GEANT4 developments for dark matter and neutrino physics

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Abstract

Recent new GEANT4 developments for dark matter and neutrino physics processes are discussed. GEANT4 calculations are compared with data for neutrino integral cross-sections and lepton (μ, e) escape angle distributions.

1 Outline

1. GEANT4 dark matter process application.
2. Neutrino-electron integral cross-sections and final state generators.
3. Neutrino-nucleus integral cross-sections.

2 Dark matter process application

1. R&D for dark matter particles and processes in the framework of GEANT4 toolkit.
2. Dark matter model → process → constructor → physics list.
3. Light dark matter (LDM) intermediate photon, LDM scalar and anti-scalar particles.
4. LDM is generated by bremsstrahlung, and decays to couple of LDM scalars.
5. LDM physics is implemented in simplified form and is subject of further R&D.

3 Neutrino-electron interactions

Historically, GEANT4 did not have neutrino interaction processes and models. Today this physics was implemented for the first time:

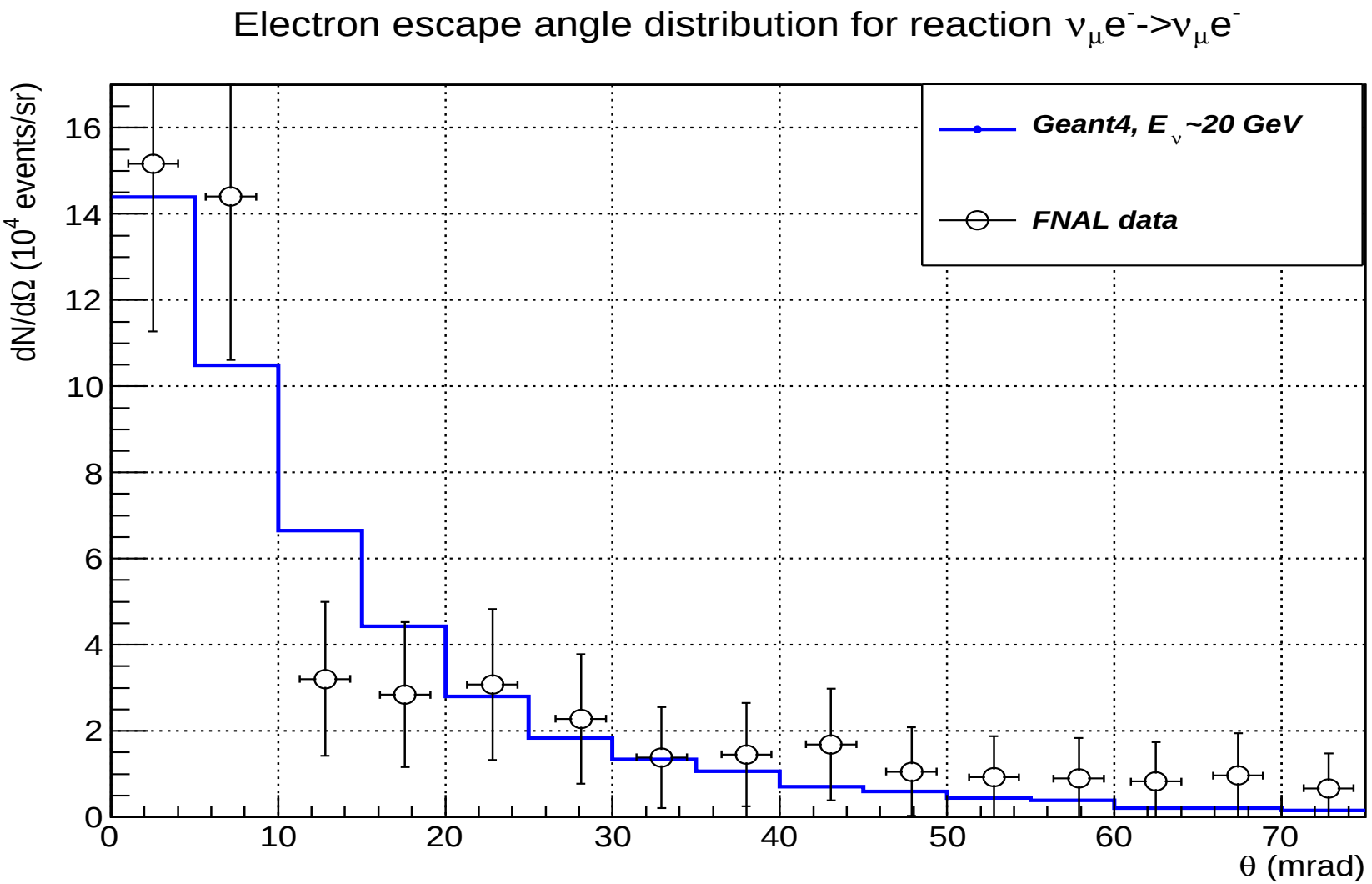
1. Neutrino-electron elastic scattering (neutral current).
2. Neutrino-electron charge current processes (like $\nu_\mu e^- \to \nu_e \mu^-$).

Both cross-sections (*G4NeutrinoElectronNc(Cc)Xsc* classes) and final state generators (*G4NeutrinoElectronNc(Cc)Model* classes) were implemented in the framework of GEANT4 library.

Neutrino-electron elastic cross-sections (divided by neutrino energy) in 10^{-42}cm^2/GeV

Process	GEANT4	experiment
$\nu_\mu e^- \to \nu_\mu e^-$	1.55	<1.55±0.21>
$\bar{\nu}_\mu e^- \to \bar{\nu}_\mu e^-$	1.34	<1.26±0.21>
$\nu_e e^- \to \nu_e e^-$	9.46	10.6±4.6±1.9

Calculations by new GEANT4 classes. Data from compilation [*Krenz W., Preprint PITHA* 84/42, *March* – 1985].

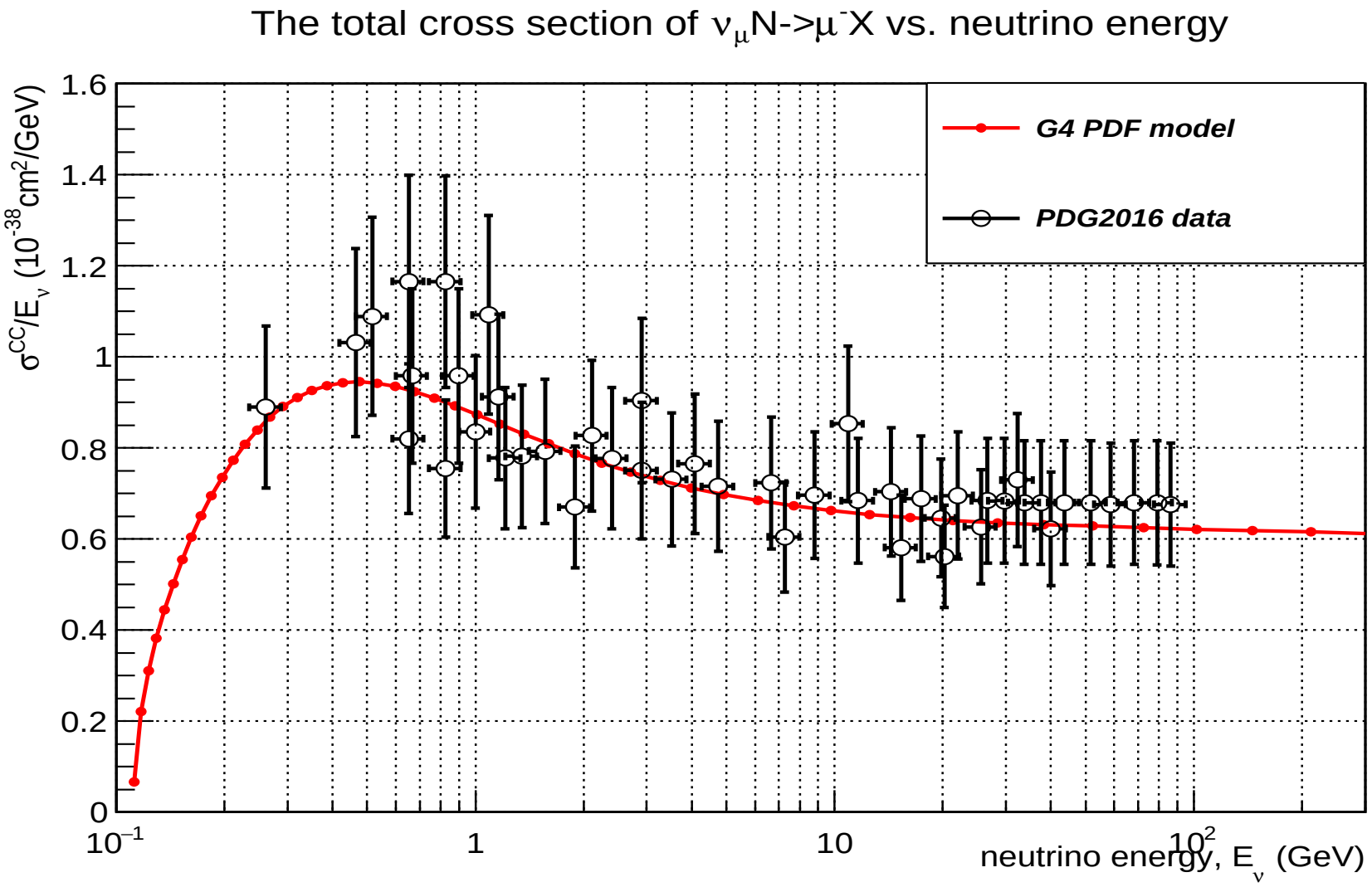


Electron escape angle distribution, data from
[*Heiserberg R.H., et al., Phys. Rev. Lett.*, 44 (1980) 635]

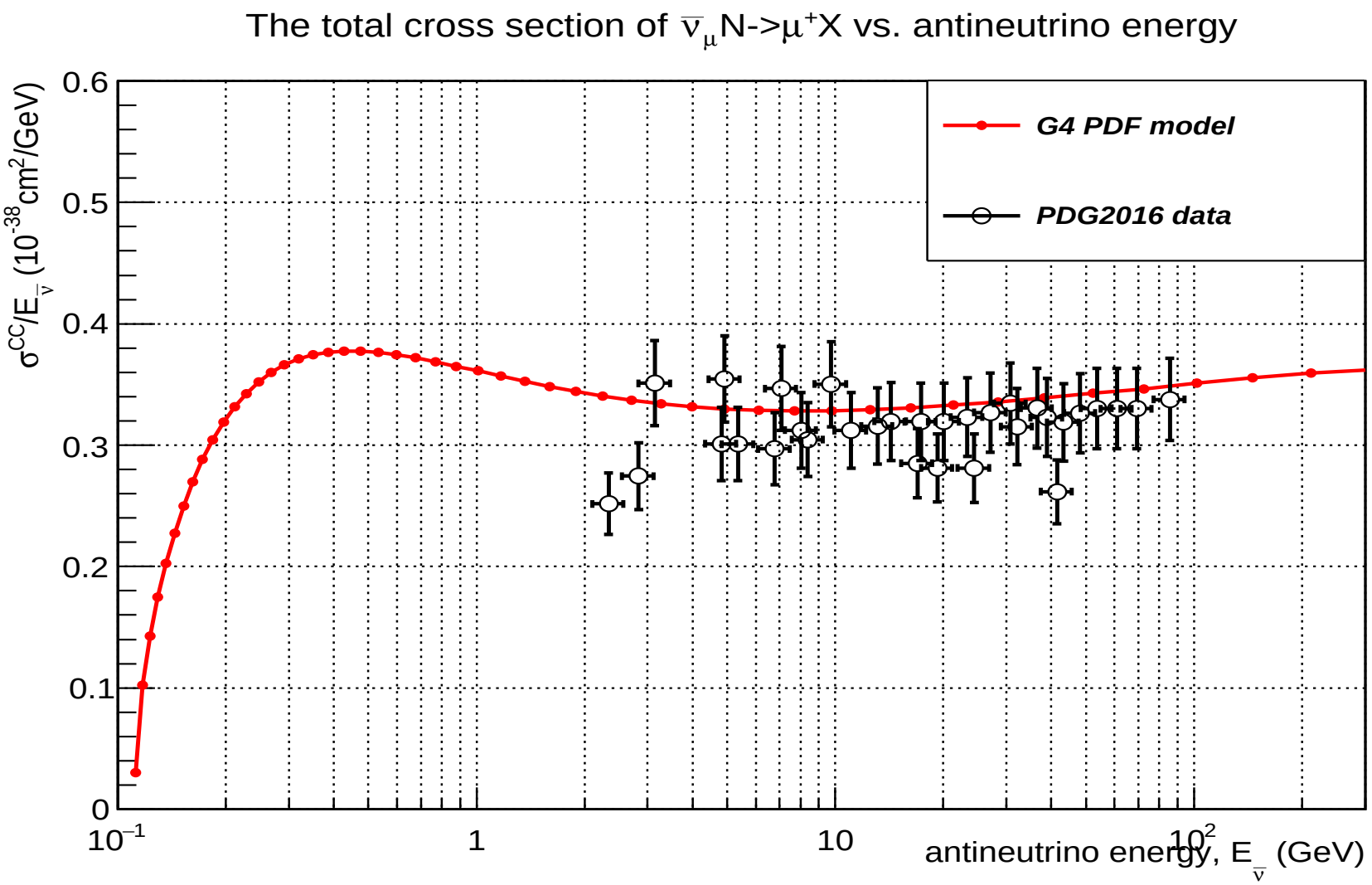
4 Neutrino-nucleus/nucleon interactions

New GEANT4 development:

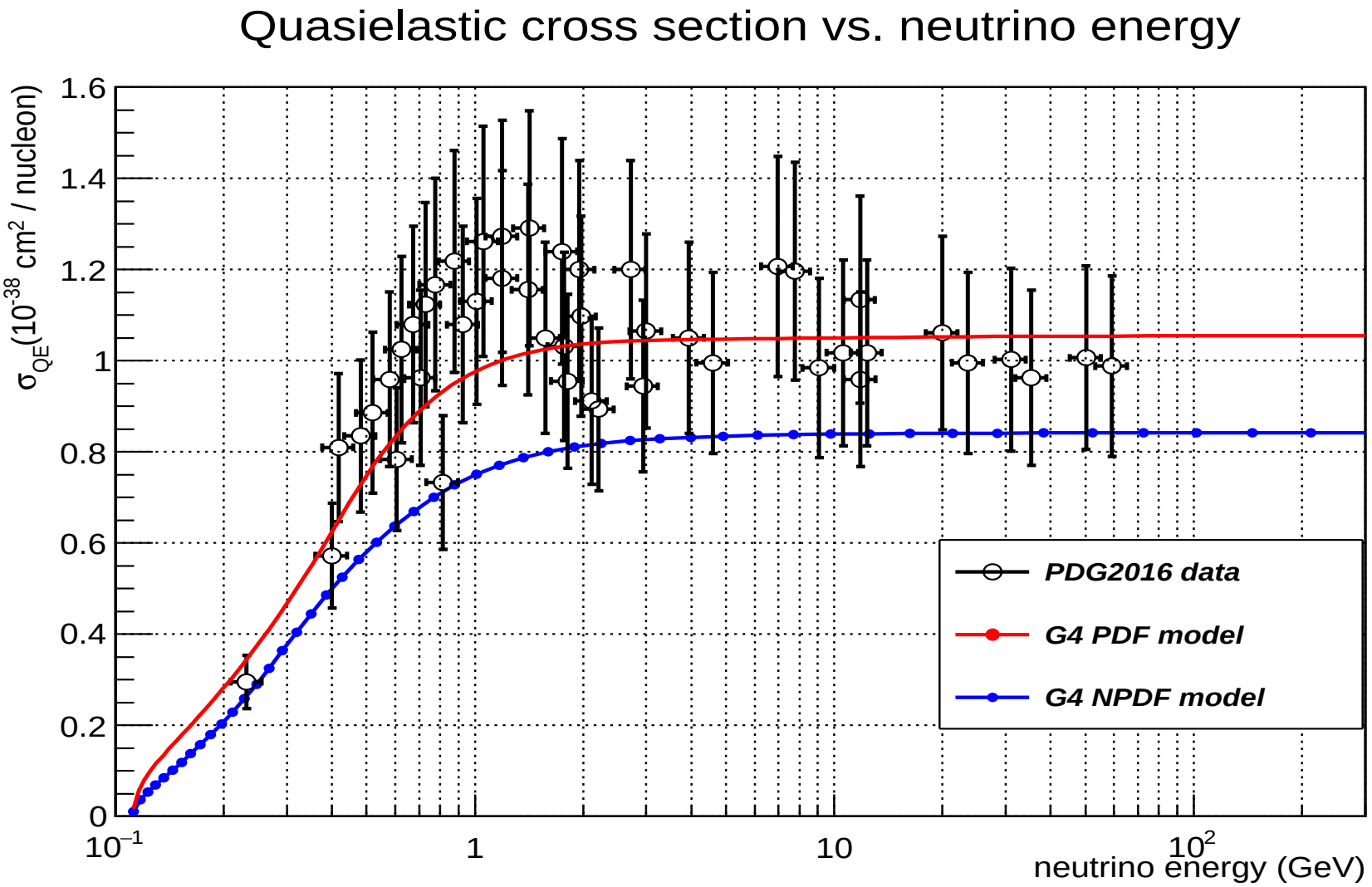
1. Double differential cross-section, $d^2\sigma/dx\,dy$ (x, y - Bjorken variables), of neutrino inelastic interactions with nuclei is expressed in terms of parton distribution functions (PDFs).
2. PDFs are parametrized according to GiBUU-project (Giessen university) tuning of the Bodek-Yang-Park (BYP) relations.
3. Low energy-momentum transfer extension (quasi-elastic, coherent pions, resonances) is based on the Capella-Kaidalov-Merino-Tanh (CKMT) approach with nuclear effects (NPDF).
4. Momentum transfer kinematics (depending on PDFs) is used for the reconstruction of the lepton final state.
5. The nuclear final state is reconstructed based on the GEANT4 hadronic models (both cascades and strings are needed depending on the momentum transfer kinematics).



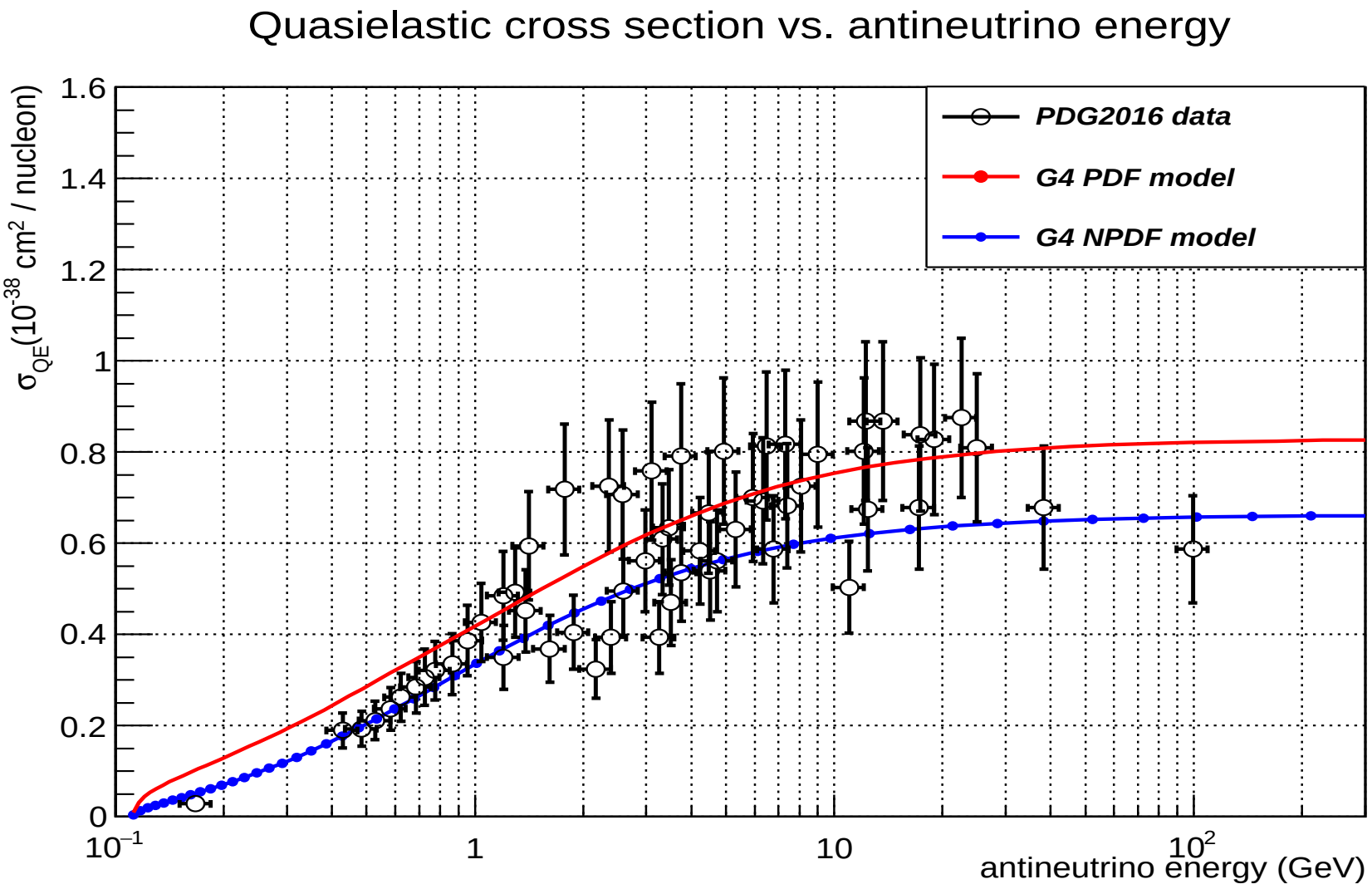
The total cross-section of muon neutrino on nucleons.



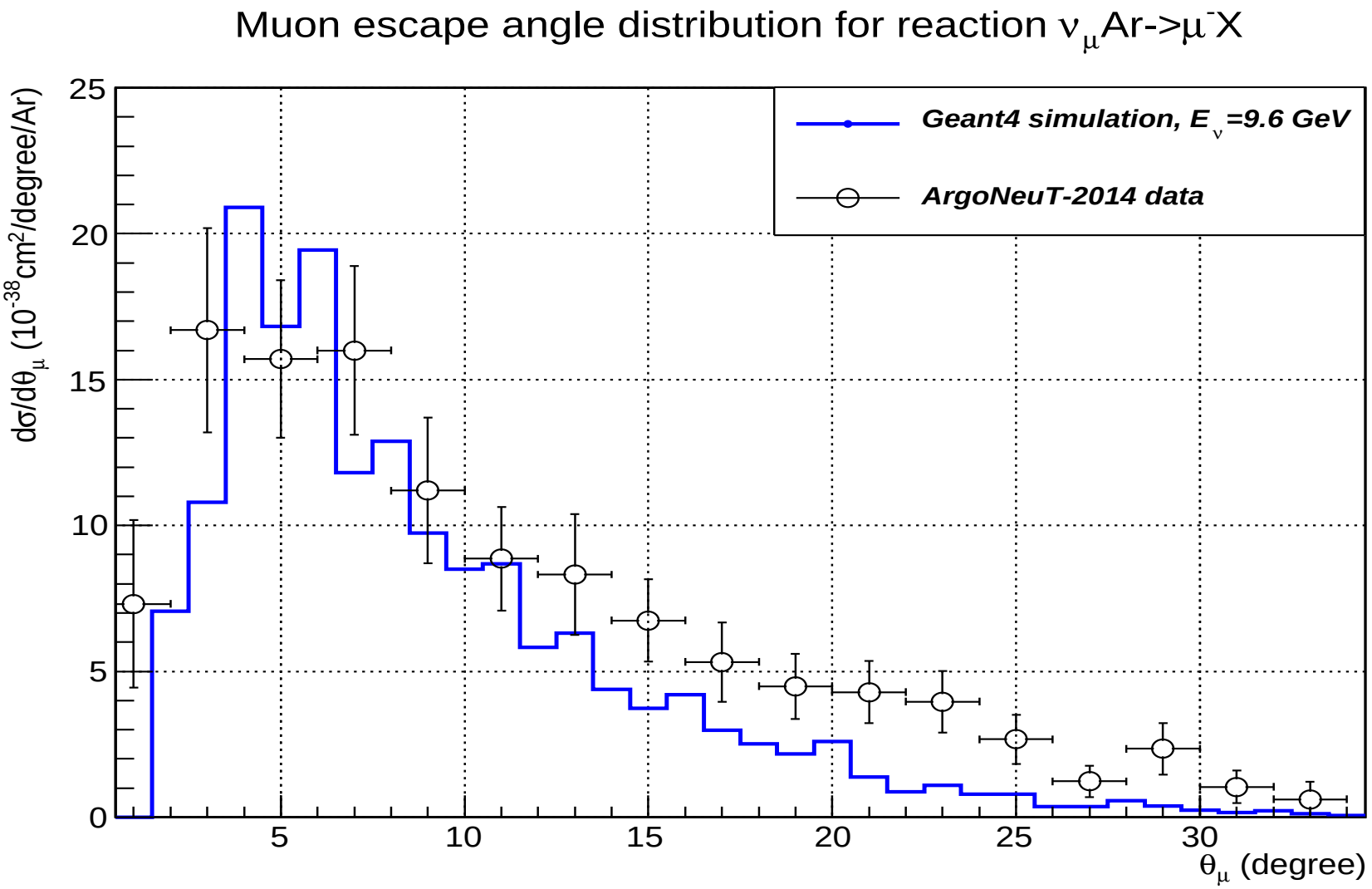
The total cross-section of muon anti-neutrino on nucleons.



The quasi-elastic cross-section of muon neutrino on nucleons.



The quasi-elastic cross-section of muon anti-neutrino on nucleons.



The muon escape angle distribution, data from
[*Acciarri R., et al., Phys. Rev., D*89 (2014) 11200]

5 Cross-section biasing

The cross-section are assumed to be biased (essentially increased).

```
fBiasingFactor = 1.;
void SetBiasingFactor(G4double bf){fBiasingFactor = bf;};
xsc *= fBiasingFactor;
```

However it would be convenient to have a possibility of fBiasingFactor tuning by GEANT4 command. It is in progress.

6 Summary

1. The dark matter process application was implemented in the framework of GEANT4 toolkit.
2. Neutrino-electron cross-section and final state generators were implemented in the GEANT4 library.
3. GEANT4 R&D is in progress concerning neutrino-nucleus cross-sections.
4. GEANT4 R&D is concerning neutrino-nucleus final state generator is under consideration.