

Possible design of the Pion Detector for the Moller Experiment

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Abstract

In this report we study a possible design of the pion detector for the Moller experiment. The detector is designed under the requirement that it can operate in a counting and a continuous mode. While a valuable design is proposed, the results reported here are just a first pass in the design procedure and if this concept is accepted the detector will be improved latter.

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I. Introduction

Moller experiment proposes to measure the parity-violating asymmetry in the scattering of longitudinally polarized 11 GeV electrons from the atomic electrons in a liquid hydrogen target [MOLLER 2012].

Nominal design parameters for the proposed measurement are shown in Table 1. While some of the design parameters could change in the future at the few percentage level as the design is further optimized, possible changes are not important for the scope of this report.

Parameter	Value
E [GeV]	≈ 11.0
E' [GeV]	1.8 - 8.8
θ_{cm}	46° - 127°
θ_{lab}	0.23° - 1.1°
$\langle Q^2 \rangle$ [GeV^2]	0.0056
Maximum Current [μA]	85
Target Length (cm)	150
ρ_{tgt} [g/cm^3] (T= 20K, P = 35 psia)	0.0715
Max. Luminosity [$\text{cm}^{-2} \text{sec}^{-1}$]	$3.4 \cdot 10^{39}$
σ [μBarn]	≈ 40
Møller Rate [GHz]	≈ 135
Statistical Width(2 kHz flip) [ppm/pair]	≈ 83
Target Raster Size [mm]	5 x 5
ΔA_{raw} [ppb]	≈ 0.6
Background Fraction	≈ 0.08
P_{beam}	$\approx 85\%$
$\langle A_{pv} \rangle$ [ppb]	≈ 35
$\Delta A_{stat} / \langle A_{expt} \rangle$	2.1%
$\delta(\sin^2 \theta_W)_{stat}$	0.00026

Table 1. Nominal design parameters for the proposed Moller measurement [MOLLER 2012].

The scope of this report is to conceptually design and estimate the properties of a pion detector for the Moller experiment. In the process of the design both, in addition to the physical properties, a possible cost of the detector was also kept in mind.

Overview of the Moller experiment detectors, including the possible position of the pion detector, is shown in Figure 1.

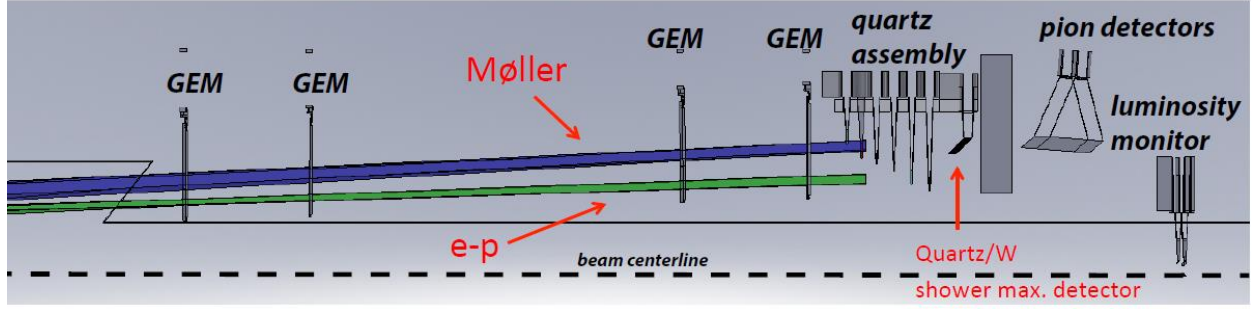


Figure 1. Schematics of the pion detector position in a relation to the position of the surrounding detectors.

The physical properties of the proposed detector were obtained using a simulation tool called FLUKA [FERRARI 2005, BATTISTONI 2007], a fully integrated particle physics Monte Carlo simulation package with many applications in high energy experimental physics and engineering, shielding, detectors and telescopes design, cosmic ray studies, dosimetry, medical physics and radio-biology. Once the incoming particles are generated and the properties of the material are known, it is straight forward to simulate the detector properties. The physical mechanisms implemented in today's simulation software are very accurate and the differences between the simulated and measured results are in the most cases negligible.

In this report detailed study of the detector properties are done for pion and electron energies at the extreme limits of the experimental acceptance, at the momenta of 1.8 and 8.8 GeV/c, related to the lowest and the highest energies in Table 1.

II. Basic Idea

The operation of the proposed Moller pion detector is similar to the Preshower (PSh) detector of the DIRAC experiment [DIRAC 2003, DIRAC2015] and it is based on electrons and pions propagating through the material differently. Compared to the electrons, the pions, as minimally ionizing particles, penetrate more deeply into the shielding material and, at the same time, deposit less energy in the detector material, generating lower amplitude signal than the electrons with similar energies. A layered detector system made of layers of shielding and detectors can be designed to separate the particles by taking those properties into account. In order to be used in a counting and continuous mode, the detector system will consist of two parts: front part where both electrons and pions penetrate and the back part where the penetration of electrons is greatly reduced, so that the energy deposited by the electrons is comparable to the energy deposited by the pions taking their rates into account. Schematic of such a system is shown in Figure 2.

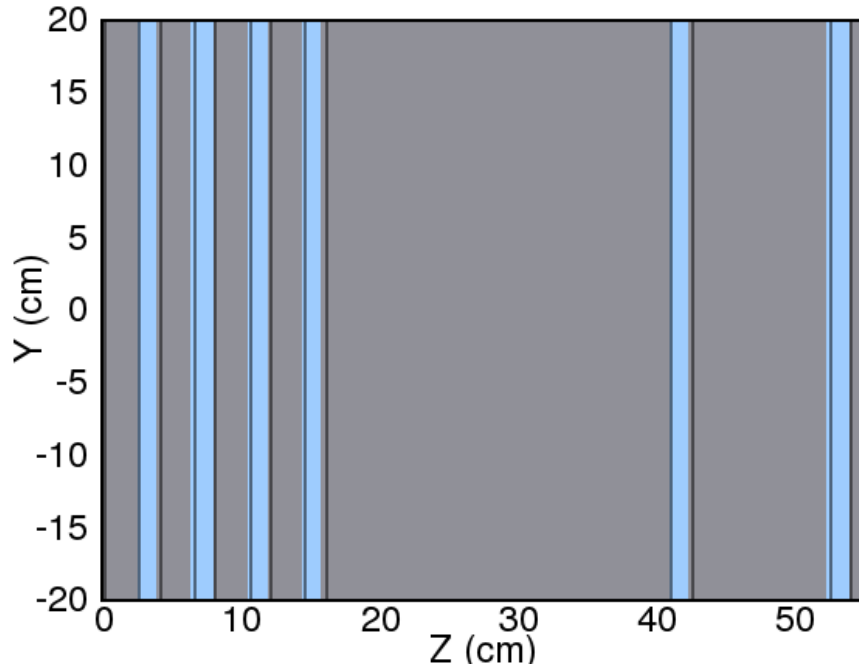


Figure 2. Schematic of a layered pion detector consisting of layers of lead (gray) and scintillators (blue).

Operation of the detector is as follows: Both, the difference in the amplitudes of the signals and the change in the difference of the signals in front four scintillators are used to separate pions from electrons in a counting mode and to calibrate the last two scintillator detectors. The thickness of the shielding in front of the last two scintillators reduces the electron energy deposition in the scintillators in order to be comparable to the pion energy deposition, taking into account electron and pion rates. Also, a large dynamic range of deposited energy 1.8 – 8.8 GeV particles is also taken into account. Since the detectors would be calibrated in the counting mode, the signal measured in the last two detectors can be used to monitor the ratio of pion to electron rates in continuous mode.

II. Details of the Detector Operation

Several simulations help in understanding the operation of pion detector. Difference in the penetration through the material between the electrons and pions can be observed by looking at the particles fluences. Electron and pion fluences integrated over all the energies are shown in Figures 3 and 4.

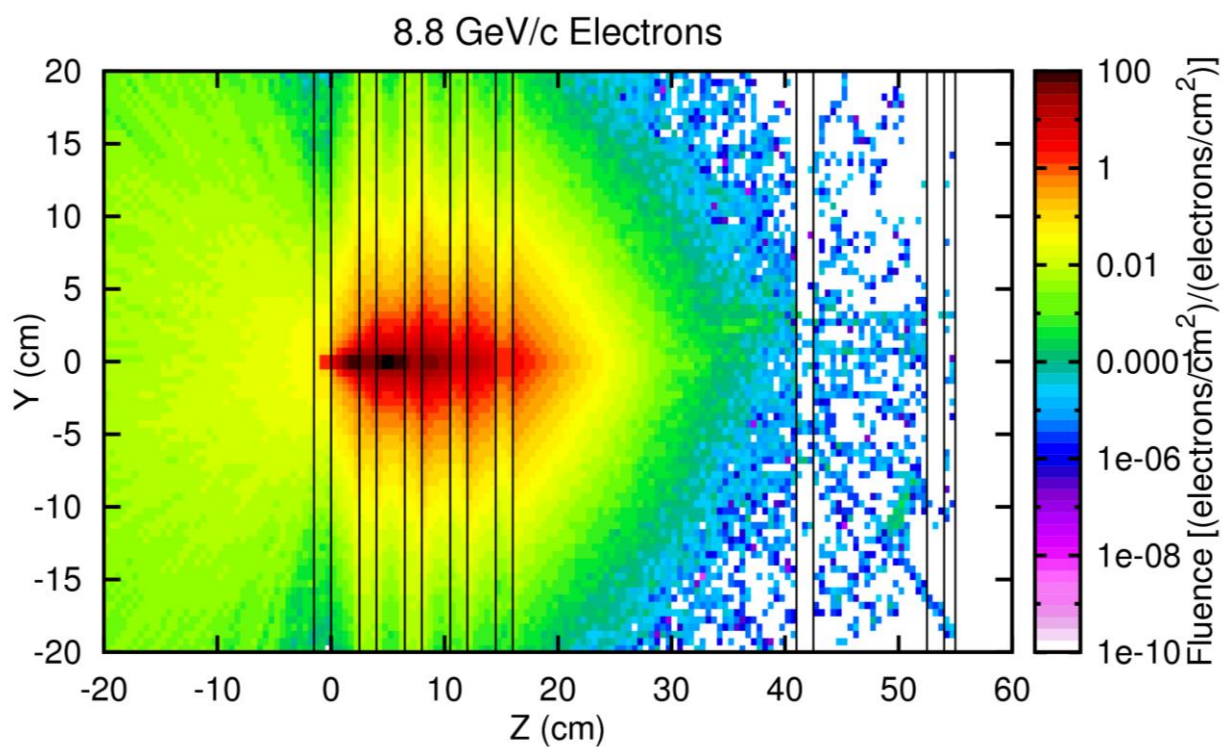
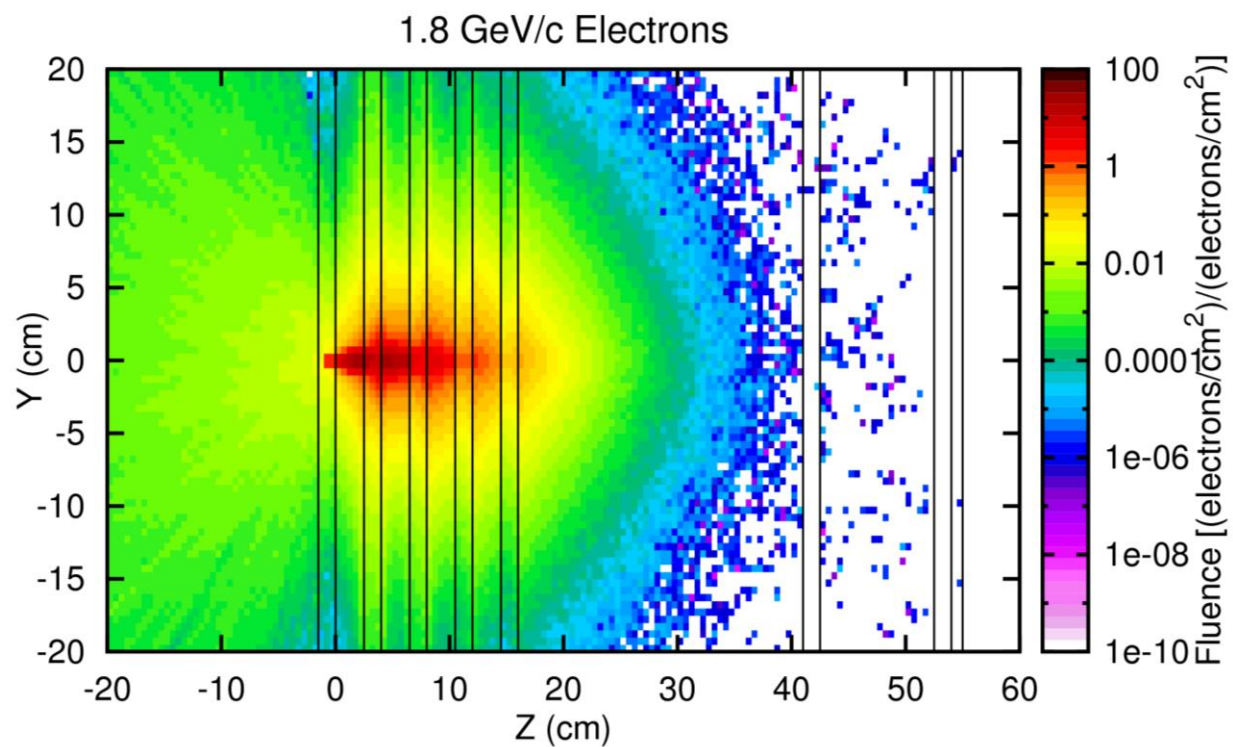


Figure 3. Electron fluences in the case of electron momenta of 1.8 and 8.8 GeV/c as a function of the detector penetration dept.

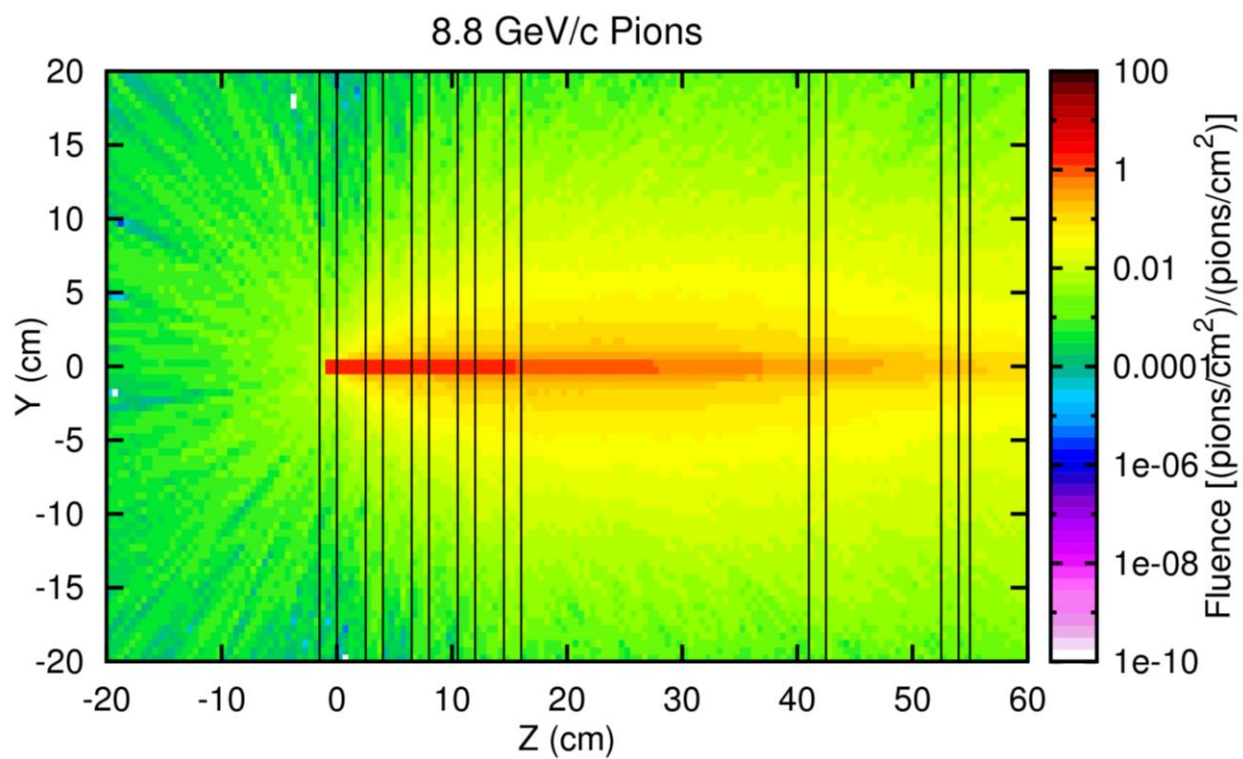
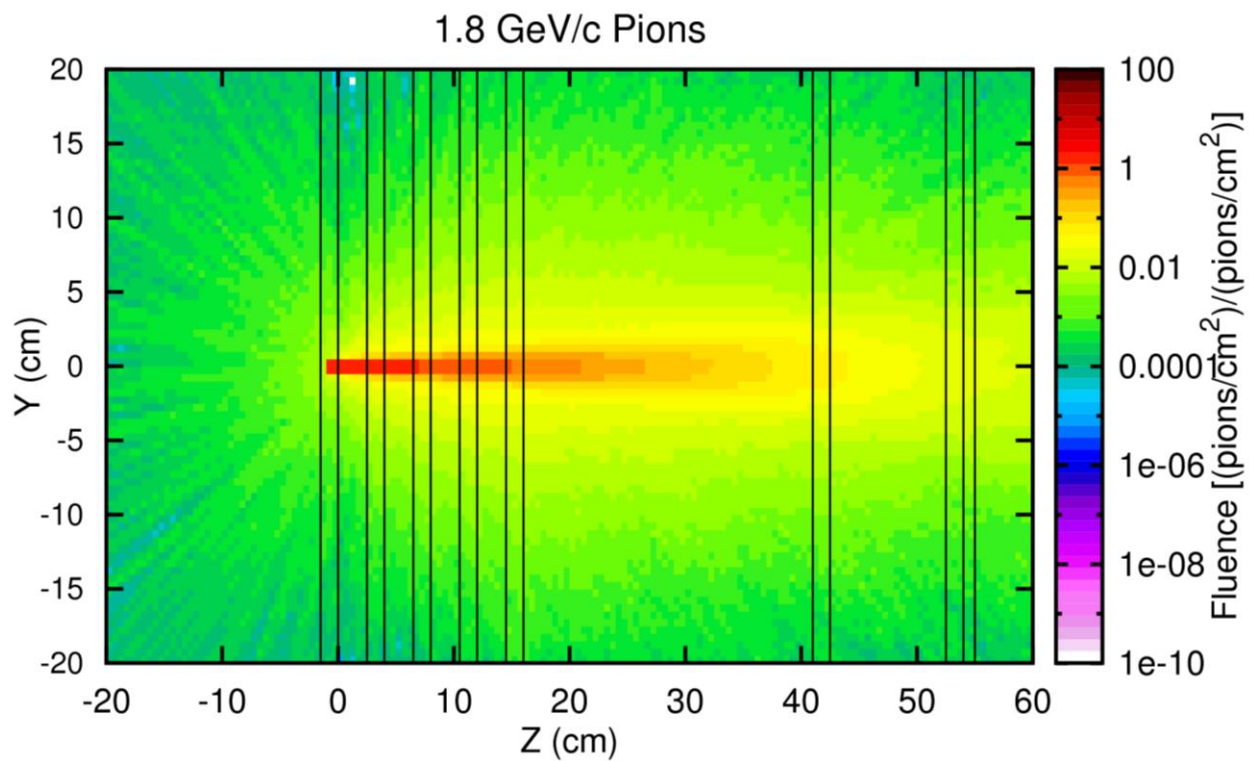


Figure 4. Pion fluences in the case of pion momenta of 1.8 and 8.8 GeV/c as a function of the detector penetration dept.

Next, in Figures 5-6 and 7-8, we plot the deposited energy. In the detectors they are directly related to the amplitude of the measured signal.

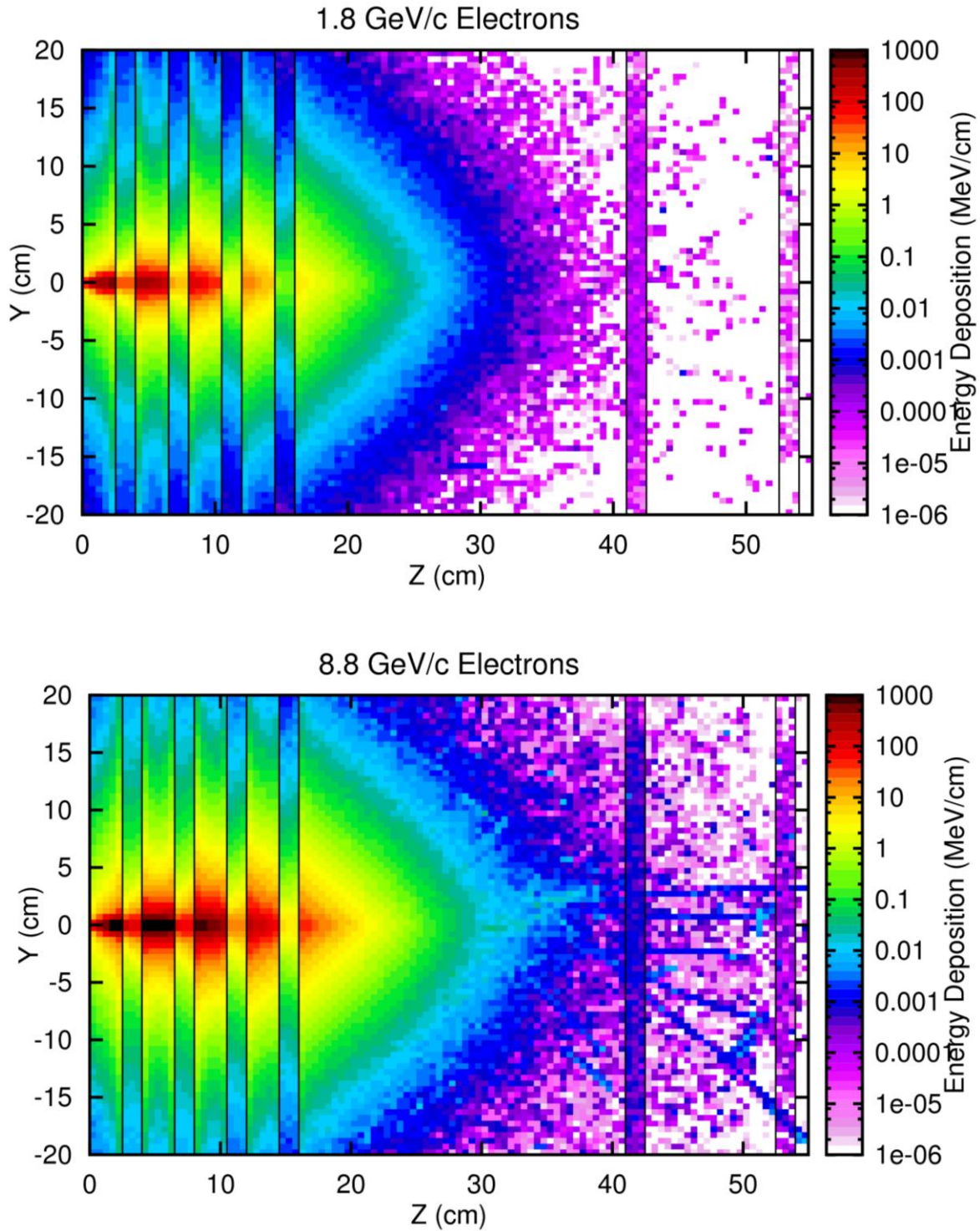


Figure 5. Electron deposited energy in the case of electron momenta of 1.8 and 8.8 GeV/c as a function of the detector penetration dept.

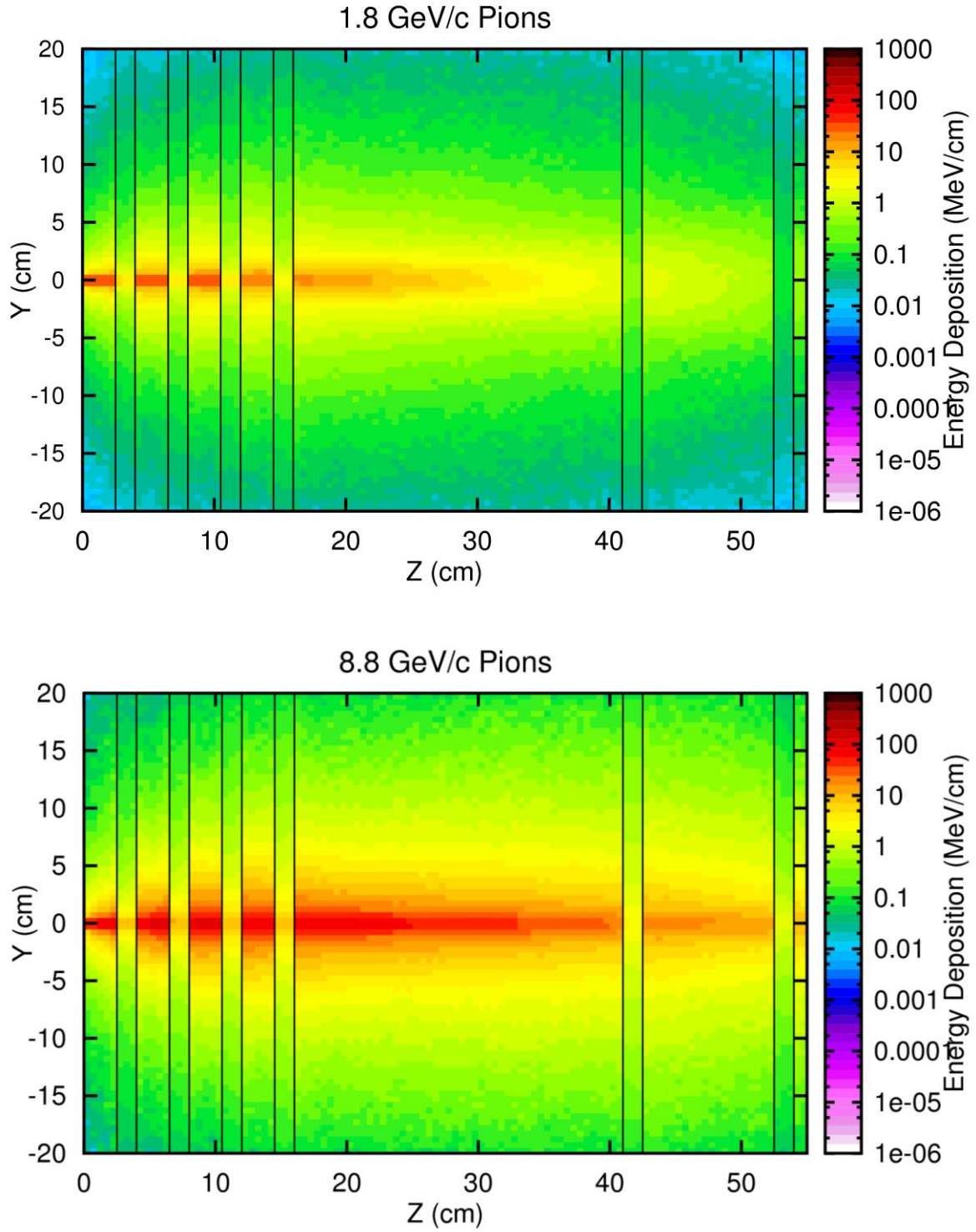


Figure 6. Pion deposited energy in the case of pion momenta of 1.8 and 8.8 GeV/c as a function of the detector penetration dept.

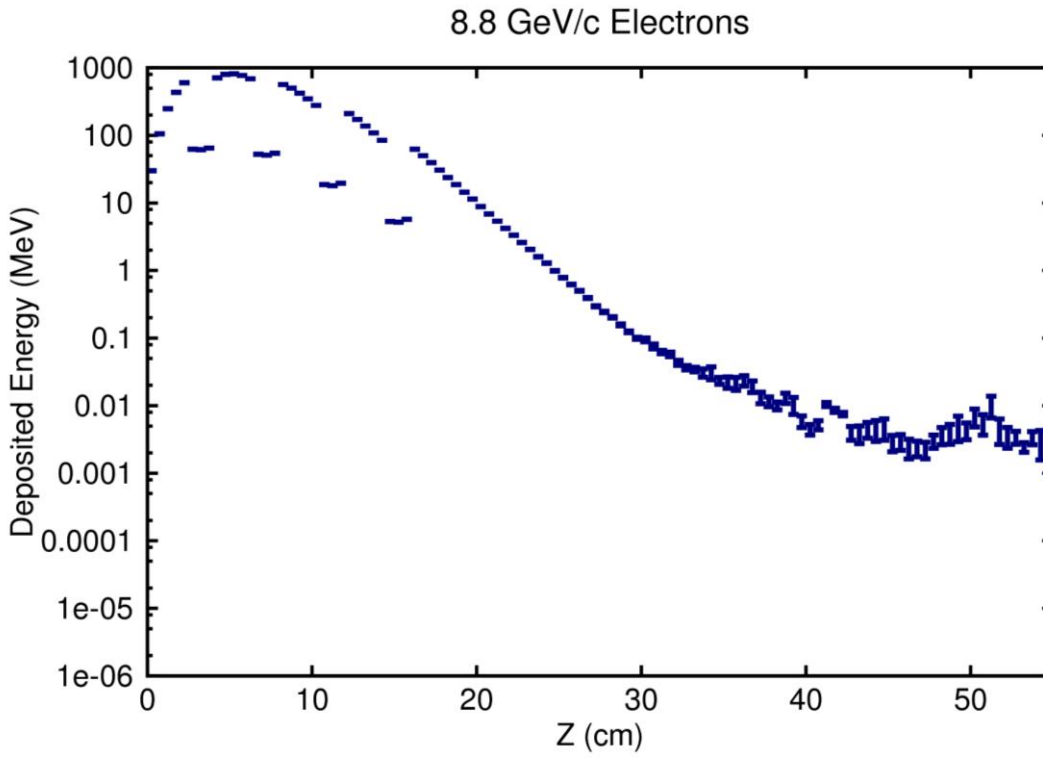
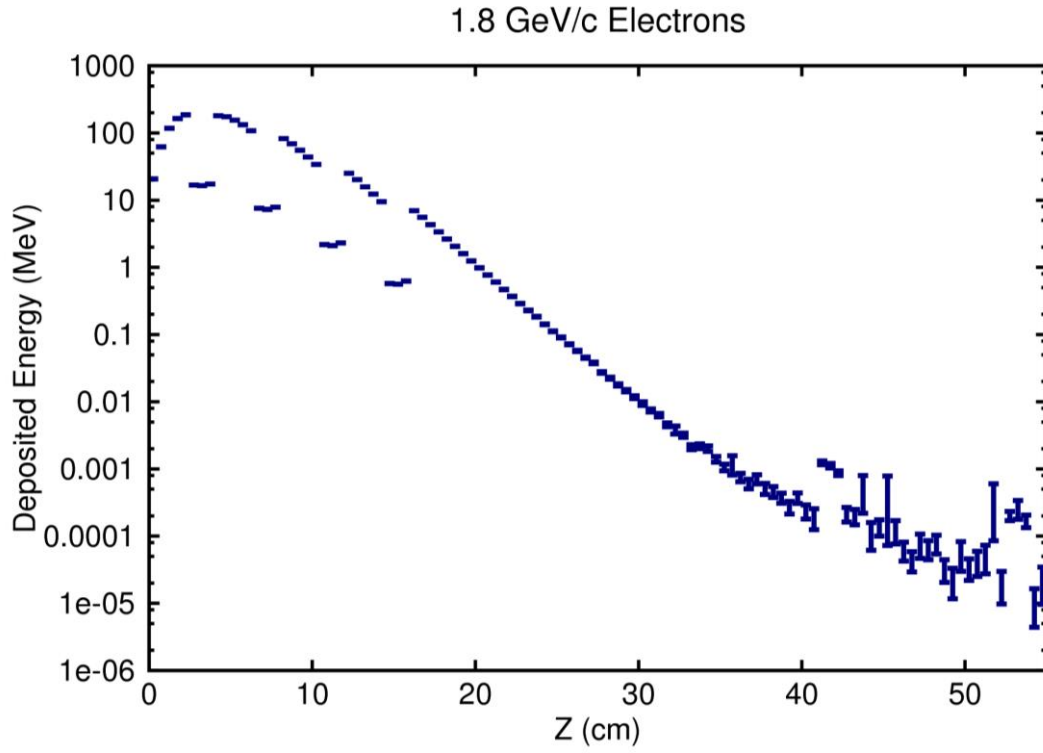


Figure 7. Electron deposited energy in 1 cm of the material in the case of electron momenta of 1.8 and 8.8 GeV/c as a function of the detector penetration.

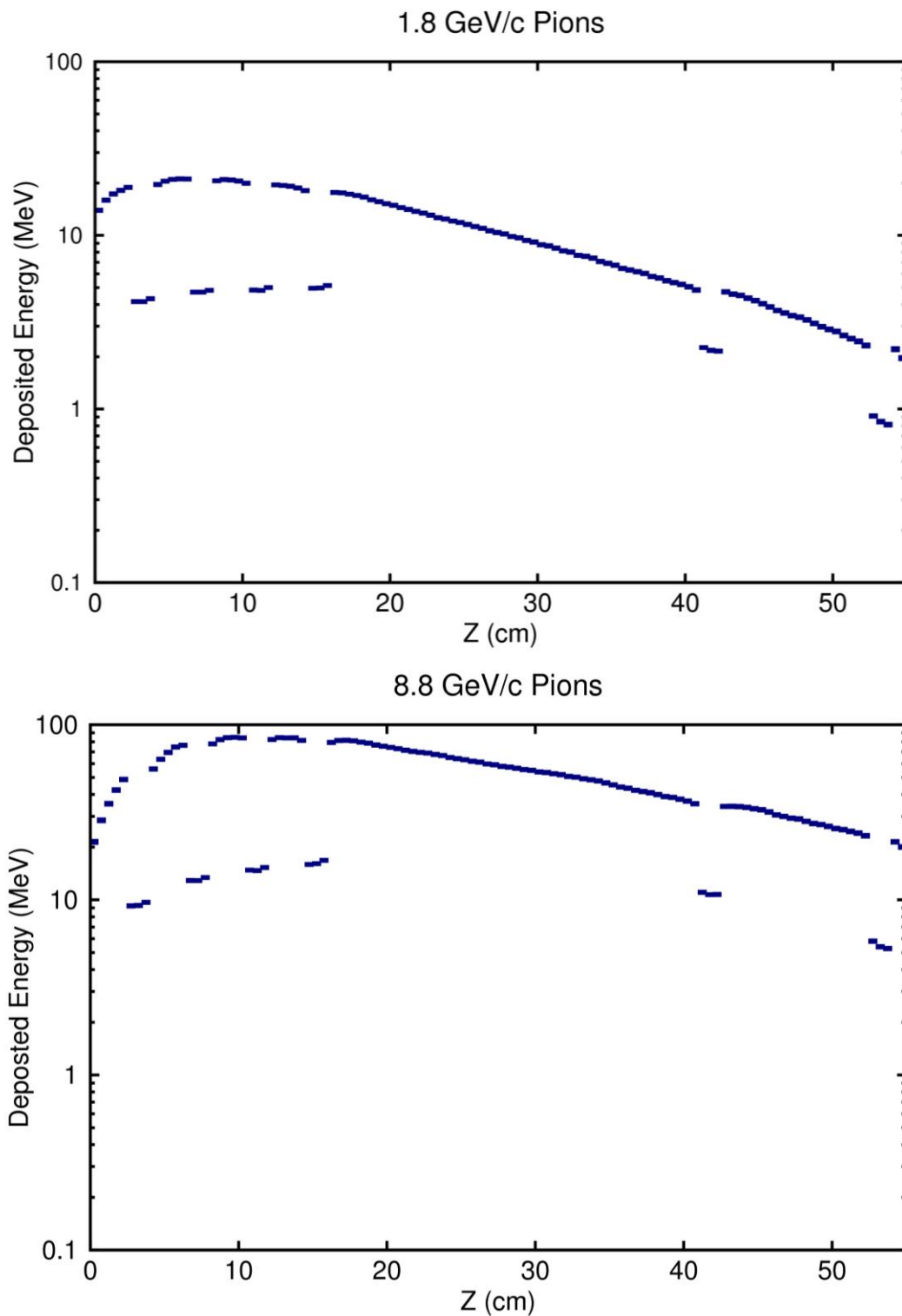


Figure 8. Pion deposited energy in 1 cm of the material in the case of pion momenta of 1.8 and 8.8 GeV/c as a function of the detector penetration dept.

III Summary and Conclusion

In this report we have proposed a possible design of a pion detector for the Moller experiment. The detector operates on a principle that electrons and pions deposit, depending on pion and electron energies, different amount of energy in the scintillator. Sandwiching the scintillators in a lead shielding enables varying the amount of the deposited energy in the scintillators and using the differences to separate pions from the electrons.

The following table summarizes the results shown in previous figures. It shows the deposited energies for 1.8 and 8.8 GeV pions and electrons in 1.5 cm thick scintillator detectors. The differences in the amount of deposited energy in the same detector for different particles and different energies can be immediately noticed. Obvious are also the differences in energy deposition as a function of the scintillator detector location or the amount of shielding in front of the detectors. Based on those differences it is possible to develop an algorithm which will separate the pions and the electrons with certain efficiency. The complexity of the desired detector system, and therefore the cost, depends on desired efficiency. Both, the detector system and the detection algorithm, can be easily developed but it requires further work.

Depending on the acceptable cost, capabilities of the detector can be improved by adding more scintillators, but the basic separation can also be achieved even by reducing the number of detectors.

		Detector 1	Detector 2	Detector 3	Detector 4	Detector 5	Detector 6
1.8 GeV/c π	Deposited Energy (MeV)	6.3	7.2	7.4	7.5	3.3	1.3
8.8 GeV/c π	Deposited Energy (MeV)	14.3	19.6	22.5	24.5	16.5	8.2
1.8 GeV/c e^-	Deposited Energy (MeV)	26.1	11.4	3.3	0.9	0.0015	0.0003
8.8 GeV/c e^-	Deposited Energy (MeV)	94.5	78.0	28.1	8.1	0.013	0.0047

Table 2. Deposited energies in different 1.5 cm thick scintillator detectors as a function of particles types and their momenta.

References

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