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HYBRID CENTRAL SHOWER COUNTERS

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I. Introduction and Summary

The purpose of this note is to update the design and cost estimate of the central hybrid shower counter system. As sketched in Fig. 1, the present plan is to have 40 modules arranged in an octagonal manner around the outside of the solenoidal coil, each octant being split along the beam into five 1-m long modules. Each module will have eight lead-scintillator cells, approximately 18-cm wide by 1-m long. The cells are read out at each end via BBQ wave-length shifter bar and light pipe to two-inch phototubes located beyond the hadron calorimeter. Each celi has a total depth of $20X_0$ with the energy deposition being sampled 66 times using 1/4" thick acrylic scintillator with a sampling thickness ti $0.3X_0$, mostly 1/16" lead sheets. Based on our experience with tests in the M5 beam and published work by the Saclay group[1] on acrylic scintillator, we anticipate an energy resolution of a_E/E = 10%/1/E.

Two layers of strip chamber will be used to give good 'ff/e separation, position resolution, two y separation, pattern recognition, and discrimination against spurious events. These chambers will be placed at depths (including the solenoidal coil) of about 2.5 and $7X_0$. They will use U-shaped Al extrusions, similar to the MAC shower detector at PEP,[2] but with cathode strips orthogonal to the wires. The expected performance characteristics of the hybrid system are summarized in Table I. The design has been studied and documented in detail in a dozen previous CDF notes, [3-14] and we simply quote the pertinent results here. Some of the more recent M5 test data and their implications are discussed below.

Preliminary cost estimates have been made and are discussed in Section III. The total cost is estimated to be $2.4M without escalation, contingency, or installation; this figure agrees well with the estimate made by H. Jensen (January 14, 1980) and is about 20% of that estimated for the total CDF system. The cost could be reduced by ti $250K if one returns to the old design of 0.6 r.l. layers in the lead-scintillator sandwich (a_E/E = 14%/1/E). Another option would be to defer one layer of strip chamber $500K).

<u>Performance</u>

A. Lead-Scintillator Energy Resolution

We consider here the effects of sampling fluctuations and photoelectron statistics. Counters with phototubes directly coupled (without wave shifting) to the scintillator are dominated by sampling fluctuations and typically obtain (CDF-24, CDF-27, Ref. 15)

$$(a/E)_s = 15\%/lETE$$

where E is in GeV and t is the sampling thickness in radiation lengths. Recent tests in the M5 beam used a module 2.5-m long with 1/8-in. layers of lead (0.6 r.1.) alternating with 1/4-in. layers of a type of Plexipop (7.5% naphthalene, 1% PPO, 0.01% POPOP). With an electron beam 0.5 m from the phototube (corresponding to the center of one of the proposed 1-m long modules) we obtained a contribution to the resolution from the photoelectron statistics of a single phototube

$$(a/E)_{pe} = 14.4\%//k;$$

combined with the sampling statistics this gave the observed resolution of

$$(°\rangle/E)\ tot = 18.5\%.$$

This will be improved by (a) using two phototubes, (b) going to 0.3 r.l. sampling (1/16-in. lead), and (c) optimizing the scintillator chemistry along the lines suggested by a Saclay group.[1] Our present plan is to use 10% naphthalene and 1% PPO; the additional naphthalene will give more light and the omission of POPOP will give a better match to the BBQ absorption spectrum. Studies by the Saclay group[1] indicate that this type of plexinonpop should give about twice the number of photoelectrons of our present scintillator. We have ordered enough of this material to make a 1-m long celi for testing in the M5 beam. As outlined in Table II, this should lead to a resolution of about 10%/i/r.

A Monte Carlo simulation of a similar shower detector[16] indicates that low energy y rays will be detected with good efficiency down to ti 100 MeV. This Monte Carlo agrees well with beam tests done at Argonne using electrons.

The mean position of the energy deposited in the lead-scintillator cells is measured by comparing the pulse heights in the phototubes at the two ends of a celi. The photoelectron statistics give an uncertainty in this measurement of

$$_x = W/N_{pe} = 0.05\ X/i/E$$

where X is the exponential attenuation length of light in the scintillator. Taking a $\_$ 100 cm,

$$\sigma_x - 5\ \mathrm{cm}/\sqrt{E}.$$

For e's and y's entering the celi at an angle, there is an additional uncertaínty arising from fluctuations in the depth of the average energy deposition in the scintillator. Analysis of the M5 beam results at 30 GeV shows this fluctuation to be ± 0.75 radiation length ± 2.5 cm in depth (averaged over layers near shower maximum, including the strip chamber gaps); the corresponding uncertainty in angle for a y ray produced at 45.0° is ± 8 mrad. This uncertainty decreases as the angle increases to more nearly normal incidence. The strip chamber measurement of ± 4 mm is, of course, much more accurate, but the scintillation counter determination provides a redundancy useful for pattern recognition and background rejection.

B. Two-Chamber Performance

As was discussed in detail in CDF-27, there are conflicting criteria for the optimal depth of a singie strip chamber embedded in a lead-scintillator sandwich. Hadron rejection, position resolution, and sensitivity to lower energy y rays are better at 2 or 3 radiation lengths, while good energy resolution and pattern recognition (high y-ray conversion efficiency) are better near shower maximum, 6 or 7 radiation lengths. Embedding two chambers, one at about 2.5 r.l. depth (including solenoid coil, etc.) and the other at 7 r.1., should not only give good performance in all these areas, but will also allow a redundancy useful in the rejection of various types of backgrounds. In particular, for those showers identified in both chambers, a check can be made that the shower points back to the production vertex.

Position Resolution. As discussed in CDF-27, the position resolution measured by a chamber appears not to depend strongly on depth, being typically ± 4 mm. If we assume the two chambers give independent information, then their average should give an effettive resolution of ± 3 mm, or slightly better than ± 2 mrad in the production angle.

Two Particle Separation. The ability to distinguish two nearby showers was studied offline by superimposing two 10-GeV electron showers from the M5 test beam. As discussed in CFD-27, a factor of 20 rejection was obtained for double showers separated by 5 cm with a cut which maintained a 95% efficiency for single showers. For these electron showers, the rejection of double showers did not depend strongly on depth, and we might hope to identify even more closely spaced showers using the two chambers together; this needs further study in the M5 beam.

Shower Direction. If the shower centroid is measured in each projected view to ± 4 mm, then using a lever arm of 12 cm between chambers, the projected angles of the shower will be measured by the two chambers to ± 50 mrad. This will allow us to check that the shower actually carne from the interaction of interest and not some other source such as upstrearn beam-gas interactions or cosmic rays. The uncertainty in the extrapolation back to the interaction location in each view will be ± 8 cm.

C. Hadron Rejection

Hadron rejection was studied in detail in CDF-25 and CDF-27 for the case of a single strip chamber. Using a full width cut on E/p of 0.17 and a pulse height cut on the shower in the strip chamber, the total rejection factor of 30-GeV n was 2×10^{-4} (for a pulse height cut at 5.5 r.l. which eliminated 7% of the electrons). This became ~ 1×10^{-4} when the sampling was done earlier in the shower. Using the two chambers together may give some small improvement on this rejection. Additional rejection may eventually be achieved by requiring a relatively well-collimated shower and by insisting that little energy remain in the shower to penetrate the hadron calorimeter (CDF-29). On the other hand, particles accompanied by other nearby particles may have somewhat poorer rejection, and the $0.6X_o$ of aluminum in the coil will probably degrade the rejection by a factor of % 2.

III. Physical Properties

The important parameters of the system are shown in Table III and a sketch of a module is shown in Fig. 1. The steel required to give the modules strength was calculated previously in some detail by K. Coover;" these results are being recalculated for the present module size. A prototype strip wire chamber has been tested in the laboratory and is described in a paper given at the 1980 Vienna Wire Chamber Conference."

Particles at normal incidence in the center modules see 0.3 r.l. per layer for a lead thickness of 1/16 inch. In order to maintain an effective value of ti 0.3 r.l. per layer, the lead in the end modules will be reduced in thickness by a factor of sin 42° = 0.67 where 42° is the production angle of a y ray produced at the center of the interaction region and passing through the center of the module. For those modules between the center and the end modules, this factor is sin 61° = 0.87.

If we were to return to the old design of 32 layers èach of 0.6 r.1., 8 inches of scintillator (0.3 absorPtion length) would be eliminated.

IV. Cost

An estimate of the costs for the materials, assembly and testing of the 40 modules is shown in Table IV. Many of these estimates are • based on our prototyping experience. Escalation, contingency, and installation are not included. The biggest single cost is for the 18000 channels of electronics for the strip chambers, estimated at $40/channel.

References

1. C. Aurouet et al., NIM 169, 57 (1980).

2. R. L. Anderson et al., IEEE Trans. Nuci. Sci. NS-25, 340 (1978).

3. CDF-23. Dependence of Shower Counter Resolution on Counter Depth - B. Musgrave.

4. CDF-24. Shower Counter Resolution - B. Musgrave.

5. CDF-25. Electron-Hadron Separation Using Longitudinal Shower Development - R. Singer.

6. CDF-27. Design of the Central Electromagnetic Shower Counter Based on M5 Test-Beam Results - M. Atac, R. Diebold, R. Loveless, B. Musgrave, J. Sauer, R. Singer.

7. CDF-29. Energy Leakage as a Function of Shower Counter Depth - B. Musgrave.

8. CDF-31. Big p_T Trigger with Strips - R. Diebold.

9. CDF-32. Identification of Electrons without a Magnet - R. Diebold.

10. CDF-33. Strip Chamber Tests in ANL Beam 5 - L. Nodulman.

11. CDF-36. Further Analysis of the Scintillator/Lead Sheet Test Beam Data - J. Sauer.

12. CDF-38. Results from Lead-Plexipop Sandwich Shower Counters with Wave-Shifter Readout - B. Musgrave.

13. CDF-39. Tests of an "Educational Prototype" for Hybrid Shower Counter Wire Chambers - L. Nodulman.

14. CDF-41. Hybrid Shower Counter Simulation - L. Nodulman.

15. S. L. Stone et al., NIM 151, 387 (1978).

16. Z. Ming Ma et al., Performance Characteristics of a Large Aperture, Segmented Lead-Scintillator Sandwich Electromagnetic Shower Detector, Michigan State preprint (1980).

17. K. P. Coover, Structural Analysis of Shower Counters for FNAL, ANL internal memo (August 1979).

18. Lawrence Nodulman, Hybrid Shower Counters for CDF, ANL-HEP-CP-80-20, to be published in Proceedings of the 1980 Vienna Wire Chamber Conference (February 1980).

Table I. Hybrid Shower Counter Performance

<u>Scintillator</u>		
a_E/E for 5-30 GeV	• 10%//E	CDF-23,24,27,29,36,38; Section IIA
at very high energy	• (1 or 2)%	Systematics achieved by similar experiments.
a_x (beam direction)	± 5 cm/i/E	CDF-27; Section IIA.
a (qh direction)	± 6 cm	Full width of cell 18 cm.
<u>Strip Chambers</u>		
a_E/E for 5-30 GeV 7 r.l.	• (25-40)% 1	CDF-27.
at very high energy	20%	
electrons at 2.5 r.l.	• 50%	
a_x (beam direction)	• 4 mm	CDF-27; Section IIB.
a (4 direction)	± 4 mm	
minimum separation for 2y separation	5- 5 cm	CDF 27; Section IIB.
interaction vertex pointing	• 8 cm	Section IIB.
<u>Hybrid System</u>		
hadron rejection at 30 GeV	% 2×10^{-4}	CDF-25, 27; Section IIC.

Table II. Extrapolation of Lead-Scintillator Resolution

	$(a/E)_s$	$(a/E_{pe}$	$(a/E)_{tot}$
start with M5 tests, one PM	11.6%h/E	14.4%/iE	18.5%//E
expected with two PM's	11.6%/iE	10.2%//E	15.4%//E
going from 0.6 to 0.3 r.l.	8.2%/iE	7.2%/lE	10.9%//E
better scintillator	8.2%/lE	5.1%h/E	9.7%/1/E

Table III. Parameters of the Hybrid Central Shower Detector

Modules	
Number required	40
Length	1 m
Width	1.3 to 1.8 m
Depth	0.6 m
Weight/module	2.5 tons
Scintillator Cells	
Number/module	8
Length	1 m
Width	16 to 22 cm
- Total depth (including coil)	20 rad. lengths 1.5 interaction lengths
Layers	
Number	66
Lead/layer	" 1/16 inch
Scintillator/layer	1/4 inch
Radiation lengths/sample	% 0.3
Scintillator type	Plexinonpop
Total area in 40 modules	4000 m2
Wave shifter	BBQ doped acrylic
Totalnumberof phototubes	640
Wire Chambers	
Number/module	2
Depth of chambers	2.5, 7 rad. lengths
Area of individuai chambers	% 1.4 x 1.0 m^2
Wire spacing	1 cm
Strip spacing	1 cm
Gap height	± 0.3 cm
Correlation of strip/wire pulse heights	± 57.
Total number of channels	18000

Table IV. Estimated Cost ($K) for Hybrid Central Shower Counter System.

	Material	Labor
Lead 70 tons @ 70¢lb	110	
Steel boxes (40)	40	215
Scintillator (20,000 pieces)	250	205
Lightguides and BBQ bars (640 each)	35	35
Phototubes (complete) 640 @ $375	240	
Module transporter and lead fixture	15	
Calibration system	20	15
Wire chambers		
Mechanical parts	90	
Electronics 18000 channels @ $40	720	
HV and pulsers	40	
Fixturing	15	
Labor		130
Module assembly and testing (4.5 man years)		225
	1575	825
Total	$2400K	

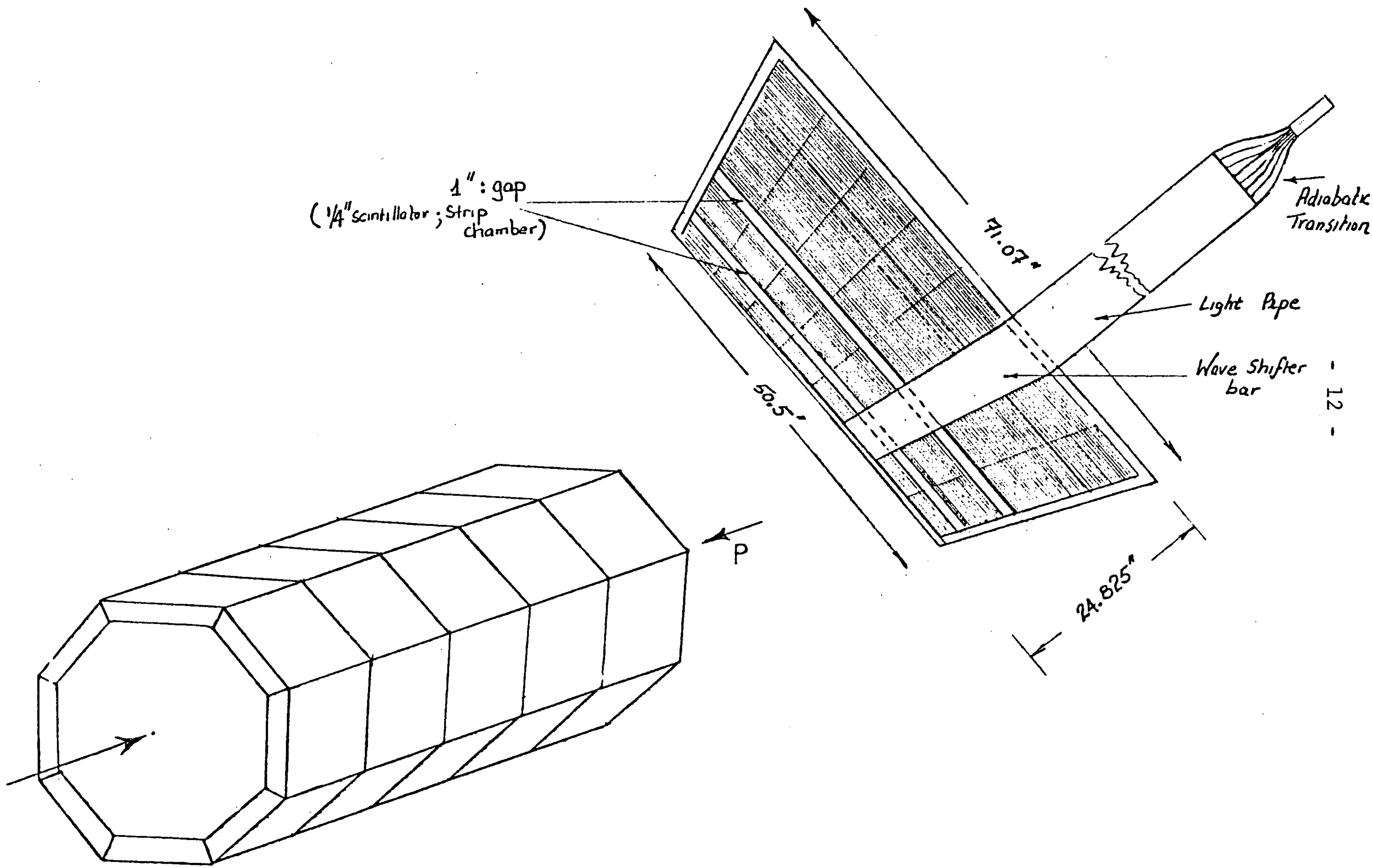

Fig. 1. Sketch of the hybrid central shower counter modules.