bin) are not a problem for the HRS PID systems.

The electron singles rates were computed using the codes of Lightbody and O'Connell to be .25 MHz over the entire acceptance, or 625 Hz in a 500 KeV bin. The number of accidentals (assuming a 2 ns timing window) is 0.26 (1.6×10^{-6}) Hz for the full (binned) acceptance, giving a signal-to-noise of 0.05 for the full acceptance or 10^4 for a bin of approximately 700 keV in missing mass. The π^- pion rates are small (3.2 KHz over the full acceptance or 8 Hz per 500 KeV bin) and the electron spectrometer PID should be able to handle them.

Making necessity into virtue, the big advantage for the proposed setup is that the kaon singles rates are dropping at this higher momentum, reducing the accidental rate. Additionally, as has been shown,[4] it is necessary to compute S/N with the binning in missing mass.

3 Other possible uses:

Another candidate for use of a septum is the class of experiments measuring parity violating asymmetries. These small asymmetries demand a large number of statistics, and might benefit from the larger cross sections at forward angles. However these experiments will use the HRS2 spectrometers to detect electrons in each arm, rather than one electron and one positively charged particle. The fields for hypernuclear experiments will point in the same direction; for two negatively charged particles the fields would need to be reversed.

There are two approved experiments in Hall A to examine the effects of parity violating asymmetries in electron scattering.[9],[10] The first of these[9] measures the parity violating asymmetry in elastic electron scattering from ^{4}He at a $Q^2 = 0.6$ GeV^2, in order to look for possible strange quark contributions. A 40% measurement of the asymmetry corresponds to a strangeness electric form factor with an uncertainty $\Delta G_E^s \sim 0.06$. The PAC feels "this measurement would profit from any reduction of the statistical error."[11] The electron scattering angle is 12.5° and a incident energy of 3.6 GeV is used. If the angle were decreased to 7.5 degrees, in order to keep the Q^2 the same the incident energy would have to be changed to 6 GeV. However the figure-of-merit (the asymmetry-squared times the cross section) increases by a factor of 3 here.

The second proposal[10] would gain even more. It proposes to measure the parity violating asymmetry in elastic scattering from hydrogen over a range of kinematics, although initially at $Q^2 = 0.7$ (GeV/c)^2. The measurement will be made to an accuracy of $\pm8\%$ of the Standard Model for this asymmetry, which is -1.4×10^{-5} in the absence of strange quarks. Again the PAC feels "this measurement would profit from any reduction of the statistical error."[11]

A septum could also be used in longitudinal-transverse (L/T) separations of response functions. There a septum would allow one to reach larger value of ϵ, meaning that the backward angle could also be moved forward. This backward angle is what usually determines the time required for the experiment, and moving it forward would mean a savings in time. [The assumption then is that a constant separation between the two values of ϵ would mean the same systematic uncertainty in the extrapolation. Alternatively, a greater difference in the two values of ϵ could also be achieved, meaning a smaller systematic uncertainty in the extrapolation.]

4 Description of Such a Device

Much more work is needed for a final design, but to see if a septum is worth pursuing, a quick look was made using TRANSPORT and RAYTRACE with the help of John LeRose. The septum is 85 cm long, with a field of 1.5 Tesla for a 3 GeV/c particle. The position of the septum overlaps the previous, "nominal" position of the target. The new, hypernuclear target is located 75 cm upstream of the nominal target. The septum is situated such that 14 cm are upstream of the nominal target, and 71 cm are downstream. The particles at 5° are 6.2 cm from the center of the beamline at the entrance to the septum, and 35 cm from the beamline as they exit the septum. This is important because you need to have enough room to put in a flux exclusion tube of some kind, in order to transport the beam to the dump. Then the impact of a septum should include modifications of the scattering chamber, target and the beam line just before the scattering chamber.

Attached is the transport input deck (Appendix A). Below is given the final transport matrix.

$$\begin{pmatrix} x \\ \theta \\ y \\ \phi \\ l \\ \delta \end{pmatrix}_{target} = \begin{pmatrix} -2.47 & 0.0 & 0.0 & 0.0 & 0.0 & 12.35 \\ -1.73 & -0.40 & 0.0 & 0.0 & 0.0 & 20.68 \\ 0.0 & 0.0 & -0.40 & -0.16 & 0.0 & 0.15 \\ 0.0 & 0.0 & 18.95 & 4.89 & 0.0 & -3.89 \\ 2.97 & -0.50 & 0.13 & 0.01 & 1.00 & -0.64 \\ 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 1.0 \end{pmatrix}_{septum} \begin{pmatrix} x \\ \theta \\ y \\ \phi \\ l \\ \delta \end{pmatrix}_{focal\_plane}$$

For comparison, the normal first order transport deck for the HRS is also given below. The optimization involves a different tune for the quadrupoles, which restores the essential features of the HRS (i.e., resolution).

$$\begin{pmatrix} x \\ \theta \\ y \\ \phi \\ l \\ \delta \end{pmatrix}_{target} = \begin{pmatrix} -2.47 & 0.0 & 0.0 & 0.0 & 0.0 & 12.37 \\ -1.56 & -0.40 & 0.0 & 0.0 & 0.0 & 20.73 \\ 0.0 & 0.0 & -0.40 & -0.16 & 0.0 & 0.0 \\ 0.0 & 0.0 & 5.65 & -0.77 & 0.0 & 0.0 \\ 3.2 & -0.50 & 0.0 & 0.0 & 1.00 & -0.64 \\ 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 1.0 \end{pmatrix}_{HRS} \begin{pmatrix} x \\ \theta \\ y \\ \phi \\ l \\ \delta \end{pmatrix}_{focal\_plane}$$

The resolution with the septum (to first order) is given by:

$$R = \frac{D}{M \times 2X_0} = \frac{R_{16}}{R_{11} \times 2 \times 100\mu} = \frac{12.4}{2.48 \times 2 \times 10^{-4}} = p/\delta p \Rightarrow \delta p/p = 4 \times 10^{-5}$$

for the standard HRS tune. As can be seen, the essential optics of the HRS is retained, meaning the septum is a "transparent" addition to the system. If the front quads were further moved back to the "small angle tune" the solid angle is reduced by a factor of 4.8. However, the resolution improves by a factor of 7/5 (D/M goes from 5 to 7). Such an improvement might still be useful for hypernuclear spectroscopy.

Figures 2 and 3 schematically show the conceptual setup. Figure 2 shows a birds-eye view of the spectrometer, with and without a septum. Figure 3 shows a side view of the septum, with the positions of the new and nominal targets marked.

5 Conclusions

Based on the potential for physics provided by the ability to reach such small angles as 5°, a Technical Advisory Panel would be useful to provide technical guidance on the design and the feasibility of reaching the small angles and high resolution required. Suggestions for an optics tune which might give a larger solid would be beneficial. Simultaneously, it is important to get feedback on the physics and whether such a program is worth the effort it would require. The CEBAF PAC is the most natural place to get such feedback from, in response to a Letter-of-Intent (LOI) to develop such a program in Hall A.

A collaboration between UMd, CEBAF and INFN/Rome is pursuing these avenues. It is worth noting that in order to carry out such a program it will take a larger collaboration than these two institutions; one purpose of this note is to alert potential collaborators.

References

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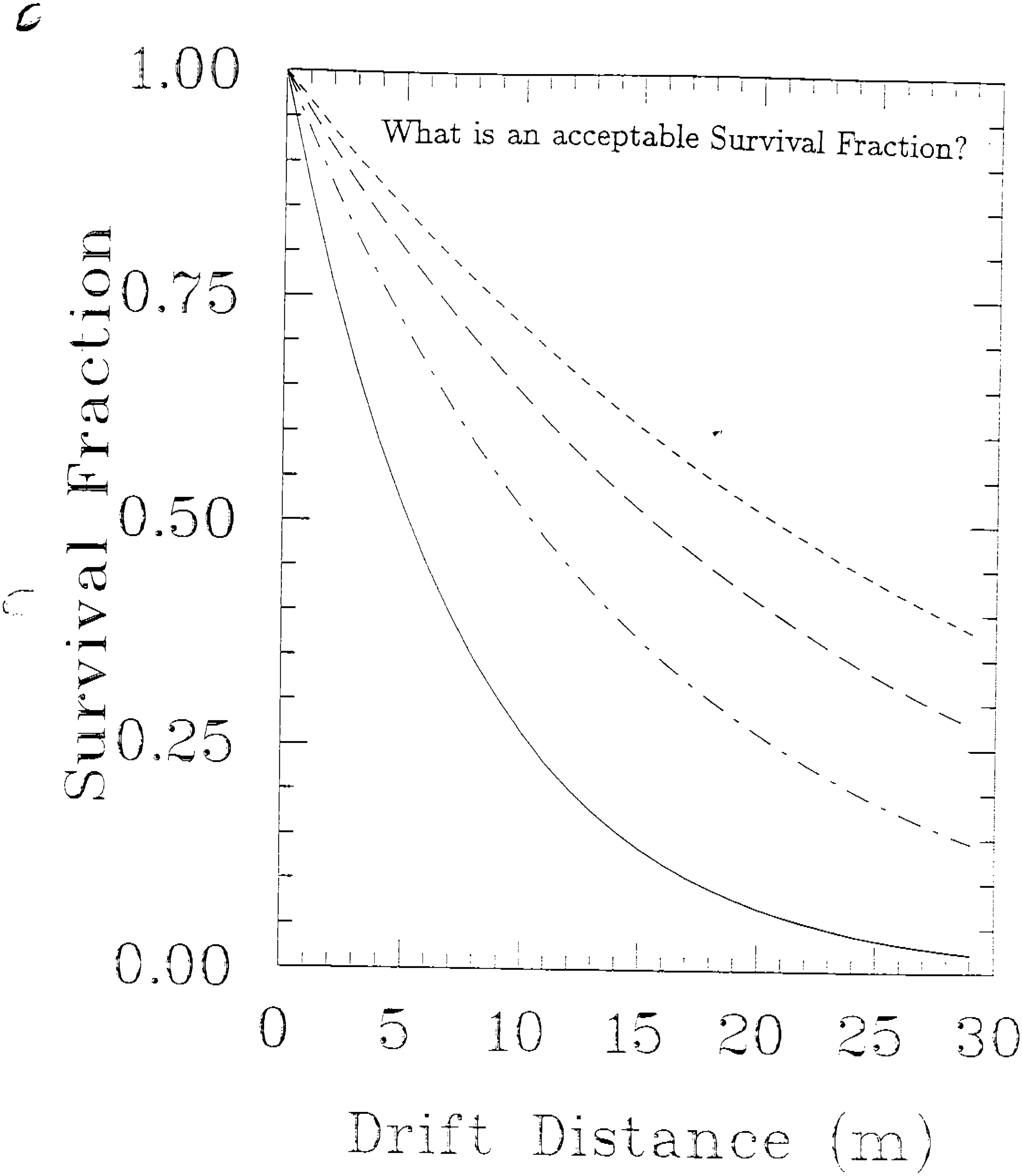
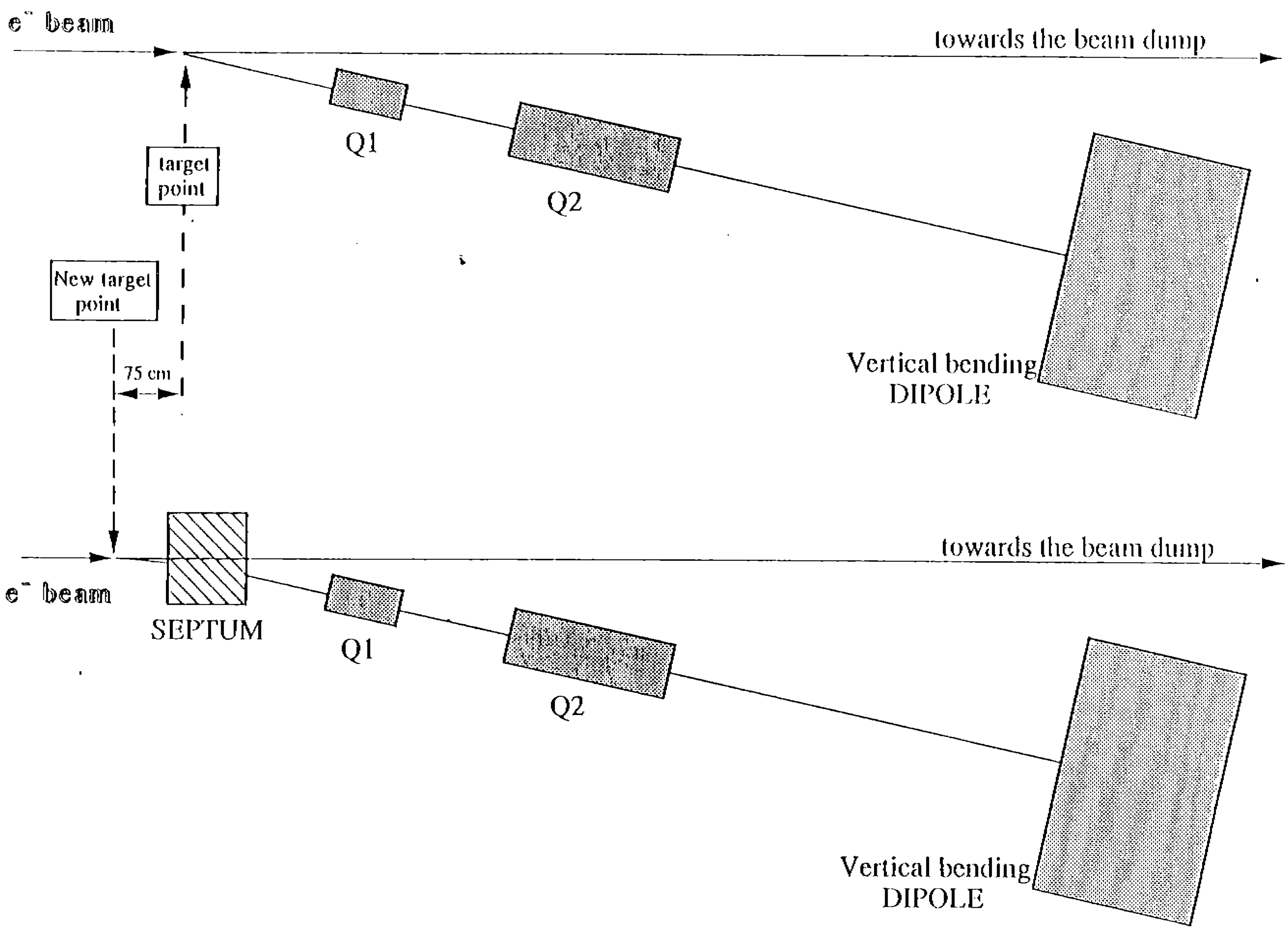

What is an acceptable Survival Fraction?
Survival Fraction
1.00
0.75
0.50
0.25
0.00
0
5
10
15
20
25
30
Drift Distance (m)


e⁻ beam
towards the beam dump
target point
Q1
Q2
New target point
75 cm
Vertical bending DIPOLE
towards the beam dump
e⁻ beam
SEPTUM
Q1
Q2
Vertical bending DIPOLE

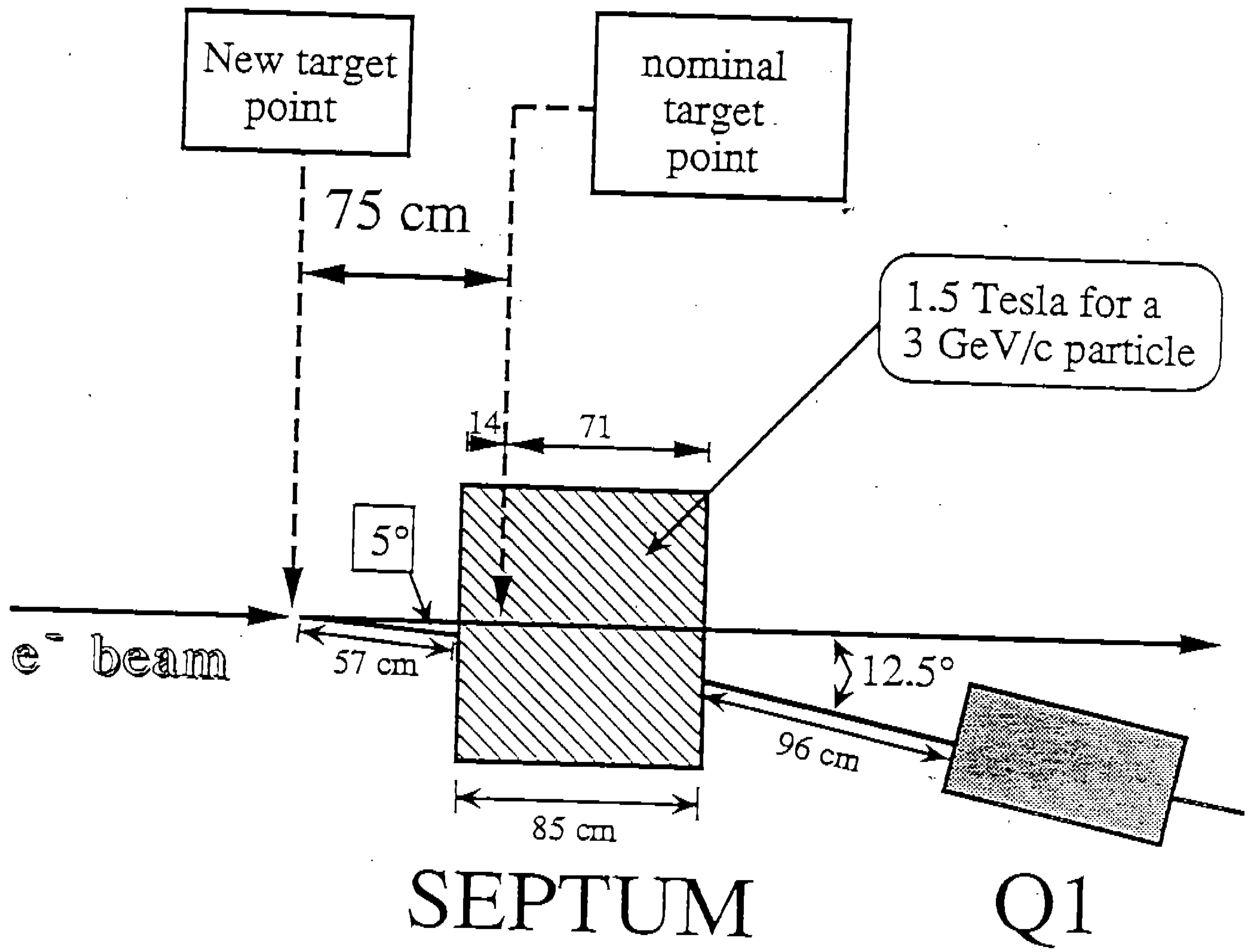

New target point
nominal target point
75 cm
1.5 Tesla for a 3 GeV/c particle
14
71
5°
e⁻ beam
57 cm
12.5°
96 cm
85 cm
SEPTUM
Q1

Table 3: **Septum TRANSPORT deck**

```
'2 GeV QQDnQ, septum added, MODIFIED 2-16-94'
0
13.0 12.; (do layout of beamline)
1. 0.01 65. 5. 30. 0. 5.00 2. 'BEAM';
16. 4. 20. ; (half aperture septum x)
16. 5. 12.5 ; (half aperture septum y)
16. 7. .6 ; (fring field k1)
16. 8. 4.4 ; (fring field k2)
3.0 0.57 'D-1'; (drift to upstream new target)
20. -90. 'ROTs'; (rotate by 90 degrees)
2. 1.30345 'rot'; (pole face rotation in deg)
4.0 0.873 10.0 'sept'; (add the septum w/o edges yet)
2. 1.30345 'rot'; (pole face rotation in deg)
20. 90. 'ROTs'; (rotate back to vertical setup)
3.0 0.96174 'D0'; (new drift to first quad)
5.01 0.8 0.45868 1. 'Q1';
3. 1.25 'D1';
18.0 .01 0.01244 1. 'SQ2';
5.01 1.78 -.16114 1. 'Q2';
18.0 .01 0.01244 1. 'SQ2';
3.0 4.41536 'D2';
16.0 12.0 0.44691 'R1';
2. -30. 'rot';
16. 4. 50. ; (half aperture dipole x)
4.00 3.32433 7.88097 -1.25 'DI';
16.0 12.0 0.;
16.0 1.0 0. 'B2';
16.0 13.0 -0.35714 'R2';
4.00 3.32433 7.88097 -1.25 'DI';
2. -30. 'rot';
3.0 1.58274 'D3';
18.0 .01 0.07815 1. 'SS';
5.01 1.78 -.15620 1. 'Q3';
18.0 .01 0.07815 1. 'SS';
3.0 3.46388 'D4';
16. 15. 55.;
3. 0. ;
16. 15. 0. ;
3. 5. ;
SENTINEL SENTINEL
```