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Experiment 787
Technical Note No. xxx

Some Studies of LESB3

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Abstract

This technote describes some studies of the performance of LESB3. It documents some of the C-line, C-target and LESB3 instrumentation and changes to that instrumentation. It also records some of the performance based on the scaler records from the end of each run in 1995–7.

<u>Outline</u>

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Target	date	material	width (in.)	height (in.)	length (cm)	segments	comments
T-95	5/12/92–6/5/95	Pt	0.2	0.4-0.15	6	3	TC in base
T-107	6/5/95–3/1/96	Pt	0.2	0.4-0.15	6	1	cracks
T-109	3/1/96–3/26/96	Pt	0.2	0.15	6	5	EB weld
T-111	3/26/96–3/29/96	Cu	0.2	0.15	8.9	5	no good
T-95	3/29/96–5/30/96	Pt	0.2	0.4-0.15	6	3	
T-112	5/30/96–present	Pt	0.2	0.25-0.05	6	6	

Table 1: E787 Targets

1 Kaon Flux

A special set of LESB3 studies were done on May 27-9, 1995. This data was collected specifically for comparison of the LESB3 performance to that expected from the design of the beam. These studies are documented in the LESB3 NIM paper. They generally were done in conditions unlike our standard running conditions; so this technote focusses on the standard running conditions.

1.1 C-line Instrumentation

An SEC (Secondary Emission Counter) was placed in the C-line, upstream of the C-target in 1992. This counter was calibrated on June 29, 1994; the calibration was found to be 1748/Tp. We take the calibration constant to be 1800 counts/Tp. A new C_{SEC} was installed during the shutdown between the 1995 and 1996 runs. This new SEC has the improved feature of being able to be moved both horizontally and vertically by remote control. C_{SEC} pump failure on 4/24/96, repaired.

Between the SEC (C_{SEC}) and the target, mounted to the target is a flag. The flag has a phosphor that is activated by the proton beam.

There is a telescope of 1/4" by 1/2" scintillators, the so called C-tel, or 90° monitor, monitoring the flux of protons hitting the C target. The C-telescope is situated about 1 m from the target, with a hole in an iron plate allowing access to the target. The hole in the iron is filled with 1"×0.7"×26" brass collimator with a 1/4" by 1/4" hole. The C-tel or 90 degree monitor was modified before the 1996 run; the scintillator was reduced in cross section to 1/8" by 1/8". The brass collimator was removed on March 3, 1996. The counters were realigned on March 7, 1996. On July 19, 1992 an attenuator of 4 mm Pb and 7.5 mm Al was installed in front of the telescope port. On June 7, 1995 an additional 3/8" Al was added and removed.

There was also an ionization chamber during the 1995-6? run. The gain was reduced to ×1 from ×10 on June 7, 1995 (HV=1100V).

1.2 C-target

A summary of the targets used by e787 since the installation of LESB3 is given in Table 1. The first target was used during 1994–5 it was Pt on a Cu base (T-95; w = 0.2" h = 0.4-0.15" l = 6cm, with 2 slots and TC at base of Pt. Made/installed May 12, 1992. The height was 0.4", but 0.15" were imbedded into a groove in the Cu.). A new Pt target, (w = 0.2" h = 0.4-0.15" l = 6cm; T-95) with no slots and one new (fast) and one old thermocouple near the top of the target (and one at the base) was installed on June 5, 1995. Visual inspection of this target via a telescope at the 90° port showed vertical and horizontal cracks after the 1995 run. At the beginning of the 1996 run a Pt target that was electron beam welded to the Cu base was installed (w = 0.2" h = 0.15" l = 6cm; 5 slots). We had evidence of a failure at the interface. This target was removed and a Cu target (T-111; w = 0.2" h = 0.15" l = 3.5"; two thermocouples in seg #2-3.) was installed on March 26, 1996. Even with extensive tuning by Phil, I-Hung and Kelvin it proved to be impossible to achieve comparable K/π and Ck/C_{SEC} ratios with the Cu target. This target was removed and the original 1994–5 target was reinstalled on March 29, 1996. A new target was installed on 5/30/96 (Cpt_4; T112: Pt w=0.2" h=0.25"-0.05" l=2.4") with separated thermocouple on the beam left side in segment #3 (6 segments, std thermocouples in seg #2, #3 right). This target was used for the entire 1997 run also.

1.3 Protons on Target

The total flux of protons on the C target, as measured by the C_{SEC} assuming a calibration of 1800 counts/Tp is shown in Figure 1 along with the total KB_L for the years 1995–7.

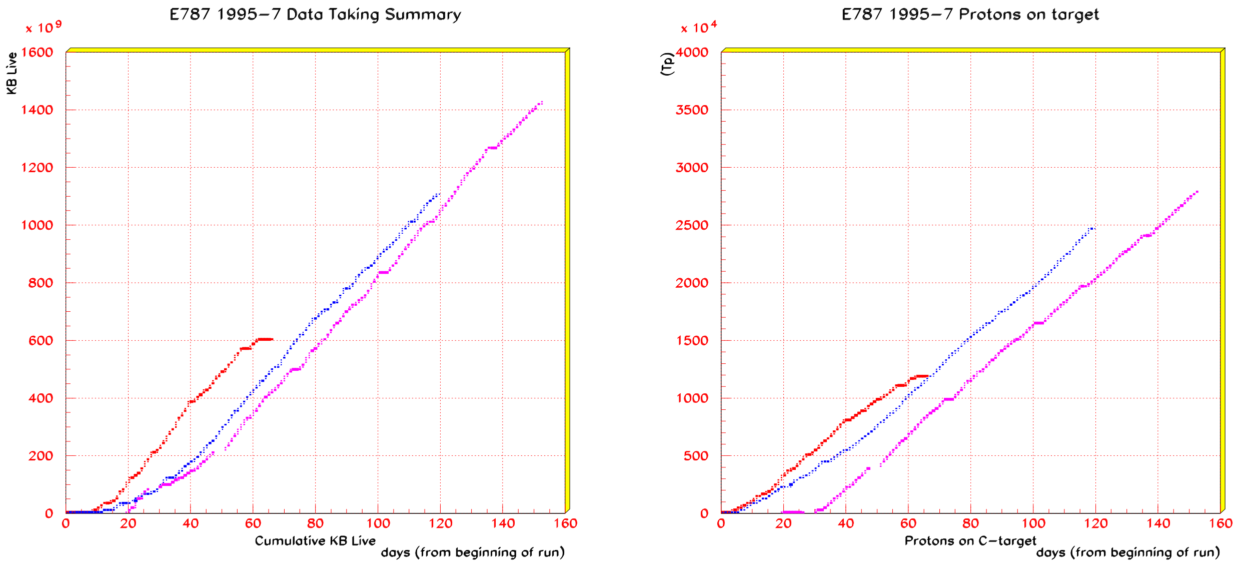

Figure 1: Total KB_L and Tp for e787 1995–7

1.4 C_{SEC} efficiency

A horizontal sweep of the new SEC on March 9, 1996 (after 5×10^4 Tp) showed the response of the SEC to be flat to better than 2% over the range of the sweep (from 1–6.5V; 1.4V/in; ~4 in. sweep). The response was measured by measuring the C_{SEC}/C-tel ratio. A sweep on 6/6/96 showed an apparent loss in efficiency of the C_{SEC} of 17% (both horizontal and vertical sweeps) at the nominal position of Hor=3.95V, Ver=4.75V (see Figure 2). However, these sweeps also

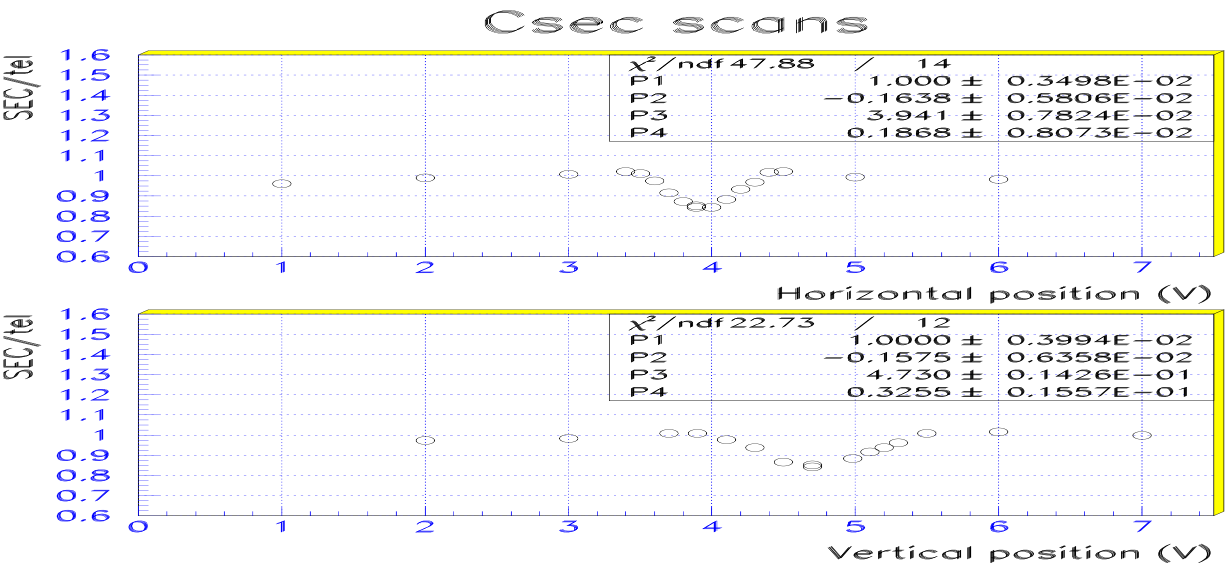

Figure 2: Horizontal and vertical C_{SEC} sweeps on June 6, 1996

showed an apparent drop in efficiency at the extreme setting of 1V and 6V. The most probable explanation is an increased efficiency in the region around the beam and a decreased efficiency in the center of the beam spot. We should therefore conclude that the actual drop in efficiency as of 6/6/96 was 15% (with 2×10^7 Tp). The fits show a constant term, and the parameters of a gaussian (height,mean,width). The width of the depleted area is larger in the vertical dimension; this is due to the stronger vertical focussing at the C-target. The C_{SEC} is 60xxx" upstream of the target. Approximately 13 measurements were made during the 1996 run from day=6–100. The apparent loss in C_{SEC} efficiency was 15% for 2×10^7 Tp. A fit to the 1996 and 1997 inefficiency measurements gives a loss of 7.7%/10^7 Tp (see Figure 3). By the end of the 1996 run, after 120 days and 2.5×10^7 Tp we expect that the efficiency would have fallen by 19%, to 81%.

During the 1997 run a horizontal sweep on 5/4/97 showed an apparent efficiency at the normal beam location of 75%, corrected to 77%. A horizontal sweep on 5/31/97 showed an efficiency of 69%, corrected to 71% and a vertical sweep showed an efficiency of 70%. During the 1997 run we estimate that the efficiency fell from 81% to 70%. A 17% drop for 1.2×10^7 Tp. This may imply that the rate of efficiency loss has increased, but is probably also consistent with a constanst loss.

We do not know the efficiency in 1995. We believe that the SEC was installed at the beginning

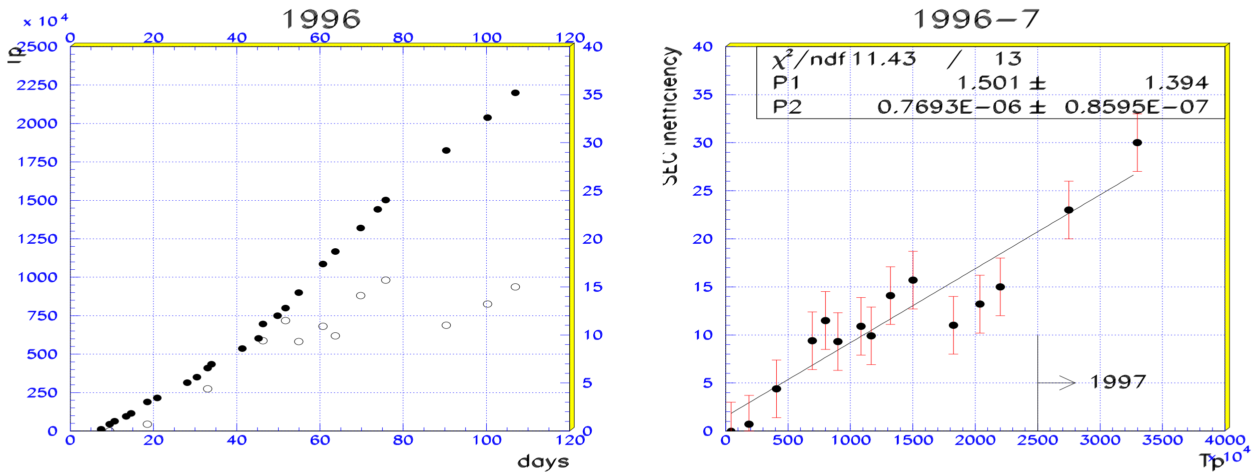

Figure 3: a) Total Tp for e787 in 1996, with C_{SEC} efficiency loss. b) Fit to SEC inefficiency vs total Tp for 1996–7.

run	date	$\epsilon_{C_{SEC}}$
22200–23600	3/06–5/16/95	80%
30500–32400	4/05–6/08/96	92%
34400–34900	4/23–5/12/97	77%
35000–35250	5/16–6/02/97	72%

Table 2: Estimated C_{SEC} efficiency.

of the LESB3 comissioning in 1992. The 1992 run was 4 weeks (July 1-31, 1992) and we assume that we took 5 Tp/spill for a total of 2×10^6 Tp. E787 did not run during 1993 (the proton run was 10 weeks), but if beam was skipped over the target there may have been 5 Tp/spill (in a different part of the SEC?). The total 1993 exposure may have been 5×10^6 Tp. During the 1994 run (May 1 - July 30, 1994) e787 may have taken 5-10 Tp/spill. For the first 8 weeks we can probably assume 5×10^6 Tp. At this time, June 29, 1994, the SEC was calibrated; with a calibration constant of 1748/Tp. E787 probably accumulated an additional 3×10^6 Tp over the final month of 1994 after the calibration. Based on an exposure of 1.2×10^7 Tp for 1992–4, before the calibration (this is likely to be an overestimation) and an assumed efficiency loss of 15% per 2×10^7 Tp we would expect a 9% loss in efficiency. Therefore an absolute calibration of a fresh SEC would be expected to give 1748*1.09 = 1905/Tp. The expected efficiency loss after the calibration is 2%. During the course of the 1995 run, after almost 3×10^7 Tp, we would expect an efficiency drop of 22%. At the start of 1995 the efficiency was presumably 89% (9+2% loss). At the end of the run the efficiency was presumably 67%.

For use later, we will estimate the C_{SEC} efficiency at 4 periods (see Table 2).

1.5 Ck/C$_{SEC}$

A plot of the kaon yield (Ck) per proton (C$_{SEC}$, uncorrected) is shown in Figure 4, along with a plot of the absolute Ck rate. The 1995 run extended from run 20000–24500; the 1996 run extended from run 29000-33000; and the 1997 run extended from run 33400-35250. One of the most dominant

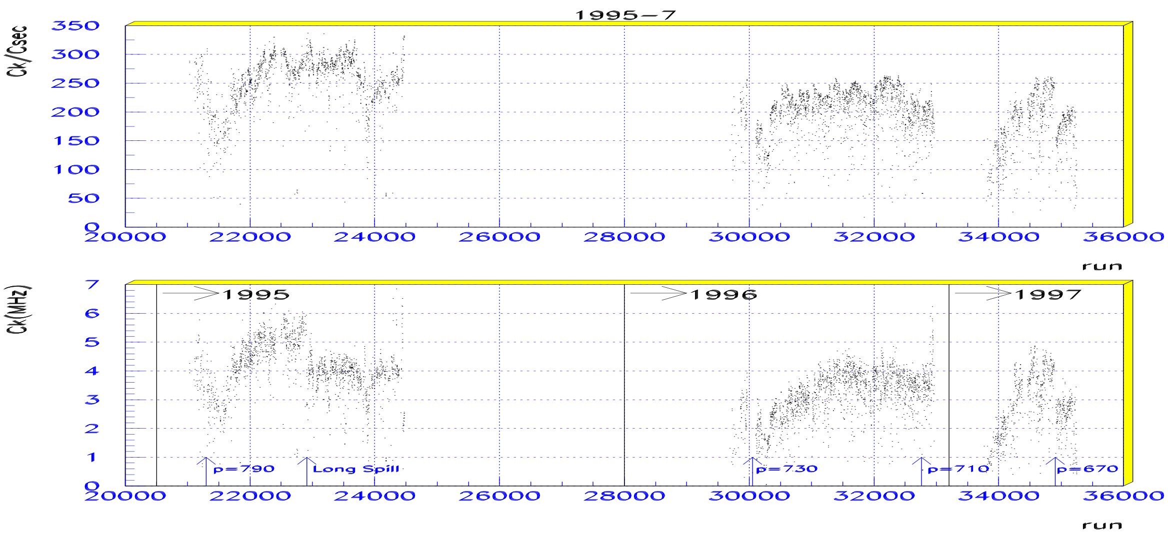

Figure 4: Kaon Yield: per C$_{SEC}$ and per second

features is the the increase in Kaon yield at the start of each running period. The drop at run 30000 occurred when the kaon momentum was lowered from 790 MeV/c to 730 MeV/c, and then a Cu production target was installed. The drop at run 32760 was when the kaon momentum was lowered from 730 MeV/c to 710 MeV/c. The drop at 34924 was from lowering the kaon momentum from 710 MeV/c to 670 MeV/c. The high rates before run 22935 are due to the short spill length (1.2 seconds, which was then increased to 1.6 sec).

The drop in yield at run $\sim$ 23600 is, as of yet, unexplained. It is however quite likely that this drop is from skipping part of the beam over the C-target to provide more beam to C-3. (There were other apparent changes in the tuning of the upstream C-line also.)

It is interesting to note that the Ck/C$_{SEC}$ ratio at the end of 1995 (790 MeV/c) was $\sim$250. At the peak of 1996 (730 MeV/c) running, run 32200 we had almost achieved the same ratio of 250. At the peak of 1997 (710 MeV/c) running, run 34700, we had again almost achieved the same ratio of 250. We were perhaps somewhat misled by the decreasing SEC efficiency into thinking we had kept the same **Ck** at the lower momentum (This would imply an increase in KB of almost 40% per proton.) Clearly by 670 MeV/c we had begun to lose some Ck, but we had less time to tune the beam at this momentum.

	Momentum			
	670	710	730	790
date	May 22, 1997	May 11, 1997	April 26, 1996	April 26, 1996
Logbook	LB7p21	LB7p09	LB6p53	LB5p23
K/π	3.6	4.8	3.9	3.5
KB/Ck	0.271	0.251	0.225	0.187
Ck/C_{SEC}	206	258	236	304
$\times\epsilon_{C_{SEC}}$	148	199	217	243

Table 3: LESB3 performance.

1.6 Beam tuning

Separator HV curves Beam LB5p7.

The tuning of LESB3 is summarized for each of the four momenta in Table 4. A summary of the performance of the beamline at each of these momenta is given in Table 3.

1.7 LESB3 Acceptance

The acceptance of LESB3 has been modelled using the Sanford-Wang kaon production cross section and the TURTLE ray tracing program. The production angle is 0° with the acceptance extending to ±12.5°. A plot of the kaon production and acceptance as a function of angle is shown in figure 5.

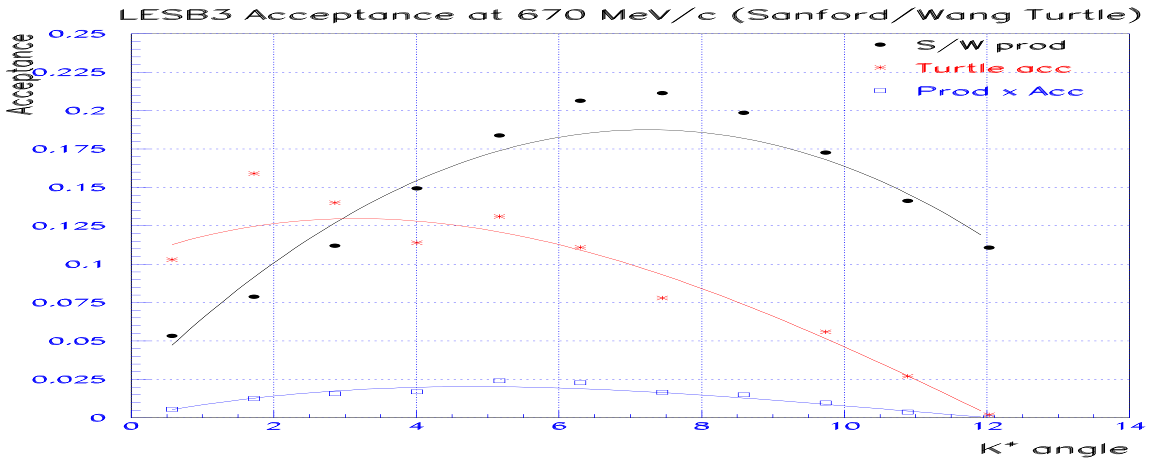

Figure 5: LESB3 Accpetance vs production angle

A table summarizing the kaon production/acceptance, including the increased accptance at lower momentum from opening the mass slits is provided in Table 5. We have assumed that the peak of the kaon distribution retains the same location in the mass slit. The table includes some spectulation

element	Momentum 670	710	730	790
Q01	2660	2834	2914	3155
Q02	1962	2090	2151	2286
D01	1950	2119	2200	2506
O01	1500	1237	1272	1378
K01	2670	2670	2670	2670
K02	2380	2380	2380	2640
K03	2050	2050	2050	2050
K04	2689	2689	2689	2689
S01	1250	1650	1355	1469
BS1	3015	3070	3020	2893
S02	1600	1811	1246	1351
Q03	2750	2914	3027	3424
Q04	2000	2173	2235	2520
K05	2716	2716	2716	2716
K06	2810	2810	2810	2810
K07	2637	2589	2604	2572
K08	2578	2530	2521	2515
Q05	3375	3600	3775	4000
S03	700	1024	1053	1141
Q06	2750	2950	3017	3283
BS2	1550	1507	1617	1620
Q07	3245	3460	3493	3757
Q08	2270	2510	2676	2899
K09	2742	2742	2688	2668
K10	2597	2597	2501	2461
D02	2910	3118	3201	3514
K11	2317	2277	2155	2180
K12	2097	2097	2077	2300
Q09	1795	1775	1838	2091
Q10	2150	2340	2332	2525
Sep 1^+	275	300	300	275
Sep 1^-	-300	-300	-300	-300
Sep 2^+	260	260	260	250
Sep 2^-	-260	-260	-260	-275

Table 4: LESB3 Tunes.

$\|\vec{p}\|$ MeV/c	SW prod×acc	MS acc msr-%	Total Acc	decay %	Calc. K^+	Meas. K^+ Ck/C_{SEC}	4-Jaw mm	mm	mm	mm	MS1 mm
790	0.1506	35.1	1.000	5.55	227.0	227±14	6.69	6.59	2.04	6.81	2.72
730	0.1471	39.0	1.085	4.38	179.5	204±11	6.69	6.59	2.04	6.81	3.29
710	0.1458	40.4	1.114	4.01	164.1	177±12	6.69	6.59	2.04	6.81	3.20
670	0.1430	44.8	1.212	3.31	139.0	134±9	6.69	6.59	2.04	6.81	4.64
625	0.1396	55.1	1.454	2.59	121.7						
600	0.1375	65.4	1.700	2.22	117.3		7.24	7.24	7.24	7.24	4.64

Table 5: LESB3 Acceptance: Sanford-Wang/TURTLE

about possible increased acceptance at lower momentum from opening the 4-Jaw collimator. We can see that the kaon production from Sanford and Wang, integrated over the LESB3 acceptance is not falling with $|\vec{p}|$ but with something closer to $|\vec{p}|^{1/3}$.

1.8 Proton Beam tuning

The targetting of the proton beam on the C-target can have significant impact on the LESB3 tune. A study of the size of the proton beam on the C-target was made on March 13, 1996. The measured beam diameter was 0.082". Questions have arisen as to the effects of an even larger spot size, as e787 takes more of the total AGS beam. In particular, there is a question as to the K/π ratio for a larger vertical spot size.

1.9 Kaon Yield

From Figure 4 we can see that we had long periods of time to develop stable tunes for 790 and 730 MeV/c. This is not the case for 710 and 670 MeV/c. It seems quite natural to select the period from run 22200–23600 for 790 MeV/c. Likewise for 730 MeV/c, runs 30500–32400. We ran at 710 MeV/c from run 32760–34900 and at 670 MeV/c from 34924–35250. At 710 MeV/c we have quite different behavior in 1996 (runs 32760–32999) than in 1997 (runs 33720–34900). We have chosen the period 34400-34900 to represent the 710 MeV/c data. We simply do not have much data at 670 MeV/c and we did not get much time to tune the beam. We chose to use runs 35000-35250.

Plots of the ratio of Ck/C_{SEC} for each of our momenta are shown in the following figures (we plot the value for all runs, the value for the selected runs and a fit for the selected runs): Figure 6 shows the values for 790 MeV/c, Figure 7 shows the values for 730 MeV/c, Figure 8 shows the values for 710 MeV/c, Figure 9 shows the values for 670 MeV/c.

If we look at the periods after some beam tuning was done at each momentum and measure the Ck/C_{SEC} ratio and then correct for the C_{SEC} efficiency we get the kaon yield per proton. This is summarized in Table 6.

Naively, the expected yield of kaons per proton should fall with a factor of $|p|$ for the kaon production cross section and a factor of $|p|$ for the beam line momentum acceptance and a factor for

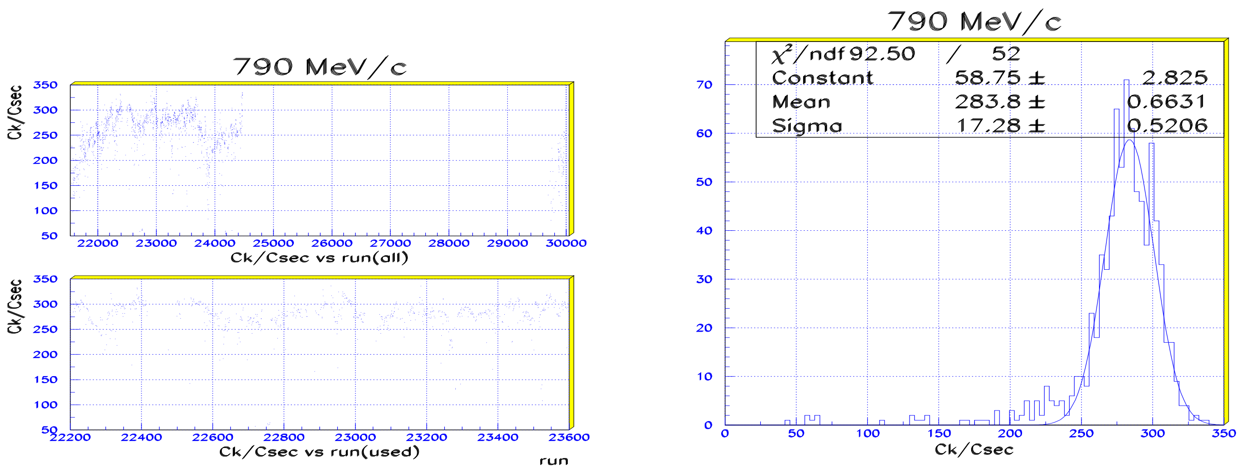

Figure 6: Ck/C$_{SEC}$ at 790 MeV/c

$\lvert\vec{p}\rvert$ (MeV/c)	runs	ϵ_{SEC} (%) est	Ck/C$_{SEC}$ meas	Ck/C$_{SEC}$ corr	Ck/C$_{SEC}$ calc
790	22200–23600	80±5	283.8±0.60	227±14	227
730	30500–32400	92±5	221.6±0.56	204±11	155
710	34400–34900	77±5	230±2.36	177±12	135
670	35000–35250	72±5	186.4±1.01	134±9	100

Table 6: Measured kaon yields.

the larger number of kaons decaying at lower momentum. (The decay factor, relative to 790 MeV/c is: 0.76 at 730 MeV/c, 0.69 at 710 MeV/c, and 0.55 at 670 MeV/c. It is given by DF = exp(-2342/p) for the 17.6m from production target to Ck.) From the fit to the Sanford-Wang production, we see that the actual kaon production goes as $|\vec{p}|^{0.33}$ and the reduced momentum bite is compensated by the increased mass slit opening, giving a K$^+$ yield that goes as $|\vec{p}|^{-0.21} \times \exp(-2342/p)$.

$$Ck/C_{SEC} = 18,090 \times \exp(-2342/p) \times p^{-0.21} \tag{1}$$

whereas if we fit our data points to the same functional form we find

$$Ck/C_{SEC} = 7028 \times \exp(-2342/p) \times p^{-0.06} \tag{2}$$

as compared to the theoretical calculation (for 17.6m) of

$$Ck/C_{SEC} = \exp(-2342/p) \times p^2/104 \tag{3}$$

The two different relations can be seen in Figure 10.

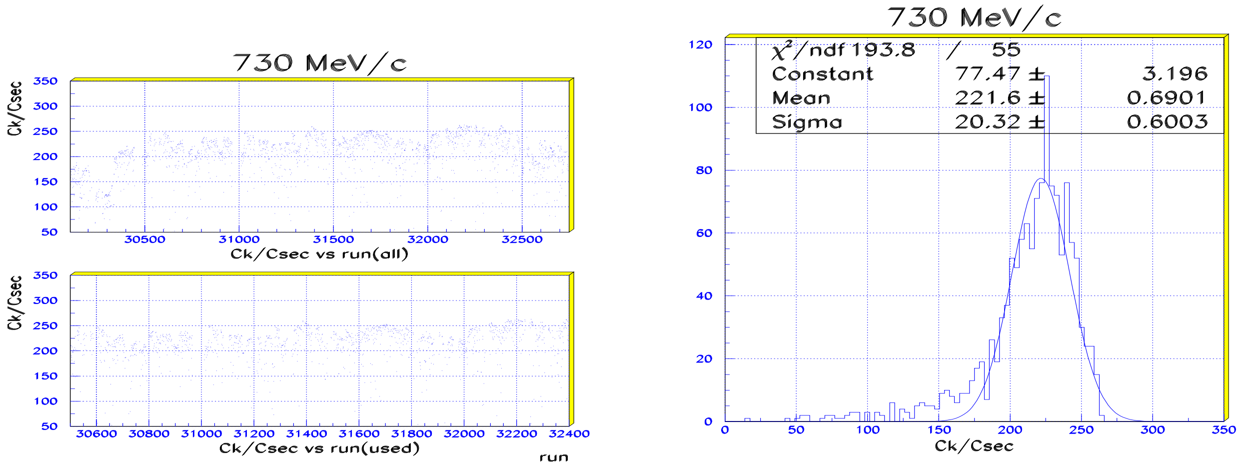

Figure 7: Ck/C$_{SEC}$ at 730 MeV/c

2 Stopping Fraction

A few words about terminology. In principle, the concept of a stopping fraction is simple: the number of stopped kaons divided by the number of incident kaons. In practice it is more complicated. Online we measure KB/Ck, and often call this our stopping fraction. Offline we define a quantity F$_S$, which is a correction to KB, to get the actual number of stopped kaons. Two major effects that F$_S$ accounts for are kaons that decay after the Cherenkov counter, with a daughter satisfying the B4 and TT requirements and kaons that deposit energy in B4 and TT, but exit the target without stopping. Sometimes we call F$_S$ the stopping fraction. I prefer to call KB$\times$F$_S$ the stopping fraction. The function of F$_S$ is to change the normalization of our experiment from KB$_L$ to the $K^+ \to \mu^+ \nu_\mu$ branching ratio.

2.1 Beam Line Detector elements

New NMC paddle 6" by 6" by 1/16" installed on 4/13/97 (integrating circuit).

The Cherenkov counter, a so-called Fitch counter, is a Lucite radiator, with two rings of 14 PMT's. The 14 π tubes are at a smaller radius and detect π^+ Cherenkov light that is totally internally reflected within the Lucite. The 14 K tubes detect K$^+$ Cherenkov light that is transmitted through the downstream face of the radiator and collected by a mirror which reflects the light to the outer ring of K tubes. The mirror for reflecting the kaon Cherenkov light to the PMT's was designed to operate at 800 MeV/c. It was calculated that the counter should operate at 99.9% efficiency from 730 MeV/c to 860 MeV/c. At the start of the 1997 run a new mirror was installed to operate at 680 MeV/c with the 99.5% efficiency points at 650 and 710 MeV/c.

The B0 counter is a 1/4" plastic scintillator 12" by 3". It was installed for the entire 1997 run, only the beginning of 1995, and most of 1996?.

The beam hole counter is a scintillator with a hole of 17.5 cm by 2.5 cm.

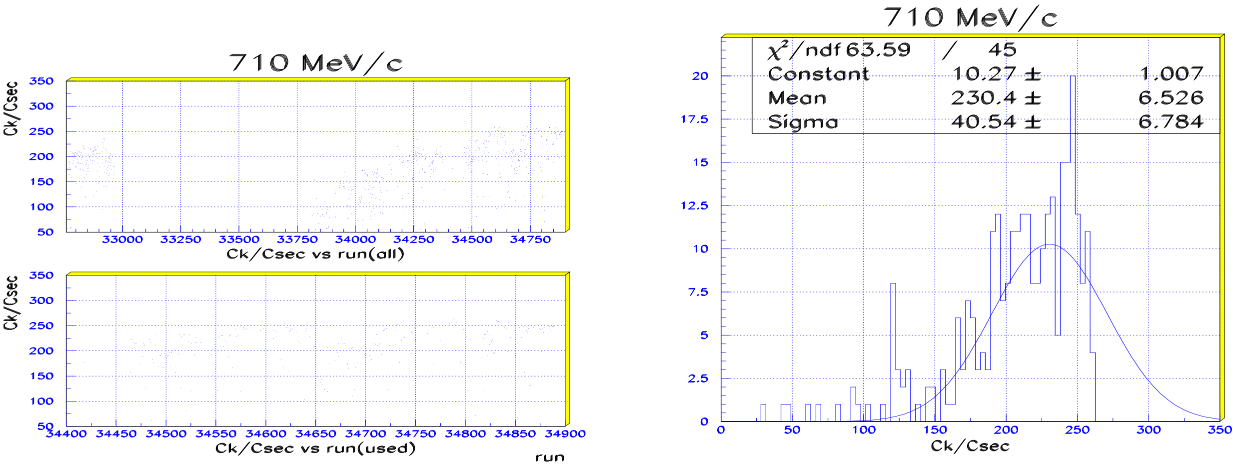

Figure 8: Ck/C_{SEC} at 710 MeV/c

The two BMWPC's are at xxx and xxx. BWPC1 is 2.5" by 7.5" with 3 views (x,u,v). BWPC2 is 4" in diameter with 2 views (x,y).

The B4 has two planes of 8 counters at xxx, with a diameter of 5" and a thickness of 0.5 cm each.

The degrader is a series of BeO plates of thickness 1/2" and 1". The thickness of the degrader at 790 MeV/c was 15". On March 20 , 1996 we lowered the momentum to 730 MeV/c and we removed 3.45" to 11.5". On June 20 , 1996 1" of BeO degrader was removed and the momentum lowered from 730 to 710 MeV/c. On May 12, 1997 the BeO was shortened to 8.5" (removing 2" of BeO and 1/4" of Lucite), as the momentum was lowered to 670 from 710 MeV/c. At the downstream end of the degrader is the active PbG degrader which is 4" long and 5" in diameter.

2.2 KB, Ck electronics

On-line we can readily measure the ratio of KB/Ck, where Ck is defined as a coincidence of, typically, 6 out of the 14 PMTs in the kaon ring of the Cherenkov counter and KB is defined as the coincidence of Ck*B4*TT*spill. The spill signal is generated by the predet and is nominally set to 1.6 (1.2) seconds. The B4 signal is an OR of the u and v planes. The TT signal is a 100 mV threshold on the analog sum of the target fibers. The electronics that define these coincidences have been refined over the years to remove deadtime and otherwise improve performance.

2.3 KB/Ck measurements

Finally, our stopping efficiency is shown in Figure 11. Note that we plot the inverse of the normal stopping fraction. We want this (Ck/KB) to be small.

The trend is good. we need to make some corrections for modifications to the electronics that reduced deadtime and increased the KB/Ck ratio. The first 3% effect was an increase in 30% of the Target PMT's HV at run 23940. The second effect was an unknown increase in KB/Ck when

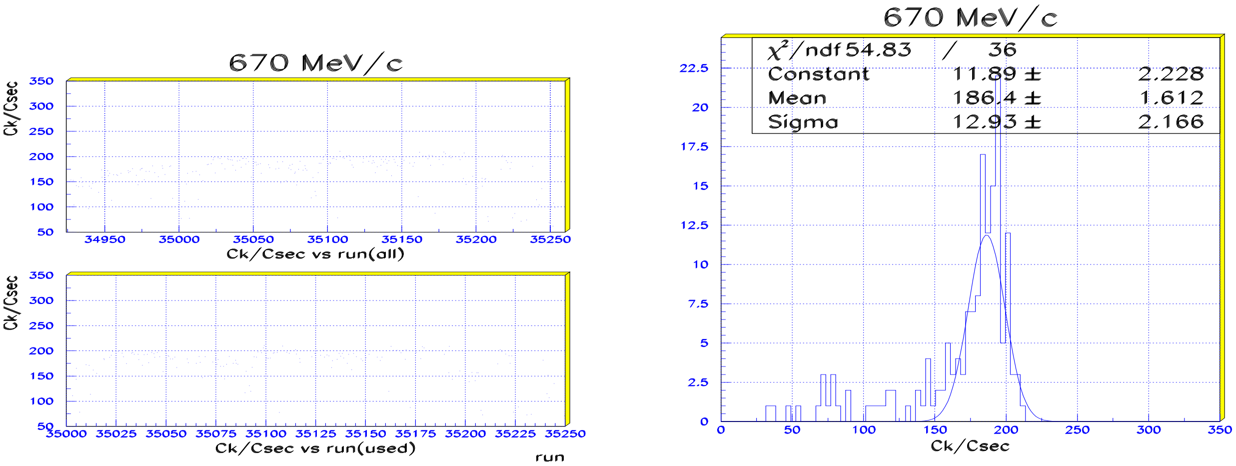

Figure 9: Ck/C_{SEC} at 670 MeV/c

$\|\vec{p}\|$ (MeV/c)	Geant sf(%)	Data KB/Ck(%)	Data corrected	F_S deduced	F_S Geant
790	14.6	18.9	21.3	0.69	0.79
730	18.2	23.4	24.9	0.73	0.81
710	19.4	24.7	25.5	0.76	0.80
670	21.8	27.5	27.5	0.79	0.85

Table 7: Measured and Monte Carlo values for the stopping fraction.

the remaining target PMT's had their HV raised at the beginning of 1996 (run 29900). A third effect was an 4% increase in KB/Ck when the B4 and TT signals were put into 'overlap mode' with a subsequent decrease in deadtime at run 32037. Finally an increase of KB/Ck of 5% at run 34642 resulted from a removal of deadtime in Ck, by putting Ck into 'overlap mode'. (This is not a first intuitive. Putting Ck into overlap mode actually makes the Ck signal wider and adds a little deadtime to Ck. The wider Ck pulse makes the KB coincidence more efficient.) After all of the above modifications the rate dependence of KB/Ck was such that there is a very small increase at higher rates (due to the deadtime in Ck).

So we need to correct our data of KB/Ck by these effects.

We can also look at the Geant and measured values for the fraction of stopped kaons in Table 7. The measured value of F_S at 790 MeV/c from the 1995 run is $F_S = 0.75 \pm 0.01$.

A fit to the Geant stopping fractions can be seen in Figure 12 gives sf = 0.69 - 0.0007$\times|\vec{p}|$. A fit to the data gives sf $= F_S \times (0.61 - 0.0005 \times |\vec{p}|)$. If we fit the uncorrected data we get sf $= F_S \times (0.75 - 0.0007 \times |\vec{p}|)$.

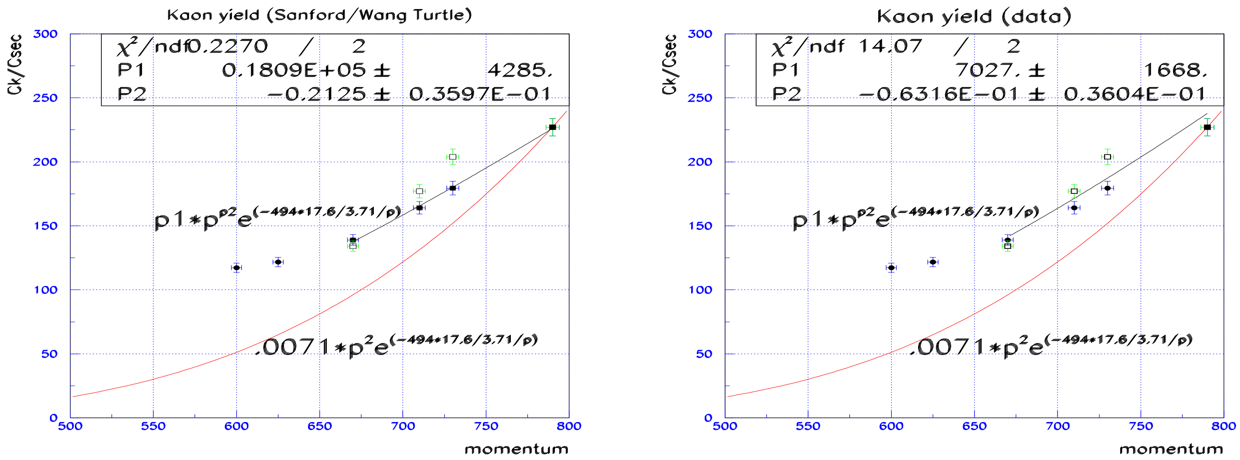

Figure 10: Ck/C$_{SEC}$ vs momentum data (points) and expectation

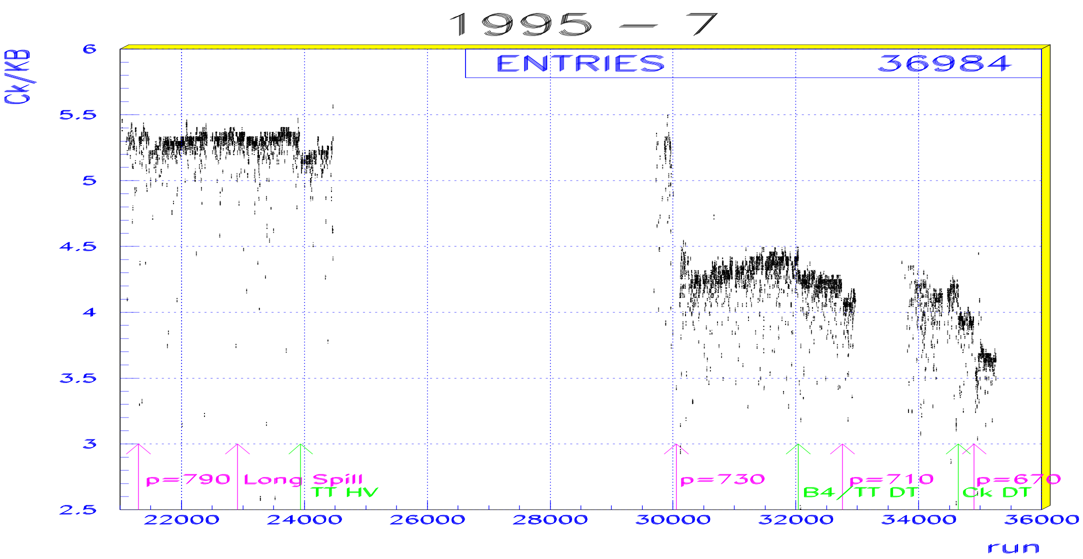

Figure 11: Ck/KB for 1995–7 data.

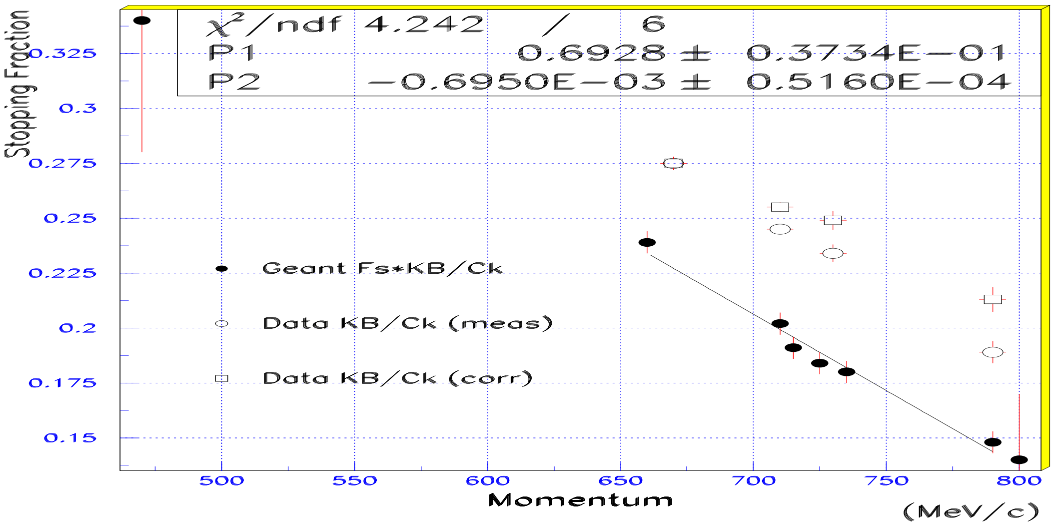

Figure 12: Stopping fraction from Geant and measured values of KB/Ck. The stopping fraction is give by (69 - 0.07*p)%.