Beam Cerenkov – differential heads

This is the second document looking at the beam cerenkov detectors for the E907 experiment. Here I will look at the specific requirements of two psudo-differential cerenkov heads that FNAL currently has. A print of the heads should be available on the E907 web site in addition to pressure curves and this document.

The cerenkov head consists of two mirrors M1, and M2. M1 is a 13" diameter spherical mirror that reflects and focuses the cerenkov light onto M2. M2 is 6" in diameter and located about 250cm from M1, and has a hole in it to discriminate between different cerenkov angles. Small angle light passes though the center and large angle light is reflected. In both cases the light hits a photomultiplier tube to record the number of photons. Particles can be identified by which photomultiplier receives photons since this is related to the angle of the cerenkov light that is related to the particle's velocity.

There are two extremes that must be investigated to determine if these cerenkov heads will work for E907. In the low momentum case there are plenty of photons, but the cerenkov light is at a large angle. One has to be careful that light will make it into the photomultiplier tube. The maximum angle can be estimated in the following way. The radius of the light ring at M2 can be calculated from

$$h \cong f\theta_c \qquad (1)$$

where h is the radius of the light ring, f is the focal length of M1 and θ_c is the cerenkov angle. The radius of M2 is 3" and the focal length of M1 is about 250cm. That gives a maximum cerenkov angle of about 30 mr.

The other extreme is the high momentum case. Here the length of the radiator is critical due to the few photons generated. In the previous write up on this detector is was found that the ratio of radiator lengths should be about .35. Looking at the pressure curves and the tables at the end of this document is seems that the following is an acceptable set up: pion-kaon 24.5m radiator with 12" pipe, kaon-proton 8.8m radiator with a 10" pipe. (Note: Those lengths are of the radiator gas and not the pipe added to the cerenkov head.) The tables at the end of the document show that the geometrical losses in either pipe are not a problem at low momentum (high n), or at high momentum (low n). There are no losses at high momentum, and because of the large number of photons at low momentum the loss is not a problem. One does find for the longer pipe that the geometrical losses start to kick in at an n of about He at STP. This should not be a problem but a smaller diameter pipe will worsen this situation, and is not desired. For the 8.8 m pipe the geometrical effect kicks in at higher n and should pose no problem even with a 10" diameter pipe.

The operating conditions of the cerenkov heads can be understood from the pressure curves that are located on the web page with this document. The plots are generated for each gas/beam energy/radiator length combination of interest. The x axis is the pressure that one sets in the chamber. The left y axis is the angle of cerenkov light emitted from the particles for that given gas pressure, and the right y axis is the number of photons that would be emitted. Keep in mind that the number of emitted photons is

not the number that are collected because of geometry effects. To see the geometry effects on must look at the tables at the end of this document.

Since these cerenkovs must work at many energies, and we want to minimized the number of changes between beam energies, I tried to pick a single angle threshold, for each cerenkov, that gives a reasonable number of photons below the threshold. I picked a criteria of about 2 photons below the threshold since it doesn't look like one can do better than that given the fixed length. The horizontal lines are to aid in determining what these thresholds will look like. I figure that a 5mr and 7mr threshold will work for the long and short pipes respectively. If one assumes that a beam movement of some angle correlates to a simple movement of the cerenkov light on M2 by the same amount (it also becomes more elliptical—it is already a bit elliptical do to the off axis optics), one can see at high momentum that a 1mr offset is about the maximum amount of movement before identification becomes more complicated. I have not determined what the effect of a translation of the beam would be, or how much addition movement could be allowed if rings move over the angle threshold, I will figure that out at a later date. The main point is that the order of magnitude of allowed beam movement is about 1 mr.

Using these plots I determined what the most likely modes of operation would be. The modes are described below along with a schedule of the modes needed for different energies.

Threshold mode : This mode is the mode that a simple threshold cerenkov would work in. One particle is above the cerenkov light threshold and one is below. The particle identification is made by either seeing light or not. The reasons for this mode are, at low energy both particles may not be above the cerenkov light threshold, and the angle/pressure curve is too steep to control well.

Differential mode : This is the mode that the heads were designed to be used. A particle is identified by light in one photomultiplier tube or the other, and there is positive identification of a particle and it's identification.

Timing mode : The index of refraction needed for the very lowest beam energy is not practical. The beam is slow enough that timing of the beam using scintillator will work well, and is therefore used.

Mixed mode : In cases were two modes can be used at the same time this will be done.

Suggested running modes

Pion-Kaon identification with the 24.5 m radiator and a 5 mr threshold.

5 GeV	Freon114	Threshold mode (kaons below cerenkov threshold)
10-20 GeV	Freon114	Threshold mode most likely (the angle/pressure curve is steep, and there are plenty of photons)

25-65 GeV	N2	Start of differential mode
70-120 GeV	He	Differential mode

Kaon-Proton identification with the 8.8m radiator and a 7mr threshold.

5GeV	Timing	Timing mode (K and P are below the cerenkov threshold in Freon114)
10GeV	Freon114 + timing	Timing and threshold mode (K just makes the cerenkov threshold)
15GeV	Freon114	Threshold mode (proton below cerenkov threshold)
20GeV	Freon114	Threshold mode likely (steep angle/pressure curve)
25-40GeV	N2	Threshold mode (protons below cerenkov threshold)
45-120GeV	N2	Differential mode
100-120GeV	Ne	Differential mode (alternative if N2 is too difficult in this energy range)

Tables

The column headings have the following meanings.

P	momentum
NpePI	number of photons from a pion
NpeK	“ kaon
NpeP	“ proton
FiltNpePI	number of photons that make it to M1. with a large cerenkov angle, not all photons make it to the mirror. This is just a geometry problem.
(mr)	the angle of cerenkov light

This table is for L=880cm pipe diameter=10in and (n-1)x10^6=900

p	NpePI	NpeK	NpeP	filt NpePI(mR)	filt NpeK(mR)	filt NpeP(mR)
5	50.57	0.00	0.00	22.77(32.04)	0.00(43.57)	0.00(43.57)
10	79.08	0.00	0.00	28.47(40.07)	0.00(43.57)	0.00(43.57)
15	84.36	34.58	0.00	29.40(41.39)	18.83(26.49)	0.00(43.57)
20	86.21	58.21	0.00	29.72(41.84)	24.43(34.37)	0.00(43.57)
25	87.06	69.14	19.34	29.87(42.04)	26.62(37.47)	14.08(19.81)
30	87.53	75.08	40.49	29.95(42.16)	27.74(39.04)	20.38(28.67)
35	87.81	78.67	53.25	29.99(42.22)	28.39(39.96)	23.37(32.88)

40	87.99	80.99	61.53	30.03(42.27)	28.81(40.55)	25.12(35.34)
45	88.12	82.58	67.21	30.05(42.30)	29.09(40.95)	26.25(36.94)
50	88.20	83.72	71.27	30.06(42.32)	29.29(41.23)	27.03(38.04)
55	88.27	84.57	74.28	30.07(42.34)	29.44(41.44)	27.59(38.83)
60	88.32	85.21	76.56	30.08(42.35)	29.55(41.59)	28.01(39.43)
65	88.36	85.71	78.34	30.09(42.36)	29.63(41.72)	28.33(39.88)
70	88.39	86.10	79.75	30.09(42.36)	29.70(41.81)	28.59(40.24)
75	88.42	86.42	80.89	30.10(42.37)	29.76(41.89)	28.79(40.53)
80	88.44	86.69	81.82	30.10(42.37)	29.80(41.95)	28.96(40.76)
85	88.45	86.90	82.59	30.10(42.38)	29.84(42.01)	29.09(40.95)
90	88.47	87.08	83.24	30.11(42.38)	29.87(42.05)	29.21(41.11)
95	88.48	87.24	83.79	30.11(42.39)	29.90(42.09)	29.30(41.25)
100	88.49	87.37	84.26	30.11(42.39)	29.92(42.12)	29.38(41.36)
105	88.50	87.48	84.66	30.11(42.39)	29.94(42.15)	29.45(41.46)
110	88.51	87.58	85.01	30.11(42.39)	29.96(42.17)	29.51(41.54)
115	88.51	87.67	85.31	30.11(42.39)	29.97(42.19)	29.57(41.62)
10000	88.58	88.58	88.58	30.13(42.41)	30.13(42.41)	30.13(42.41)

This table is for L=880cm pipe diameter=10in and (n-1)x10^6=45

p	NpePI	NpeK	NpeP	filt NpePI(mR)	filt NpeK(mR)	filt NpeP(mR)
5	0.00	0.00	0.00	0.00(8.94)	0.00(8.94)	0.00(8.94)
10	0.00	0.00	0.00	0.00(8.94)	0.00(8.94)	0.00(8.94)
15	0.20	0.00	0.00	0.20(2.03)	0.00(8.94)	0.00(8.94)
20	2.05	0.00	0.00	2.05(6.46)	0.00(8.94)	0.00(8.94)
25	2.91	0.00	0.00	2.91(7.69)	0.00(8.94)	0.00(8.94)
30	3.38	0.00	0.00	3.38(8.28)	0.00(8.94)	0.00(8.94)
35	3.66	0.00	0.00	3.66(8.62)	0.00(8.94)	0.00(8.94)
40	3.84	0.00	0.00	3.84(8.83)	0.00(8.94)	0.00(8.94)
45	3.96	0.00	0.00	3.96(8.97)	0.00(8.94)	0.00(8.94)
50	4.05	0.00	0.00	4.05(9.07)	0.00(8.94)	0.00(8.94)
55	4.12	0.41	0.00	4.12(9.14)	0.41(2.89)	0.00(8.94)
60	4.17	1.05	0.00	4.17(9.20)	1.05(4.62)	0.00(8.94)
65	4.21	1.55	0.00	4.21(9.24)	1.55(5.62)	0.00(8.94)
70	4.24	1.95	0.00	4.24(9.28)	1.95(6.29)	0.00(8.94)
75	4.27	2.27	0.00	4.27(9.30)	2.27(6.79)	0.00(8.94)
80	4.29	2.53	0.00	4.29(9.33)	2.53(7.17)	0.00(8.94)
85	4.30	2.75	0.00	4.30(9.34)	2.75(7.47)	0.00(8.94)
90	4.32	2.93	0.00	4.32(9.36)	2.93(7.71)	0.00(8.94)
95	4.33	3.09	0.00	4.33(9.37)	3.09(7.91)	0.00(8.94)
100	4.34	3.22	0.10	4.34(9.38)	3.22(8.08)	0.10(1.42)
105	4.35	3.33	0.50	4.35(9.39)	3.33(8.22)	0.50(3.19)
110	4.36	3.43	0.85	4.36(9.40)	3.43(8.34)	0.85(4.16)
115	4.36	3.51	1.16	4.36(9.41)	3.51(8.45)	1.16(4.84)
10000	4.43	4.43	4.43	4.43(9.49)	4.43(9.49)	4.43(9.49)

This table is for L=880cm pipe diameter=10in and (n-1)x10^6=130

p	NpePI	NpeK	NpeP	filt NpePI(mR)	filt NpeK(mR)	filt NpeP(mR)
5	0.00	0.00	0.00	0.00(17.32)	0.00(17.32)	0.00(17.32)
10	3.29	0.00	0.00	3.29(8.17)	0.00(17.32)	0.00(17.32)
15	8.58	0.00	0.00	8.58(13.20)	0.00(17.32)	0.00(17.32)
20	10.43	0.00	0.00	10.35(14.55)	0.00(17.32)	0.00(17.32)
25	11.29	0.00	0.00	10.76(15.13)	0.00(17.32)	0.00(17.32)
30	11.75	0.00	0.00	10.98(15.44)	0.00(17.32)	0.00(17.32)
35	12.03	2.88	0.00	11.11(15.63)	2.88(7.64)	0.00(17.32)
40	12.22	5.20	0.00	11.20(15.74)	5.20(10.28)	0.00(17.32)
45	12.34	6.80	0.00	11.25(15.83)	6.80(11.75)	0.00(17.32)
50	12.43	7.94	0.00	11.29(15.88)	7.94(12.70)	0.00(17.32)
55	12.50	8.79	0.00	11.32(15.92)	8.79(13.35)	0.00(17.32)
60	12.55	9.43	0.77	11.35(15.96)	9.43(13.83)	0.77(3.95)
65	12.59	9.93	2.55	11.36(15.98)	9.93(14.20)	2.55(7.19)
70	12.62	10.33	3.96	11.38(16.00)	10.29(14.48)	3.96(8.97)
75	12.64	10.65	5.10	11.39(16.02)	10.45(14.70)	5.10(10.18)
80	12.66	10.91	6.04	11.40(16.03)	10.58(14.88)	6.04(11.07)
85	12.68	11.13	6.81	11.41(16.04)	10.69(15.03)	6.81(11.76)
90	12.69	11.31	7.46	11.41(16.05)	10.77(15.15)	7.46(12.30)
95	12.70	11.46	8.01	11.42(16.06)	10.85(15.25)	8.01(12.75)
100	12.72	11.59	8.48	11.42(16.06)	10.91(15.34)	8.48(13.11)
105	12.72	11.71	8.88	11.43(16.07)	10.96(15.41)	8.88(13.42)
110	12.73	11.80	9.23	11.43(16.07)	11.01(15.48)	9.23(13.68)
115	12.74	11.89	9.53	11.43(16.08)	11.05(15.53)	9.53(13.91)
10000	12.81	12.81	12.81	11.47(16.12)	11.47(16.12)	11.46(16.12)

This table is for L=2450cm pipe diameter=12in and (n-1)x10^6=20

p	NpePI	NpeK	NpeP	filt NpePI(mR)	filt NpeK(mR)	filt NpeP(mR)
5	0.00	0.00	0.00	0.00(7.07)	0.00(7.07)	0.00(7.07)
10	0.00	0.00	0.00	0.00(7.07)	0.00(7.07)	0.00(7.07)
15	0.00	0.00	0.00	0.00(7.07)	0.00(7.07)	0.00(7.07)
20	0.00	0.00	0.00	0.00(7.07)	0.00(7.07)	0.00(7.07)
25	1.25	0.00	0.00	1.25(3.01)	0.00(7.07)	0.00(7.07)
30	2.54	0.00	0.00	2.54(4.30)	0.00(7.07)	0.00(7.07)
35	3.32	0.00	0.00	3.32(4.92)	0.00(7.07)	0.00(7.07)
40	3.83	0.00	0.00	3.83(5.28)	0.00(7.07)	0.00(7.07)
45	4.18	0.00	0.00	4.18(5.52)	0.00(7.07)	0.00(7.07)
50	4.43	0.00	0.00	4.43(5.68)	0.00(7.07)	0.00(7.07)
55	4.61	0.00	0.00	4.61(5.80)	0.00(7.07)	0.00(7.07)
60	4.75	0.00	0.00	4.75(5.88)	0.00(7.07)	0.00(7.07)
65	4.86	0.00	0.00	4.86(5.95)	0.00(7.07)	0.00(7.07)
70	4.95	0.00	0.00	4.95(6.00)	0.00(7.07)	0.00(7.07)
75	5.02	0.00	0.00	5.02(6.05)	0.00(7.07)	0.00(7.07)

80	5.07	0.19	0.00	5.07(6.08)	0.19(1.19)	0.00(7.07)
85	5.12	0.80	0.00	5.12(6.11)	0.80(2.41)	0.00(7.07)
90	5.16	1.30	0.00	5.16(6.13)	1.30(3.08)	0.00(7.07)
95	5.19	1.73	0.00	5.19(6.15)	1.73(3.55)	0.00(7.07)
100	5.22	2.10	0.00	5.22(6.17)	2.10(3.91)	0.00(7.07)
105	5.25	2.41	0.00	5.25(6.18)	2.41(4.19)	0.00(7.07)
110	5.27	2.69	0.00	5.27(6.20)	2.69(4.43)	0.00(7.07)
115	5.29	2.93	0.00	5.29(6.21)	2.93(4.62)	0.00(7.07)
10000	5.49	5.49	5.49	5.40(6.32)	5.40(6.32)	5.40(6.32)

This table is for L=2450cm pipe diameter=12in and (n-1)x10^6=400

p	NpePI	NpeK	NpeP	filt NpePI(mR)	filt NpeK(mR)	filt NpeP(mR)
5	3.75	0.00	0.00	3.75(5.22)	0.00(34.63)	0.00(34.63)
10	83.21	0.00	0.00	21.01(24.63)	0.00(34.63)	0.00(34.63)
15	97.92	0.00	0.00	22.79(26.72)	0.00(34.63)	0.00(34.63)
20	103.07	25.04	0.00	23.38(27.41)	11.53(13.51)	0.00(34.63)
25	105.46	55.51	0.00	23.65(27.73)	17.16(20.12)	0.00(34.63)
30	106.75	72.07	0.00	23.80(27.90)	19.55(22.92)	0.00(34.63)
35	107.53	82.05	11.23	23.88(28.00)	20.86(24.46)	7.72(9.05)
40	108.04	88.53	34.31	23.94(28.07)	21.67(25.40)	13.49(15.81)
45	108.39	92.97	50.13	23.98(28.11)	22.21(26.03)	16.31(19.12)
50	108.63	96.15	61.45	24.01(28.14)	22.58(26.48)	18.06(21.16)
55	108.82	98.50	69.82	24.03(28.17)	22.86(26.80)	19.25(22.56)
60	108.96	100.29	76.19	24.04(28.18)	23.07(27.04)	20.11(23.57)
65	109.07	101.68	81.15	24.05(28.20)	23.22(27.23)	20.75(24.32)
70	109.15	102.78	85.08	24.06(28.21)	23.35(27.37)	21.25(24.90)
75	109.22	103.67	88.25	24.07(28.22)	23.45(27.49)	21.64(25.36)
80	109.28	104.40	90.85	24.08(28.23)	23.53(27.59)	21.95(25.74)
85	109.33	105.01	93.00	24.08(28.23)	23.60(27.67)	22.21(26.04)
90	109.37	105.51	94.80	24.09(28.24)	23.66(27.74)	22.43(26.29)
95	109.40	105.94	96.33	24.09(28.24)	23.71(27.79)	22.61(26.50)
100	109.43	106.31	97.63	24.09(28.25)	23.75(27.84)	22.76(26.68)
105	109.45	106.62	98.75	24.10(28.25)	23.78(27.88)	22.89(26.83)
110	109.48	106.90	99.73	24.10(28.25)	23.81(27.92)	23.00(26.96)
115	109.49	107.13	100.57	24.10(28.25)	23.84(27.95)	23.10(27.08)
10000	109.69	109.69	109.69	24.12(28.28)	24.12(28.28)	24.12(28.28)

This table is for L=2450cm pipe diameter=12in and (n-1)x10^6=30

p	NpePI	NpeK	NpeP	filt NpePI(mR)	filt NpeK(mR)	filt NpeP(mR)
5	0.00	0.00	0.00	0.00(6.32)	0.00(6.32)	0.00(6.32)
10	0.00	0.00	0.00	0.00(6.32)	0.00(6.32)	0.00(6.32)
15	0.00	0.00	0.00	0.00(6.32)	0.00(6.32)	0.00(6.32)
20	1.60	0.00	0.00	1.60(3.42)	0.00(6.32)	0.00(6.32)
25	3.99	0.00	0.00	3.99(5.39)	0.00(6.32)	0.00(6.32)
30	5.29	0.00	0.00	5.29(6.21)	0.00(6.32)	0.00(6.32)

35	6.07	0.00	0.00	5.68(6.65)	0.00(6.32)	0.00(6.32)
40	6.57	0.00	0.00	5.91(6.92)	0.00(6.32)	0.00(6.32)
45	6.92	0.00	0.00	6.06(7.10)	0.00(6.32)	0.00(6.32)
50	7.17	0.00	0.00	6.17(7.23)	0.00(6.32)	0.00(6.32)
55	7.36	0.00	0.00	6.25(7.32)	0.00(6.32)	0.00(6.32)
60	7.50	0.00	0.00	6.31(7.39)	0.00(6.32)	0.00(6.32)
65	7.60	0.21	0.00	6.35(7.44)	0.21(1.24)	0.00(6.32)
70	7.69	1.32	0.00	6.39(7.49)	1.32(3.10)	0.00(6.32)
75	7.76	2.21	0.00	6.42(7.52)	2.21(4.01)	0.00(6.32)
80	7.82	2.94	0.00	6.44(7.55)	2.94(4.63)	0.00(6.32)
85	7.86	3.54	0.00	6.46(7.57)	3.54(5.08)	0.00(6.32)
90	7.90	4.05	0.00	6.48(7.59)	4.05(5.43)	0.00(6.32)
95	7.94	4.48	0.00	6.49(7.61)	4.48(5.71)	0.00(6.32)
100	7.97	4.84	0.00	6.50(7.62)	4.84(5.94)	0.00(6.32)
105	7.99	5.16	0.00	6.51(7.63)	5.16(6.13)	0.00(6.32)
110	8.01	5.43	0.00	6.52(7.64)	5.37(6.29)	0.00(6.32)
115	8.03	5.67	0.00	6.53(7.65)	5.49(6.43)	0.00(6.32)
10000	8.23	8.23	8.23	6.61(7.75)	6.61(7.75)	6.61(7.75)