MARS Simulation of the Mercury Target Experiment

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Abstract

MERIT collaboration proposed to perform a proof-of-principle test of a target station suitable for a Neutrino Factory or Muon collider source using a 24-GeV proton beam incident on a target consisting of a free mercury jet that is inside a 15-T capture solenoid magnet. Realistic 3-D geometry together with material and magnetic field distributions have been implemented into MARS code. Prompt and residual radiation distributions and particle fluxes in the experimental hall and elements of detector are calculated. Energy and time spectra of produced particles in small scintillation detectors are also presented.

1 Introduction

MERIT collaboration proposed to perform a proof-of-principle test of a target station suitable for a Neutrino Factory or Muon collider source using a 24-GeV proton beam incident on a target consisting of a free mercury jet that is inside a 15-T capture solenoid magnet [1]. It is planned to sent about 100 pulses of 310^{13} proton on thick mercury target. It is important to estimate absorbed dose and residual activity in experimental hole and elements of detector. Scintillation or other counters will monitor the flux of secondary pions produced during each of the each of the 1-4 bunches of a beam pulse to provide a measure of possible beam-induced reduction of density of the liquid jet. Simulation of particle fluxes, energy and time spectra are needed to find optimal positions of such detectors.

2 MARS modeling

Realistic 3-D geometry together with material and magnetic field distributions have been implemented into MARS code [2]. Some projections are presented in fig.1-4. In order to obtain the required 100-mrad angle between the mercury jet and the axis of the solenoid, combined magnet and Hg jet system are tilted. Magnetic axis is tilted by 67 mrad with respect to the proton beam.

Absorbed dose calculations are presented on fig. 5. Note, that acceptable levels for electronic devices 50-100 Gy. Residual activity after 30 day of irradiation and 1 day of cooling are shown on fig.6. Acceptable activation levels are about 1 mSv/hr at FNAL, 0.1 mSv/hr at CERN.

Important part of HG delivery system is mercury vapor analyzer. Two positions of analyzer were considered: on the top (position 1) and downbeam end (position 2) of secondary containment. Absorbed dose in mercury vapor analyzer are 630 Gy in first and 14 Gy in second position. Residual dose rate in a tissue-equivalent body on contact after 5 day of irradiation and 1 hour of cooling:

- mercury vapor analyzer (position 1) - 0.17 mSv/hr
- mercury vapor analyzer (position 2) - 0.007 mSv/hr
- hydraulic fluid (Quintolubric 880) in pump - 0.021 mSv/hr
- mercury vapor filter - 0.18 mSv/hr

Secondary radiation for different irradiation and cooling conditions are presented in fig 7-8.

So, absorbed dose and activation of mercury vapor analyzer mounted onto downbeam end of secondary containment do not exceed acceptable levels. Activation of hydraulic fluid in the pump is also low enough, activation in the hydraulic lines should be lower then in the pump.

3 Particle flux calculations

Results of simulations of different particle fluxes are presented on fig.9-12 Neutron and gamma fluxes are dominated. Detectors with low sensitivity to neutral particles are needed.

Four small detectors ($6 \cdot 6cm^2$ and 0.1 cm thick) were considered. Detectors has been placed at 0, 6.7, 11.5 and 45 degrees. Its positions are shown by black marks on fig.9-12. Energy spectra and time distributions for charged pions, protons, muons, electrons, gammas and neutrons in this detectors are presented in fig 13-20.

References

[1] J.R. Bennet et al, *Studies of a Target System for a 4-MW, 24-GeV Proton Beam*, CERN-INTC-2004-016 (2004);

[2] N.V. Mokhov, *The MARS Code System User's Guide*, Fermilab-FN-628 (1995); N.V. Mokhov, K.K. Gudima, C.C. James et al, *Recent Enhancements to the MARS15 Code*, Fermilab-Conf-04/053 (2004); http://www-ap.fnal.gov/MARS/.

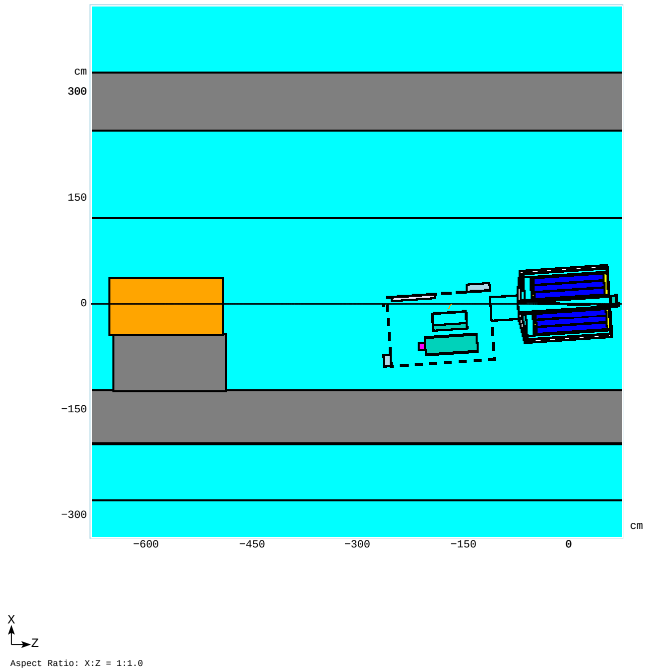

Figure 1: General view of detector. XZ projection.

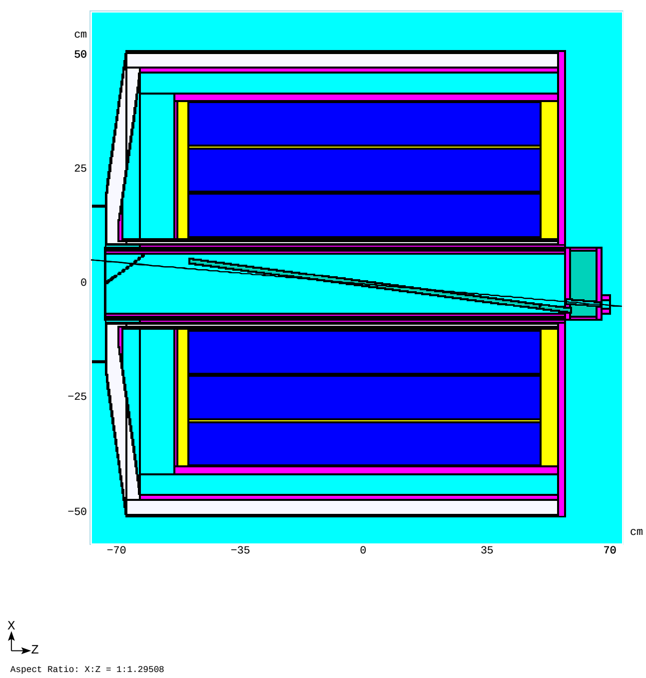

Figure 2: Solenoid and cryostat. XZ projection.

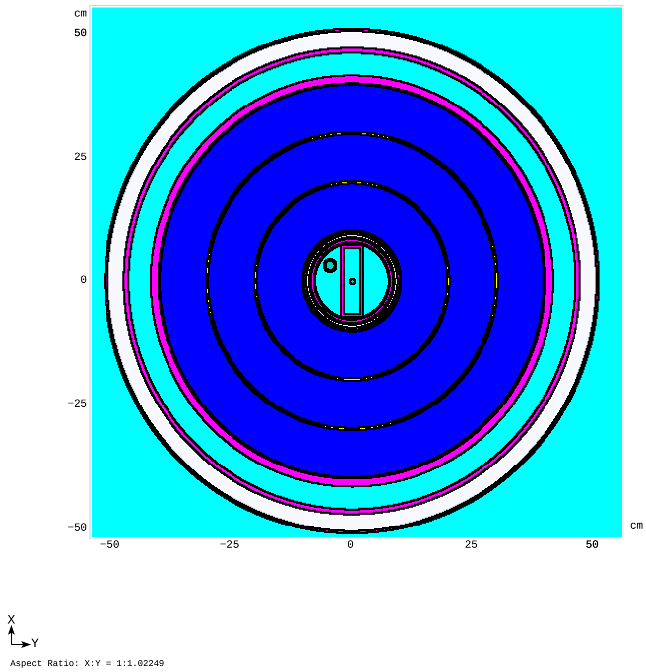

Figure 3: Solenoid and cryostat. XY projection.

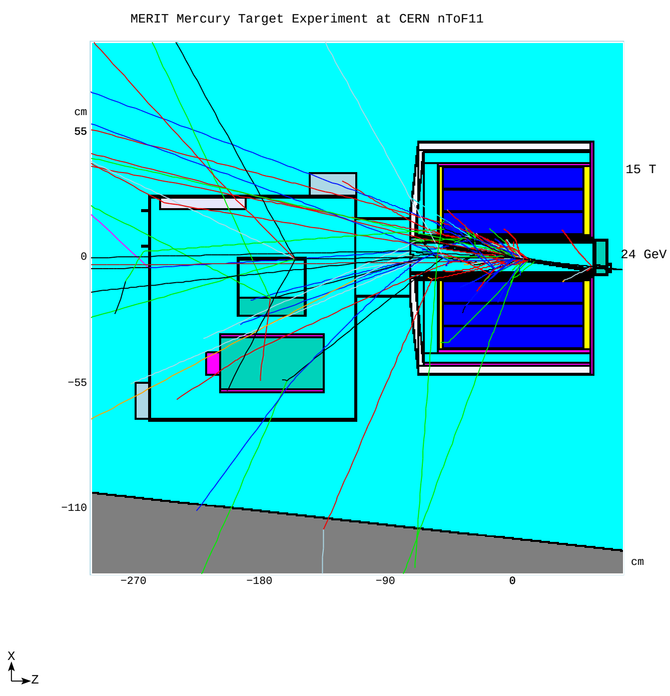

Figure 4: Beam on mercury target. XZ projection.

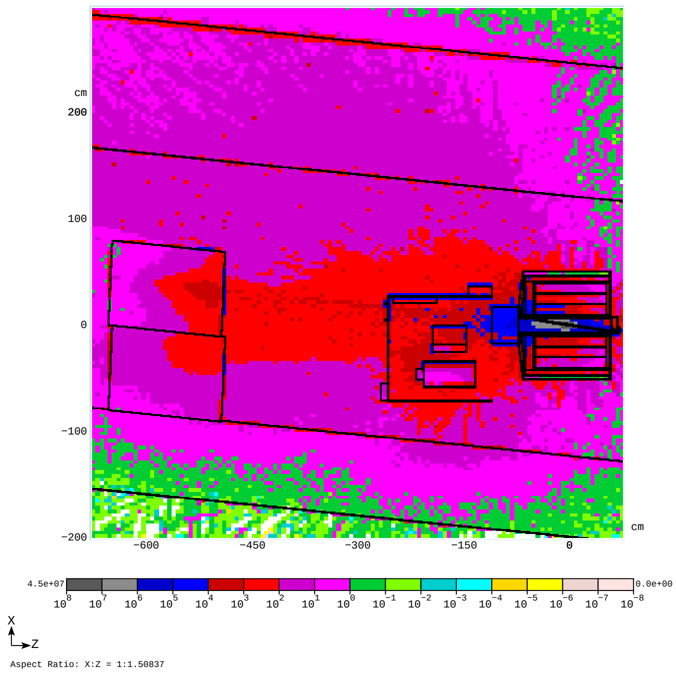

Figure 5: Absorbed dose in Gy/$3 \cdot 10^{15}$ protons.

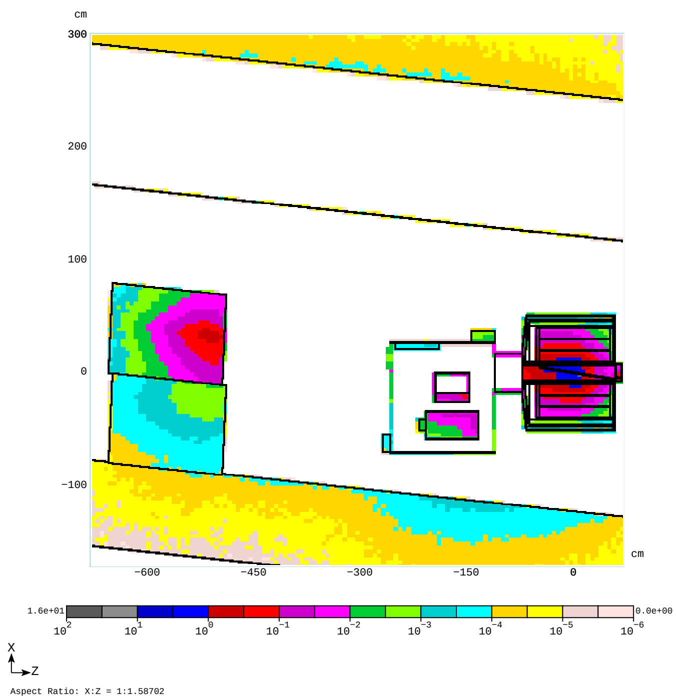

Figure 6: Residual dose (mSv/hr) after 30 day of irradiation and 1 day cooling. $3 \cdot 10^{15}$ protons/30 day.

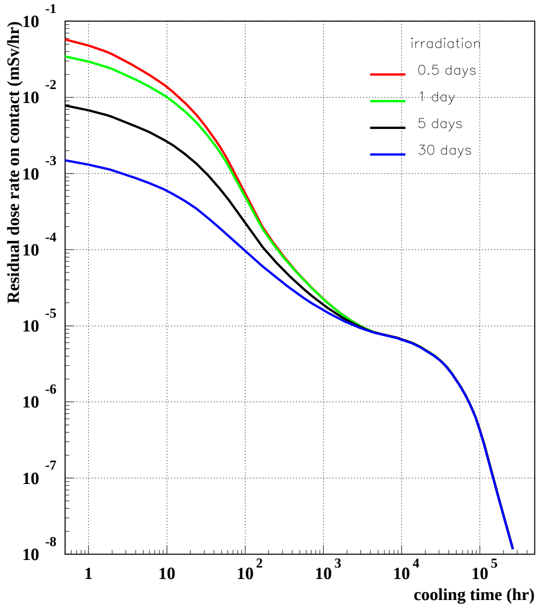

Figure 7: Residual dose in contact with mercury vapor analyzer (position 2).

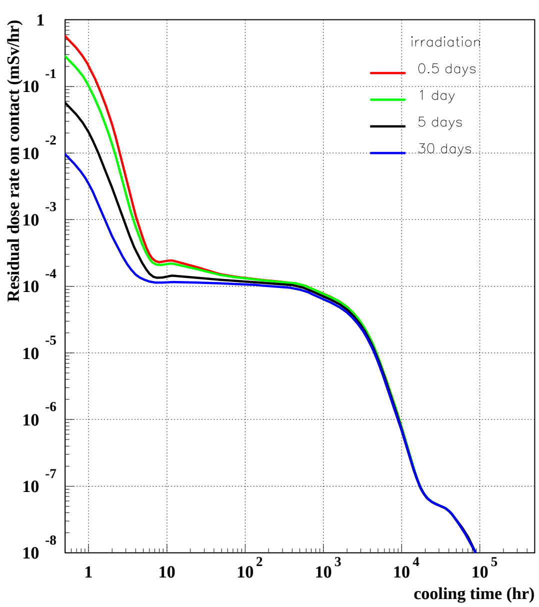

Figure 8: Residual dose in contact. Quintolubric hydraulic fluid.

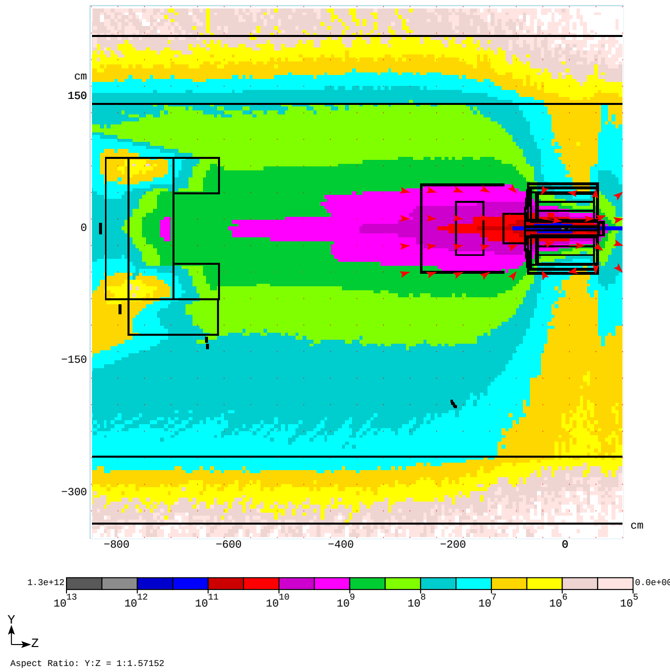

Figure 9: Charged hadrons flux (particle per pulse).$E > 200$ keV.

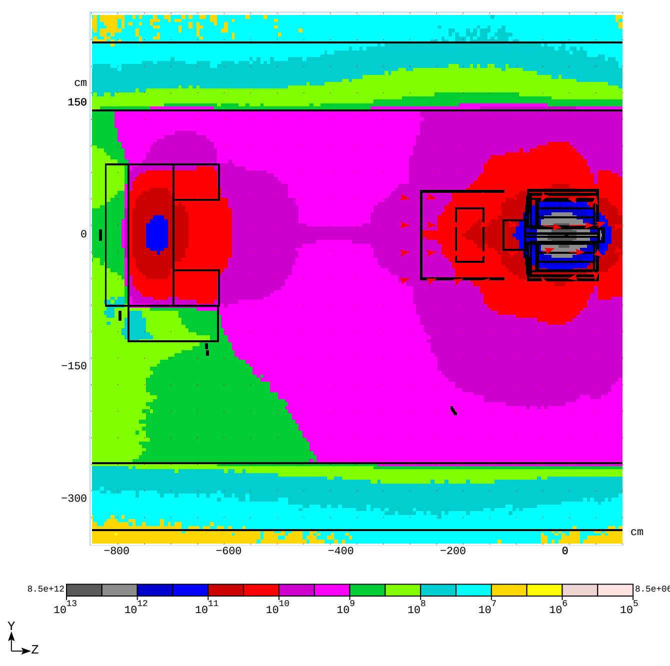

Figure 10: Neutron flux (particle per pulse). $E > 200$ keV.

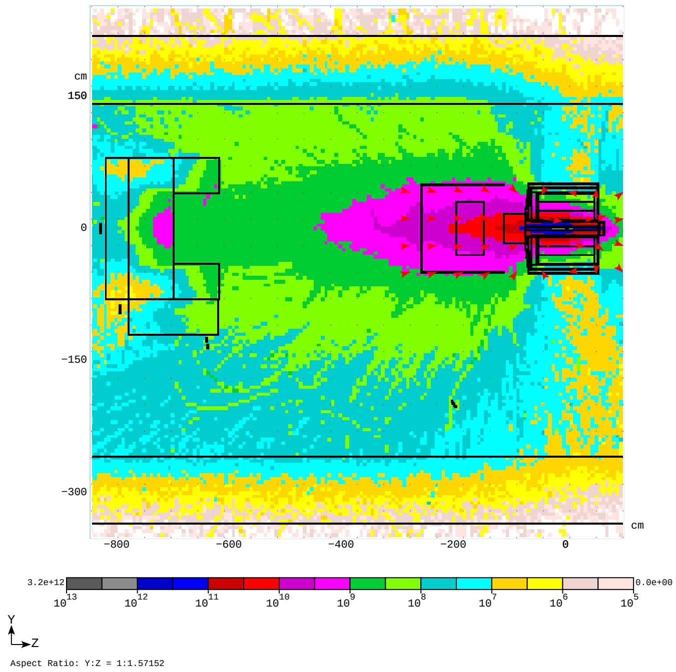

Figure 11: Electron flux (particle per pulse).$E > 200$ keV.

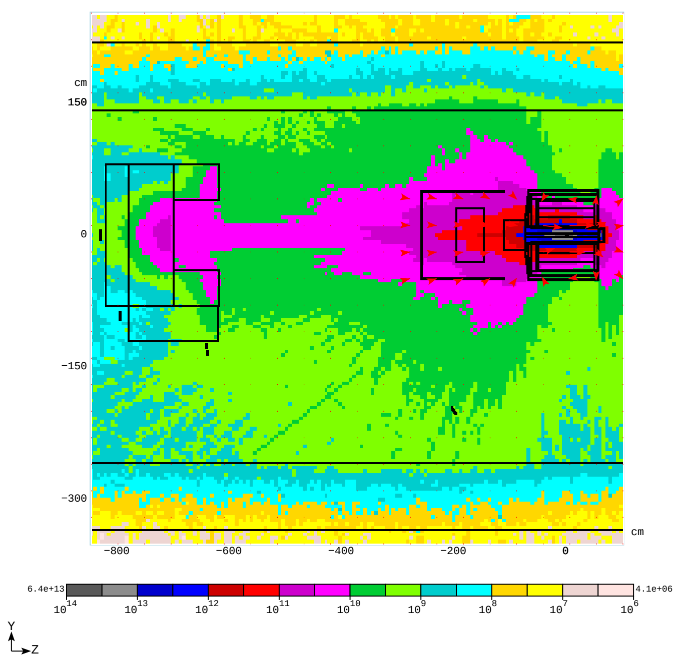

Figure 12: Gamma flux (particle per pulse).$E > 200$ keV.

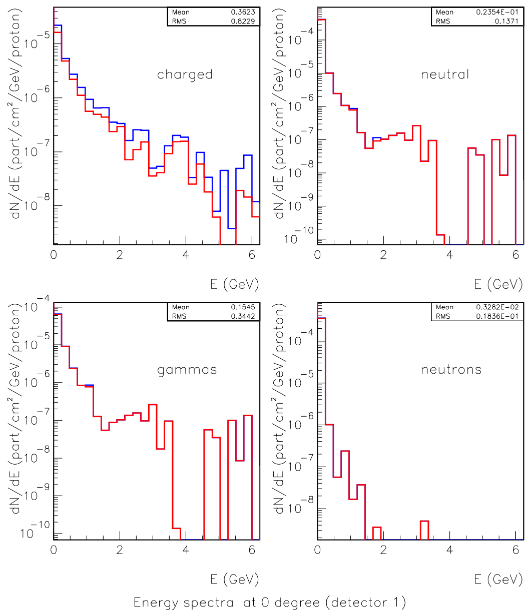

Figure 13: Energy spectra at 0 degree detector. Red lines - particles produced in attenuator, blue lines - all particles.

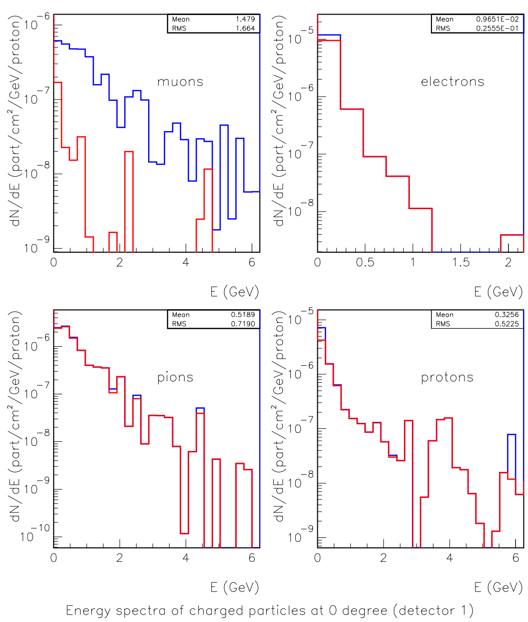

Figure 14: Energy spectra at 0 degree detector. Red lines - particles produced in attenuator, blue lines - all particles.

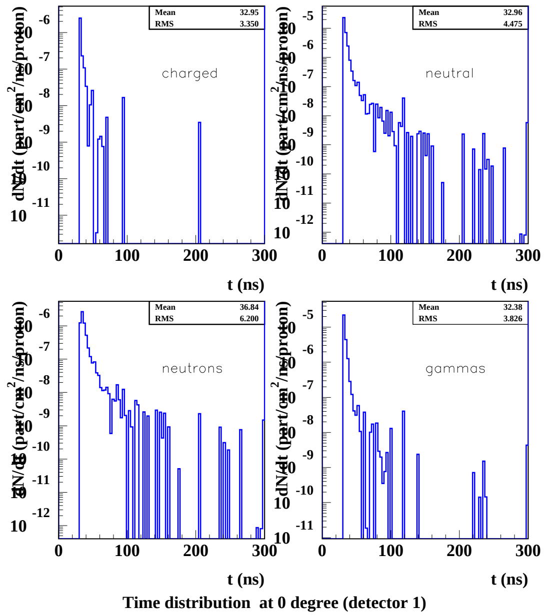

Figure 15: Time distributions at 0 degree detector.

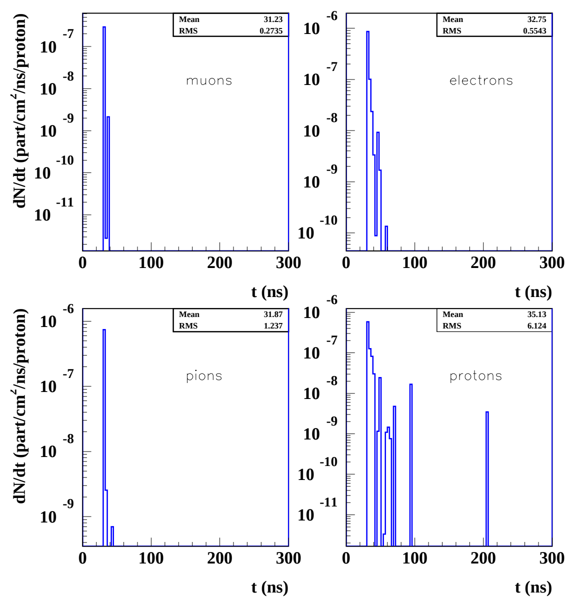

Figure 16: Time distribubtions at 0 degree detector.

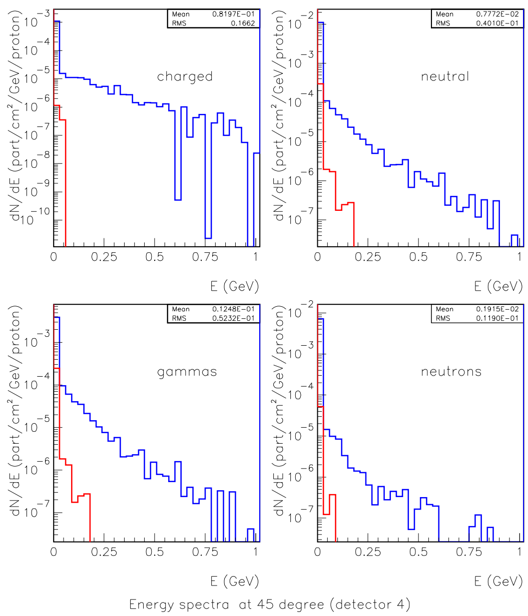

Figure 17: Energy spectra at 45 degree detector. Red lines - particles produced in attenuator, blue lines - all particles.

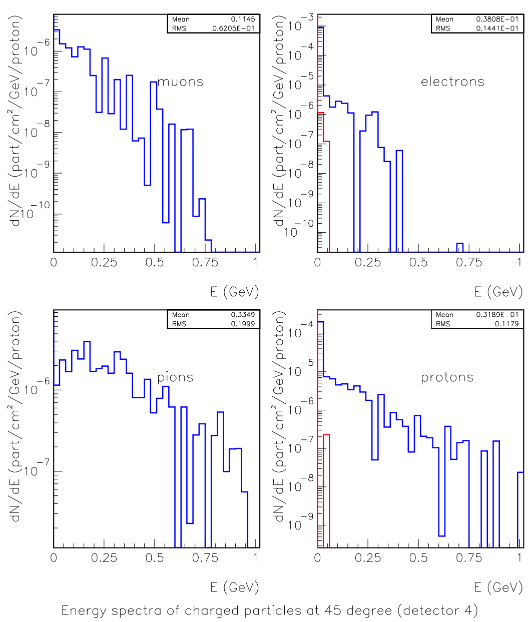

Figure 18: Energy spectra at 45 degree detector. Red lines - particles produced in attenuator, blue lines - all particles.

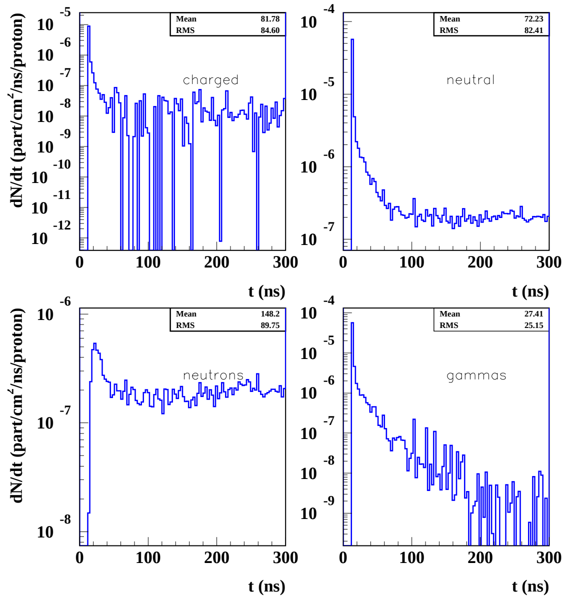

Figure 19: Time distributions at 45 degree detector.

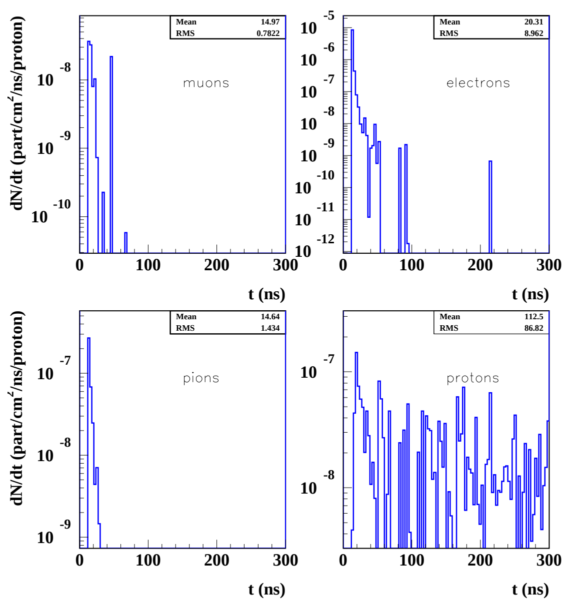

Figure 20: Time distributions at 45 degree detector.