SHMS Collimator Design

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(Dated: February 5, 2009)

A good understanding of the SHMS acceptance is essential for precision L/T separations that are proposed for 12 GeV running in Hall C. Slit systems are designed to reduce the systematic uncertainty by providing a region with a well understood acceptance. This report describes the design of the SHMS collimator and sieve slit system and presents their placement in Hall C.

I. INTRODUCTION

The currently approved 12 GeV Hall C experiments can be categorized according to their requirements for understanding the SHMS acceptance. For instance, L/T separations, such as the pion form factor of pion factorization experiments require point-to-point systematics of 0.4% in a region of fractional momentum acceptance of -15% to +10%. In contrast, the main constraint for asymmetry measurements is typically the data rate rather than the systematic uncertainty. Table I lists a representative sample of Hall C experiments and their requirements.

Experiment	Target (cm)	SHMS angles (deg)
Fpi12	8	5.5-13
Pion Factorization	8	5.5-23
R=σ_L/σ_T	15	5.5
$x > 1$	15	8-16
$g2$ (A_N^1)	40	11-15.5 (5.5-30.0)
G_Ep	30	15.7-25.0
PV LD2	40	13.5

TABLE I: *Requirements for selected experiments approved by PAC30, PAC32 and PAC34 for Hall C at 12 GeV. The L/T separation experiments are shown in red.*

The purpose of the collimator is to define a geometrical acceptance in which the spectrometer optical properties are sufficiently well understood. The acceptance depends on the fractional momentum dp/p (δ) and the effective target length. The spectrometer acceptance is characterized through event loss,

$$Acceptance = 1 - Loss, \tag{1}$$

where loss due to geometric effects, i.e., the apertures, is well understood, while the efficiency of the optical transport is more difficult to model.

The sieve slit allows for studies of the variation of optical properties over the full solid angle acceptance of the spectrometer. It allows for populating a region in the acceptance with multiple particle trajectories and their optical studies. A more detailed discussion of sieve slits and their use in the 6 GeV Hall C spectrometers can be found in Ref. [1]

II. SHMS ACCEPTANCE AND SLIT SYSTEM DESIGN

The acceptance of the SHMS is limited by well known magnet sizes and magnet gradients. Monte Carlo studies have shown that losses before the dipole are dominated by loss at the aperture of the first quadrupole (Q1). Figure 1 illustrates the δ dependence of the acceptance after the quadrupoles. Events in the red region fall outside of at least one of the nominal detector apertures. The green lines denote the acceptance determined by the nominal detector configuration [2].

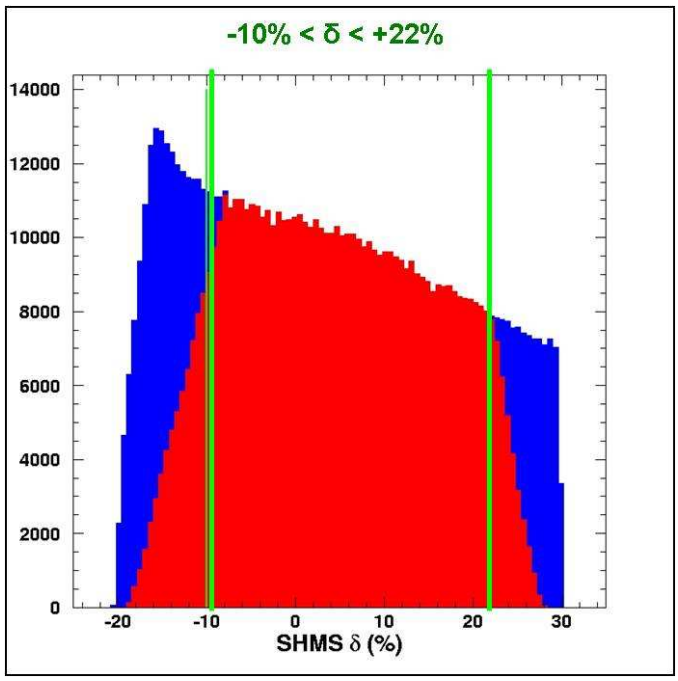


FIG. 1: *The horizontal acceptance of the SHMS. Events in the red region fall outside of at least one of the nominal detector apertures.*

As illustrated in Figure 2 there are two possible locations for a collimator/sieve slit system for the SHMS: 1) before the horizontal bender (HB), and 2) before Q1. The location before HB has advantages and disadvantages for placement of a sieve slit. On the other hand, for an aperture defining slit, the location before HB may be optimal, since one has an acceptance that can be calculated from geometry assuming that all other losses are negligible. This may not be unreasonable as the optics design assumes that perturbations due to the HB are small. The position in front of Q1 for a sieve slit has the advantage that one has midplane symmetry from there on. However, for the angles from the sieve slit, one has to rely on a separate calibration, e.g., a special calibration sieve slit before the HB.

The SHMS collimated acceptance is illustrated in Figure 3. The acceptance excludes losses before the dipole and detector geometry. The yellow and blue bands indicate the maximum δ range needed for L/T separations at positive δ. The acceptance does not change significantly between the locations at the front of the HB and the front of Q1, and thus suggests that two aperture defining collimators are not necessary.

The collimator reduces uncertainties due to optics. Events lost at the magnet apertures, e.g., event loss at Q1, is due to geometric effects, which are well understood and do not lead to any additional model uncertainties. Figure 4 illustrates the event loss at all SHMS magnet apertures.

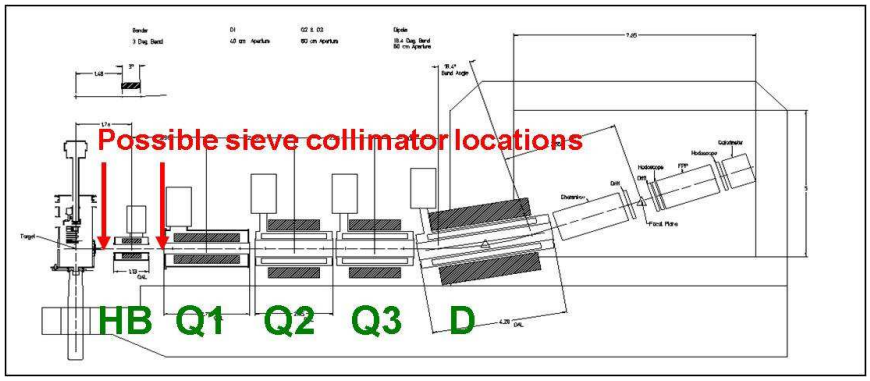
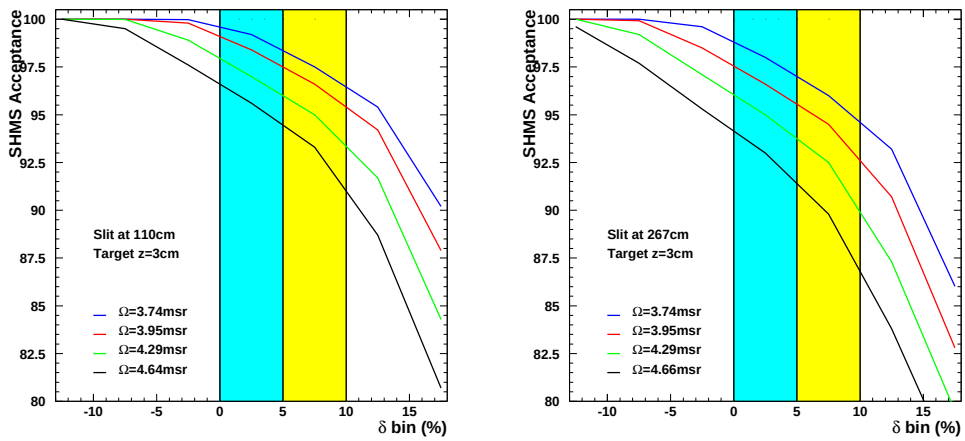


FIG. 2: *The two possible options for placing a collimator in the SHMS system, e.g., before the horizontal bender and before Q1.*



(a) *SHMS collimator before HB*

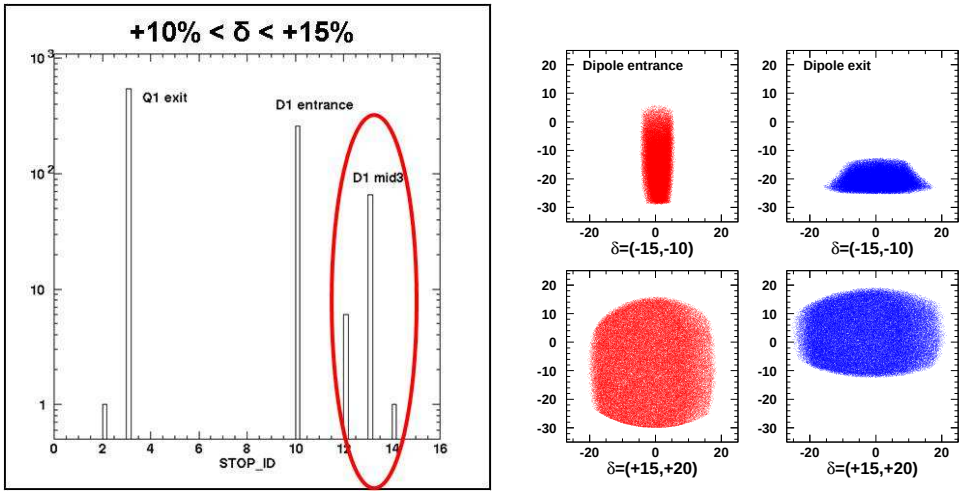
(b) *SHMS collimator before Q1*

FIG. 3: *SHMS collimated acceptance including loss at dipole entrance. An octagonal collimator was used in these studies.*

Events labeled 10-15 correspond to events lost at a dipole aperture. However, not all events lost at dipole apertures are lost due to optics effects. Indeed, the acceptance at the dipole entrance depends on both aperture and δ. Events at negative δ are, for instance, focused more as illustrated in Figure 4. Events that are lost at the dipole entrance are thus not contributing to the systematic uncertainty. Events that are lost inside the dipole, however, require a very good understanding of the SHMS optics.

Figure 5 illustrates the SHMS acceptance including losses inside the dipole and exit. Our understanding of losses inside the dipole could be improved through optics studies using actual data or precise mapping of the fields.

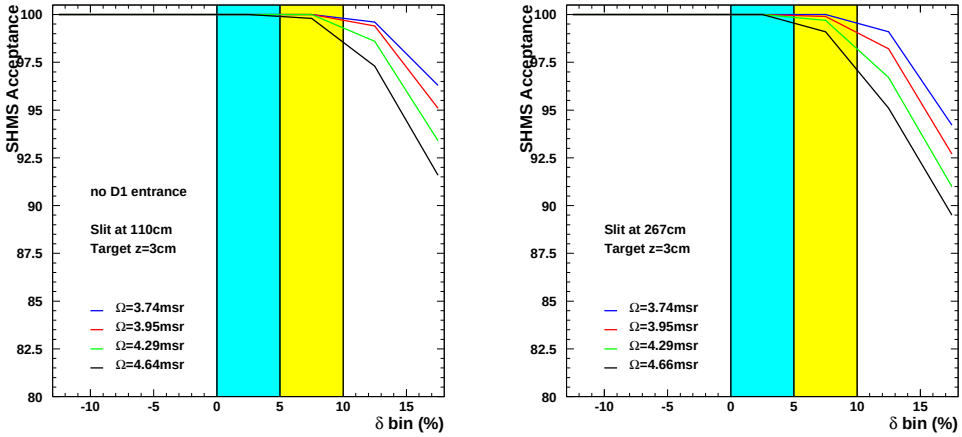
A collimator can eliminate events that would be lost inside the dipole, and thus reduces model dependent uncertainties. The size of the collimator depends, in general, on the target length. The *effective* target length for all L/T separations, which require a very good understanding of the acceptance function, is ≤ 5 cm, so a small collimator would be appropriate. For experiments, where rates are more important than systematics, a larger collimator may be more suitable. This is



(a) *SHMS event loss at magnet apertures and inside and at the exit of the dipole*

(b) *SHMS event loss at the entrance and exit of the dipole.*

FIG. 4: *SHMS event loss at magnet apertures and at dipole entrance and exit.*



(a) *SHMS collimator before HB*

(b) *SHMS collimator before Q1*

FIG. 5: *SHMS collimated acceptance including losses inside the dipole and exit. Losses at the dipole entrance are geometrical and are thus excluded.*

similar to the collimator design for the HMS, which includes two different sizes of aperture defining collimators and one sieve slit [1].

III. COLLIMATOR MECHANICAL DESIGN CONSIDERATIONS

The main mechanical constraint for the SHMS slit system are space limitations in front of the bender magnet and Q1. In both cases, the depth of the slit box is the critical dimension. For the location before Q1, the width of the slit box, and for the location before HB, the height of the slit box, are also critical. Space limitations before HB exclude the installation of a permanent slit box including both collimators and sieve slits. The optimal location for the SHMS slit system is

thus before Q1 as shown in Figure 6. The front of the collimator is then at 82 cm after the HB center or at z=258 cm from the pivot. The size of the collimator at this location is ± 14.2 cm high and ± 7.7 cm wide.

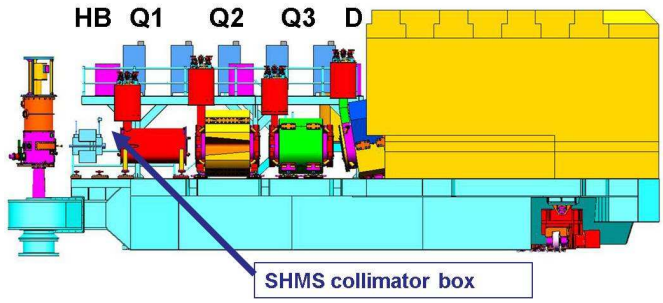


FIG. 6: *Placement of the SHMS slit box before Q1.*

In order to conform to the limitation in the width before Q1 (35 cm is the maximal width possible), the guiding rods with tooling balls would be installed on top and bottom instead of the back or the sides as done in the HMS design. This design reduces the required width by 8 cm as illustrated in Figure 7, and increases the depth to 13.4 cm. The details of the slit box dimensions are summarized in Table II. This design has the additional benefit that the slit box can be inserted vertically rather than at a 45° angle, which would complicate the alignment, in particular for the sieve slit studies. The slit box will be remotely controlled. It will move horizontally from SHMS left towards the beam axis, and will include a mechanically surveyed stop on the SHMS right side.

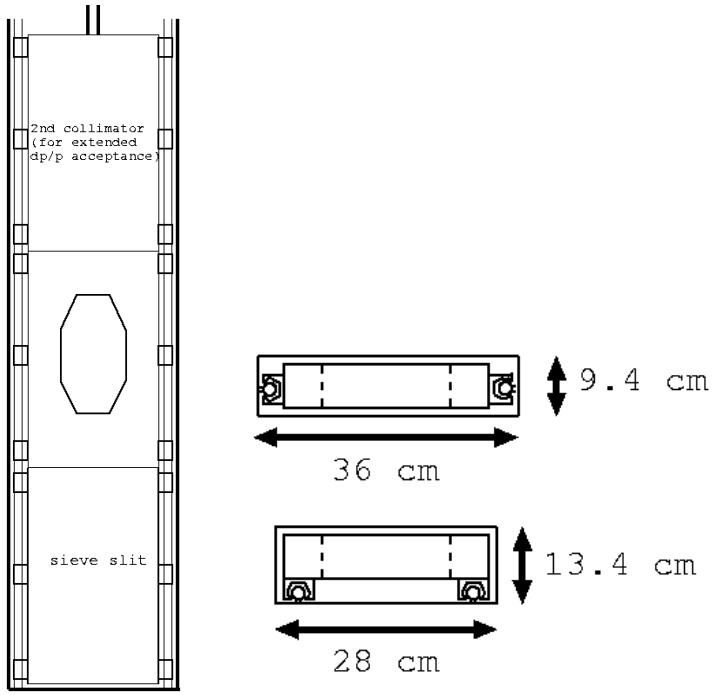
Type	Thickness (cm)
Box material thickness	0.9
Empty space for motion	0.6
Collimator thickness	6.4
Rod/tooling ball space	4.6
Box/material thickness	0.9
Total depth of slit box	13.4

TABLE II: *Contributions to the total depth of the SHMS slit box.*

The collimator box will contain two octagonal collimators of different size and a sieve slit. The octagonal collimators will be made of 6.4cm thick heavymet [3]. The total amount of heavymet material is at least 40cm by 25 cm per collimator assuming ± 5 cm. The sieve slit will be made of the same material and would be 3.2 cm thick.

IV. SPECIAL CALIBRATION SIEVE SLIT

Standard optics calibrations of the SHMS can be done with the sieve slit before Q1. Preliminary simulations show small distortions of the mid-plane symmetry. The size of the sieve holes



(a) *SHMS slit box design* (b) *Options for guiding rods and tooling balls*

FIG. 7: *The mechanical design of the SHMS slitbox.*

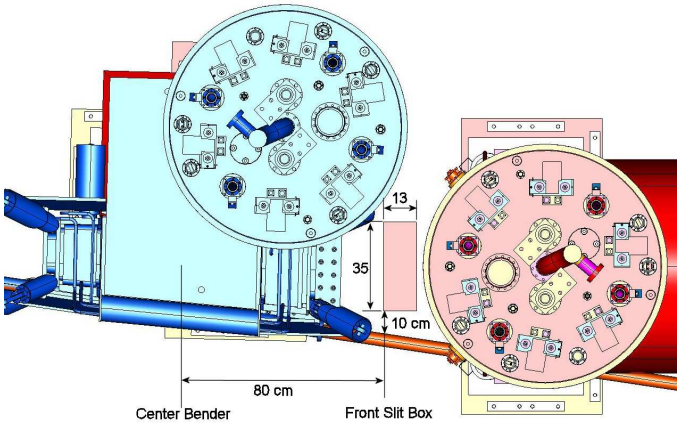


FIG. 8: *SHMS slitbox in Hall C. The front of the slit box is located at 80 cm after the HB center or at 256 cm from the target center. This location is sufficiently far away from the HB to have the minimum contribution to stray fields. The HB gap is 35 cm by 36 cm.*

can be 3 mrad, which does not pose any technical challenge. The HMS sieve holes diameter is 0.504 cm (3 mrad) [1]. Further studies will optimize the sieve hole distances and their sizes.

For additional optics calibrations, a special sieve slit could be temporarily inserted before HB. The focal plane pattern of such a sieve shows a strong δ dependence of the bending. This

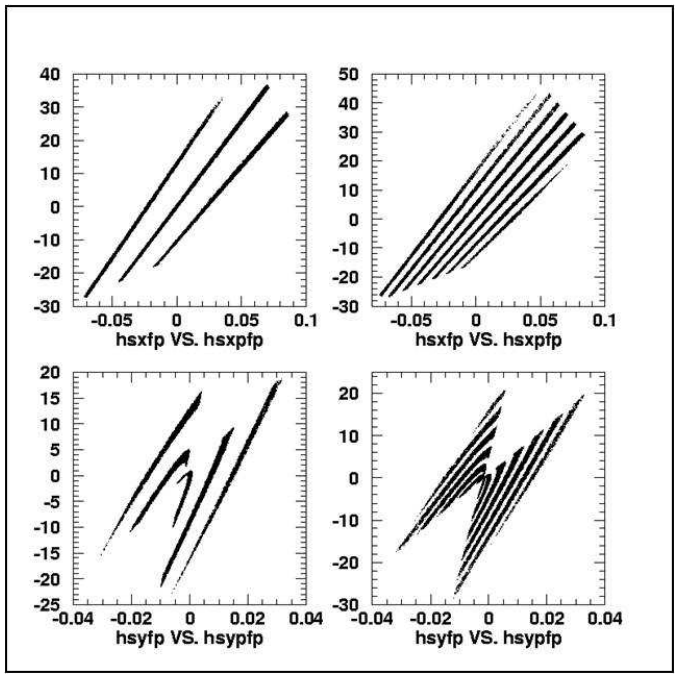


FIG. 9: *SHMS sieve slit simulations*

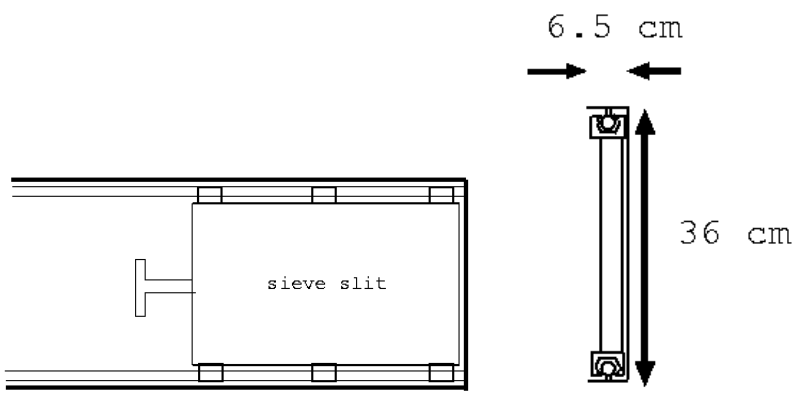
special sieve slit would be located at 56 cm in front of the HB center or at 120 cm from the pivot. The active area of the sieve would have to cover at least ± 6.6 cm in height and ± 3.6 cm in width for a point target.

The special sieve slit would be made of heavymet and would weigh about 40 kg assuming dimensions of 30cm by 25 cm (width by height). Since it is relatively light, the additional sieve would be movable by hand. It would move from SHMS left towards the beam axis and would only be inserted for special calibration runs. It would not be part of the spectrometer vacuum system.

In order to conform to the limitation in the width before HB, the guiding rods with tooling balls would be installed on top and bottom. This design results in a height of the sieve slit as shown in Figure 10. The detailes of the additional sieve slit dimensions are summarized in Table III.

Type	Thickness (cm)
Thickness of guide before sieve	0.5
Sieve slit thickness	3.2
Rod/tooling ball thickness	5.1
Thickness of guide after sieve	0.5
Back wall material thickness	0.9
Total depth of slit box	6.5

TABLE III: *Contributions to the total depth of the SHMS additional sieve slit box.*



(a) *SHMS slit box design* (b) *Options for guiding rods and tooling balls*

FIG. 10: *The mechanical design of the special SHMS sieve slitbox.*

Type	Thickness (cm)
Wall thickness	0.9(x2)
Rod/tooling ball thickness	4.6(x2)
Sieve slit height	25.0
Total depth of slit box	36.0

TABLE IV: *Contributions to the total height of the SHMS additional sieve slit box.*

V. ALTERNATIVE OPTICS CALIBRATION TECHNIQUES

Alternative spectrometer calibration methods are also being discussed. One method could be to use the ^{1}H$(e, e'p)$ reaction, where the proton would be detected in the HMS. However, this method has the limitation that the reaction could not be used any longer as a check of the optical properties.

VI. CONCLUSION

A slit system provides a small region of spectrometer acceptance that is well understood. High precision L/T separation experiments approved for Hall C at 12 GeV require a very good understanding of the acceptance function, and thus a slit system is essential. The optimal solution for the SHMS slit system consists of two different size aperture defining collimators and a sieve slit installed before the first quadrupole. A special calibration sieve slit can be inserted manually in front of the horizontal bender.

[1] H. Blok, T. Horn, *et al.*, Phys. Rev. **C78**, 045202 (2008).

[2] The δ acceptance changed slightly after the horizontal bender magnet was added. Good coverage was determined for -10% to +22% in δ. However, a limited amount of events is lost due to detector cuts below -8%.

[3] heavymet consists of 90% tungsten and 10% CuNi and has a density of 17.0 g/cm^3