Летняя научная школа «Супер с-тау фабрика». 25-29 Июля 2022 НЦФМ, МГУ (Саров)

Рассеяние высокоэнергетичных мюонов

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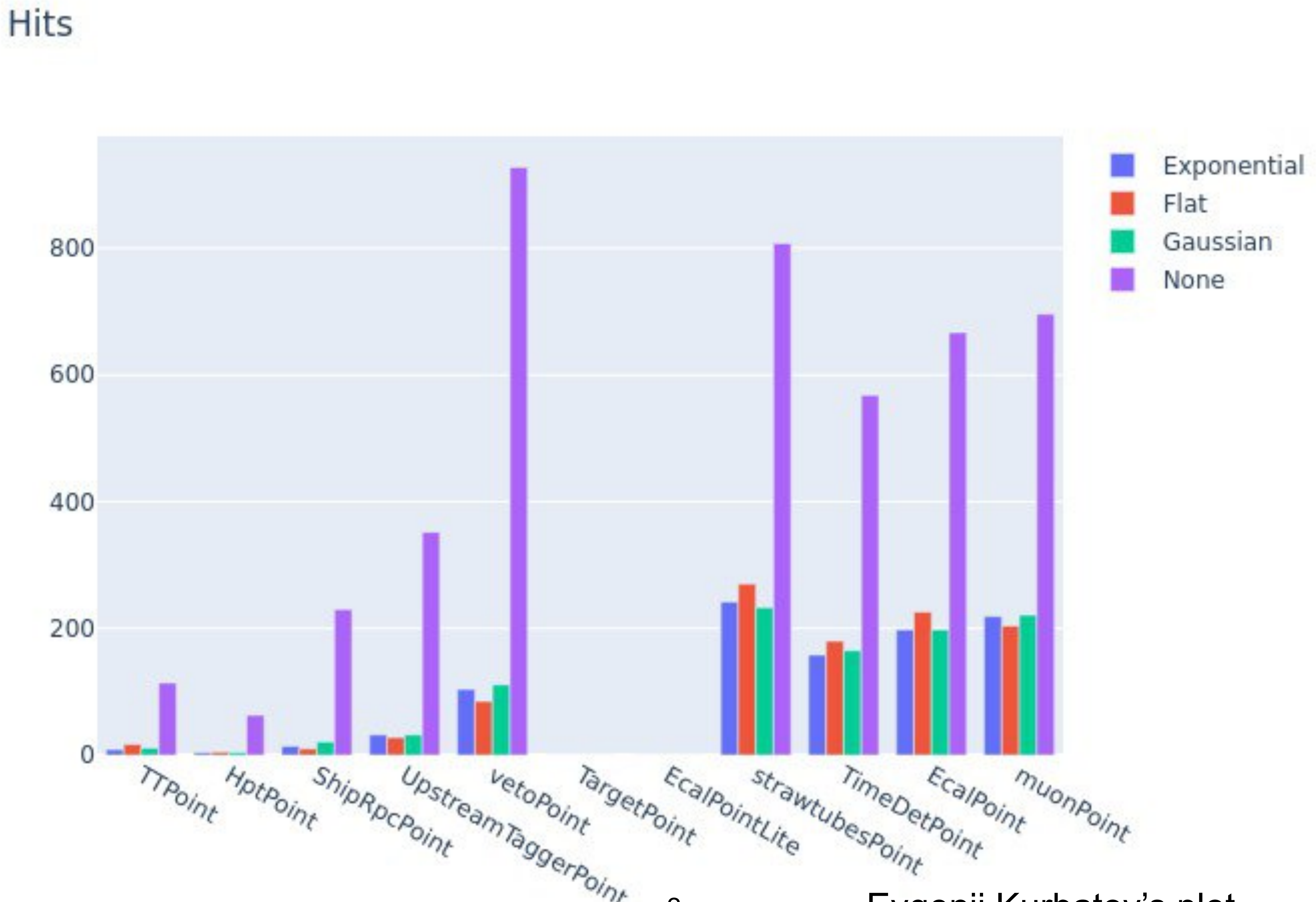
Muon rate in muon shield with various form-factors (from GEANT4 10.7)

The task is to reduce the number of background muons by many orders of magnitude, for the optimisation of the muon shield *it is necessary to describe with high accuracy the processes of muon scattering in iron*.

It is essential that the simulation is well tuned that we can get the right estimates of the muon flux after the shield and residual muons that reach the detector.

The largest muon background corresponds to the “None” (FF=1, point-like charge of nucleus) scattering form factor.
https://personalpages.manchester.ac.uk/staff/Sean.Freeman/pc3121/formfactors.pdf



Evgenii Kurbatov’s plot

Tuning of the form factor for muon scattering in lead was carried out in the work: Large-angle scattering of multi-GeV muons on thin Lead targets, A. Longhin, A. Paoloni, F. Pupilli, INFN, arXiv:1506.08759v1, 2015

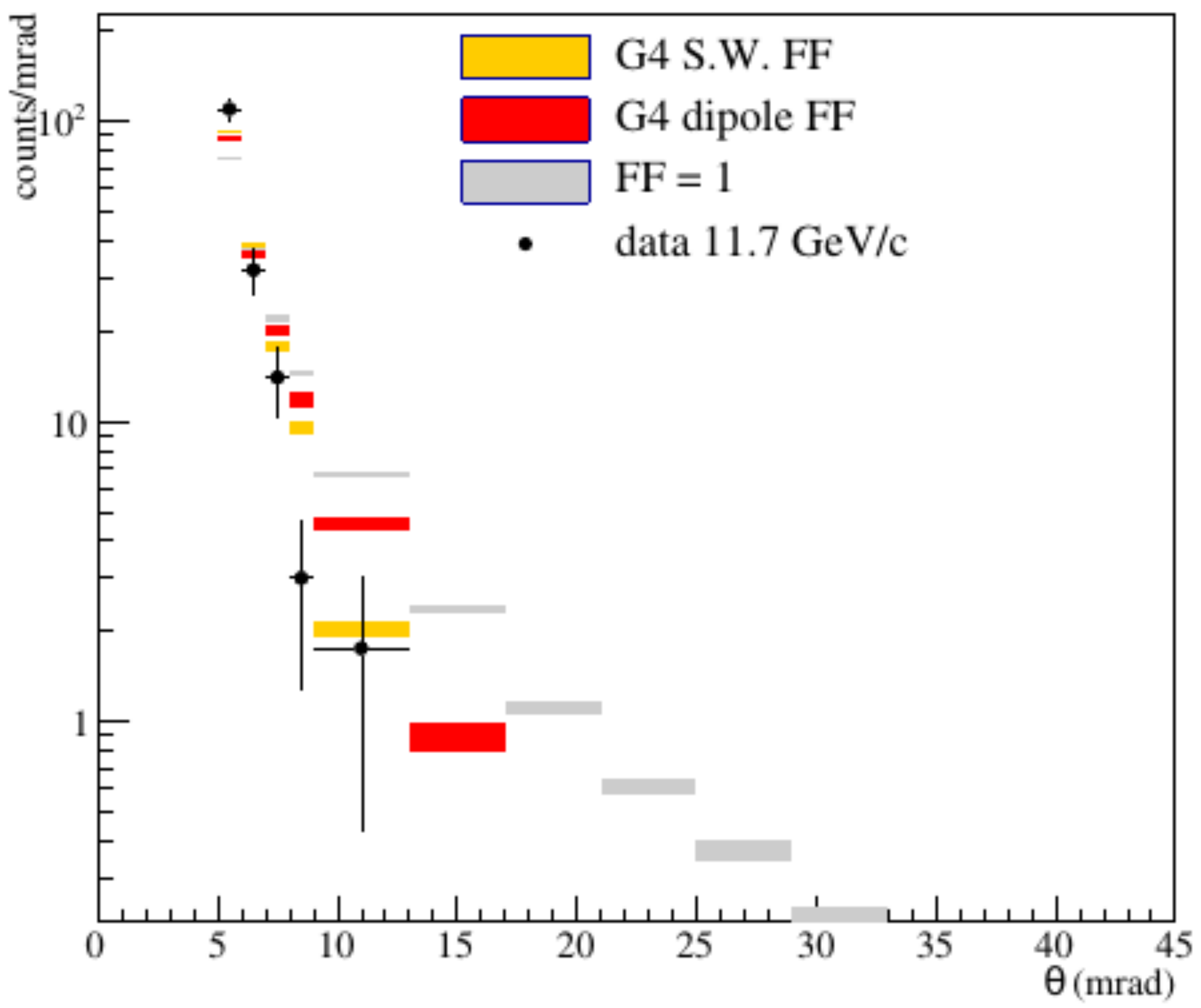


Fig. 6. Comparison of the Monte Carlo simulation to the 11.7 GeV/c data-set. Data have been obtained by digitisation from the original paper[14].

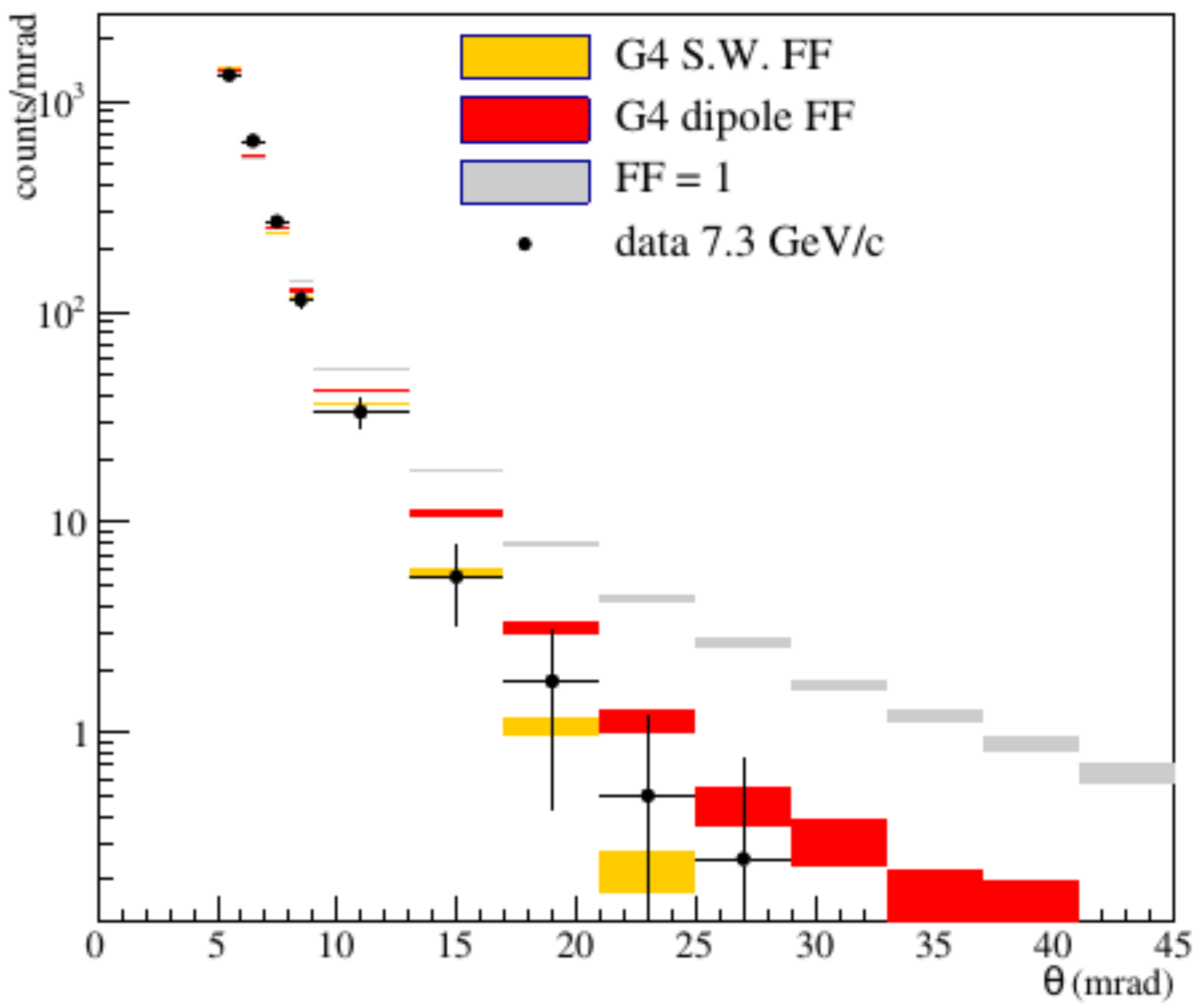


Fig. 7. Comparison of the Monte Carlo simulation to the 7.3 GeV/c data-set. Data have been obtained by digitisation from the original paper[14].

Physics Reference Manual. Release 10.7

Geant4 Collaboration, Rev5.0: December 4th, 2020

In a first Born approximation the elastic scattering cross section can be obtained as:

$$\frac{d\sigma^{(W)}(\theta)}{d\Omega} = \frac{(ze^2)^2}{(p\beta c)^2}\frac{Z(Z+1)}{(2A+1-\cos\theta)^2}$$

The total elastic cross section:

$$\frac{d\sigma(\theta)}{d\Omega} = \frac{d\sigma^{(W)}(\theta)}{d\Omega}\left(\frac{Z}{(1+\frac{(qR_N)^2}{12})^2}+1\right)\frac{1}{Z+1}$$

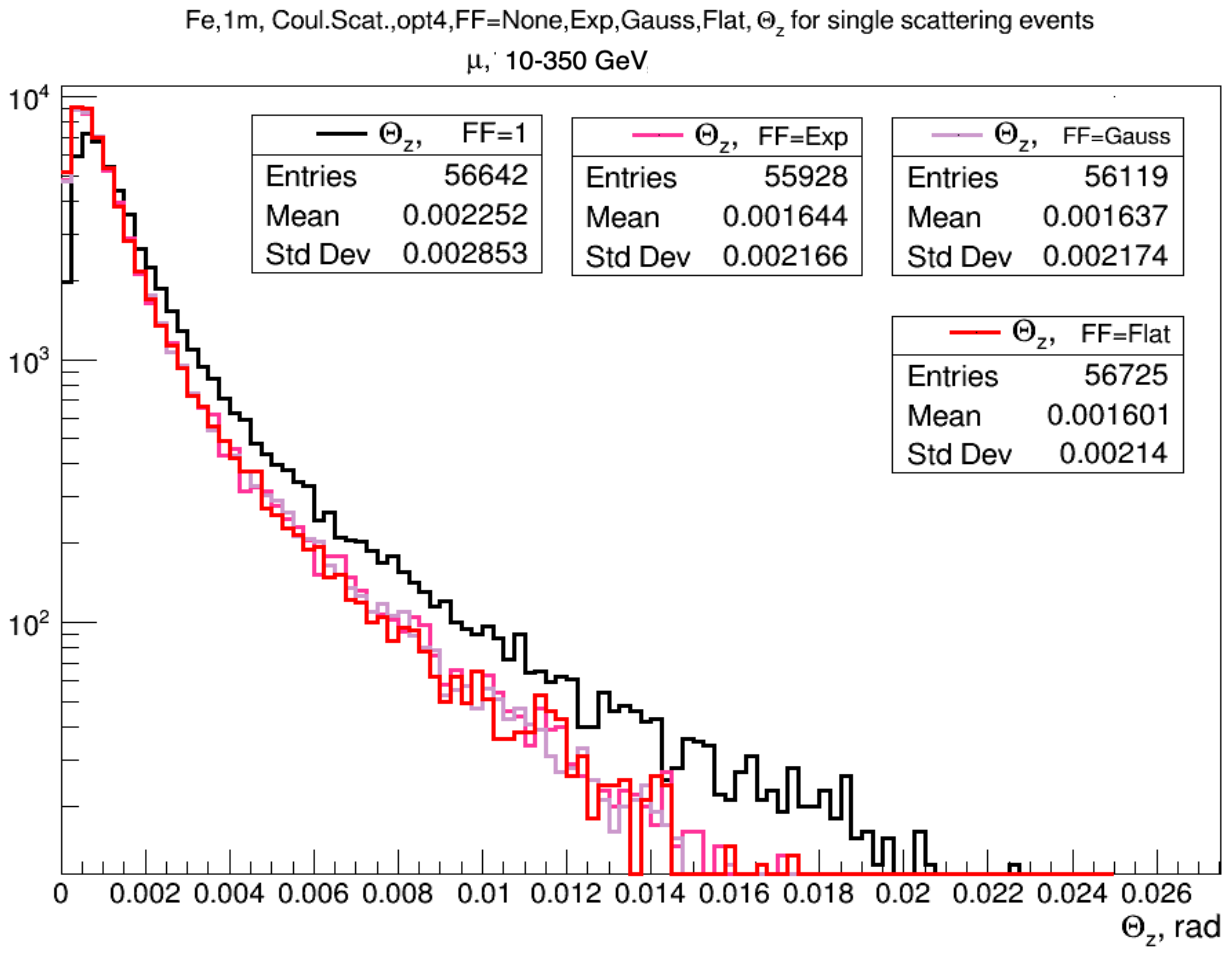
The probability for the occurrence of large-angle scattering for multi-GeV muons in 1 mm thick lead targets has been addressed using a mixed-approach simulation program based on the GEANT4 libraries.
A realistic parametrisation of the lead nuclear density has been implemented (Saxon-Woods) and scattering off single protons has been considered.
The developed algorithm has been validated by means of theoretical considerations and supported by experimental data from the literature.

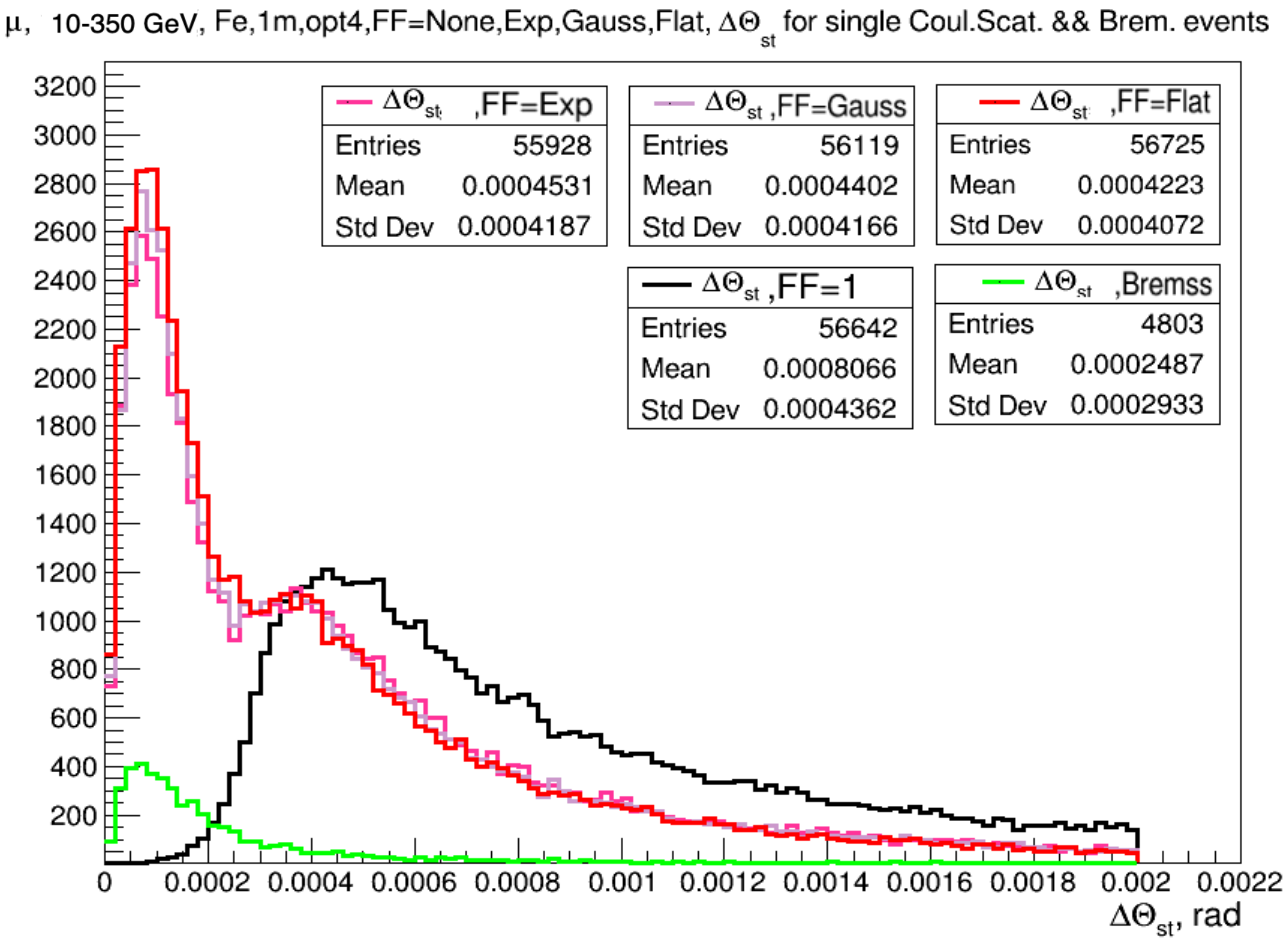
The impact of the form factor on angular distribution of muons

Left: accumulated scattering angle (), after the muons passage through iron 1m thick for different form factors;

Right: the angle of deflection due to a single Coulomb scattering acts () for different form factors (information was derived **only for a single** Coulomb scattering process)

The largest deflection angle corresponds to the “None” (FF=1) scattering form factor.

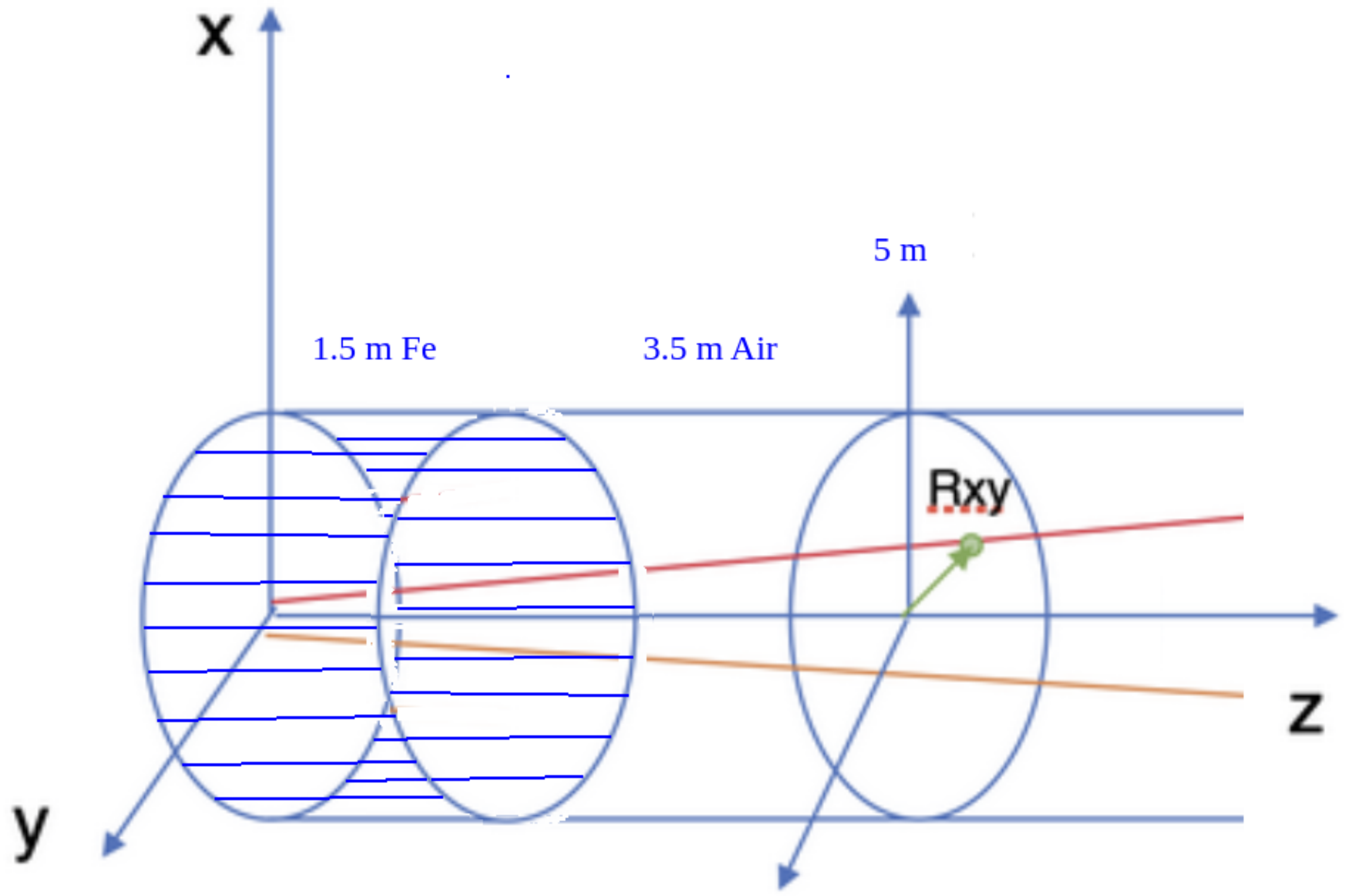


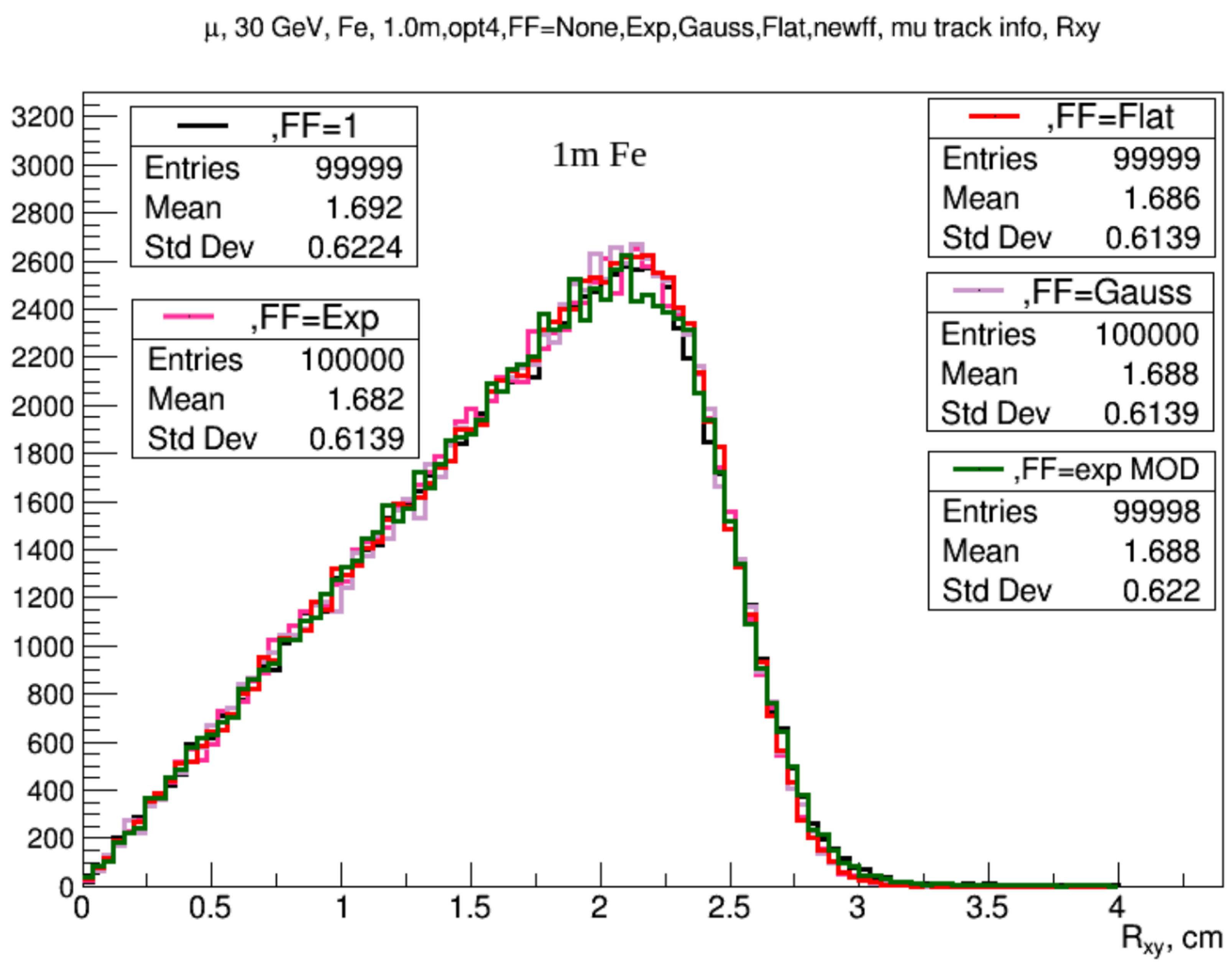


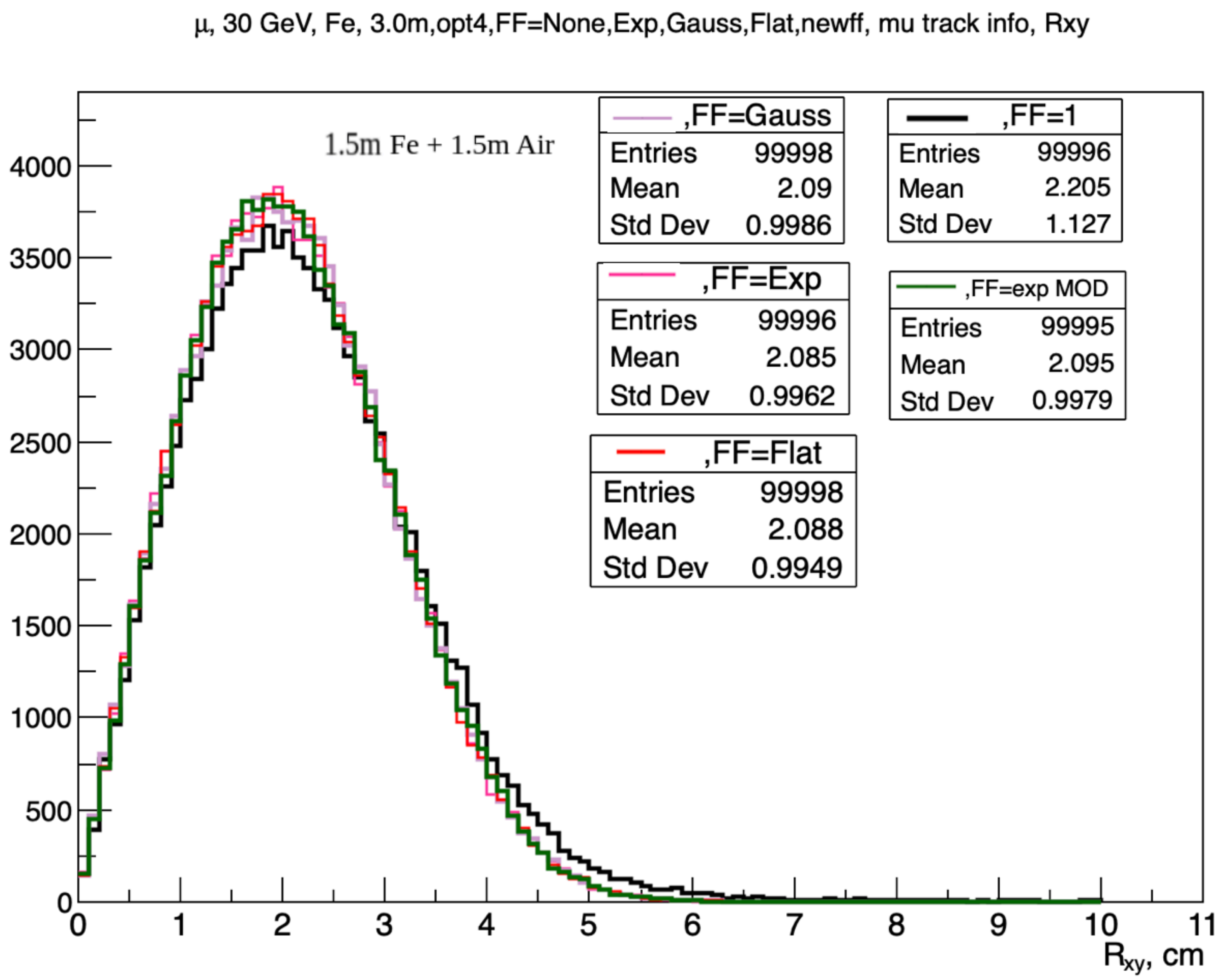
SIMULATION RESULTS

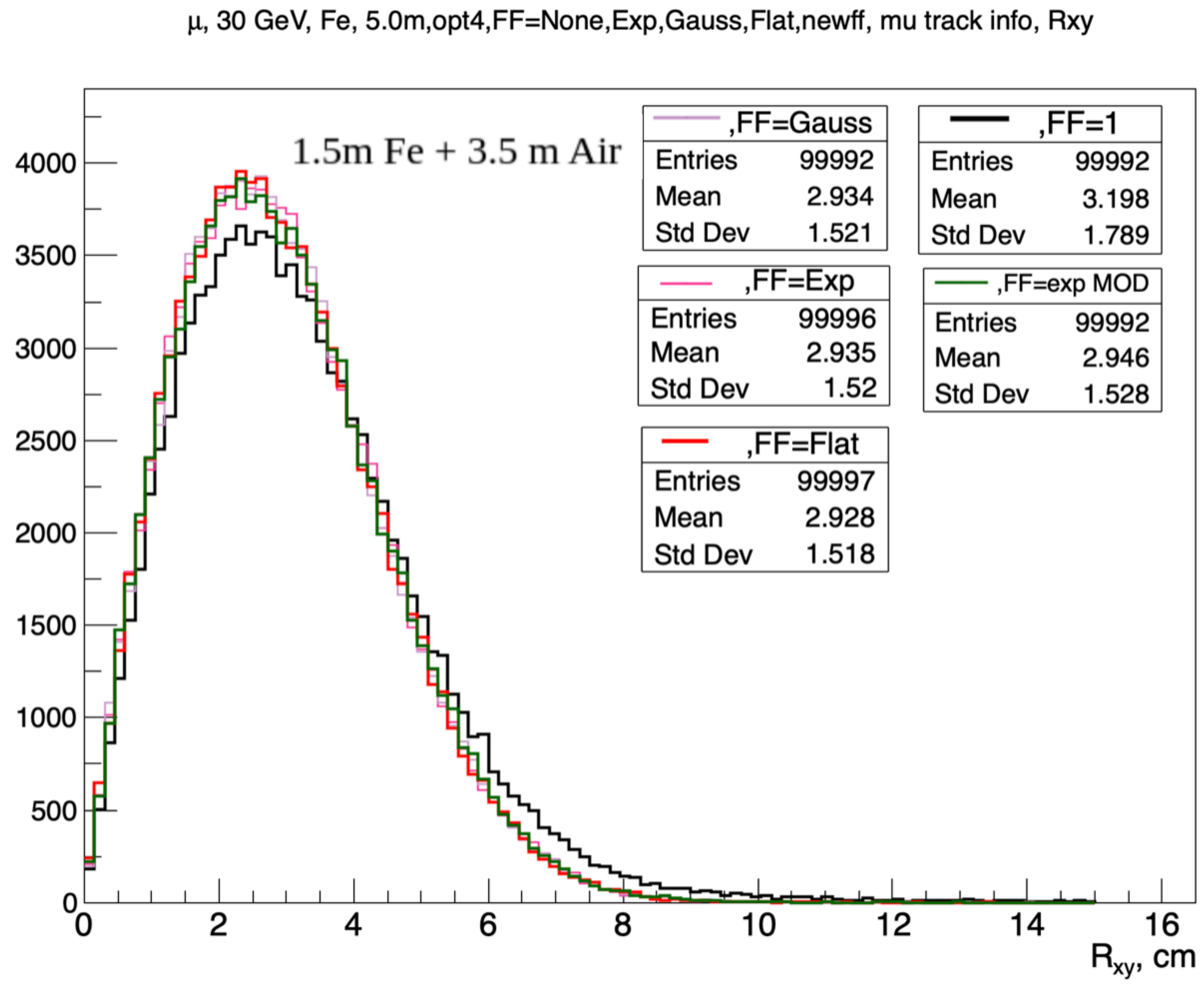
Consider the spatial distribution of muons with a fixed energy at 30 GeV, we considered three variants:

1. inside the iron absorber - after 1 m iron;
2. after passing 1.5m of iron absorber at a distance 1.5 m of air
3. after passing 1.5 m of iron absorber at a distance 3.5 m of air







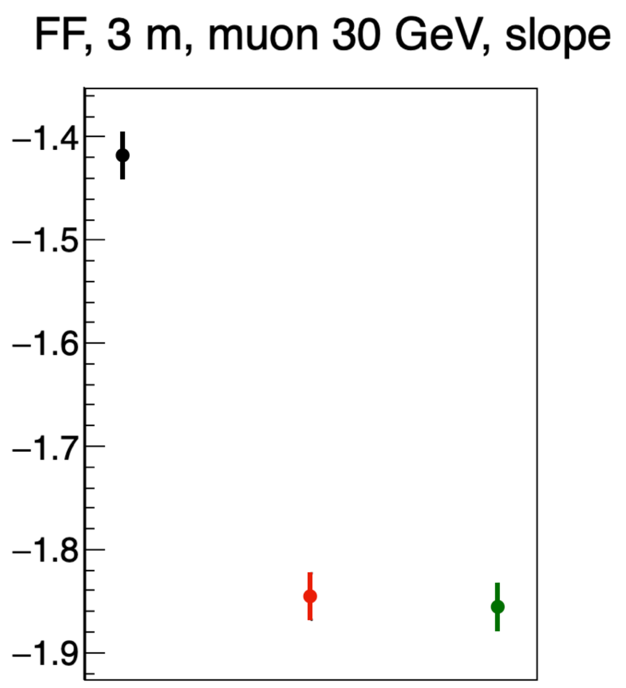


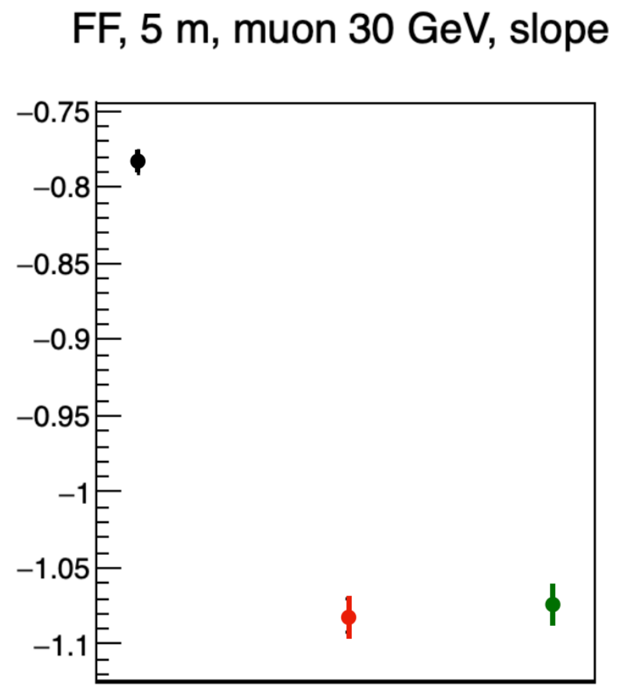
The spatial distribution reaches up to 10 cm

Intermediate distribution

Comparison the transverse distributions of 100,000 muons with an energy of 30 GeV (3m and 5m) for standard GEANT4 form factors and modified, intermediate, exponential form factors (green distributions).

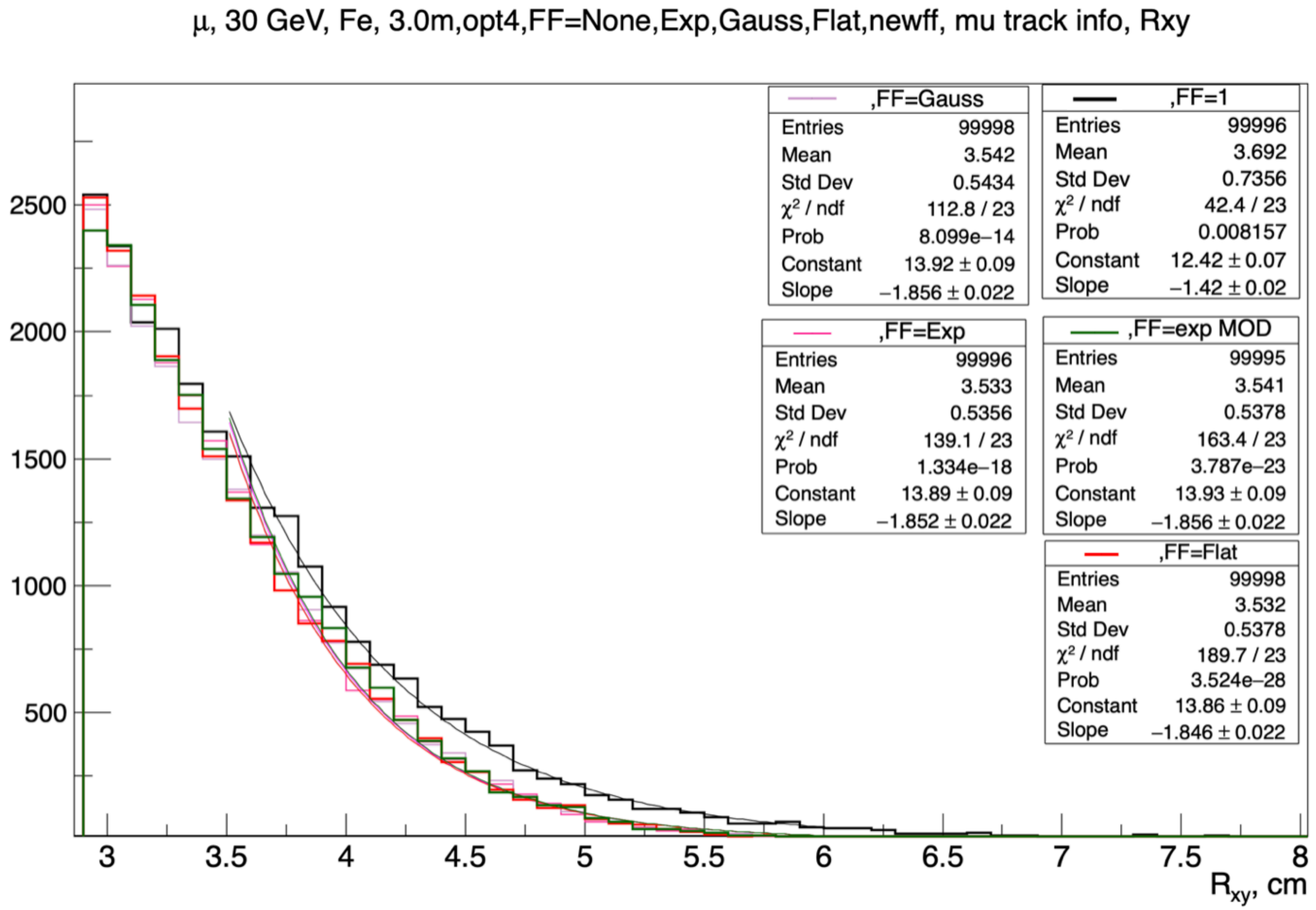
$$\frac{d\sigma(\theta)}{d\Omega} = \frac{d\sigma^{(W)}(\theta)}{d\Omega}\left(\frac{Z}{\left(1+\frac{(qR_N)^2}{12}\right)^{1.8}}+1\right)\frac{1}{Z+1}$$

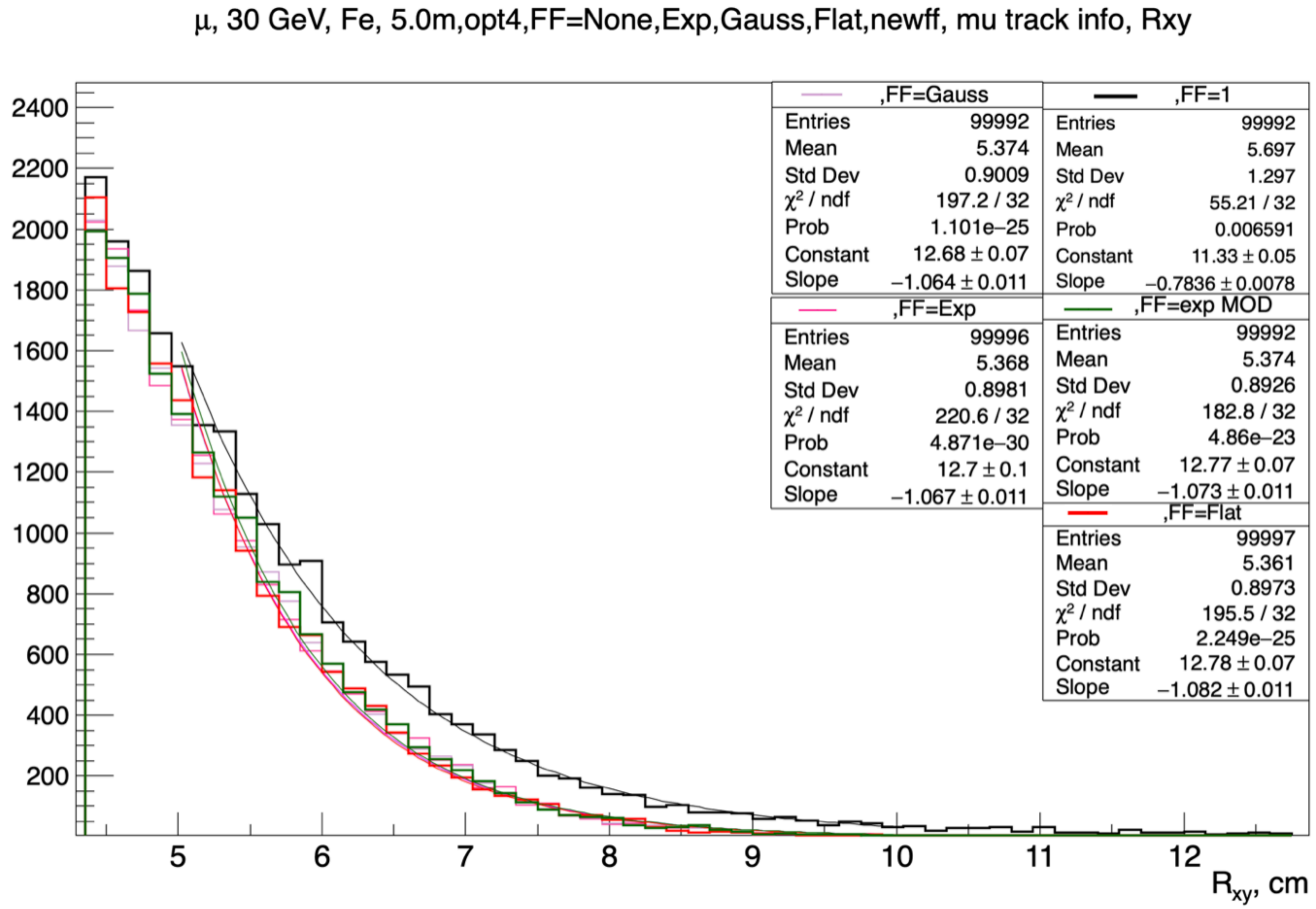




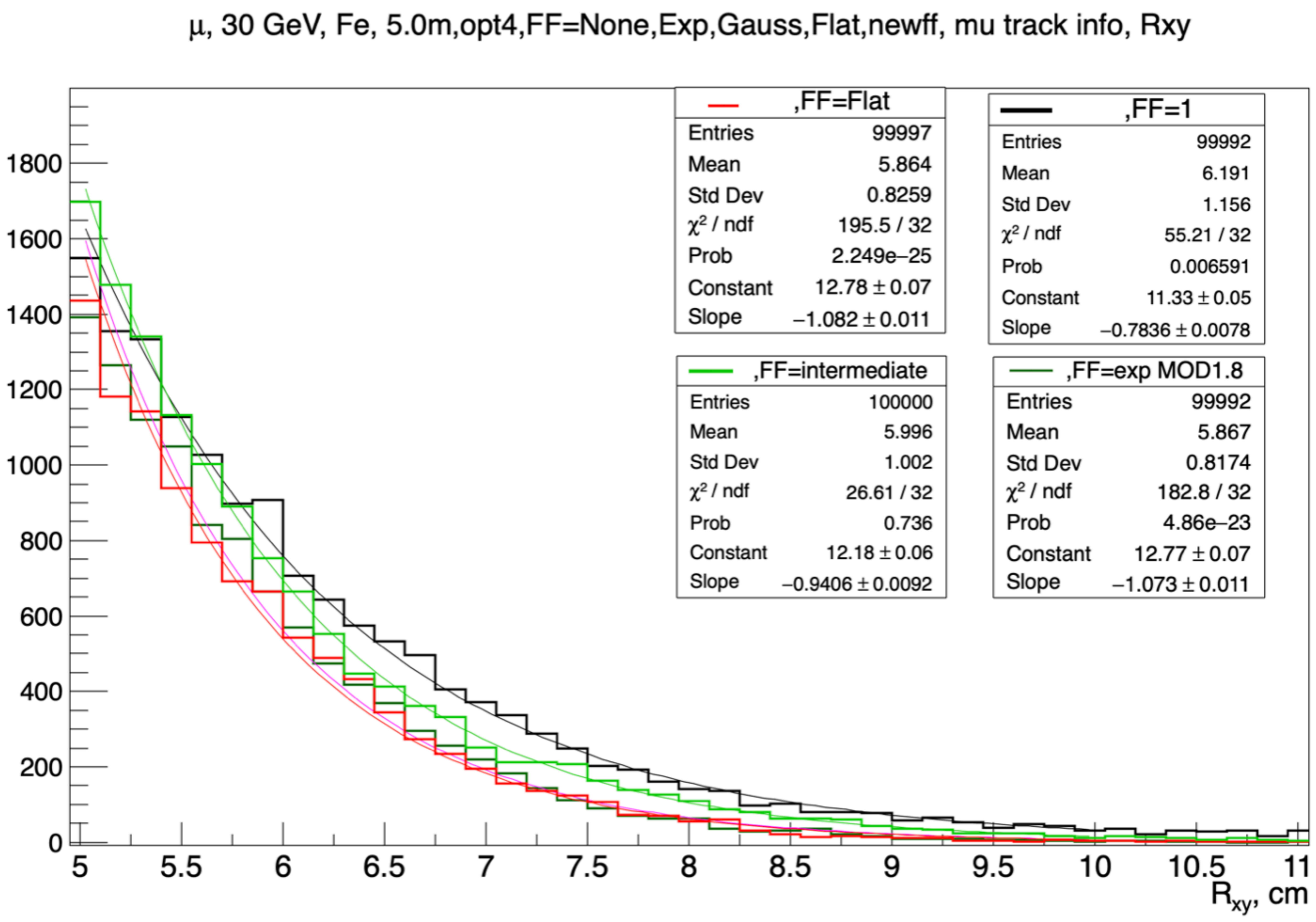
The accuracy with which we can distinguish between red and green distributions:

σ = 0.45 (3m) **σ = 0.82** (5m)

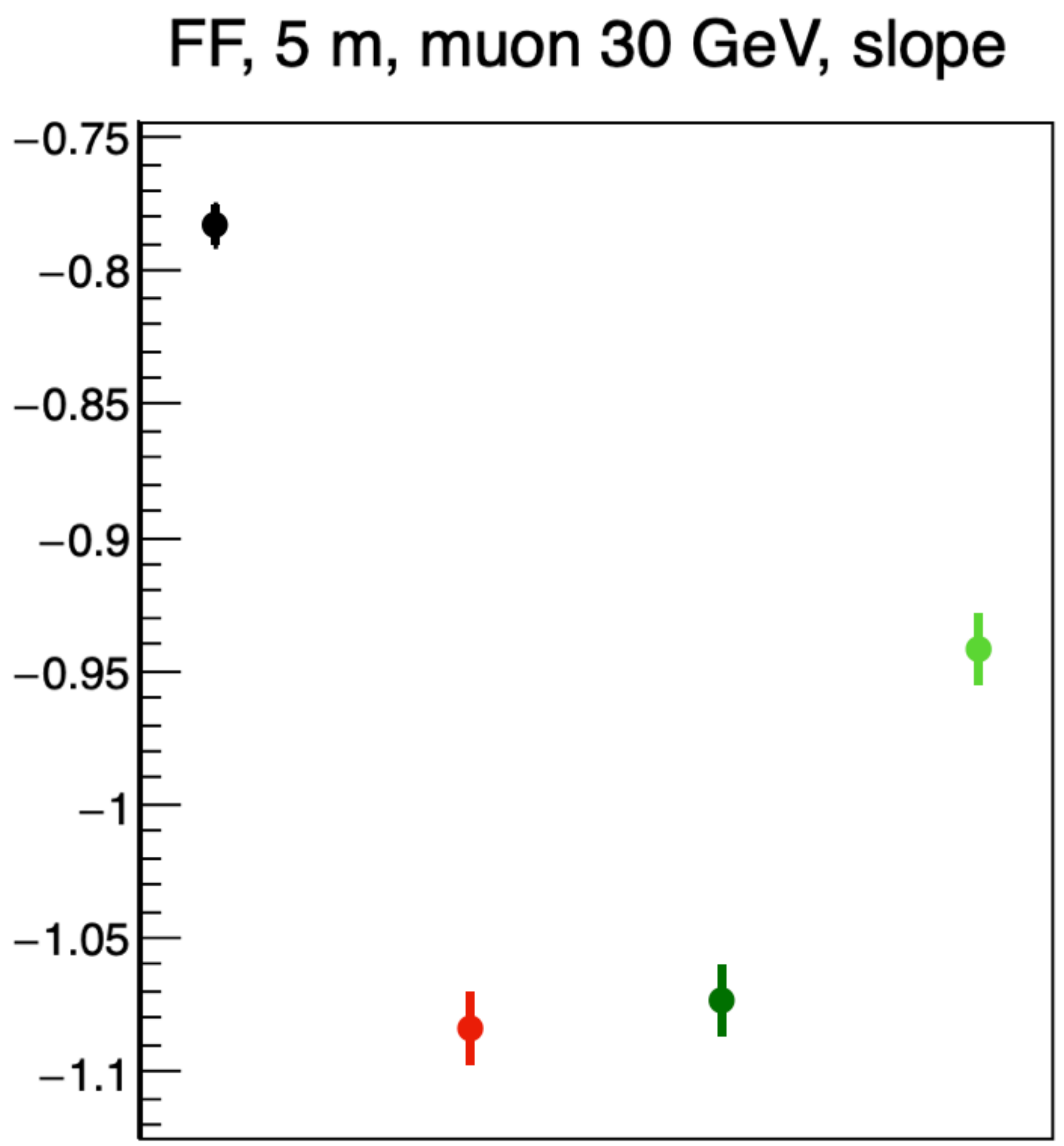




Intermediate distribution for artificial form factors (green points)



Light green and red differ:
σ = 7
there is a possibility to distinguish the intermediate distributions



Summary

1. It is possible that the form factors used in GEANT4 for iron at high energies are far from real;
2. There is no experimental data on the passage of high-energy muons (>10 GeV) through an iron absorber;
3. As a result of the test beam experiment it will be possible to reduce the systematic error in the design of the muon shield using realistic description of form factor.

Thank you !

Muons in the SHiP muon shield

At first stage we considered muons with energies 10-355 GeV which entered muon shield

Left: stopping (or exiting) points for muons in 30m iron shield.
Right: spatial (transverse) muon distributions in iron shield at the exit (30 m).

Muons scattering with different form-factors have various spatial distribution.