Geant4 Hadron Elastic Scattering Model Comparison

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Abstract

Existing Geant4 hadron elastic scattering models are compared with experimental data in sampling mode.

1 GEANT4 hadron elastic scattering models

GEANT4 has four models for hadron-nuclear elastic scattering.

1. GHEISHA elastic model is implemented in G4LElastic class using simplified parametrization (J. Ranft, 1973) in terms of invariant transfered momentum $t < 0$. For atomic weight, $A < 62$:

$$\frac{d\sigma_{el}}{d\Omega} = A^{1.63}\exp(-14.5\,A^{0.66\,t}) + 1.4\,A^{0.33}\exp(10\,t),$$

   and for $A \geqslant 62$:

$$\frac{d\sigma_{el}}{d\Omega} = A^{1.33}\exp(-60.0\,A^{0.33\,t}) + 0.4\,A^{0.4}\exp(10\,t),$$

2. CHIPS approach (G4QElastic) is based on a more dedicated parametrization of invariant differential cross section: $d\sigma_{el}/dt$, $\sigma_{el,>t}$, and $\sigma_{el,>0} = \sigma_{el}$.
3. Coherent elastic model (G4ElasticHadrNucleusHE) utilizes the Glauber approach, when a nucleus is considered as a set of $\sim A$ nucleons.

4. The diffuse model (G4DiffuseElastic) is based on optical approach when a nucleus is considered as a drop of absorptive and refractive medium:

$$\frac{d\sigma_{el}}{d\Omega} = R^2 F_d^2(k\,d\,\theta)\left\{\frac{J_1^2(k\,R\,\theta)}{\theta^2} + \left[(\gamma\,k)^2 + (\delta\,k^2\,\theta)^2\right] J_0^2(k\,R\,\theta)\right\}, \quad d\Omega = 2\pi\sin\theta\,d\theta,$$

where γ is the refraction parameter, δ is parameter of spin-orbital interaction, R and d are parameters for the Woods-Saxon type density:

$$\rho(r) = \rho_o\left\{1 + \exp\left[\frac{(r-R)}{d}\right]\right\}^{-1} \rightarrow F_d(k\,d\,\theta) = \frac{\pi\,k\,d\,\theta}{\sinh(\pi\,k\,d\,\theta)}.$$

k is the projectile wave vector (in GEANT4 $k = p/\hbar\,c$, where p is the projectile momentum multiplied by c), F_d is the dumping factor. The model can be modified for charged ze particles:

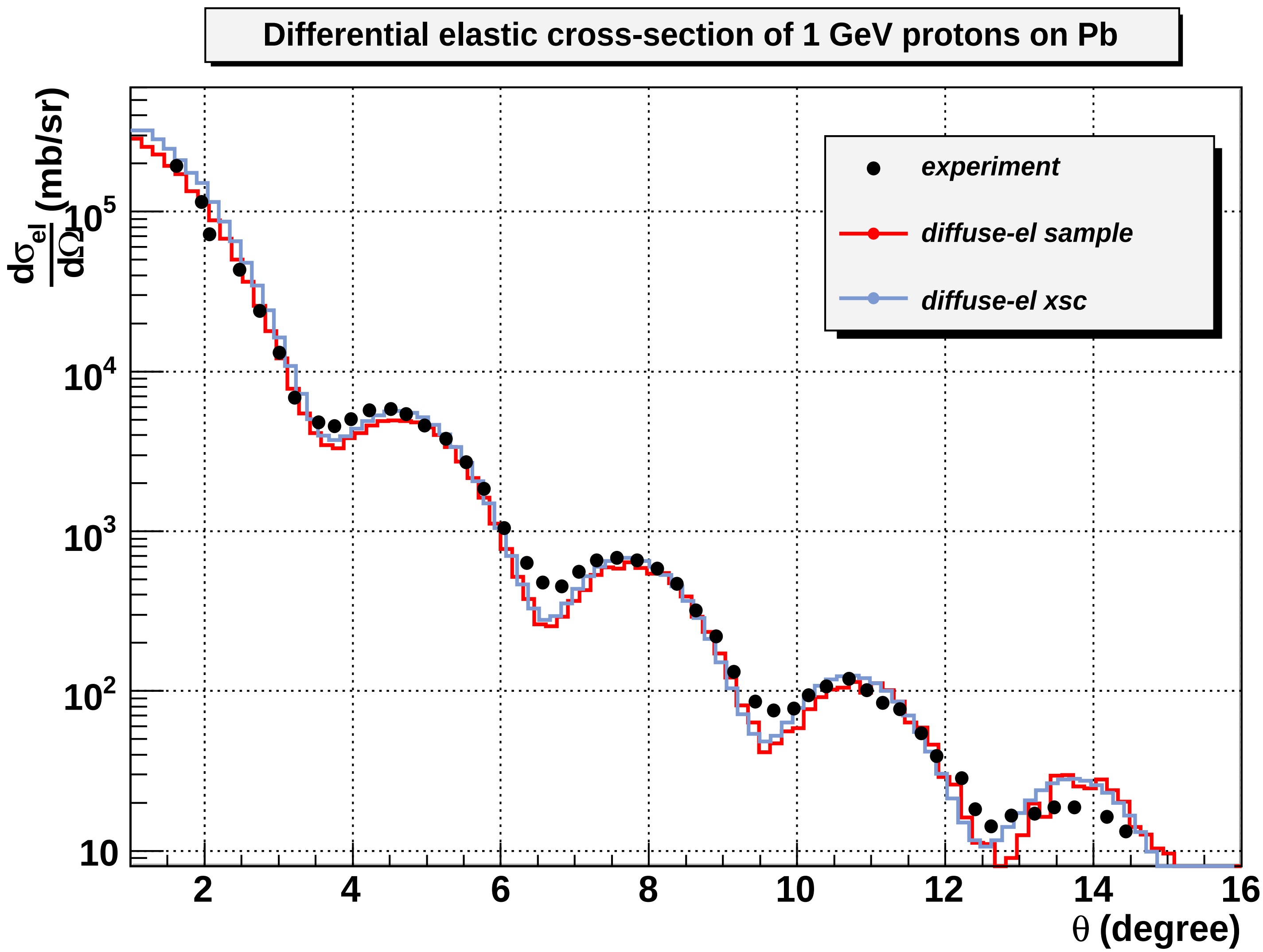
$$\gamma\,k \rightarrow \gamma\,k + \frac{n}{2kR}\left[\sin^2(\frac{\theta}{2}) + A_m\right]^{-1}, \quad A_m = \frac{1.13 + 3.76n^2}{(1.77ka_oZ^{-1/3})^2}, \quad n = \frac{\alpha z Z}{\beta} \ll kR,$$

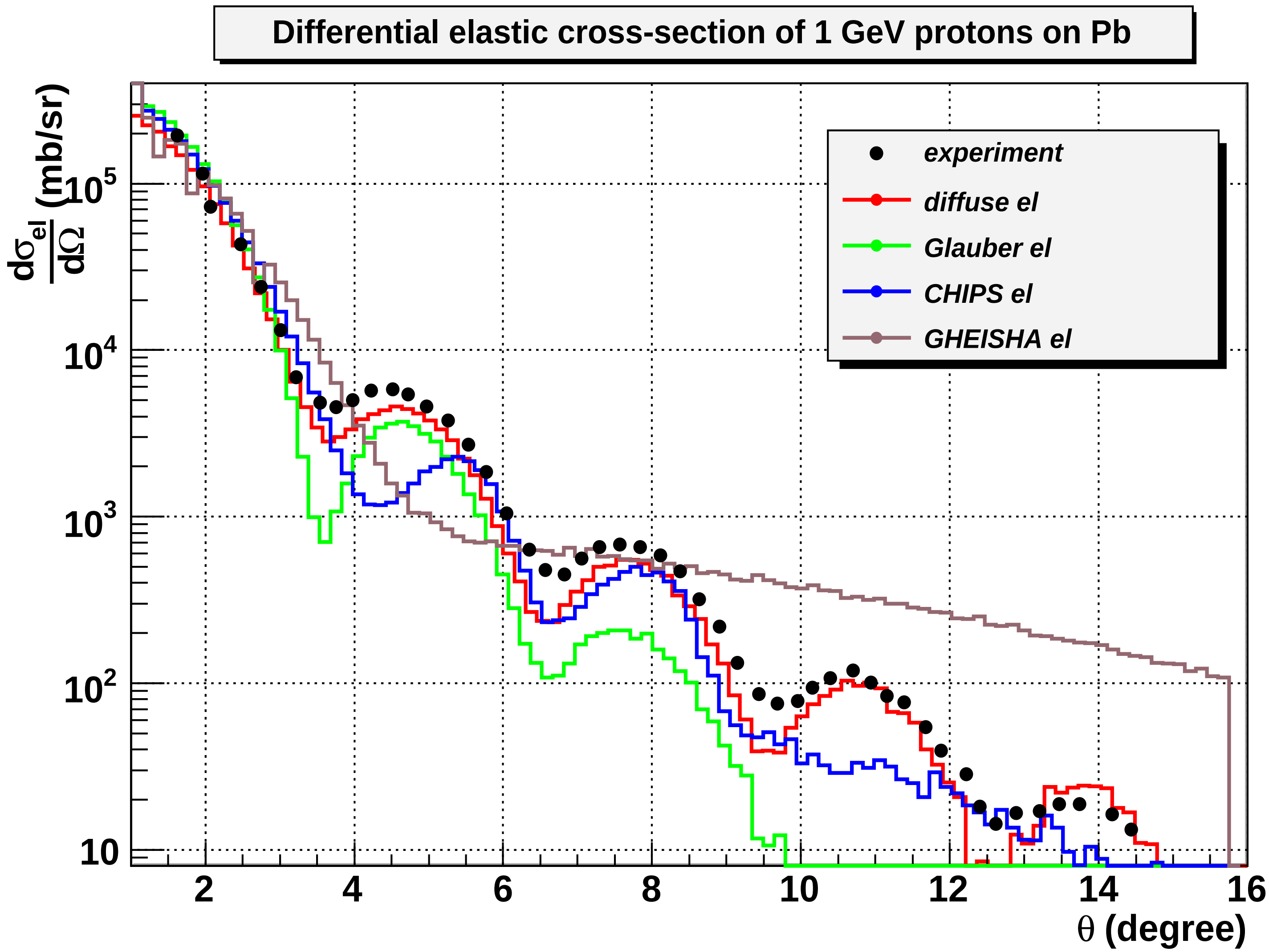
where a_o is the Bohr radius, and Z is the atomic number.

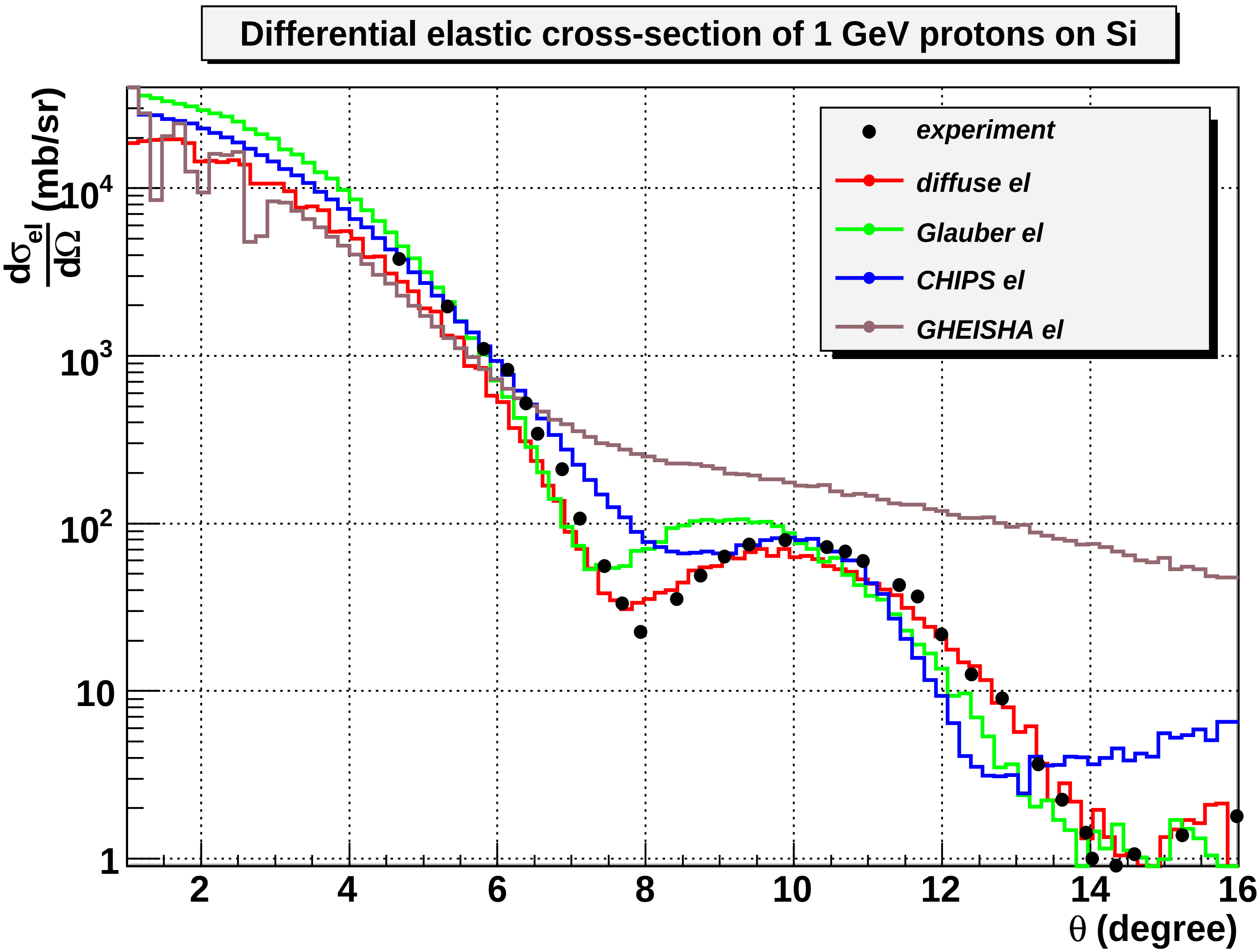
2 Sampling test

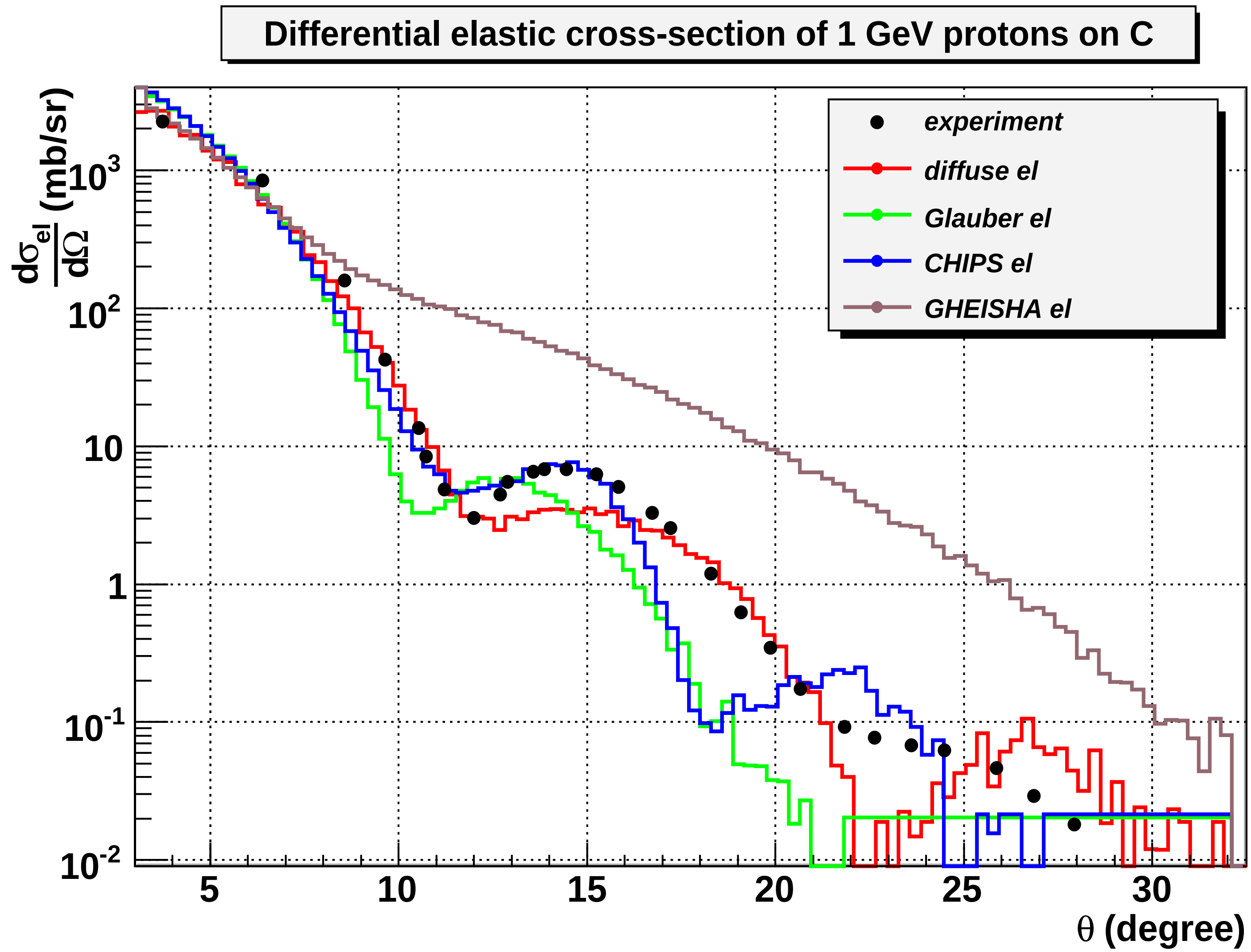
Sampling was performed in terms of t, invariant momentum transfer. Then, if needed the t values were transformed to scattering angles in C- or L- systems. The typical statistics was $\sim 10^6$ events.

```
tDif         = diffelastic->SampleTableT(theParticleDefinition, ptot, Z, A);
thetaLabDif =  SampleThetaLab( theDynamicParticle, m2, tDif );

tGhe         = g2*gElastic->SampleT(tmax/g2,m1,m2,G4double(A));
thetaLabGhe = SampleThetaLab( theDynamicParticle, m2, tGhe );

tGla         = hElastic->SampleT(theParticleDefinition,plab,Z,A);
thetaLabGla = SampleThetaLab( theDynamicParticle, m2, tGla );

G4VQCrossSection* qCManager   = G4QElasticCrossSection::GetPointer();
cs           = qCManager->GetCrossSection(false,plab,Z,N,projPDG); cs *= 1.;
tChi         = qCManager->GetExchangeT(Z,N,projPDG);
thetaLabChi = SampleThetaLab( theDynamicParticle, m2, tChi );
```

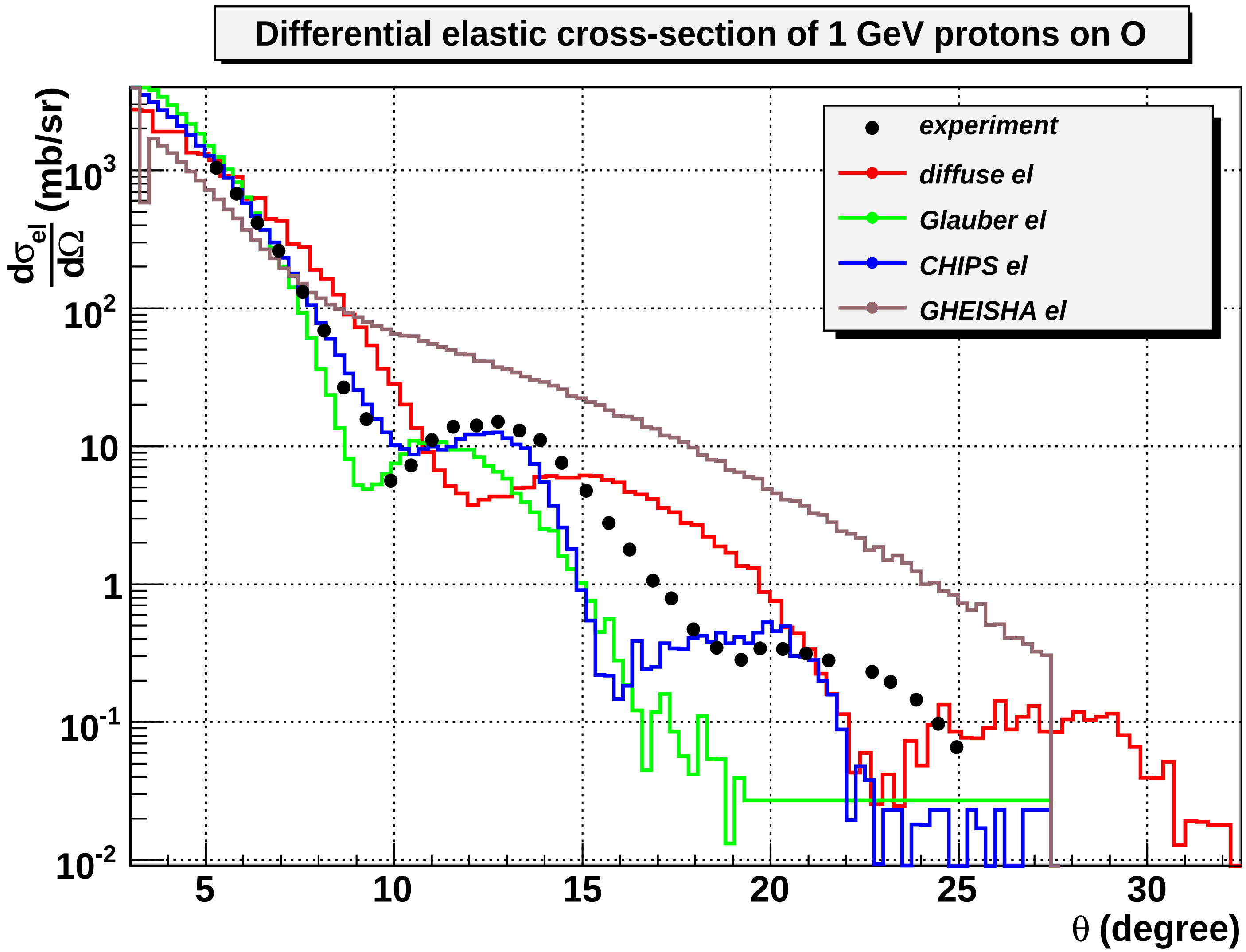

Differential elastic cross-section of 1 GeV protons on Pb
dσel/dΩ (mb/sr)
10
10²
10³
10⁴
10⁵
2
4
6
8
10
12
14
16
θ (degree)
experiment
diffuse-el sample
diffuse-el xsc


Differential elastic cross-section of 1 GeV protons on Pb
dσel/dΩ (mb/sr)
10
10^2
10^3
10^4
10^5
2
4
6
8
10
12
14
16
θ (degree)
experiment
diffuse el
Glauber el
CHIPS el
GHEISHA el

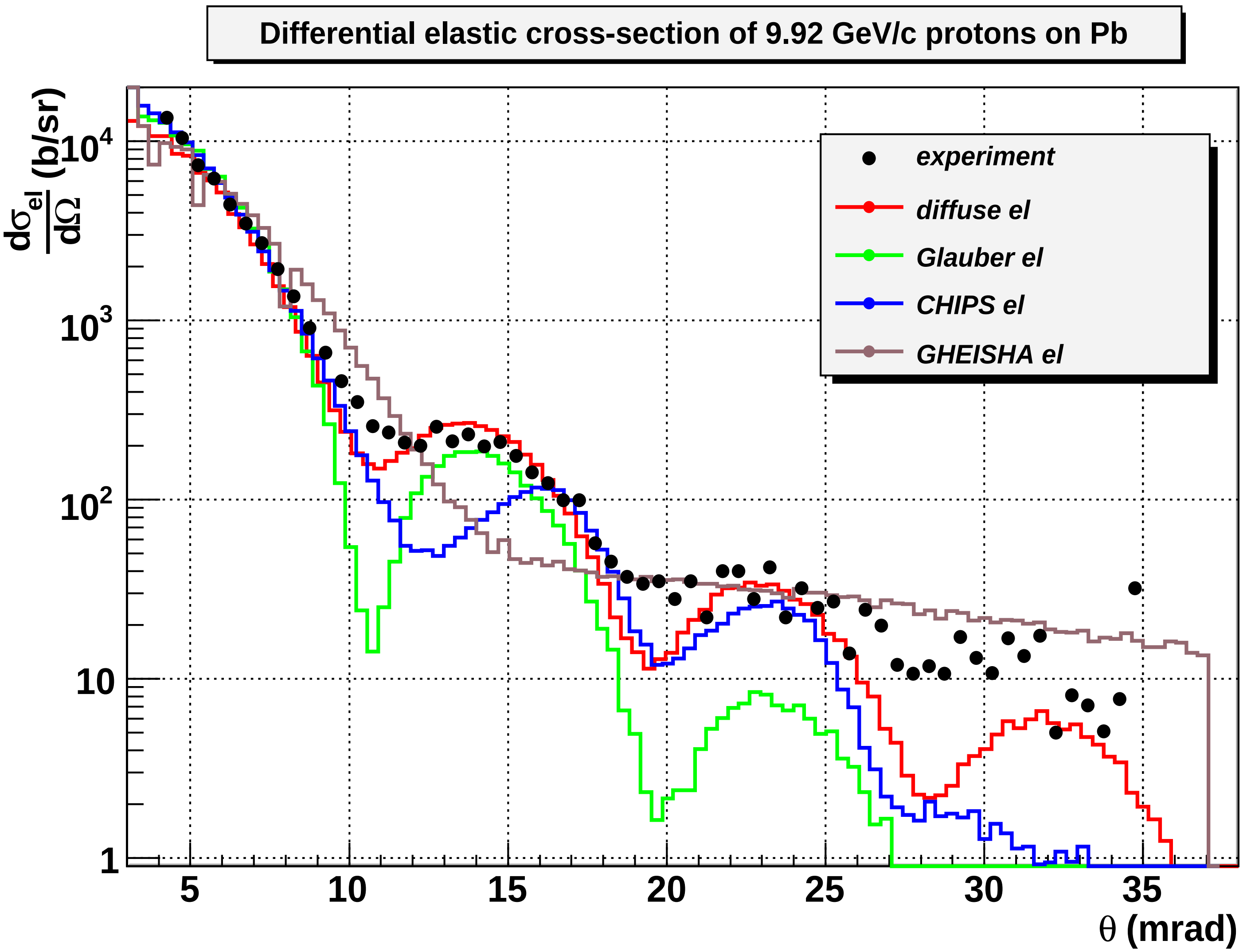

Differential elastic cross-section of 1 GeV protons on Si
experiment
diffuse el
Glauber el
CHIPS el
GHEISHA el
$\frac{d\sigma_{el}}{d\Omega}$ (mb/sr)
10^4
10^3
10^2
10
1
2
4
6
8
10
12
14
16
θ (degree)

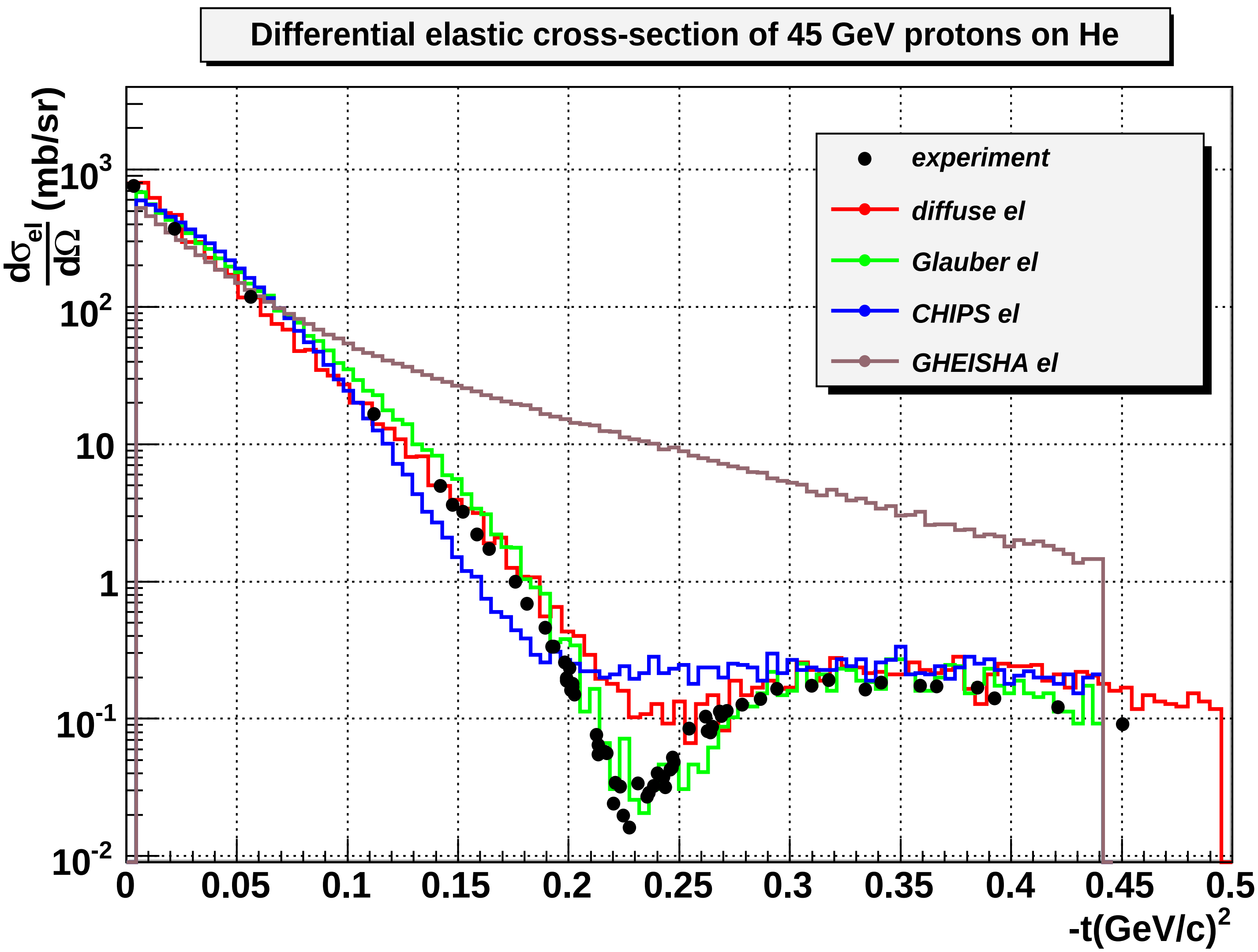


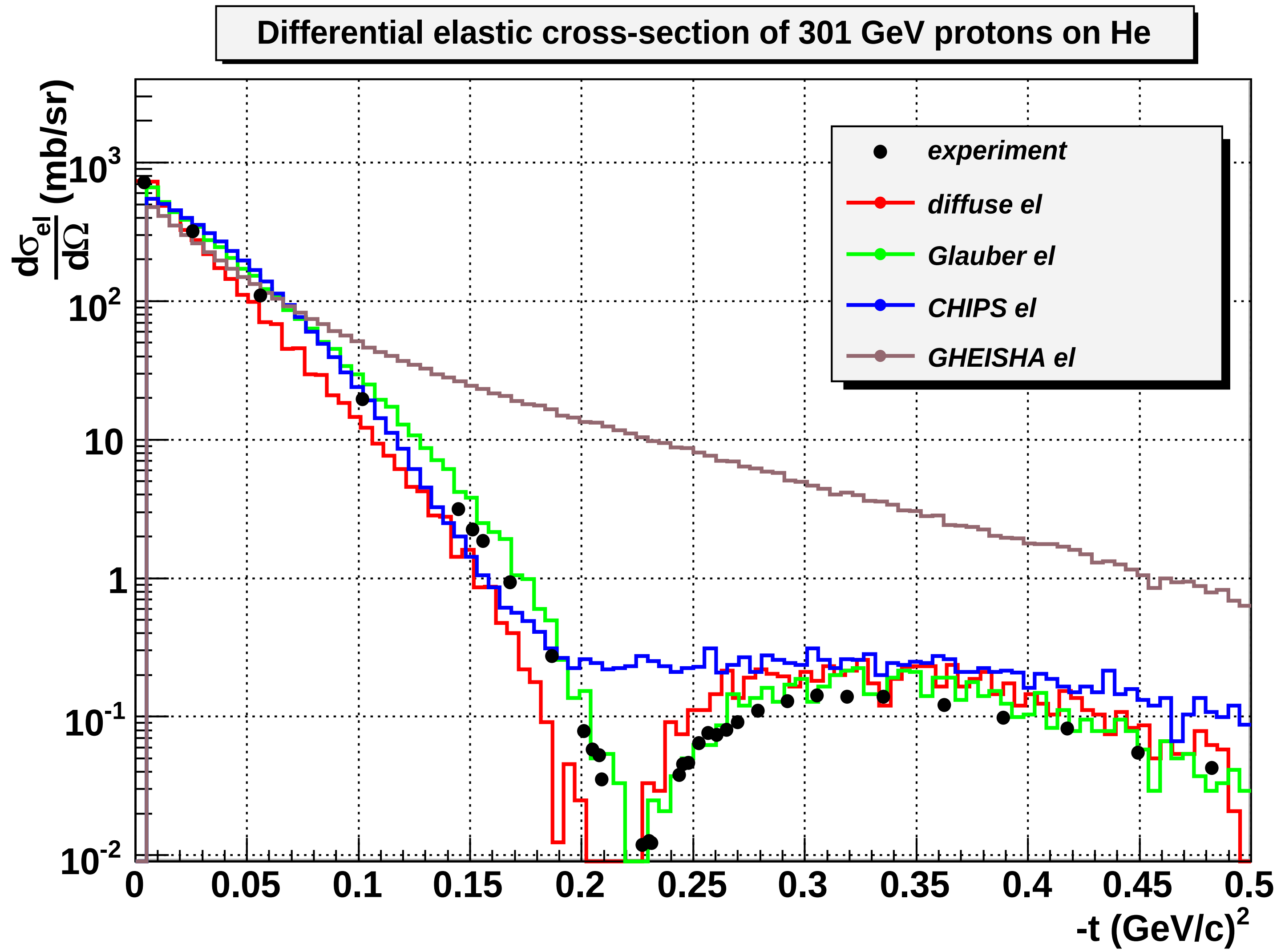
Differential elastic cross-section of 1 GeV protons on C
experiment
diffuse el
Glauber el
CHIPS el
GHEISHA el
dσel/dΩ (mb/sr)
10^3
10^2
10
1
10^-1
10^-2
5
10
15
20
25
30
θ (degree)

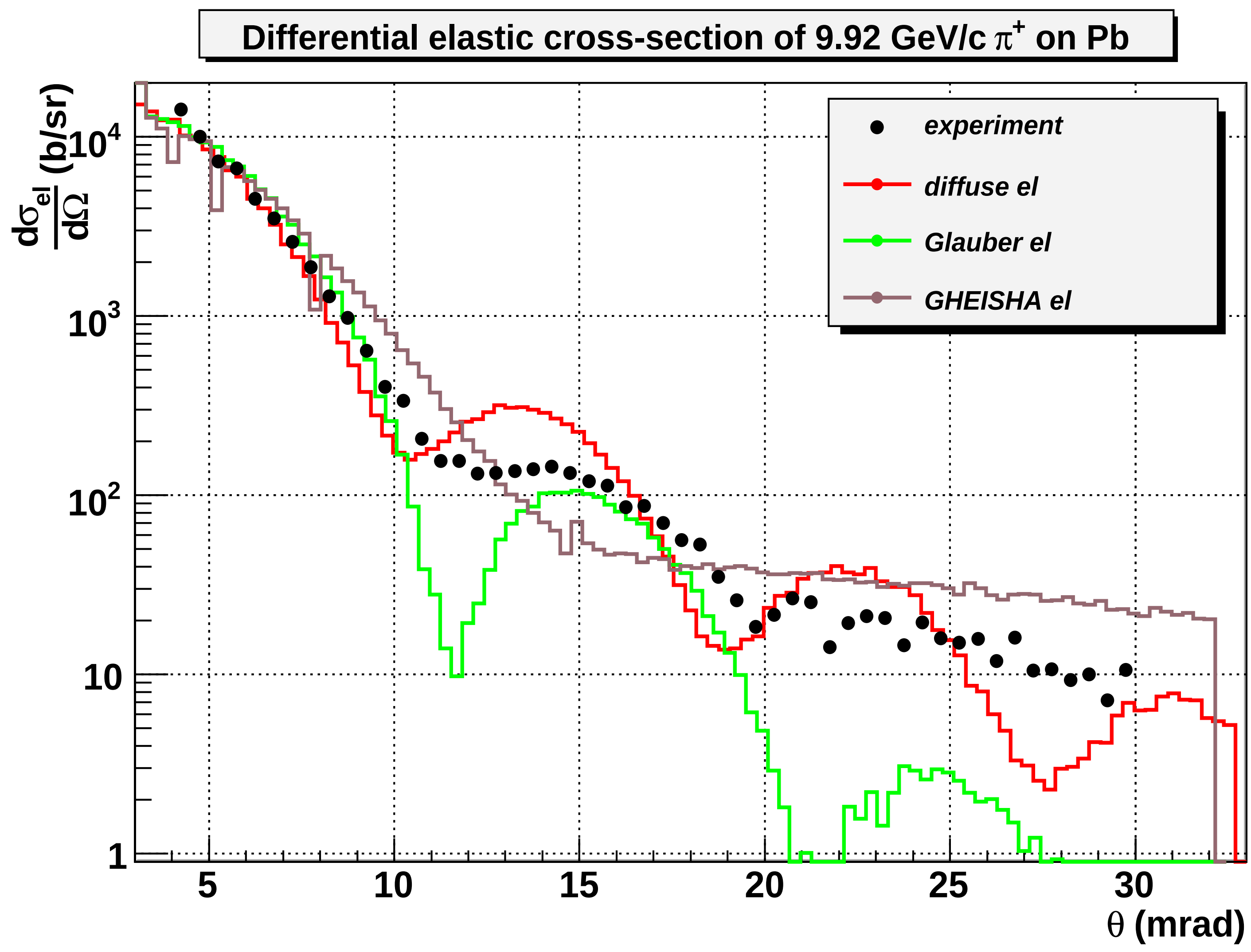


Differential elastic cross-section of 1 GeV protons on O
experiment
diffuse el
Glauber el
CHIPS el
GHEISHA el
dσ_el/dΩ (mb/sr)
10^3
10^2
10
1
10^-1
10^-2
5
10
15
20
25
30
θ (degree)

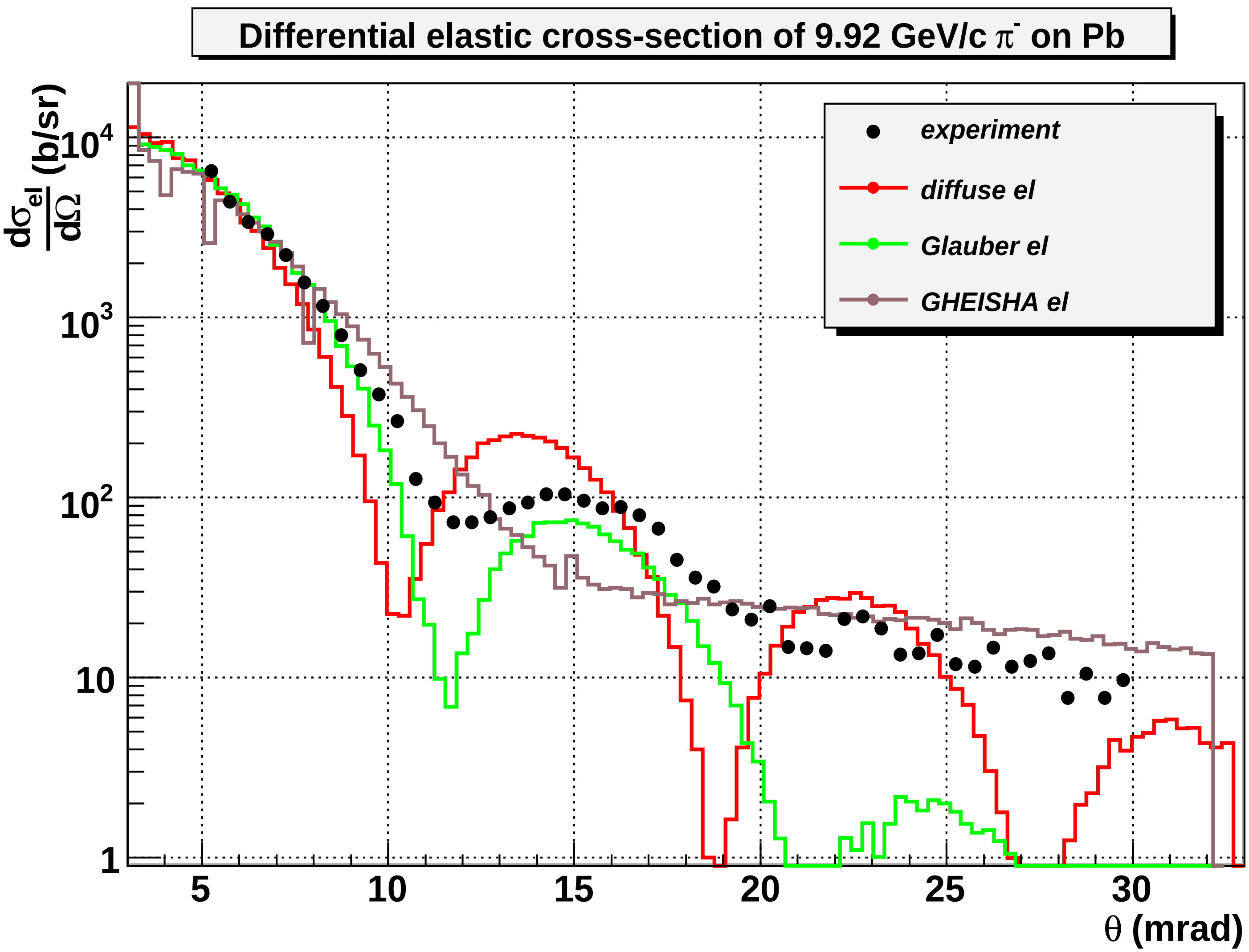

Differential elastic cross-section of 9.92 GeV/c protons on Pb
$\frac{d\sigma_{el}}{d\Omega}$ (b/sr)
θ (mrad)
experiment
diffuse el
Glauber el
CHIPS el
GHEISHA el
1
10
10^2
10^3
10^4
5
10
15
20
25
30
35

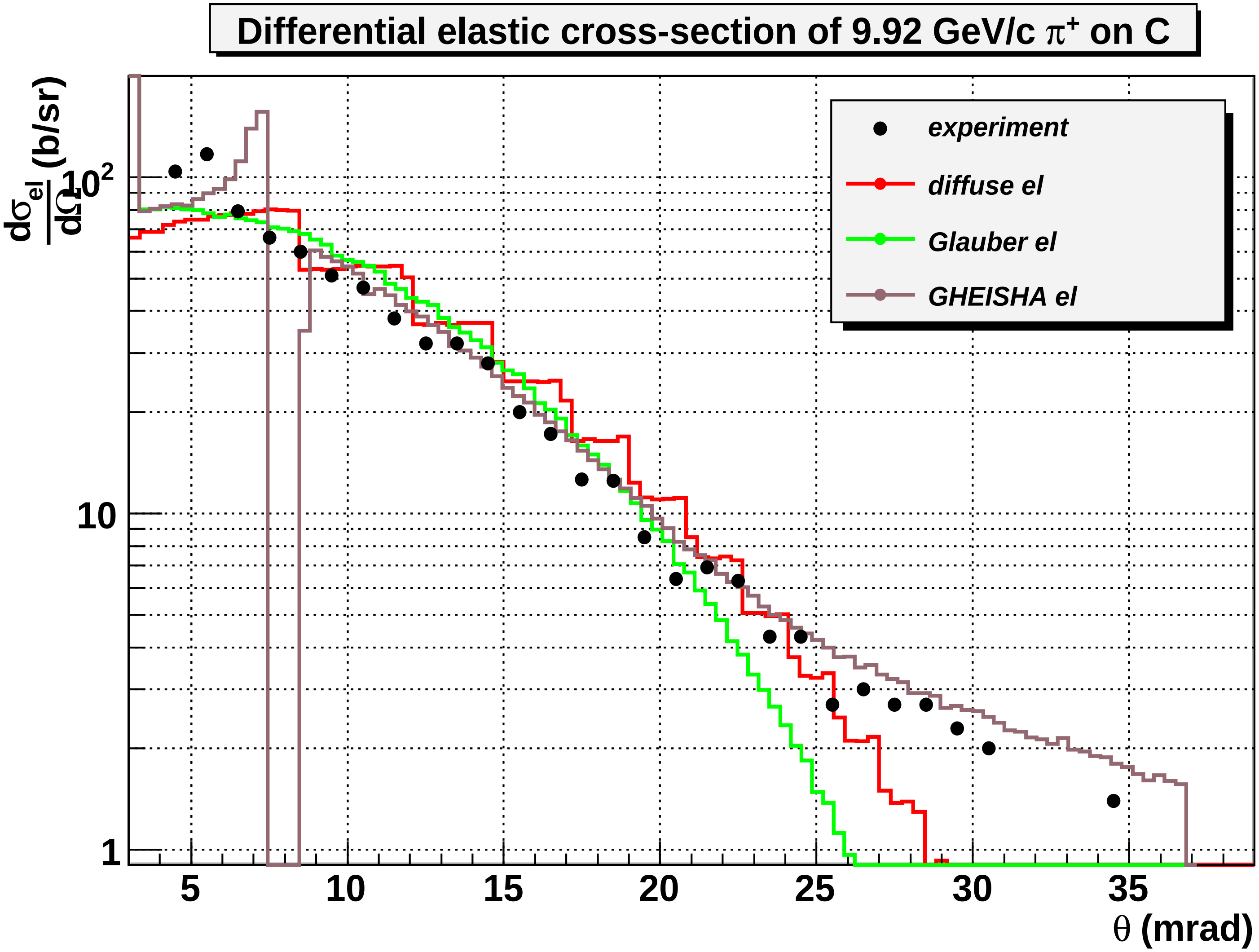

Differential elastic cross-section of 45 GeV protons on He
experiment
diffuse el
Glauber el
CHIPS el
GHEISHA el
dσel/dΩ (mb/sr)
-t(GeV/c)²
10³
10²
10
1
10⁻¹
10⁻²
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5


Differential elastic cross-section of 301 GeV protons on He
dσel/dΩ (mb/sr)
10^3
10^2
10
1
10^-1
10^-2
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
-t (GeV/c)^2
experiment
diffuse el
Glauber el
CHIPS el
GHEISHA el



Differential elastic cross-section of 9.92 GeV/c π+ on Pb
dσel/dΩ (b/sr)
10^4
10^3
10^2
10
1
5
10
15
20
25
30
θ (mrad)
experiment
diffuse el
Glauber el
GHEISHA el


Differential elastic cross-section of 9.92 GeV/c π⁻ on Pb
dσel/dΩ (b/sr)
10⁴
10³
10²
10
1
5
10
15
20
25
30
θ (mrad)
experiment
diffuse el
Glauber el
GHEISHA el


Differential elastic cross-section of 9.92 GeV/c π+ on C
dσel/dΩ (b/sr)
10²
10
1
5
10
15
20
25
30
35
θ (mrad)
experiment
diffuse el
Glauber el
GHEISHA el

The table of performance (s) of different hadron elastic generators for 1 (or 0.1-10) GeV protons on lead.

Statistics	Diffuse	CHIPS	GHEISHA	Glauber
1 (init tables)	0.84	0	0	1.29
10^6, 1 GeV	3.04	2.35	5.33	2.7
10^6, 0.1-10 GeV	3.41	2.49	5.27	2.76

3 Conclusions

1. GHEISHA hadron elastic scattering describes roughly the first peak only. It describes however $\pi^{\pm}$ data.

2. Diffuse model is in relatively (to other models) good agreement with data.

3. CHIPS shows also quite good agreement with proton data and it is a bit faster (check for generator only).

4. Glauber model is a bit better for energies more than 10 GeV.

5. Performance (in terms of generator) is comparable for all models, except of GHEISHA which is twice more slow.