**(H1 Internal Note)**

# $\chi^2$ fit of nonlinearity

Main goal of this work is to get the best realistic estimate of the calibraton constants of the FNC operating with HV with the boost from the data from the CERN testbeam runs that were taken without boost.

In linear case, there are strictly speaking only 2 constants ($Cal$, $\alpha$ ) which transfer the FADC amplitude to the Energy of a shower in the preshower and the main calo.

$$E_{beam} = Cal \times (\langle \sum_{i=1}^{32} FADC_{maincalo} + \alpha \sum_{i=1}^{18} FADC_{preshower} \rangle) \tag{1}$$

Detailed study of the nonlinearity of photomultiplyers XP2282B which is induced by the dividers designed for a fixed boost voltages (see FNC minutes 29.05.02) shows a similar behaviour of responses for different Tubes. A deflection from the linearity grows with the anod curent rather than with a charge of the signal. But the Amplitudes normalised to the light flood and to the PM gain charge lie on the universal curve (Fig.1) which can be approximated by different formulas. The simplest is:

$$y = (a * x + b * x^d) * gainPM, \tag{2}$$

where $a$ and $d$ can be fixed from the data mentioned above and $gainPM$ is the relative gain of PM in the FNC. In case of

$$y \equiv chargeQ_{boost}, \qquad x \equiv chargeQ_{noboost}$$

the amplitude of the PM signal (FADC unit) in first approximation

$$a_1 = 0.36, \quad d_1 = 2.66$$

for all PM with relative low current (main calo) and

$$a_2 = 0.43, \quad d_2 = 3.3$$

for all PM with high current (preshower).
Another parameters:

$$b_1,\ b_2,\ gainPM_i, \quad (i = 1, 50)$$

we should choose so that the data is described in best way:

**A** to get linearity in energy with $\sim 0$ offset at zero energy;

**B** to get linear correlations between the different modules;

**C** with the min dispersion ($\sigma$) of the FNC response to the fixed energy beam.

The items A and C are used for the minimazation of a differences between the mean measured values of response in the calo and the true energies e.g. the hadron beam energies in the CERN testbeam (0, 120, 150, 180, 200, 300, 350 GeV). In case of the linear response of the calorimeter there is a minimal $\sigma$ for each point. A point at the energy 0.05 GeV is simulated data with a small Gaussian dispersion ($\sim 0.01 Gev$ for each chanel). This point garantees for the small zero offset. Since the parameters are highly correlated the process of minimization is iterative. The lowerest value of $\chi^2$ does not give the realistic value of parameters (i.e. 0 or negative). Between the iterations the item B has to be checked.

The fits to hadron data are done separately for the main calo (32 chanels) and the preshower (18 chanels). The fitting procedure for the determination of correction functions for the PM is done first for the main calo. Then the found parameters are fixed and the FADC data for the main calo are corrected and added to the data from the preshower for a determination of parameters for the preshower.

For the determination of the parameters for the main calo only data with the cluster type 2 (mip in preshower) were used and the FADC amplitudes of signals were written to a file. To minimize the effect of correlation of parameters the simplest fit model was choosen: the 4 amplitudes of the central towers and the 4 summary amplitudes of peripheryc towers of each module:

$$es(4,1), es(4,2), es(4,3), es(4,4),$$
$$\sum es(i,1), \sum es(i,2), \sum es(i,3), \sum es(i,4) (i = 1-3, 5-8),$$

Each amplitude is transformed by a function

$$par(i,j) * (par(1) * x + par(2) * x^{par(3)}), \tag{3}$$

where $par(1)$, $par(2)$, $par(3)$ are the same for all 32 PMs. Additional constrain for the first 16 towers of main calo we get from the CERN testbeam measurement with the bost HV (only available in Logbook) with 120 GeV electrons (FNC meeting minutes 29.05.02 ).

The constant $\alpha$ that defines the ratio between the responses to the hadronic showers in the preshower and the main calo for the case of HV with the boost we can check and finely fix from the proton beam-gas data from HERA by plotting the correlation of these values (Fig.2). This correlation also shows that with the boost HV the behaviour is linear.

The result of the fit is always a compromise between a nonlinearity in the energy response and the resolution in the energy. The best resolution for the main calo have been achieved with following parameters:

$$par(1) = 0.367,\ par(2) = 0.139,\ par(3) = 2.56,\ Cal = 151.1$$

and the relative gains of central PM for all 4 modules:

$$0.973,\ 1.205,\ 1.136,\ 2,014$$

The relative gains of periferic PM averaged for towers (1–3, 5–8) in each of 4 modules are:

$$0.725,\ 0.875,\ 0.839,\ 0.50.$$

The ratios of the resolution ($\sigma$)to the mean value are
for 120 GeV – 7.38Gev/121.0Gev
for 350 GeV – 13.10Gev/347.5Gev
i.e. the non-linearity calculated from the mean value is about $3.5Gev/230Gev \approx 1.5\%$, which is rather high for present statistic.
A variation of $par(3)$ in rather wide limits has no influence on the result and should be fixed from the PM researching which was done at DESY.

For the determination of parameters for the preshower the the FADC amplitudes of the main calo are corrected and a new data file is created with events of cluster type 3 (a hadronic showers start in preshower and develop in the main calo). For the fit, the central 6 channels were selected in $x - y$ direction (3x $\times$ 3y) and the sum of amplitudes of all other channels:

$$ex(4),\ ex(5),\ ex(6),\ \sum ex(i),\ i = 1-3; 7-9$$
$$ey(5),\ ey(6),\ ey(7),\ \sum ex(i),\ i = 1-4; 8-9$$

The FADC amplitudes of the preshower signals are transformed by the same function as for the main calo multiplied by $\alpha$ and summed with the corrected amplitude of the main calo. Identical parametres $par(1)$, $par(2)$, $par(3)$ are used for all PMs of the preshower.

The result of the fit is shown in Fig.3. The differences between the mean energy response and the beam energy and the corresponding energy resolutions are shown on right side of picture:

| Beam energy $[GeV]$ | 120 | 180 | 300 | 350 |
|---|---|---|---|---|
| $\Delta E$ $[GeV]$ | -0.08 | -1.4 | -1.2 | -0.9 |
| $E$ resolution $[GeV]$ | 8.9 | 10.9 | 14.0 | 15.4 |

The fixed parameters for the main calo are:

$$par(1) = 0.367,\ par(2) = 0.139,\ par(3) = 2.56,$$

and the parameters of the preshower from a fit are:

$$par(1) = 0.48,\ par(2) = 0.04,\ par(3) = 3.30,\ \text{and}\ Cal = \mathit{151.1},\ \alpha = \mathit{0.15}$$

Fig.4 shows the spectra of the signals of central chanels of the main calo for the beam-gas data taken with 677 GeV proton beam at HERA both with boost HV and without boost HV (runs 320510 and 320518, respectively). The spectra measured without boost are corrected by function with parameters as determined above. Here we took into account the additional calibration constants which are determined from the ratio of LED signals (see FNC minutes of V.I.Efremenko): a factor 1.56 due to change of PM gain between CERN and DESY (March 2001) measurements (taken without HV boost) and a factor 1.53 due to change of PM gain in DESY between March 2001 and August 2002 (taken with HV boost). The spectra are normalised to number of events.

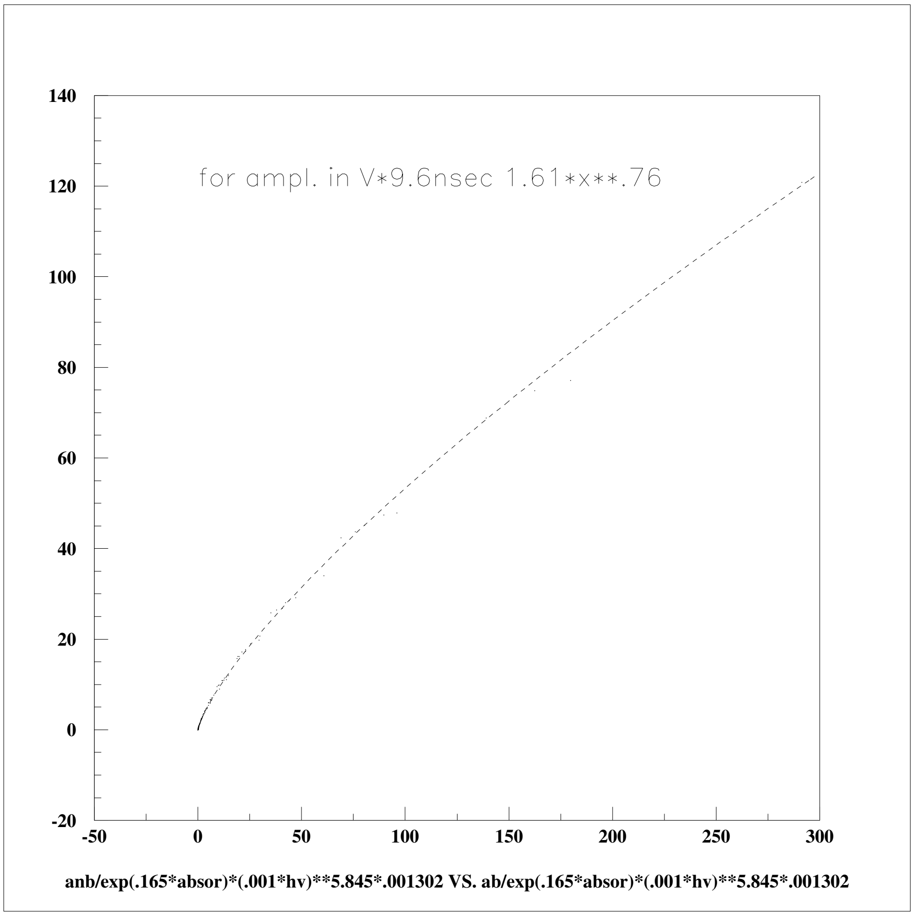


Figure 1: The normalised charge amplitude dependence. anb - amplitude without boost; ab - amplitude with boost; ext(.165*absor) is the light flood normalisation; (.001*hv)**5.845 is higt voltage normalisation.

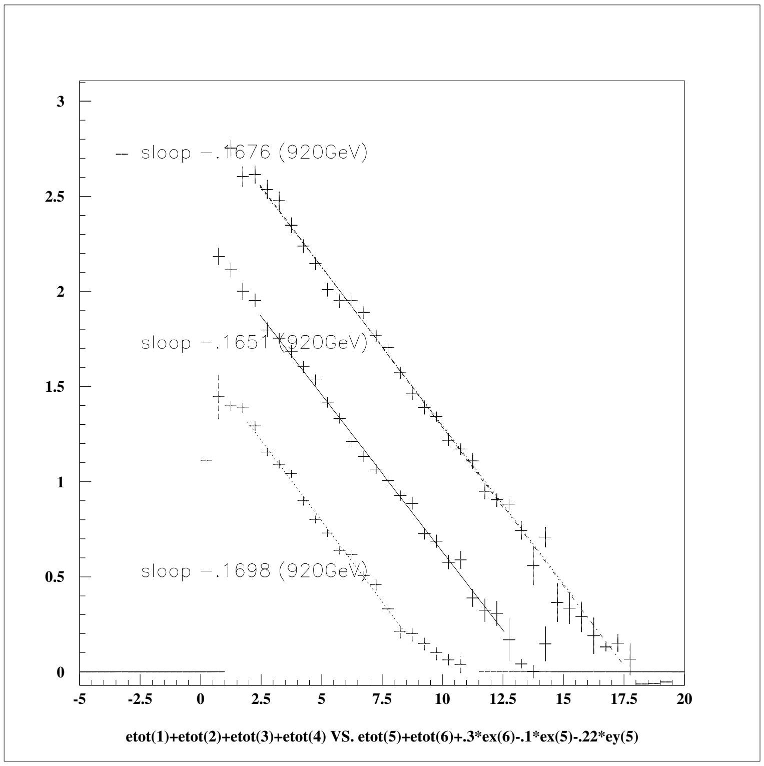


Figure 2: The ratio between the Amplitudes of Preshower and Main calo for different small intervals of neutron energy from the p-gas data.

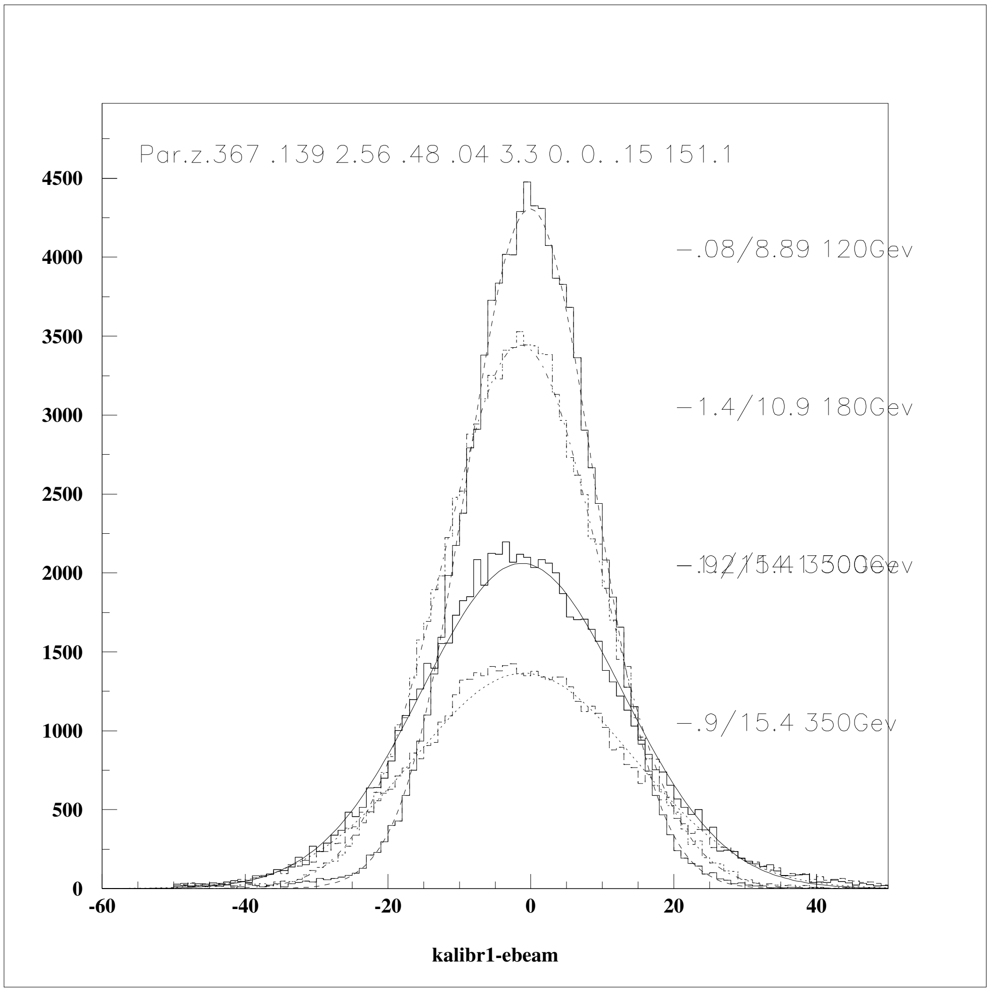


Figure 3: The fit results of the CERN testbeam data

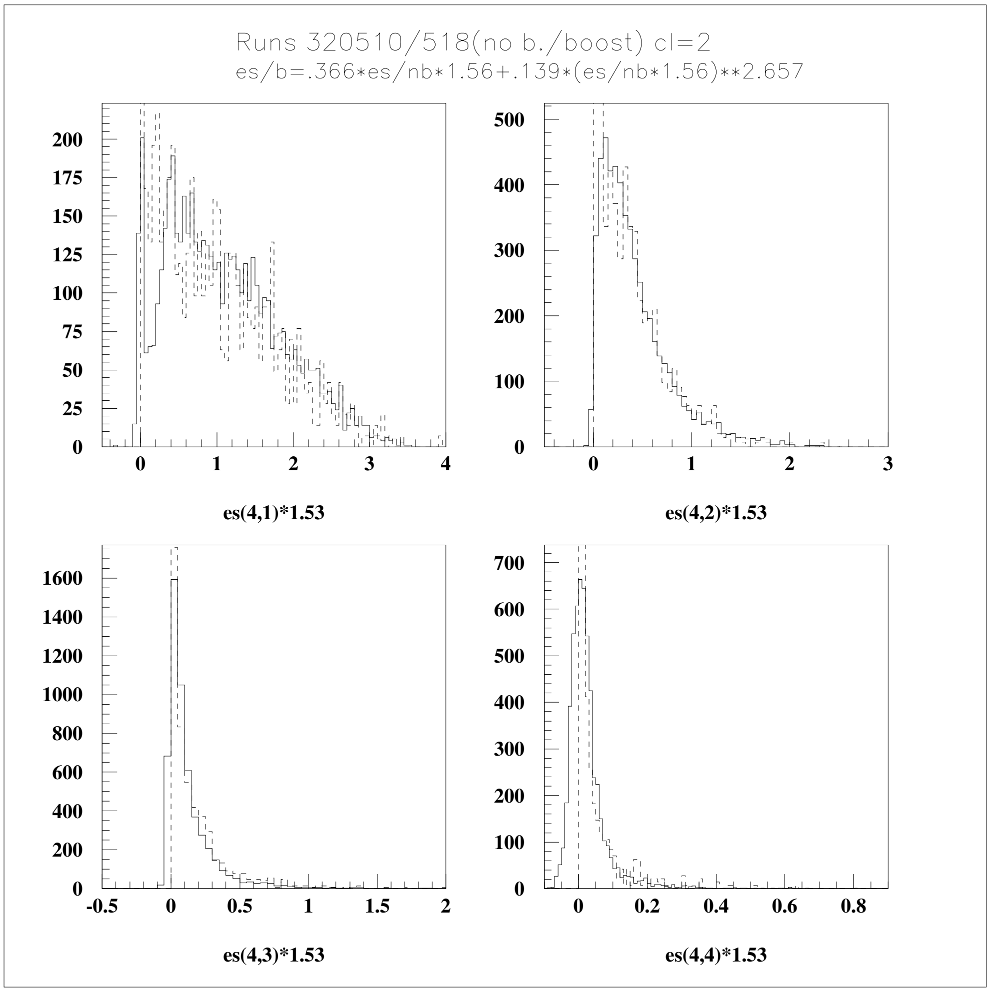


Figure 4: Energy spectra measured in the central modules of the proton beam-gas data with boost and without boost