Verification and development of pA elastic scattering.

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1. **Proton-proton and proton-deuteron elastic scattering**
2. **Proton-helium and proton-beryllium elastic scattering**
3. **Conclusion.**

Approximation of pp elastic scattering

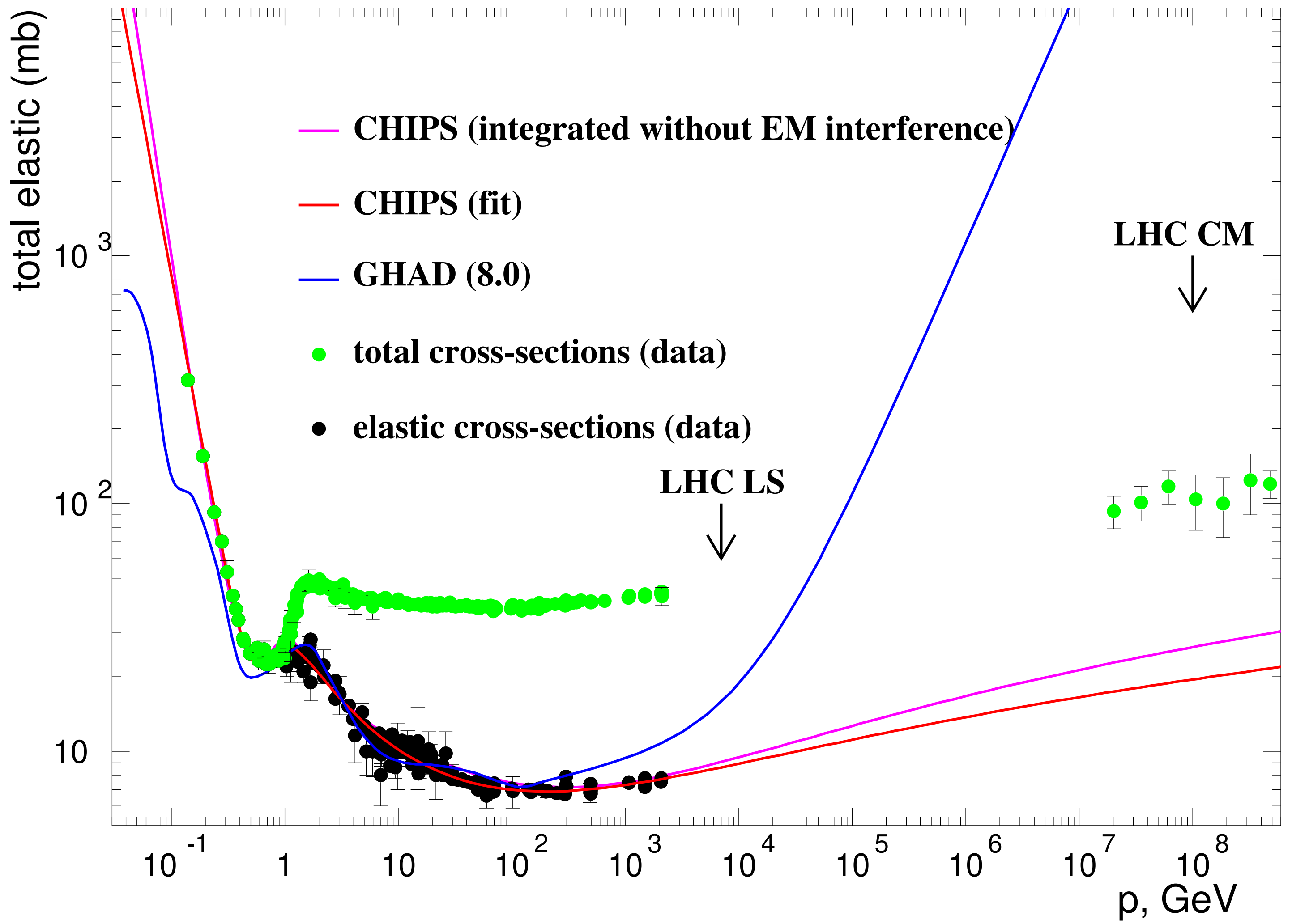
$$\mathbf{\frac{d\sigma}{dt} = \left(A_1 \cdot \frac{e^{-B_1|t|^{1/2}}}{|t|^{1/2}} \right) + A_2 \cdot e^{B_2 t} + A_3 \cdot e^{B_3 t} + A_4 \cdot e^{B_4 t}}$$

1. Interference with electromagnetic scattering.
2. Diffraction on a nucleon.
3. Diffraction on quarks.
4. Diffraction on gluons.

Usually the interference term is not included in the elastic cross section.

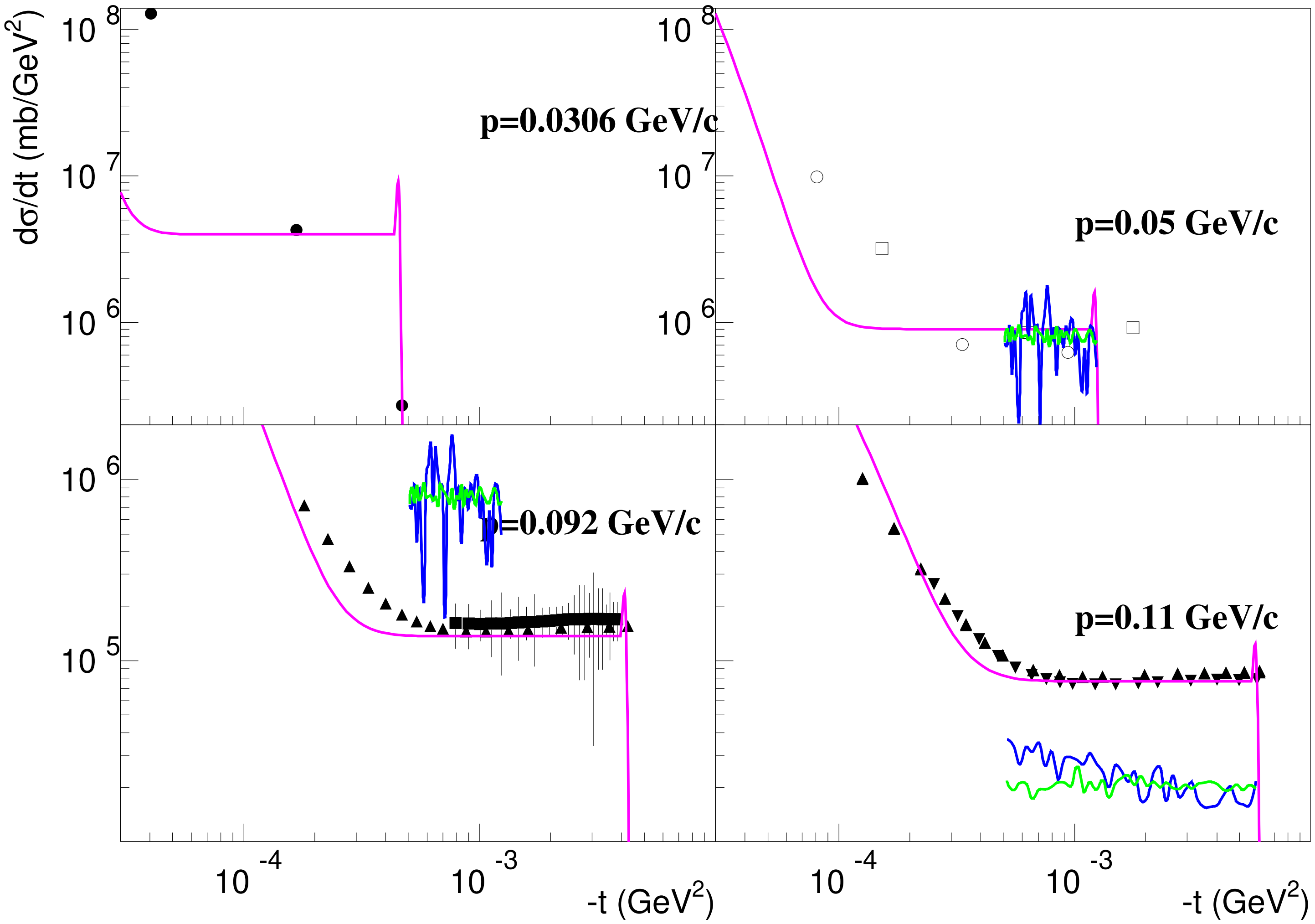
Low energy is usually parameterized by SAID (phase analysis) model.

The red line approximation is CHIPS, green is G4LElastic, blue is G4LElasticB (conserves energy). The last two are practically coinciding.



total elastic (mb)
10 3
10 2
10
CHIPS (integrated without EM interference)
CHIPS (fit)
GHAD (8.0)
total cross-sections (data)
elastic cross-sections (data)
LHC LS
LHC CM
10 -1
1
10
10 2
10 3
10 4
10 5
10 6
10 7
10 8
p, GeV

Verification and development of pA elastic scattering.



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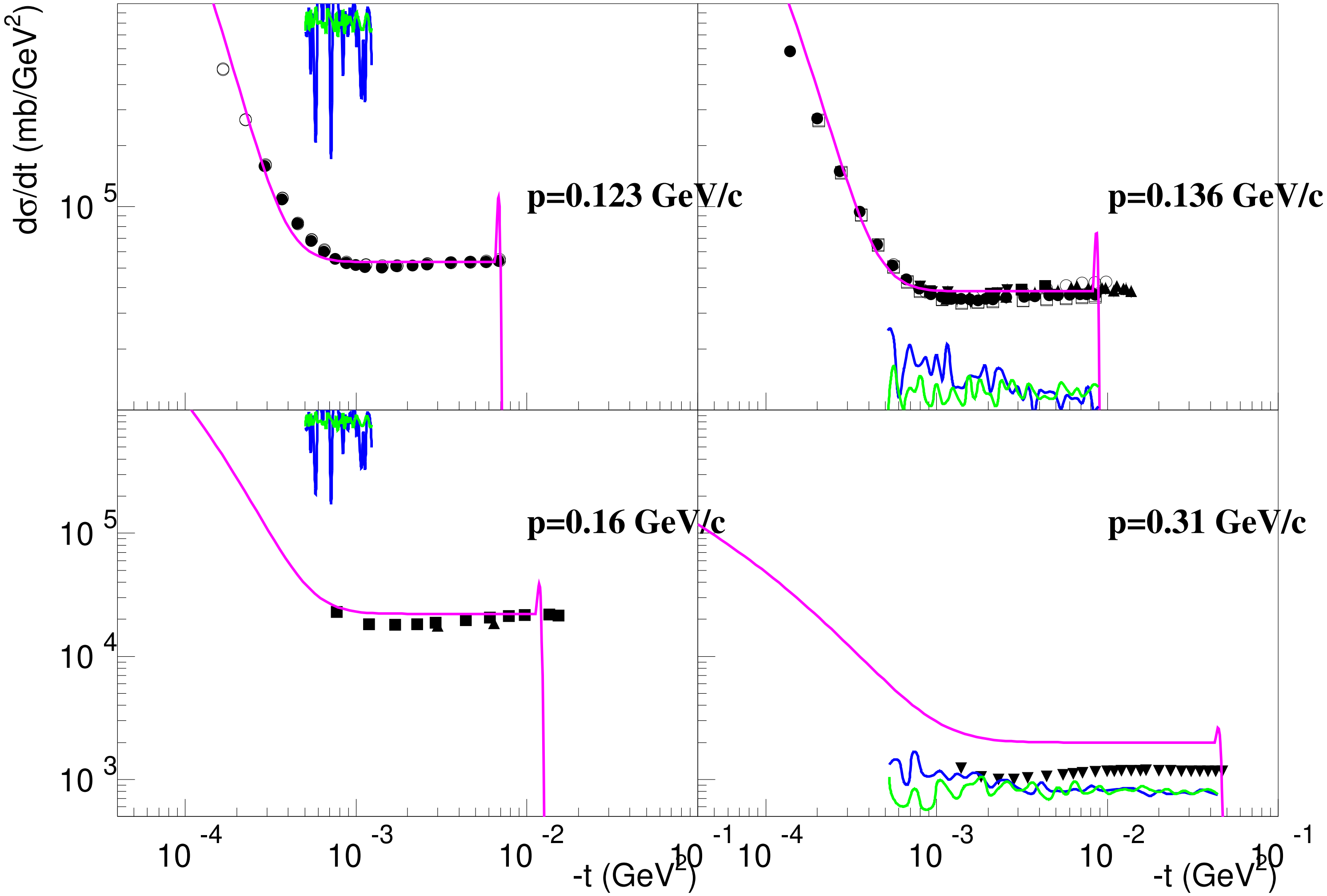
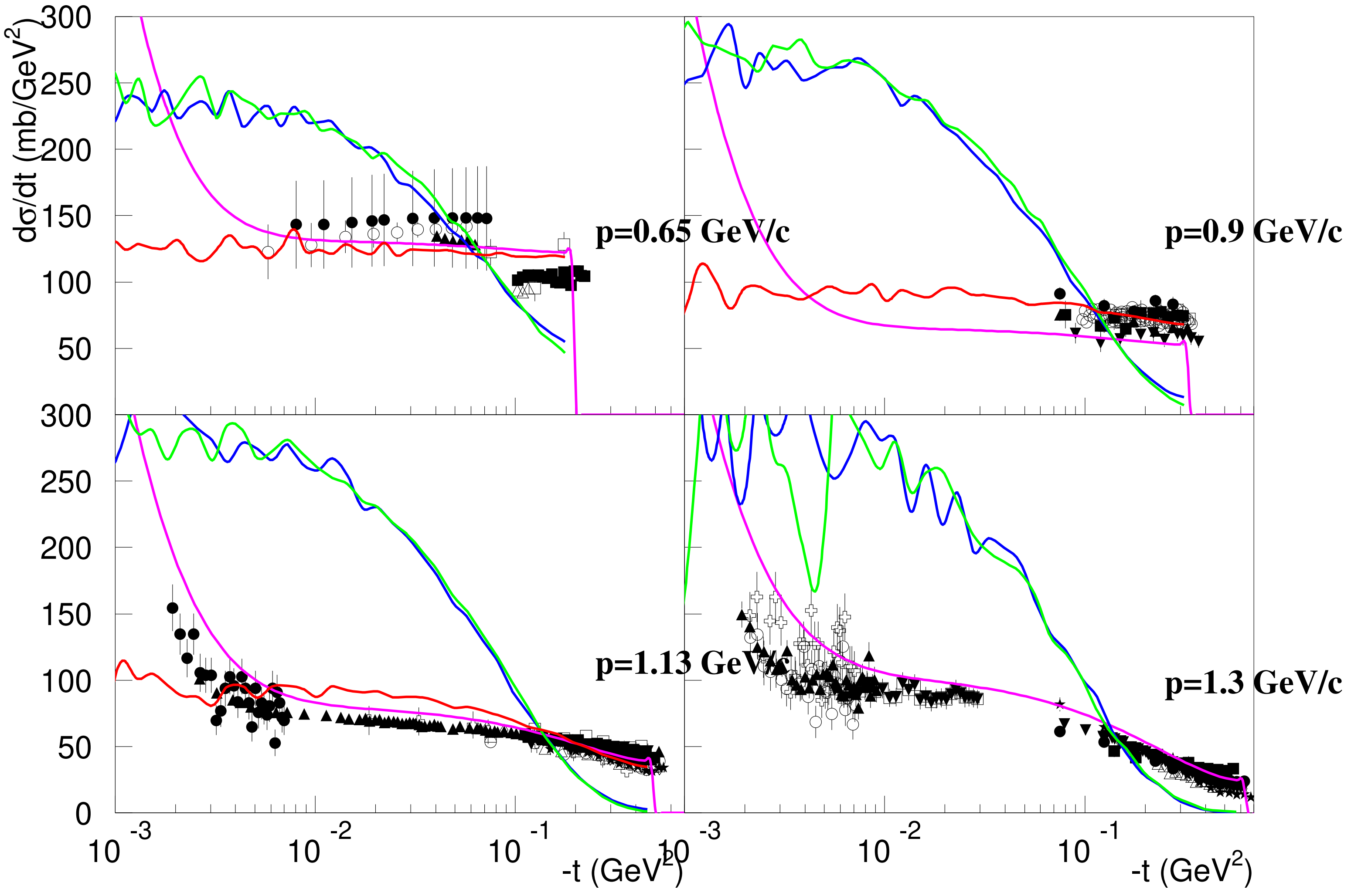


dσ/dt (mb/GeV^2)
p=0.123 GeV/c
p=0.136 GeV/c
p=0.16 GeV/c
p=0.31 GeV/c
10^5
10^4
10^3
10^{-4}
10^{-3}
10^{-2}
10^{-1}
-t (GeV^2)

CERN



dσ/dt (mb/GeV^2)
300
250
200
150
100
50
0
p=0.65 GeV/c
p=0.9 GeV/c
p=1.13 GeV/c
p=1.3 GeV/c
10^{-3}
10^{-2}
10^{-1}
-t (GeV^2)

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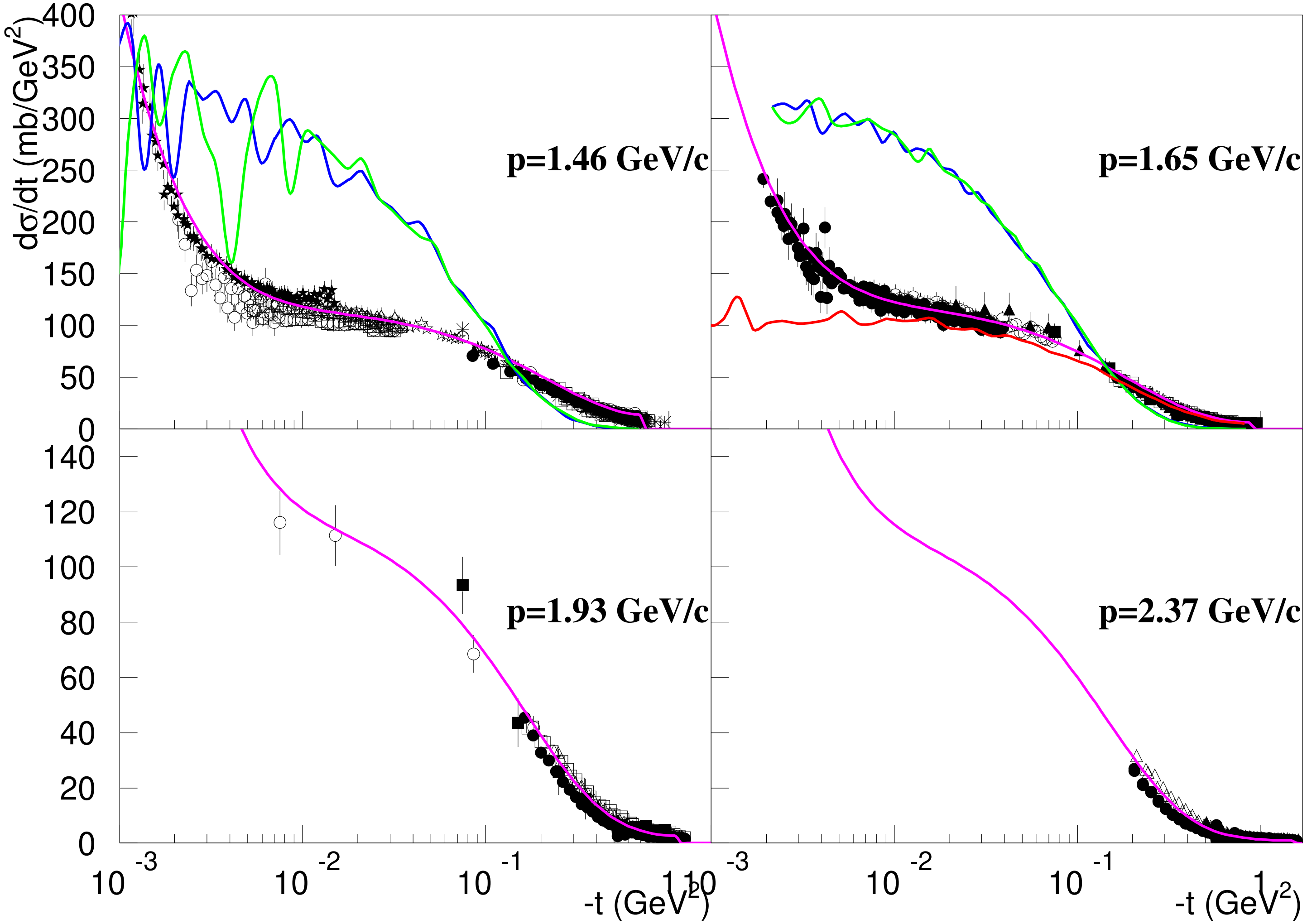
Verification and development of pA elastic scattering.



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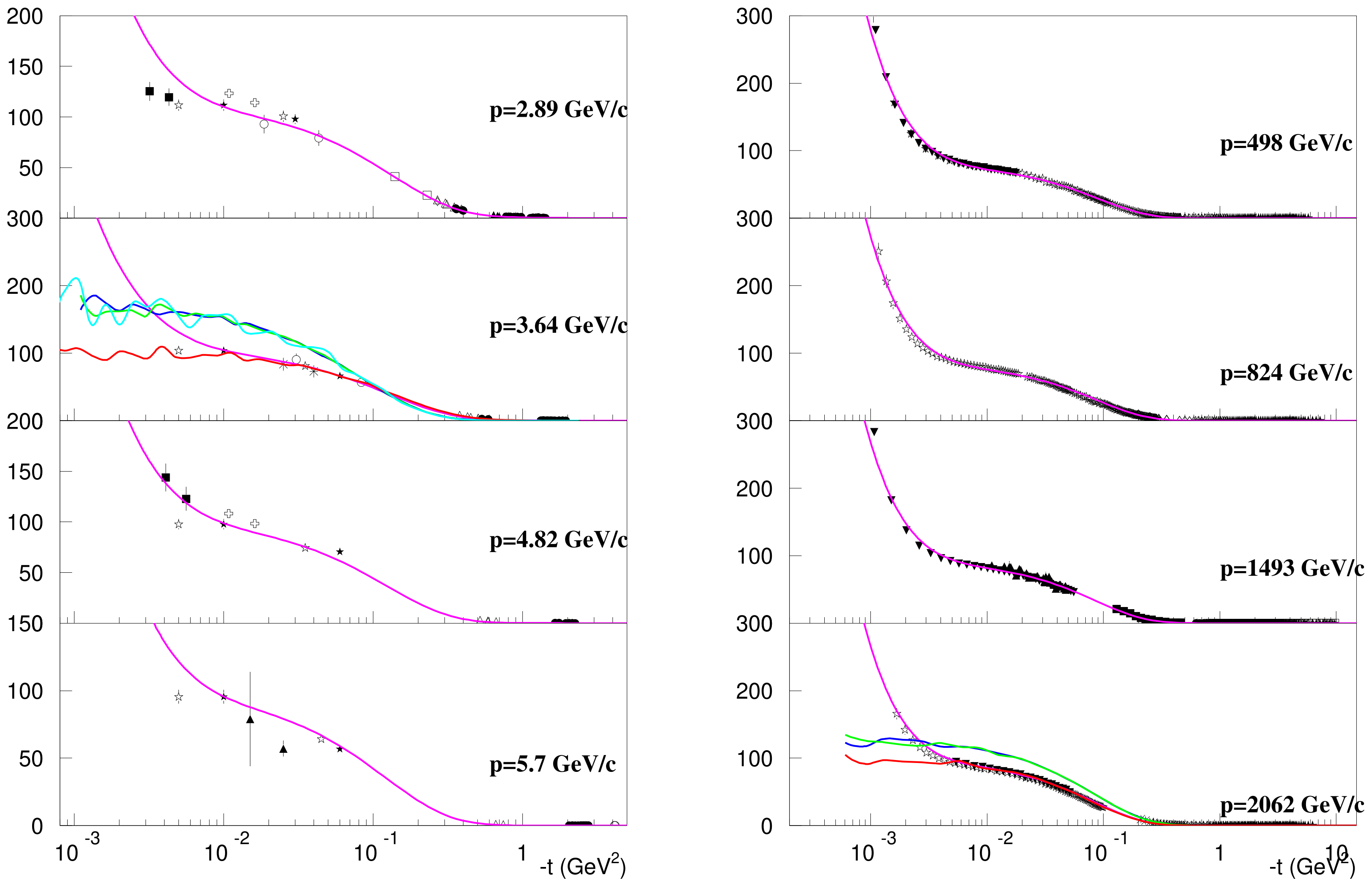
Verification and development of pA elastic scattering.



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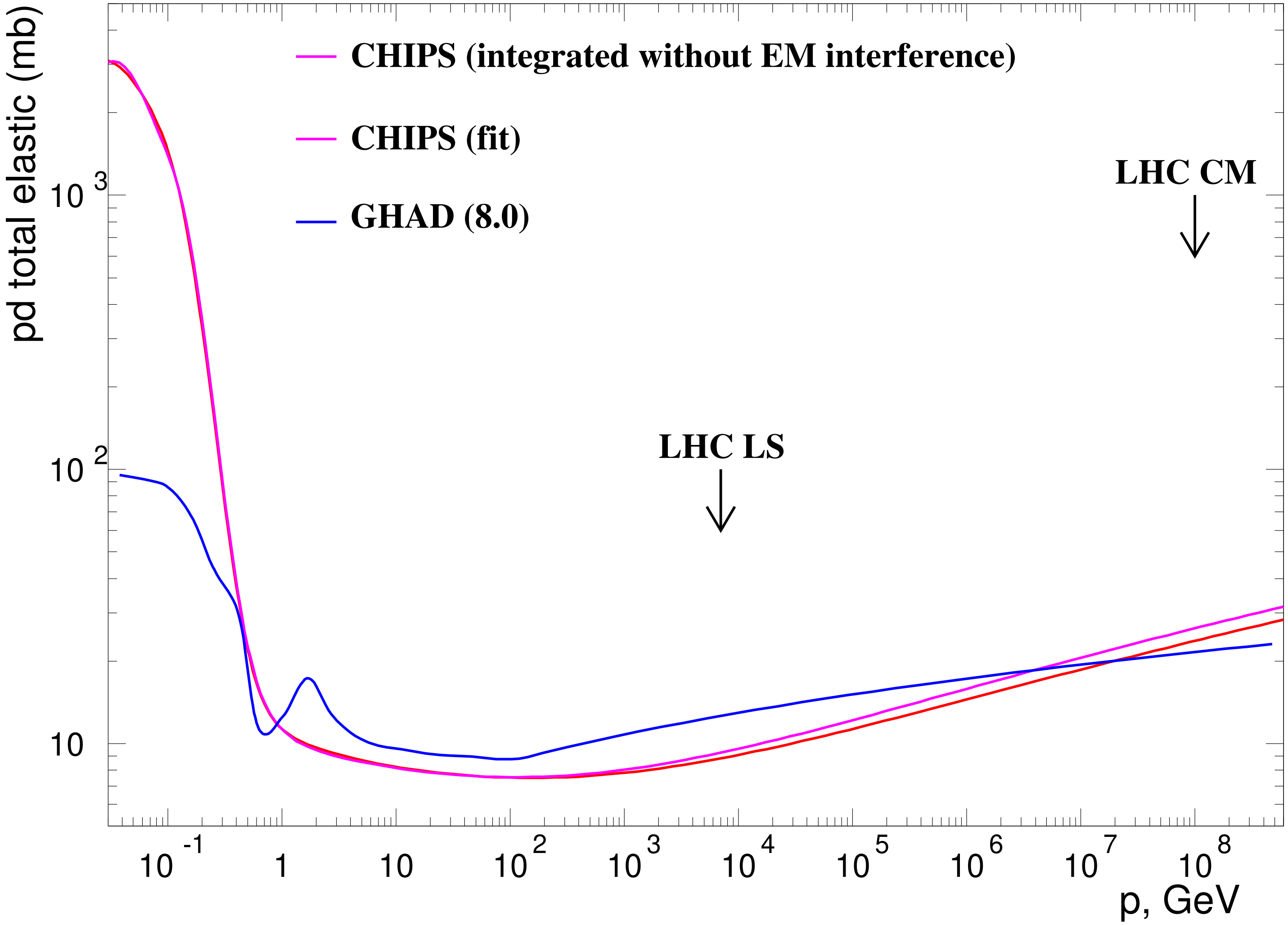
Approximation of pd elastic scattering

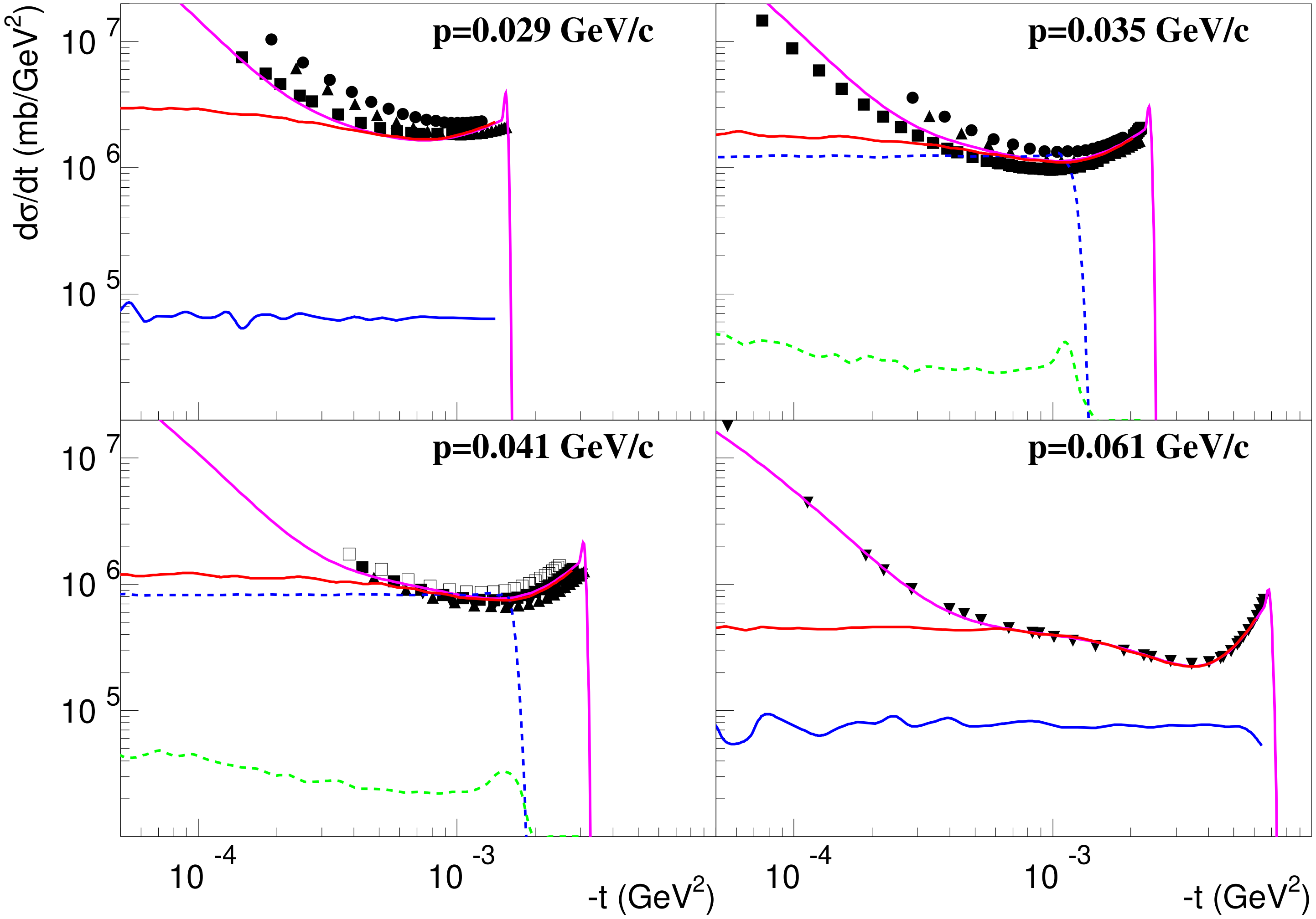
$$\frac{d\sigma}{dt} = A_1 \frac{e^{-B_1|t|^{1/2}}}{|t|^{1/2}} + A_2(B_2 - 2C_2 t)e^{(B_2 - C_2 t)\cdot t} + A_3 e^{B_3 t} + A_4 e^{B_4 u}$$

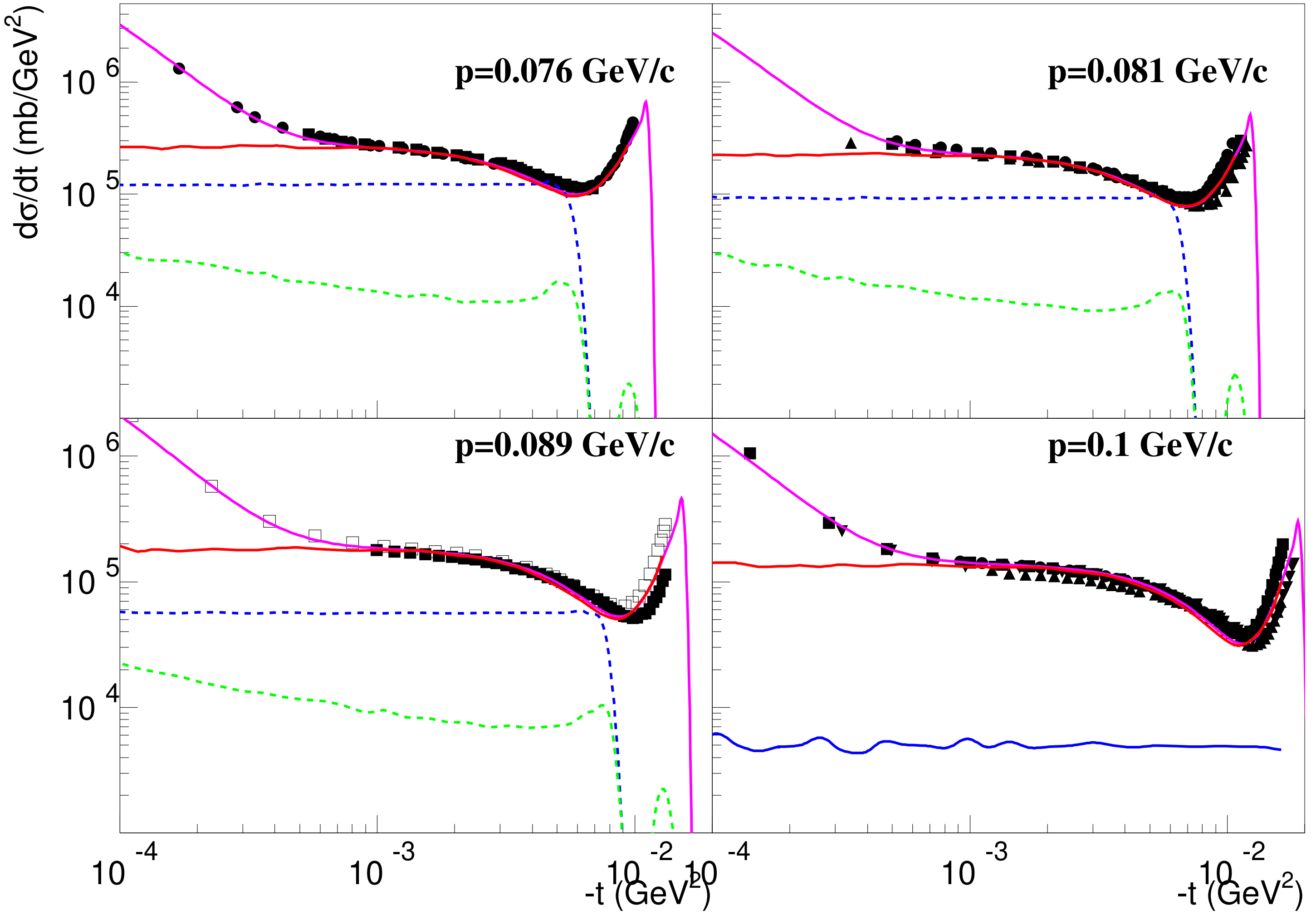
1. Interference with electromagnetic scattering.
2. Diffraction on a nucleon.
3. Diffraction on quarks.
4. Nuclear gloria.

Usually the interference term is not included in the elastic cross section.

The pink line is CHIPS approximation, the red line is simulation by CHIPS, the green line is G4LElastic simulation, the blue line is G4LElasticB simulation (conserves energy). Dashed lines are all events, solid lines are events with a deuteron in the final state.

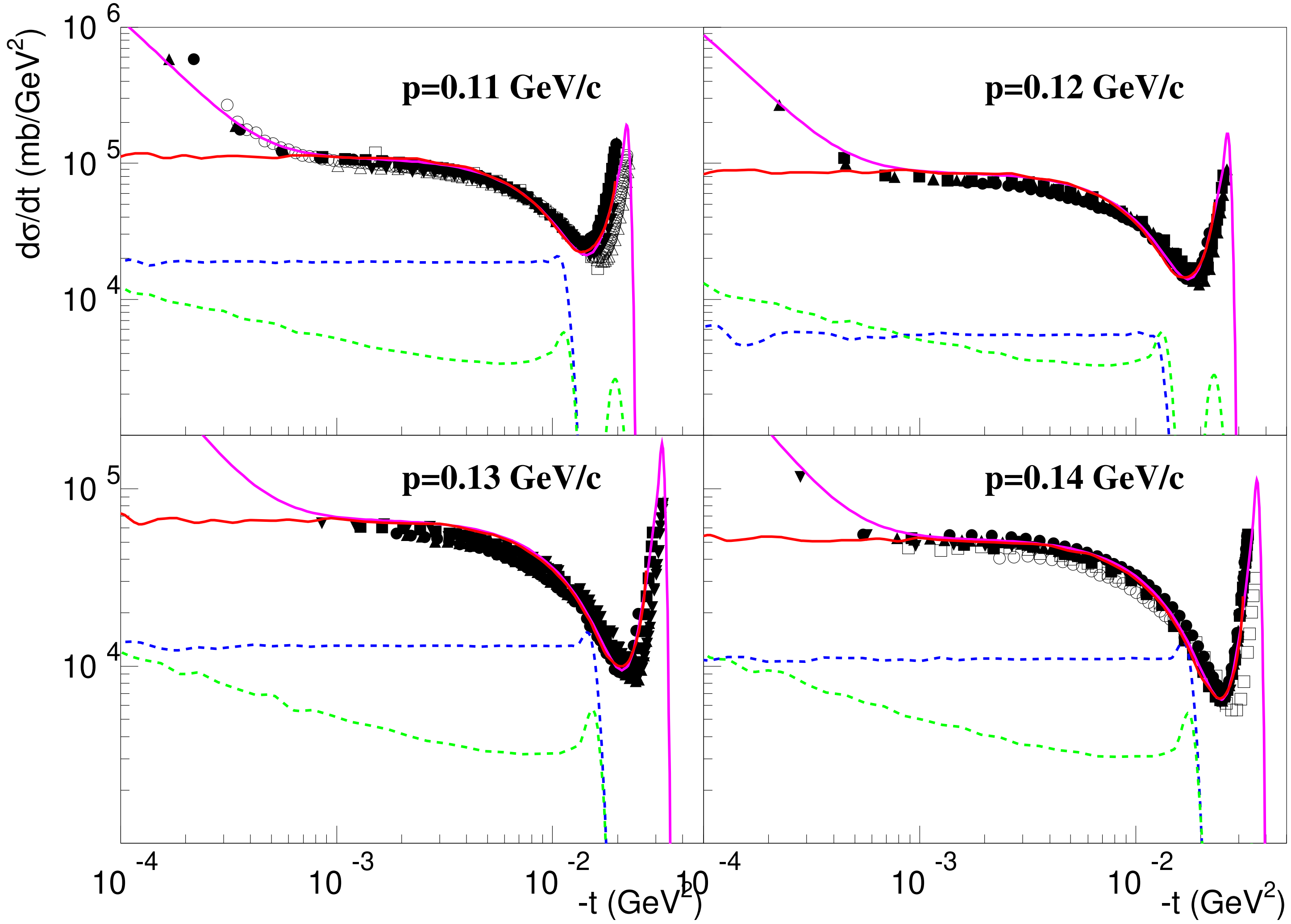

pd total elastic (mb)
10 3
10 2
10
CHIPS (integrated without EM interference)
CHIPS (fit)
GHAD (8.0)
LHC CM
LHC LS
10 -1
1
10
10 2
10 3
10 4
10 5
10 6
10 7
10 8
p, GeV


p=0.029 GeV/c
p=0.035 GeV/c
p=0.041 GeV/c
p=0.061 GeV/c
dσ/dt (mb/GeV^2)
10 7
10 6
10 5
10 -4
10 -3
-t (GeV^2)



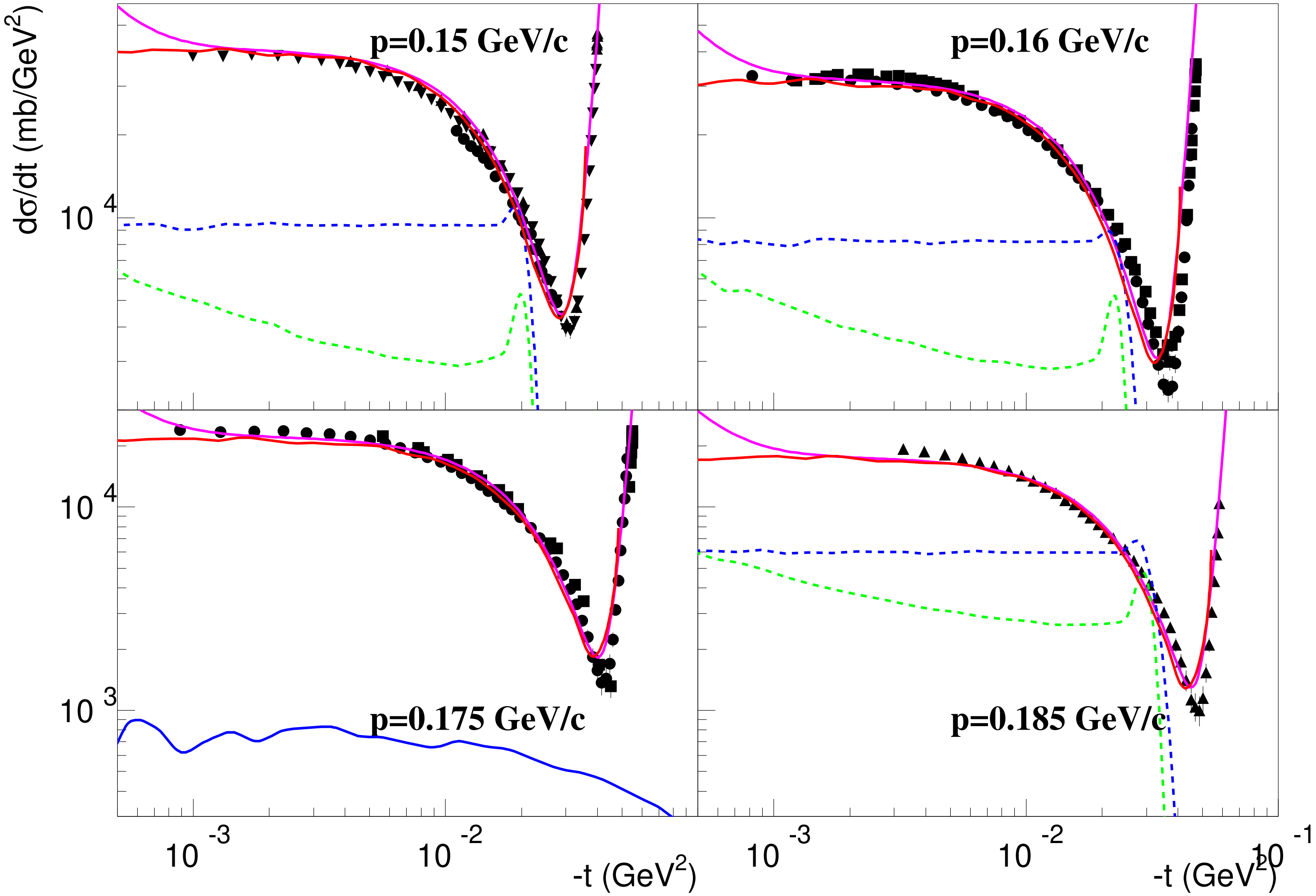
dσ/dt (mb/GeV^2)
p=0.076 GeV/c
p=0.081 GeV/c
p=0.089 GeV/c
p=0.1 GeV/c
10^6
10^5
10^4
10^{-4}
10^{-3}
10^{-2}
-t (GeV^2)

CERN



p=0.11 GeV/c
p=0.12 GeV/c
p=0.13 GeV/c
p=0.14 GeV/c
dσ/dt (mb/GeV^2)
-t (GeV^2)

Verification and development of pA elastic scattering.



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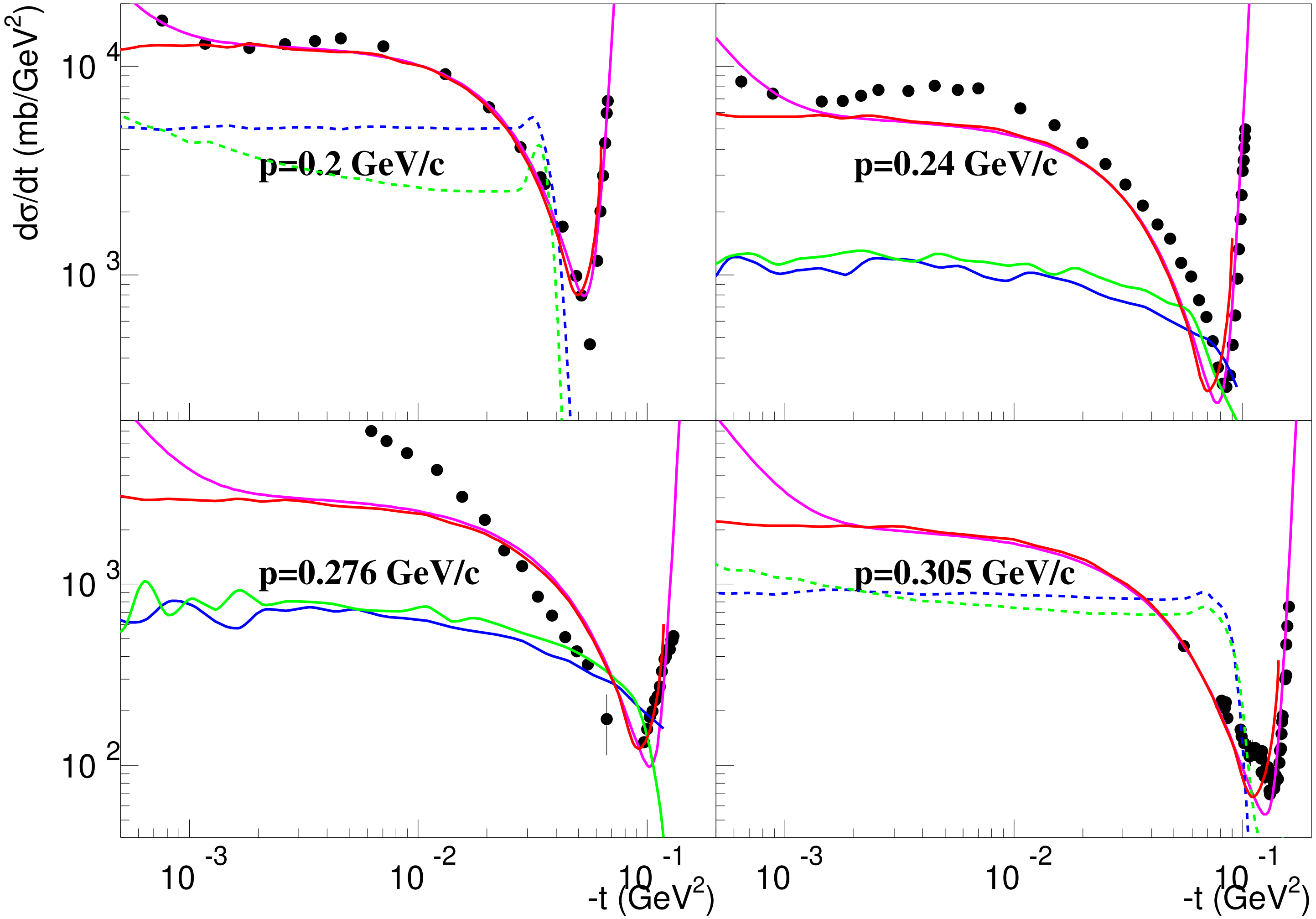
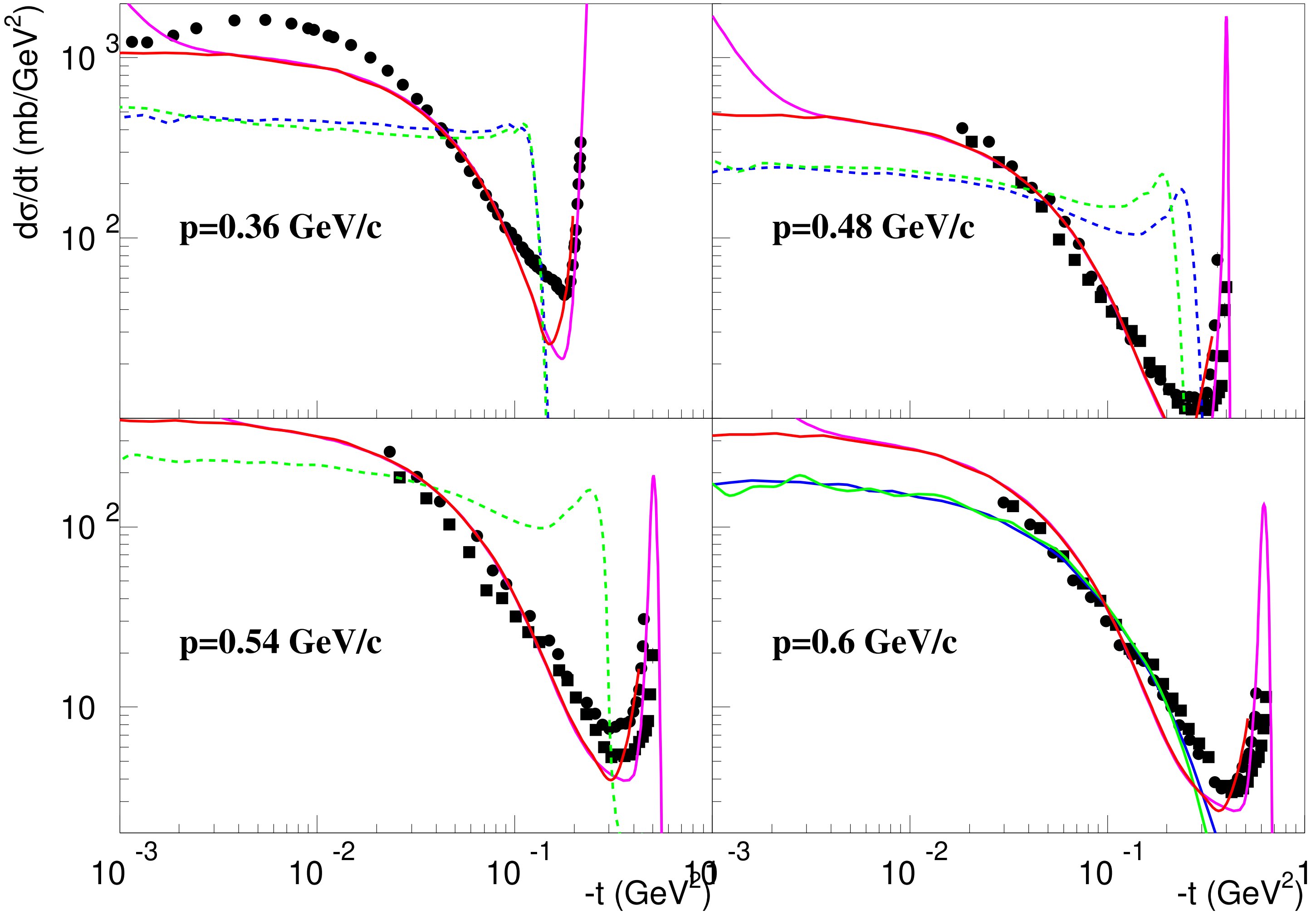
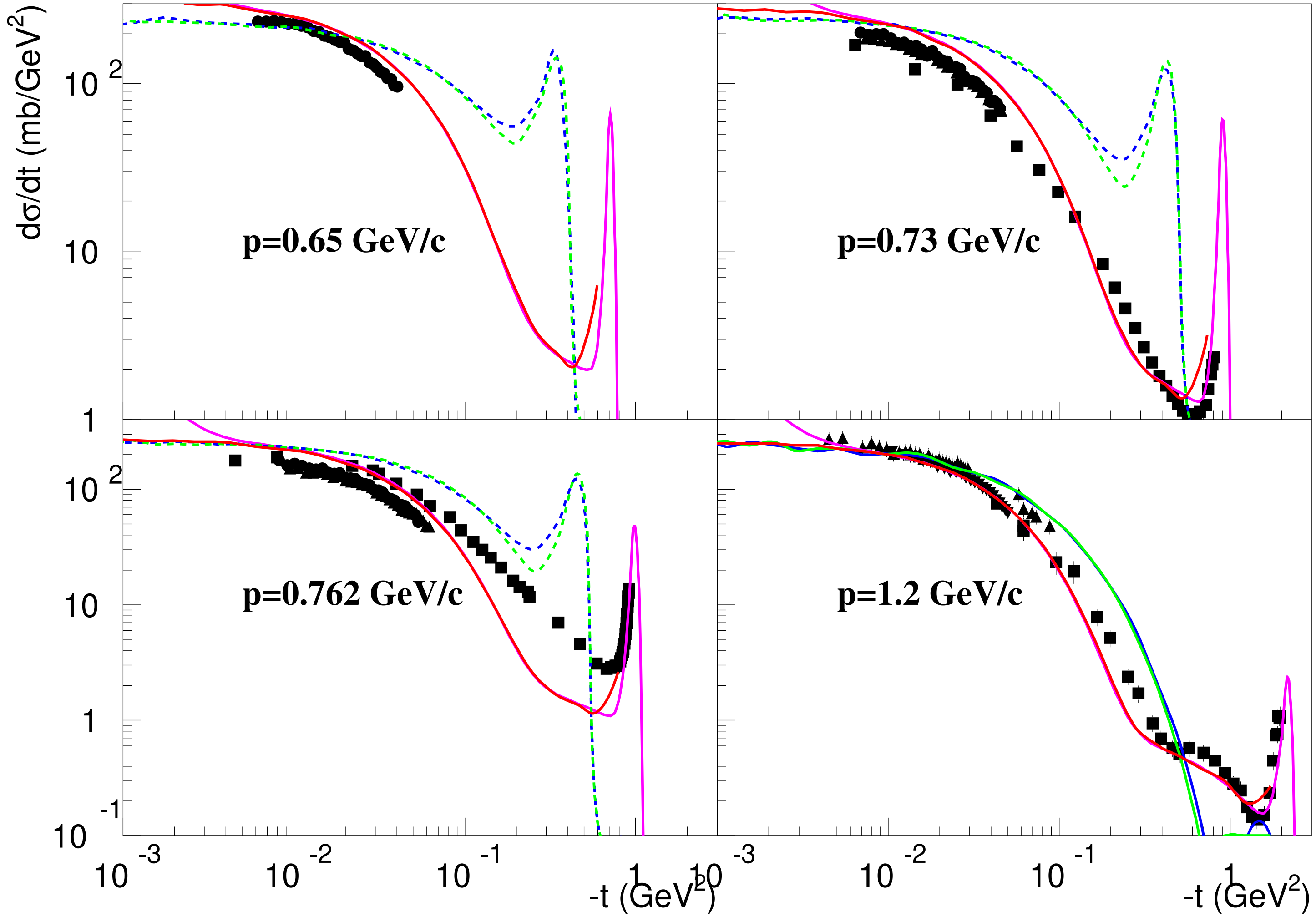
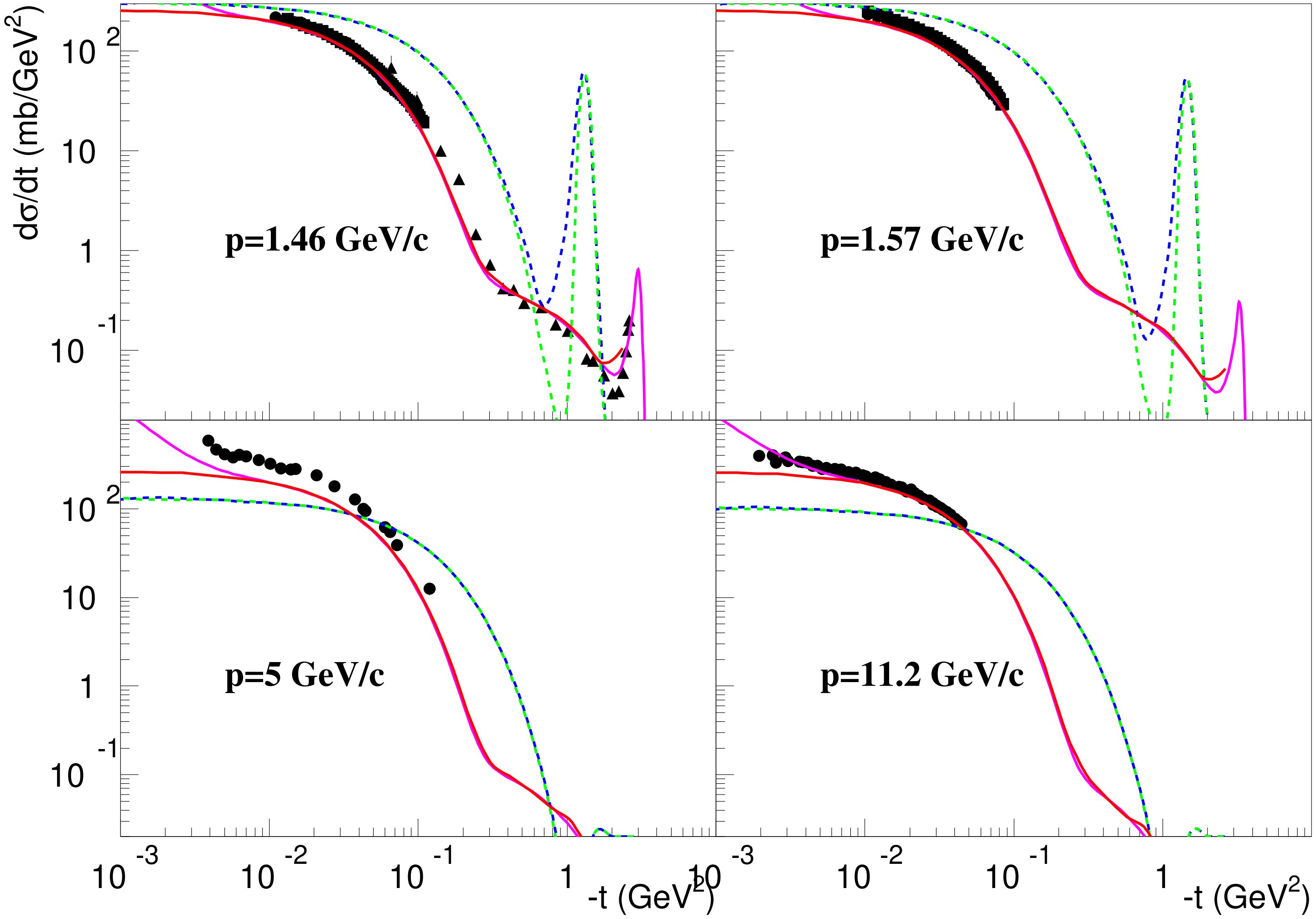
Verification and development of pA elastic scattering.

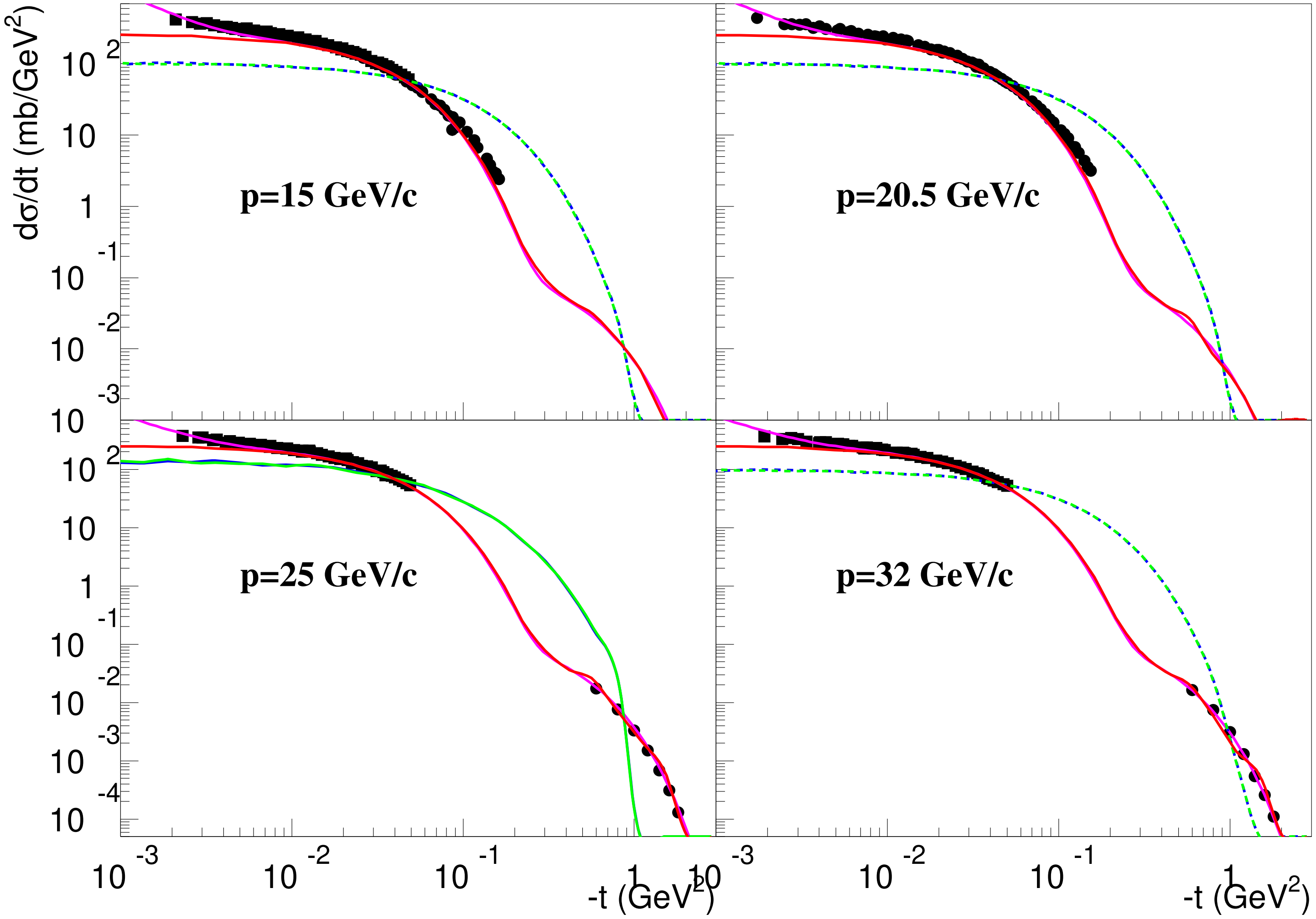



dσ/dt (mb/GeV^2)
p=0.36 GeV/c
p=0.48 GeV/c
p=0.54 GeV/c
p=0.6 GeV/c
-t (GeV^2)
-t (GeV^2)


dσ/dt (mb/GeV^2)
p=0.65 GeV/c
p=0.73 GeV/c
p=0.762 GeV/c
p=1.2 GeV/c
-t (GeV^2)
-t (GeV^2)

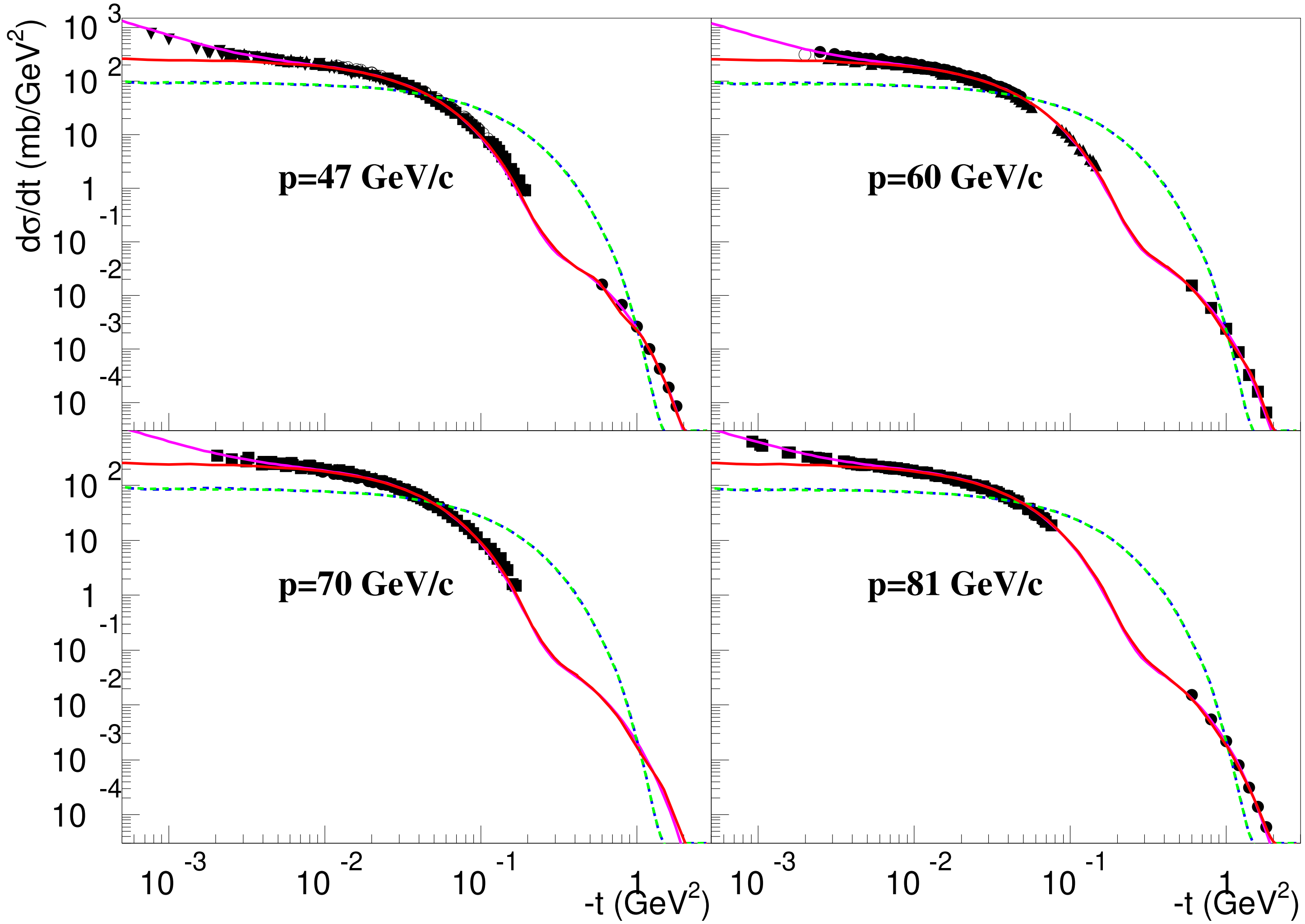
Verification and development of pA elastic scattering.

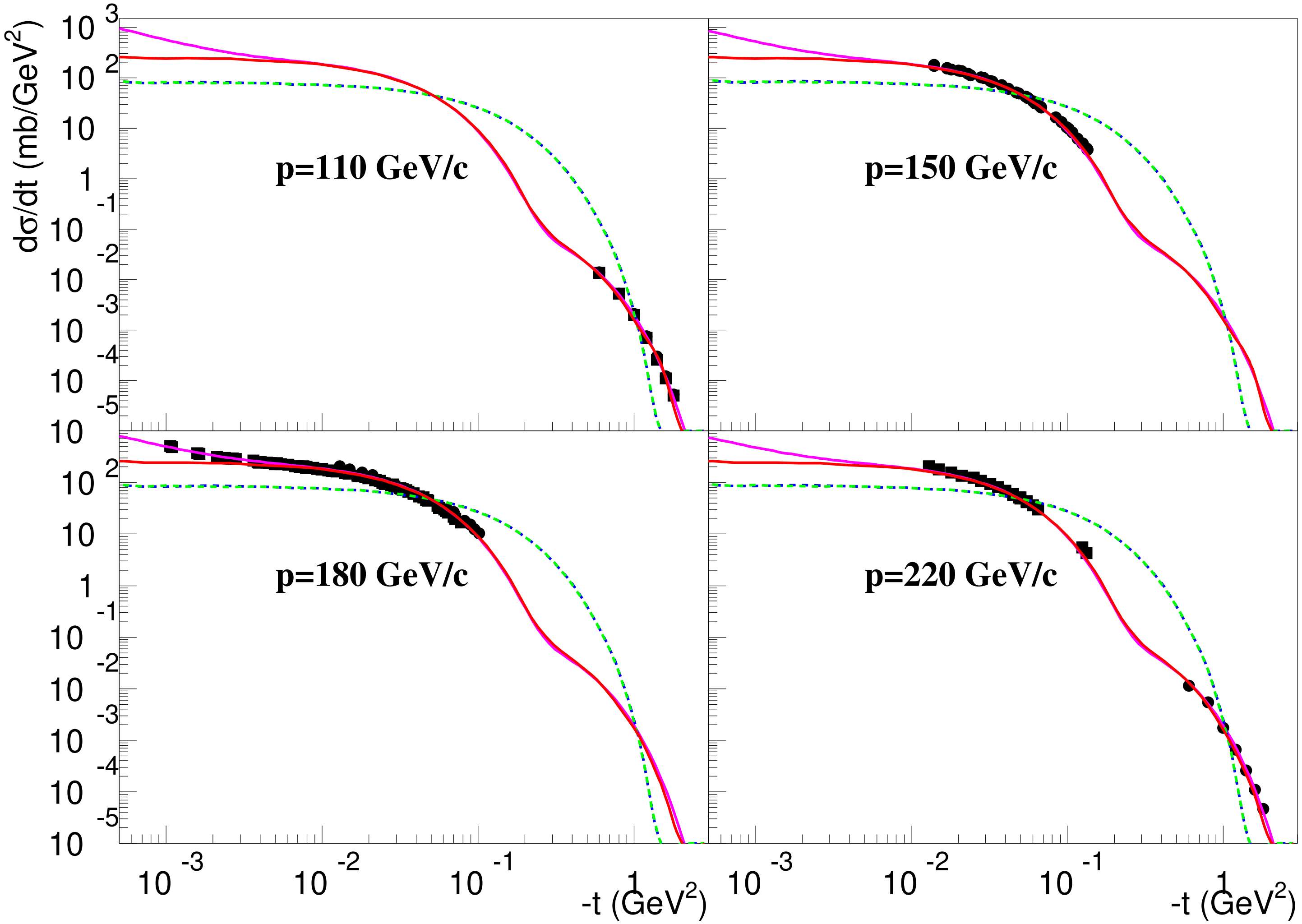


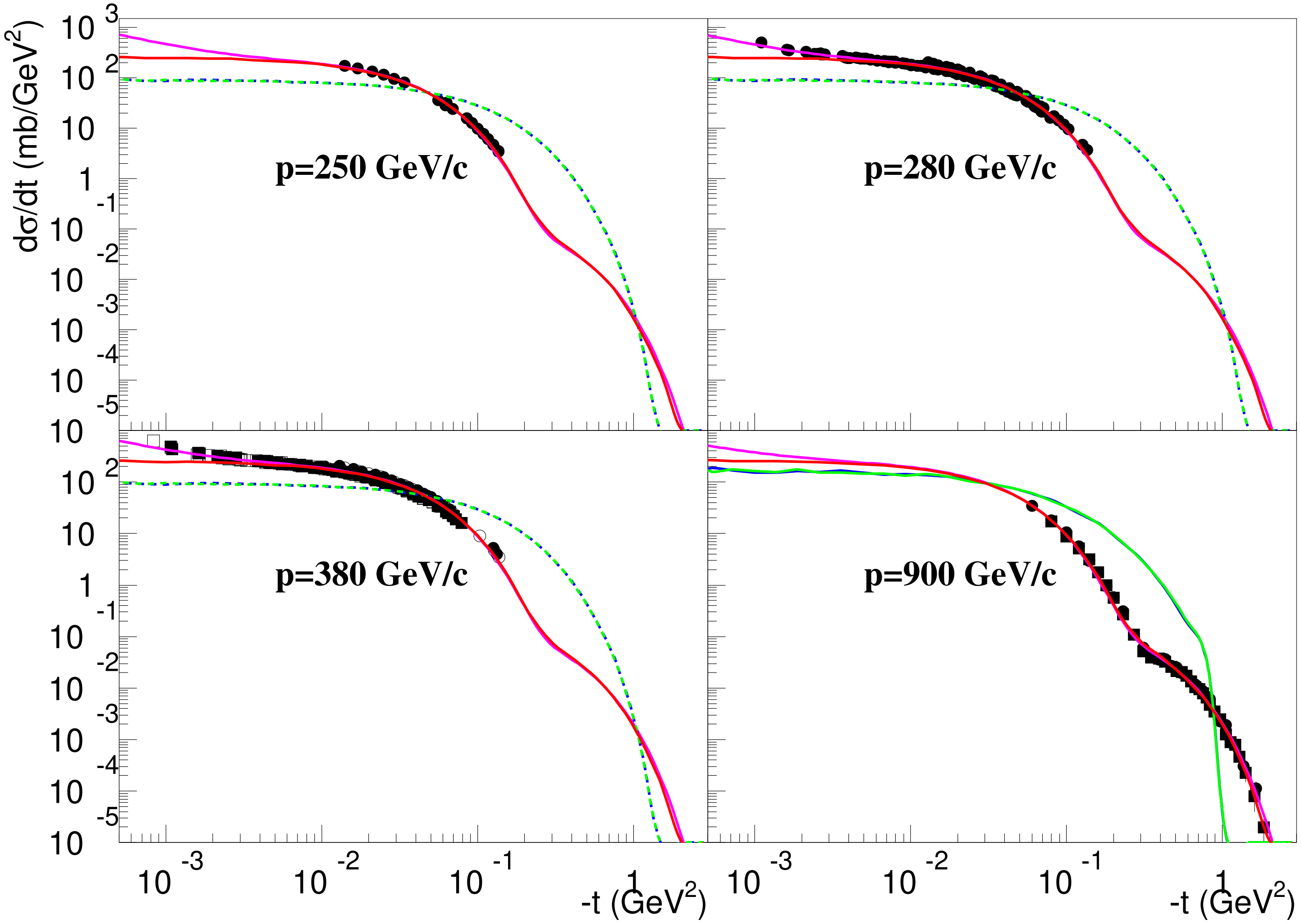


CERN

Verification and development of pA elastic scattering.




dσ/dt (mb/GeV²)
p=110 GeV/c
p=150 GeV/c
p=180 GeV/c
p=220 GeV/c
-t (GeV²)
-t (GeV²)


dσ/dt (mb/GeV^2)
p=250 GeV/c
p=280 GeV/c
p=380 GeV/c
p=900 GeV/c
-t (GeV^2)
-t (GeV^2)

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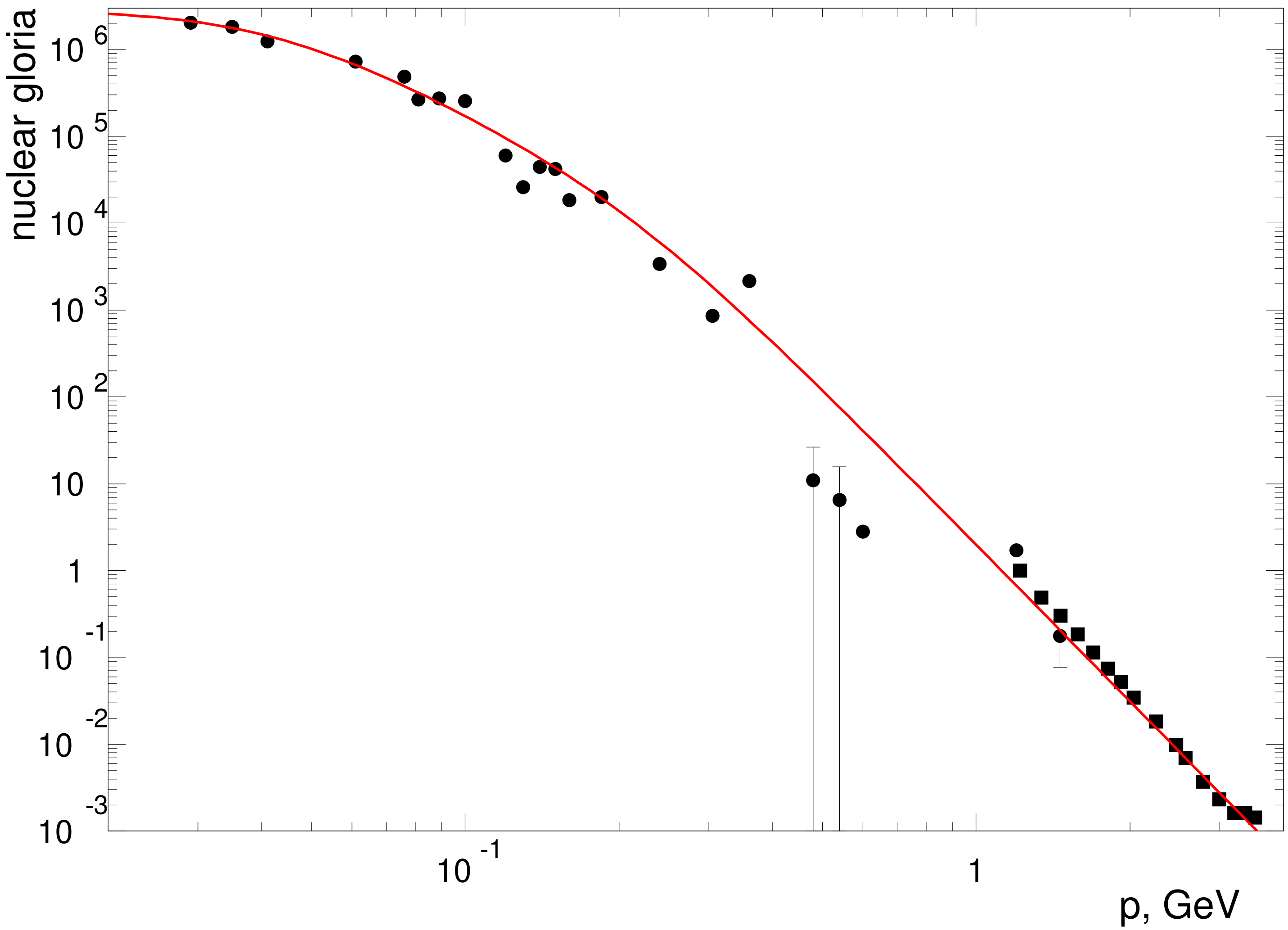

nuclear gloria
10^6
10^5
10^4
10^3
10^2
10
1
10^-1
10^-2
10^-3
10^-1
1
p, GeV

Approximation of pHe elastic scattering

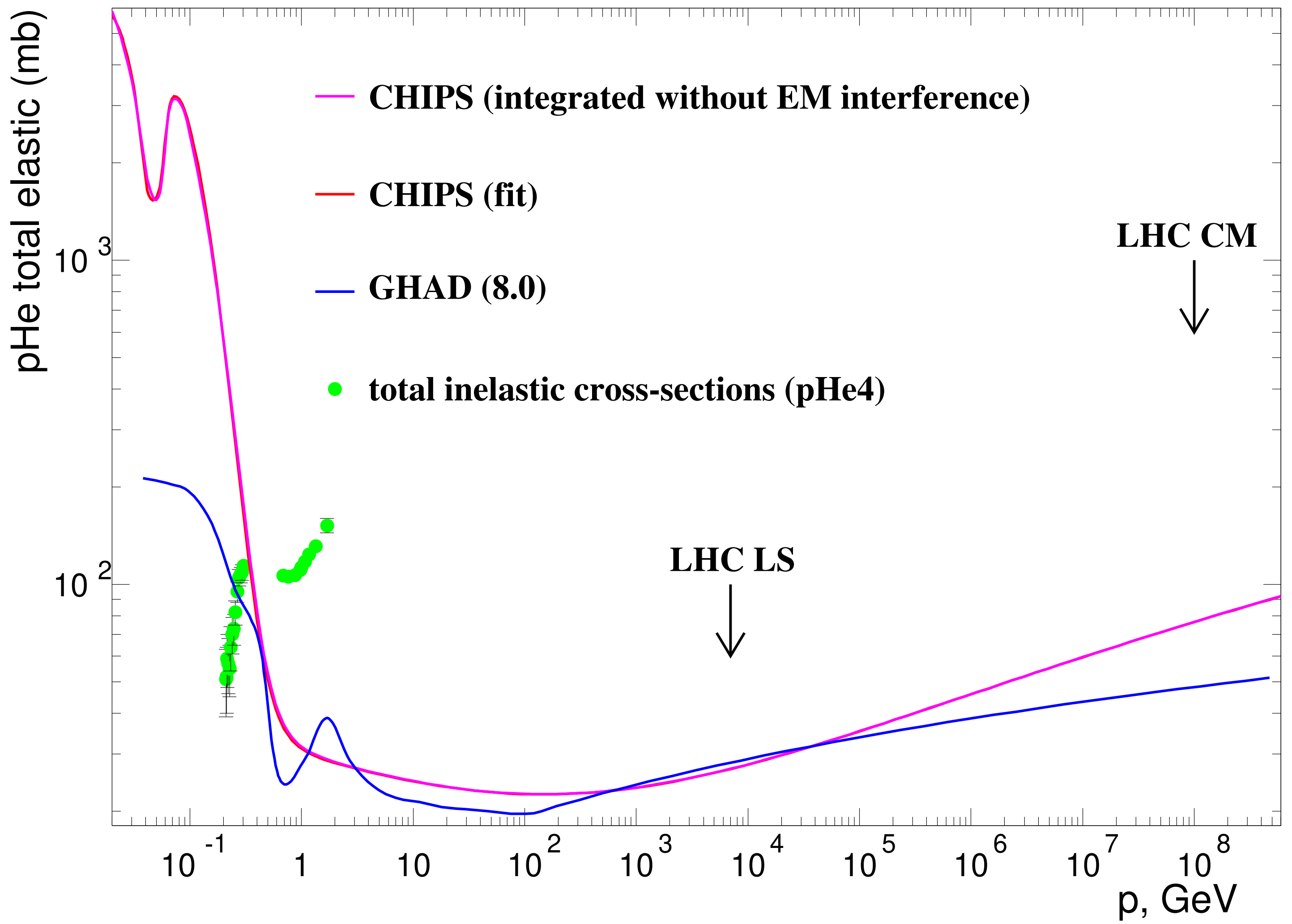
$$\frac{d\sigma}{dt} = A_1 \frac{e^{-B_1|t|^{1/2}}}{|t|^{1/2}} + A_2(B_2 - 2C_2 t)e^{(B_2 - C_2 t)\cdot t} + A_3 e^{B_3 t} + A_4 e^{B_4 u}$$

1. Interference with electromagnetic scattering.
2. Diffraction on a nucleon.
3. Diffraction on quarks.
4. Nuclear gloria.

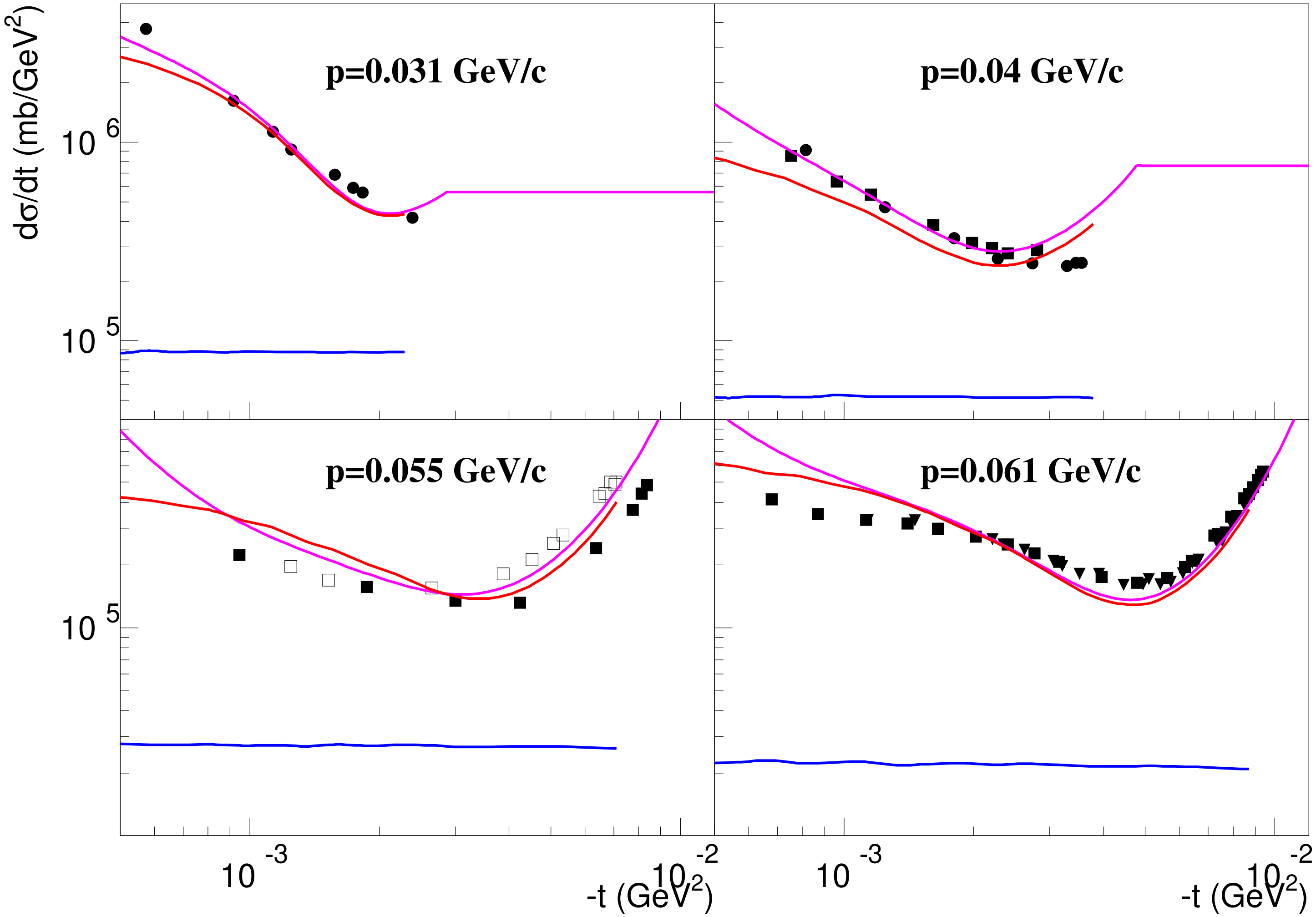
Usually the interference term is not included in the elastic cross section.

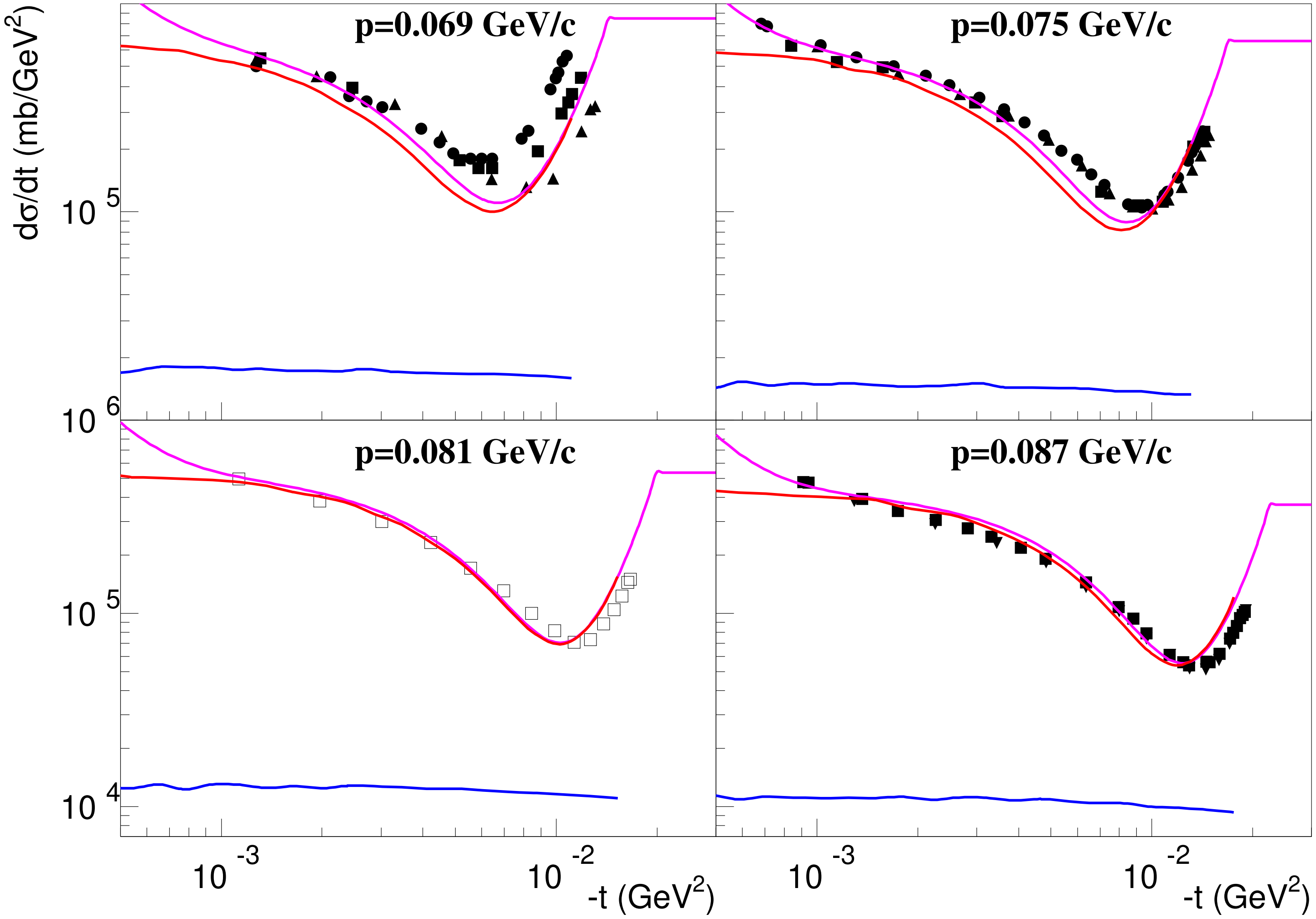
The pink line is CHIPS approximation, the red line is simulation by CHIPS, the green line is G4LElastic simulation, the blue line is G4LElasticB simulation (conserves energy). Dashed lines are all events, solid lines are events with a deuteron in the final state.

Verification and development of pA elastic scattering.



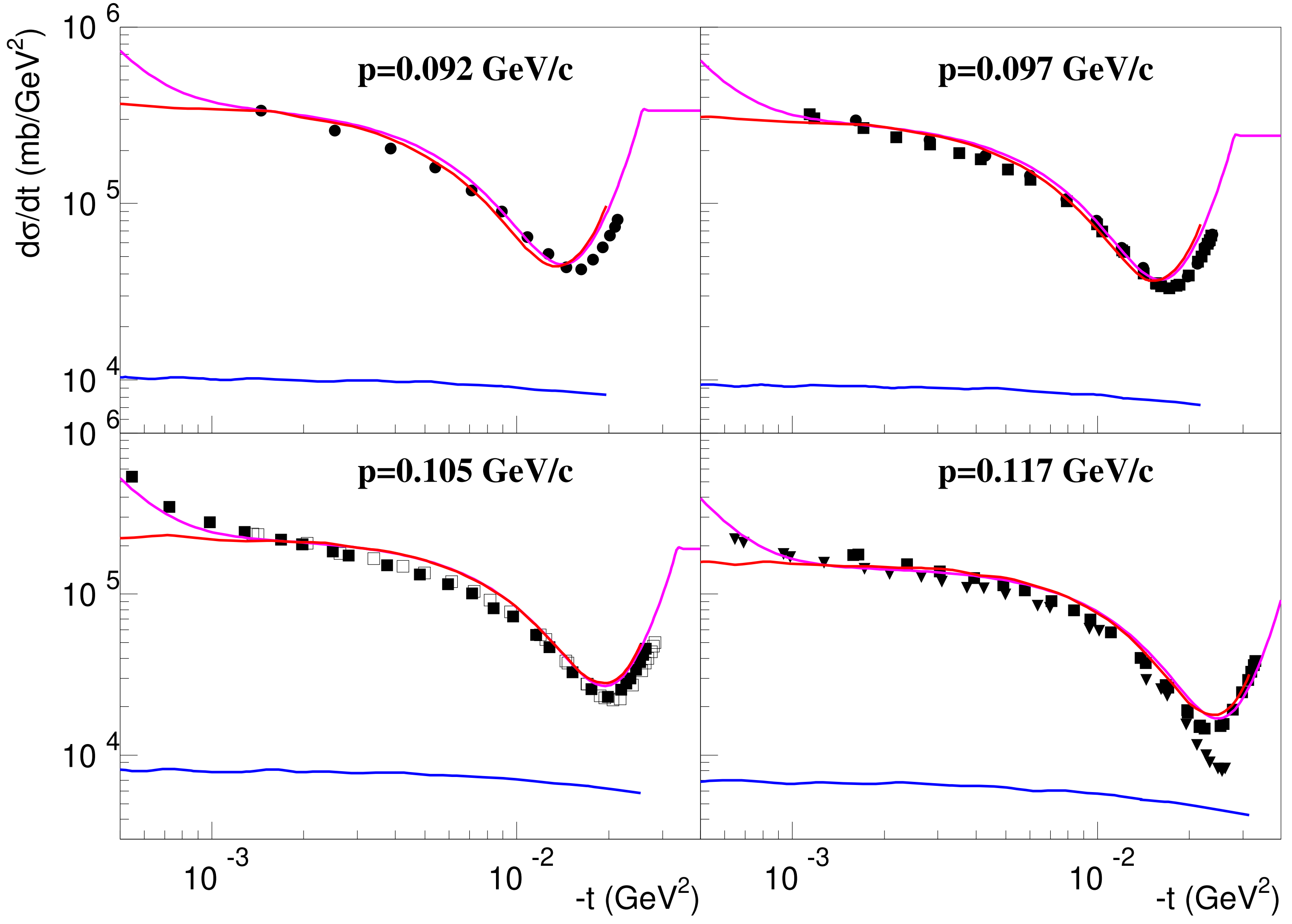
CERN

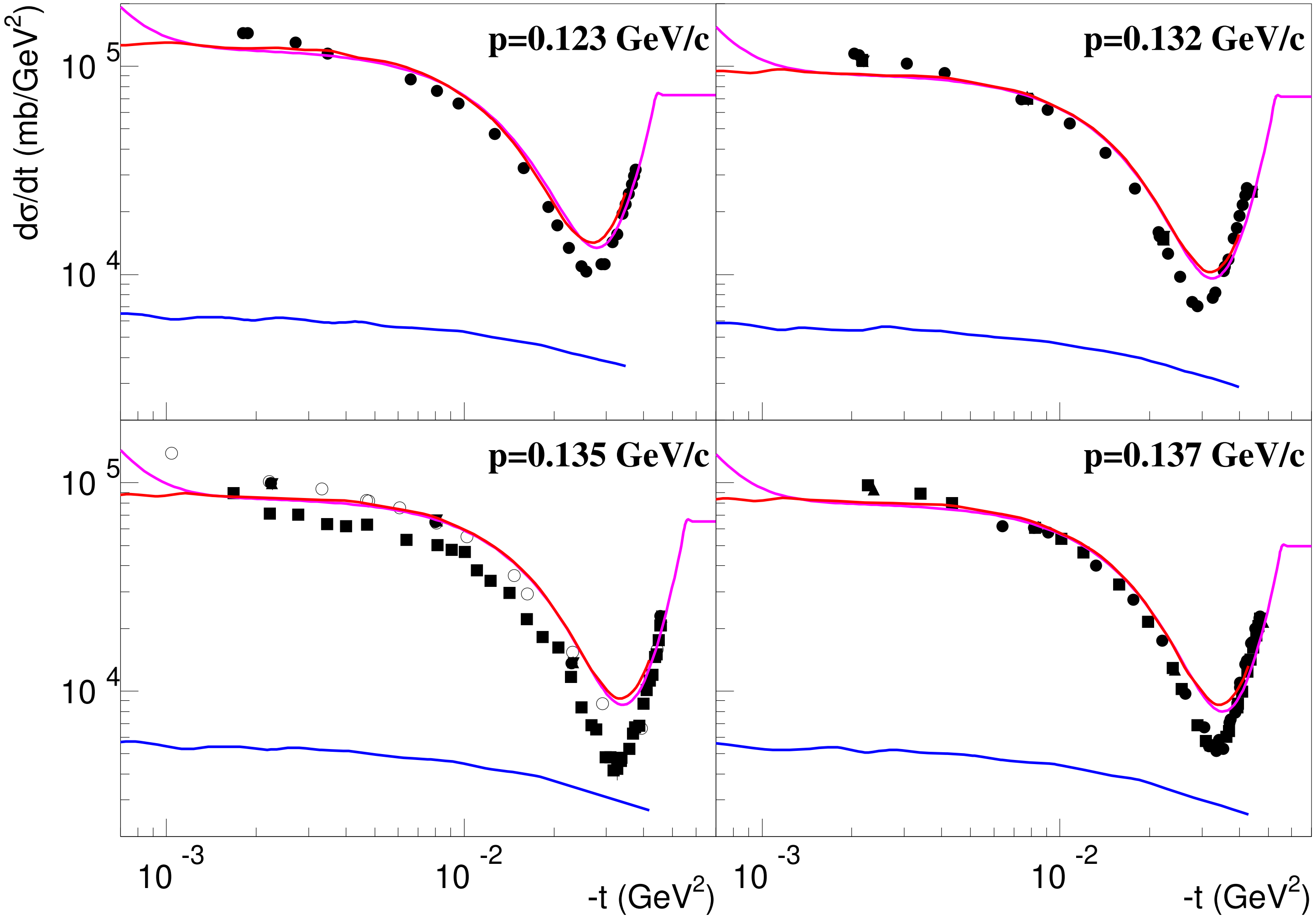

p=0.031 GeV/c
p=0.04 GeV/c
p=0.055 GeV/c
p=0.061 GeV/c
dσ/dt (mb/GeV^2)
10^6
10^5
10^5
10^{-3}
10^{-2}
10^{-3}
10^{-2}
-t (GeV^2)
-t (GeV^2)


p=0.069 GeV/c
p=0.075 GeV/c
p=0.081 GeV/c
p=0.087 GeV/c
dσ/dt (mb/GeV^2)
10^5
10^6
10^5
10^4
10^{-3}
10^{-2}
-t (GeV^2)
10^{-3}
10^{-2}
-t (GeV^2)

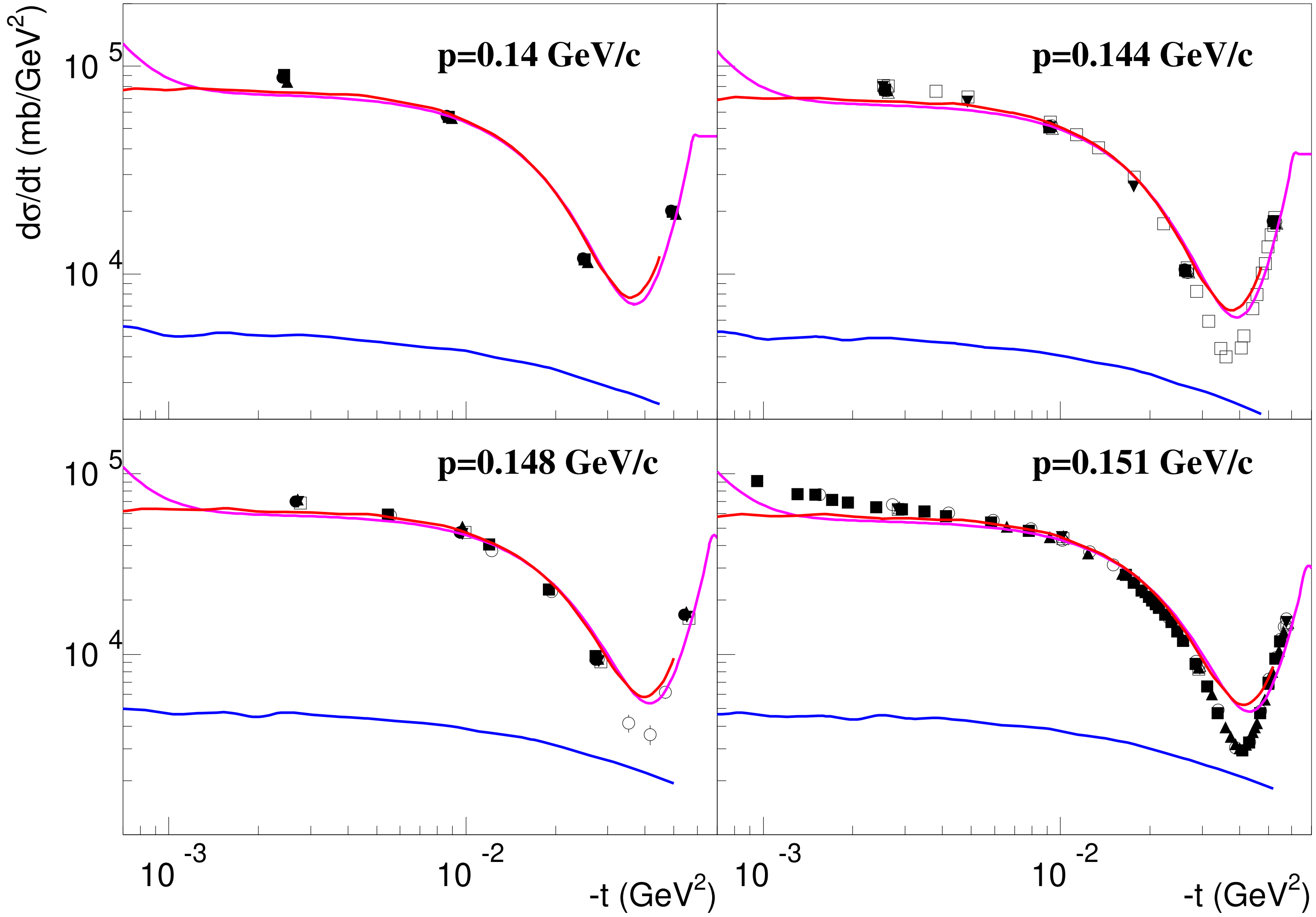
CERN

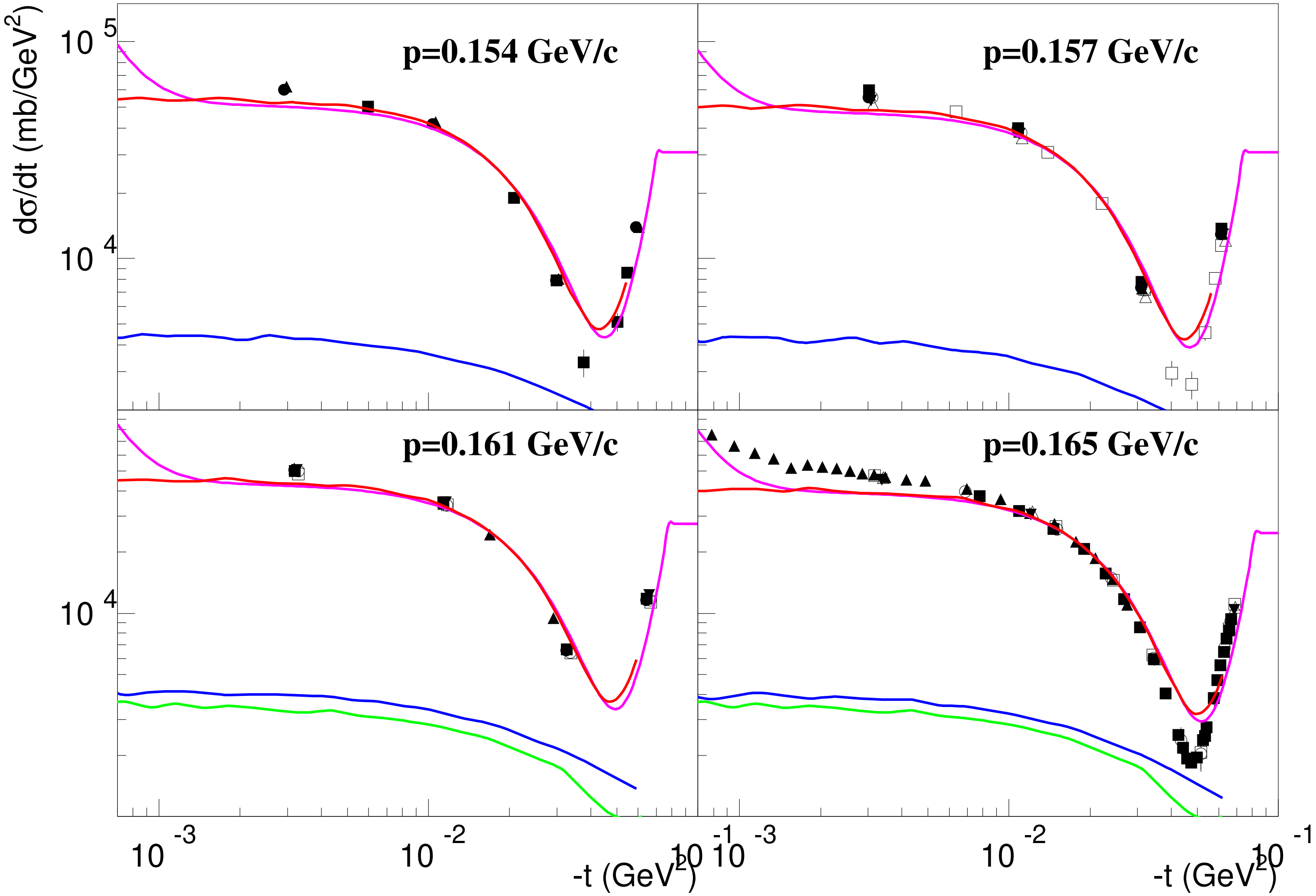
Verification and development of pA elastic scattering.

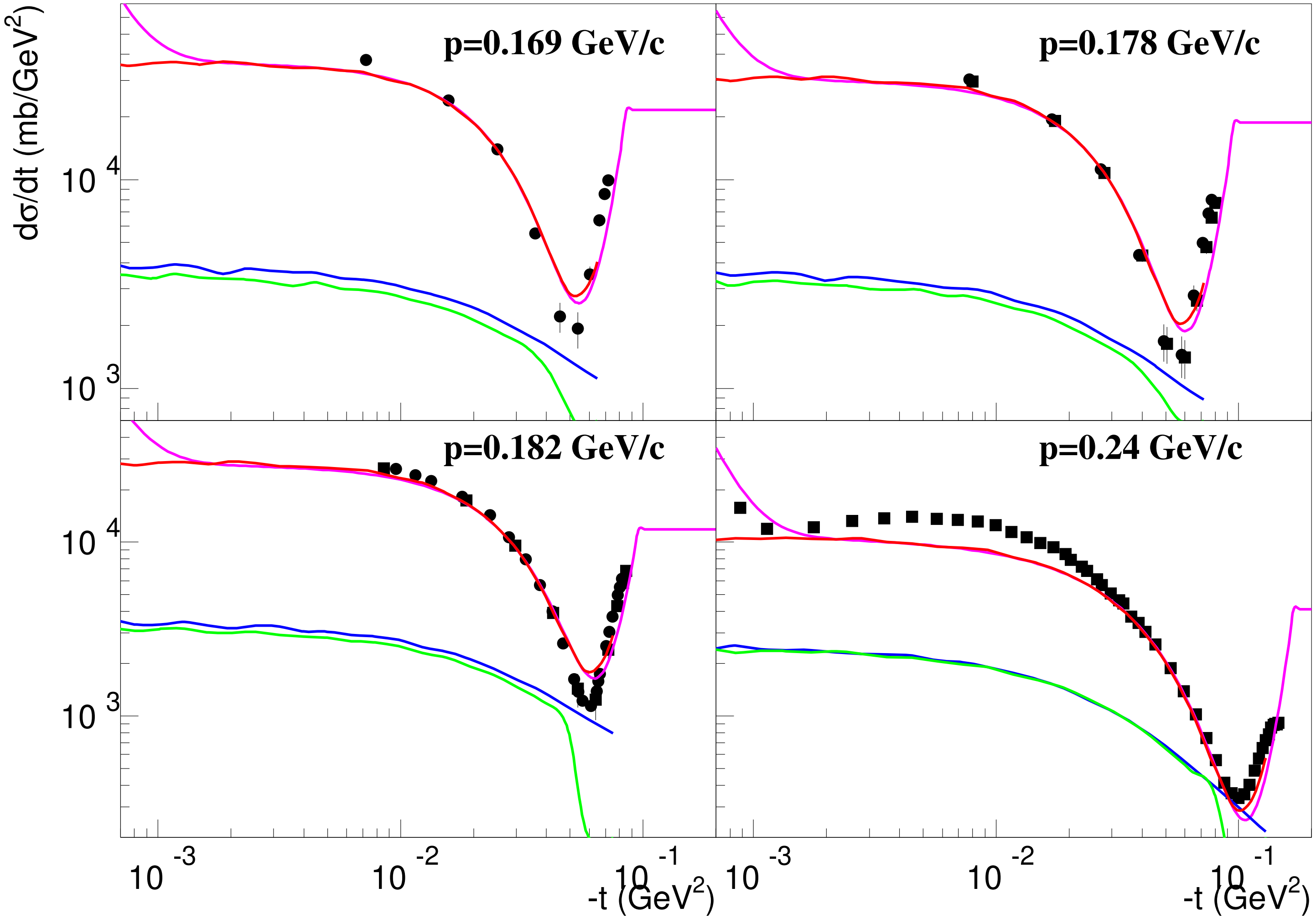


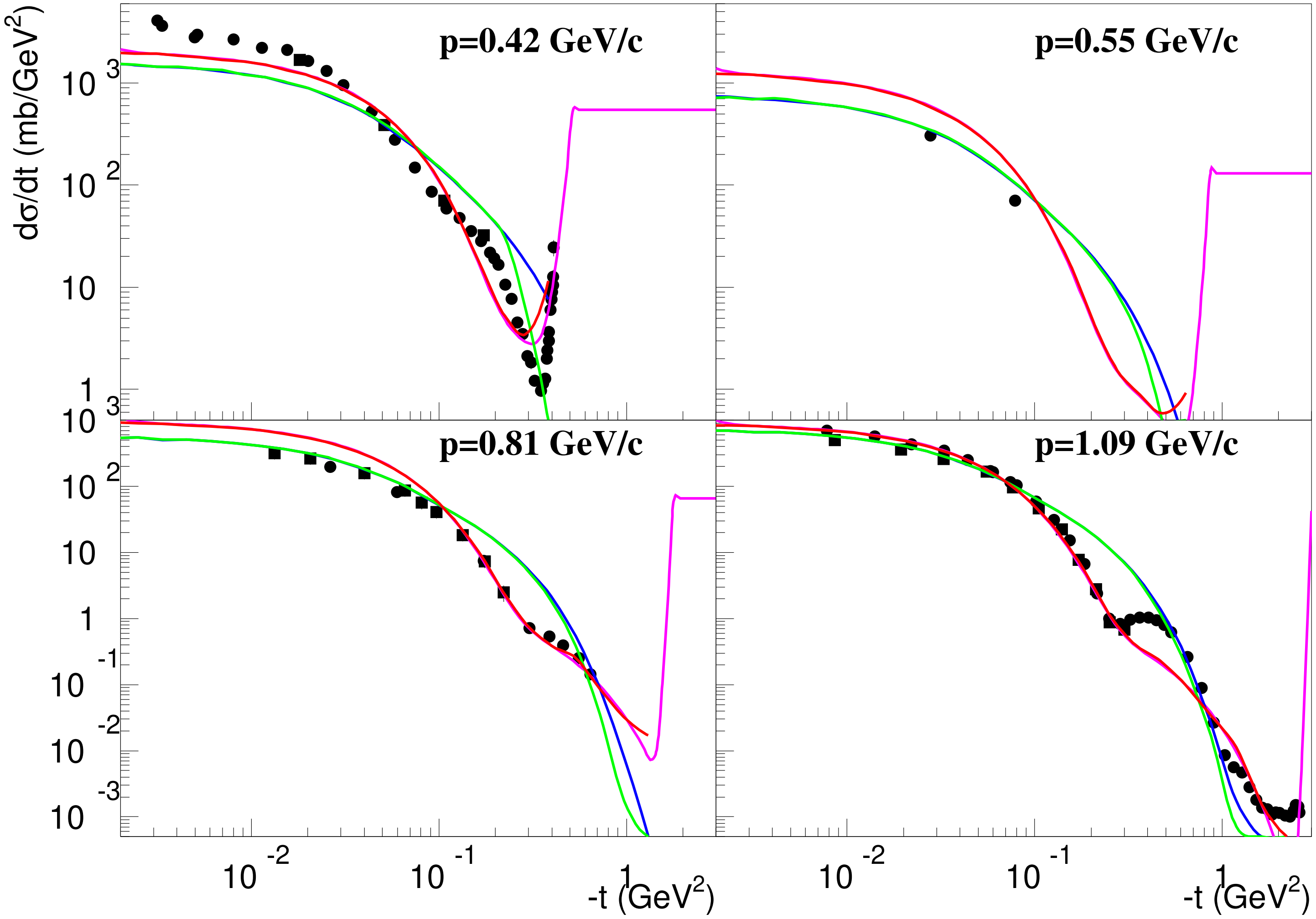

p=0.123 GeV/c
p=0.132 GeV/c
p=0.135 GeV/c
p=0.137 GeV/c
dσ/dt (mb/GeV^2)
10^5
10^4
10^{-3}
10^{-2}
-t (GeV^2)

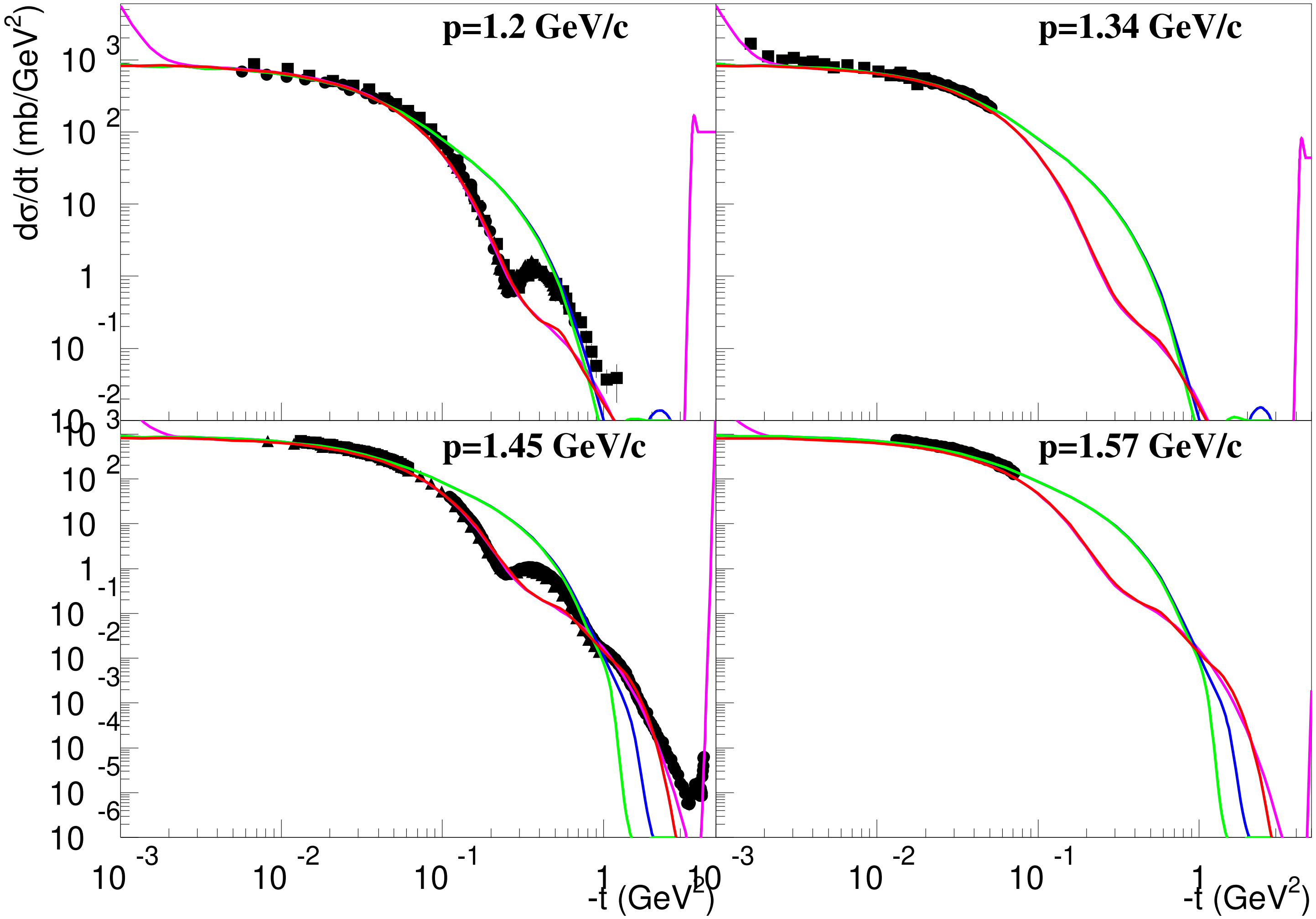
CERN


p=0.14 GeV/c
p=0.144 GeV/c
p=0.148 GeV/c
p=0.151 GeV/c
dσ/dt (mb/GeV²)
-t (GeV²)
10⁵
10⁴
10⁻³
10⁻²

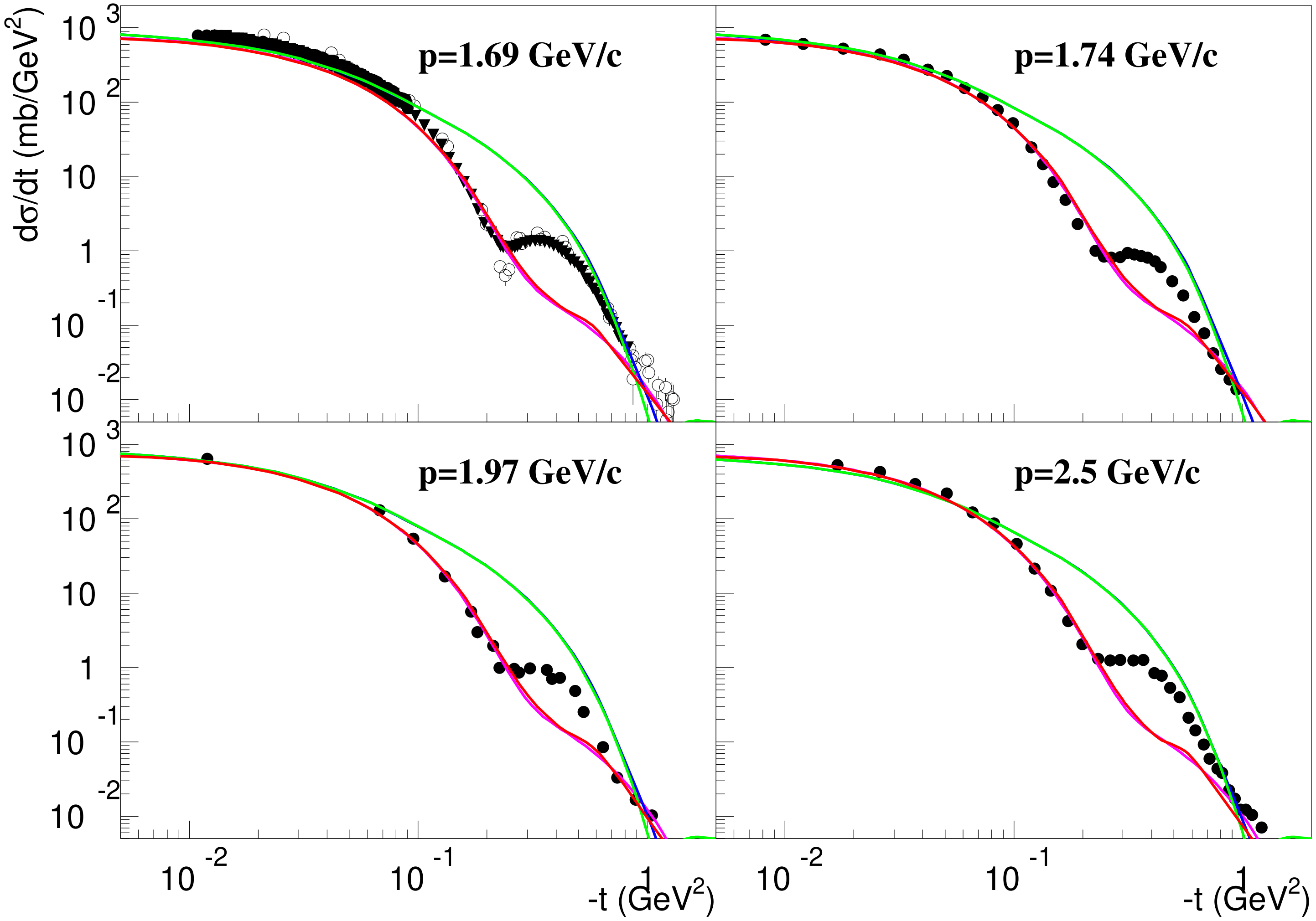

p=0.154 GeV/c
p=0.157 GeV/c
p=0.161 GeV/c
p=0.165 GeV/c
dσ/dt (mb/GeV^2)
10 5
10 4
10 4
10 -3
10 -2
10 -1
-t (GeV^2)

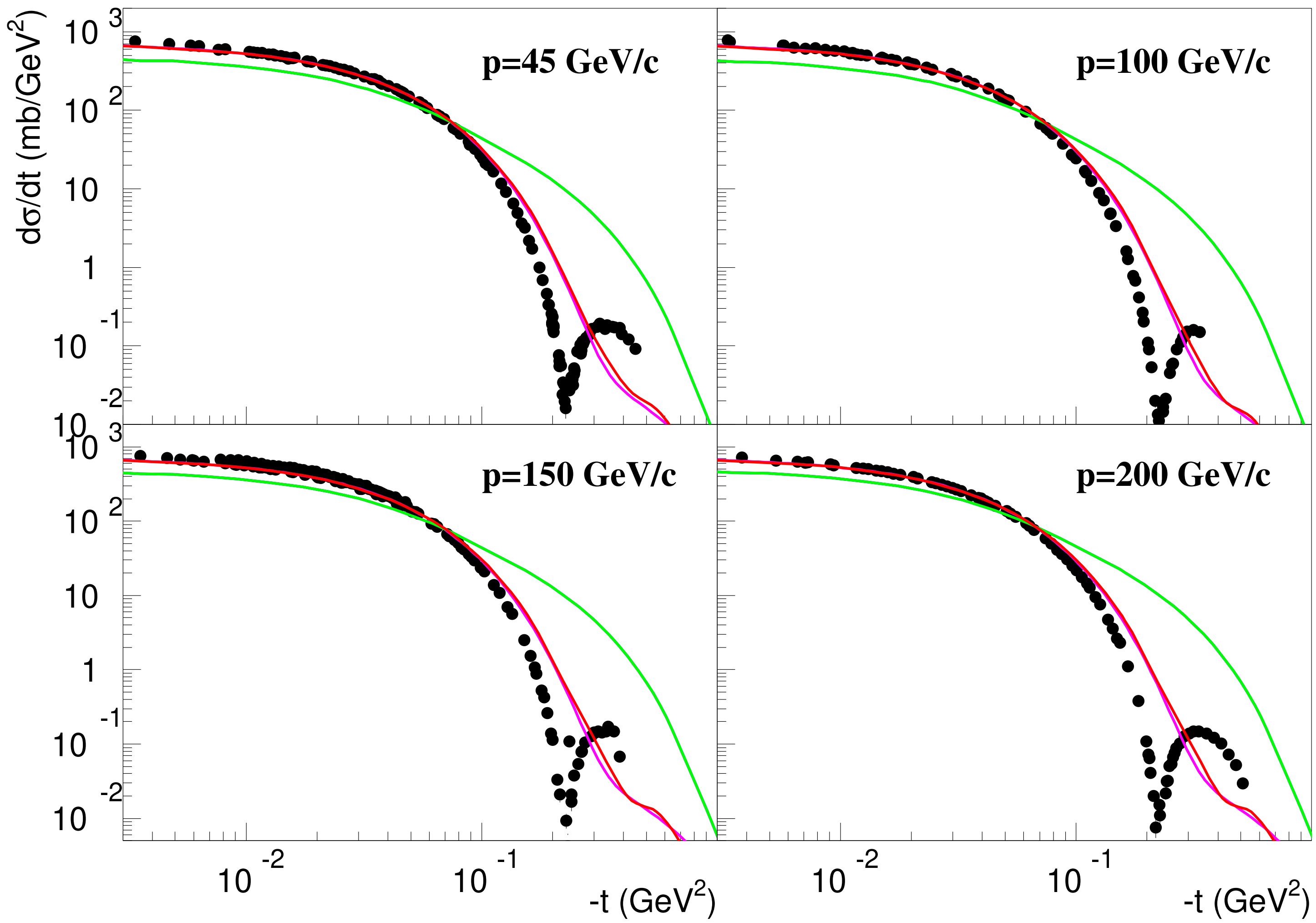

p=0.169 GeV/c
p=0.178 GeV/c
p=0.182 GeV/c
p=0.24 GeV/c
dσ/dt (mb/GeV^2)
10^4
10^3
10^{-3}
10^{-2}
10^{-1}
-t (GeV^2)


p=0.42 GeV/c
p=0.55 GeV/c
p=0.81 GeV/c
p=1.09 GeV/c
dσ/dt (mb/GeV^2)
-t (GeV^2)
-t (GeV^2)
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-2}
10^{-1}

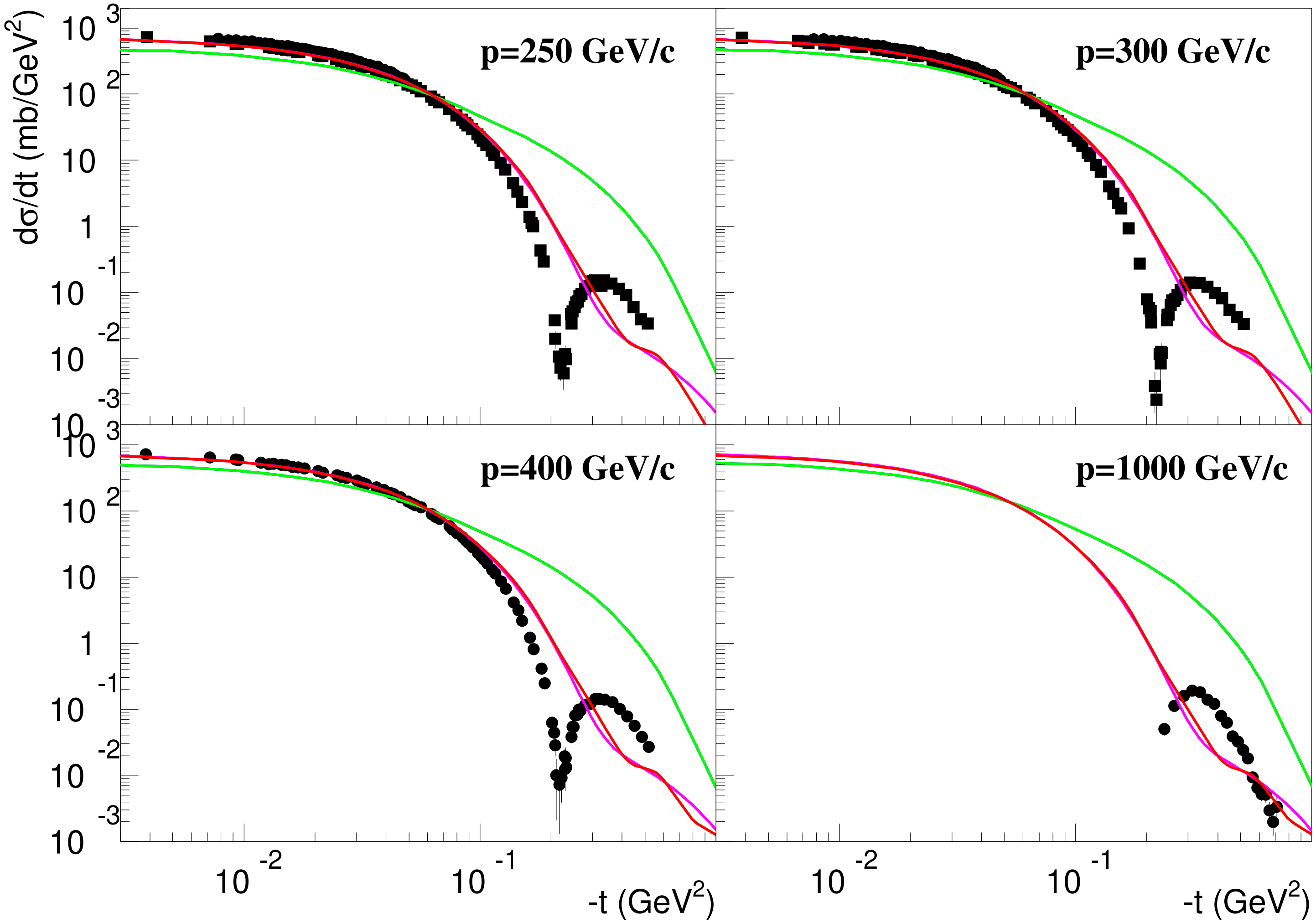


CERN


p=1.69 GeV/c
p=1.74 GeV/c
p=1.97 GeV/c
p=2.5 GeV/c
dσ/dt (mb/GeV^2)
-t (GeV^2)
-t (GeV^2)


p=45 GeV/c
p=100 GeV/c
p=150 GeV/c
p=200 GeV/c
dσ/dt (mb/GeV^2)
-t (GeV^2)
-t (GeV^2)

CERN


p=250 GeV/c
p=300 GeV/c
p=400 GeV/c
p=1000 GeV/c
dσ/dt (mb/GeV²)
-t (GeV²)
-t (GeV²)

Approximation of pBe elastic scattering

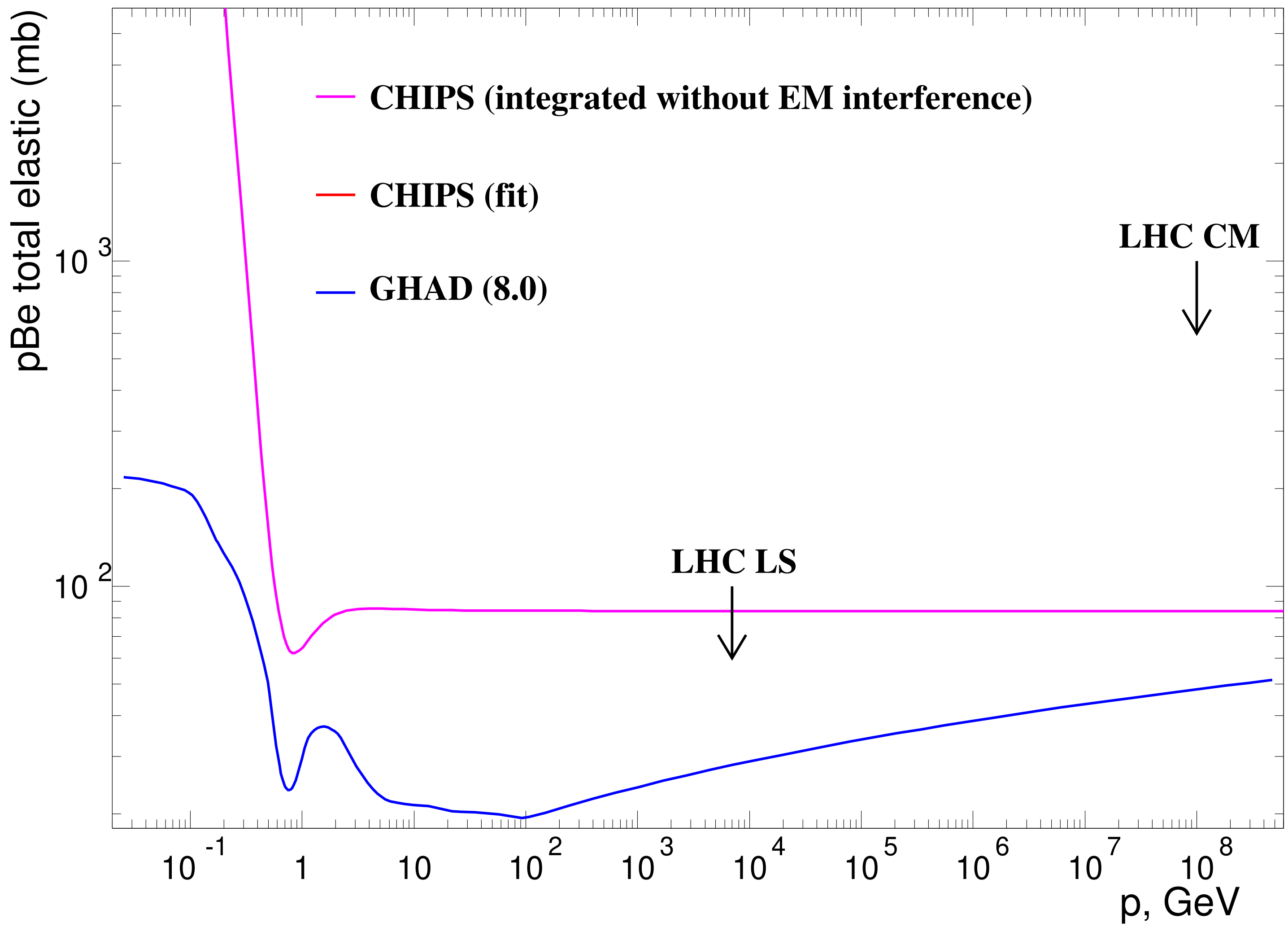
$$\mathbf{\frac{d\sigma}{dt} = A_1 \frac{e^{-B_1|t|^{1/2}}}{|t|^{1/2}} + A_2 B_2 e^{B_2 \cdot t} + \frac{A_3 B_3}{n} (B_3|t|)^{n-1} e^{-(B_3|t|)^n}}$$

1. Interference with electromagnetic (Coulomb) scattering.
2. The main maximum of diffraction (a diffraction cone)
3. The second maximum of diffraction
4. *** There is no nuclear gloria. ***

The Coulomb parameters are the same as for pHe (practically no data).

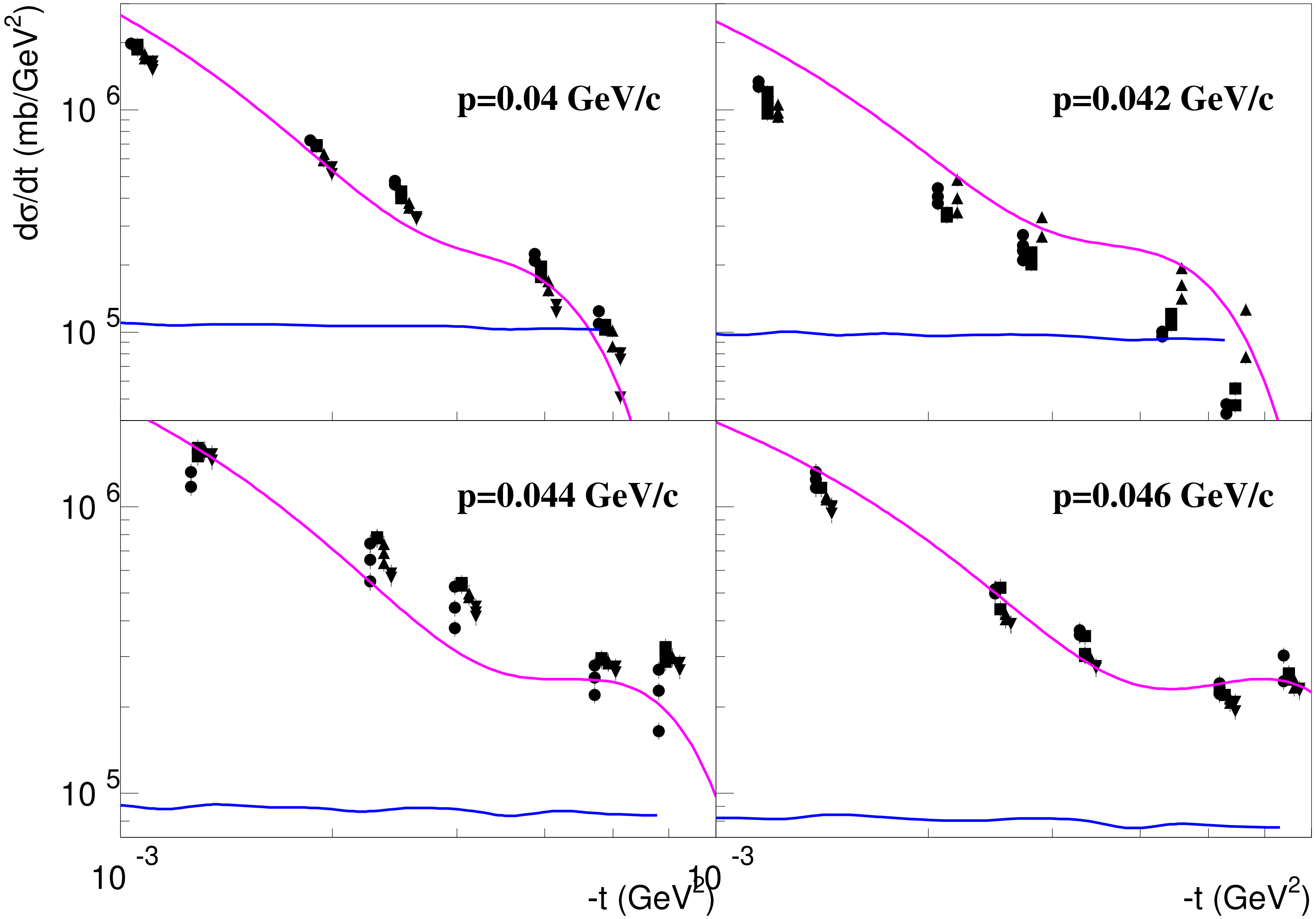
A new approximation method for the second diffraction maximum is used.

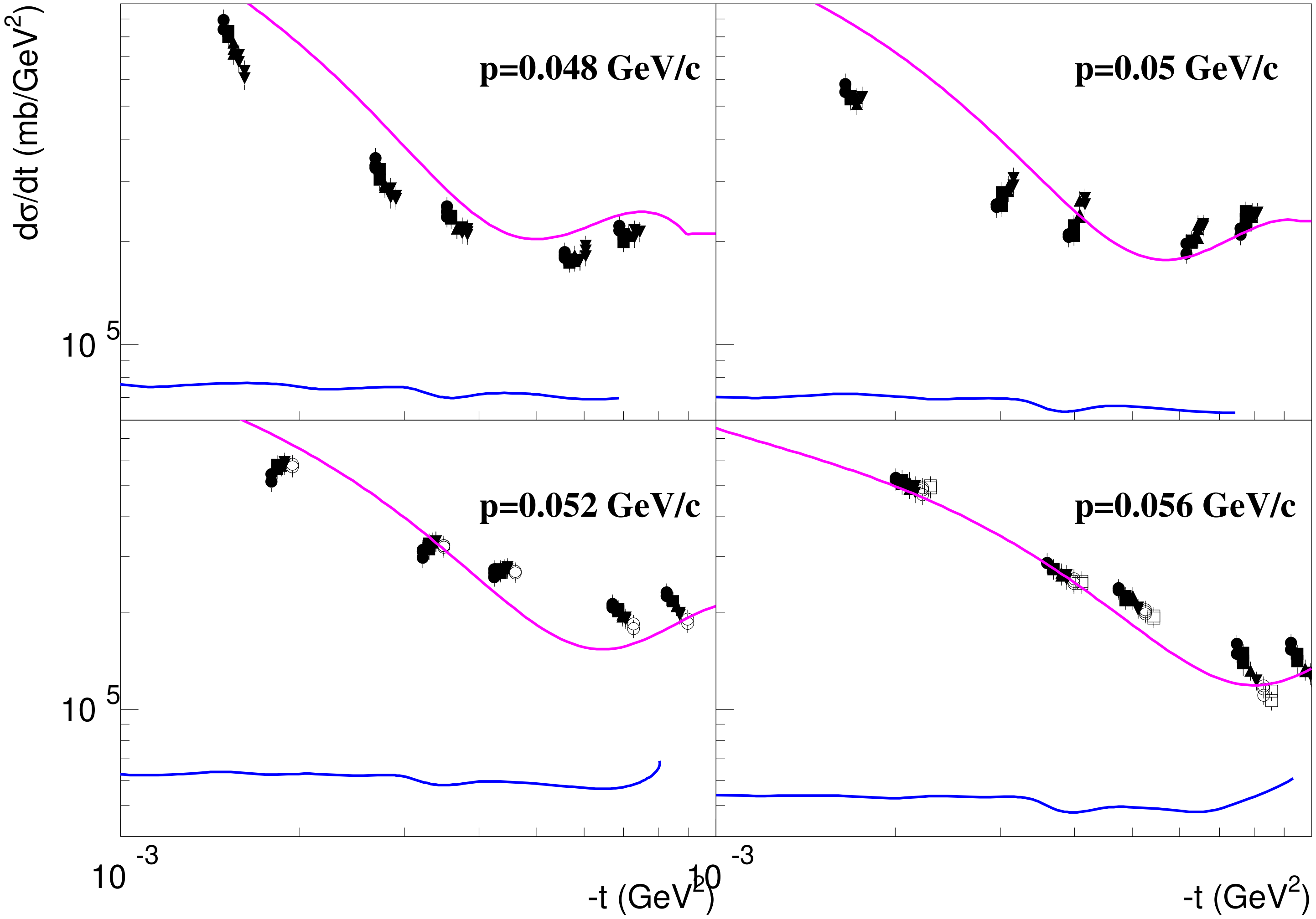
The measurements above T = 1 GeV do not exist, so the Glauber model must be used for the primary t-distributions.



CHIPS (integrated without EM interference)
CHIPS (fit)
GHAD (8.0)
LHC CM
LHC LS
pBe total elastic (mb)
10^3
10^2
10^{-1}
1
10
10^2
10^3
10^4
10^5
10^6
10^7
10^8
p, GeV

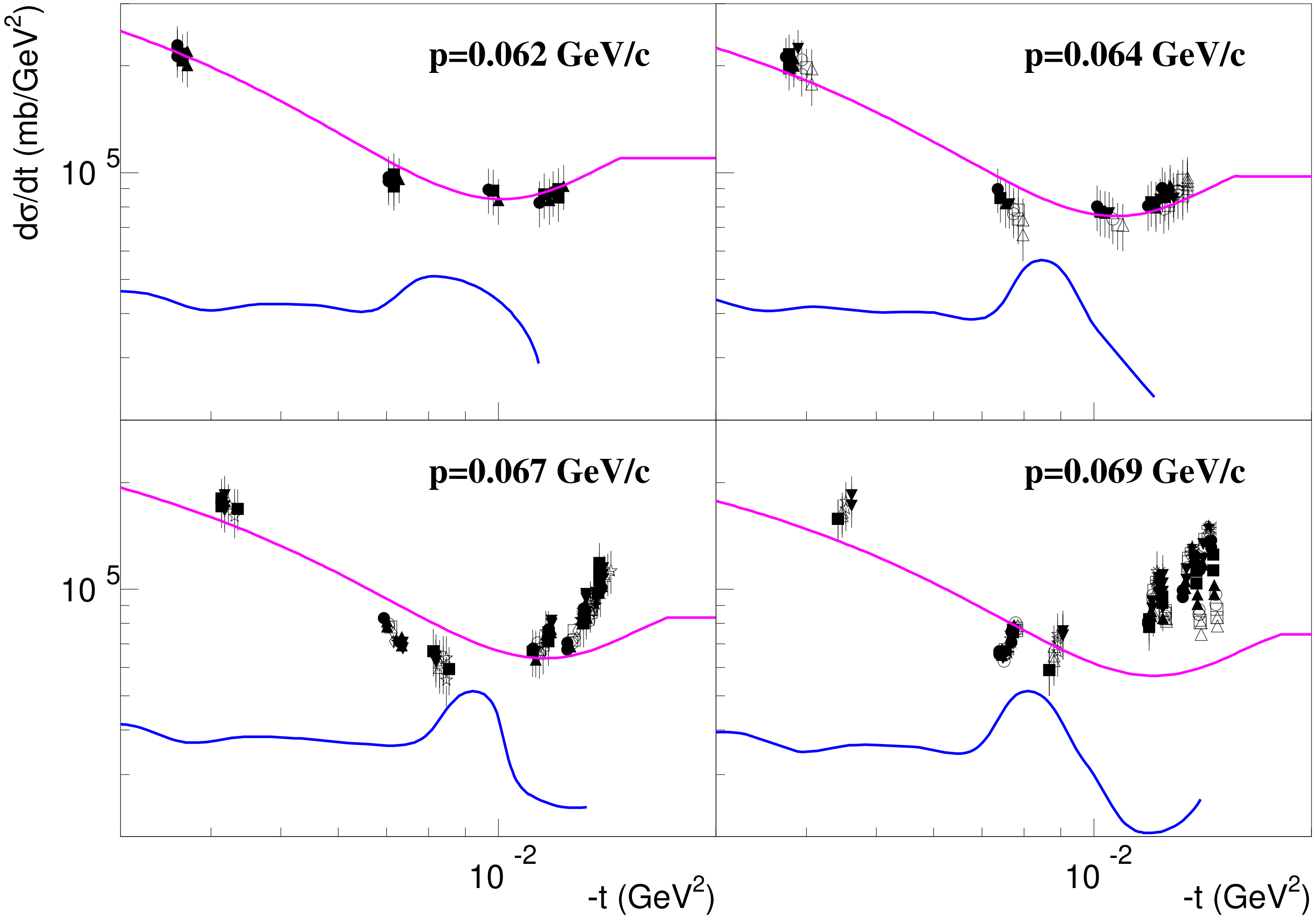
CERN

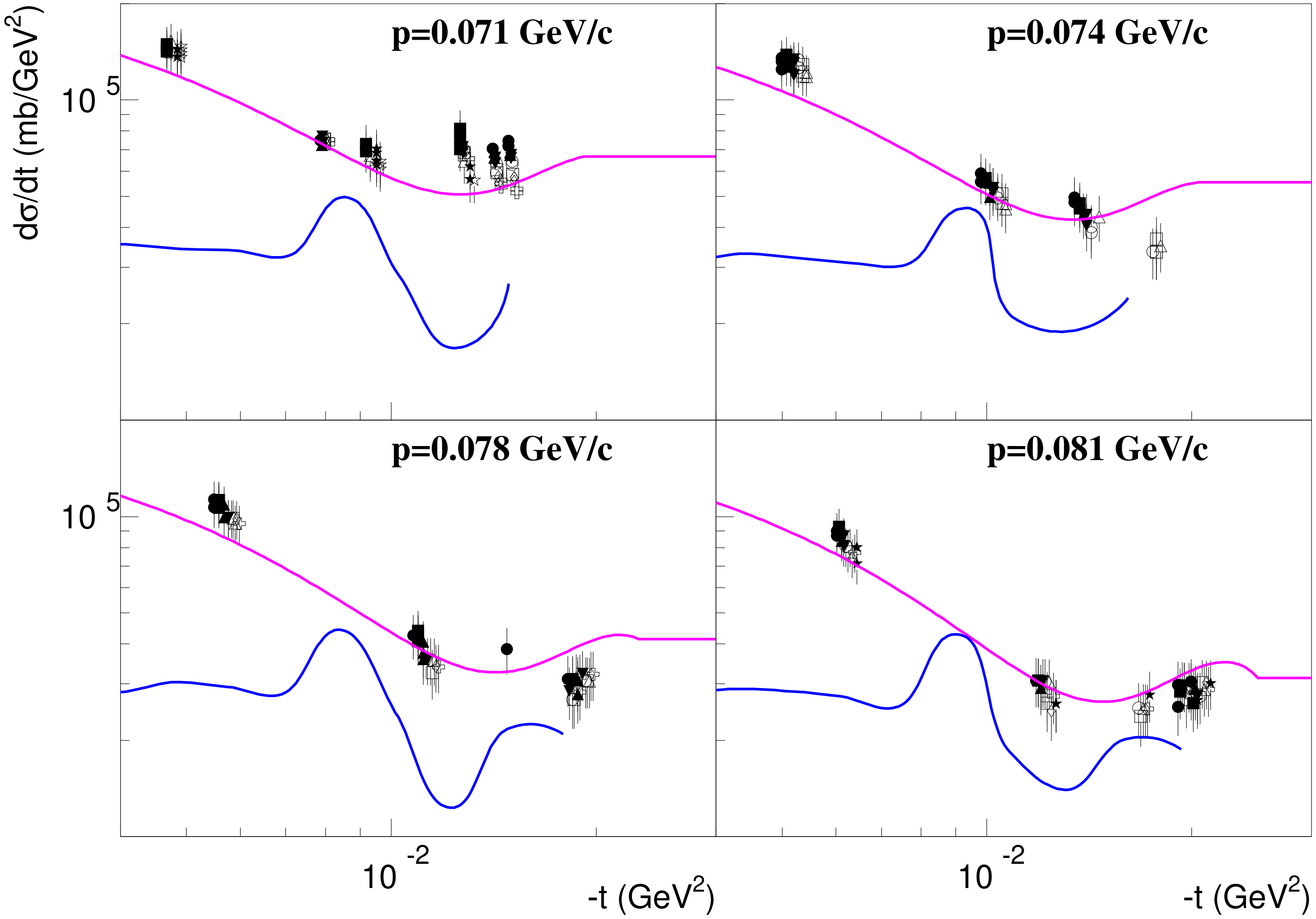

dσ/dt (mb/GeV^2)
p=0.04 GeV/c
p=0.042 GeV/c
p=0.044 GeV/c
p=0.046 GeV/c
10^6
10^5
10^{-3}
-t (GeV^2)



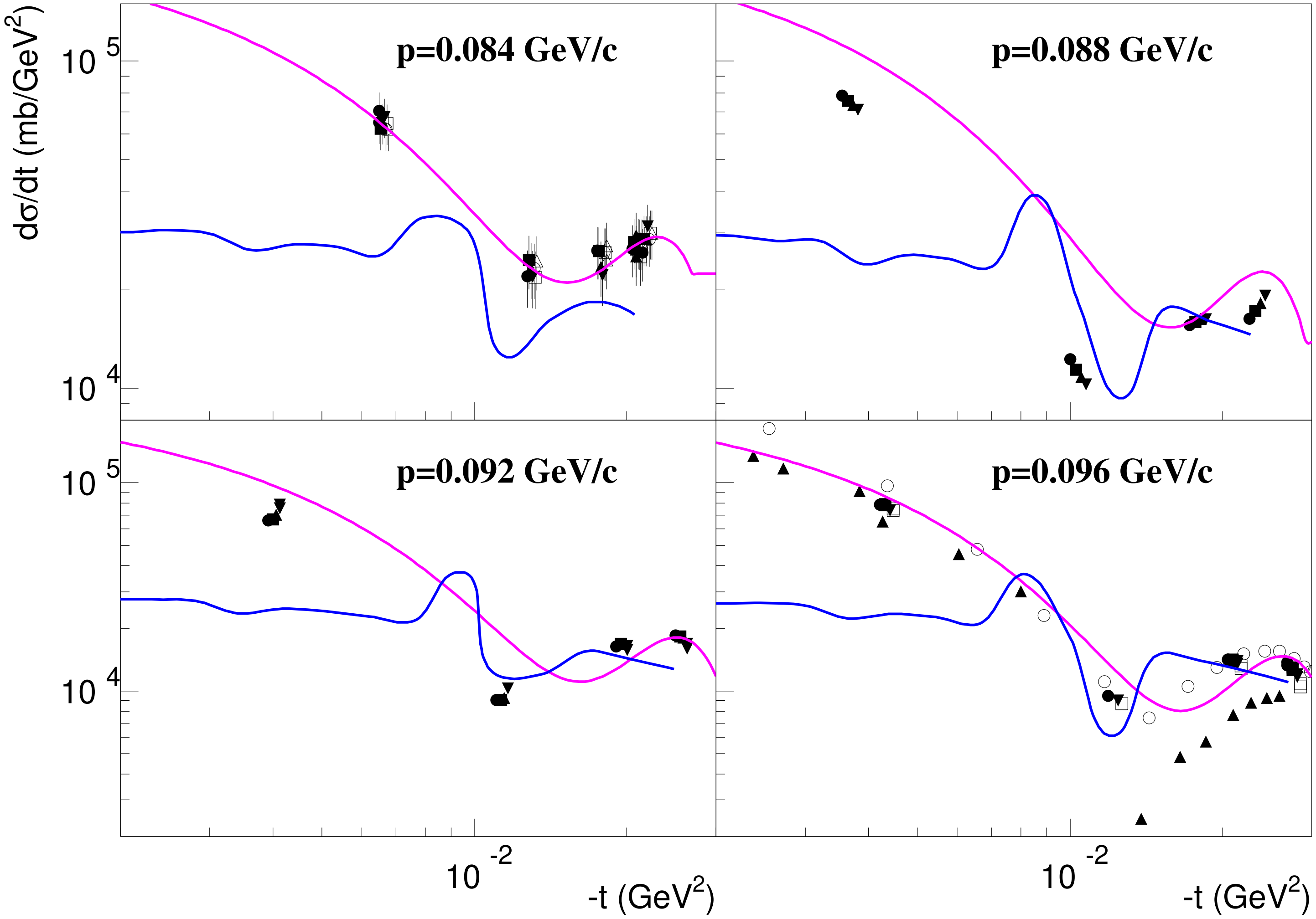
p=0.048 GeV/c
p=0.05 GeV/c
p=0.052 GeV/c
p=0.056 GeV/c
dσ/dt (mb/GeV^2)
10 5
10 5
10 -3
10 -3
-t (GeV^2)
-t (GeV^2)

CERN


p=0.062 GeV/c
p=0.064 GeV/c
p=0.067 GeV/c
p=0.069 GeV/c
dσ/dt (mb/GeV^2)
10 ^{5}
10 ^{5}
10 $^{-2}$
10 $^{-2}$
-t (GeV^2)
-t (GeV^2)

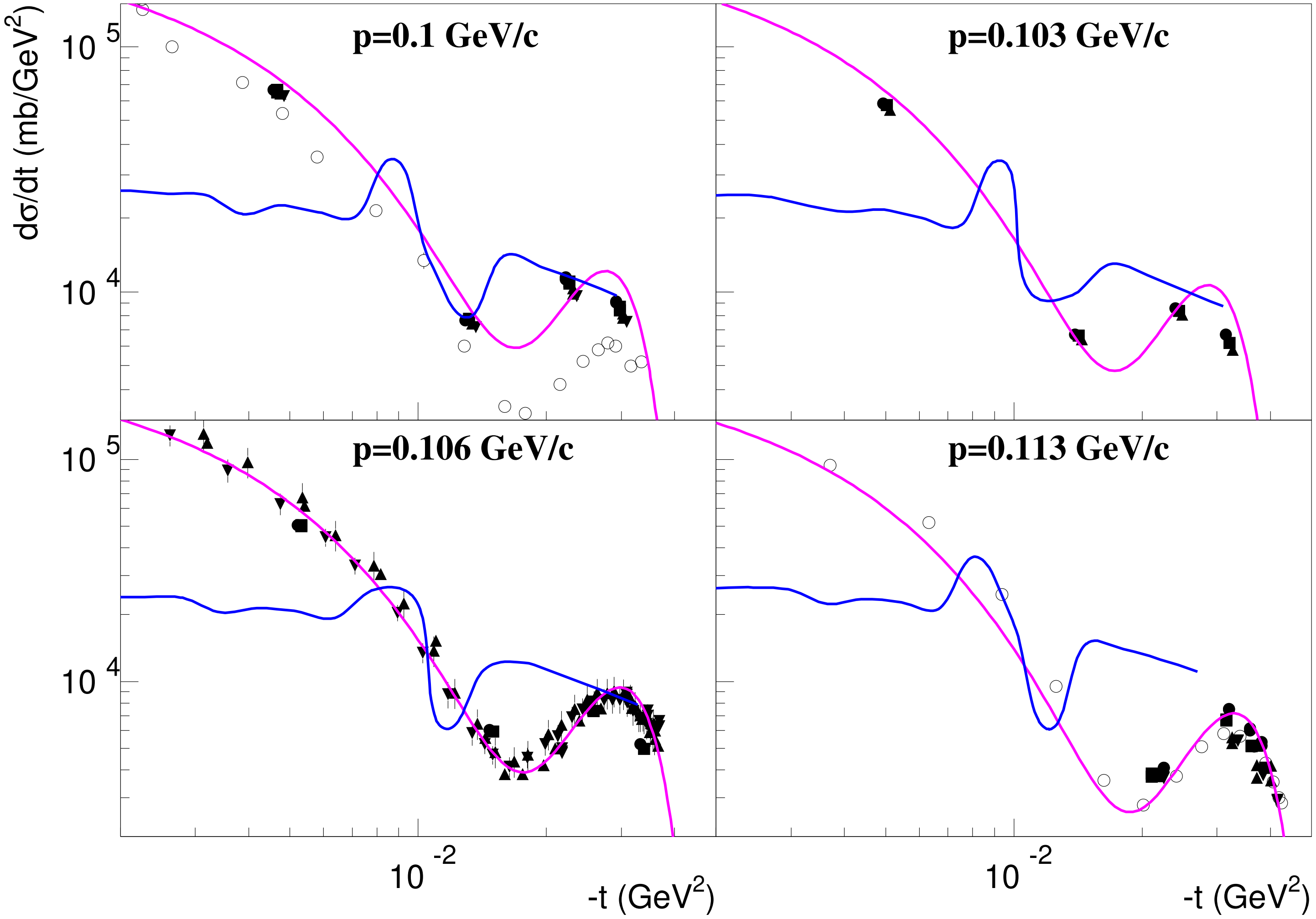

p=0.071 GeV/c
p=0.074 GeV/c
p=0.078 GeV/c
p=0.081 GeV/c
dσ/dt (mb/GeV^2)
10^5
10^5
10^{-2}
10^{-2}
-t (GeV^2)
-t (GeV^2)

CERN

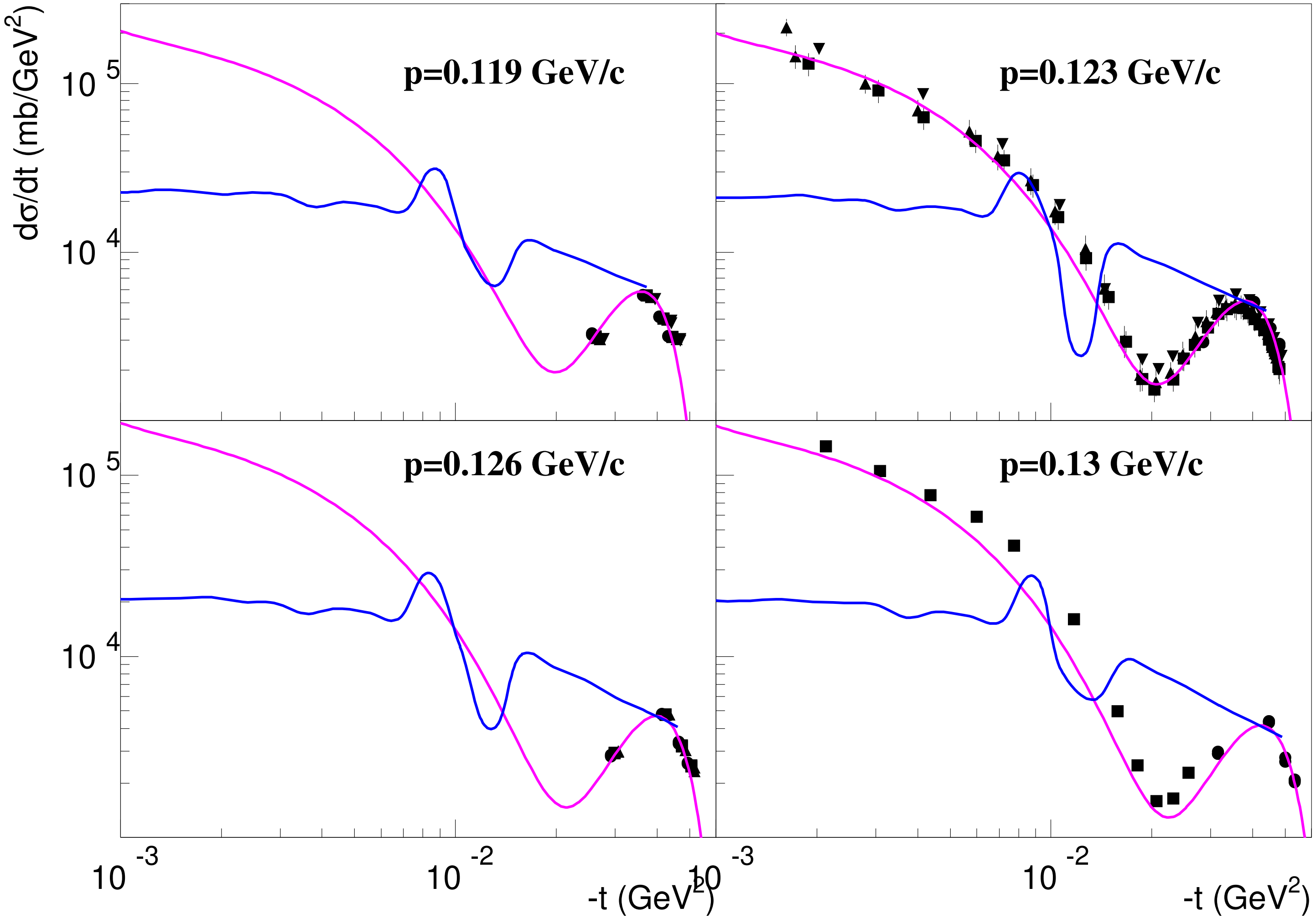

p=0.084 GeV/c
p=0.088 GeV/c
p=0.092 GeV/c
p=0.096 GeV/c
dσ/dt (mb/GeV^2)
10^5
10^4
10^{-2}
-t (GeV^2)

CERN

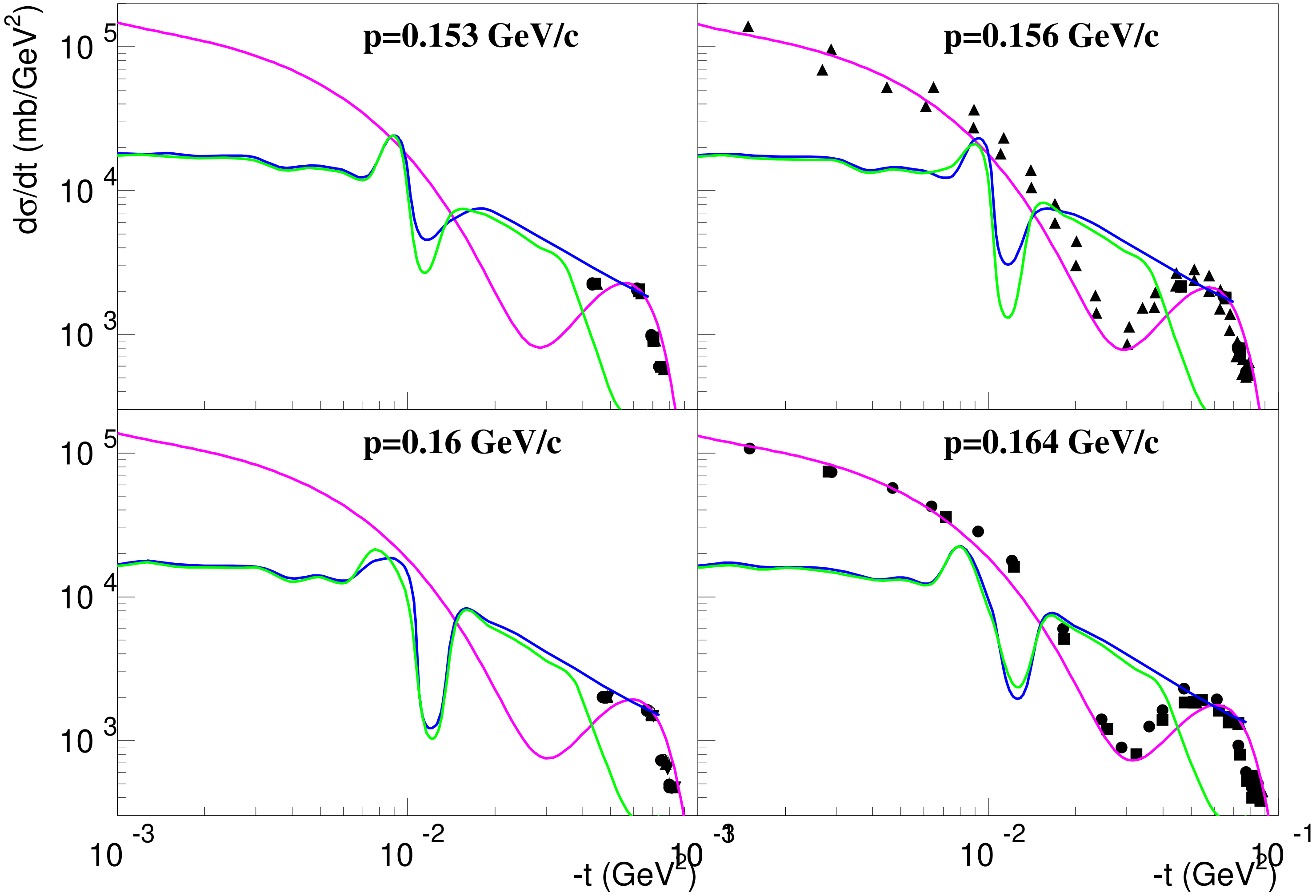
Verification and development of pA elastic scattering.

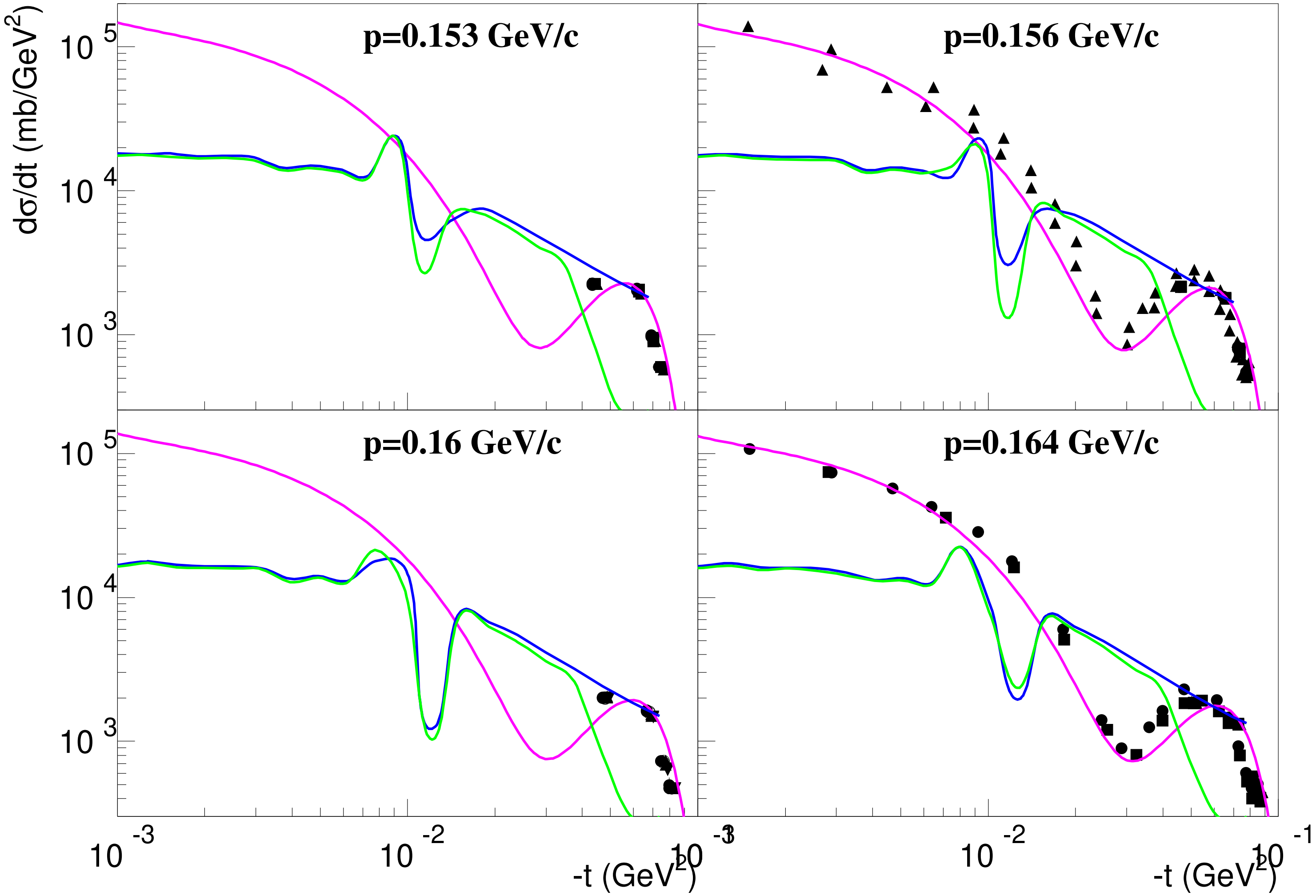


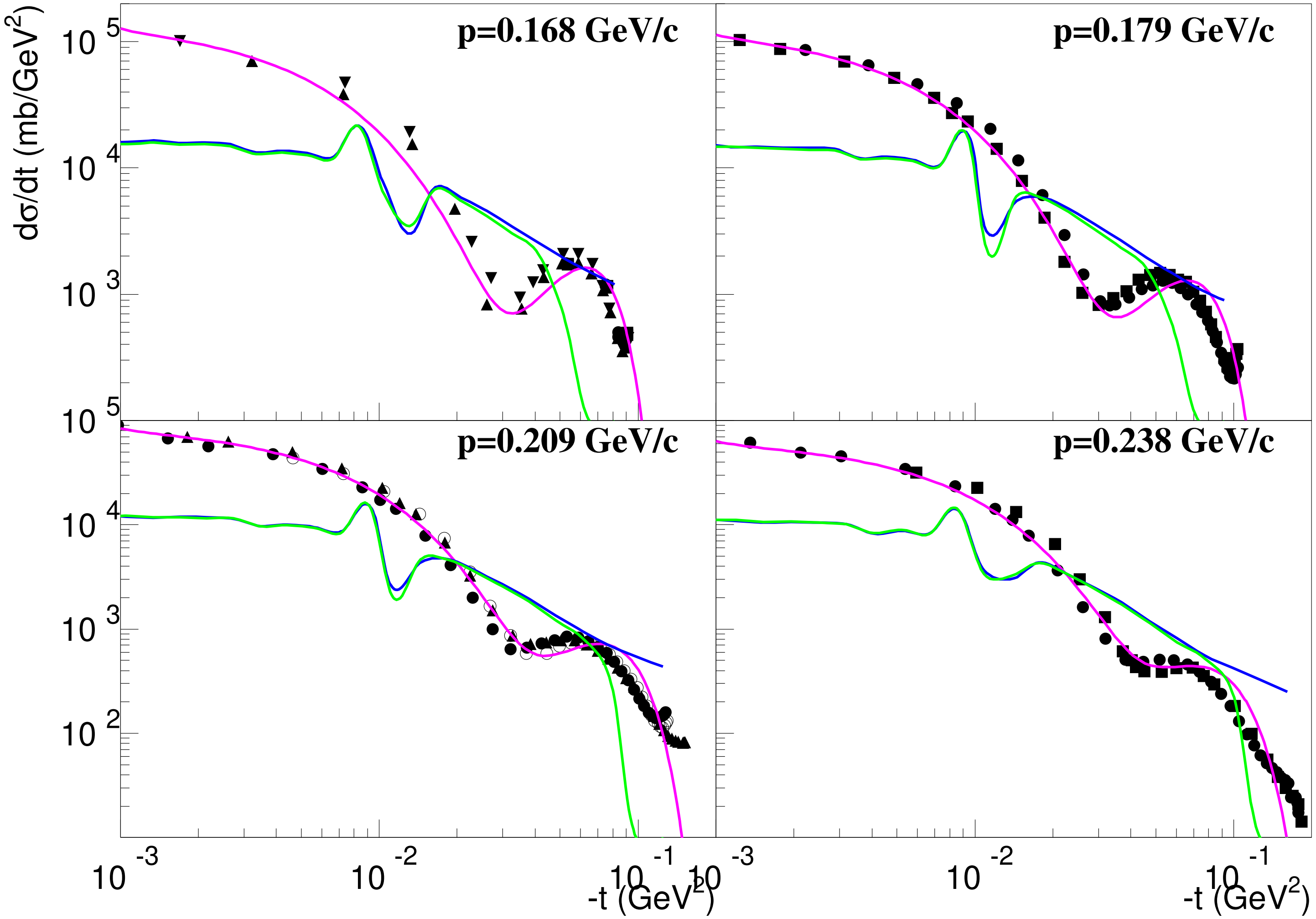
CERN


p=0.119 GeV/c
p=0.123 GeV/c
p=0.126 GeV/c
p=0.13 GeV/c
dσ/dt (mb/GeV^2)
10^5
10^4
10^{-3}
10^{-2}
-t (GeV^2)

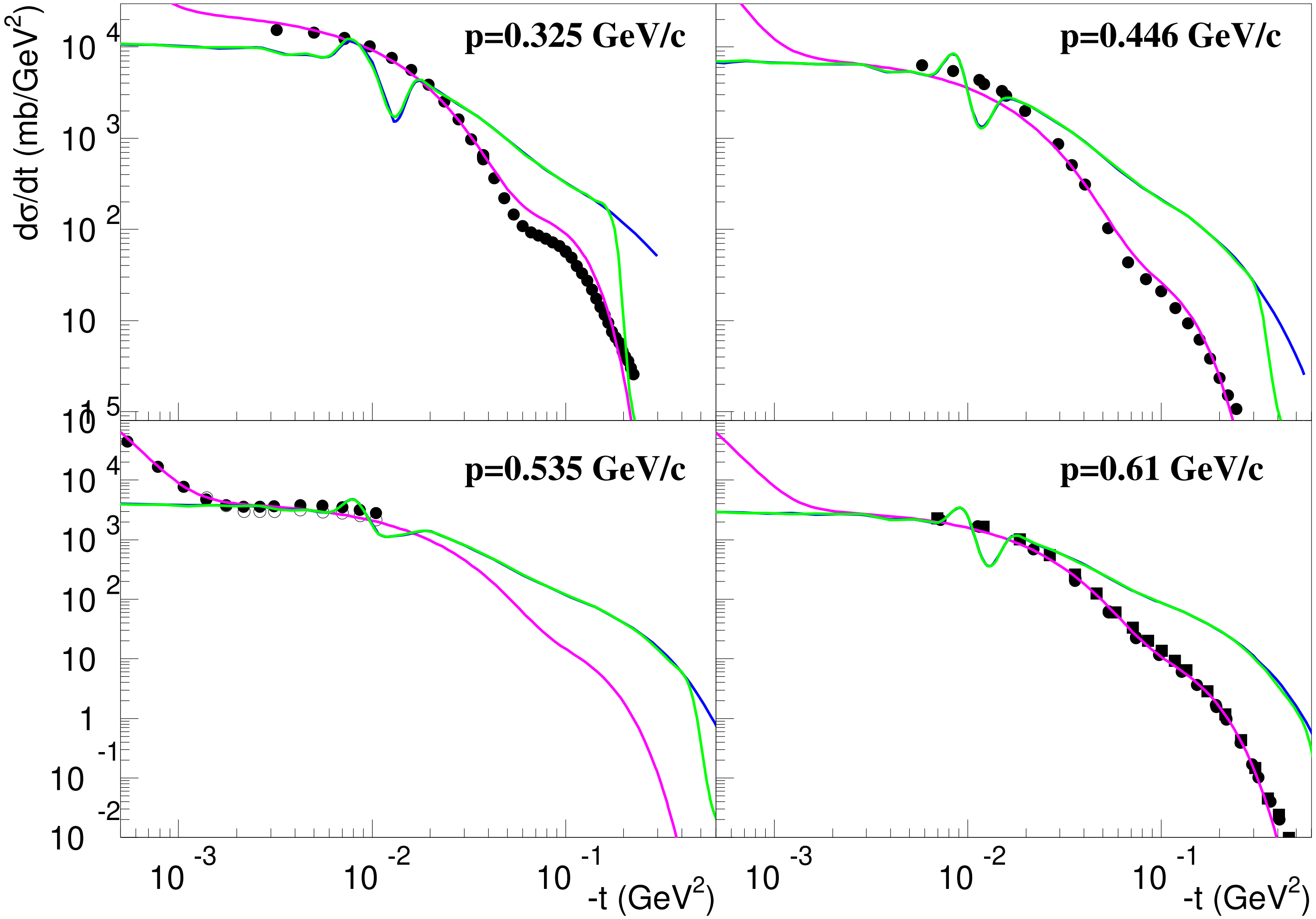
CERN


p=0.153 GeV/c
p=0.156 GeV/c
p=0.16 GeV/c
p=0.164 GeV/c
dσ/dt (mb/GeV²)
10 5
10 4
10 3
10 -3
10 -2
10 -1
-t (GeV²)

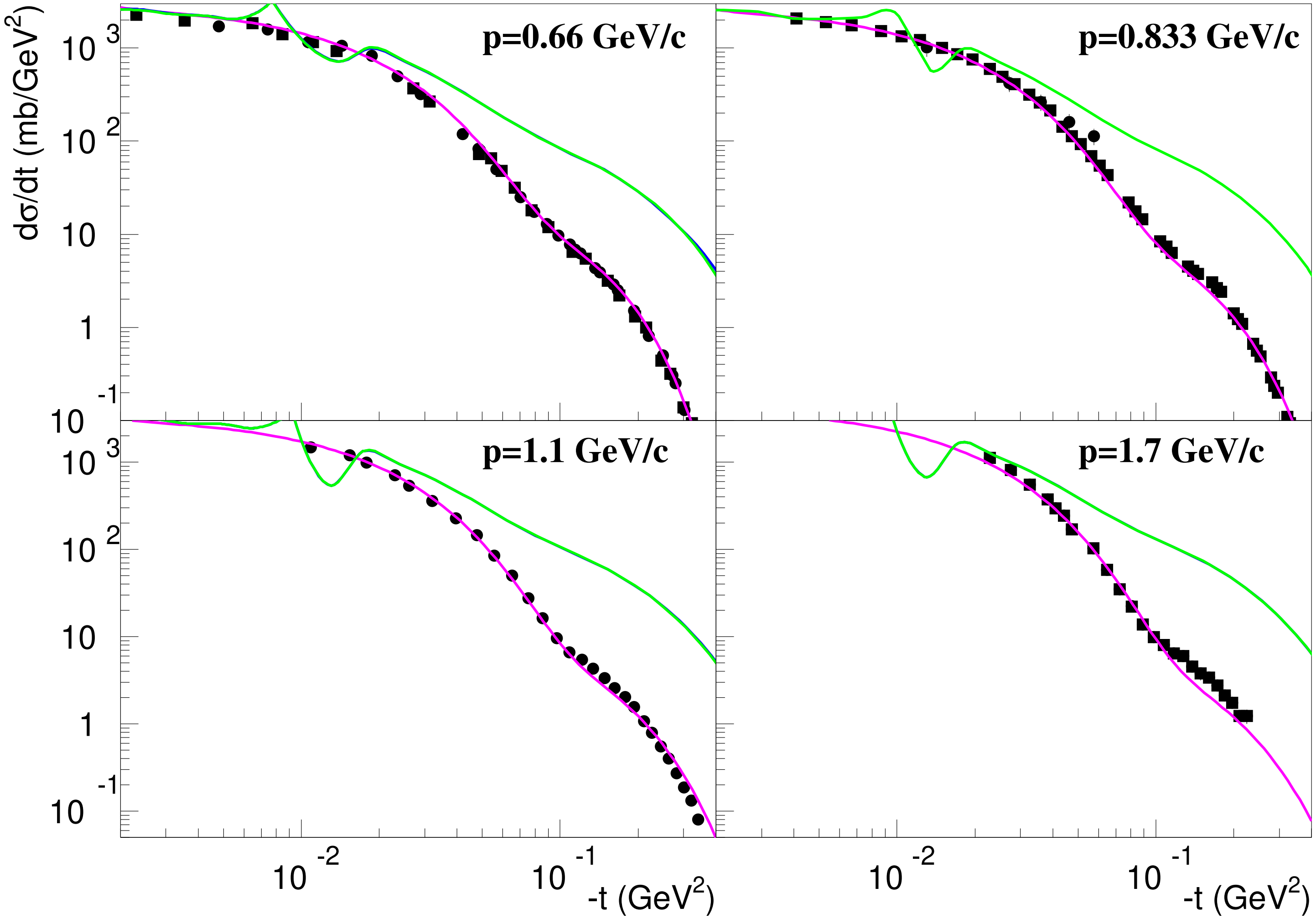

p=0.153 GeV/c
p=0.156 GeV/c
p=0.16 GeV/c
p=0.164 GeV/c
dσ/dt (mb/GeV^2)
-t (GeV^2)
-t (GeV^2)


p=0.168 GeV/c
p=0.179 GeV/c
p=0.209 GeV/c
p=0.238 GeV/c
dσ/dt (mb/GeV^2)
-t (GeV^2)
-t (GeV^2)

CERN


p=0.325 GeV/c
p=0.446 GeV/c
p=0.535 GeV/c
p=0.61 GeV/c
dσ/dt (mb/GeV^2)
-t (GeV^2)
-t (GeV^2)

CERN


p=0.66 GeV/c
p=0.833 GeV/c
p=1.1 GeV/c
p=1.7 GeV/c
dσ/dt (mb/GeV²)
-t (GeV²)
-t (GeV²)

Conclusion

- CHIPS gives a detailed approximation of the existing data;
- ***BUG*** In GHAD neither G4HadronCrossSection, nor G4HadronElasticProcess are sensitive for the isotope content of the G4Element, so at present a deuterium target can not be simulated;
- For internal use the G4QElastic process is made up to pHe-elastic;
- The existing GHAD (G4LElastic) approximation is bad everywhere and below 100 MeV/c does not produce a recoil nucleus;
- G4LElasticB produces the recoil nucleus everywhere, but looks to be too isotropic;
- G4ElasticHadrNucleusHE and G4ElasticCascadeInterface do not work.