ATLAS Internal Note

MUON-NO-XXX

September 15, 1998

EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH

MDT Noise Measurements in the X5 and H8 Test Beam

Martin Aleksa[a], **Nigel Hessey**[b], **Werner Riegler**[c]

[a]CERN
[b]University of Munich
[c]Harvard University

Abstract

Different measurements of the MDT noise level were performed in the X5 test beam, using the Seattle/Boston EMS chamber equipped with BNL preamplifiers and shapers [1]. This note shows the results of these measurements and compares them to calculations and to measurements with the Munich BOS chamber in the H8 test beam.

Measurements with a charge sensitive ADC confirm the Gaussian shape of the noise distribution. Different methods agree on a σ_{noise} of ~ 3.8 ionisation e$^-$ respectively an Equivalent Noise Charge (ENC) of $\sim 5470\,$e$^-$. This is close to the calculated thermal noise originating from the termination resistor ($\sigma_{noise}^{calc} \approx 3\,$ionisation e$^-$) plus the impact of parasitic capacitance in front of the preamplifier, leading to a total of 3.5 ionisation e$^-$, which represents a theoretical minimum. A check of the noise level of the Munich BOS chamber shows an increased σ_{noise} of ~ 4.8 ionisation e$^-$, which can partly be explained by the additional capacitance from signal traces.

Contents

1 Pulser Measurements

1.1 Experimental Setup

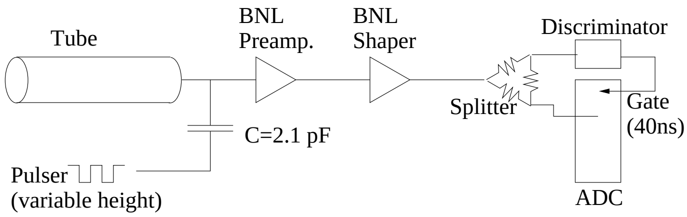

Figure 1: *Experimental setup for the noise measurement using a pulser and a capacitor C for calibrating the ADC. The ADC gate was chosen to be 40 ns.*

The measurements were performed in the X5 test beam with the Seattle/Boston EMS chamber equipped with BNL preamplifiers and shapers. The tube was connected to the preamplifier with a 5 cm cable. The preamp+shaper peaking time was 15 ns. The setup is shown in figure 1. For this noise measurement the high voltage was switched off but the HV cables were still connected.

The ADC was calibrated by injecting well defined amounts of charge into the preamplifier and reading the corresponding ADC channel number. A voltage step U through a capacitor C injects a charge of

$$q = C \cdot U \tag{1}$$

so by varying the pulseheight we derive the desired calibration curve.

The nominal capacitance C_{nom} of the capacitor was 1.8 pF. The true capacitance C was larger because of additional parallel capacitances from the wires, etc., hence the capacitance C was measured to $C = (2.09 \pm 0.05)$ pF.

Since the shaper output signal shows significant undershoot, an ADC gate of 40 ns was chosen in order to integrate only the positive part of the signal.

For gates slightly longer than two times the preamplifier peaking time ($t_p = 15$ ns) the charge sensitive ADC readings correspond very well to an amplitude measurement. Still, this represents a source of a systematic error, which can be estimated to about 20 %.

1.2 Measurement

Figure 2 shows the ADC calibration. One obtains the following relation between the charge q injected into the preamplifier and the ADC channel number N_{ADC}:

$$q = C \cdot [(-1.596 \pm 0.702) + (0.068 \pm 0.001) \cdot N_{ADC}], \tag{2}$$

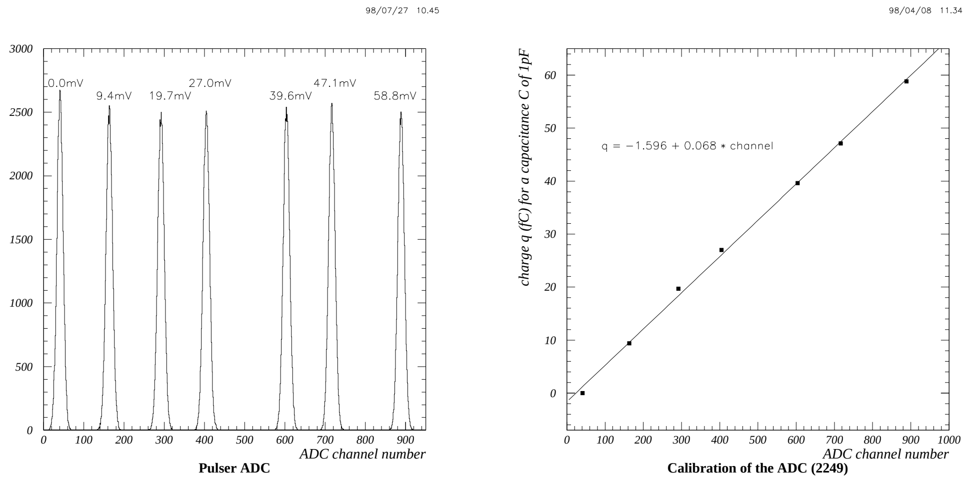

Figure 2: *The left plot shows the ADC readings for different pulser voltages. The right plot shows a straight line fit to the data yielding the relation between charge and channel number.*

with C in pF and q in fC.

The width of the ADC value distributions in figure 2 corresponds to the noise level that we want to measure. Figure 3 shows a Gaussian fit to the first distribution ($0\,\mathrm{mV}$, $\chi^2 = 2.131$) and the last distribution ($58.8\,\mathrm{mV}$, $\chi^2 = 1.015$). The not perfectly Gaussian shape of the first distribution is probably due to a nonlinearity of the ADC for negative input voltages. The perfect gaussian shape of the second distribution shows that there are no noise contributions from pickup or oscillations.

According to the Gaussian fit in figure 3 the σ of the distribution is 7.64 ± 0.02 channels which – using equation 2 – corresponds to a σ in terms of charge of (capacitance C in pF)

$$\sigma = C \cdot (0.520 \pm 0.008)\,\mathrm{fC} \equiv C \cdot (3246 \pm 50)\,\mathrm{e}^-, \tag{3}$$

hence we yield the Equivalent Noise Charge (ENC):

$$\mathrm{ENC} = C \cdot (3250 \pm 650)\,\mathrm{e}^- \approx (6780 \pm 1400)\,\mathrm{e}^-, \tag{4}$$

with the capacitance $C = (2.09 \pm 0.05)\,\mathrm{pF}$.

In order to get this number in units of ionisation electrons one has to calculate the fraction of charge collected in the first 15 ns (which is the peaking time t_p of preamplifier+shaper).

The current signal induced on the wire is given by

$$i(t) = -\frac{q}{V} v(t) E(r(t)), \qquad v(r(t)) = \mu E(r(t)), \tag{5}$$

where q is the charge moving with a velocity $v(t)$ at a position $r(t)$. Using the expression

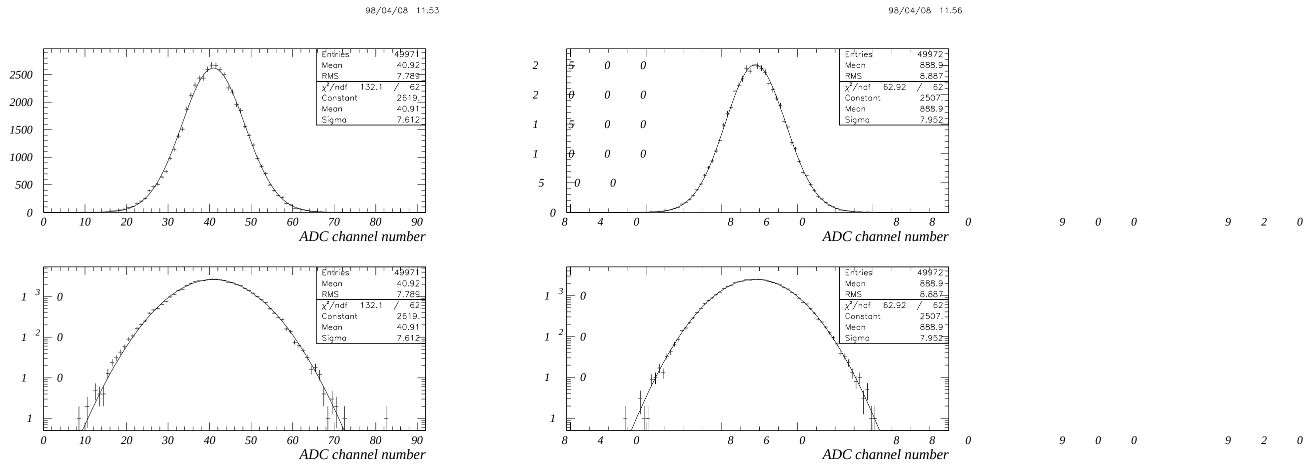

Figure 3: *Histograms of the ADC readings for pulser voltages of 0 mV and 58.8 mV. The imperfection of the Gaussian distribution of the ADC readings for 0 mV is probably due to an ADC nonlinearity for negative input voltages. The distribution on the right hand side is perfectly gaussian.*

for a cylindrical field $E(r) = \frac{V_0}{r \log \frac{b}{a}}$ one gets:

$$\begin{aligned} i(t) &= \frac{q}{2\log\frac{b}{a}}\,\frac{1}{t+t_0}, \qquad t = 0...t_{max}, \\ t_0 &= \frac{\log\frac{b}{a}}{2V_0\mu}a^2, \\ t_{max} &= \frac{\log\frac{b}{a}}{2V_0\mu}(b^2-a^2), \end{aligned} \tag{6}$$

with $b = 1.46\,\mathrm{cm}$ the tube radius, $a = 25\,\mu\mathrm{m}$ the wire radius, $\mu = 0.51\,\mathrm{cm^2/Vs}$ the ion mobility, $V_0 = 3270\,\mathrm{V}$ the wire potential and t_{max} the ion drift time.

With these equations and the numbers given above one can calculate the parameters:

$$t_0 = 11.9\,\mathrm{ns}, \qquad \text{and} \qquad t_{max} = 4.07\,\mathrm{ms}. \tag{7}$$

The peaking time t_p of the preamplifier and shaper was 15 ns. Since for this calculation the peaking time of a real signal (not a delta pulse) has to be taken into account, we set $t_p < t_p^{signal} = (18 \pm 2)\,\mathrm{ns}$. Hence the fraction R_q of charge arriving before the peaking time t_p^{signal} is given by

$$R_q = \frac{\int_0^{t_p^{signal}} \frac{1}{t+t_0}\,dt}{\int_0^{t_{max}} \frac{1}{t+t_0}\,dt} = \frac{\log\left(\frac{t_p^{signal}+t_0}{t_0}\right)}{\log\left(\frac{t_{max}+t_0}{t_0}\right)} = (7.2 \pm 0.5)\,\%. \tag{8}$$

So for a gas gain G of $2 \cdot 10^4$ one ionisation electron induces the charge of $R_q G = (1450 \pm 100)\,\mathrm{e}^-$ in the time t_p^{signal}. Now the numbers in equation 3 can be expressed in ionisation electrons ($C = (2.09 \pm 0.05)$ pF):

$$\boxed{\sigma_{noise} = C \cdot (2.2 \pm 0.5)\,\text{ionisation e}^- = (4.7 \pm 1.1)\,\text{ionisation e}^-.} \tag{9}$$

2 Rate Measurements

As a second method to determine the noise level, the noise count rate was measured as a function of threshold. This measurement was performed with and without high voltage on the wire.

2.1 Noise level without high voltage

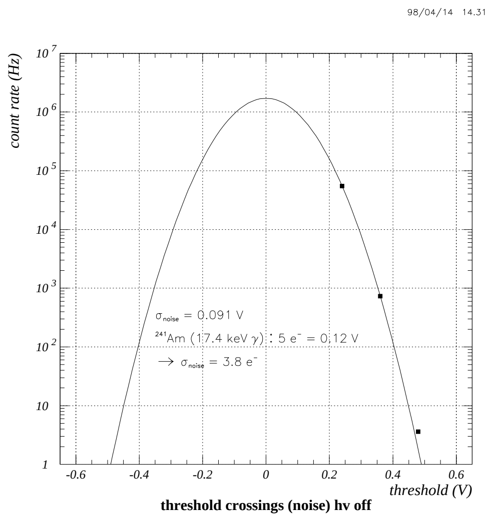

Figure 4: *Noise level without high voltage on the wire.*

Figure 4 shows a Gaussian fit to the measurements with the center forced to zero. To convert the voltage into units of ionisation electrons, pulses of 17.4 keV photons which leave a localised cluster of 670 electrons in the counting gas, were recorded. Dividing the pulseheight by 670 yields the voltage corresponding to a single ionisation electron. The measurement result was: 1 ionisation $e^- \equiv 0.0242\,\mathrm{V}$.

Hence in terms of ionisation electrons the σ_{noise} is

$$\boxed{\sigma_{noise} = 3.8\,\mathrm{ionisation\,e^-},} \tag{10}$$

which is – within the expected errors – in accordance with the value given in equation 9.

The statistical errors on the result given in equation 10 are about 0.1 %, but the systematic error can be much larger due to fixing the maximum of the normal distribution in figure 4 at zero which relies on a base line exactly at 0 mV. Nevertheless this measurement displays the actual noise level with much higher accuracy than the measurement described in section 1.

By using expression 8 we can calculate the ENC for the σ_{noise} given in equation 10:

$$\mathrm{ENC} = R_q G \sigma_{noise} \approx 5470\,\mathrm{e^-}. \tag{11}$$

2.2 Noise level with high voltage

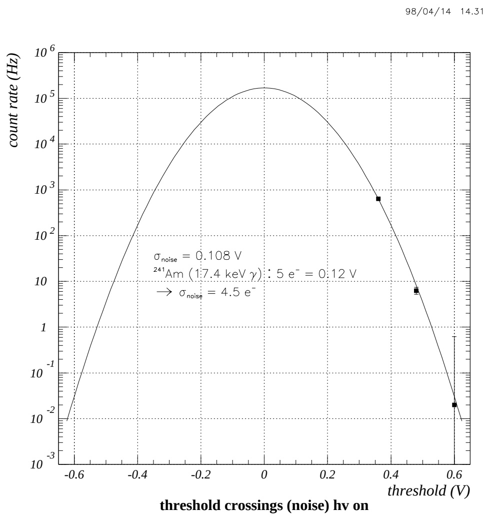

Figure 5: *Noise level with high voltage on the tube switched on.*

Figure 5 shows the noise level with 3270 V on the wire (cathode voltage 0 V). The cosmic rate, which was 56.78 Hz for our 190 cm long tube, had to be subtracted from the measured value. Like for the case with the high voltage switched off a gaussian distribution centered at zero was fitted.

With the calibration given in section 2.1 one yields

$$\boxed{\sigma_{noise}^{hv\ on} = 4.5\,\text{ionisation e}^- = \sqrt{\sigma_{noise}^2 + (2.4)^2}.} \tag{12}$$

Hence the additional contribution of the high voltage is 2.4 ionisation e$^-$. One can eliminate this contribution by either using a more stable HV supply or filtering the HV with an appropriate low pass filter. The noise level of the BOS chamber did not change when switching on the high voltage (see section 3).

3 Noise Measurements on the Munich BOS Chamber

These measurements were performed in the H8 test beam. The BOS chamber was equipped with BNL preamplifiers on the hedgehog board. The high voltage end and the electronics end were protected by a Faraday cage.

The signal was shaped by the BNL-shapers, 48 of them on one board in a crate, connected with 10 m long cables to the chamber.

Since in X5 the same setup was used (apart from the chamber itself), the calibration from this test beam – performed with a ^{241}Am source + Mo foil – was taken over. 1 mV of the output signal of the shapers corresponds to ~ 1.1 ionisation electrons.

By histogramming the noise with a digital scope we got:

$$\boxed{\sigma_{noise} = 4.8 \pm 0.3\,\text{ionisation e}^-.} \tag{13}$$

The measurements were done with the high voltage switched on, switched off and the high voltage cable unplugged. No significant change of the noise level was observed.

The difference between the noise level on EMS and on BOS cannot be explained by different wire lengths (EMS: $l = 1.9$ m, BOS: $l = 4.0$ m), since a longer wire decreases the ENC (see equation 15, $R_1 = 0$):

$$\sigma_{noise} \propto \frac{1}{\sqrt{R_t + l \cdot r_{wire}}}, \tag{14}$$

where l is the length of the tube, r_{wire} the resistance of the wire per unit length ($r_{wire} \approx 44\,\Omega/\text{m}$) and $R_t = 382\,\Omega$ the termination resistor. Equation 14 would predict a $\sim 10\,\%$ smaller noise level for the BOS chamber than for the EMS chamber.

One reason for the additional noise on BOS is the additional capacitance of the signal traces on the hedgehog board between the tube and the preamplifier (see section 4).

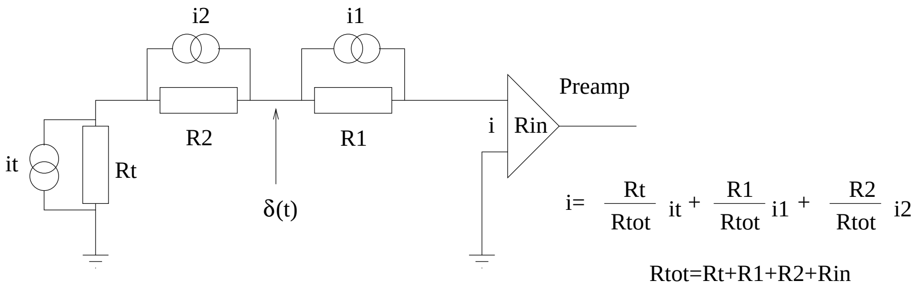

Figure 6: *Thermal noise can be modelled as a current source parallel to a noiseless resistor. R_1 and R_2 are the wire resistances left and right of the impact point [2].*

4 Calculation of the Noise Level

The main contribution to the noise level is the thermal noise of the termination resistor. The derivation of the termination resistor noise is given in [2].

The thermal noise of a resistor R can be represented as a current noise source in parallel with a noiseless resistor R and having a mean square current magnitude of $i^2_{rms} = \frac{4kT}{R}df$, where k is the Boltzmann constant, T the temperature of the resistor and df the frequency interval [3].

Using the circuit shown in figure 6 the following Equivalent Noise Charge (ENC) in electrons is obtained:

$$\mathrm{ENC} = \frac{\sqrt{R_t(R_1+R_2+R_t)}}{R_2+R_t}\frac{1}{e_0}\frac{e^n}{2^n}n^{-(n+\frac{1}{2})}\sqrt{t_p\frac{kT}{R_t}(2n)!}\,, \tag{15}$$

where n is the number of integrations of the preamplifier, e_0 is the electron charge and t_p the preamp peaking time. For the electronics used in the test beam use $n \approx 3$, $t_p = 15\,\mathrm{ns}$. Since we injected charge next to the preamplifier we have to set $R_1 = 0$.

Neglecting the wire resistance ($R_1 = R_2 = 0$) equation 15 predicts a thermal noise of ~ 3 ionisation electrons ([2]) for the setup used in the test beam.

If we take parasitic capacitance into account [4], we get ($R_1 = 0$)

$$\mathrm{ENC} = \frac{1}{e_0}\frac{e^n}{2^n}n^{-(n+\frac{1}{2})}\sqrt{kT(2n)!}\left[\sqrt{t_p\frac{R_t+R_2+R_N}{(R_t+R_2)^2}} + \sqrt{\frac{2C_{in}^2R_N}{t_p}}\right], \tag{16}$$

where R_N is the noise resistance of the preamplifier, which is to a good approximation equivalent to the input impedance, and C_{in} the capacitance to ground in front of the preamplifier. The capacitance of the tube itself (8.7 pF/m) does not add to C_{in} as long as the tube is terminated (like in our case), but the end plug (6 pF) on the preamp side (the other one contributes far less) and the cables (signal traces) to the preamp have to be taken into account.

The BNL-preamplifier has a noise resistance of $R_N \approx 100\,\Omega$. If we take into account the capacitance of one end plug plus the connections (X5: $\sim$ 9 pF), we calculate $\sigma_{noise} =$ 3.5 ionisation e$^-$.

Since on the BOS chamber the connections between the tube and the preamplifier are made with signal traces ($\sim$ 10 cm), the capacitance is higher. An additional capacitance of $\sim$ 20 pF would explain the entire difference of the noise levels. This seems to be too much, since the signal traces have a capacitance to the ground of $\sim$ 1 pF/cm. Nevertheless the calculated values are very close to the measurements.

5 Conclusion

Noise measurements on the Seattle/Boston EMS chamber in the X5 test beam were performed. The result was $\sigma_{noise} \approx 3.8$ ionisation e^- which has to be compared to a theoretical lower limit of ~ 3.5 ionisation e^- resulting from thermal noise of the termination resistor (3 ionisation e^-) plus noise from the capacitance of the end plug (0.5 ionisation e^-).

Measurements on the Munich BOS chamber show a $\sigma_{noise} \approx 4.8$ ionisation e^-. Part of the difference to the measurements in X5 can be explained by additional capacitance in front of the preamp because of signal traces.

The capacitance of the tube does not contribute since the tube is terminated.

The perfect Gaussian shape of the noise distribution shows that there is no noise contribution from pickup or oscillations.

Closing the Faraday cage did not change the noise level for the EMS chamber.

References

[1] Common base preamplifier IO-354-2 and shaping smplifier IO532-01, Instrumentation Division, Brookhaven National Laboratory

[2] W. Riegler, Limits to Drift Chamber Resolution, Doctoral Thesis, p. 25–26 and 29–33, 1997.

[3] P.W. Nicholson, Nuclear Electronics, John Wiley and Sons.

[4] E. Hazen et al., An Integrated Multi-Channel Readout for ATLAS MDTs, `http://ohm.bu.edu/bmc/lerb2/paper_html/paper_html.html`.