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Studies of dE/dx capabilities of a TPC for the future Linear Collider TESLA

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1 Introduction [1]

The average energy loss of ionizing particles in matter, $\frac{dE}{dx}$, follows a Bethe-Bloch equation and is a universal function of $\beta\gamma = \frac{p}{m}$ for all particle species. Such a function has the following shape:

- a decrease with $\frac{1}{\beta^2}$
- a minimum around $\beta\gamma = 3$ to 4
- a logarithmic rise ("relativistic rise region")
- saturation ("Fermi plateau")

For different masses, the curves separate as a function of p. Measurements of energy loss should therefore allow identification of particles. In the region of the relativistic rise, the separation is only about 10 % for different particle species. One thus need $\frac{dE}{dx}$ measurements with resolutions $\sigma(\frac{dE}{dx})$ of a few % only.

The ionization energy loss is a statistical process and follows a Landau-like distribution in a gas. Such a distribution presents a broad peak and is characterized by a long high energy loss tail. For a single gas sample, the width of the distribution (typically about 70 % FWHM) is much larger than the size of the small energy loss difference of order 10 % in the relativistic rise region. The way around this problem is to sample the ionization energy loss many times along each track.

A question then arises with regard to how many samples would be optimal in terms of $\frac{dE}{dx}$ performances.

This note describes some simulation studies of the $\frac{dE}{dx}$ capabilities of the time projection chamber of a detector for the future Linear Collider TESLA.

2 Procedure

The studies presented here are based on a toy Monte Carlo program simulating $\frac{dE}{dx}$ measurements in a given Time Projection Chamber (TPC). The principle of the Monte Carlo program which has been developed is as follows:

1. Choice and definition of the characteristics and parameters of the TPC to be simulated (geometry, gas mixture, readout characteristics, number of samples, etc..., as listed in the next section).
2. Generation of straight minimum ionizing particle tracks through the TPC.
3. Generation of clusters on a random basis along each track. The number of clusters per unit length follows a Poisson distribution which mean value depends on the gas mixture.
4. Choice of the cluster size for each primary ionization, and generation of the total number of electrons per cluster. The cluster size distribution depends on the gas components.
5. Subjection of each individual electron to transverse diffusion. The amount of diffusion to be applied follows a gaussian distribution with a mean value which depends on the gas mixture, on the electric and magnetic fields and on the drift length of the electron in the TPC.
6. Application of a randomly chosen amplification factor for each secondary electron arriving at the readout plane of the TPC. The gas gain follows a logarithmic distribution.
7. Subdivision of the track length into a fixed number of samples, N_{samp}, and count of the final number of electrons in each sample.
8. Addition of electronic noise in each sample, on a random basis.
9. Application of some cross-talk between samples.
10. Cut below a given threshold: only samples with a signal (number of electrons after amplification) larger than some fixed threshold can be taken into account in the $\frac{dE}{dx}$ determination.
11. Conversion of the distribution of the number of electrons per sample into a distribution of the number of electrons per unit length. Analysis of the resulting energy loss distribution (Landau distribution). The mean energy loss for the current track is obtained using a truncated mean technique. After fixing an upper truncation parameter, X_{up}, the largest (100-X_{up}) % of the energy loss measurements are discarded before calculating the mean. In other words, the energy loss measurements of (100-X_{up}) % of the samples are not taken into account in the calculation of the mean energy loss of the considered track. This truncated mean method gives better resolution than when averaging all data. Similarly, the truncated mean technique may be applied using also a lower truncation parameter, X_{low}, in which case the lowest (100-X_{low}) % of the energy loss measurements are discarded before calculating the mean.

12. The whole procedure (from points 2 to 11) is repeated with enough generated tracks to have a statistically significant set of mean energy loss values for individual tracks. The mean energy loss distribution is a gaussian distribution with a central value of $< \frac{dE}{dx} >$ and a width of $\sigma(\frac{dE}{dx})$. The $\frac{dE}{dx}$ resolution of the simulated TPC is then $\frac{\sigma(\frac{dE}{dx})}{<\frac{dE}{dx}>}$.

In summary:

- Generate tracks
  - For each track:
    - generate clusters along the track
  - For each cluster:
    - generate electrons (cluster size)
  - For each electron:
    - apply transverse diffusion
    - apply gas gain
- Subdivide track length into N_{samp} samples
  - For each sample:
    - get the signal amplitude (number of electrons after gas gain)
    - add some electronic noise
    - include cross-talk between samples
    - apply a threshold
  - For each track:
    - get the truncated mean of the Landau distribution
- Get the distribution of truncated means
  $\rightarrow$ Its width and central value give $\sigma(\frac{dE}{dx})$ and $< \frac{dE}{dx} >$.

3 Input parameters

The following is a list of characteristics and parameters to be defined for simulating the behaviour of a TPC:

1. The gas mixture.

2. The gas pressure.

3. The mean number of primary electrons released (or clusters) per unit of length for minimum ionizing particles, N_p, for each gas component. The number of clusters per unit of length for each gas component will then follow a Poisson distribution with mean value N_p. The values of N_p are given in Table 1 for various gas components considered in this study.

Pure gas	N_p[1/cm]
He	8
Ar	94
CO_2	91
CH_4	53
C_2H_6	111
iC_4H_{10}	195

Table 1: Mean number of primary electrons released per unit of length for minimum ionizing particles.

4. The cluster size distribution for each gas component. Cluster size distributions have been measured by H. Fischle and collaborators [2] for a number of gas components: argon, helium, CO_2, CH_4, C_2H_6 and iC_4H_{10}. They are shown in Figures 1a and b for argon and CH_4 and in Figures 2a and b for helium and CO_2. The cluster size distributions for C_2H_6 and iC_4H_{10} are the same as for CH_4.

5. The size of an electron cloud drifting from its point of origin to the end-cap sector of the TPC is determined by diffusion and is given by $\sigma_T = D_T\sqrt{l}$ in the direction transverse to the drift direction, where l is the drift length and D_T is the transverse diffusion coefficient of the gas in an electric and a magnetic fields. The transverse diffusion coefficients of various gas components and gas mixtures are computed using the MAGBOLTZ program [3], which solves the Maxwell Boltzman equation and gives the transport parameters of gas mixtures.

6. The electric field, E. The operation electric field of the TPC, is set to the value at which the drift velocity as a function of electric field presents a local maximum (requirement for minimizing the sensitivity of the system to distortions in electric field).

7. The magnetic field, B.

8. The mean gas gain, or amplification.

9. The number of readout samples (or readout channels), N_{samp}.

10. The mean value of the electronic noise to be added in each readout sample.

11. The cross-talk between a sample (readout channel) and its first few neighbours.

12. The threshold of the TPC readout system.

13. The upper and lower truncation parameters X_{up} and X_{low}.

Parameters 1 to 6 depend on the gas mixture and gas properties, while parameters 8 to 12 depend on the TPC readout (geometry and electronics).

4 Simulation of existing TPCs

Before simulating a TPC for the detector of the future Linear Collider TESLA, one should check that the results obtained with the toy Monte Carlo program do reproduce the performances of existing TPCs. For this purpose, the parameters of five existing TPCs have been used successively: the TPCs of OPAL, ALEPH and DELPHI at LEP, TOPAZ at TRISTAN and TPC/2γ at PEP. Their relevant characteristics and parameters are listed in Table 2 (see [1] and references therein). The quoted magnetic fields are parallel to the drift electric fields.

On Figure 3 are shown the drift velocity curves as a function of electric field for the four gas mixtures used in these TPCs, for a pressure of 1 bar. The operation drift electric field is the one for which the drift velocity curve presents a local maximum, E. Note that for a gas pressure p, the operation drift electric field is $E \times p$.

On Figure 4 are shown the transverse diffusion coefficients as a function of electric field for the five TPCs with their corresponding magnetic field. The actual transverse diffusion coefficients, D_T, of the TPCs are obtained for an electric field E. Note that for a gas pressure p the transverse diffusion coefficient becomes $\frac{D_T}{\sqrt{p}}$. The values quoted in Table 2 take into account the gas pressures.

In addition to the parameters listed in Table 2, one has in hand a number of additional pieces of information:

- The electronic noise: the preamplifiers of the OPAL and the ALEPH TPCs have an electron equivalent noise of a few hundred to a thousand electrons rms. I have taken the value from ALEPH, of 600 electrons equivalent noise, for the simulation of all TPCs.

- The normal gas gain of the OPAL TPC is around 10^4. This value is taken for the simulation of all TPCs.

- For the OPAL TPC, the cross-talk from a wire to its i^{th} neighbour is given in Table 3 up to the 5^{th} neighbour: in case of a single track (where all the wires have signals), a certain wire sees a total cross-talk of 21 % from wires up to the 5^{th} neighbours. The polarity of the cross-talk signals being opposite to that of the wire itself, the wire will therefore see 79 % of the signal only.

  In addition, by means of a resistor network just enough signal with the right polarity is coupled from wire to wire to compensate for cross-talk effects from the first and the second neighbours. Therefore, in the simulation, one should implement cross-talk effects only from the third neighbours onwards.

  Having not found information about cross-talk effects in the other TPCs, I have used the values available for OPAL and assumed they were valid for all other simulated TPCs.

Figure 5 shows the simulated Landau distributions for the OPAL TPC assuming three different situations: no cross-talk effects, cross-talk effects with no compensation and compensated cross-talk effects. On the same figure is shown the measured Landau distribution [4]. As expected, the simulated Landau distribution obtained with compensated cross-talk effects matches best the measured Landau distribution. In what follows the OPAL compensated cross-talk effects are always taken into account in the simulations of all TPCs. The remaining difference between simulated and measured Landau distributions shows clearly that some features of the TPC are being ignored on the Toy Monte Carlo simulation program.

Detector	Gas mixture	Pressure [bar]	N_p [1/cm]	E [V/cm]	B [T]	D_T [μm/$\sqrt{(\text{cm})}$]	d_{len} [mm]	t_{len} [mm]	N_{samp}	l_{samp} [mm]	X_{low} [%]	X_{up} [%]
OPAL	$Ar/CH_4/iC_4H_{10}$ (88.2/9.8/2)	4	368	890	0.435	135.	0.–240.	1590.	159	10.	0.	70.
ALEPH	Ar/CH_4 (91/9)	1	90.3	128	1.5	101.	2200.	1352.	338	4.	8.	60.
DELPHI	Ar/CH_4 (80/20)	1	85.8	218	1.2	110.	1350.	768.	192	4.	0.	80.
TOPAZ	Ar/CH_4 (90/10)	3.5	314.7	480	1.0	77.	1100.	700.	175	4.	0.	65.
TPC/2γ	Ar/CH_4 (80/20)	8.5	729.3	935	1.375	34.	1000.	732.	183	4.	0.	65.

Table 2: Characteristics and parameters of five existing TPCs.

Neighbour	Cross-talk
1^{th}	6.7 %
2^{th}	2.1 %
3^{th}	0.9 %
4^{th}	0.5 %
5^{th}	0.3 %

Table 3: Cross-talk from a wire to its neighbours in the OPAL TPC.

Detector	Simulated	Measured
OPAL	2.6 %	2.8 %
ALEPH	4.2 %	4.5 %
DELPHI	5.2 %	5.7 %
TOPAZ	3.5 %	4.4 %
TPC/2γ	2.5 %	3.0 %

Table 4: Measured and simulated $\frac{dE}{dx}$ resolutions of five existing TPCs.

On Figure 6 is shown the distribution of truncated mean obtained for the simulation of the OPAL TPC. The resulting $\frac{dE}{dx}$ resolution is 2.63%.

Table 4 shows the simulated $\frac{dE}{dx}$ resolutions of the five considered existing TPCs aswell as their measured values as given in [1] and references therein. Although the simulation systematically underestimates the $\frac{dE}{dx}$ resolutions by about 10 %, the agreement between simulated and measured $\frac{dE}{dx}$ resolutions is rather good.

5 Simulation of a TPC for TESLA

The whole idea of this study is to help designing a TPC for the detector of the future Linear Collider TESLA and to understand the $\frac{dE}{dx}$ capabilities of such a TPC. For that purpose various simulations have been performed varying some of the TPC parameters:

- The gas mixture, and therefore N_p, E and σ_T
- The magnetic field. A 3 T magnetic field was assumed in the Conceptual Design Report [5] (CDR) of the TESLA detector, and a 4 T magnetic field is now assumed in the Technical Design Report (TDR). Although most of the studies presented here have been performed assuming 3 T, both values have been considered.
- The number of samples, N_{samp}, and therefore the sample length l_{samp}.
- The cross-talk effects. Three options are considered: either no cross-talk effects at all, or compensated cross-talk effects as in OPAL, or full cross-talk effects (as in OPAL, but with no compensation).
- The readout threshold
- The truncation parameters X_{up} and X_{low}

5.1 Varying N_{samp} and X_{up}

In the first study I have fixed all parameters but the number of samples and the upper truncation parameter, N_{samp} and X_{up}:

- The gas mixture consists of 90 % argon and 10 % CH_4
- The electric field is 135 V/cm
- The magnetic field is 3 T
- The transverse diffusion coefficient is then 55 μm/$\sqrt{(\text{cm})}$
- The inner and outer radii of the TPC are 40 and 160 cm respectively, giving a track length of 120 cm when tracks are perpendicular to the beam direction (and therefore parallel to the readout plane of the TPC)
- The TPC is 5 m long, giving a maximum drift length of 250 cm
- The electronic noise is the same as for ALEPH, that is 600 electrons equivalent
- The cross-talk effects are as in the OPAL TPC
- The readout threshold is 0
- The lower truncation parameter is 0

Figure 7 shows the simulated Landau distributions for the TESLA TPC as described above for different numbers of samples.

The resulting simulated truncated mean distributions are shown on Figure 8 for 100 and 400 samples and for two different values of upper truncation parameter: 80 % and 95 %. Clearly the $\frac{dE}{dx}$ resolution depends strongly on the number of samples and on the upper truncation parameter, X_{up}.

On Figure 9 are plotted the $\frac{dE}{dx}$ resolution, $\frac{\sigma(\frac{dE}{dx})}{<\frac{dE}{dx}>}$, as a function of X_{up} for various numbers of samples (100, 400, 700 and 1000 samples). One can see that the value of X_{up} giving the best $\frac{dE}{dx}$ resolution depends on the number of samples. Indeed, as shown on Figure 10 the optimal value of X_{up} ranges between about 61 % for 20 samples and about 85 % for 1000 samples.

Finally, Figure 11 shows the $\frac{dE}{dx}$ resolution as a function of the number of samples. Two cases are considered: either the upper truncation parameter is fixed to a value of 70 % for all numbers of samples considered; or the value of X_{up} used for a given number of samples is chosen to be the value giving the best $\frac{dE}{dx}$ resolution for that specific number of samples (that is, the optimal value of X_{up}).

5.2 Varying N_{samp} and the readout threshold

In the next study the TPC I have simulated for TESLA has the same characteristics as in Section 5.1 but:

- The upper truncation parameter is fixed and is 70 %

- The readout threshold is allowed to vary. It is set to 0, to 1 electron equivalent or to 2 electrons equivalent. Applying a readout threshold of N electrons equivalent consists in using only the samples which have a signal (number of electrons after amplification) larger than $N \times G$, where G is the mean amplification factor of the TPC readout.

On Figure 12 is given the $\frac{dE}{dx}$ resolution as a function of the number of samples for a readout threshold of 0, 1 and 2 electrons equivalent. If no readout threshold is applied (threshold of 0), the $\frac{dE}{dx}$ resolution decreases as a function of the number of samples until it reaches a plateau for about 240 samples (that is for a sampling length of 0.5 cm). 240 samples would then be enough to reach the smallest resolution on $\frac{dE}{dx}$. On the other hand, if a readout threshold is applied (for example a 1 electron equivalent readout threshold), the $\frac{dE}{dx}$ resolution decreases continuously! The effect is all the more significant that the threshold is higher. From such a plot one would be tempted to conclude that the more samples there are, the better the $\frac{dE}{dx}$ resolution and therefore the better the design of the TPC.

A good $\frac{dE}{dx}$ resolution is however not the only criteria to be considered. Indeed, a good stability of $\frac{dE}{dx}$ measurements is essential: the measured values of $\frac{dE}{dx}$ should depend as little as possible on fluctuating parameters of the TPC. For example, a $\frac{dE}{dx}$ measurement should depend as little as possible on the actual value of the readout threshold which is subject to changes due to changes of temperature, etc... Figure 13 shows the simulated $\frac{dE}{dx}$ values as a function of the number of samples for various readout threshold values (0, 1 and 2 electrons equivalent). Up to about 240 samples, $\frac{dE}{dx}$ measurements are rather independent of the readout threshold value. Choosing 240 samples is therefore a rather good compromise for getting a good $\frac{dE}{dx}$ resolution aswell as a good $\frac{dE}{dx}$ measurement stability.

5.3 Varying X_{up} and X_{low}

The following study for the TESLA TPC consists in looking at the $\frac{dE}{dx}$ resolution as a function of upper and lower truncation parameters, X_{up} and X_{low}. The simulated TPC has the same characteristics as in Section 5.1 but:

- The number of samples is fixed and is 240. That is, the sampling length is 0.5 cm.
- Both the lower and the upper truncation parameters are allowed to vary.

As an example, a number of simulated truncated mean distributions for the TESLA TPC described here are shown on Figure 14. They have been obtained with an upper truncation parameter of $X_{up} = 80$ % and a lower truncation parameter of $X_{low} = 0$, 15 %, 30 %, and 55 %. The resulting $\frac{dE}{dx}$ resolutions range between 4.15 % for X_{low} =0 and 4.69 % for $X_{low} = 55$ %.

Figure 15 shows the four simulated $\frac{dE}{dx}$ resolution as a function of lower truncation parameter obtained with four different values of upper truncation parameter: X_{up} =60 %, 70 %, 80 % and 95 %. The value of X_{low} for which the $\frac{dE}{dx}$ resolution is the smallest, that is the optimal value of X_{low}, depends strongly on the chosen value of X_{up}.

On Figure 16a is given the optimal value of X_{low} as a function of the chosen value of X_{up}. In addition, as already seen, the $\frac{dE}{dx}$ resolution depends on both the values of X_{low} and X_{up}. Figure 16b shows the $\frac{dE}{dx}$ resolution obtained with the optimal lower truncation parameter as a function of the upper truncation parameter (the optimal value of X_{low} itself depending on X_{up}). From this figure one can see that the optimal value of X_{up} (giving the best $\frac{dE}{dx}$ resolution) is 80 %. This value corresponds to what could be inferred from Figure 10 for 240 samples.

5.4 Varying the readout thresold, X_{up} and X_{low}

It is also interesting to study how the dependence of the $\frac{dE}{dx}$ resolution of the TESLA TPC on X_{up} and X_{low} changes with the readout threshold. For this study, the simulated TPC has the same characteristics as in the previous section but the readout threshold is allowed to vary.

On Figure 17 is shown the $\frac{dE}{dx}$ resolution for the optimal lower truncation parameter as a function of upper truncation parameter. Three cases are presented: using a readout threshold of 0, 1 and 2 electrons equivalent. The three curves are very similar, the optimal upper truncation parameter is 80 % for all three values of readout threshold, and the $\frac{dE}{dx}$ resolution is almost the same (between 4.16 % for a readout threshold of 0 and 4.14 % for 2 electrons equivalent).

5.5 Changing the gas mixture and the magnetic field

The choice of 90 % argon and 10 % CH_4 as the gas mixture of the TPC for TESLA is reasonable but not the only possibility. Four gas mixtures have then been considered:

- 90 % argon and 10 % CH_4
- 70 % argon and 30 % CH_4
- 90 % argon and 10 % CO_2
- 92 % argon, 5 % CH_4 and 3 % CO_2

On Figure 18 are shown the drift velocity curves as a function of electric field for these four gas mixtures, for a pressure of 1 bar. The operation electric fields (corresponding to the local maxima of the curves) are indicated on the figure by means of asterisks for each of the gas mixtures. On Figure 19 are shown the transverse diffusion coefficients as a function of electric field for the four gas mixtures in a 3 T magnetic field. Again the asterisks indicate the operation electric fields.

A magnetic field of 3 T has been chosen as in the CDR of the TESLA detector [5]. However, one could probably choose a 4 T magnetic field. The effect of such an increase in magnetic field is also considered here. On Figure 20 are shown the transverse diffusion coefficients as a function of electric field for the four gas mixtures in a 4 T magnetic field.

The geometric characteristics of the TESLA TPCs simulated in this study are the same as the ones given in Section 5.1. In addition, the following characteristics have been used:

- The electronic noise is 600 electrons
- The cross-talk effects are as in the OPAL TPC
- The readout threshold is 0
- The lower truncation parameter is 0
- The upper truncation parameter is 80 %

The simulated $\frac{dE}{dx}$ resolution is plotted as a function of the number of samples in Figure 21 for the four gas mixtures considered and for a magnetic field of 3 T. For 240 samples the $\frac{dE}{dx}$ resolution ranges between 4.10 % for 70 % argon and 30 % CH_4, and 4.35 % for 92 % argon, 5 % CH_4 and 3 % CO_2.

Gas mixture	N_p [1/cm]	E [V/cm]	B [T]	D_T [μm/$\sqrt{(\text{cm})}$]	$\frac{\sigma(\frac{dE}{dx})}{<\frac{dE}{dx}>}$ [%]
Ar/CH_4 (90/10)	84.6	128	3	55.	4.15
			4	41.	4.13
Ar/CH_4 (70/30)	65.8	300	3	53.	4.10
			4	40.	4.08
Ar/CO_2 (90/10)	84.6	775	3	153.	4.35
			4	125.	4.26
$Ar/CH_4/CO_2$ (92/5/3)	91.9	300	3	101.	4.22
			4	76.	4.16

Table 5: Characteristics and performances of simulated TESLA TPCs with four different gas mixtures and with a magnetic field of 3 T or 4 T.

On Figure 22 are shown the simulated truncated mean distributions of such a TPC with 240 samples, in a 3 T magnetic field and for two of the four gas mixtures considered.

Table 5 gives a summary of the TPC characteristics related to the four gases and lists the $\frac{dE}{dx}$ resolutions obtained for the TPC described in this section, with 240 samples.

5.6 Changing the cross-talk

For completeness I have also looked at the influence of the cross-talk effect on the $\frac{dE}{dx}$ resolution. For this study I have assumed a TPC with the same geometric characteristics as in Section 5.1. In addition,

- The gas mixture consists again in 90 % argon and 10 % CH_4
- The magnetic field is 3 T
- The electronic noise is 600 electrons
- The readout threshold is 0
- The lower truncation parameter is 0
- The upper truncation parameter is 80 %

Three options for the cross-talk effects have been considered:

- There is no cross-talk effect at all
- There is cross-talk between the readout channels, but it is partially compensated for as in the OPAL TPC (see Section 4)

- There is cross-talk between the readout channels as in the OPAL TPC, but not compensated for.

The $\frac{dE}{dx}$ resolution obtained by simulation is then 4.13 % if no cross-talk effects are considered, 4.15 % if there are cross-talk effects which are compensated à la OPAL, and as large as 4.41 % if there are cross-talk effects not compensated for.

6 Conclusion and comparison with the performances of existing detectors

From the above studies one could infer that using 240 samples seems a good choice for the TPC to be designed for the TESLA detector. Choosing an upper truncation parameter of 80 % and no lower truncation parameter would give a $\frac{dE}{dx}$ resolution of about 4.15 %. If only 120 samples are used, as was suggested in the CDR [5] of TESLA, on would get a $\frac{dE}{dx}$ resolution as large as 4.59 %.

As was done by I. Lehraus [6] in 1983 and then more recently by M. Hauschild [1] in 1996, a comparison between the $\frac{dE}{dx}$ performances of various existing or previously used large detectors can be performed. By doing such a comparison, I. Lehraus showed that the $\frac{dE}{dx}$ resolutions essentially depend on the total detector depth L, where $L = N_{samp} \times l_{samp} \times$ pressure. On Figure 23 are indicated the measured $\frac{dE}{dx}$ resolutions for existing detectors as a function of the total detector depth L. As described in [1] a fit to the measured $\frac{dE}{dx}$ resolutions obtained with single tracks (full circles on Figure 23) results in: $\frac{\sigma(\frac{dE}{dx})}{<\frac{dE}{dx}>} = 5.5 \times L^{-0.36}$ (%), for L in $m \times bar$. The result of the fit is also shown on Figure 23.

For comparison, I have added on the figure the results of the simulation of the TPCs of some of the existing detectors, as given in Section 4 and Table 4. In addition, the expected $\frac{dE}{dx}$ resolution for the TESLA TPC as obtained by simulation is also indicated on Figure 23.

References

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[3] S. F. Biagi, Nucl. Instr. Meth. A 283 (1989) 716.

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[5] "Conceptual Design of a 500 GeV e^+e^- Linear Collider with Integrated X-ray Laser Facility", DESY 1997-048, ECFA 1997-182.

[6] I. Lehraus, Nucl. Instr. Meth. 217 (1983) 43.

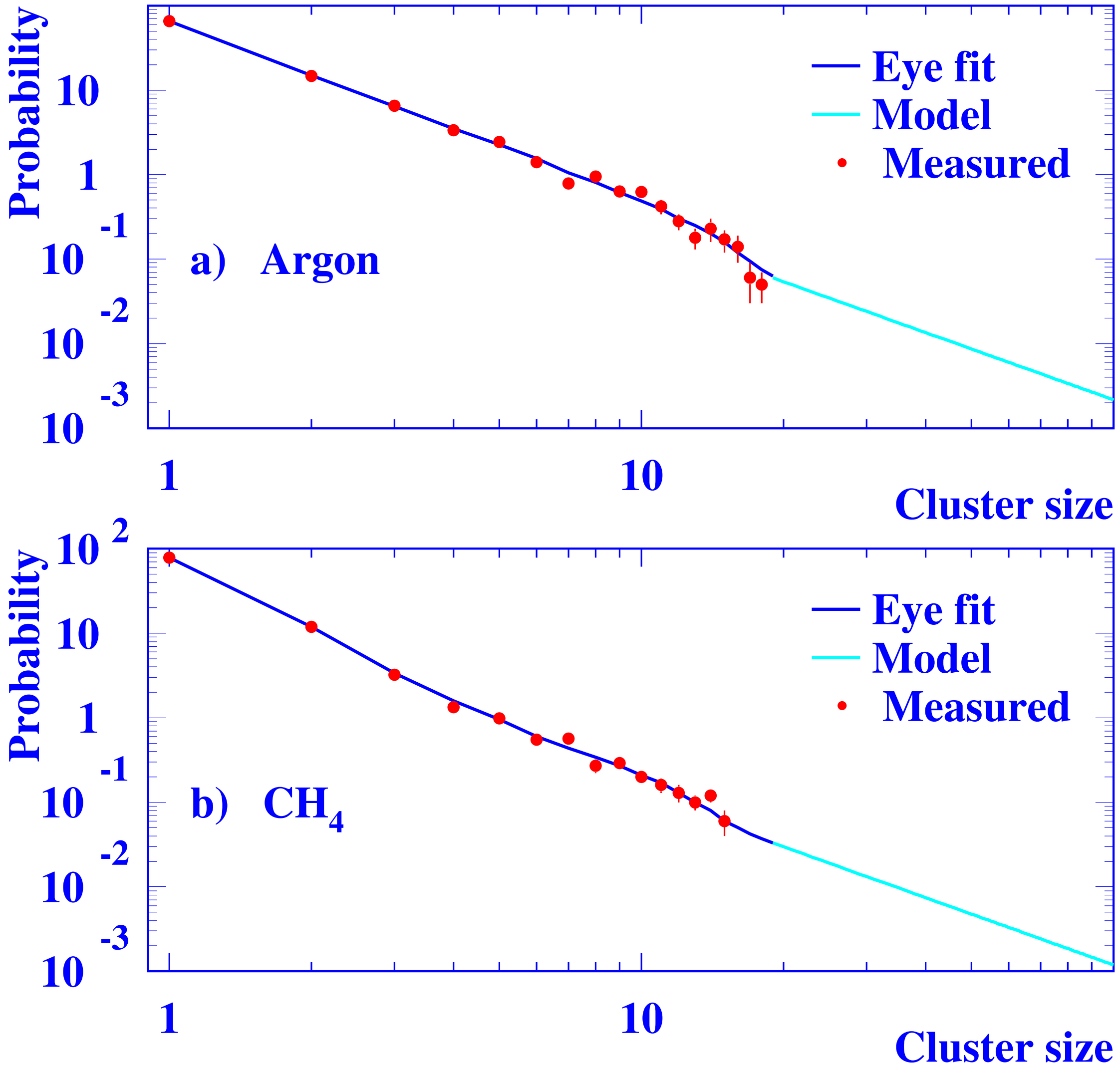

Figure 1: Cluster size distributions for a) pure argon and b) pure CH_4. The points are the measured data. The dark line corresponds to an eye-fit through the data points. The light line is the prediction of the model described in reference [2]. The cluster size distributions of b) are also valid for pure C_2H_6 and for pure iC_4H_{10}.

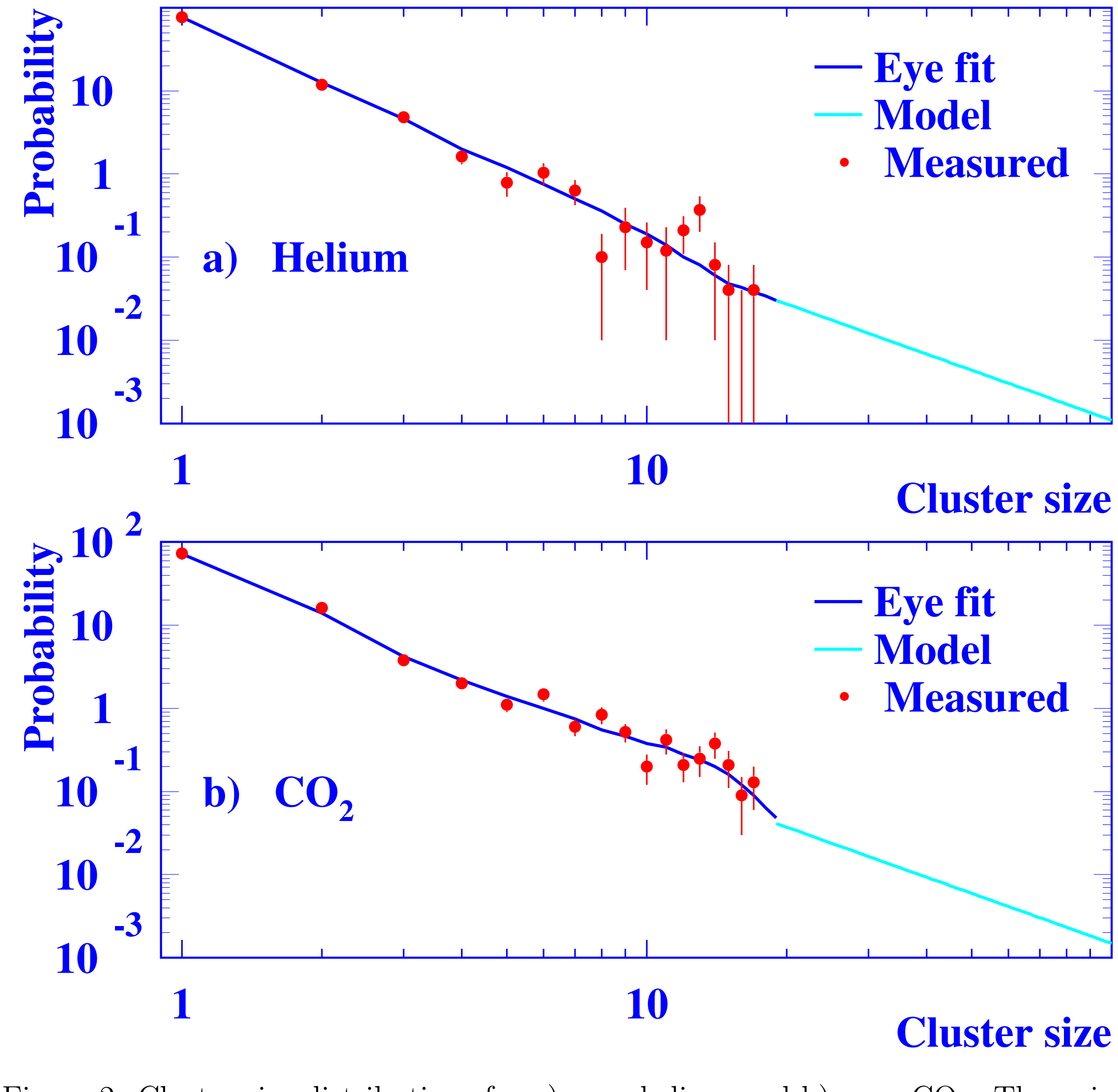

Figure 2: Cluster size distributions for a) pure helium and b) pure CO_2. The points are the measured data. The dark line corresponds to an eye-fit through the data points. The light line is the prediction of the model described in reference [2].

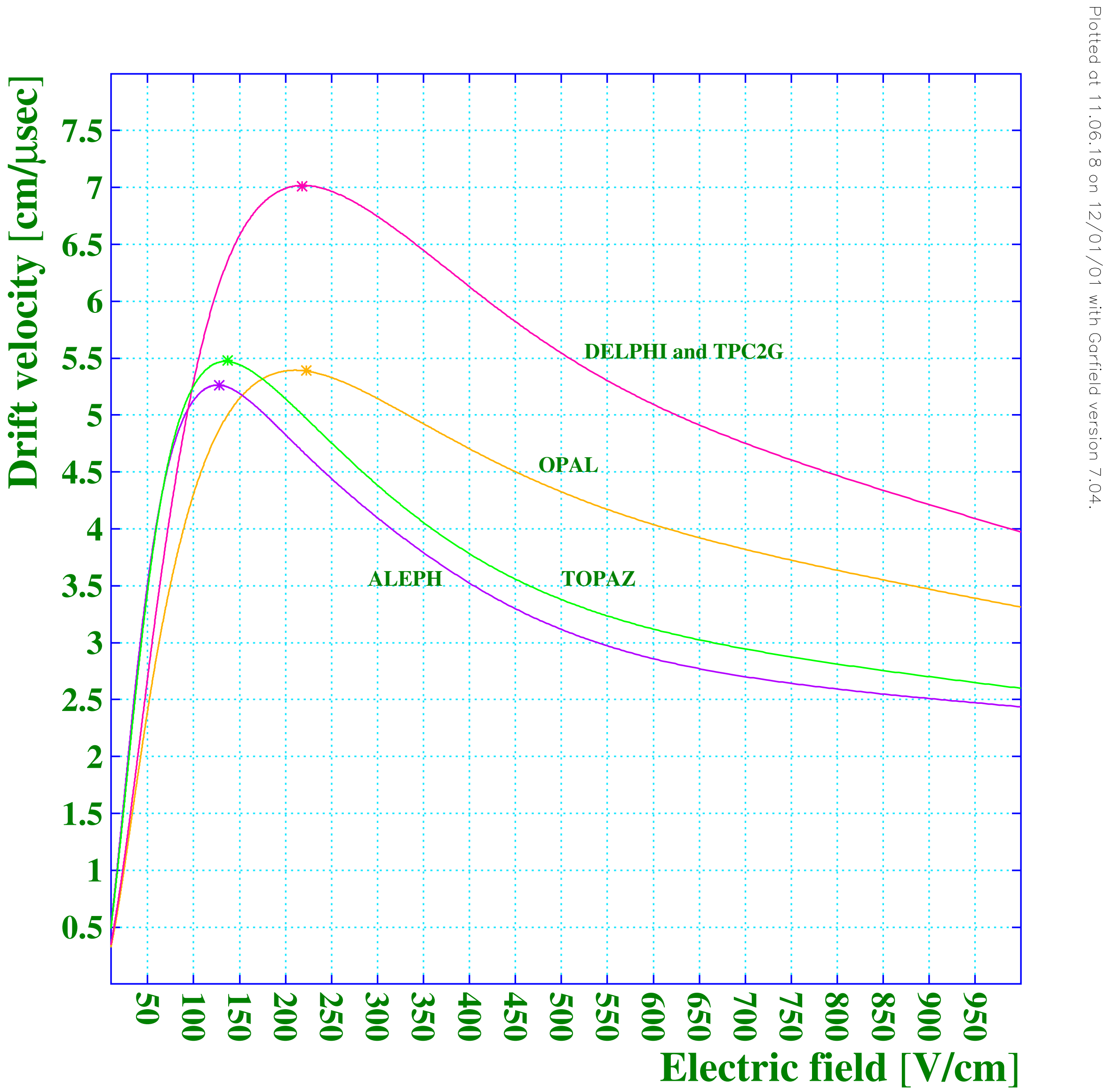

Figure 3: Drift velocity as a function of electric field for the gas mixtures used in the existing TPCs which are simulated in this note. A pressure of 1 bar is used. The asterisks show the operation points.

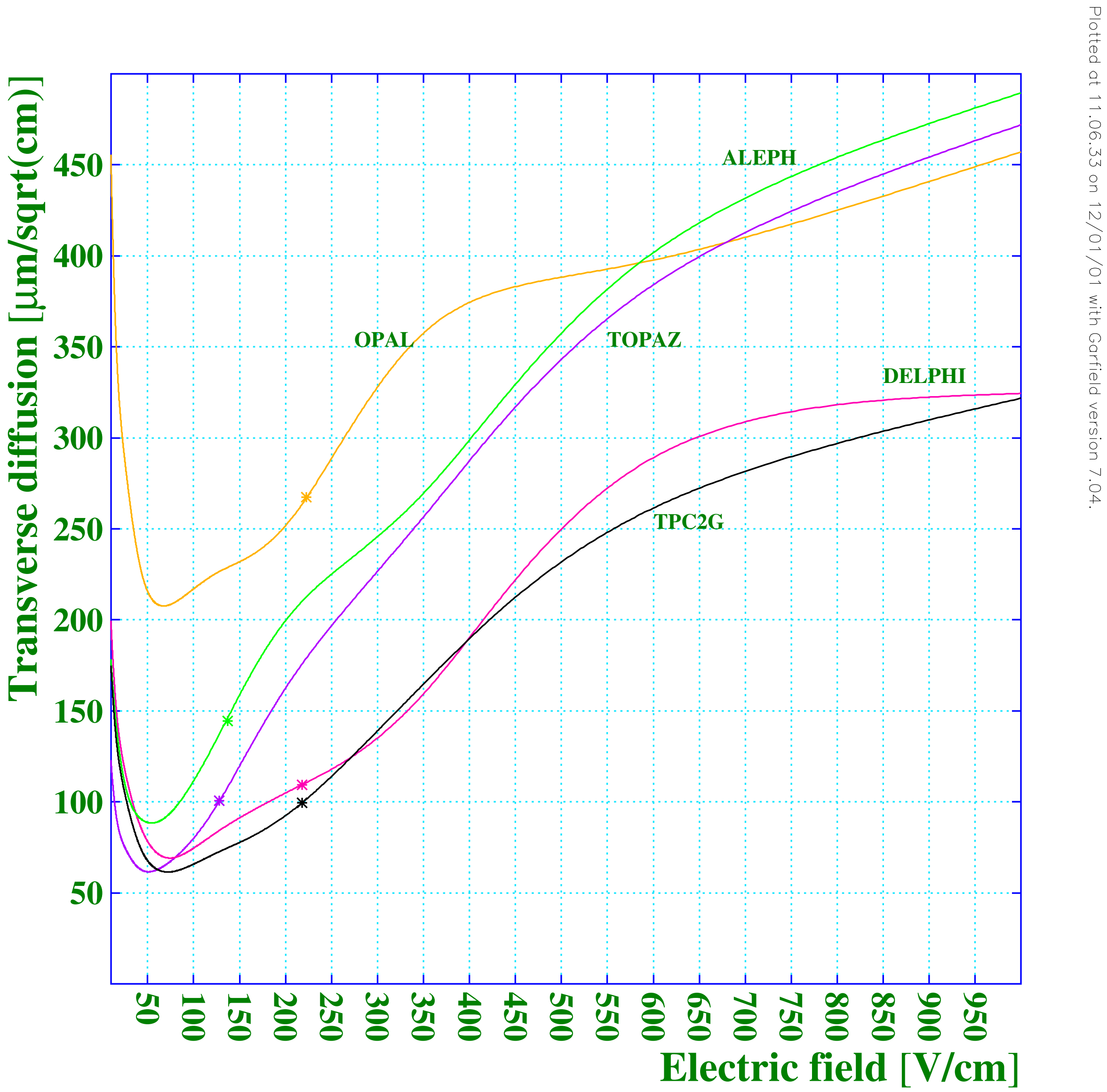

Figure 4: Transverse diffusion coefficient as a function of electric field for the gas mixtures used in the existing TPCs which are simulated in this note. A pressure of 1 bar is used. The asterisks show the operation points.

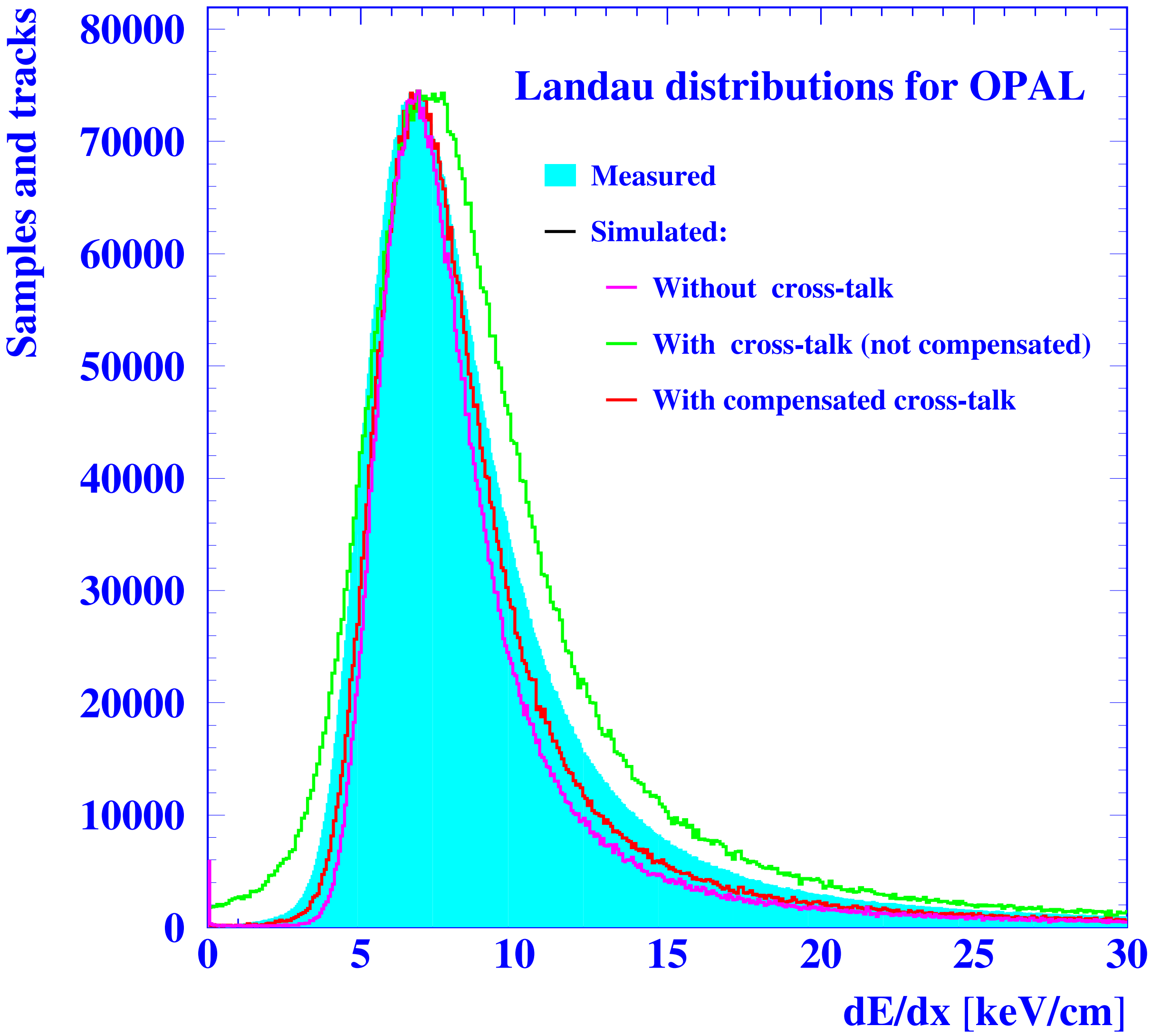

Figure 5: Measured and simulated Landau distributions for the OPAL TPC.

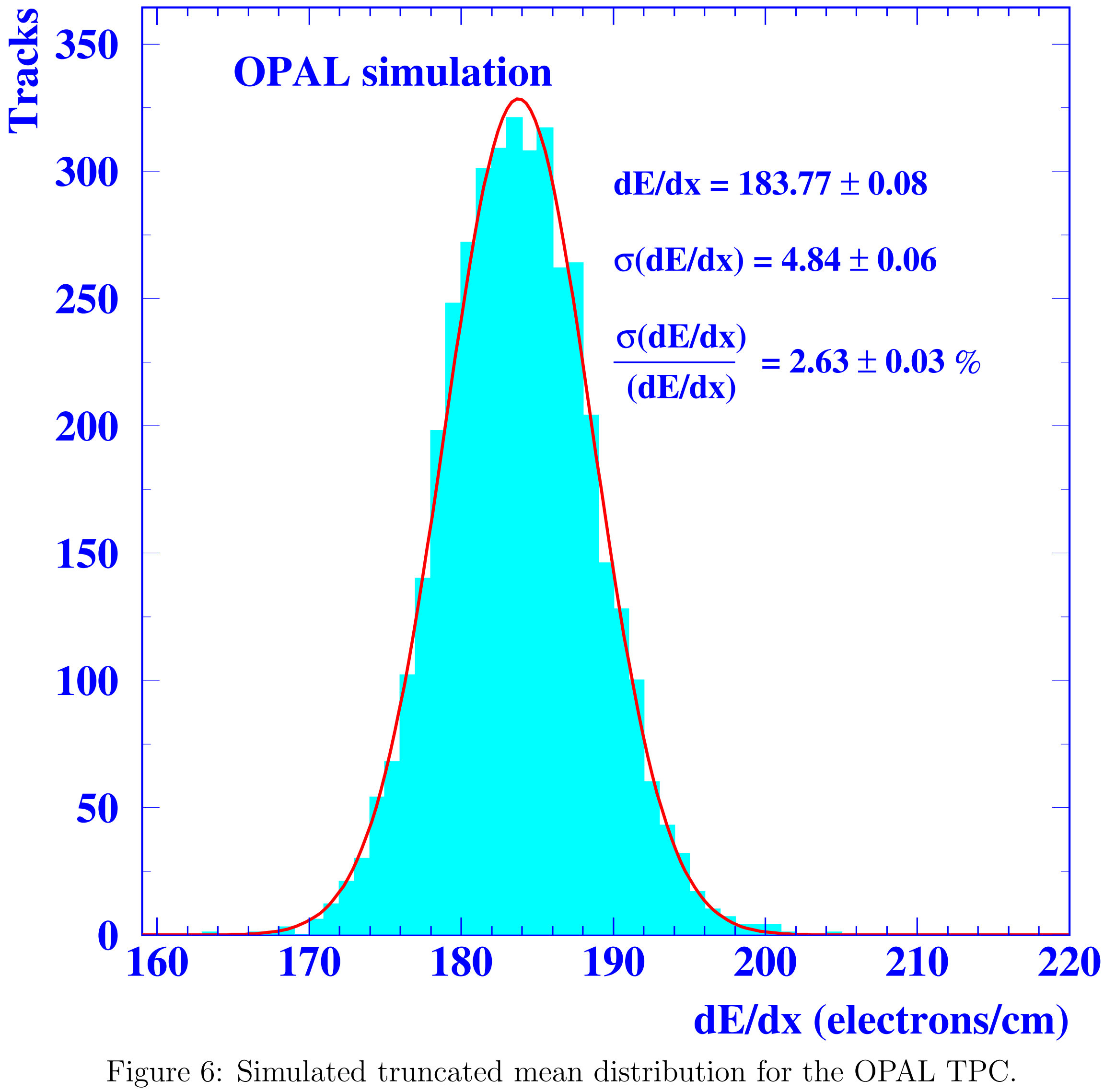

Figure 6: Simulated truncated mean distribution for the OPAL TPC.

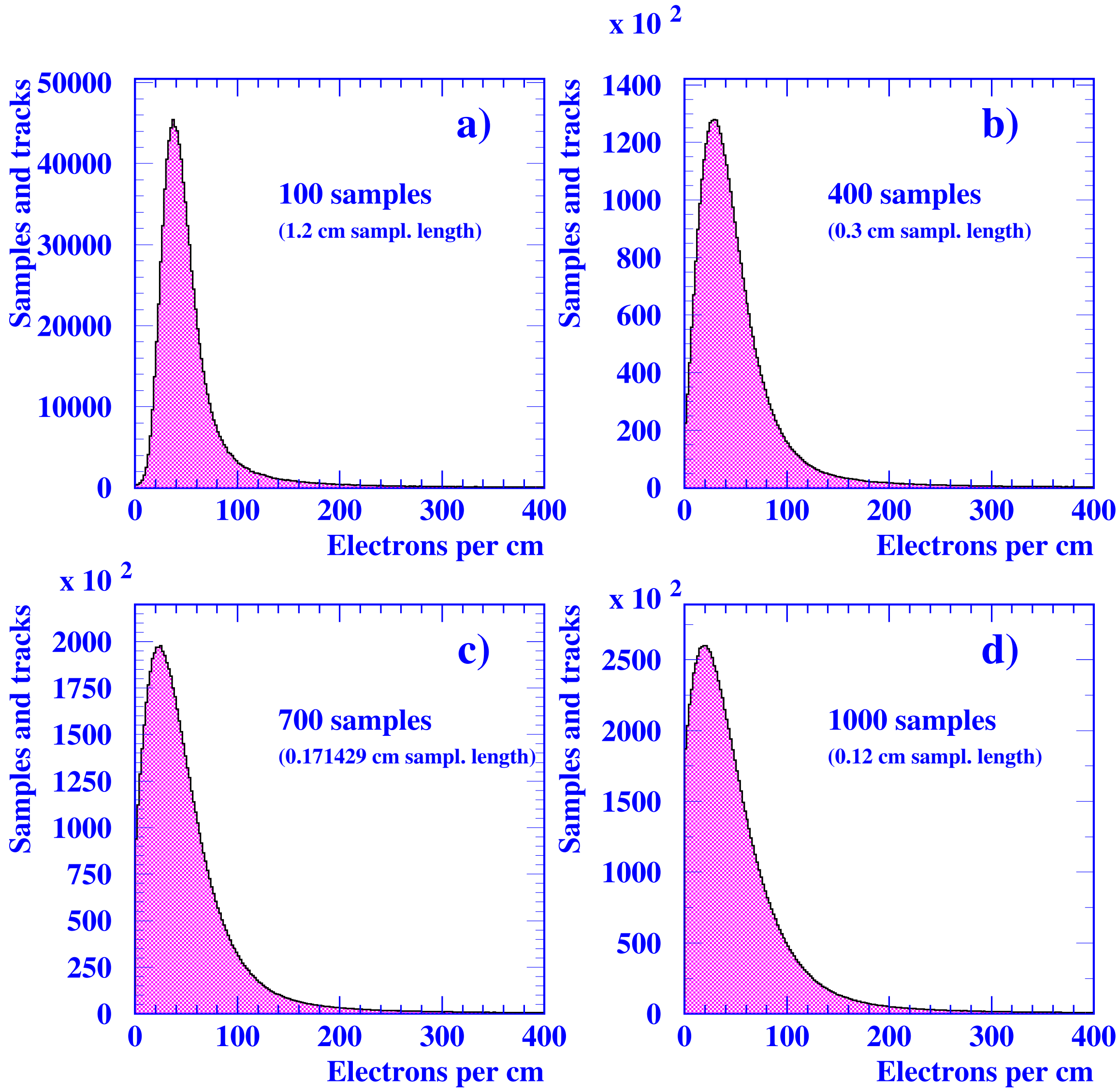

Figure 7: Simulated Landau distributions for the TESLA TPC described in Section 5.1, for a) 100, b) 400, c) 700 and d) 1000 samples.

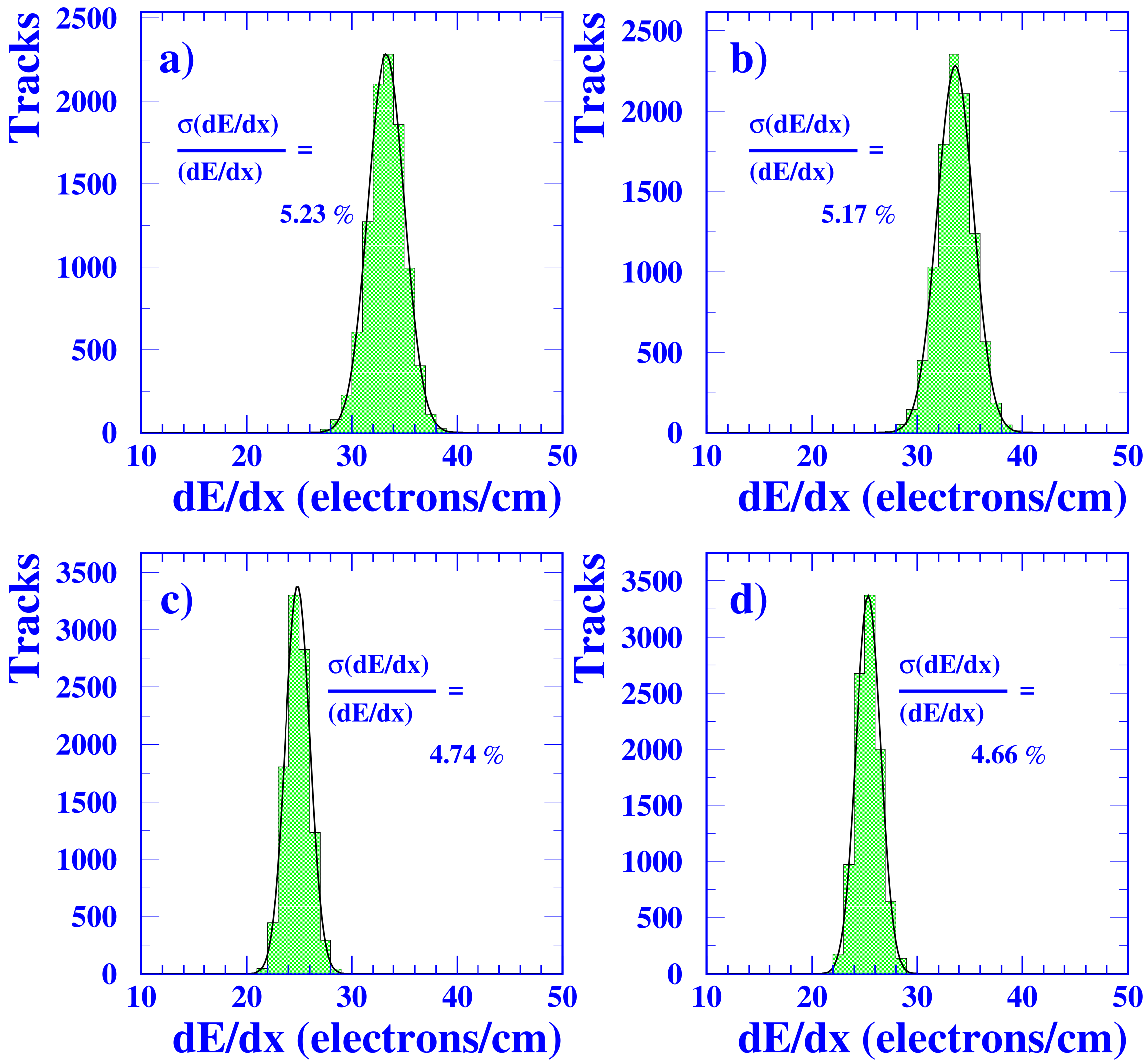

Figure 8: Simulated truncated mean distributions for the TESLA TPC described in Section 5.1 for a) 100 samples and $X_{up} = 80$ %, b) 100 samples and $X_{up} = 95$ %, c) 400 samples and $X_{up} = 80$ % and d) 400 samples and $X_{up} = 95$ %.

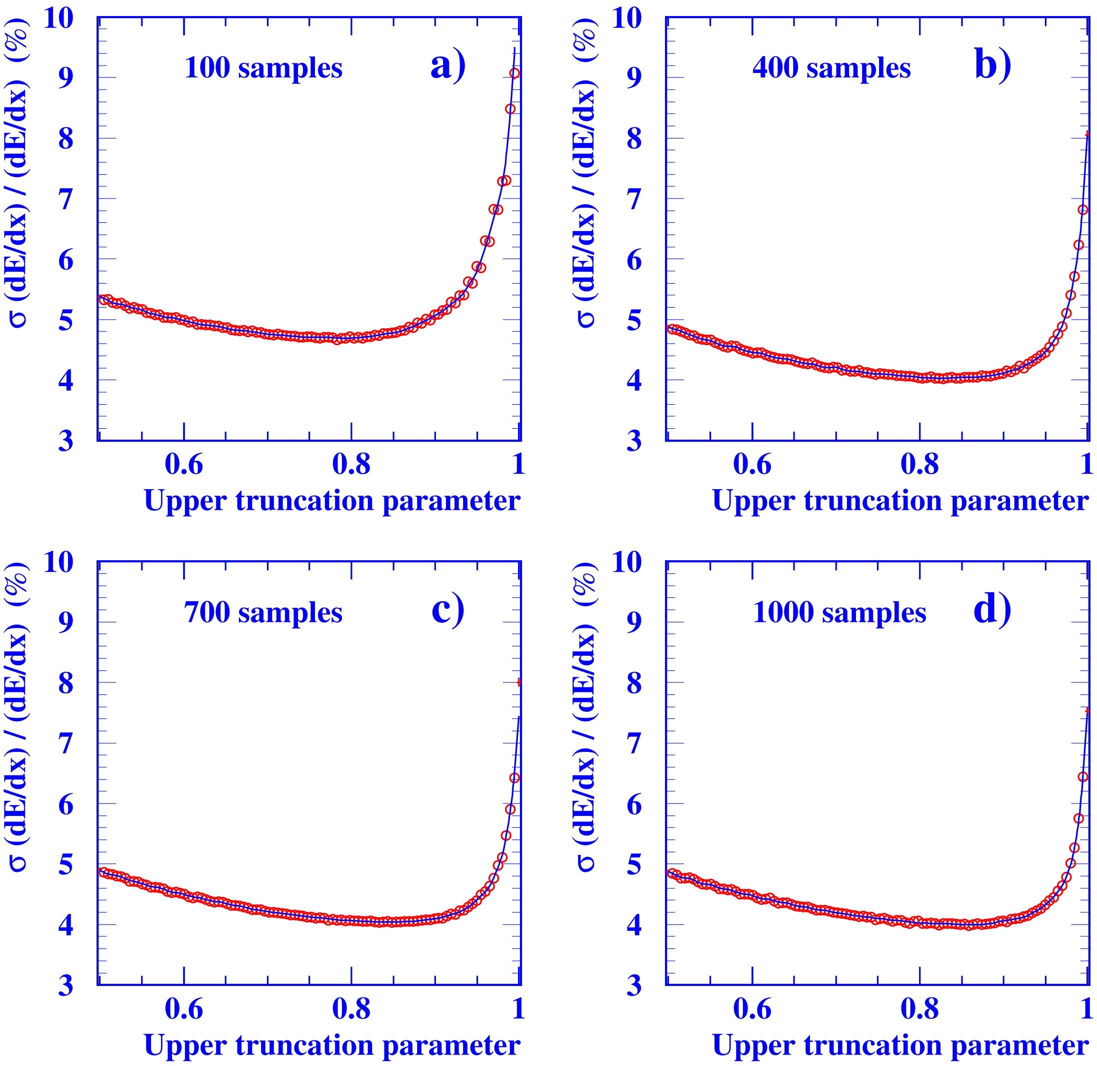

Figure 9: $\frac{dE}{dx}$ resolution as a function of upper truncation parameter for the TESLA TPC described in Section 5.1 for a) 100, b) 400, c) 700 and d) 1000 samples.

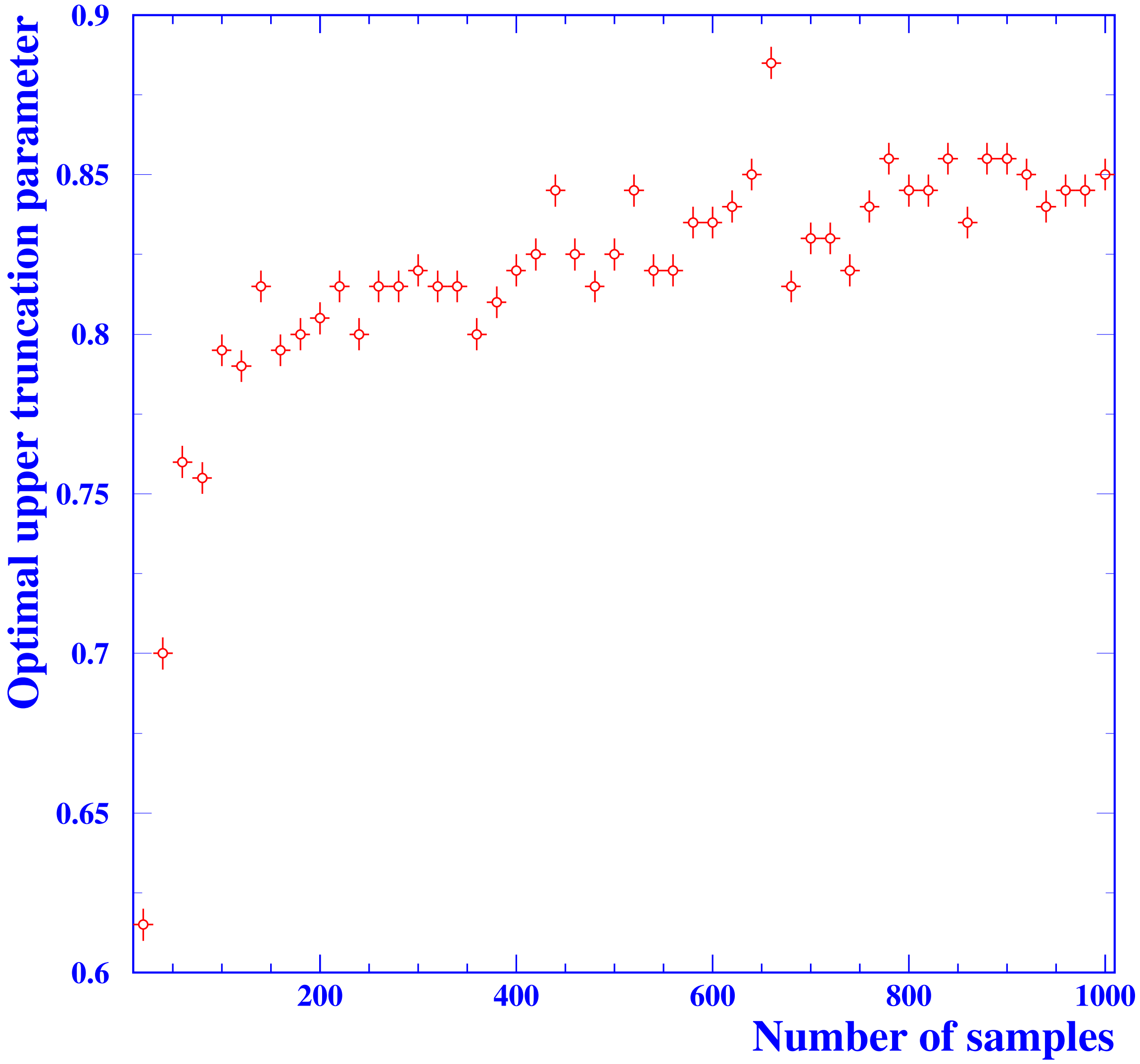

Figure 10: Optimal upper truncation parameter as a function of the number of samples for the TESLA TPC described in Section 5.1.

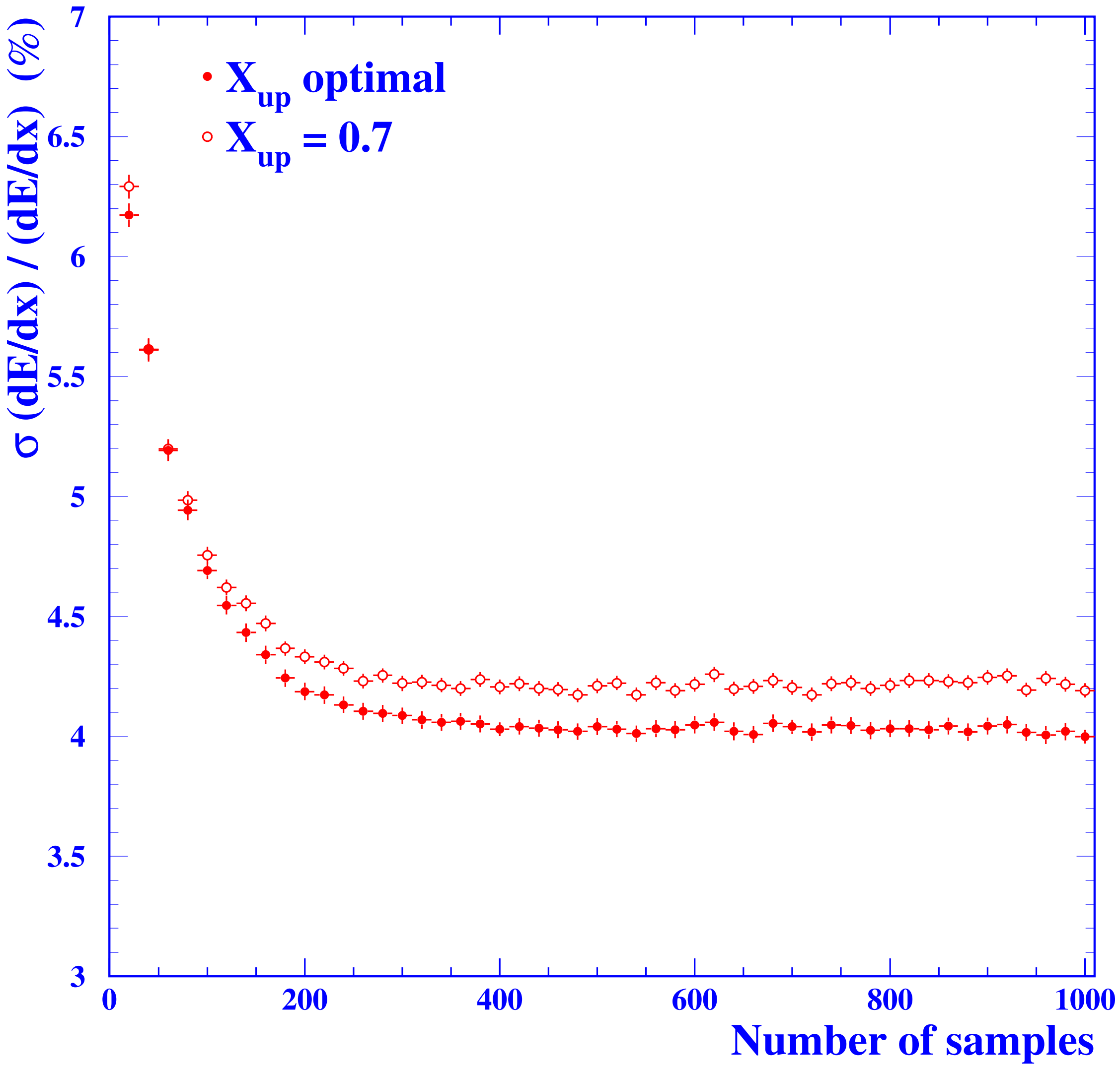

Figure 11: $\frac{dE}{dx}$ resolution as a function of the number of samples for the TESLA TPC described in Section 5.1 for $X_{up} = 70$ % and for the value of X_{up} giving the best $\frac{dE}{dx}$ resolution.

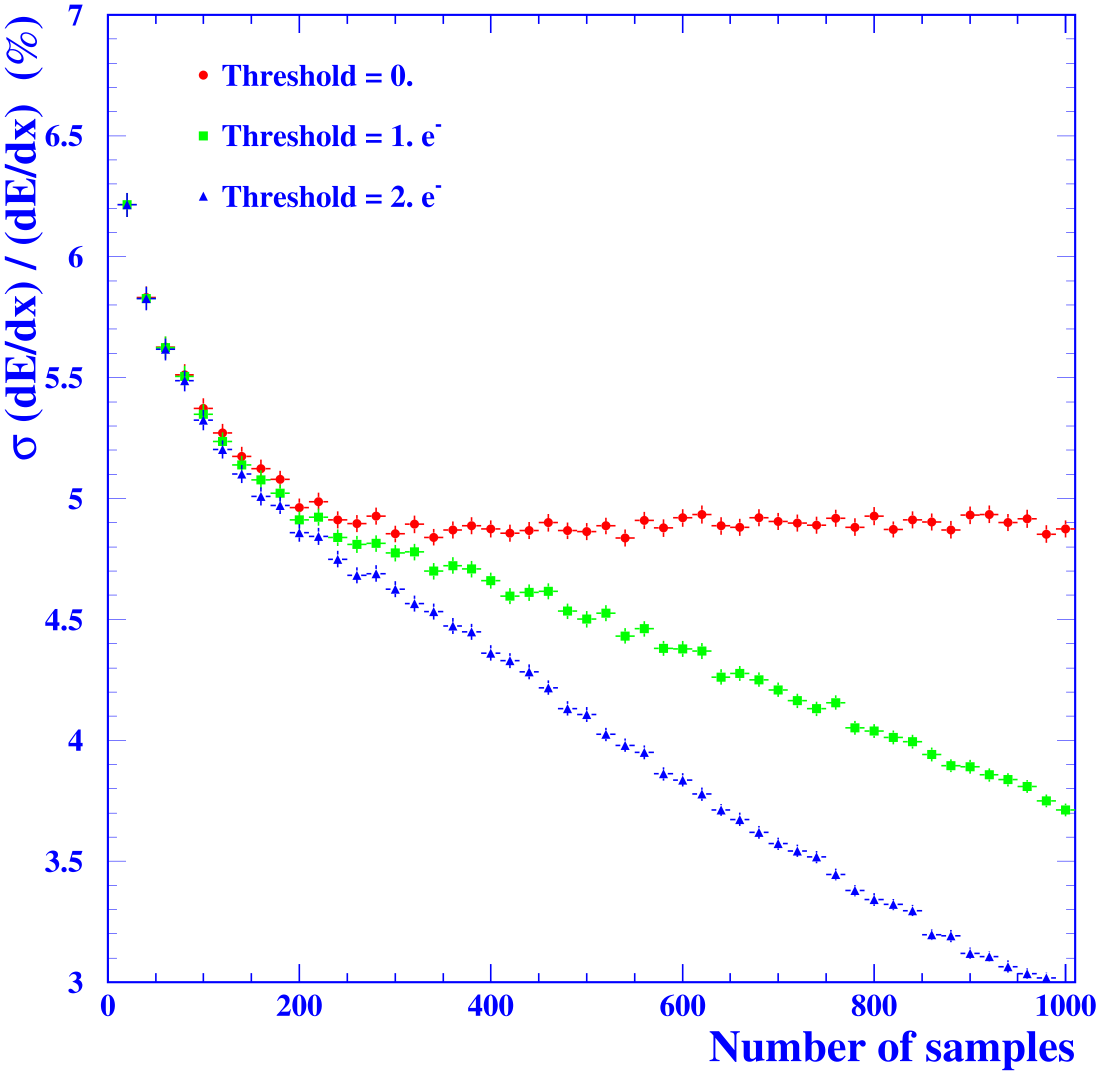

Figure 12: $\frac{dE}{dx}$ resolution as a function of the number of samples for the TESLA TPC described in Section 5.2 for $X_{up} = 70$ % and for a readout threshold of 0, 1 and 2 electrons equivalent.

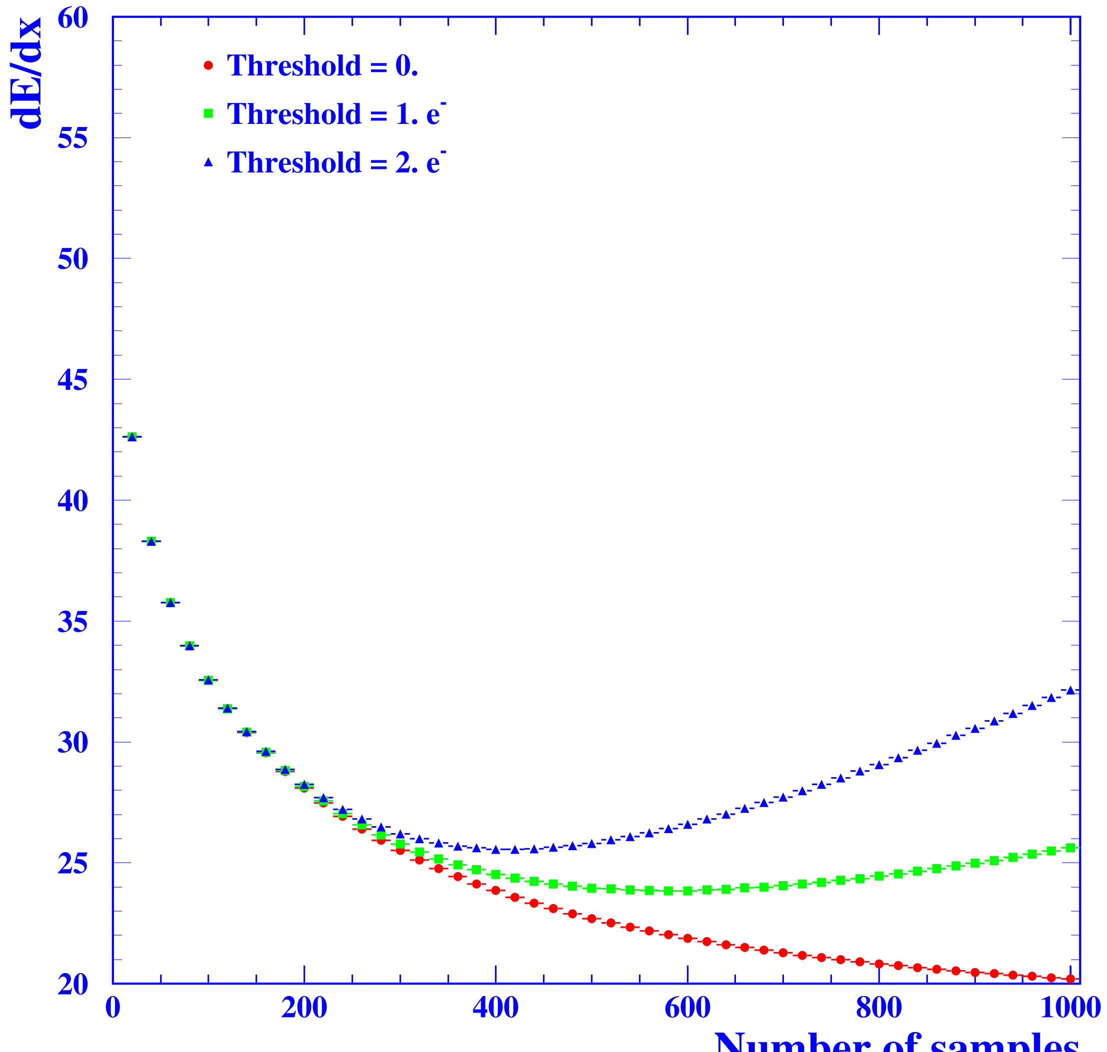

Figure 13: $\frac{dE}{dx}$ as a function of the number of samples for the TESLA TPC described in Section 5.2 for $X_{up} = 70$ % and for a readout threshold of 0, 1 and 2 electrons equivalent.

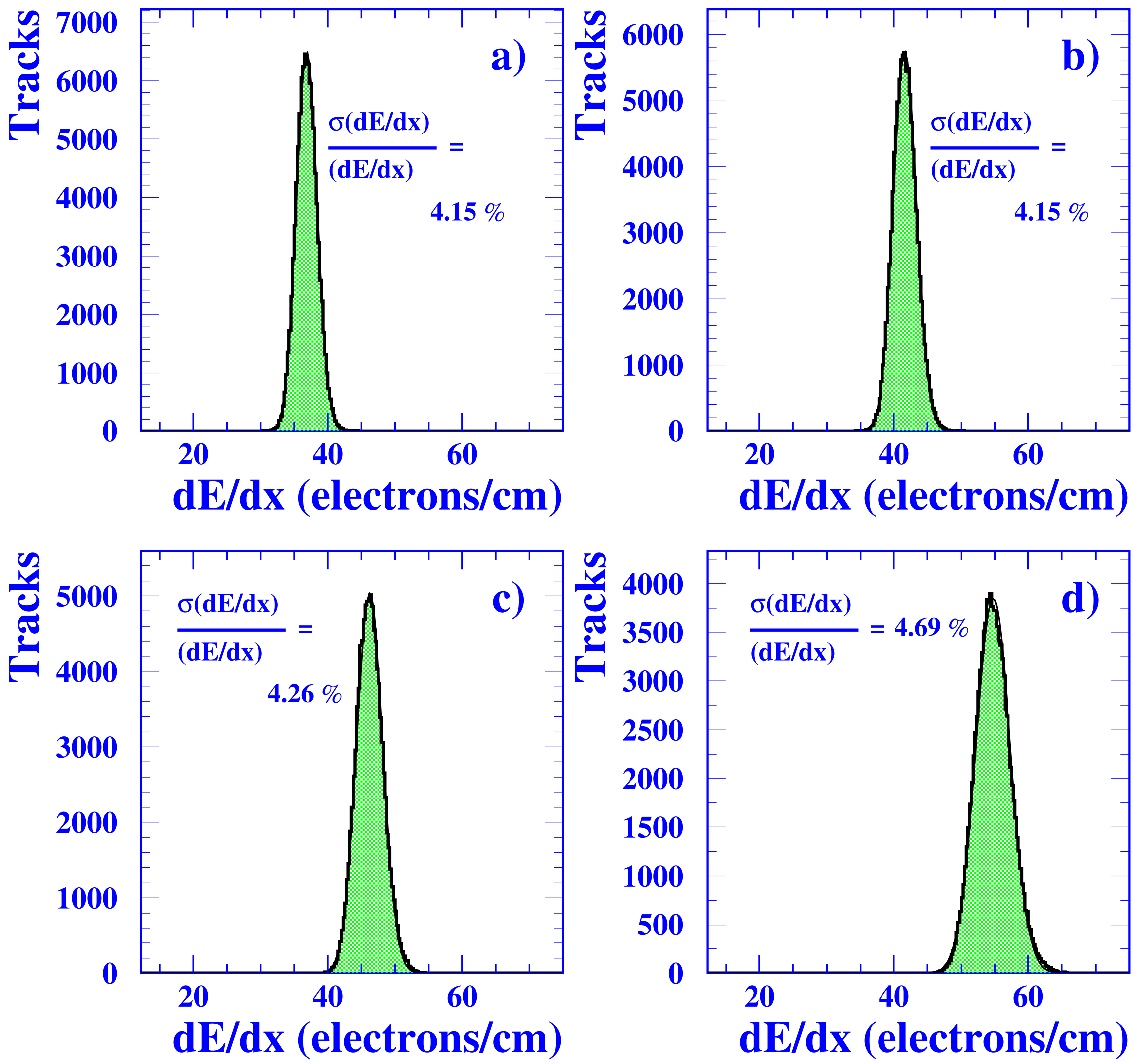

Figure 14: Simulated truncated mean distributions for the TESLA TPC described in Section 5.3 for $X_{up} = 80$ % and for a) $X_{low} = 0$, b) $X_{low} = 15$ %, c) $X_{low} = 30$ %, and d) $X_{low} = 55$ %.

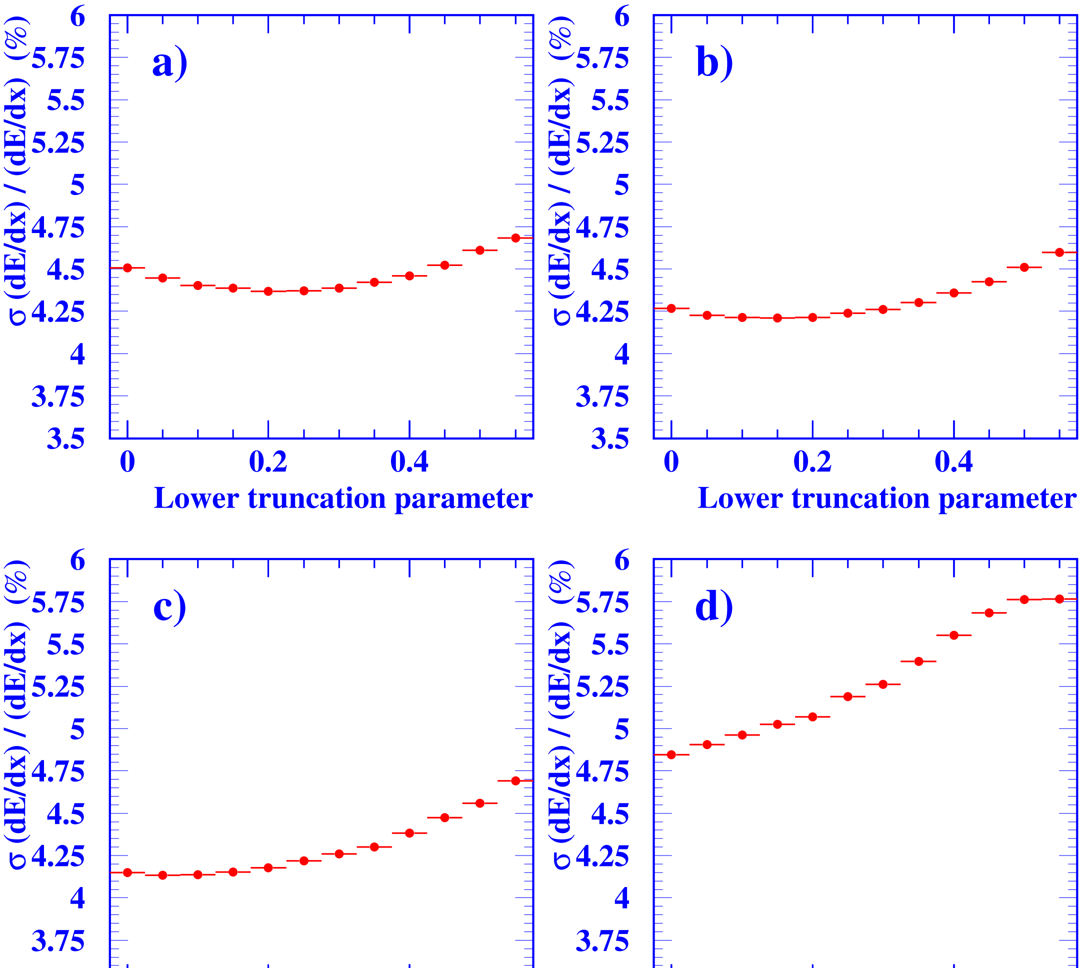

Figure 15: $\frac{dE}{dx}$ resolution as a function of lower truncation parameter for the TESLA TPC described in Section 5.3 for a) $X_{up} = 60$ %, b) $X_{up} = 70$ %, c) $X_{up} = 80$ % and d) $X_{up} = 95$ %.

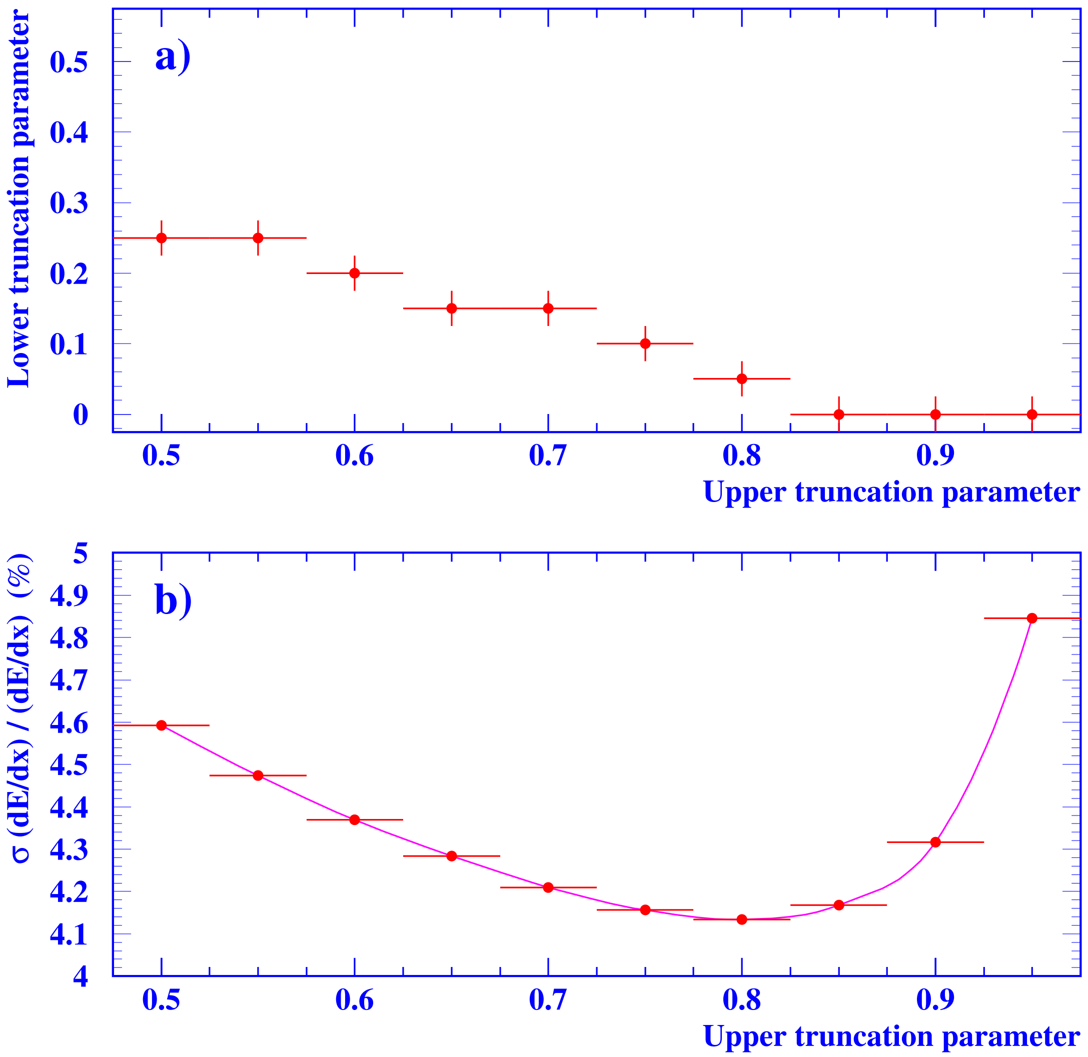

Figure 16: a) Optimal lower truncation parameter (that is the value of X_{low} giving the best $\frac{dE}{dx}$ resolution) as a function of upper truncation parameter for the TESLA TPC described in Section 5.3. b) Corresponding $\frac{dE}{dx}$ resolution (obtained with the optimal lower truncation parameter) as a function upper truncation parameter.

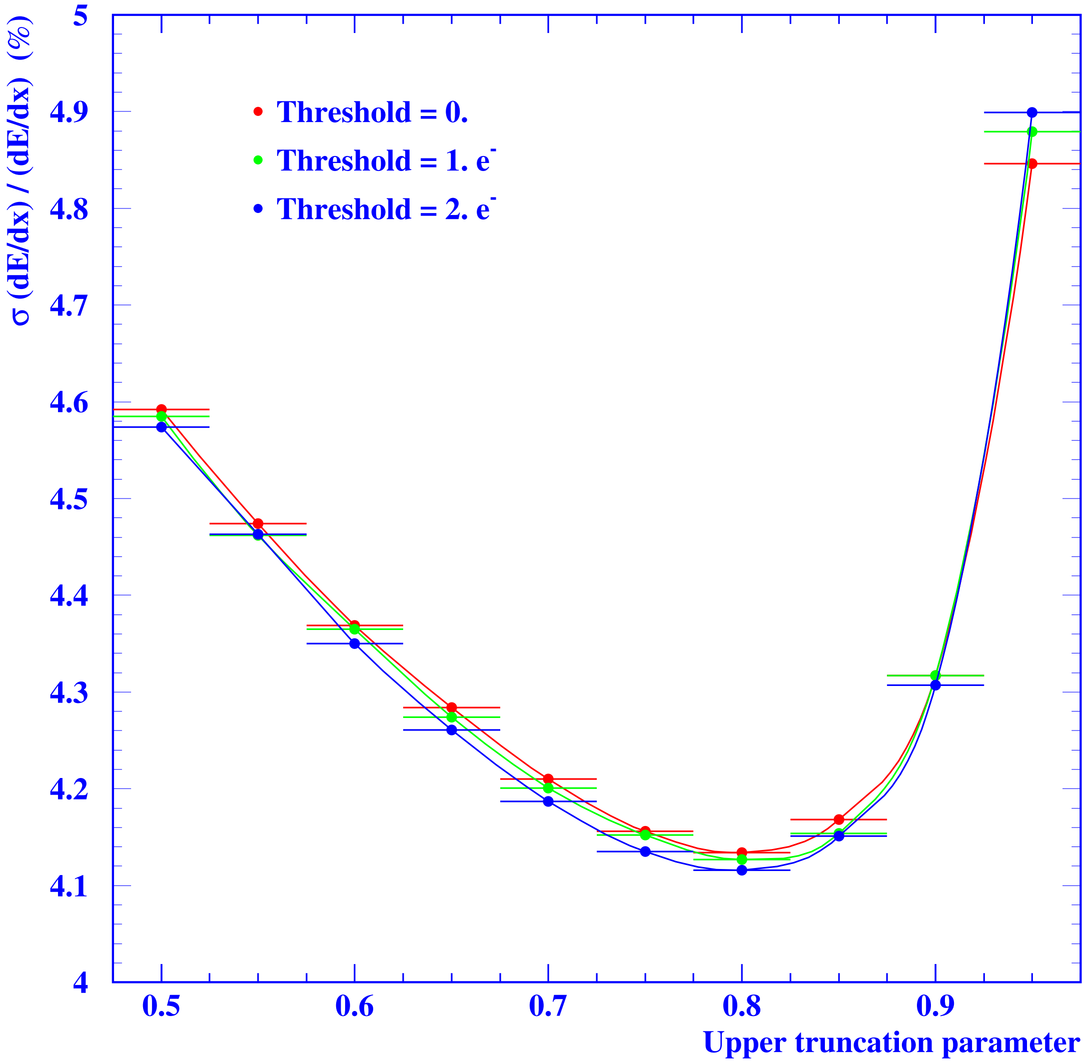

Figure 17: $\frac{dE}{dx}$ resolution for the optimal lower truncation parameter as a function of upper truncation parameter for the TESLA TPC described in Section 5.3 for a readout threshold of 0, 1 and 2 electrons equivalent.

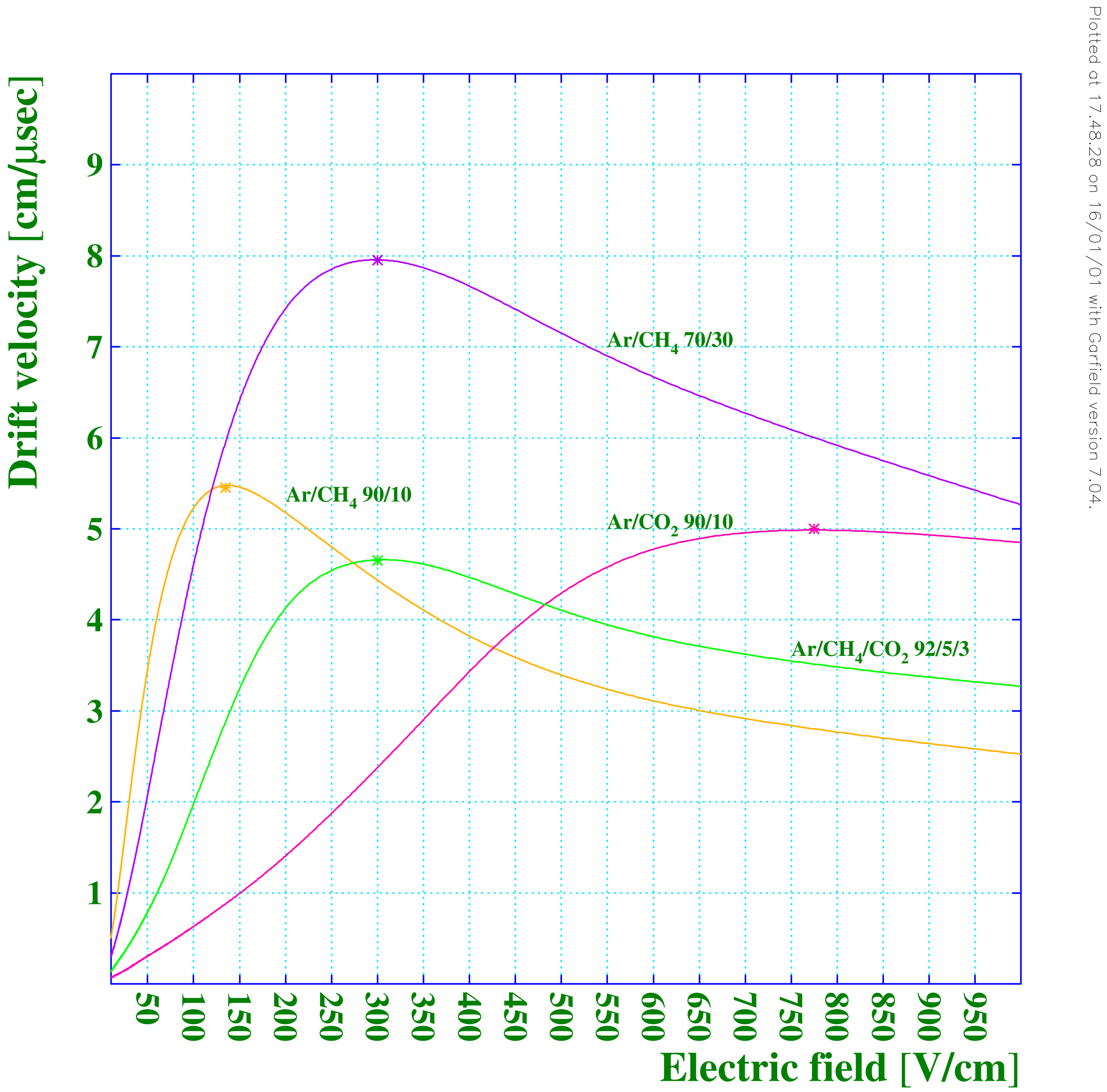

Figure 18: Drift velocity as a function of electric field for the gas mixtures used in the simulation of the TESLA TPC. A pressure of 1 bar is used. The asterisks show the operation points.

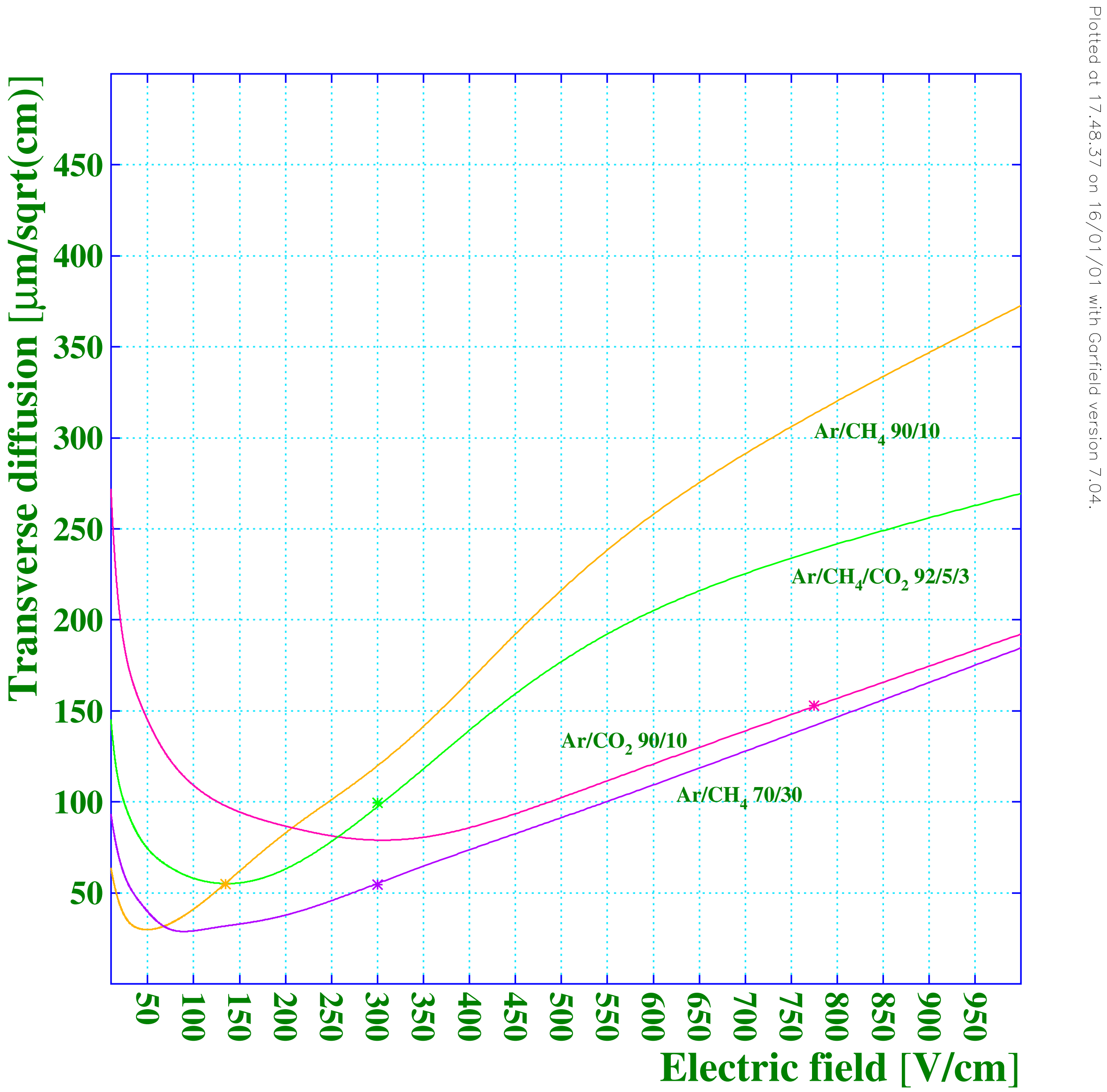

Figure 19: Transverse diffusion coefficient as a function of electric field for the gas mixtures used in the simulation of the TESLA TPC, with a 3 T magnetic field. A pressure of 1 bar is used. The asterisks show the operation points.

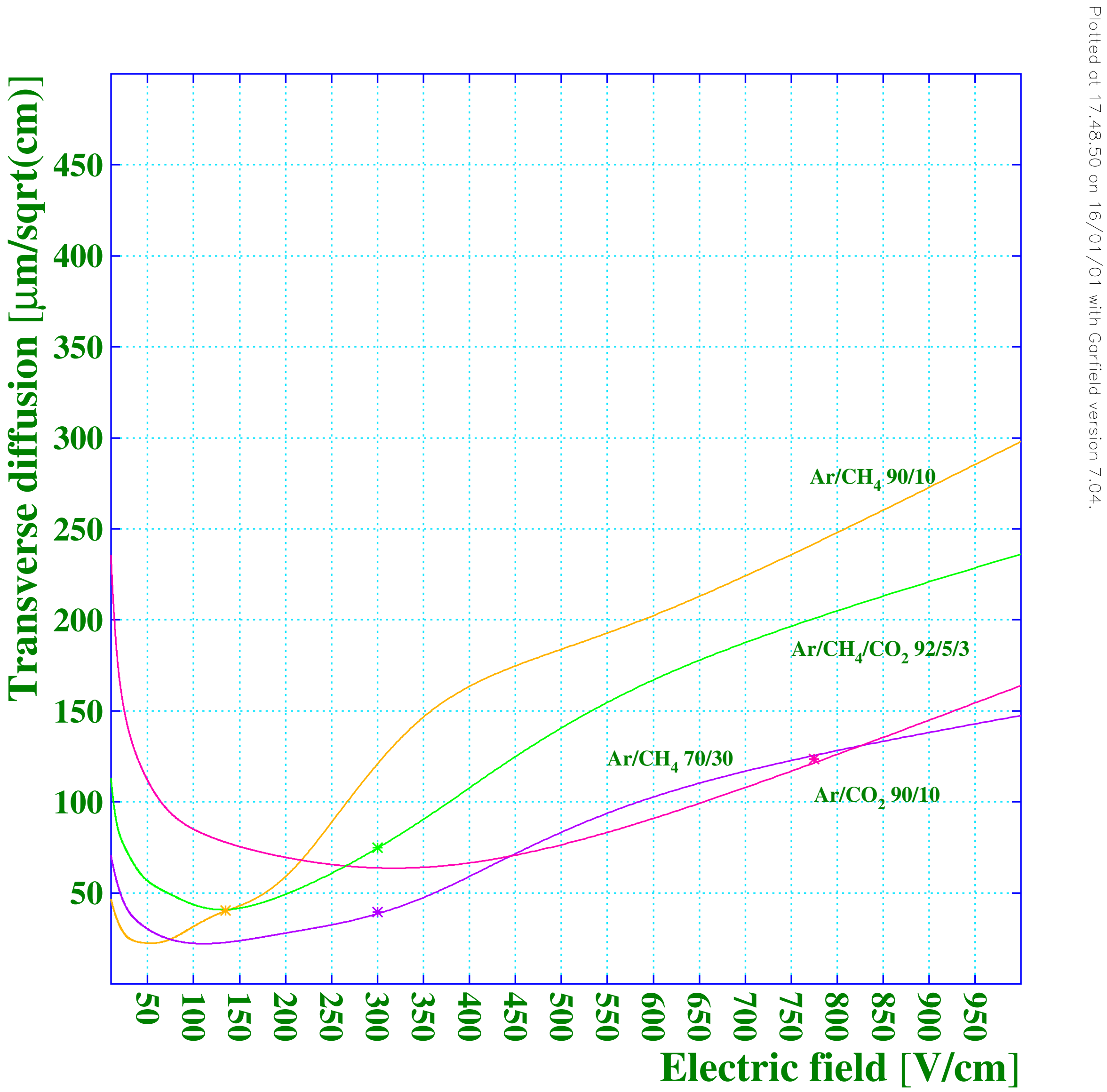

Figure 20: Transverse diffusion coefficient as a function of electric field for the gas mixtures used in the simulation of the TESLA TPC, with a 4 T magnetic field. A pressure of 1 bar is used. The asterisks show the operation points.

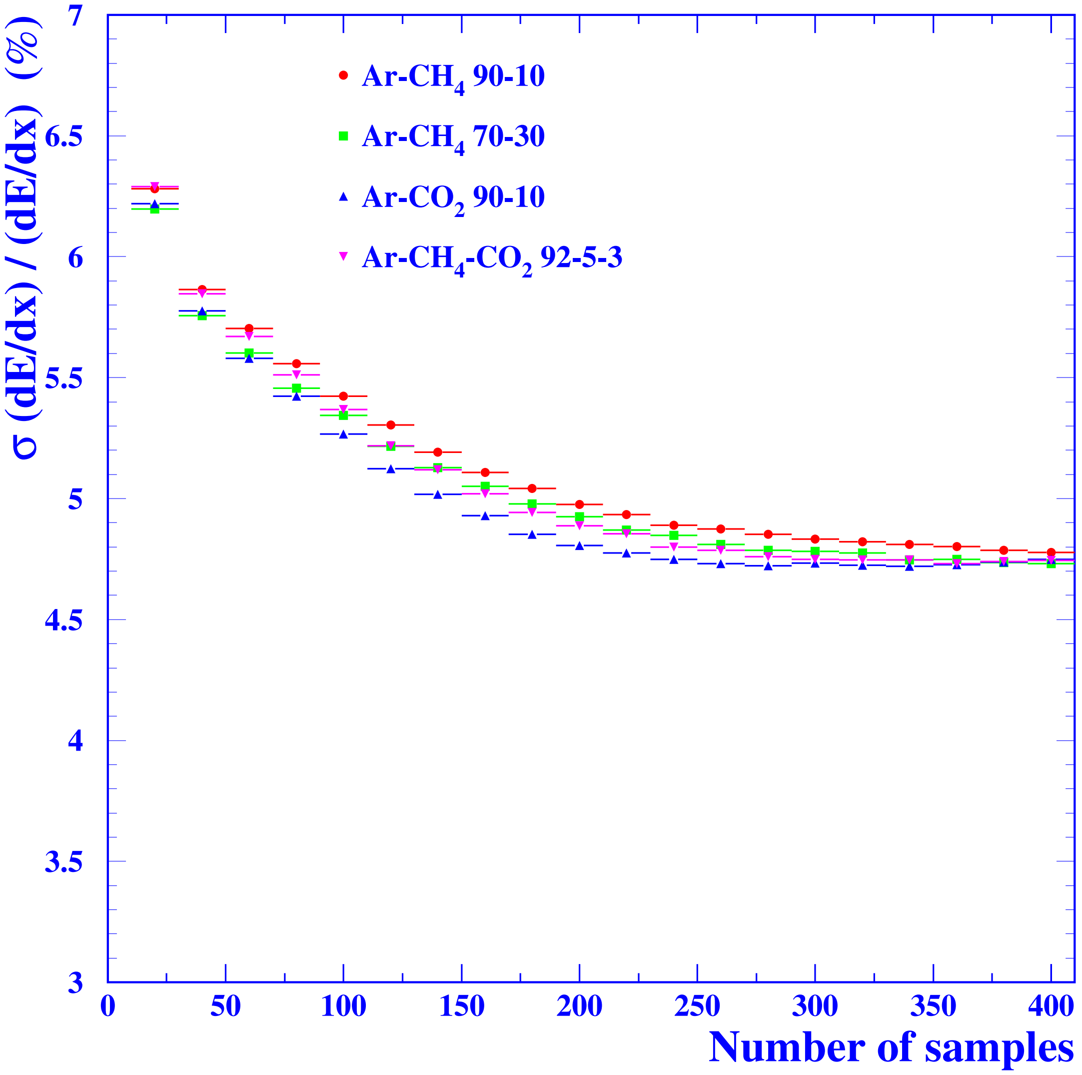

Figure 21: $\frac{dE}{dx}$ resolution as a function of the number of samples for the TESLA TPC described in Section 5.5, for a gas mixture of Ar/CH_4 -90/10, Ar/CH_4 -70/30, Ar/CO_2 -90/10 and $Ar/CH_4/CO_2$ -92/5/3.

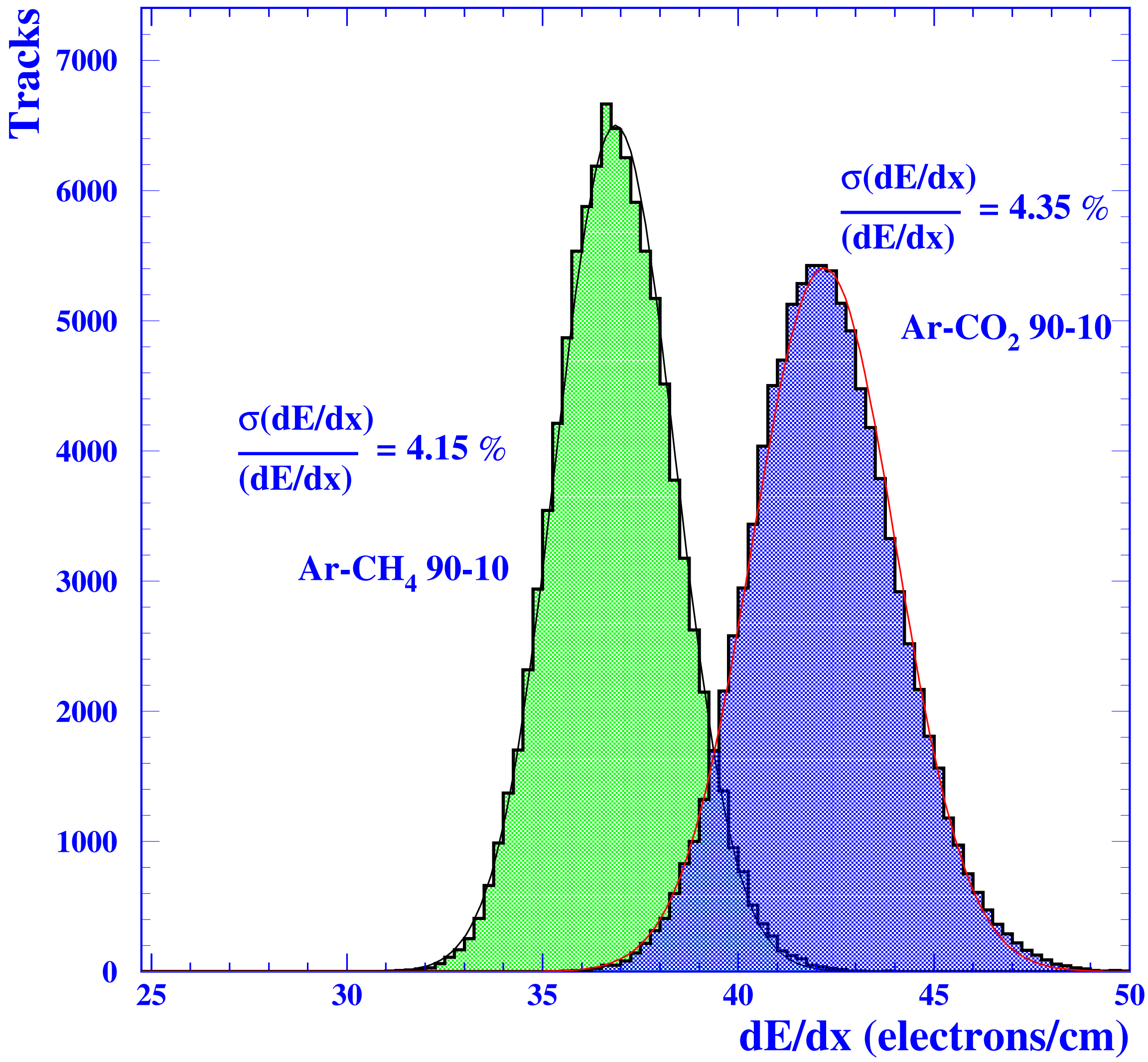

Figure 22: Simulated truncated mean distributions for the TESLA TPC described in Section 5.5 with 240 samples and for two gas mixtures: Argon/CH_4-90/10 and Argon/CO_2-90/10.

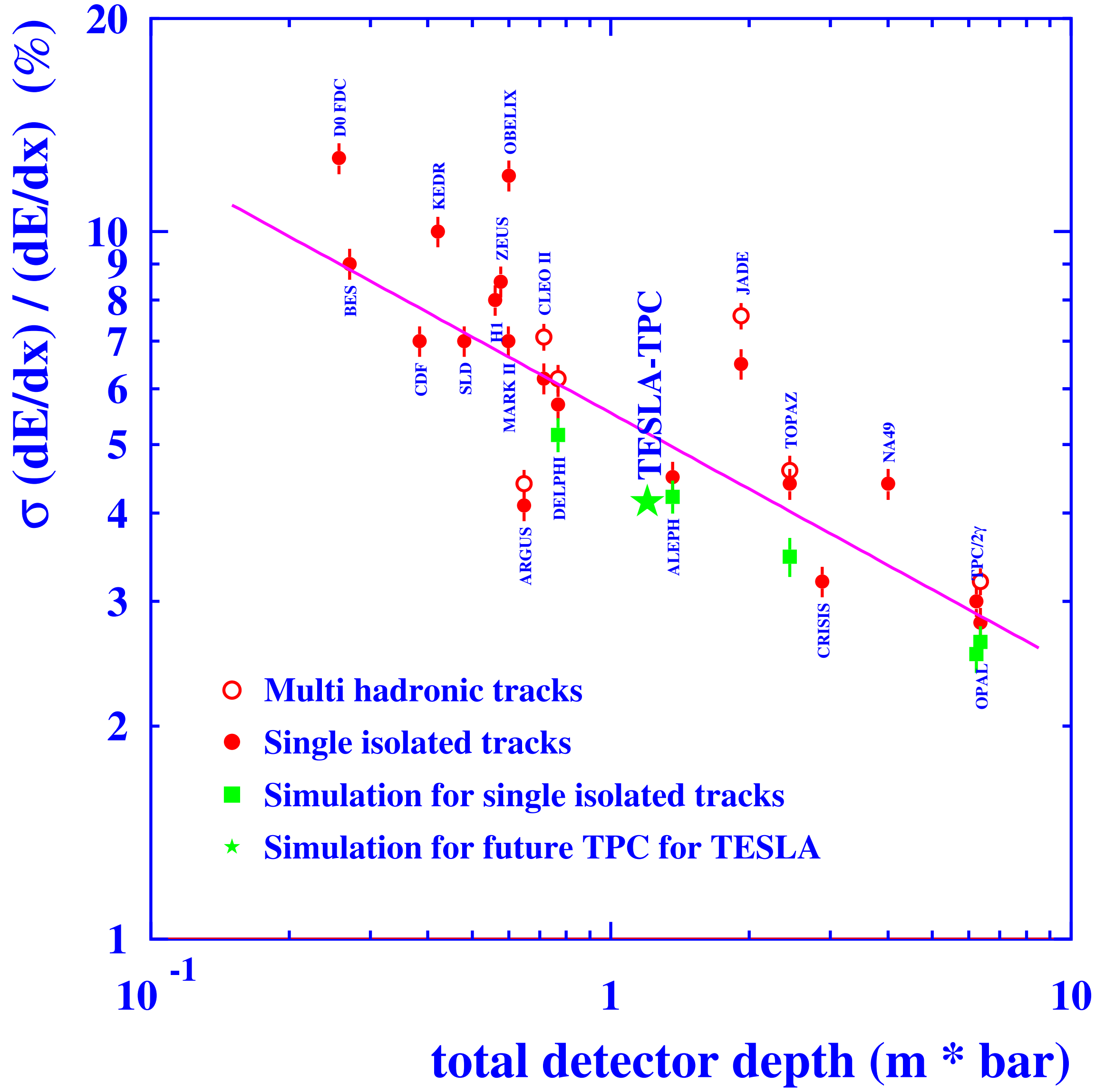

Figure 23: Measured $\frac{dE}{dx}$ resolutions for existing detectors as a function of the total detector depth $L = N_{samp} \times l_{samp} \times$ pressure. Full circles represent the resolution for single isolated tracks, and open circles the resolution for tracks in multi hadronic events, where available. The solid line is the result of a fit to the single isolated tracks resolutions assuming an error of 5 % for each individual point (see [1]). The full squares represent the $\frac{dE}{dx}$ resolutions obtained by simulation. The star shows the expected $\frac{dE}{dx}$ resolution for the TESLA TPC, as obtained by simulation.