GEM TN-92-168

Accordion Liquid Argon/Krypton Calorimetry for GEM: Response to Questions from the Collaboration

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September 1, 1992

Abstract:

Responses to questions from the GEM Collaboration concerning the Accordion Liquid Argon/Krypton Calorimetry option.

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Response to Questions from the Collaboration
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O. Benary, [9] , S. Cannon, [5] , W. Cleland[7] , I. Ferguson[2] , C. Finley[5] , A. Gordeev[6] , H. Gordon[3] , E. Kistenev[3] , P. Kroon[3] , M. Leltchouk[5] , D. Lissauer[3] , H. Ma[3] , D. Makowiecki[3] , A. Maslennikov[4] , S. McCorkle[3] , D. Onoprienko[6] , A. Onuchin[4] , Y. Oren[9] , V. Panin[4] , J. Parsons[5] , V. Radeka[3] , L. Rogers[3] , D. Rahm[3] , S. Rescia[3] , J. Rutherfoord[2] , M. Seman[5] , M. Smith[3] , J. Sondericker III[3] , R. Steiner[1] , D. Stephani[3] , E. Stern[7] , I. Stumer[3] , H. Takai[3] , H. Themann[8] , Y. Tikhonov[4]

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Questions From The Executive Committee

B. Requirements for LAr-Kr technology : **Question:** 1. Demonstrate by beam tests stochastic term in resolution for non-projective geometry $\leq 7\%/\sqrt{E}$. Determine angular dependence of this resolution.

by August 1, 1992

Answer: We have measured the stochastic term in a beam test at the AGS and achieved this goal both with the "1 mm" stack in argon and the "2 mm" stack in krypton.

Fig. 1 shows the linearity of the electron signal in the "2 mm" accordion for 5, 10, 15 and 20 GeV. The deviation from a straight line is less than 0.5%. Fig. 2 shows the energy resolution for the same 4 momenta. The straight line is a fit with the parameters $(6.72 \pm 0.035)\%/\sqrt{E} \oplus (0.0 \pm 0.2)\%$ (after subtracting the beam spread of (0.5%) and 0.080 GeV measured pedestal width. Fig. 3 shows a histogram of the discriminator developed at

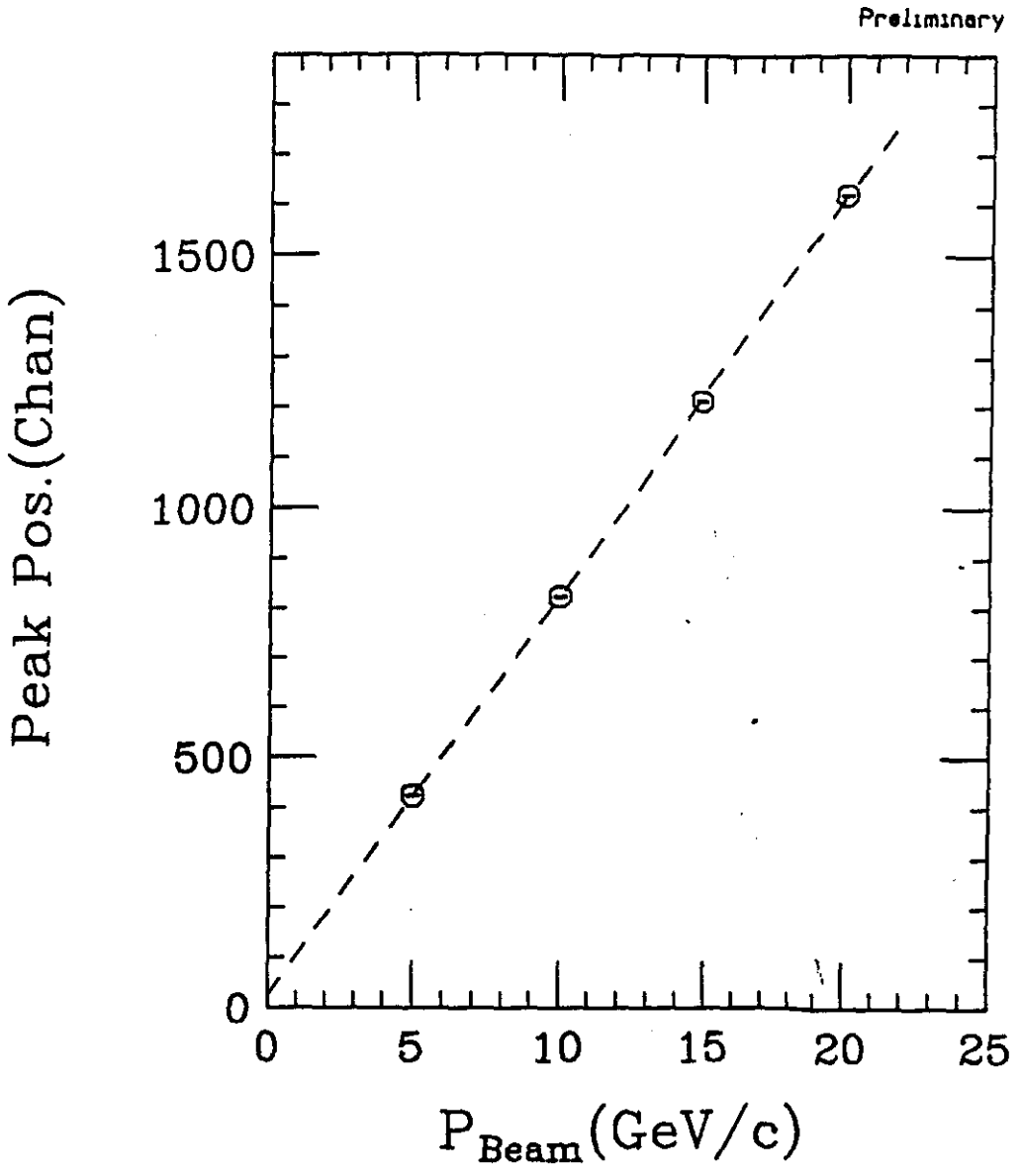


Figure 1: Energy (ADC counts) vs. beam momentum for the "2 mm" accordion with krypton.

the U. of Pittsburgh which compares the signal and its integral. This histogram was taken with taken with 15 GeV electrons and shows a timing precision of $\approx 1ns$. Fig. 4 and Fig. 5 shows the response vs. x and y in cell units for 15 GeV electrons. The y variation shows the 3 cells that make up a readout cell as seen in the RD3 data at CERN. Corrections are

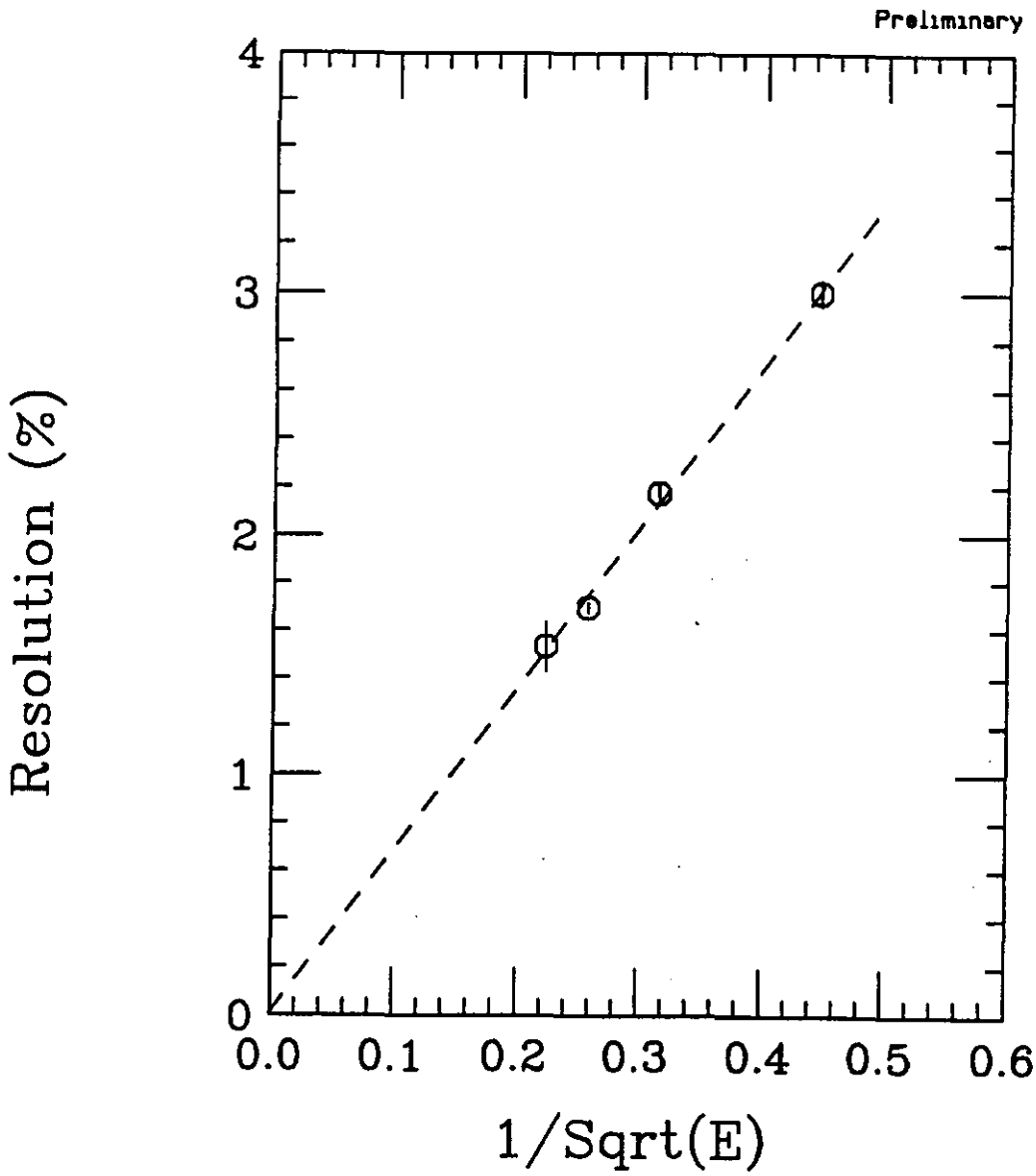


Figure 2: The energy resolution σ/E vs. $1/\sqrt{E}$ for the "2 mm" accordion with krypton.

applied to the data to remove the $< 1\%$ modulation seen. In the x direction, the variation is much less than 0.5%.

Also on Aug. 9, 1992, Paul Mockett showed $7\%/\sqrt{E}$ for his parallel plate calorimeter in argon.

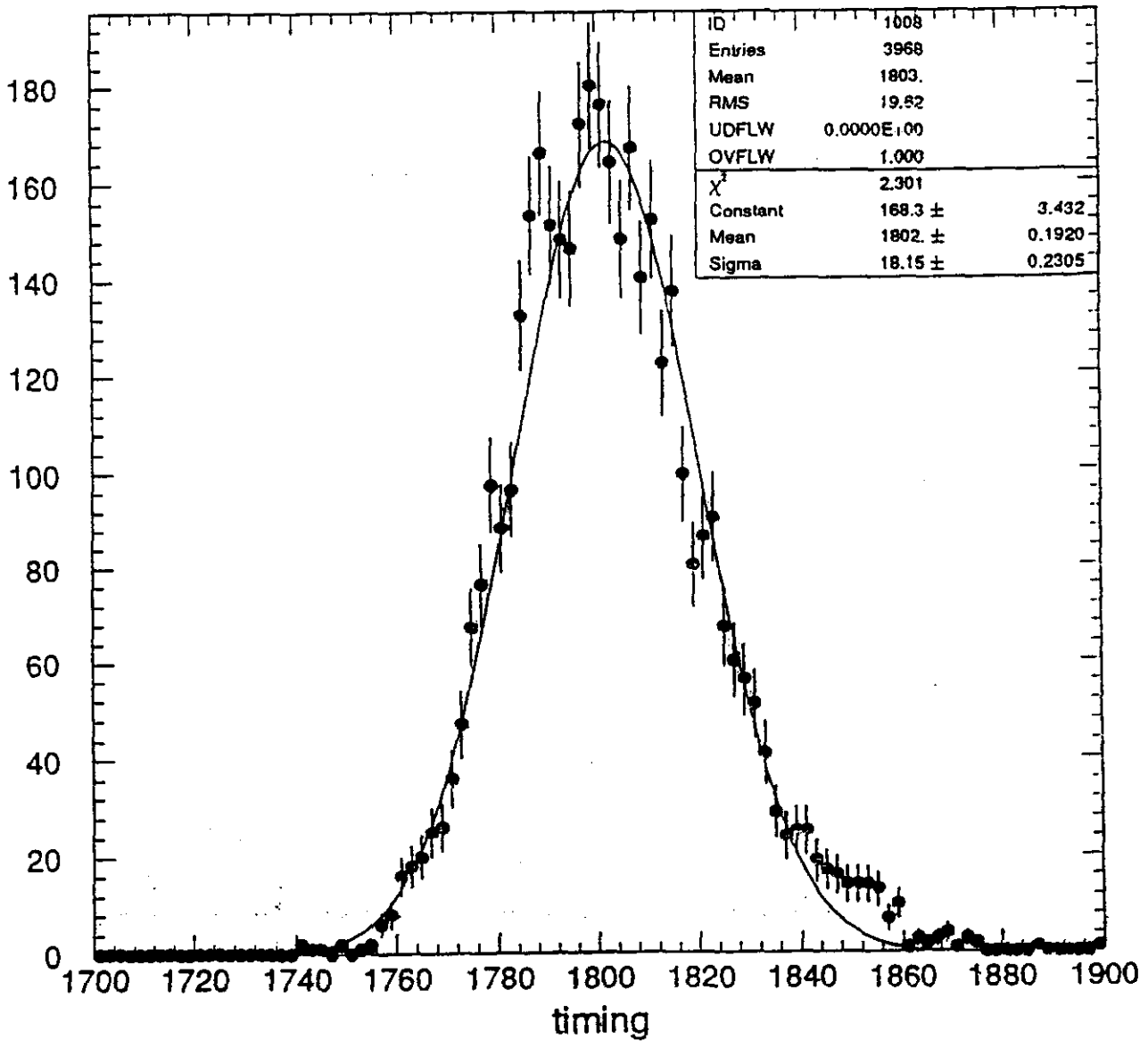


Figure 3: Timing resolution for the "2 mm" accordion with krypton. The units are TDC counts of 50 ps/count. This is for 15 GeV electrons using the U. of Pittsburgh circuit.

Unfortunately due to time pressure in the test beam, we did not have an opportunity to measure the angular dependence of the non-projective accordion stack. We had designed a stack with chevron electrodes to do this measurement. We need to rely on the Monte Carlo results. Last year there was a lack of confidence in the Monte Carlo correctly

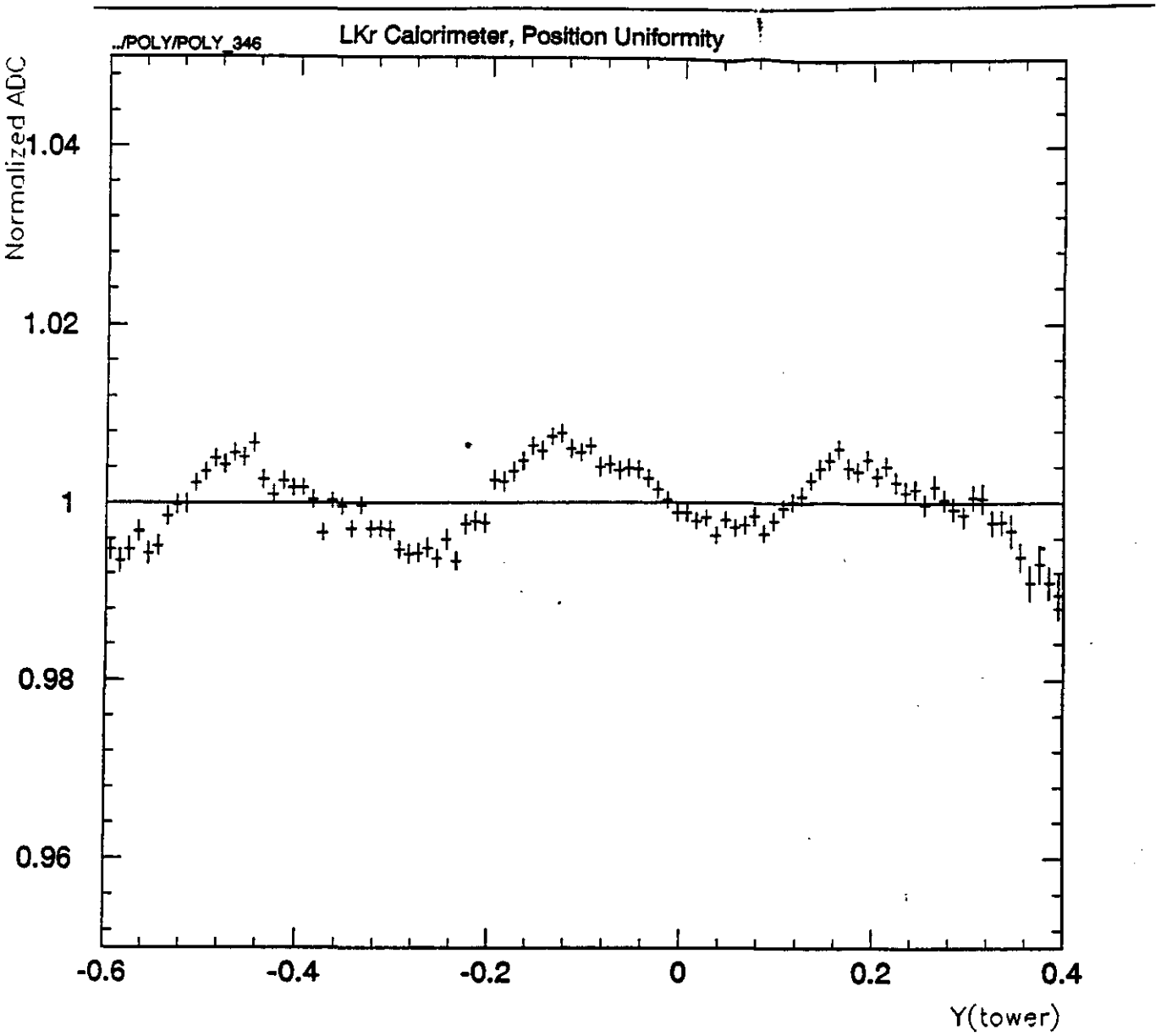


Figure 4: Relative response of 15 GeV electrons in the "2 mm" accordion with krypton vs. y(cell units).

predicting the RD3 results, since the beam measurement was $\approx 10\%/\sqrt{E}$ while the Monte Carlo predicted $8.6\%/\sqrt{E}$. It was assumed that there must be something intrinsic to the accordion structure - perhaps the corners or the electric field effects - which caused this discrepancy. However, we have measured the resolution with 3 different configurations and the data agrees quite well with that predicted by the Monte Carlo. We attribute this

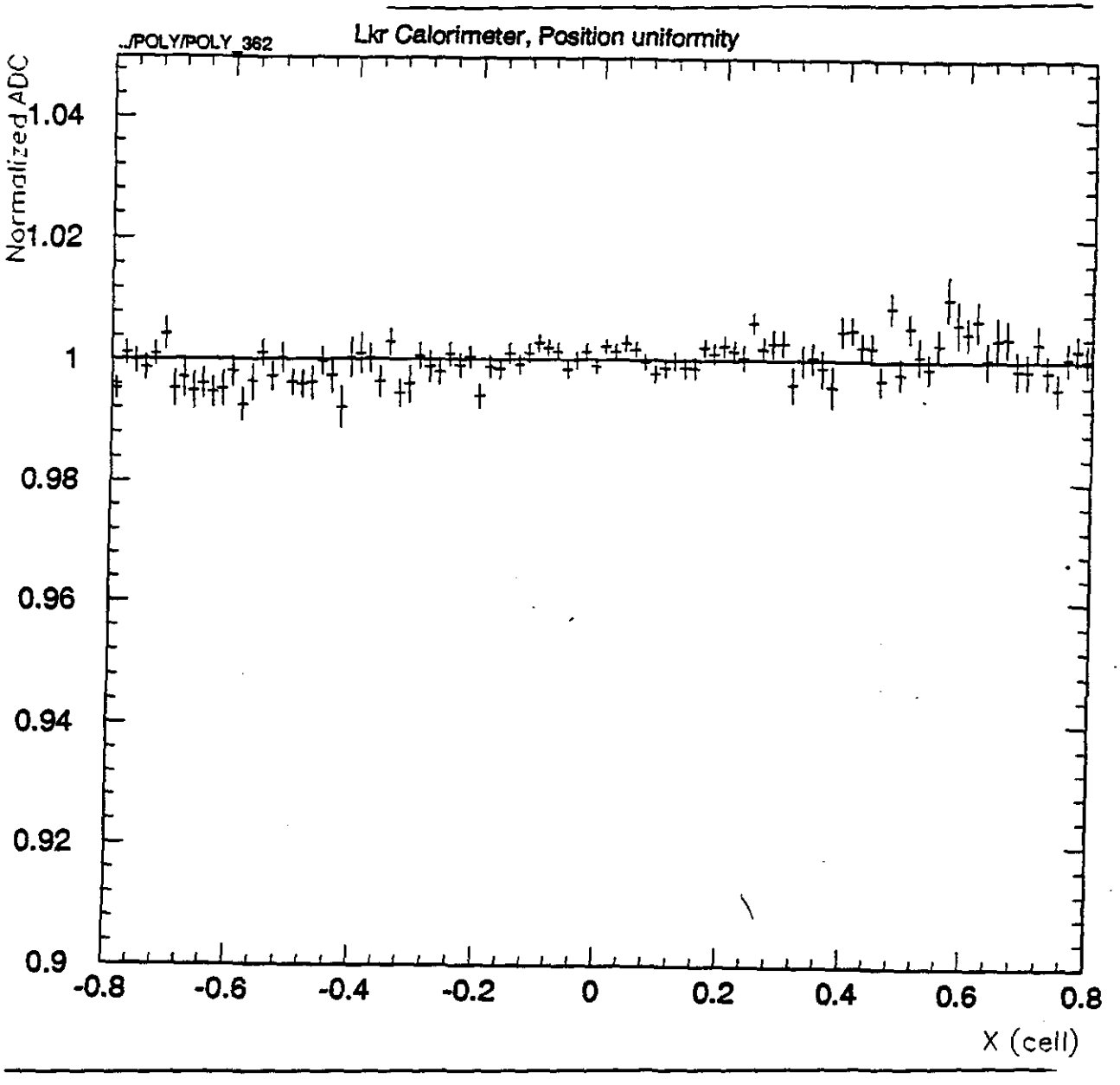


Figure 5: Relative response of 15 GeV electrons in the "2 mm" accordion with krypton vs. x(cell units).

success to the new calibration system we have used this year. The data and Monte Carlo results are given in the following table

Energy Resolution $\sigma/\sqrt{E}$		
Stack	Measurement*	Monte Carlo
1 mm Ar	6.1 - 5.8	6.25
2 mm Ar	7.5 - 7.8	7.3
2 mm Kr	6.3 - 6.9	6.3

* after subtracting beam spread of 0.5-0.7%

We plan to change the ratio of lead to stainless steel in discrete steps of η to keep the resolution from rising in the barrel as particles approach smaller incident angles. For example, Michal Seman and Misha Leltchouk calculated for the projective accordion that the resolution with 0.94 mm lead is $5.3\%/\sqrt{E}$ at 90° but rises to $8.8\%/\sqrt{E}$ at 30°. However, the resolution can be reduced to $5.8\%/\sqrt{E}$ at 30° when the lead is reduced to 0.44 mm.

Question:

2. Produce detailed mechanical design/analysis of EM barrel and end caps with optimization of gap between barrel and end cap, wall thicknesses, etc.

by July 1, 1992

Answer:

This is described in detail in GEM-TN-92-140 and was reviewed by the Liquid Argon Engineering Review Meeting, chaired by Bill Wisnewski on August 14, 1992.

Question:

3. Demonstrate by MC simulations for realistic projective geometry and full angular range (between 90 and 5.7 degrees) the resolution $<= 7\%/\sqrt{E} + 0.4\%$ and physics consequences of the gap between barrel and end cap, wall thicknesses, etc.

by July 1, 1992

Answer:

We referred above to the work of Seman and Leltchouk that have answered this question and this has been presented to the collaboration. We assume that the gap between the

barrel and end cap will be not be suitable for precision measurements as needed for such processes as $H \rightarrow \gamma\gamma$. This will be a loss of η of from $\approx 1.40 - 1.54$ for the baseline design.

Additional requirements for LAr-Kr technology :

(proposed by individual members of exec. committee and members of calorimeter group)

by the time of EM decision :

Question:

1. Show Higgs $- > 2\gamma$ spectra (mass range 80-150 GeV) for realistic EM LAr-Kr detector and background simulations.

   Answer:

   Ren-yuan Zhu and Hiro Yamamoto have done most of these simulations as summarized in GEM-TN-92-126. In particular refer to Table 5 for the effect of energy resolution on the length of time it will take to find a Higgs vs. the mass of the Higgs. Figure 14 shows the signal and background with the assumptions made in this report. We feel that the analysis procedure was not optimized for the liquid ionization detector. There was a significant start towards rectifying this deficiency in the work of Tomasz Skwarnicki presented during the $H \rightarrow \gamma\gamma$ Task Force Meeting on August 4, 1992. The analysis procedure that Tomasz suggested requires more work and more detailed simulations, but shows the promise that the background from γ+jet and jet+jet can be reduced below the "irreducible" background. The tracker had not yet been employed to help in rejecting jets. We suggest that by selecting tracks with $p_T > 2\ GeV$ will allow an additional rejection of jets.

   Question:

2. Provide detailed practical plan for calibration of LAr-Kr detector in situ. Provide an evidence that electronic calibration is equivalent to the detector calibration with the required accuracy.

   Answer:

   Fig. 6 shows a schematic of the calibration system that was used in our beam tests this summer. We have measured that the system is linear to better than 0.1% over most of the dynamic range necessary for the SSC EM calorimeter.

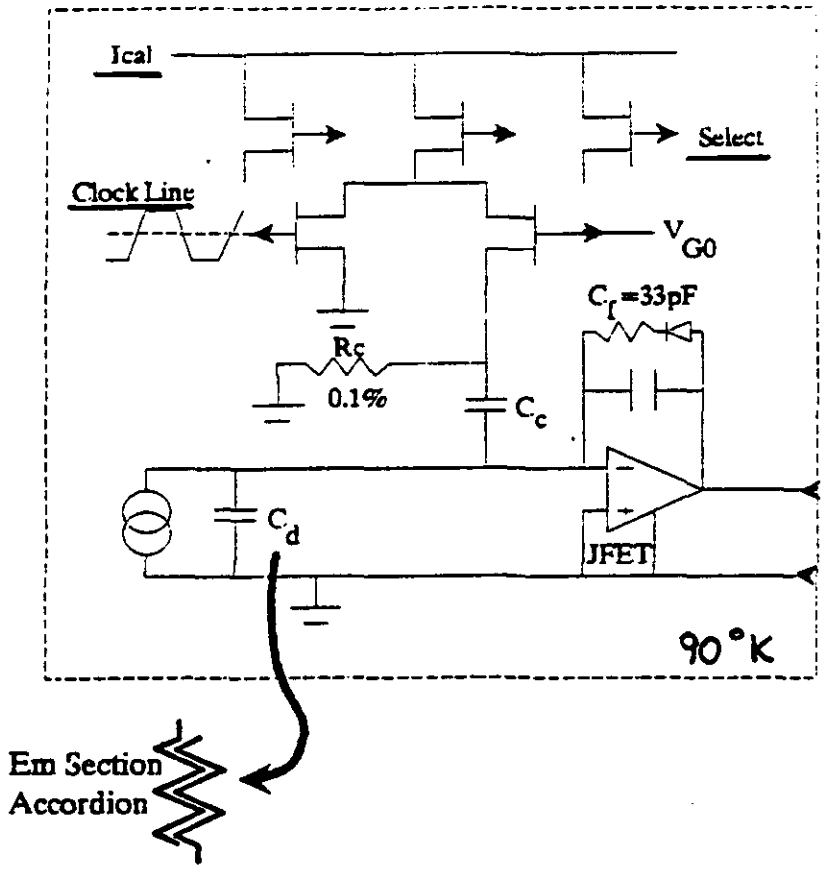


Figure 6: Calibration system used during 1992 Beam Tests

Fig. 7 shows the nonlinearity of the calibration system, preamplifier, and shaper with peaking time of 25 ns. There is no problem at the high end where 5 ma corresponds to $\approx 6TeV$. This system uses a DC current which is easily transported accurately over the large geometric distances of the detector. There are fast switches very close to each preamp to allow this current to simulate the liquid argon signal.

The evidence that this calibration system has the required accuracy is that we used only this calibration to set the gains of each channel in the beam test and then were able to measure the resolutions that agreed with the Monte Carlo. In fact we measured an improvement in the resolution in going from 3×3 cells to 5×5 cells as predicted by the Monte Carlo but which was not observed in the RD3 measurements at CERN. This calibration system will be used to equalize the response of all channels.

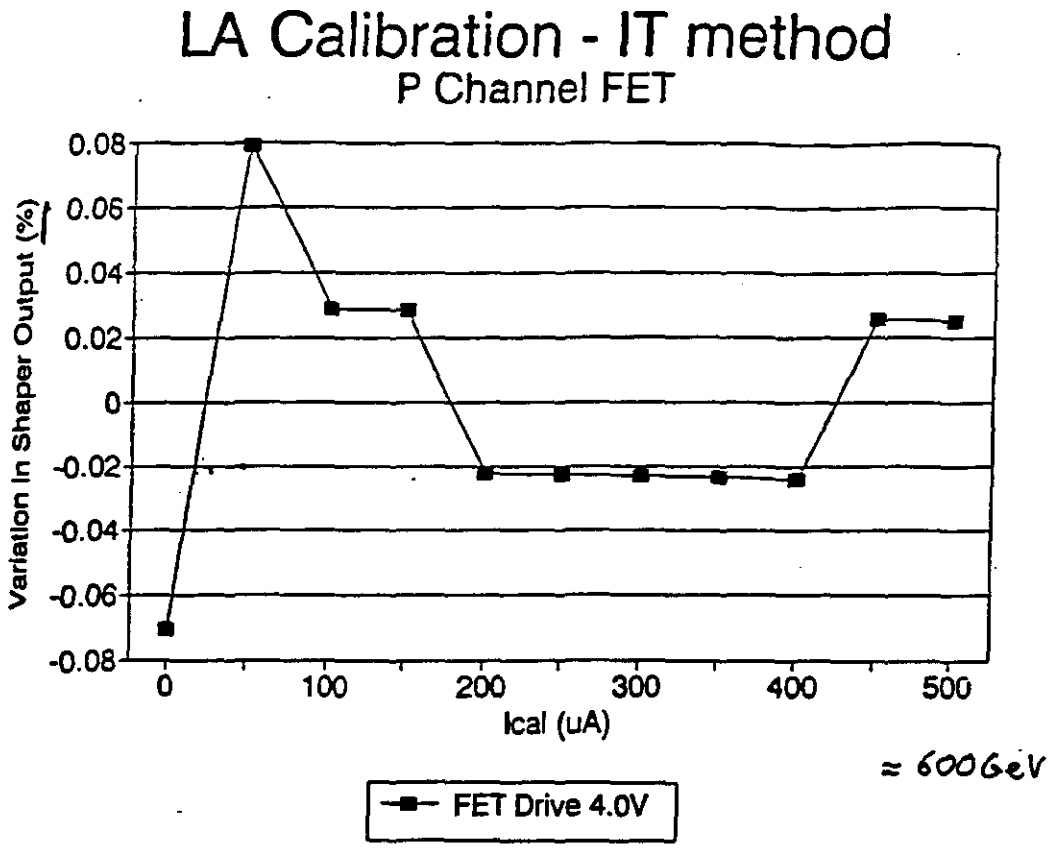


Figure 7: Nonlinerarity of the calibration system, preamplifier, and shaper used during 1992 Beam Tests

We also expect to use $Z^{\circ} \rightarrow e^{+}e^{-}$ and other physics processes for absolute calibration and to monitor the performance of the detector *in situ*.

3. Provide experimental proof of radiation stability of LAr-Kr EM system (for actually used materials).

   We refer to the CERN yellow report 82-10 Compilation of Radiation Damage Test Data for evaluations of materials to be used. For example polyimide(Kapton) and glass laminate epoxy(G10) are good to beyond 10^9 rads. We intend to refer to this reference for the use of all actual materials that are to be used in the final design of the calorimeter.

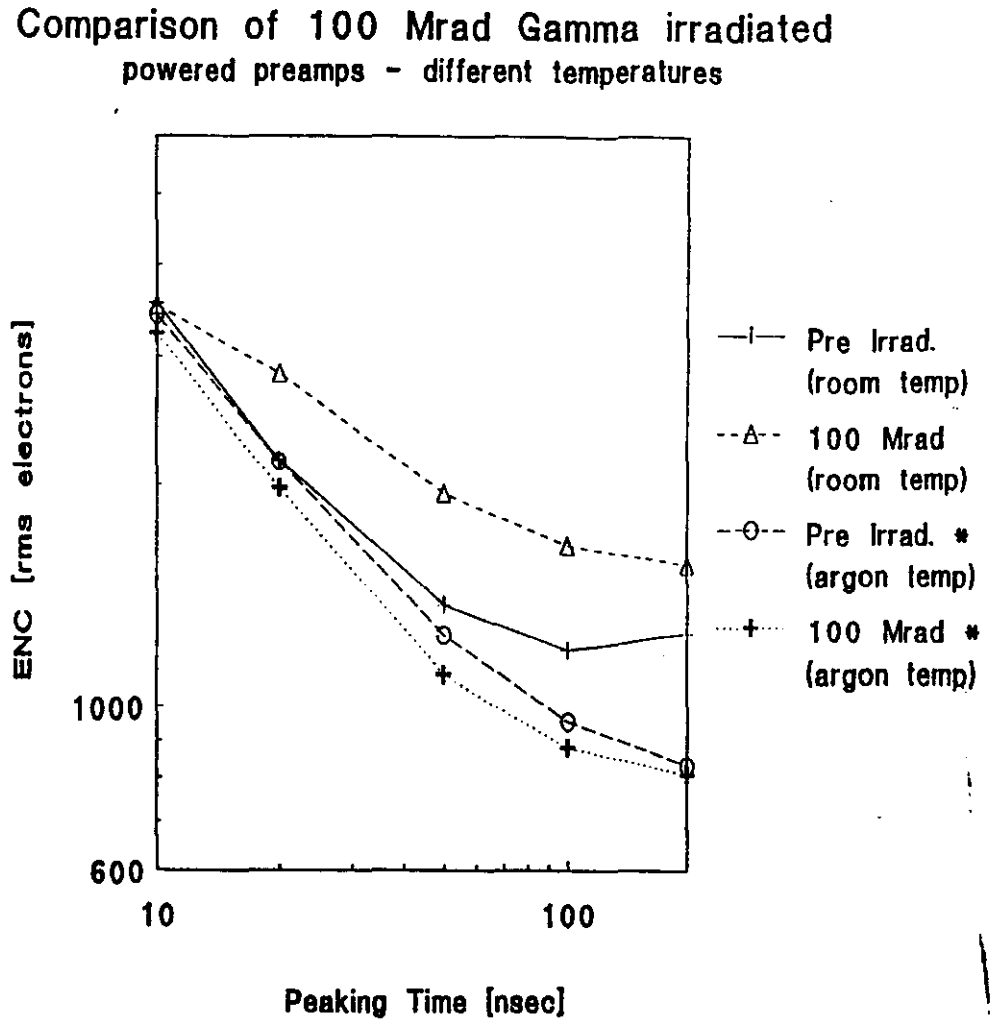


Figure 8: Measured noise for Si JFET preamps irradiated with ^{60}Co vs. peaking time.

Preamplifiers have been tested up to 100 Mrads and 4×10^{14}neutrons/cm^2. Fig. 8, and Fig. 9 summarize the results.

Question:

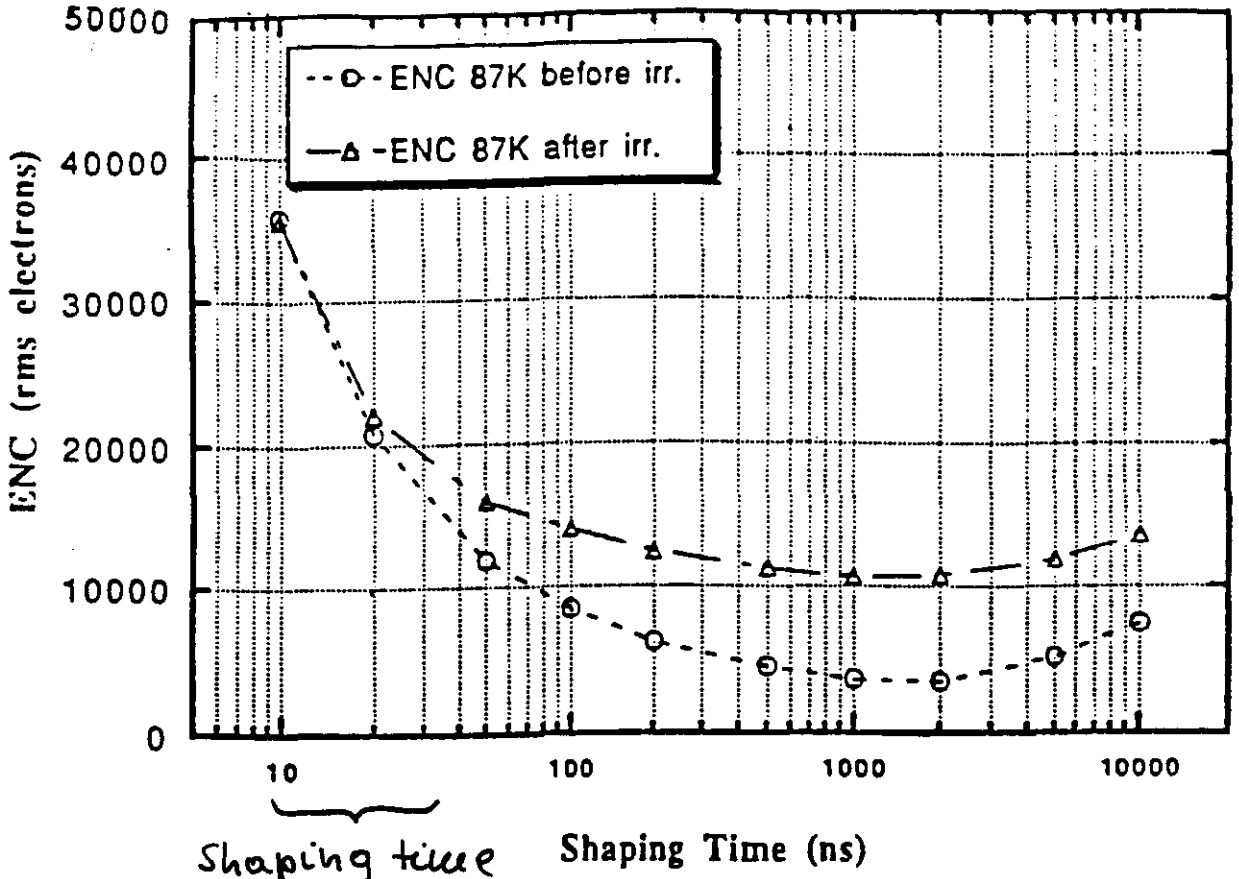
4. Provide the results of the benchmark tests of LAr-Kr electronics which demonstrate required linearity, dynamic range, white and coherent noise in the real accordion system, cross talks and means of linearity calibration.

Answer:

In our test coherent noise was measured to be negligible in sums of up to about 150 channels. The total noise was proportional to the sqrare root of the number of channels as expected if there would be no coherent noise.

Preamplifiers - Neutron Irradiation - 4×10^{14} n/cm^2

Si JFET, SNJ 450 H, BNL preamp



Shaping time for high rad. fields

Figure 9: Measured noise in Si JFET irradiated by neutrons vs. shaping time.

POINTS OF COMPARISON FOR TWO EM CALORIMETER TECHNIQUES IN GEM

- EM resolution constant term with separate contributions break down (to be prepared by H. Gordon and H. Newman)

  Answer:

  We have measured the contribution of the electronics to be better than 0.1%. This will be our goal.

- E-m resolution stochastic term (to be prepared by H.Gordon and H.Newman)

  Answer:

We measured better than 7% with krypton and 1.3 mm lead plates. By going to 0.94 mm plates as Michal Seman calculated, the resolution should be better than 6%.

- $\pi^0 - \gamma$ separation, shower shape analysis, preradiator - or more generally - background suppression capability (to be prepared by H.Ma, R.Zhu, K.Shmakov, Yu.Efremenko, Higgs Task Force ...) [see also report GEM TN 91-33]
- Pointing (to be prepared by K.Shmakov, Yu.Efremenko, X.Shi ...)

Question:

- Significance vs luminosity (Higgs$\rightarrow \gamma\gamma$ example, ...) (to be prepared by J.Rutherfoord ...)

Answer:

At the High Luminosity Workshop held in Boulder, CO in July, 1992, Jim Brau, Bill Cleland, Frank Paige, and John Rutherfoord tried to determine the optimal luminosity (L) for $H \rightarrow \gamma\gamma$. The following remarks and graphs are from that Workshop and may not be quantitatively accurate but the trends and qualitative effects are probably correct. As the L increases, the p_T threshold on EM clusters (γ candidates) must rise in order to keep the Level I and Level II trigger from saturating. This reduces the trigger efficiency as L increases as shown in

Fig. 10.

The statistical significance for the signal is equal to the number of signal events divided by the square root of the number of background events: $\sigma = S/\sqrt{(N)}$. Therefore σ increases linearly with with L due to the increase of the signal but the background events increase due to three factors: 1) the increase in L, 2) as the isolation cut degrades with increasing L, 3) as the mass resolution degrades due to extra vertices. An attempt to take all these factors into account is shown in

Fig. 11. The optimal luminosity appears to be very near the SSC design of $10^{33} cm^{-2} s^{-1}$.

- Pileup noise (to be prepared by T.Skwarnitski, Peter Denes ...)
- Thermal noise (coherent noise) (to be prepared by R.Zhu, H.Gordon ....)

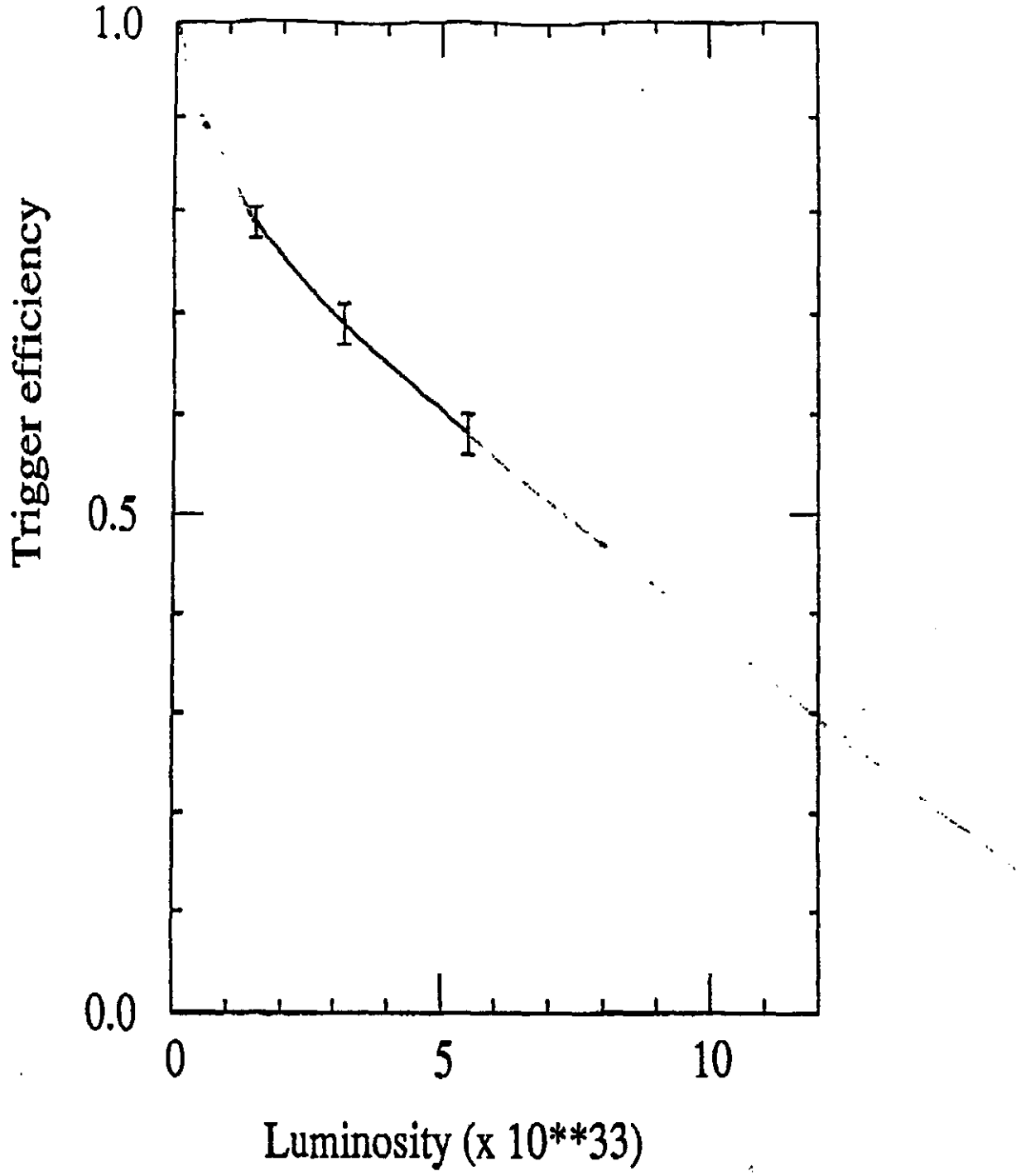


Figure 10: Trigger efficiency for $H \rightarrow \gamma\gamma$ vs. L for a liquid argon calorimeter $|\eta| < 2$.

We have measured 0.085 GeV for 5×5 towers (including both depths). The krypton had not quite reached the final purity which would raise the signal

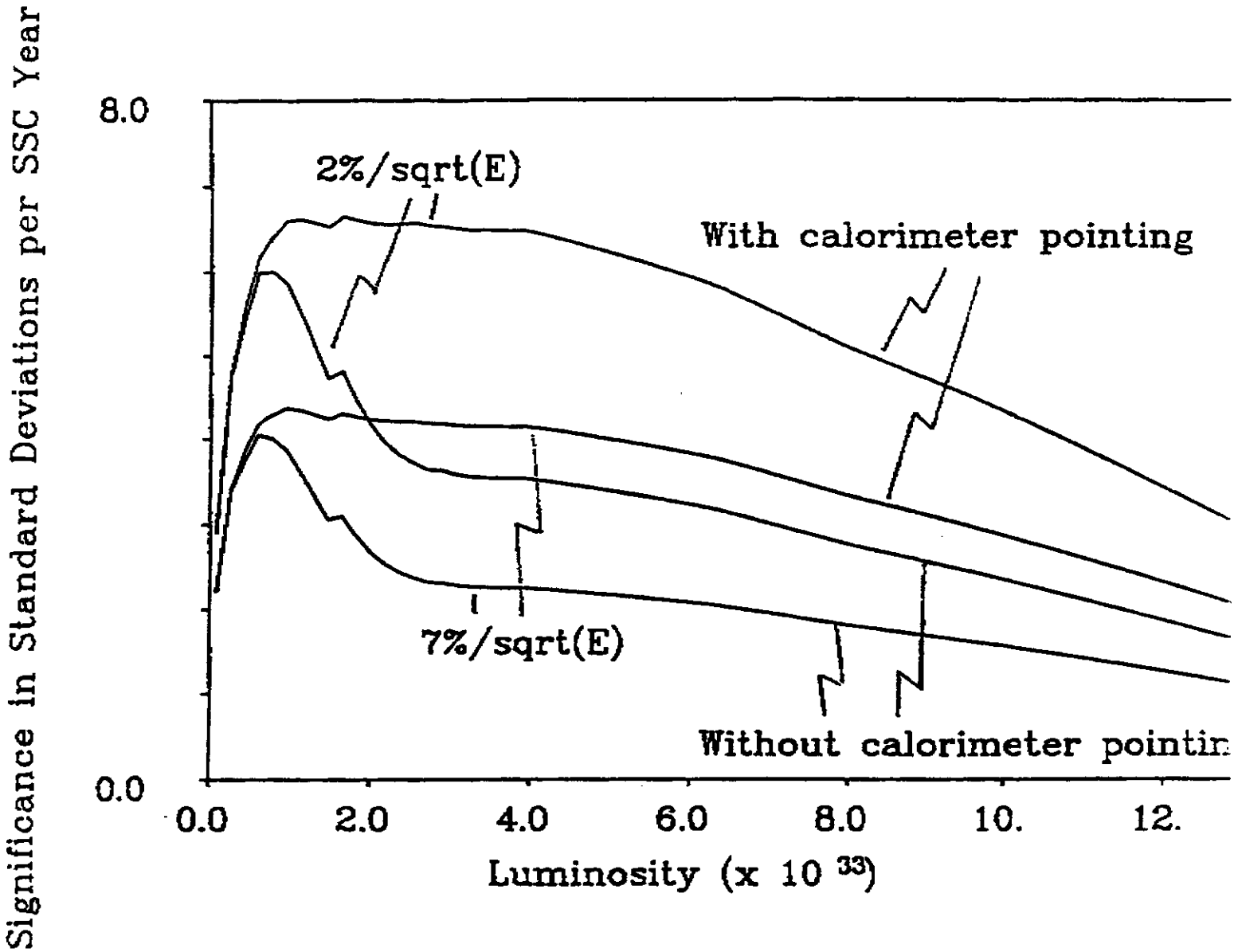


Figure 11: Significance in Standard Deviations per SSC Year vs. Luminosity for $H \rightarrow \gamma\gamma$.

somewhat. But also the calorimeter was not deep enough, which would raise the noise somewhat, so ≈ 0.100 GeV is a reasonable value.

- Radiation damage and response stability
  (to be prepared by H.Newman, H.Gordon ...)

  Answer:

  See above.

- Calibration strategy and accuracy
  a)calibration of the detector
  b)calibration of the electronics
  (to be prepared by ORNL group, H.Gordon, R.Zhu ...)

  Answer:

  See above.

- Digitization, electronics, required dynamic range etc. Is electronics technology independent? (to be prepared by P.Denes, D.Marlow(?) ...)
- Reliability, falure rates - consequences for physics
  (to be prepared by H.Newman, H.Gordon)

  We plan to test the preamps, and connections before sealing the cryostat sufficiently to guarantee that the failure rate is much less than 0.1% over the lifetime of the experiment. We have confidence from our experience with the cold preamps in years of running in NA34 at CERN and the last two years of beam tests at BNL and CERN that this can be reached - provided sufficient pre-testing is done. We have confidence from the experience with D0, SLD, and H1 that the overall reliability of the calorimeter can be met.

- mechanical design (status, risk, possibility to be produced outside the US)
  (to be prepared by M. Rennich)
- Schedule and manufacturing plan
  (to be prepared by M. Rennich)
- Risk (to be prepared by M. Rennich)
- Cost $ US, part of the cost which should be spent inside US
  (to be prepared by M. Rennich)

Answer: In our cost estimate there are 694,302 person hours for fabrication, assembly and test of the modules, the cryogenics and the calorimeter. We have identified at least 388,883 person hours that can be done in a foreign country. This represents $12.3 M in the cost estimate. We would also assume that most of the $ 41.0 M of materials would come from foreign sources. Until the responsibility is settled with our foreign collaborators, we can not estimate how much of the $ 14 M EDIA will be done overseas. In total, significantly more than 50% of the cost can be expected to be shifted to foreign sources.

- Who will build the calorimeter? Responsibility and quality control. (to be prepared with collaboration management)

Further questions

Concerns about the consequences of a possible choice for LAr/LKr as the GEM electromagnetic calorimeter

The worries of the SSCintCAL members mainly concern the following aspects: *Timing (1), Hermeticity (2) and Liquid purity (3).* Apart from that, the recent prototype studies at BNL have generated a number of questions about the performance of this type of detector.

1) *Timing.* The charge collection in a calorimeter operating in the ionization chamber mode is an intrinsically slow process. Bipolar pulse shaping does allow to extract reasonably fast signals (at the expense of the amount of collected charge and thus the signal/noise ratio), but the question arises if these signals are indeed fast enough, given the time scale dictated by the rate of SSC collisions. The time resolution is quoted to be "less than 1 ns". However, the data that should support this statement were obtained with constant fraction discrimination of monoenergetic pulses from one and the same cell, with no pileup taken into account. This data has no relevance to the practice of an experiment at the SSC, where the calorimeter has to be self-triggering, on signals with an arbitrary pulse height, coming from many different detector cells, using a waveform fitting method that samples 16 times slower than the quoted time resolution, in the presence of considerable pileup disturbance. We are therefore worried that the time resolution in practice may turn out to be much worse

than 1 ns, which may lead to unacceptable consequences like assigning large numbers of events (partially) to the wrong bunch crossing. These worries are fueled by the initial experience at HERA, where ZEUS (unlike H1) is able to trigger on the signals from the (still rare) $e-p$ interactions by using the time difference between the signals from the front and rear sections of their calorimeter. The time resolution of the H1 LAr calorimeter is absolutely inadequate for this purpose.

Answer:

Timing in a Liquid Ionization Calorimeter

The timing resolution which can be expected from a liquid ionization calorimeter operating at the SSC can be reliably estimated from a knowledge of the thermal and pileup noise. In the regime where both pileup and thermal noise are present, corresponding to typical operating conditions at the SSC, a lower limit (for the case where the entire waveform is sampled, and optimal shaping time is used) for $A\sigma_\tau$ is given by the simple formula

$$A^2\sigma_\tau^2 = \sqrt{8t_d^3\,\rho_t^3\,\rho_p}$$

in which t_d is the drift time, ρ_t is a constant which determines the level of thermal noise, and ρ_p is the corresponding constant for pileup noise. For the liquid argon calorimeter in accordion geometry, a single cell covering .04 $\times$.04 will have $\rho_t \approx 8$ MeV $\sqrt{ns}$ and at a luminosity of 10^{33}, ρ_p will be about 3.75 MeV/$\sqrt{ns}$ for the same size cell. This leads to a value of $A\sigma_\tau$ of about 1 GeV$\times ns$ for an electromagnetic cell. Detailed calculations for 5 samples and a shaping (measurement) time of 50 ns give a value of about 1.4 GeV$\times ns$, so the above simple formula needs to be multiplied by a factor of about 1.4 for the realistic case. Thus in the offline analysis, signals of 1 GeV or greater can easily be assigned to the correct crossing.

Using this equation, it is easy to calculate the scaling of the time resolution with tower sum size. The pileup noise scales as $A^{0.76}$ and the thermal noise scales as $A^{0.5}$. Thus $A\sigma_\tau$ will scale as $A^{0.56}$. A trigger tower of 5$\times$5 cells will therefore have a time resolution figure of about 8.5 GeV-ns. Gamma showers

of any energy of interest can therefore also be correctly assigned to the correct crossing.

A timing discriminator exploiting the recently developed principle of detecting the point at which the waveform is equal to a constant times its integral (a point which is independent of the amplitude of the waveform) has recently been tested in the LAr/LKr beam test. A calculation of the resolution expected on the basis of thermal noise alone in a 5×5 sum is about 10 GeV-ns, higher than the resolution obtainable from digitized samples. The discriminator has been shown on the bench to exhibit a precision of better than 1 ns when examining signals of amplitude between 20 mV and its upper range of 4 V. The timing is then independent of the energy over a large dynamic range. It should be pointed out that, unlike a constant fraction discriminator, this circuit is extremely simple and requires no adjustments. The module which was tested at BNL was simply plugged into a NIM bin and the result recorded in a TDC. We achieved a resolution of 1.1 ns with signals of energy 10-15 GeV. This being a prototype module, improvements are possible. We are encouraged by the ease with which adequate resolution for a first level EM trigger was obtained. Intrinsic timing accuracy with noble liquids is very good because the statistical fluctuations in the waveform are very small due to a large number of electrons produced by ionization ($\approx 3 \times 10^6/GeV$).

Question:

2) *Hermeticity.* Everybody who has seen the BNL setup makes the comment that one has to stretch the imagination very far to include the accordion calorimeter in a detector system that has hermeticity as one of its prime design goals.

Answer:

We agree that it would be difficult to visualize an EM liquid calorimeter inside of a scintillating fiber calorimeter. This is why we have supported the Baseline design - an integrated EM + HAD liquid calorimeter. This puts the services at the outer radius where they can be fit in without any degradation of physics performance.

Question:

3) *Liquid purity.* In the BNL tests, the LKr signal changed considerably with time (up by 75% in a test cell with an α-source over a period of 2 weeks). This was the result of ongoing purification of the liquid. It is questionable if the liquid in the complex GEM configuration can be equally recirculated, such as to avoid these effects. If possible, this is likely to imply considerable extra complications (cost!) in the detector, including extra plumbing, which may further jeopardize the hermeticity. If not, local "poisoning" of the liquid could occur, possibly enhanced by the effects of radiation. The accordion contains many components that may decompose under the effects of radiation (G-10, kapton, plastic insulators, etc.) and induce impurities in the liquid.

Answer: We were rushed in our preparations for the beam tests this year and used Rohacell foam which caused contamination. This contamination was recoverable with purification, but we would like to make sure that such material will not be used in our design. However, even in this case, the purity of the liquid was measured and the response to particles was correctable with the data from the alpha and beta cells.

Fig. 12 shows the response of one of the typical ^{243}Am test cells in the DØ calorimeter from data taken over 4 months in 1992. The stability is $< 0.2\%$. Since the response to $\alpha's$ is much more sensitive to impurities than electromagnetic or hadronic showers, the stability of the calorimeter for physics measurements should be better than 0.2%. This system has no purification system and the argon is not circulated.

At the Dallas conference in Aug., 1992, the H1 collaboration reported a stability of $< 0.2\%$ during a year of operation for their liquid argon calorimeter.

Question:

As to the results of the BNL tests, we would like to remark that

a) The studies were done with a *nonprojective* structure and therefore not representative for the real case.

Answer:

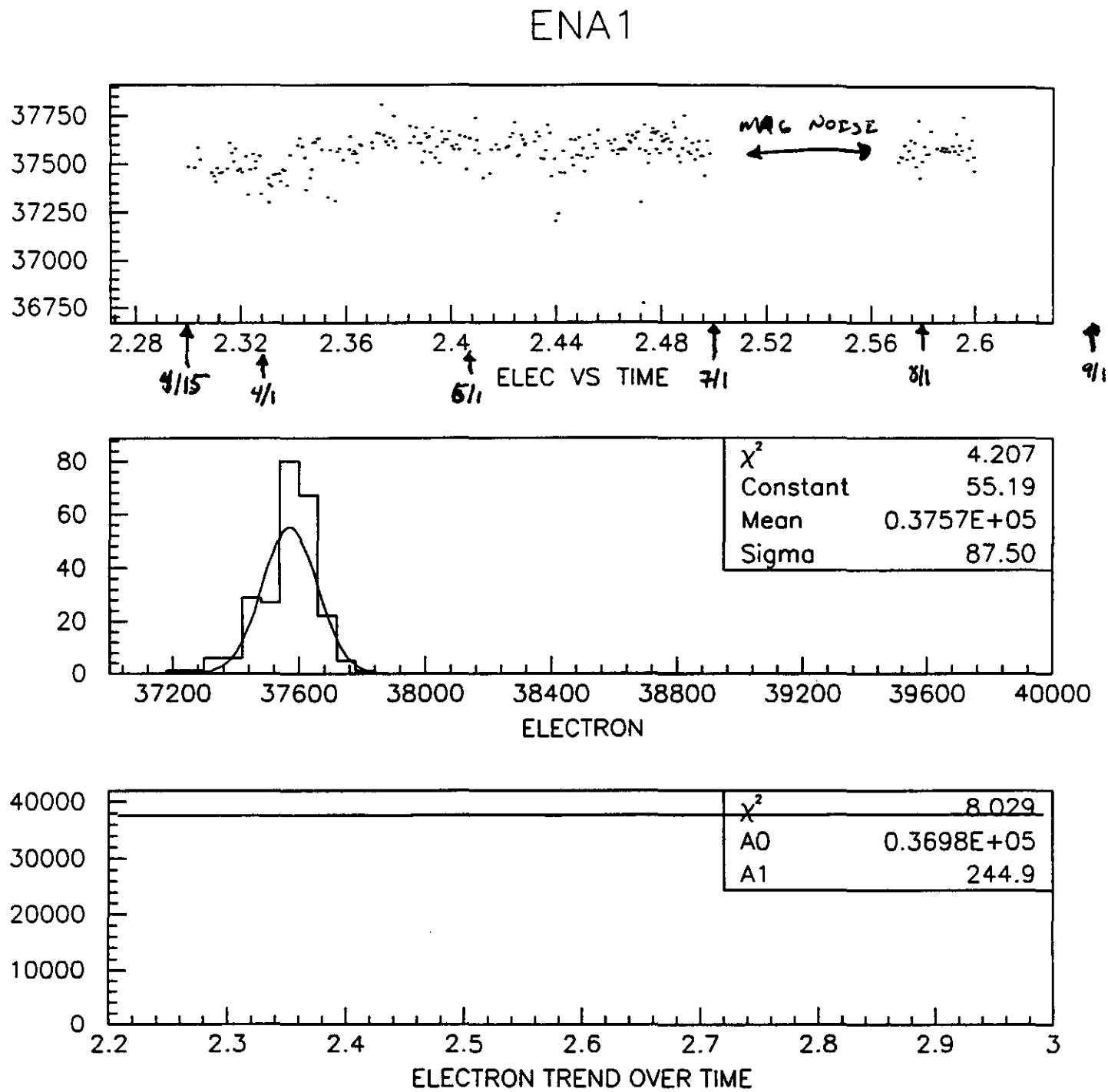


Figure 12: Mean value of a typical α cell in the final D0 calorimeter vs. time (in years - 1990) (private communication from G. Blazey)

As noted above, the Monte Carlo had been shown to agree quite well with our results for the non-projective accordion and so we now have confidence in the results for the projective accordion of Seman and Leltchouk.

Question:

b) The studies were done, or at least the presented results were obtained with "track & hold" electronics, rather than with the "waveform" electronics (16 ns sampling) needed for GEM. Apart from that, we would like to ask the following questions about the data obtained during these tests.

- Regarding the point just mentioned, we understand that some data was taken with the AMU-ZEUS waveform electronics. We would like to see a comparison between the ADC signal distributions reconstructed from this electronics and the ones presented by D. Lissauer.

Answer:

We point out that the track & hold procedure is simpler than the waveform digitization in that only a single point is measured. We also took data with the Nevis electronics using a modified ZEUS AMU with samples every 18 ns. That data is currently being analyzed. In principle, multiple samples are more accurate since one can fit to a wave form. The analysis in this case is more complicated but if the readout electronics is sufficiently good, the results should be better than with a single sample. This is common to all EM readouts.

Question:

- It is claimed that the on-line calibration is extremely good and that no corrections to the calibration factors are needed to obtain the energy resolution. Raw data at 15 GeV were shown to illustrate this point. We would also like to see the ADC distributions measured at the other energies: 1, 5, 10 and 20 GeV. That would also allow us to judge if the parametrization of the energy resolution into a scaling term and a noise term (but no constant term) is reasonable.

- We would like to see the results (signal, resolution) of the spatial scans that were performed over the surface of the calorimeter. Since the calibration is apparently excellent, the raw ADC signal distributions should reveal the calorimeter nonuniformities, if any.
- Tests at CERN (RD3) showed an angular dependence of the calorimeter signals for this type of detector. Were angular studies done at BNL and, if so, what were the results?

  Answer:

  See discussion above.

  Question:
- We are particularly concerned about the high noise level of this detector. Therefore, we would like to see the residual response in an "isolation cone" outside the region hit by an electron, e.g. an area of 15×15 cells (minus the 5×5 area containing the shower), representing a cone with $R \approx 0.6 - 0.7$.

  Answer:

  There was no evidence of any coherent noise. That is the width of the pedestal scaled by the square root of the number of channels that were added together. The noise values for any number of towers then can be determined by using the 17 MeV/tower we measured with krypton in the 2 mm stack. We actually expect that the number would be less than that due to many factors - but this is an actual measurement.

  Question:
- The energy resolution results that were shown concern detector volumes of 3×3 or 5×5 detector cells. It is our understanding that the analog sum signal of these cells was digitized for this purpose. However, in practice one will have to work with individual detector cells. Therefore, we would like to know what happens to the energy resolution when the signals from the 25 detector cells are separately digitized.

  Answer: The σ/mean for the 2 mm krypton data was below 2%. Measurements in this range bring out all the weak links in a system. For us the weak link was the LeCroy FERA ADC's. When we did our calibration using various

amplitudes, we saw a non-linearity. All other parts of the system were checked before and were found to be linear to better than 0.1%. This is why we have first analyzed the analog sum data, however, we are beginning to understand the data from the individual channels and will present this data as soon as possible.

Question:

- It is unclear to us why the signal/noise ratio of the "1 mm LAr accordion" is so much worse than for the "2 mm Lar accordion" , given the fact that the sampling fractions and the widths of the LAr gaps are about the same in both cases.

Answer: There is only a single 2 mm argon gap for every "1 mm" absorber plate, so the signal is roughly 15% than that in the "2 mm" case. Also the capacitance is larger in the 1 mm case due to the single argon gap. This accounts for the larger noise.

Question: from Harvey Newman

Just a few things that bother me about LAr/LKr, since so much is at stake, and since we are on the verge, it appears to me, of proving (far sooner than is normally required for a project of this type), the practicality of a high precision BaF2/SSCinstCal system:

(1) In contrast to the crystals, where each one is a "module" with edges, the LAr/LKr accordion phi-segments have real gaps. What is the resolution across these gaps ? Even after the engineering report (see below) I have no feeling at all for the overall detector resolution. We understand in great detail, from L3 especially what happens across the crystal boundary. No lower-precision detector can implement similar corrections to similar precision, from one module to the next.

Answer:

We will design the calorimeter so that there will be no difference in response in going across a ϕ module boundary. This is achieved by having one side of the module end with an absorber plate and the other side with a signal board. We see from our test beam data that there is plenty of information to allow

corrections to the data in going from readout cell to readout cell even without boundaries. We see only the $\approx 1\%$ modulation due to the accordion structure.

Question:

(2) Supports: the entire engineering book answering questions on LAr/LKr avoids the two key questions:

(a) How are the modules fixed to the cryostat. What is the analysis of where and how the loads are transmitted ? (b) What are the differential thermal effects on the accordions, under different constraint (support) scenarios, and in different orientations. Only gravity is mentioned in the engineering report; this is hardly the main source of forces that may distort the structure,or worse.

Answer:

Answer Reference: 1. Responses to Questions Regarding Engineering Issues of the GEM Noble Liquid Calorimetery Options , August 14,1992 Meeting at SSCL

Finite element analysis was performed to determine the effects of thermal contraction on the behavior of the accordion plate. The results of this analysis were presented at the August 14,1992 meeting at the SSCL. The following information was obtained from the handout distributed at this meeting as GEM-TN-92-14.

As stated on p.25 :

"Since the effective axial coefficient of expansion of the accordion plate is almost identical to that of the cryostats no mechanical compensation is required"

"Analysis was performed to determine the effective axial thermal coefficient of expansion of the absorber plate for thermal cooldown from 296K to 77K. For the baseline lay-up(0.4mm stainless, 0.2mm G10 and 1.3mm Lead) the effective per cent change in length(Δ L/L) in the axial direction is 0.35% as compared with that of aluminum of 0.37%. Therefore, the accordion plate should contract like the aluminum cryostat in the axial direction during thermal cooldown."

"The radial(across the folds) thermal contraction of the accordion plates is known to be greater than the simple contraction of the material..."

"Analysis has shown that the baseline accordion plate radial thermal contraction due to thermal cooldown to 77K is 0% greater than the simple contraction of the material, based on plane stress assumptions. ... For the baseline layup(0.4mm stainless, 0.2mm G10 and 1.3mm Lead) the effective per cent change in length($\Delta L/L$) in the radial direction is 0.47% "

The current EM support configuration allows for free contraction of the accordion plate in the axial and radial direction. However, R&D activity will be required to determine the structural behavior of the lead alloy. Since lead tends to creep at low stress levels, this would have a large effect on the overall thermal contraction of the accordion plate. Once this behavior is understood sufficient space will be provided in the axial and radial direction to allow for the relative motion of the accordion plate and cryostat during thermal contraction.

The outer radius of the barrel EM has a "Tee" shaped "Outer Clevis" every 9 degrees at each of 3 axial locations, Z=-2045.5, 0.0,+2045.5 for a total of 120 clevises (Reference Figure 1-1). These Outer Clevises are supported by channels inside the cryostat (Reference Figure 1-3a) providing radial and tangential support. The 40 Outer Clevises at Z=0 are fixed axially with the rest being free to slide axially. The Inner Clevises attach the accordion to the Cryostat only at Z=0 by means of an Alignment Pin and Alignment Plug. The Alignment Pins allow radial motion between the inner cryostat wall and the inner radius of the accordion EM (Reference Figure 1-3a). The EM is "fixed" axially and tangentially by the inner Alignment Pins.

The outer radius of the EM will be designed to shrink the same as the aluminum stay that supports it ($\Delta L/L$=0.0036). This is accomplished by "prescribing" the layup of the G10 spacers on the outer radius to shrink as $\Delta L/L$=0.0033 such that the "cell" shrinkage matches the shrinkage of aluminum (0.0036). G10 properties normally fall in the range of 0.0063 for resin to 0.0021 with 30% fiber woven in the plane of a board.

Outer "Ring"			
	Cell Thickness(mm)	$\Delta L/L$	ΔL
G10 spacer	4.4075	0.0033	0.0145
Kapton	0.4	0.0033	0.0013
G10 spacer	4.4075	0.0033	0.0145
Stainless Steel	0.2	0.00281	0.0006
Prepreg	0.1	0.0063	0.0006
Lead	1.3	0.00577	0.0075
Prepreg	0.1	0.0063	0.0006
Stainless Steel	0.2	0.00281	0.0006
	11.115	0.0403	

Equivalent $\Delta L/L = 0.0036$

Aluminum $\Delta L/L = 0.0036$

An accordion plate has an effective radial shrinkage of 0.0047 including effects of the many bends. An accordion plate free to shrink radially at the inner radius would shrink as follows:

Location	Warm Radius	Cold Radius	Notes
Outer radius	1421	1415.88	1421*(1-.0036)
inner radius	877	874.44	1421*(1-.0036)-(1421-877)*(1-.0047)

Effective shrinkage of inner radius= 0.00292 = 1-(877/874.44).

To achieve this effective shrinkage of the inner radius, the G10 in the inner ring would ideally have thermal index ΔL/L=0.0018.

Inner "Ring"			
	Cell Thickness(mm)	$\Delta L/L$	ΔL
G10 spacer	2.317	0.00180	0.0042
Kapton	0.4	0.00330	0.0013
G10 spacer	2.317	0.00180	0.0042
Stainless Steel	0.2	0.00281	0.0006
Prepreg	0.1	0.00630	0.0006
G10 insert	1.3	0.00630	0.0082
Prepreg	0.1	0.00630	0.0006
Stainless Steel	0.2	0.00281	0.0006
		6.934	0.0202

Aggregate $\Delta L/L = 0.00292$

Unrestrained $\Delta L/L = 0.00292$

(3) Related to (2): What is the cryostat wall required. As usual, the physicists say 0.5 X0, but the engineers 1.5 X0 to 3 X0. Which is correct ? Perhaps one could ask: how much internal structure is required to get a useful cryostat wall of this size, with less than 1.5 X0.

Answer:

The current design has a 9 mm aluminum vacuum wall and a 16 mm aluminum liquid wall for the barrel. This represents 0.28 X_0 at 90° and only 0.56 X_0 at 30° - so the cryostat walls are not the problem. However the baseline was designed for argon with a few cm of liquid. We need to optimize the design for krypton. This has not yet been completed however our engineers believe that one can keep the dead material in addition to the cryostat walls $< 1X_0$ We had always planned on a massless gap incorporated in the accordion structure which would measure the energy lost before the accordion.

Question:

(4) Stability: If it is to be LKr, then there is no proof at all. With BaF2, we are WILL have stability, although it might take (in the real world) a couple of weeks rather than a couple of hours to educate people on this point. There is no corresponding evidence for the LAr/LKr case. Purification and radiolysis make LKr an intrinsically unstable system.

Answer:

We are confident from our experience with krypton purification that stability can be achieved. See above discussion on D0 and H1 stability.

Question:

(5) System performance: while this is an EM choice, one cannot ignore the match with the HCAL. No one accepts, to my knowledge, a LKr/LAr HCAL hybrid, and the LKr/scintillating hybrids looked just awful in terms of acceptance, edges, cracks, shower sharing laterally between different technologies, etc. With the present state of knowledge, the risk of LKr for the viability of the detector – for doing useful physics – is extreme. I think it is fair to say that, in terms of physics studies, the LKr hybrid is in a much more primitive state than L* when we did our 7/90 studies for the PAC.

Answer:

This is why we are supporting the integrated EM + HAD BASELINE design as has been implemented in D0, SLD, and H1. Physics signals have been seen in all these experiments. For example, the two jet cross section from D0 was shown in Dallas. The GEM design employs an aluminum cryostat which will have less radiation lengths of dead material between the barrel and endcap than in D0.