Geant4 user interface for neutrino-electron physics

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Abstract

Recent new Geant4 developments for neutrino physics processes are discussed. Geant4 calculations are compared with data for neutrino integral cross-sections and lepton (μ, e) escape angle and energy distributions.

1 Outline

1. GEANT4 Neutrino-electron messenger, constructor and process.
2. GEANT4 Neutrino-electron integral cross-sections.
3. Cross section biasing.
4. Neutrino-electron final state generators.

2 GEANT4 Neutrino-electron messenger, constructor and process

G4EmMessenger and *G4EmExtraPhysics*, being part of many GEANT4 physics lists, manage to activate *G4NeutrinoElectronProcess* with biased charge and neutral current cross-sections in a detector logical volume:

```
/physics_lists/em/NeutrinoActivation   true    # activation (true or false)
/physics_lists/em/NuEleCcBias          1.0     # charged current is not biased
/physics_lists/em/NuEleNcBias          5.0e14  # neutral current is biased
/physics_lists/em/NuDetectorName       lTarget # detector logical volume name
```

The process gets the cross-sections as well as charge and neutral current final state models.

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.

In addition, neutron-electron elastic cross sections (∼50-100 μb) and final state generator (based on the the Rosenbluth model) were implemented in GEANT4 (*G4NeutronElectronElXsc*, *G4NeutronElectronElModel*). ($T_e \sim T_n m_e/m_n$)

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

Process	GEANT4	experiment
$\nu_\mu e^- \to \nu_\mu e^-$	1.55	$<1.55\pm0.21>$
$\bar{\nu}_\mu e^- \to \bar{\nu}_\mu e^-$	1.34	$<1.26\pm0.21>$
$\nu_e e^- \to \nu_e e^-$	9.46	$10.6\pm4.6\pm1.9$

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

4 Cross-section biasing

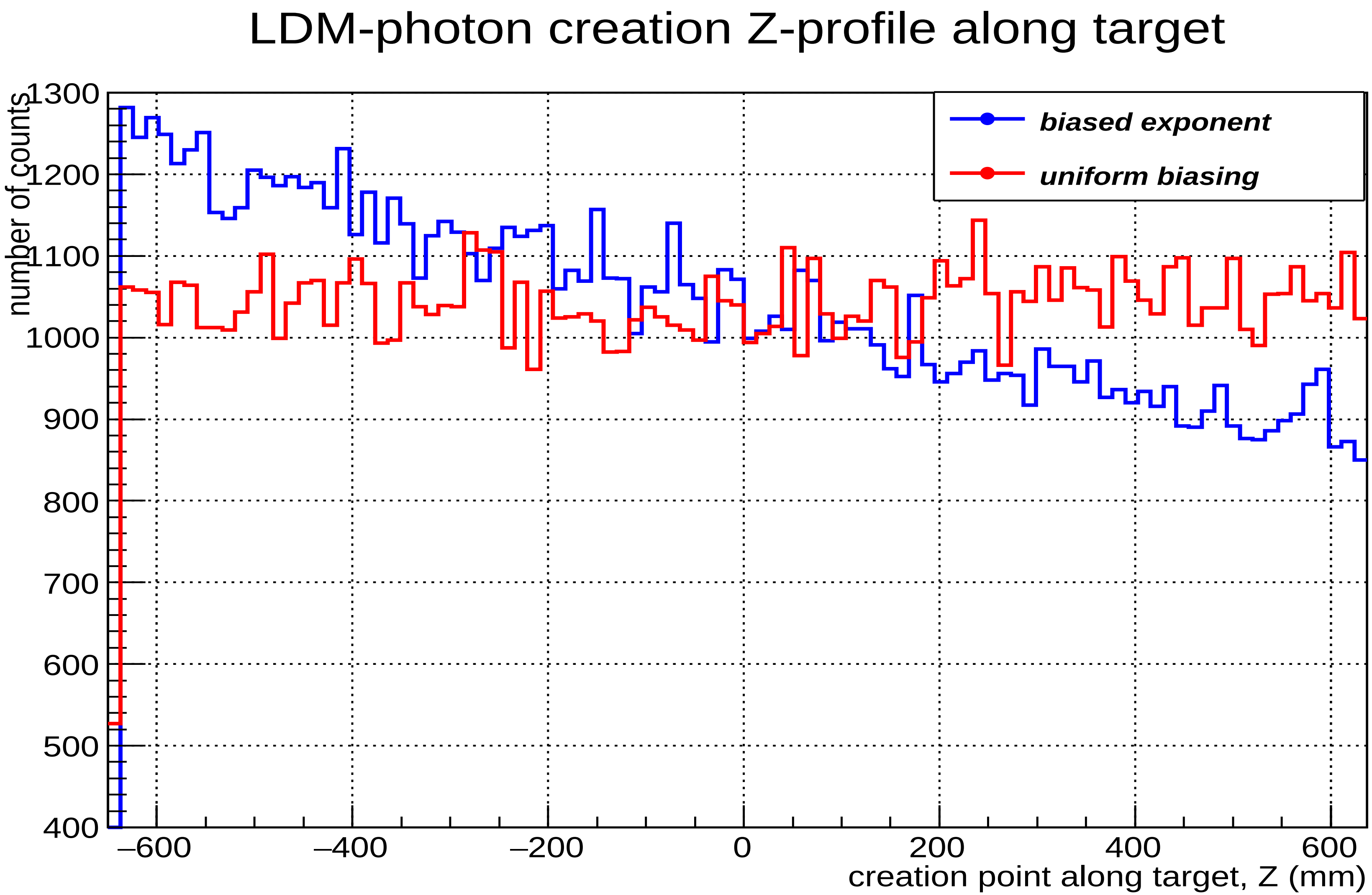
The cross-section are assumed to be biased (essentially increased).

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

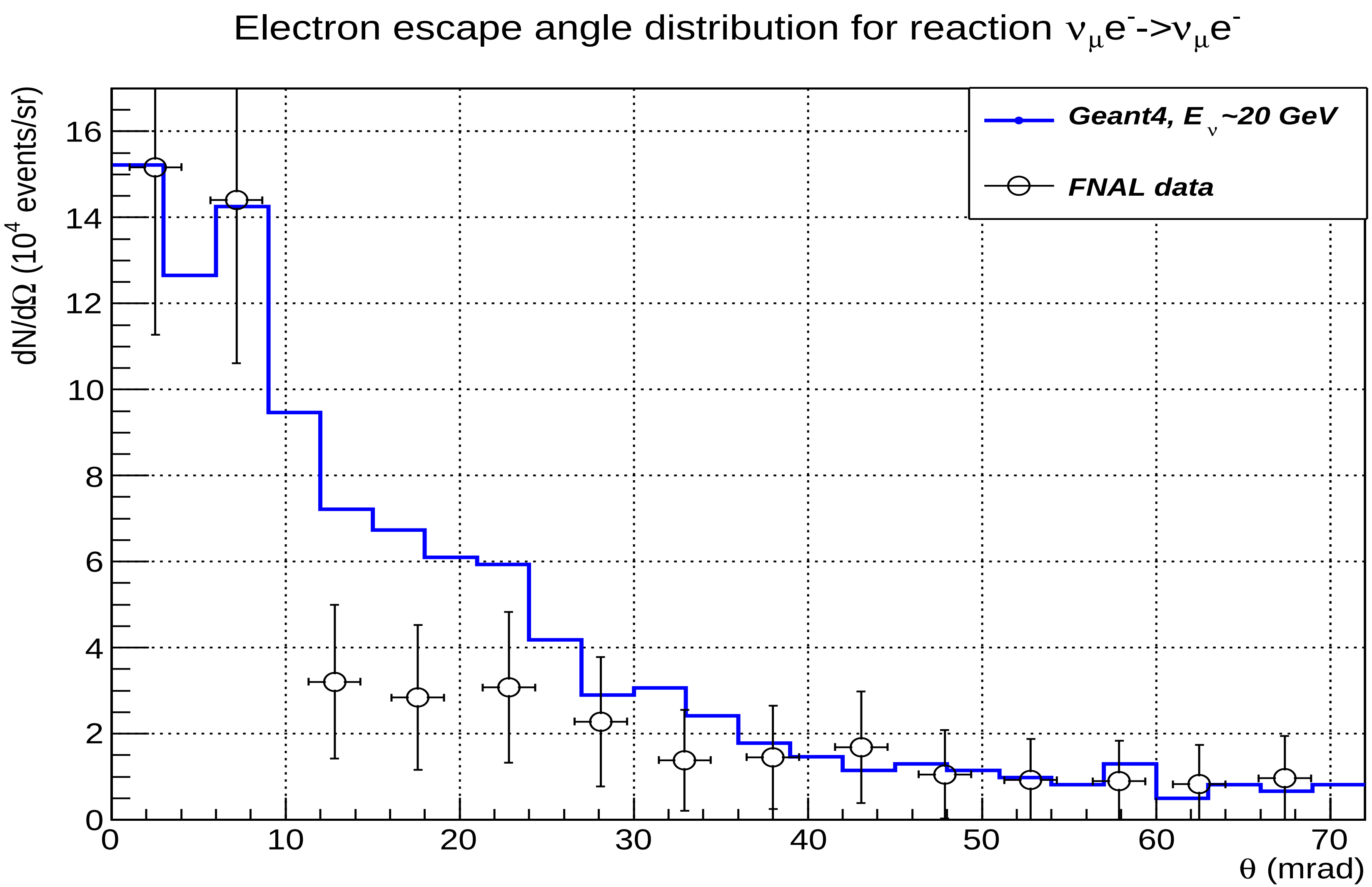
Then to restore the uniform distribution of normal rare events in a detector, we use $G4NeutrinoElectronProcess :: PostStepDoIt(track, step)$, where one has access to local solid distance to in/out values. The event point is then uniformly distributed over the track distance in the sensitive detector. To re-normalize back to the natural cross sections one should multiply the bin counts by:

$$\frac{D/\lambda}{1 - \exp(-D/\lambda_{biased})}, \quad D \sim \lambda_{biased} \ll \lambda$$

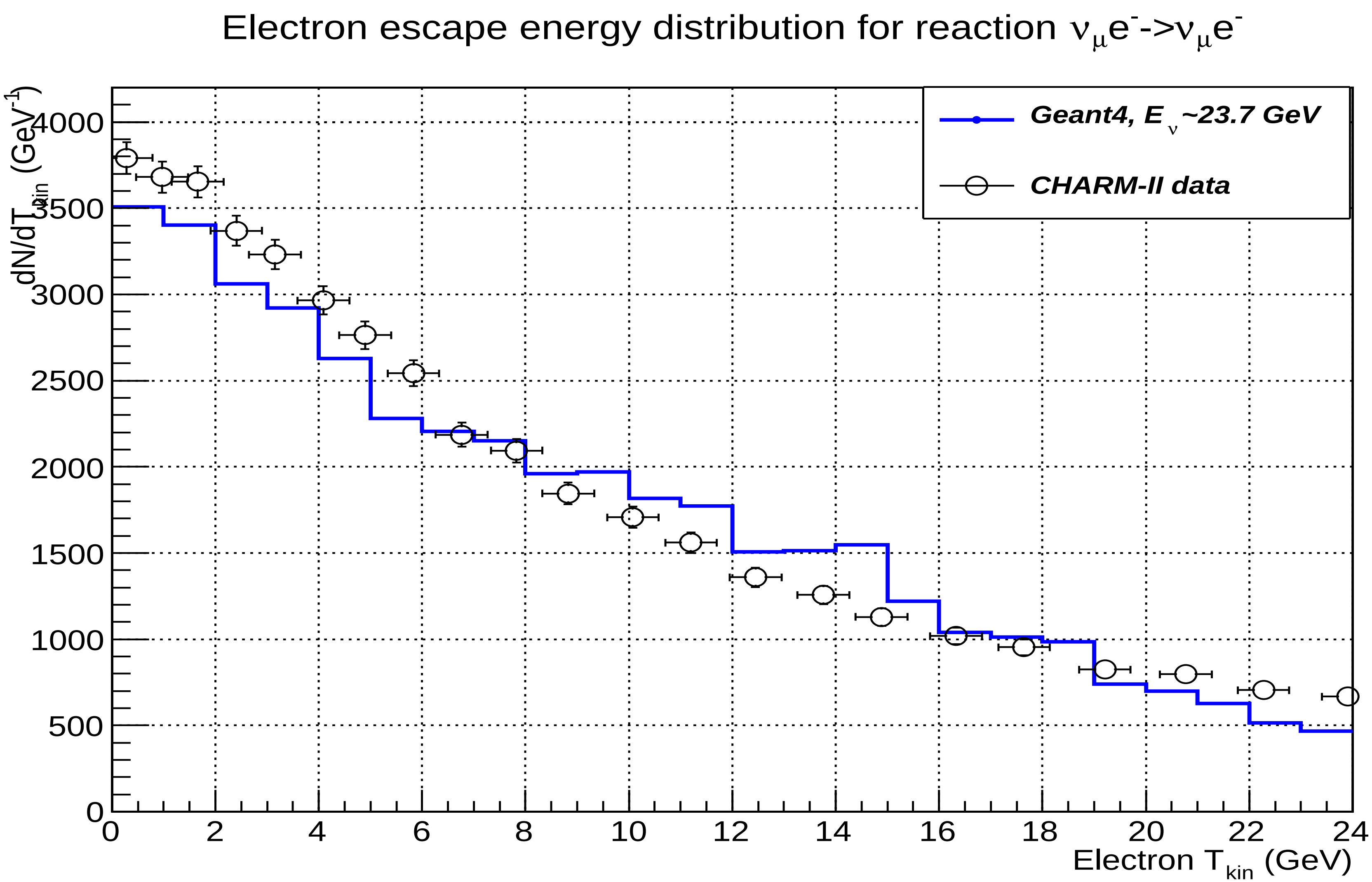
where D is the track distance, λ is the neutrino mean free path in the detector material and $\lambda_{biased} \sim D$ is the biased mean free path. $G4SafetyHelper$ informs GEANT4 navigation that the process moved the interaction point inside the detector volume.



The uniform and exponential sampling for biased events of the light dark matter photon production point along the target (400 GeV protons in tungsten).



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



Electron escape energy distribution, data from CHARM-II:
$[CHARM2Collaboration, Phys.Lett., B281(1992)159]$

5 Summary

1. Geant4 neutrino-electron user interface (messenger, constructor, process, cross-sections and final state generator models) were implemented in the Geant4 library.
2. The interface will be available starting Geant4 10.4 (summer 2018).