Initial nucleon state (impulse approximation)

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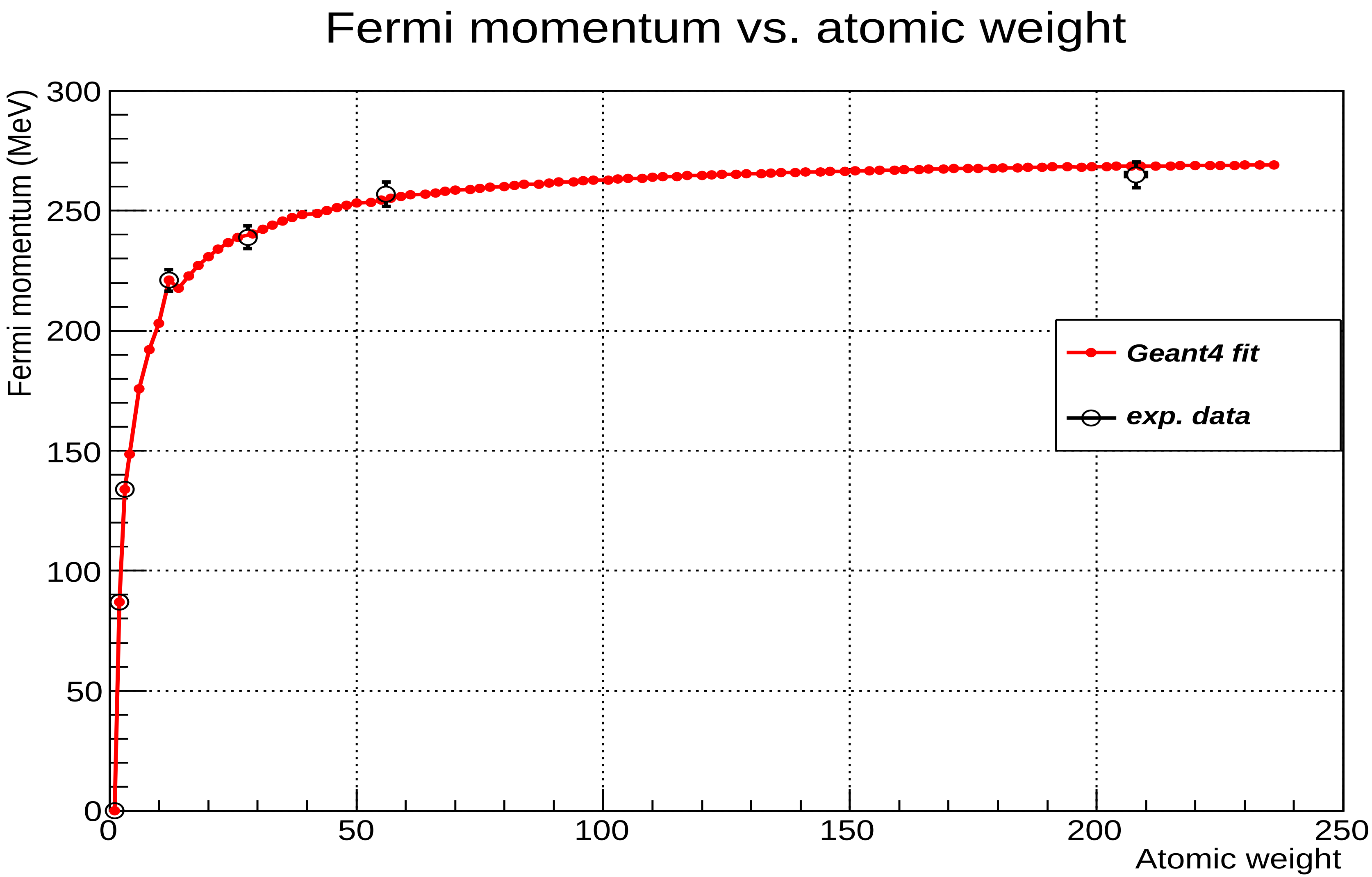
Abstract

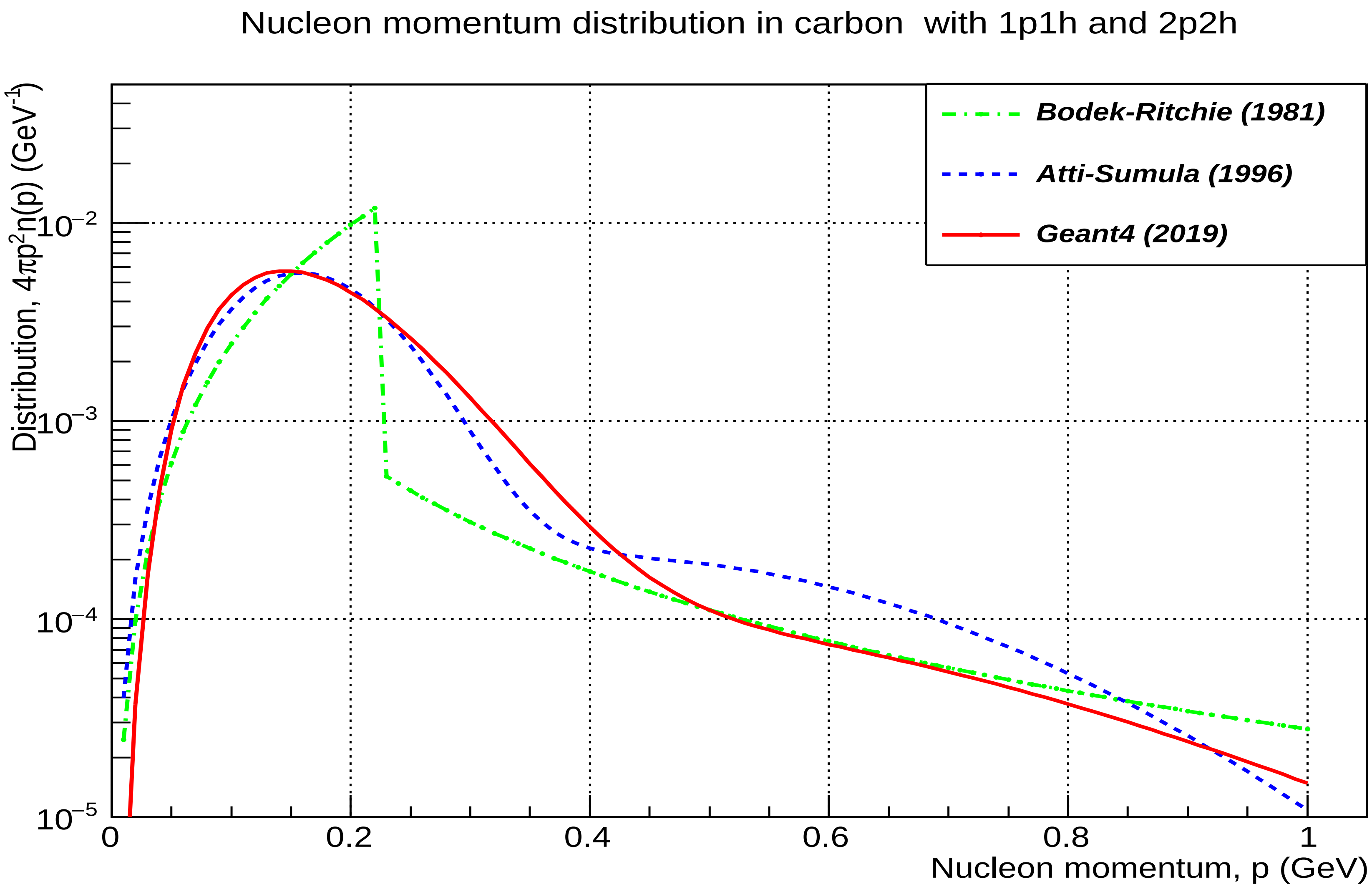
The initial nucleon state is discussed in the impulse approximation, when the interacting nucleon takes all 4-momentum transfer from a projectile, while the rest of nucleus behaves as spectator. The dependence of Fermi momentum (relativistic Fermi gas (RFG) model) versus the atomic weight is parametrized. The nucleon momentum sampling based on 2Γ-generator is proposed and compared with experimental data. The nucleon invariant mass distributions are shown for both 1p1h- (one particle, one hole) and 2p2h-kinematics, utilizing the nucleon momentum 2Γ-sampling.

Outline

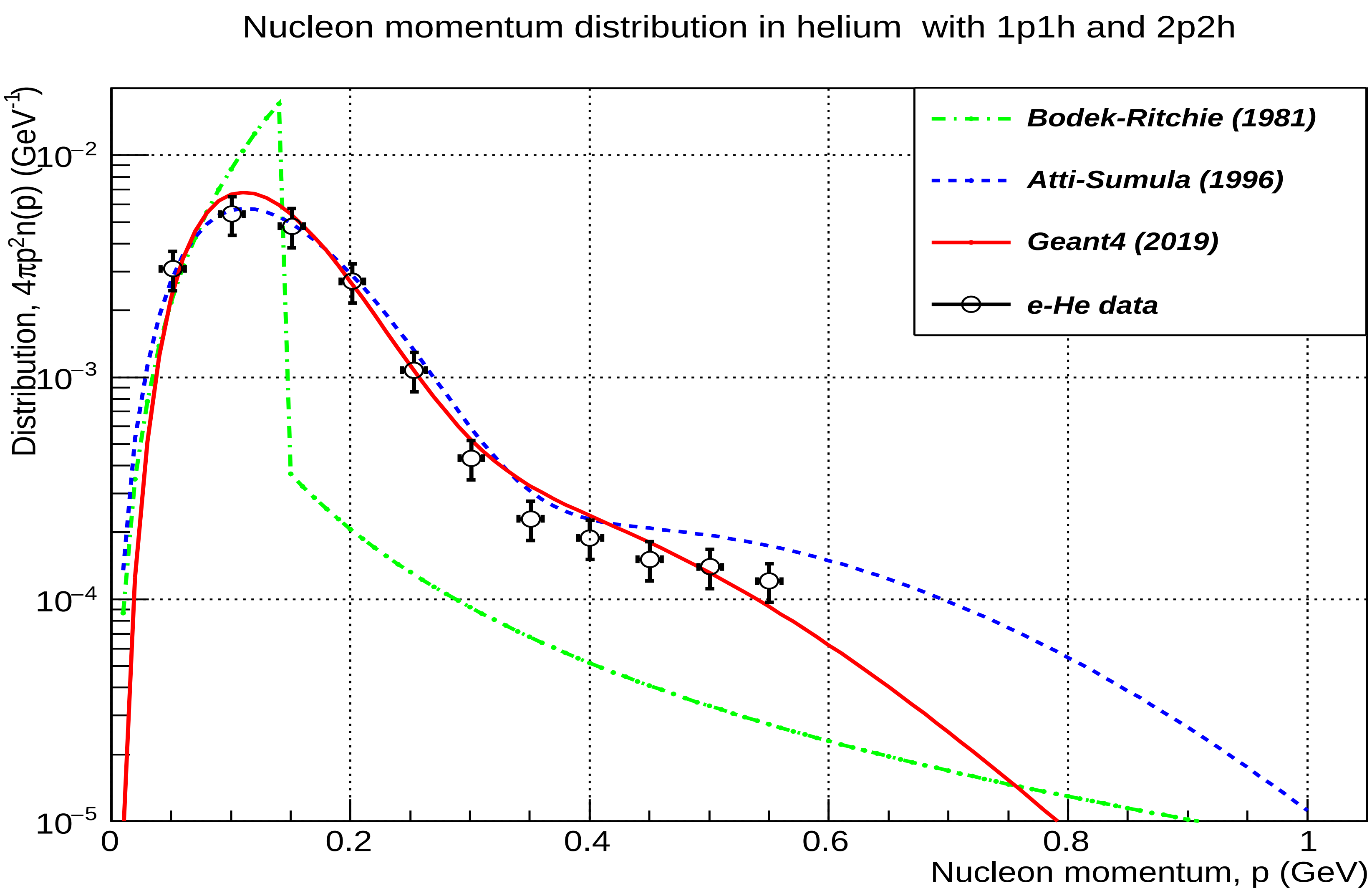
1. RFG Fermi momentum versus atomic weight.
2. Nucleon momentum distributions and sampling.
3. 1p1h- and 2p2h-kinematics.
4. Invariant nucleon mass distributions.
5. Summary.



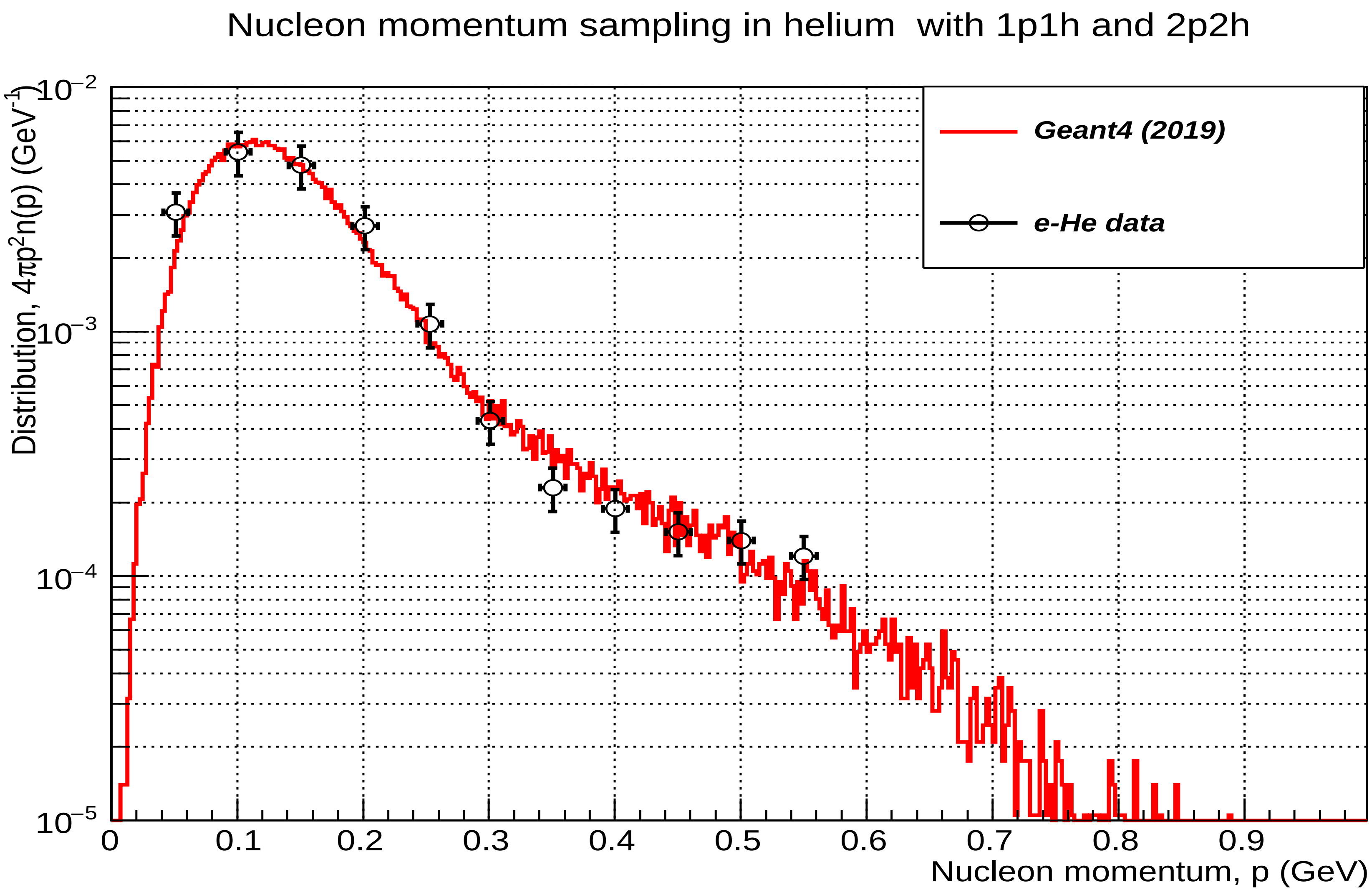
Fermi momentum vs. atomic weight for β-stable nuclei. The mean value is 251 MeV (close to the GEANT4 value of 250 MeV)



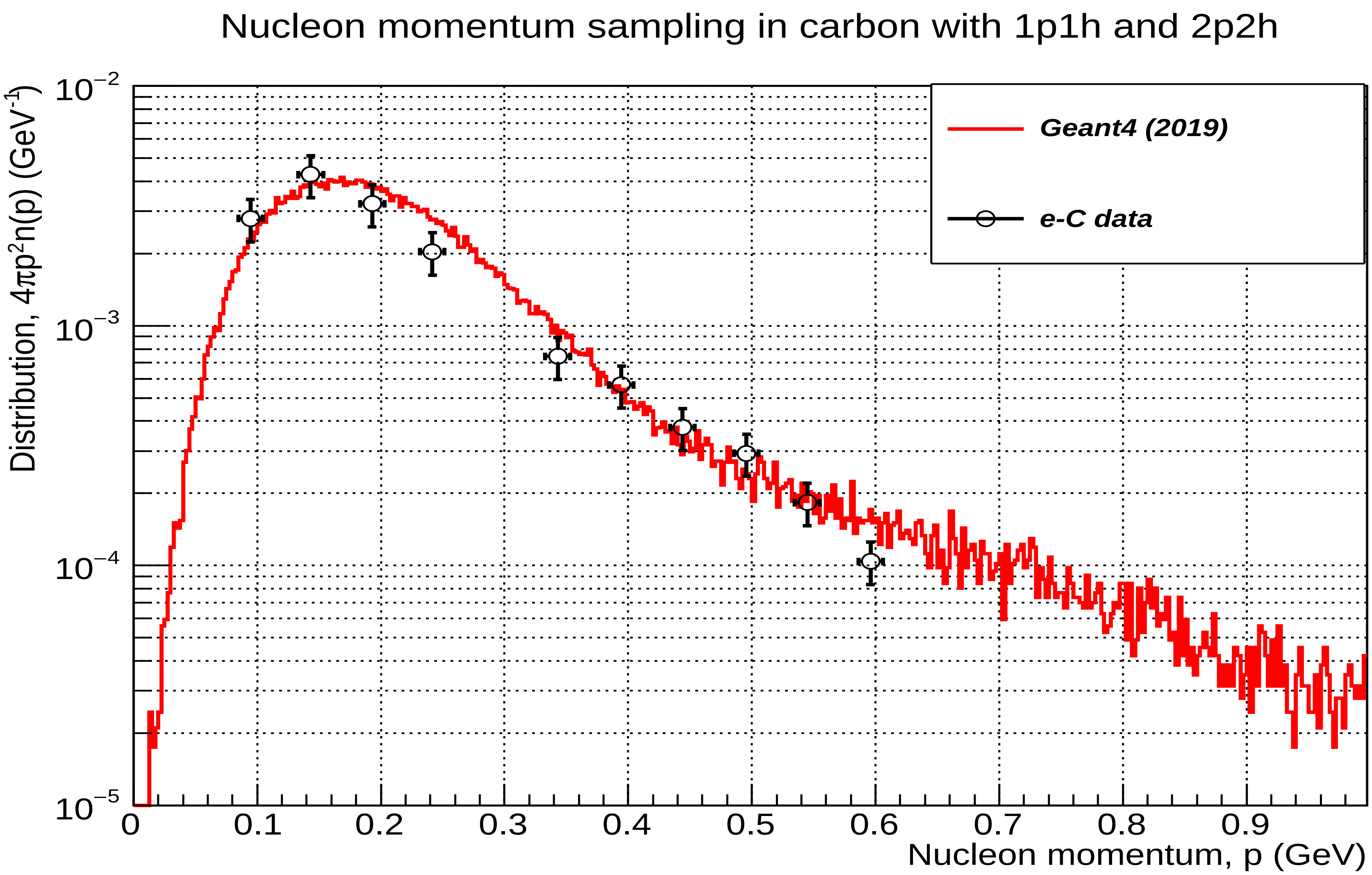
Nucleon momentum spectra for carbon (AS-model is extracted from the nucleon spectral function).



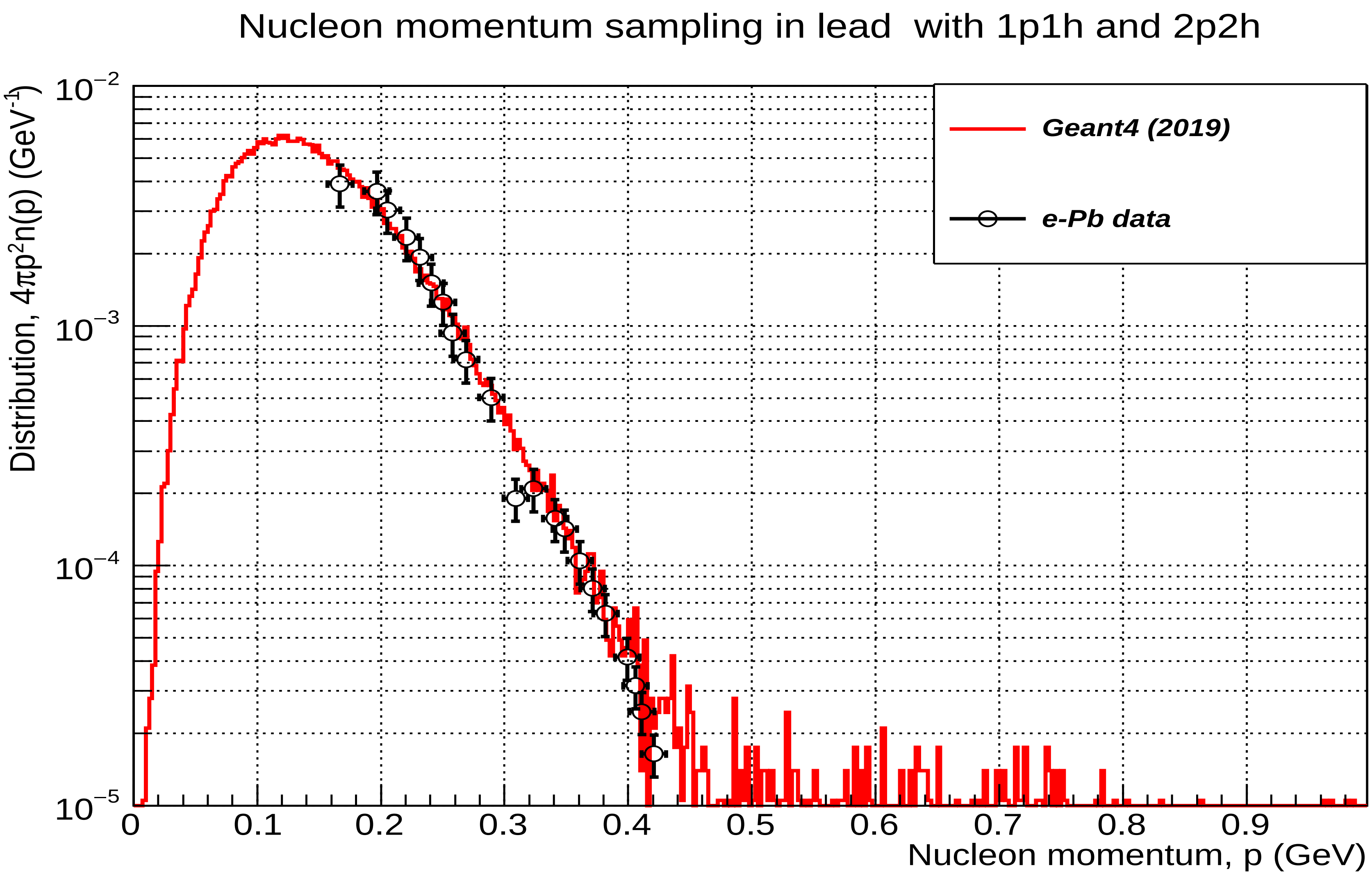
Nucleon momentum spectra for helium.



GEANT4 sampling (two Γ-functions) of nucleon momentum spectra for helium.



GEANT4 sampling (two Γ-functions) of nucleon momentum spectra for carbon.



GEANT4 sampling (two Γ-functions) of nucleon momentum spectra for lead.

1p1h-kinematics

A projectile, say ν, interacts with a on-shell nucleus in the rest, $(M_A, \mathbf{0})$. Inside the nucleus, nucleons move being interacting and bound. Then the nucleon(s) and the rest $(A-1)$ of the nucleus are off-shell. We suppose that the nucleon has momentum, $\mathbf{k}$, sampled according to the nucleon momentum distribution. Then, the initial nucleus state kinematics reads, in terms of the Lorentz vectors:

$$nucleon: \quad (M_A - \sqrt{(M_{A-1}+E_x)^2 + k^2},\ \mathbf{k}),$$

$$(A-1) - spectator: \quad (\sqrt{(M_{A-1}+E_x)^2 + k^2}, -\mathbf{k}),$$

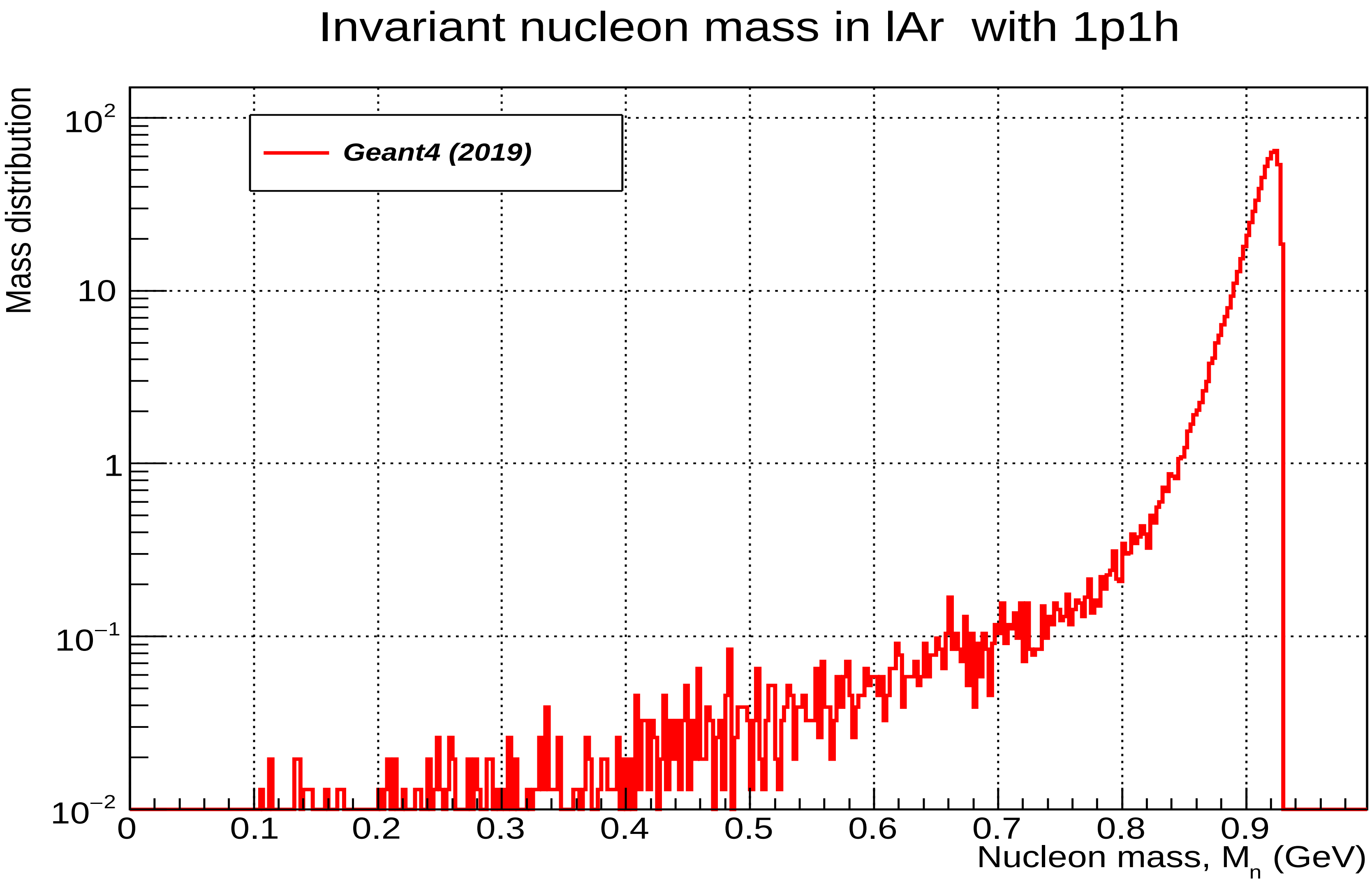
$$A - nucleus, \Sigma: \qquad (M_A, \mathbf{0}),$$

where E_x is the excitation energy of the rest nucleus depending on the atomic weight $(A-1)$.

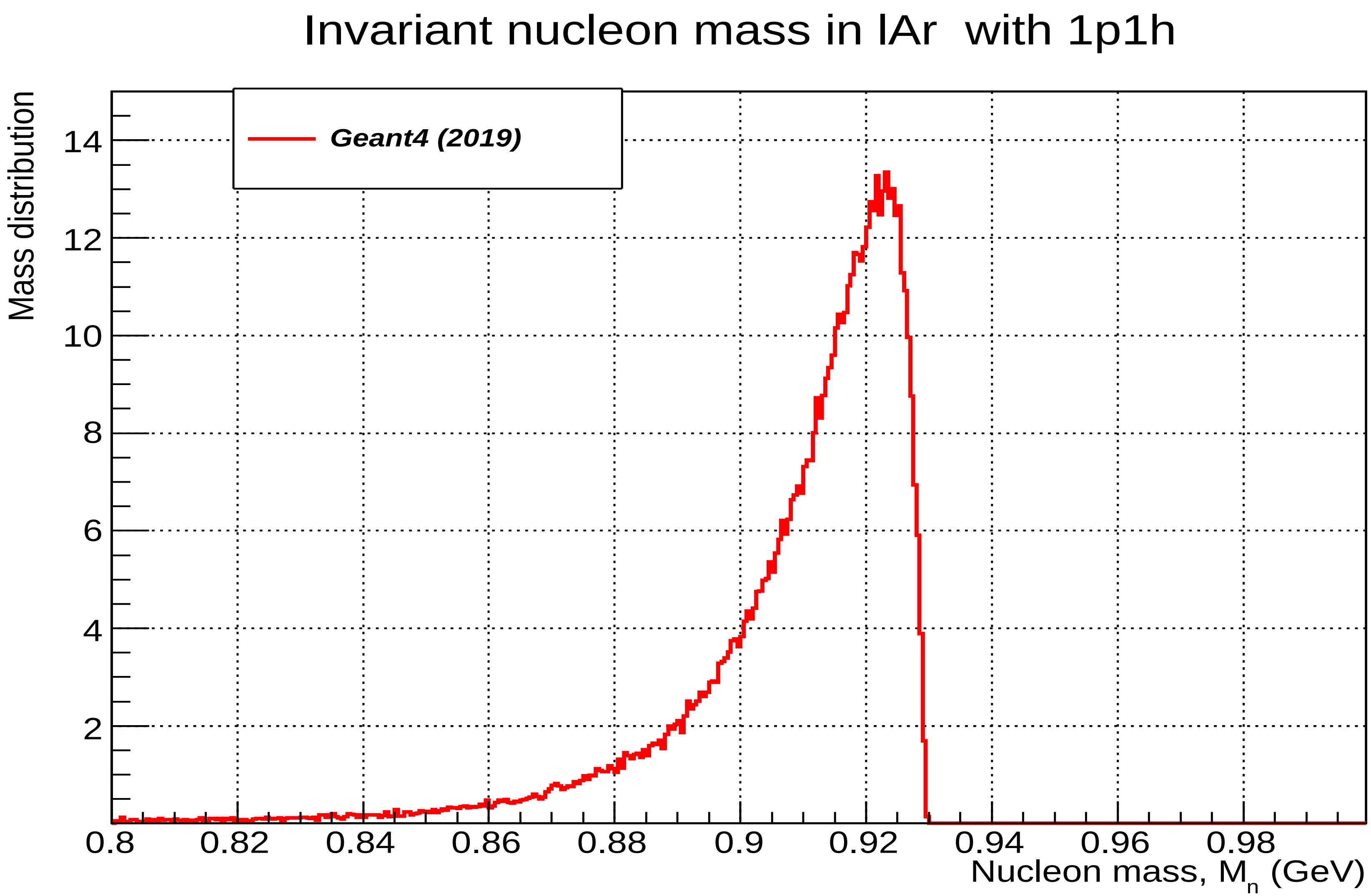
The nucleon invariant mass, M_n, is distributed according:

$$M_n^2 = \left[M_A - \sqrt{(M_{A-1}+E_x)^2 + k^2}\right]^2 - k^2.$$

M_n is typically smaller (and spreaded) than the mass of free nucleon.



Invariant nucleon mass in argon



Invariant nucleon mass in argon (linear scale), MAX∼923 GeV, FWHM∼20 MeV.

2p2h-kinematics

If the nucleon momentum more than k_F (say, $k > 2k_F$), it is supposed that such high momenta can come from the interaction between individual nucleons through their hard-core potential. The kinematics reads:

$$1 - nucleon: \quad (\frac{1}{2}\left[M_A - M_{A-2} - 2E_x\right], \; \mathbf{k}),$$

$$2 - nucleon: \quad (\frac{1}{2}\left[M_A - M_{A-2} - 2E_x\right], \; -\mathbf{k}),$$

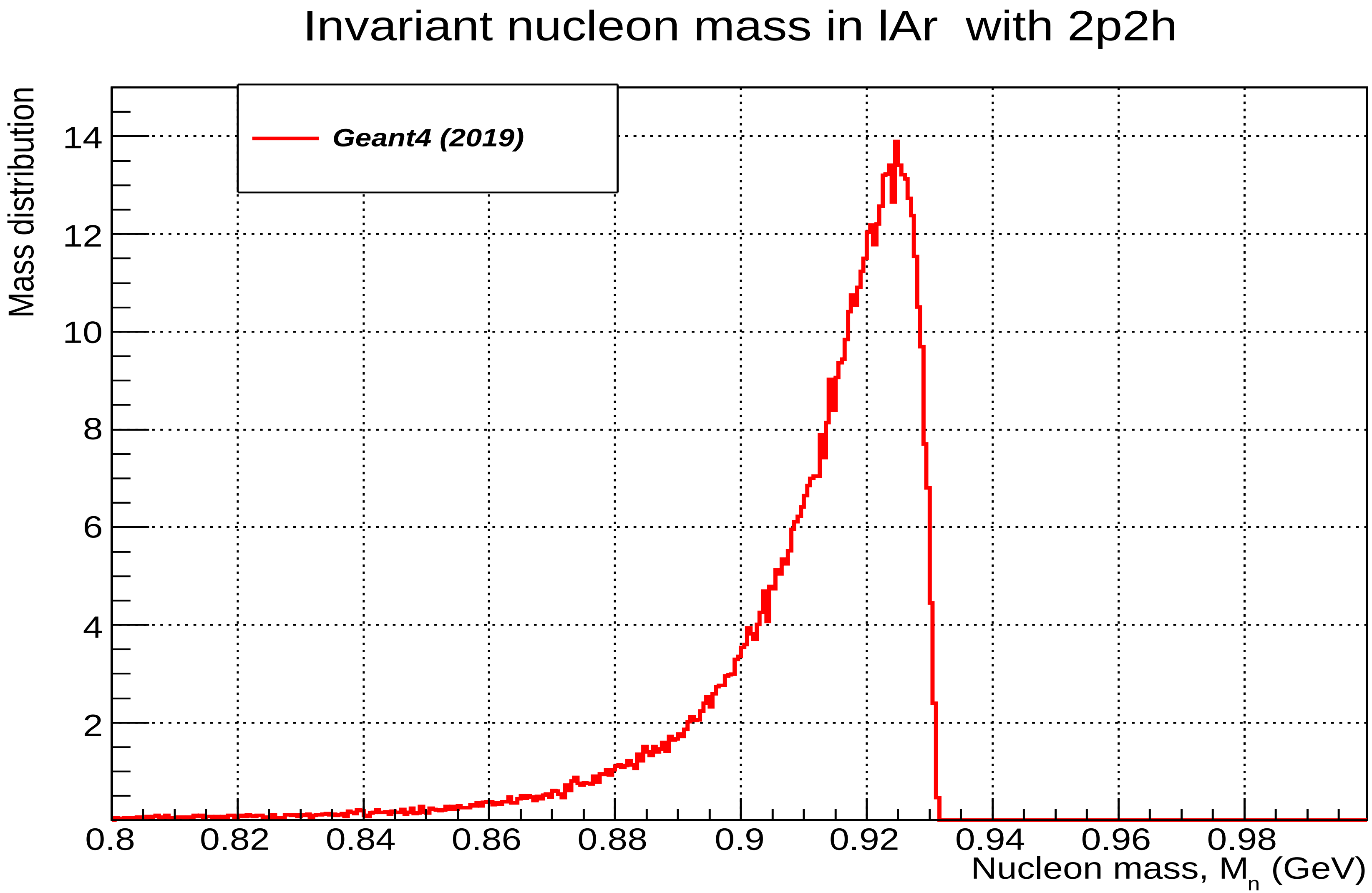
$$(A-2) - spectator: \quad (M_{A-2} + 2E_x, \mathbf{0}),$$

$$A - nucleus, \Sigma: \quad (M_A, \mathbf{0}),$$

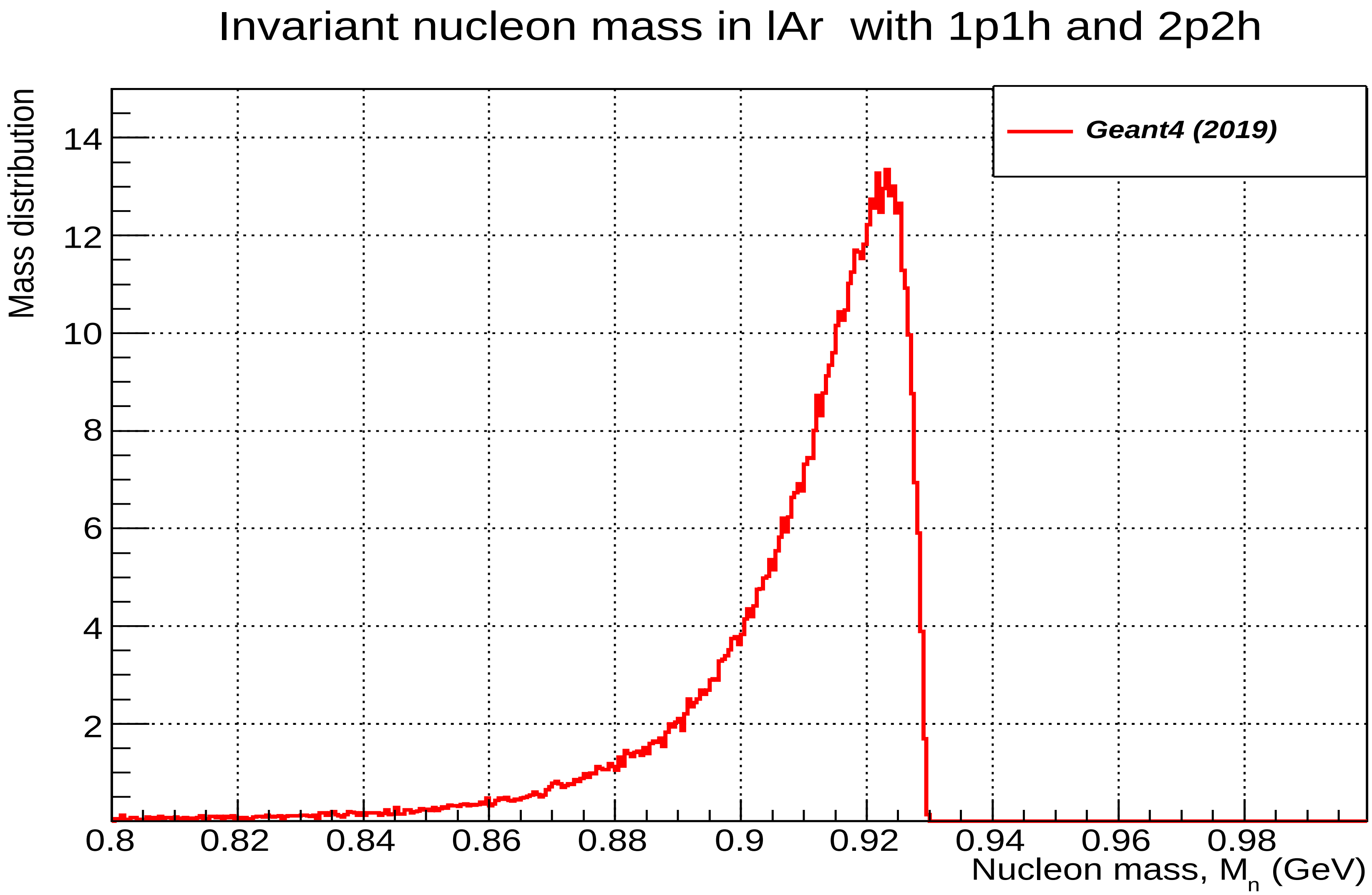
where E_x is the excitation energy of the rest nucleus depending on the atomic weight $(A-2)$.

The nucleon invariant mass, M_n, is distributed according:

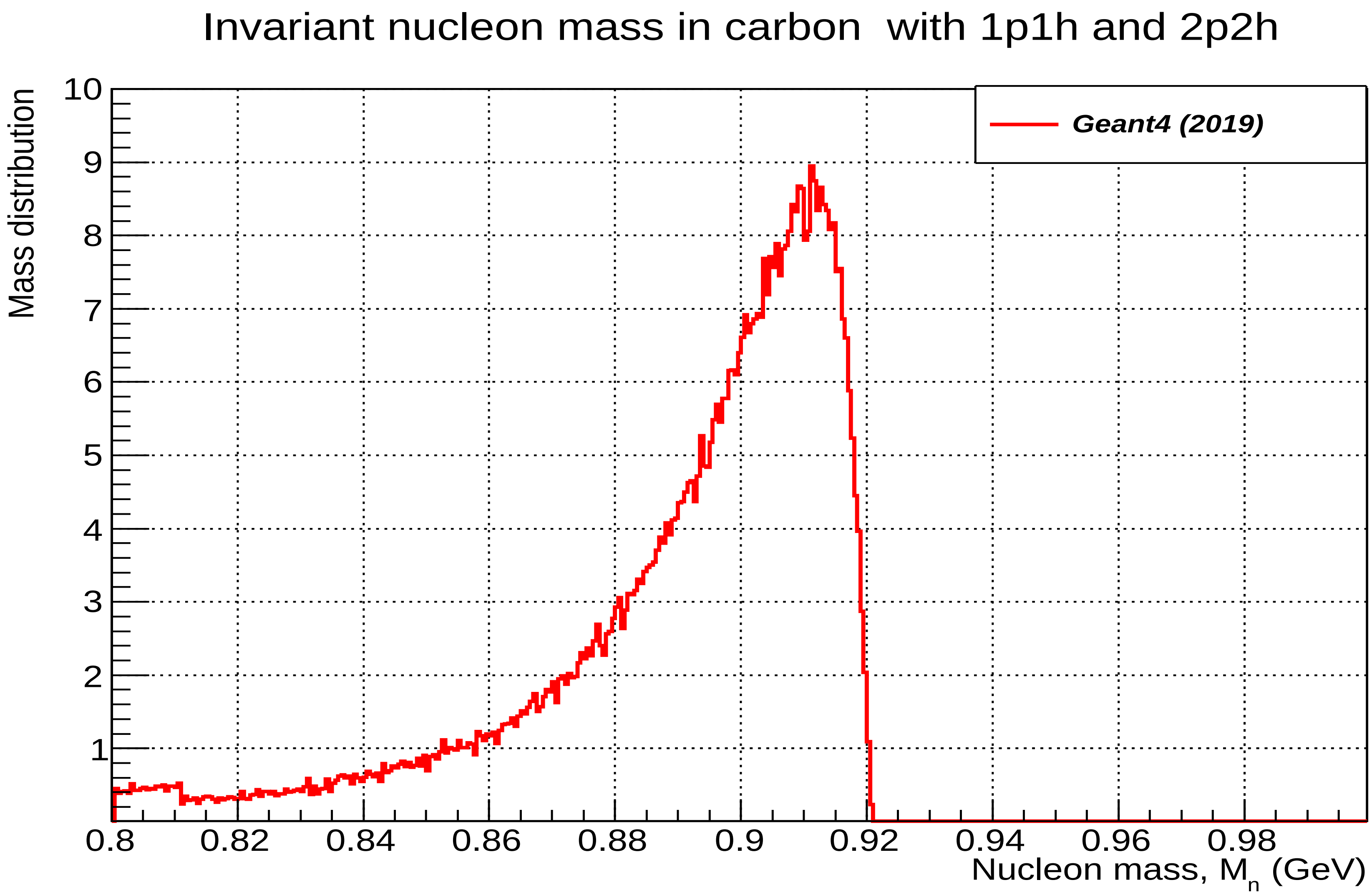
$$M_n^2 = \frac{1}{4}\left[M_A - M_{A-2} - 2E_x\right]^2 - k^2.$$



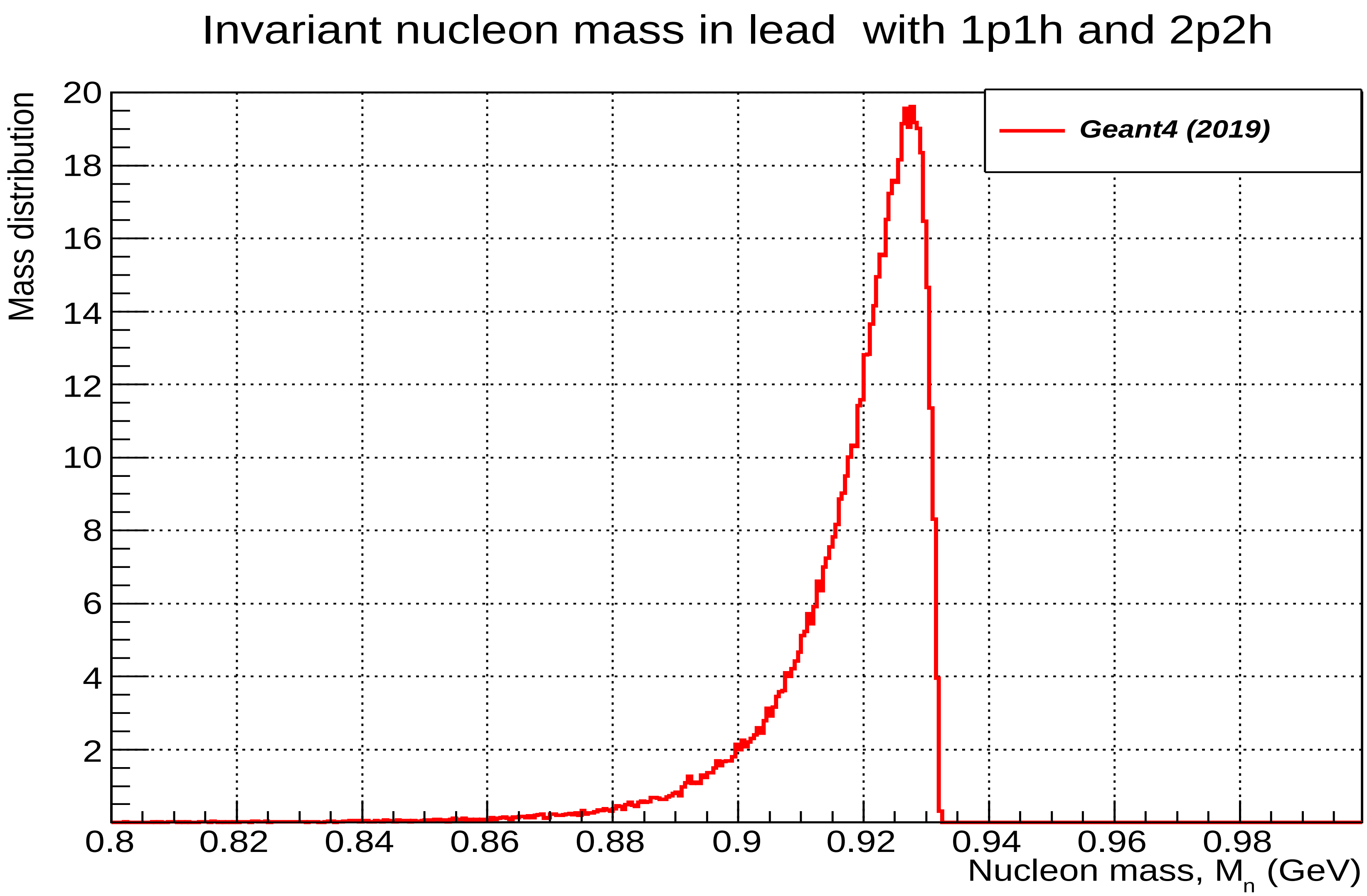
Invariant nucleon mass in argon (linear scale), MAX∼925 MeV, FWHM∼20 MeV.



Invariant nucleon mass in argon (linear scale, 1p1h→2p2h at $2k_F$), MAX∼923 MeV, FWHM∼20 MeV.



Invariant nucleon mass in carbon (linear scale, 1p1h→2p2h at $2k_F$), MAX∼911 MeV, FWHM∼30 MeV.



Invariant nucleon mass in lead (linear scale, 1p1h→2p2h at $2k_F$),
MAX∼923 MeV, FWHM∼14 MeV.

Summary

1. The RFG Fermi momentum is paramerized for different nuclei.
2. The nucleon motion is sampled according to a simplified model (two Γ-functions)
3. The initial nucleon state in terms of the Lorentz vector is combined for both 1p1h- and 2p2h-kinematics using the nucleon momentum distribution.
4. The nucleon invariant mass distributions are shown for both 1p1h- and 2p2h-kinematics, reflecting the nucleon momentum distribution dependence on A.
5. Two new static methods, $GetFermiMomentum(Z, A)$ and $SampleNucleonMomentum(Z, A)$ can be proposed for new $G4NucleonMotion$ class (or for existing $G4FermiMomentum$).