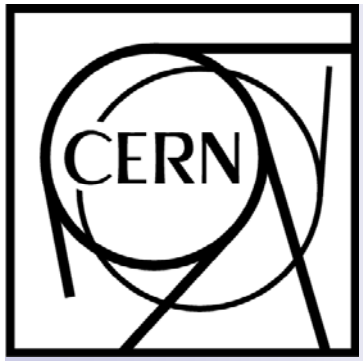
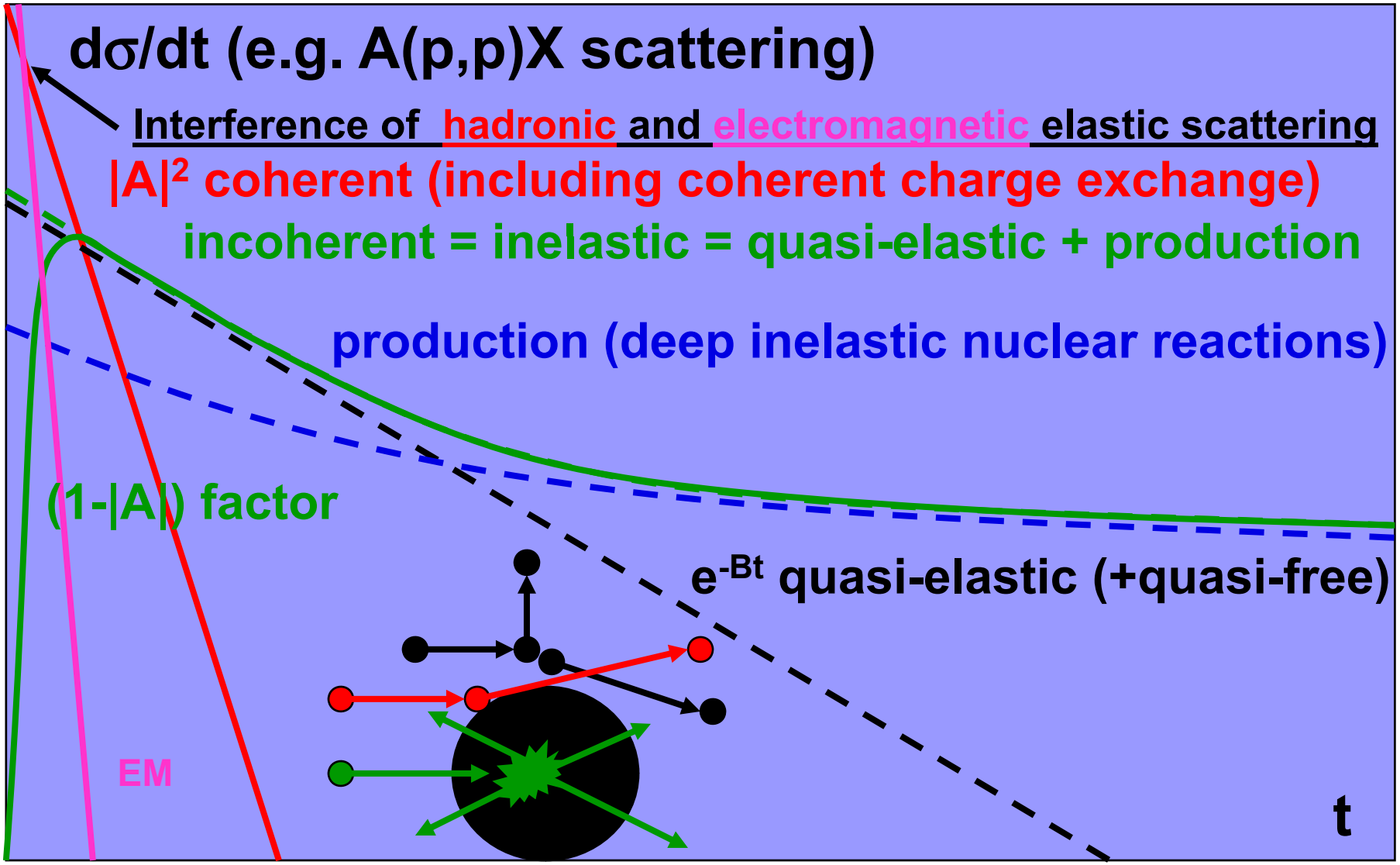


CHIPS R&D for Geant4 Hadronic Applications

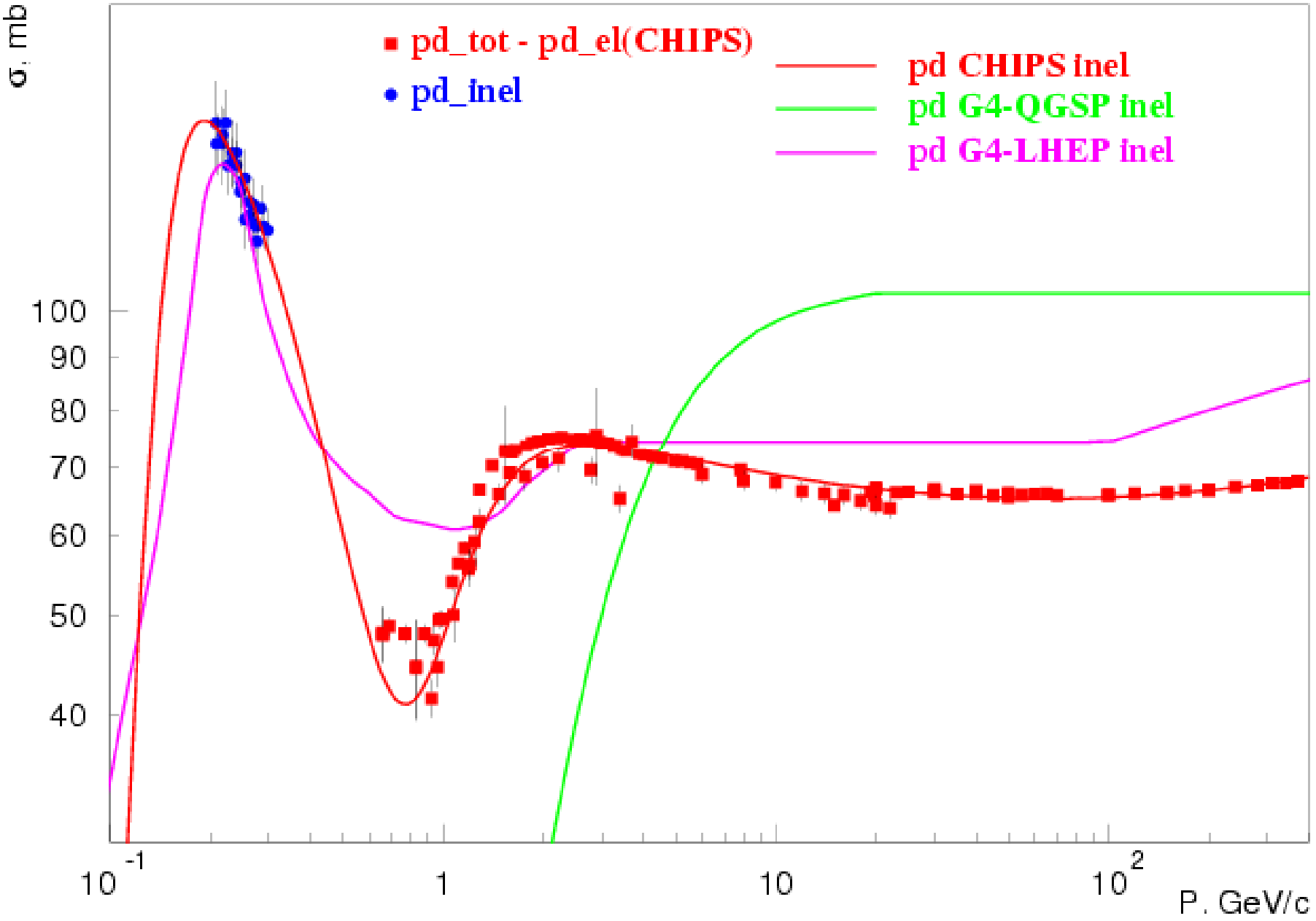
Mikhail Kosov, 12th Geant4 Workshop (GB, Sept. 2007)

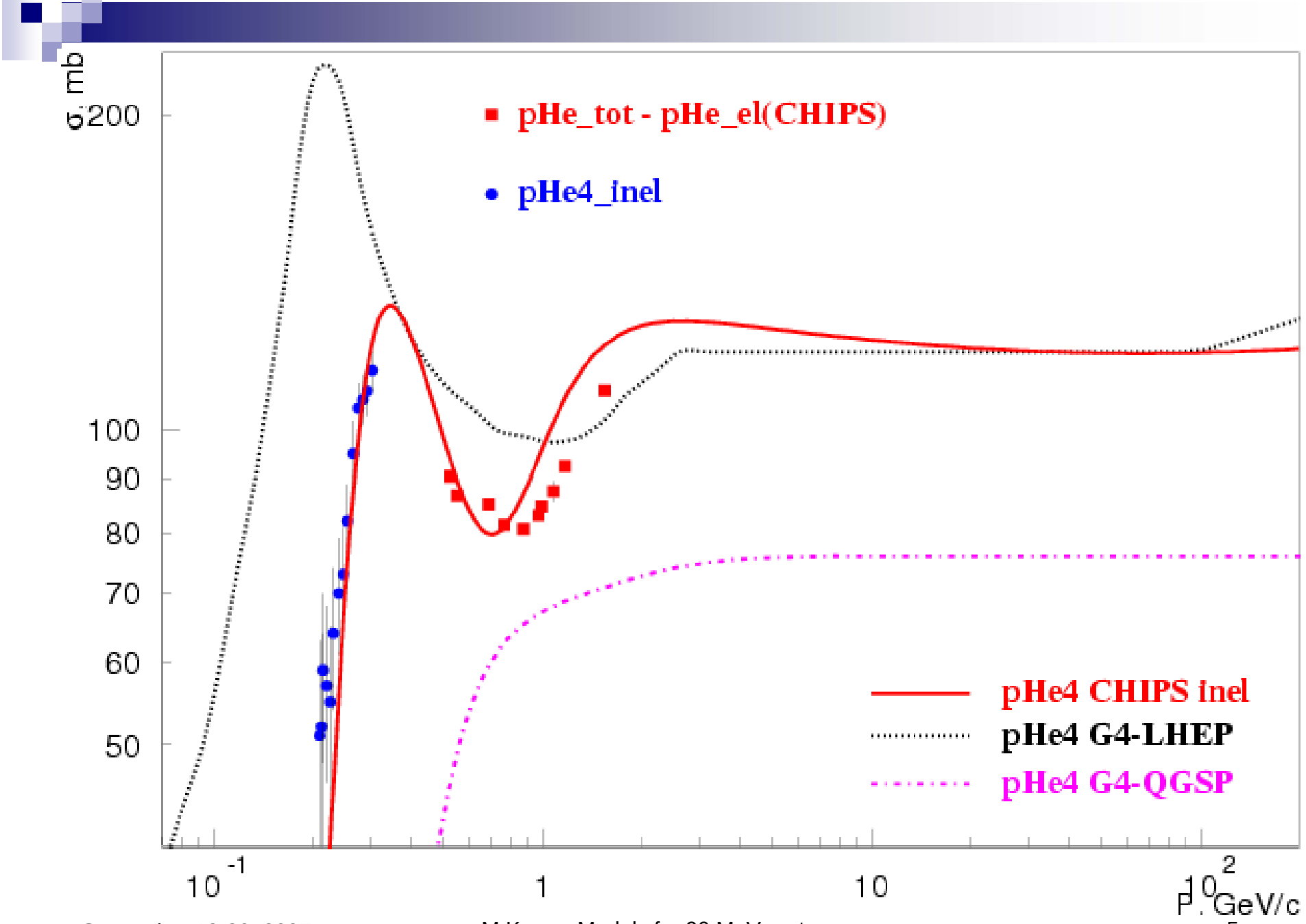
High energy Glauber approach

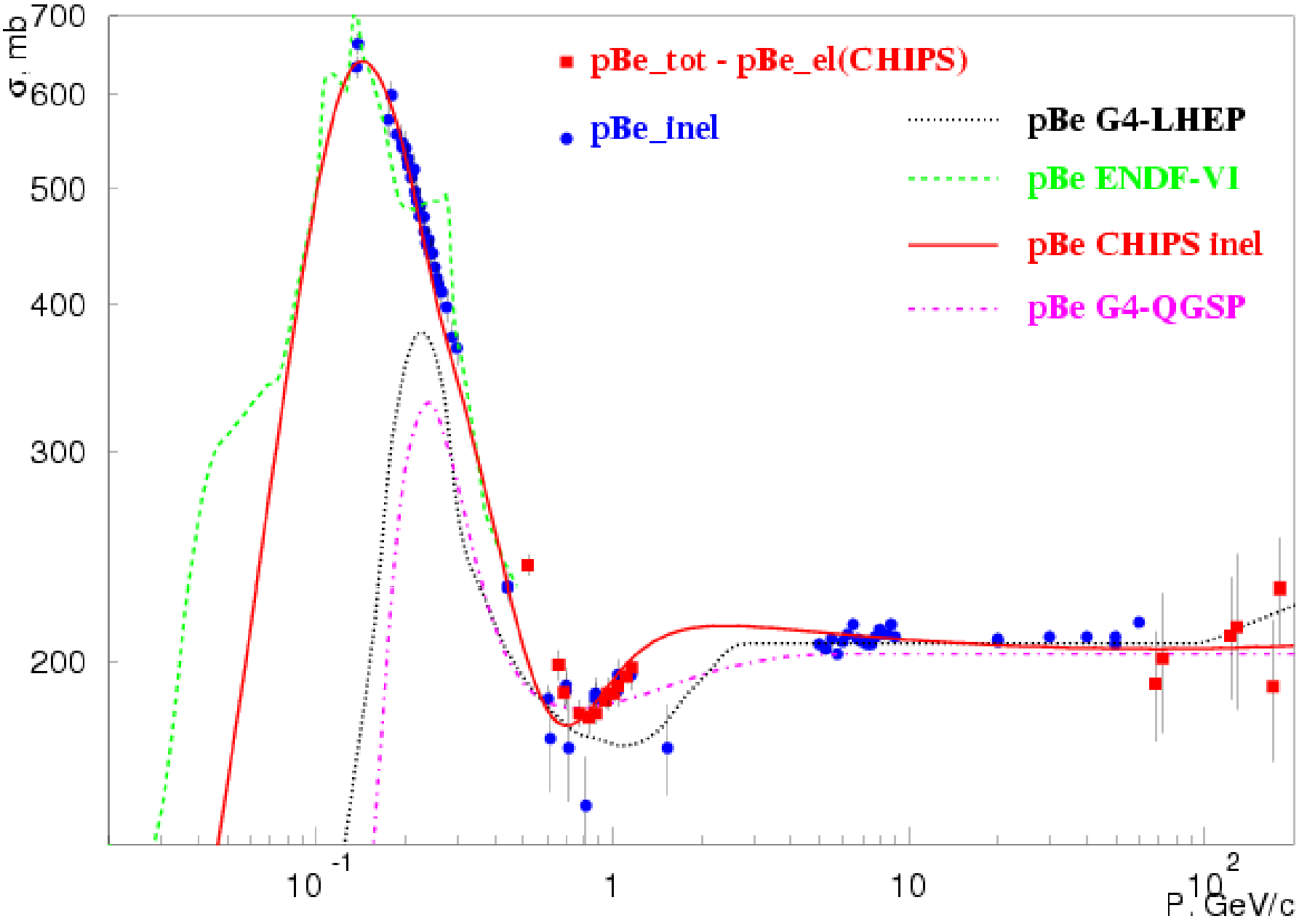


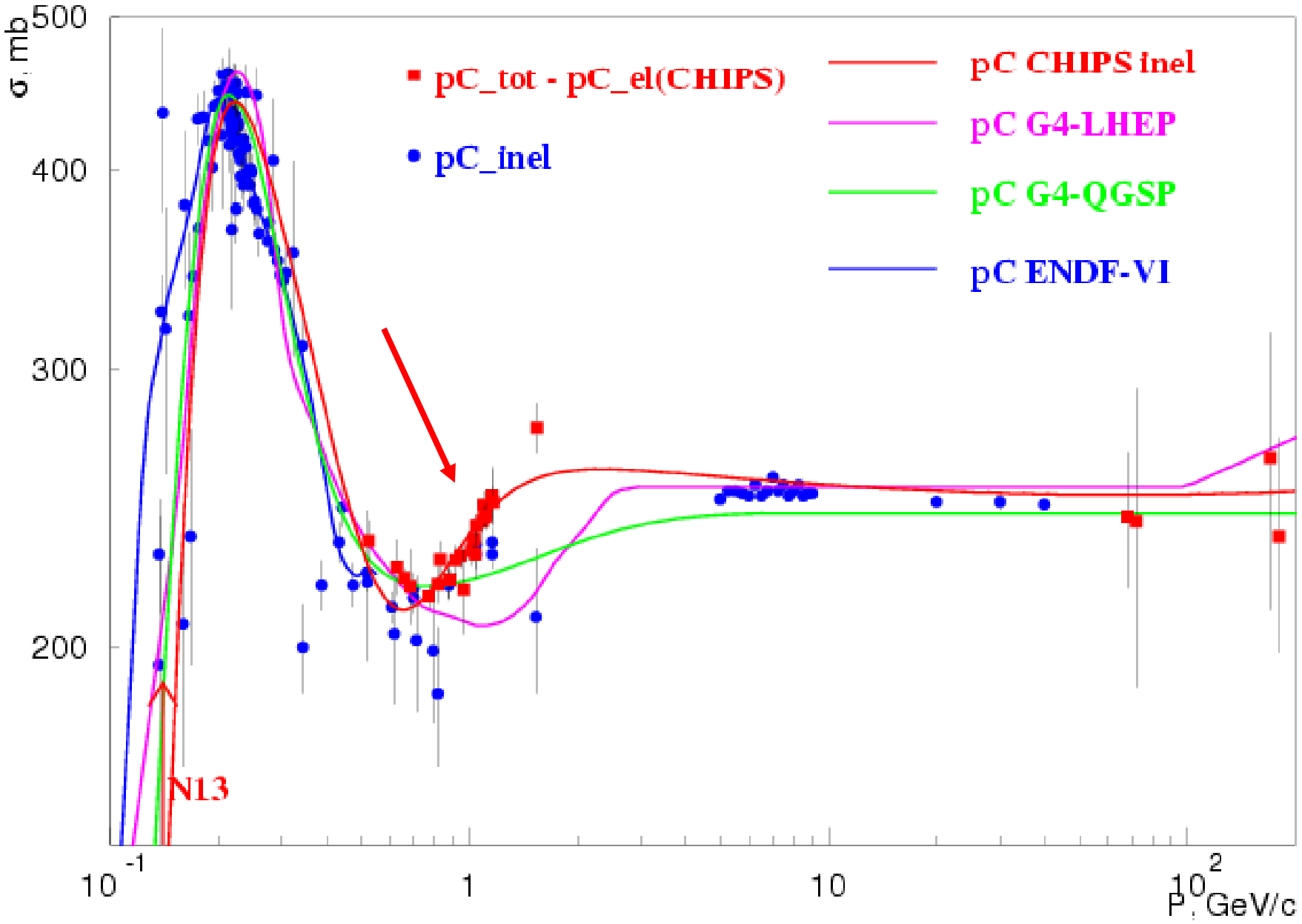
Consistent approximation of $\sigma_{in}=\sigma_{tot}-\sigma_{el}$

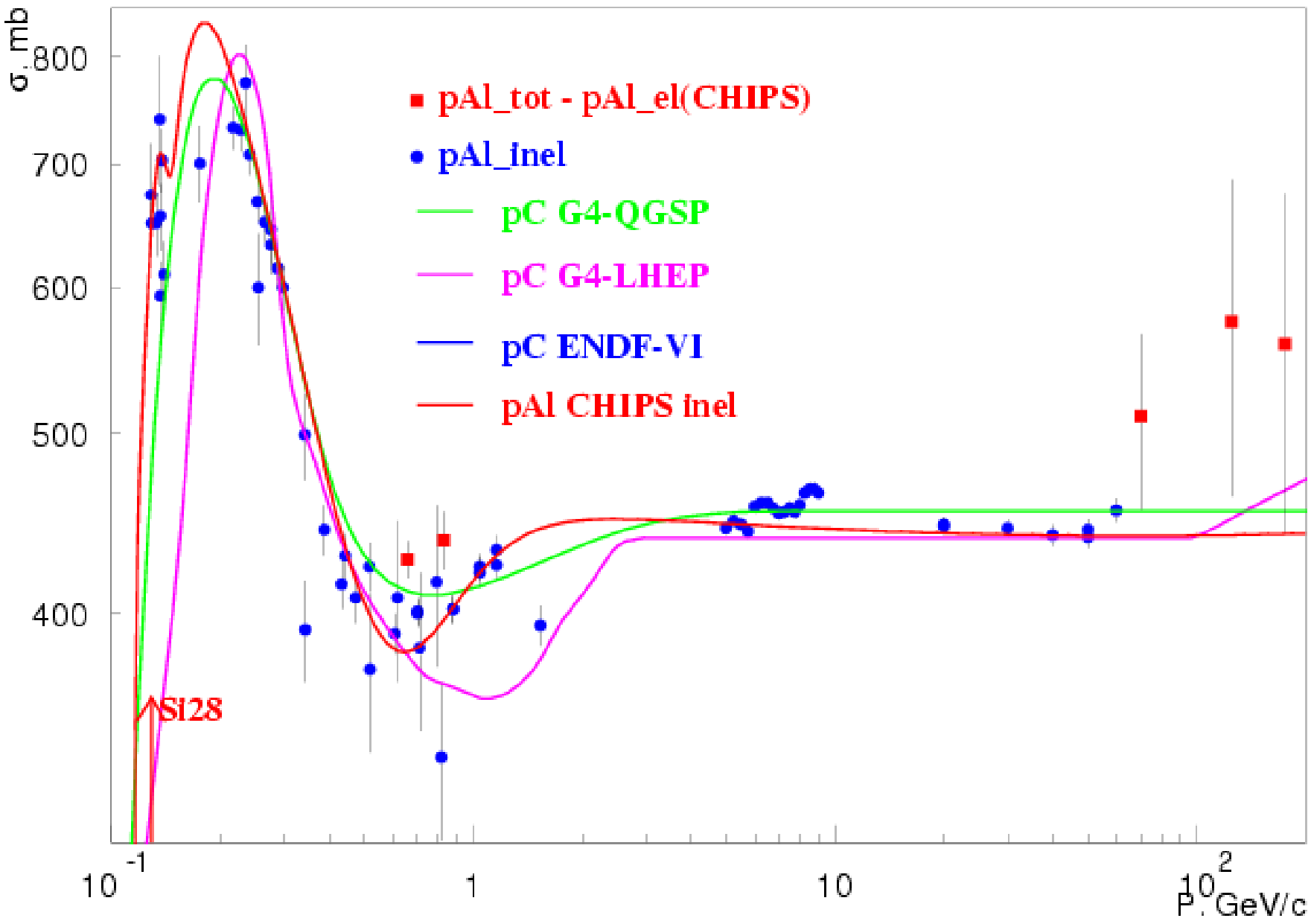
- σ_{el} and σ_{in} cross-sections are fitted separately in Geant4, but together they must be equal to σ_{tot}
- Elastic cross-sections (σ_{el}) are difficult to measure, because they need integration over squared transverse momentum (**-t**), while at low **-t** the hadronic elastic scattering should be disentangled from the electromagnetic elastic scattering, which are interfering on the amplitude level
- As soon as the σ_{el} are integrated and the σ_{el}(A,P) parameterization is found, the σ_{tot}-σ_{el} values can be used along with σ_{in} in the consistent σ_{in} fit
- $d\sigma_{el}/dt$ was integrated & σ_{el}(A,p) was found in CHIPS

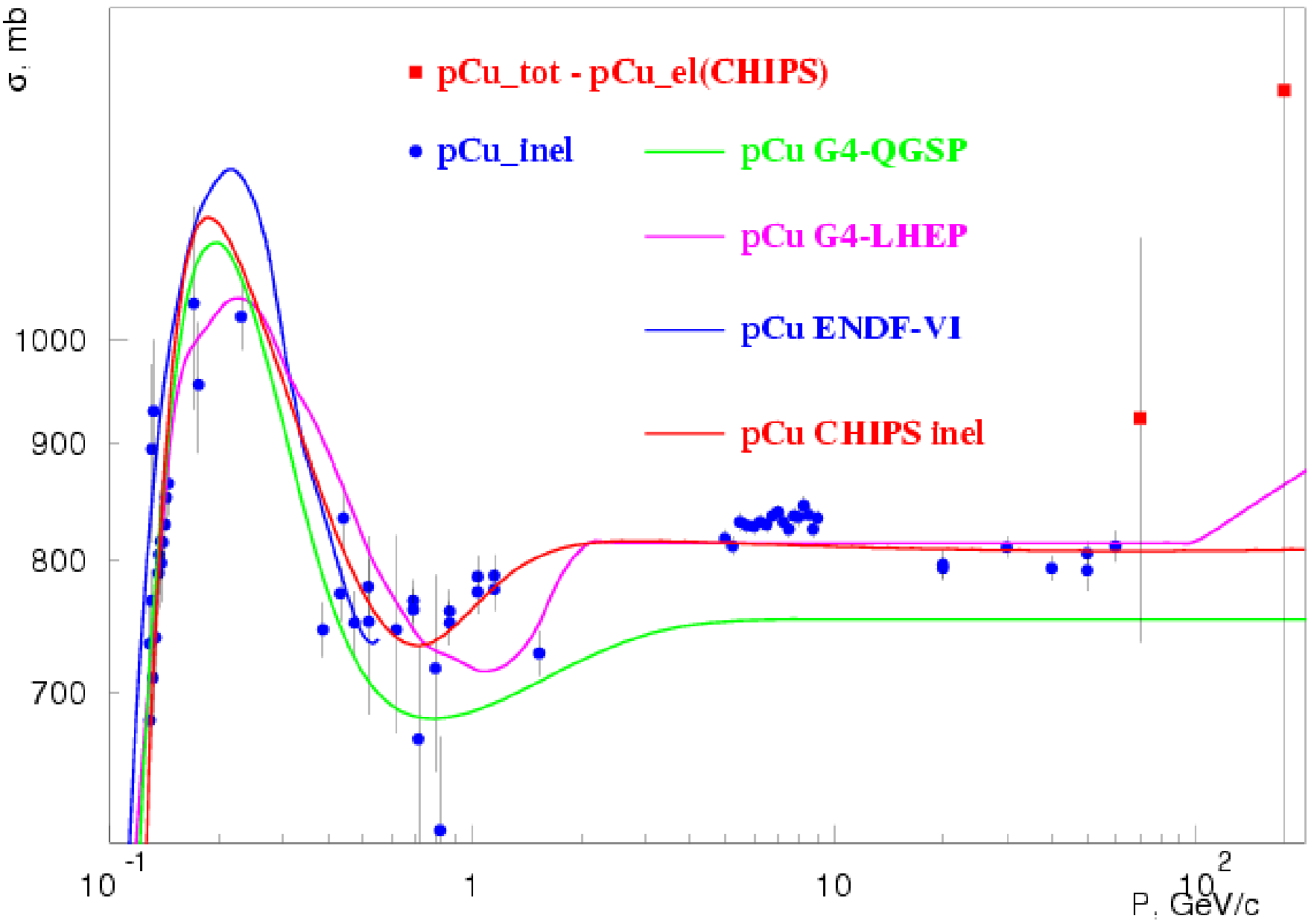

σ, mb
pd_tot - pd_el(CHIPS)
pd_inel
pd CHIPS inel
pd G4-QGSP inel
pd G4-LHEP inel
100
90
80
70
60
50
40
10^-1
1
10
10^2
P, GeV/c

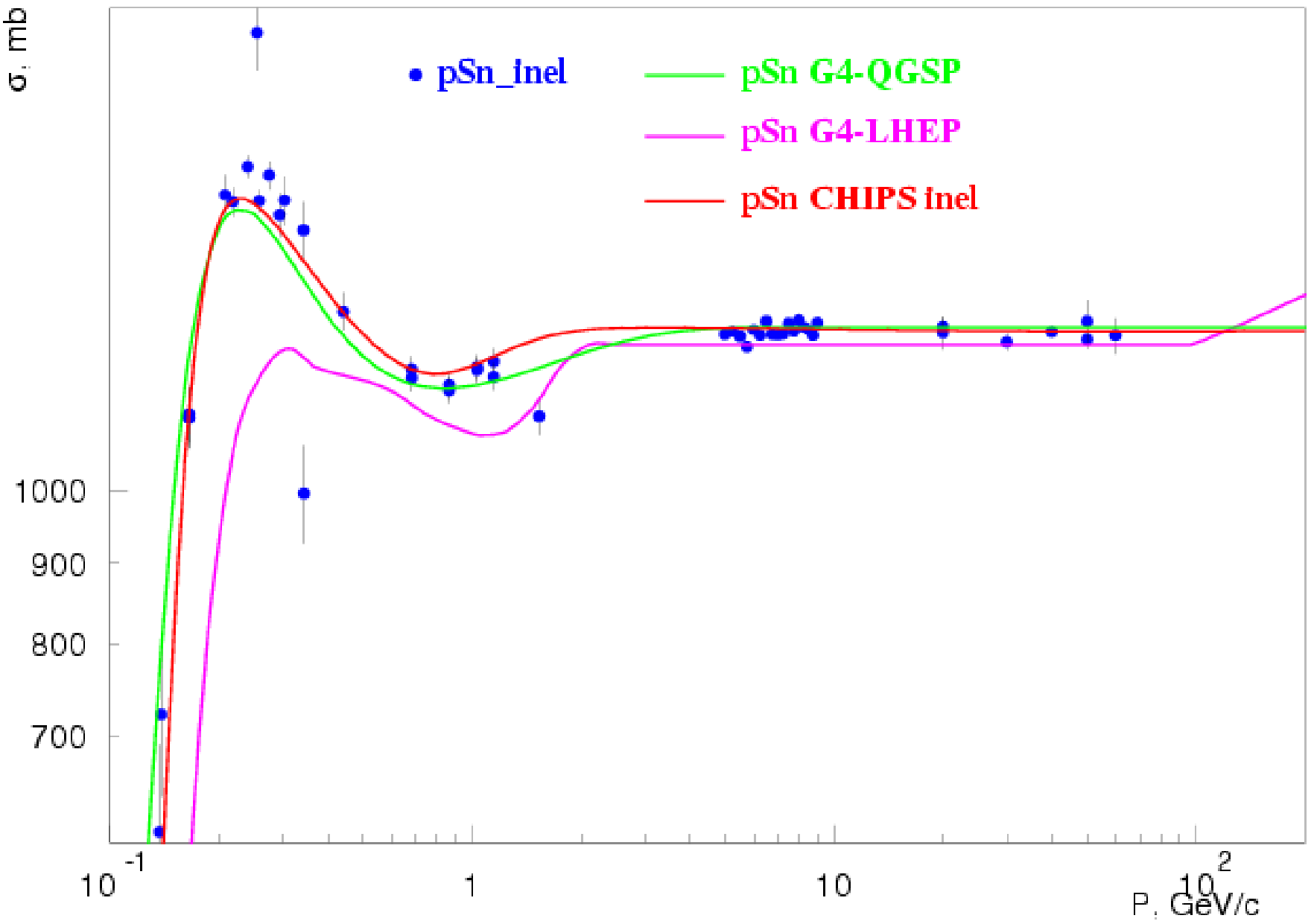

σ, mb
200
100
90
80
70
60
50
pHe_tot - pHe_el(CHIPS)
pHe4_inel
pHe4 CHIPS inel
pHe4 G4-LHEP
pHe4 G4-QGSP
10^-1
1
10
10^2
P, GeV/c

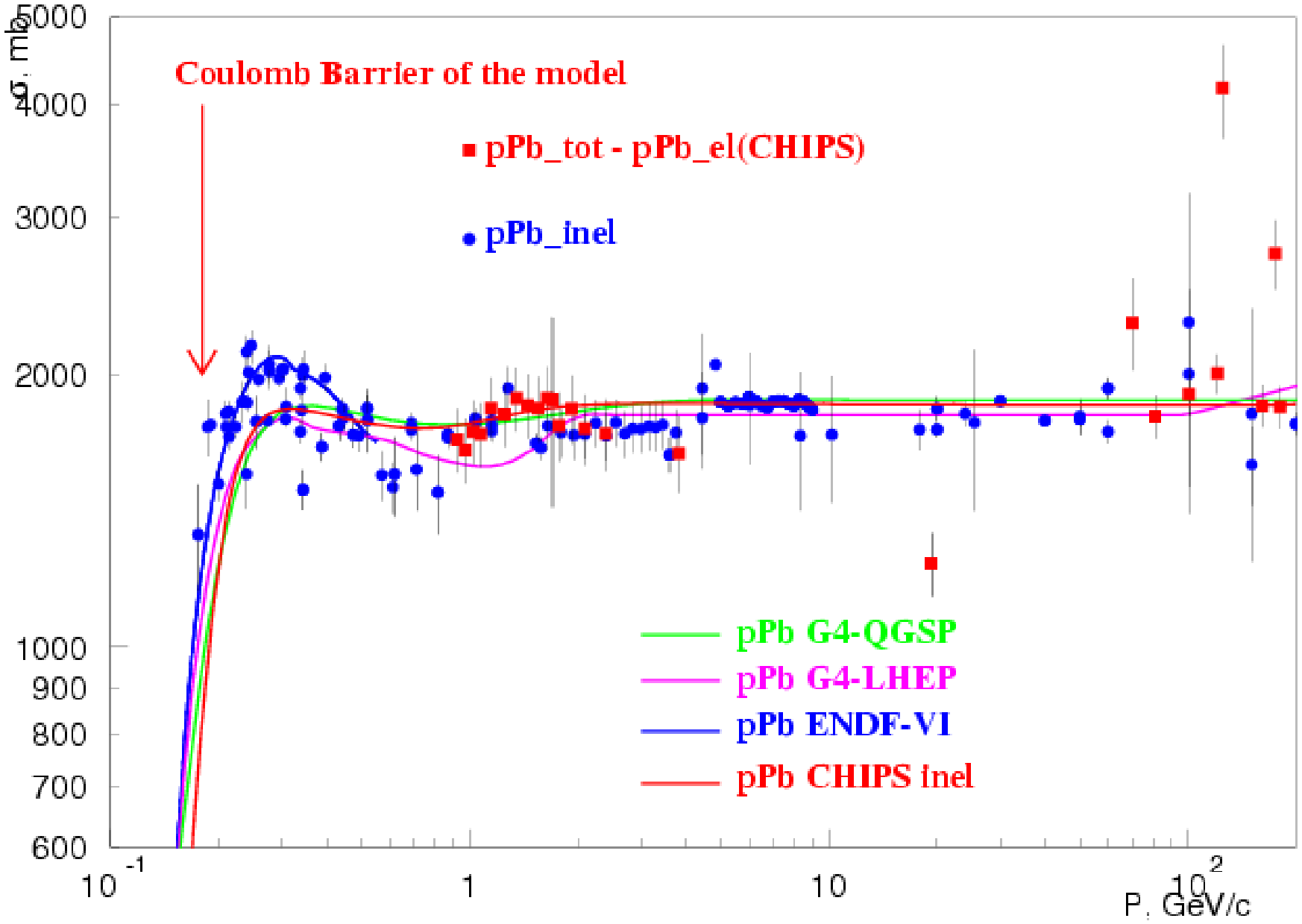

σ, mb
700
600
500
400
300
200
pBe_tot - pBe_el(CHIPS)
pBe_inel
pBe G4-LHEP
pBe ENDF-VI
pBe CHIPS inel
pBe G4-QGSP
10^-1
1
10
10^2
P, GeV/c


σ, mb
500
400
300
200
pC_tot - pC_el(CHIPS)
pC_inel
pC CHIPS inel
pC G4-LHEP
pC G4-QGSP
pC ENDF-VI
N13
10^-1
1
10
10^2
P, GeV/c


σ, mb
800
700
600
500
400
pAl_tot - pAl_el(CHIPS)
pAl_inel
pC G4-QGSP
pC G4-LHEP
pC ENDF-VI
pAl CHIPS inel
Si28
10^-1
1
10
10^2
P, GeV/c


σ, mb
pCu_tot - pCu_el(CHIPS)
pCu_inel
pCu G4-QGSP
pCu G4-LHEP
pCu ENDF-VI
pCu CHIPS inel
1000
900
800
700
10^-1
1
10
10^2
P, GeV/c


σ, mb
pSn_inel
pSn G4-QGSP
pSn G4-LHEP
pSn CHIPS inel
1000
900
800
700
10^-1
1
10
10^2
P, GeV/c

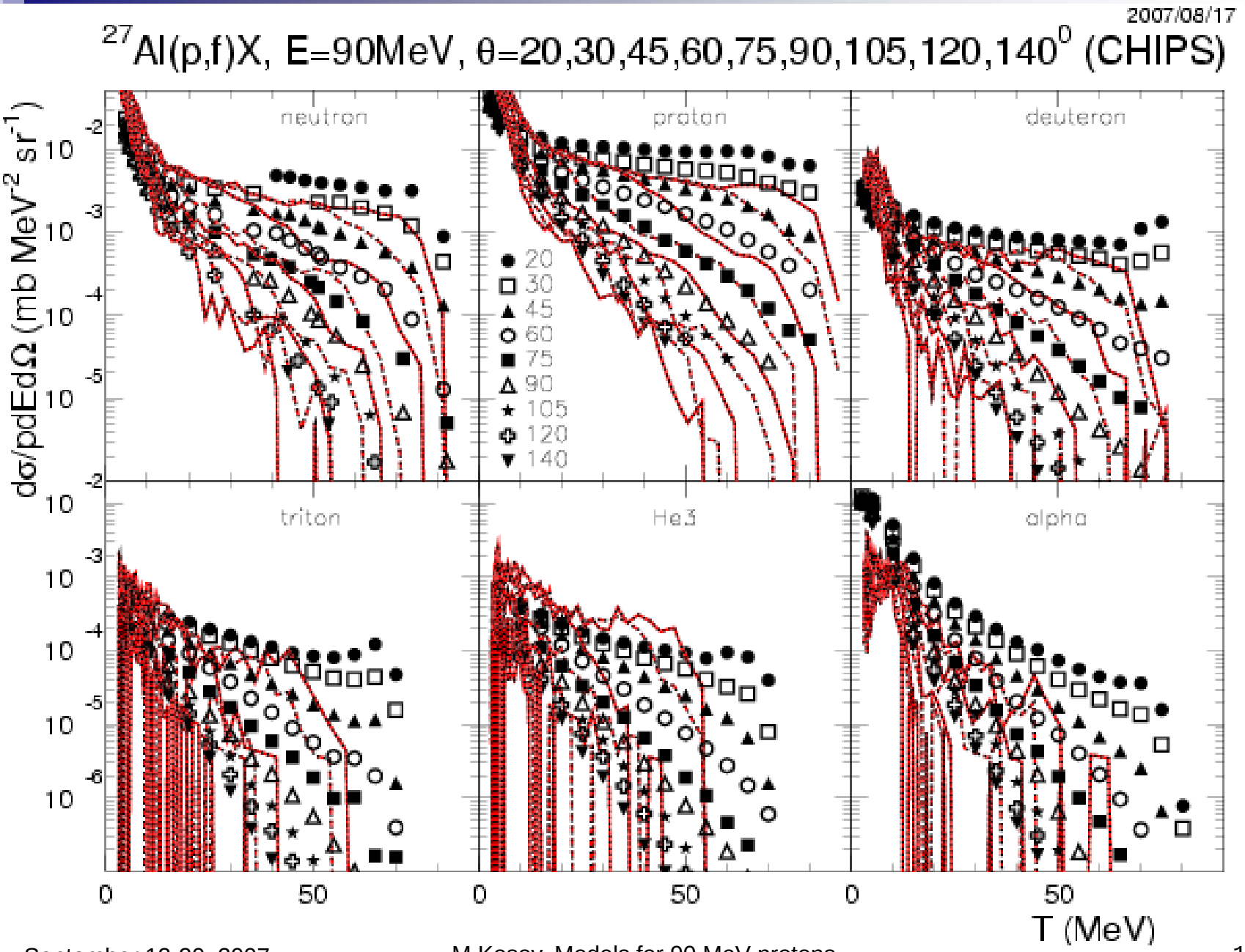

Coulomb Barrier of the model
pPb_tot - pPb_el(CHIPS)
pPb_inel
pPb G4-QGSP
pPb G4-LHEP
pPb ENDF-VI
pPb CHIPS inel
σ, mb
P, GeV/c
5000
4000
3000
2000
1000
900
800
700
600
10^-1
1
10
10^2

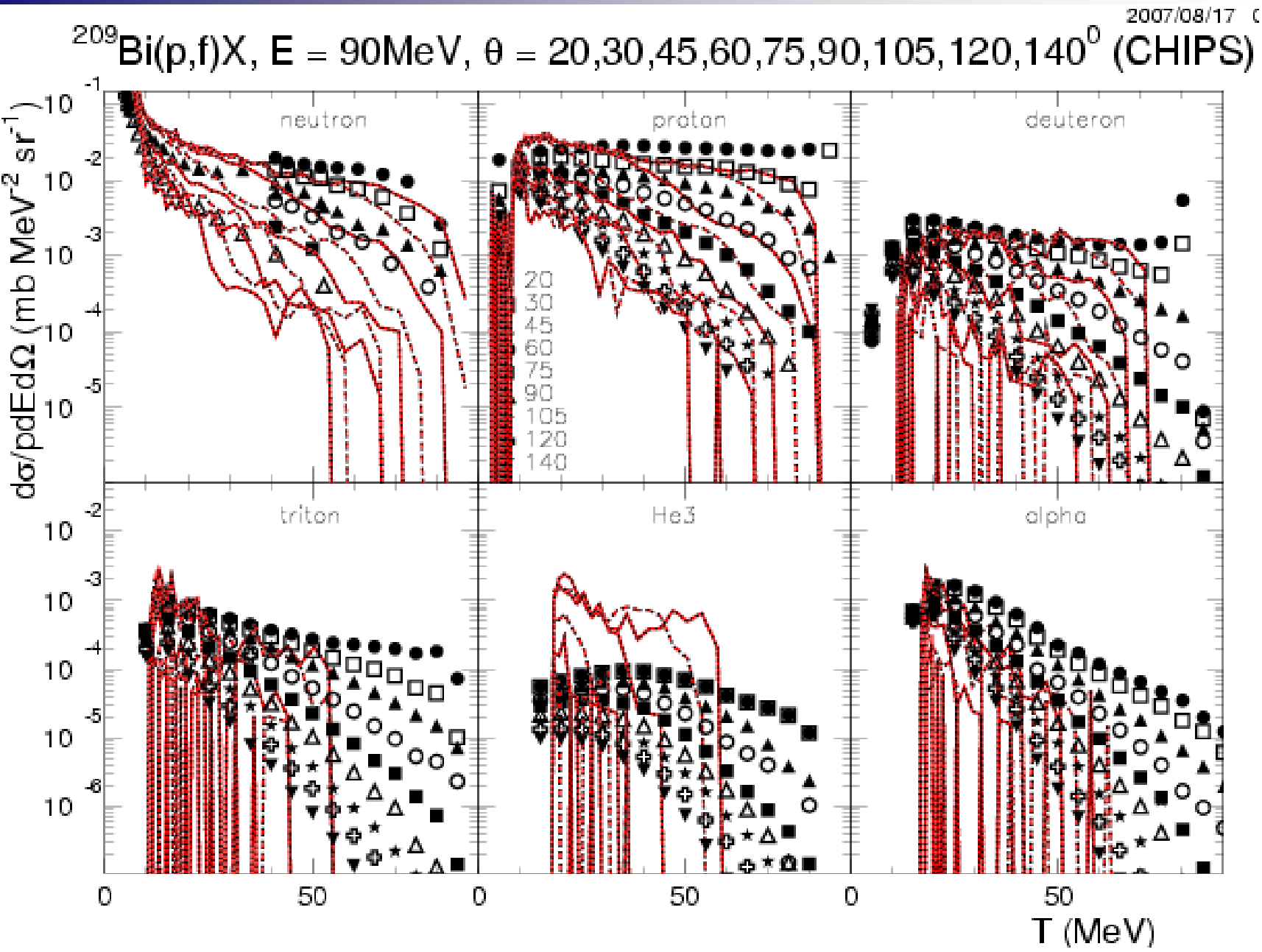
Conclusion for CHIPS pA cross-sections

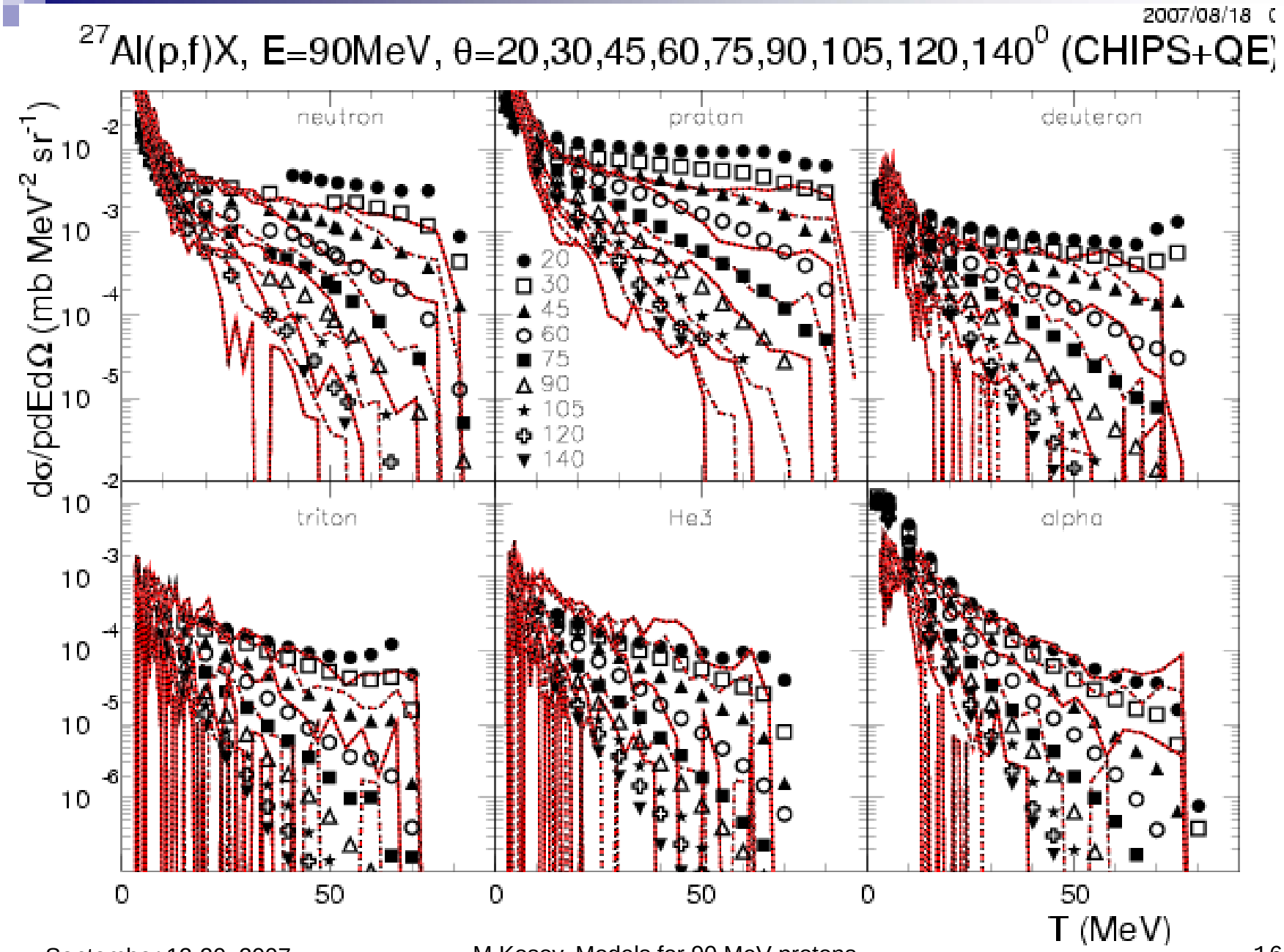
- The low energy analysis shows that the proton-nuclear cross-sections in Geant4 ought to be upgraded.
- The CHIPS consistent approximation of inelastic cross-sections can be used as the upgrade, but it needs better fitting at very high energies (logarithmic increase).
- An advantage of the CHIPS fit is the analytic A-dependence instead of the individual parameterization for different A

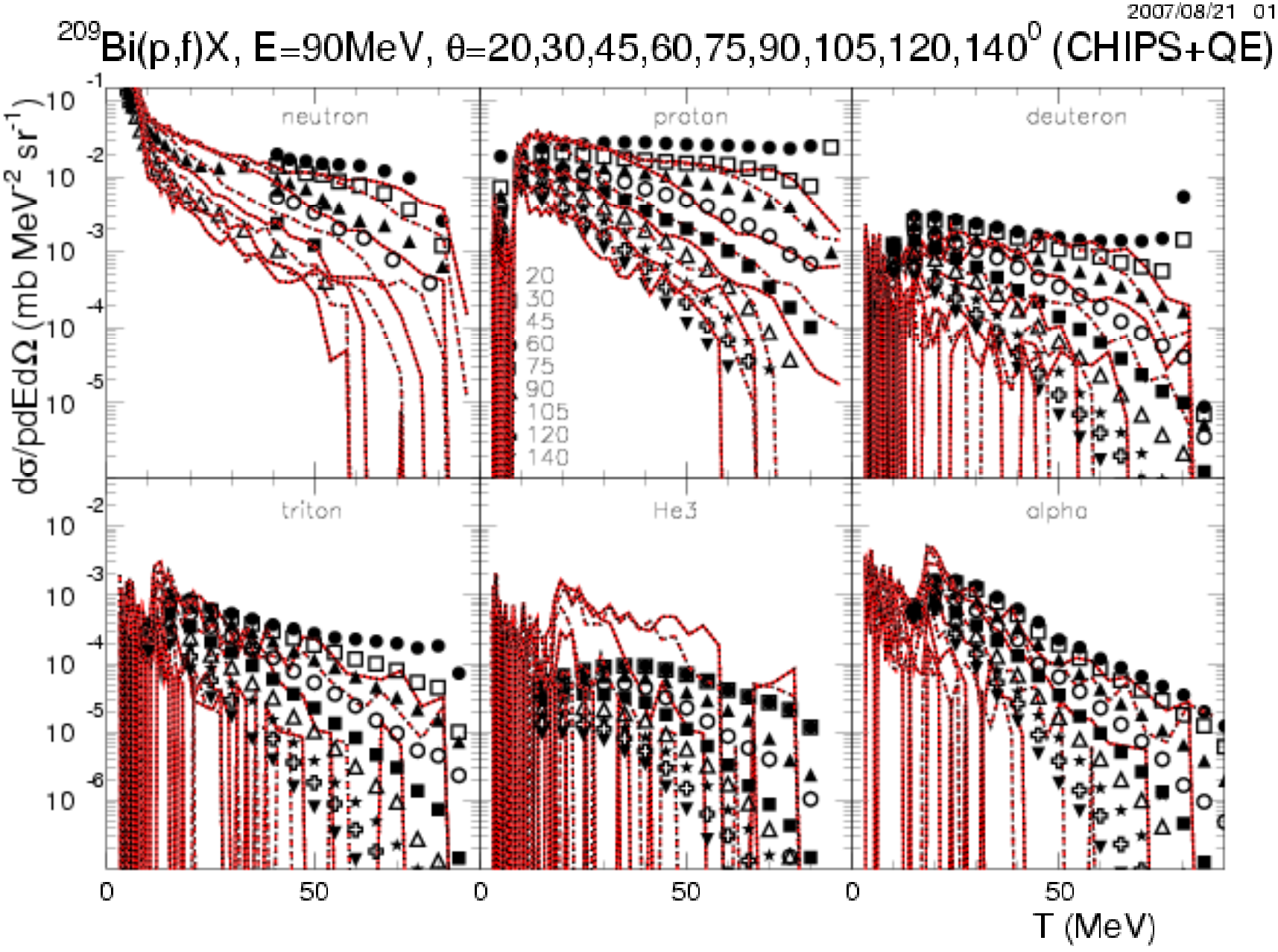
R&D Hadronic Low Energy CHIPS models

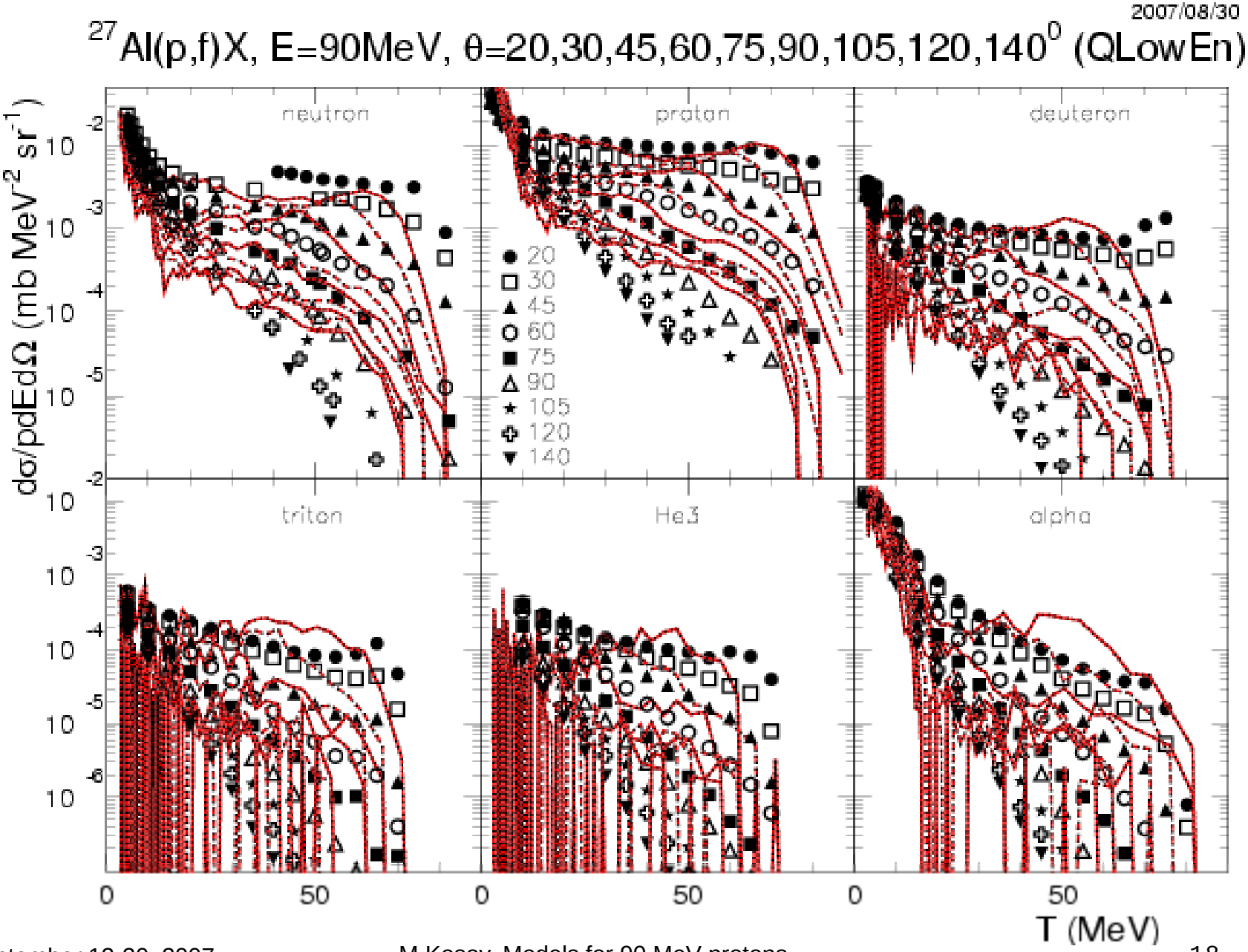
- CHIPS G4QCollision process at low energy
  - At present only for low energy protons. Needs XS.
  - Fragmentation engine is the same as for stopping
  - Quasi-Elastic (G4QuasiFreeRatios) is necessary
  - Only the first try: parameters should be tuned
  - There is no γ-deexcitation: only one final photon
- Universal CHIPS G4QLowEnergy process
  - Universal nuclear- & hypernuclear-nuclear process
  - Uses G4QEvaporation model as a back-end model
  - SU(3)-symmetric fast generator of fragments (A<5)

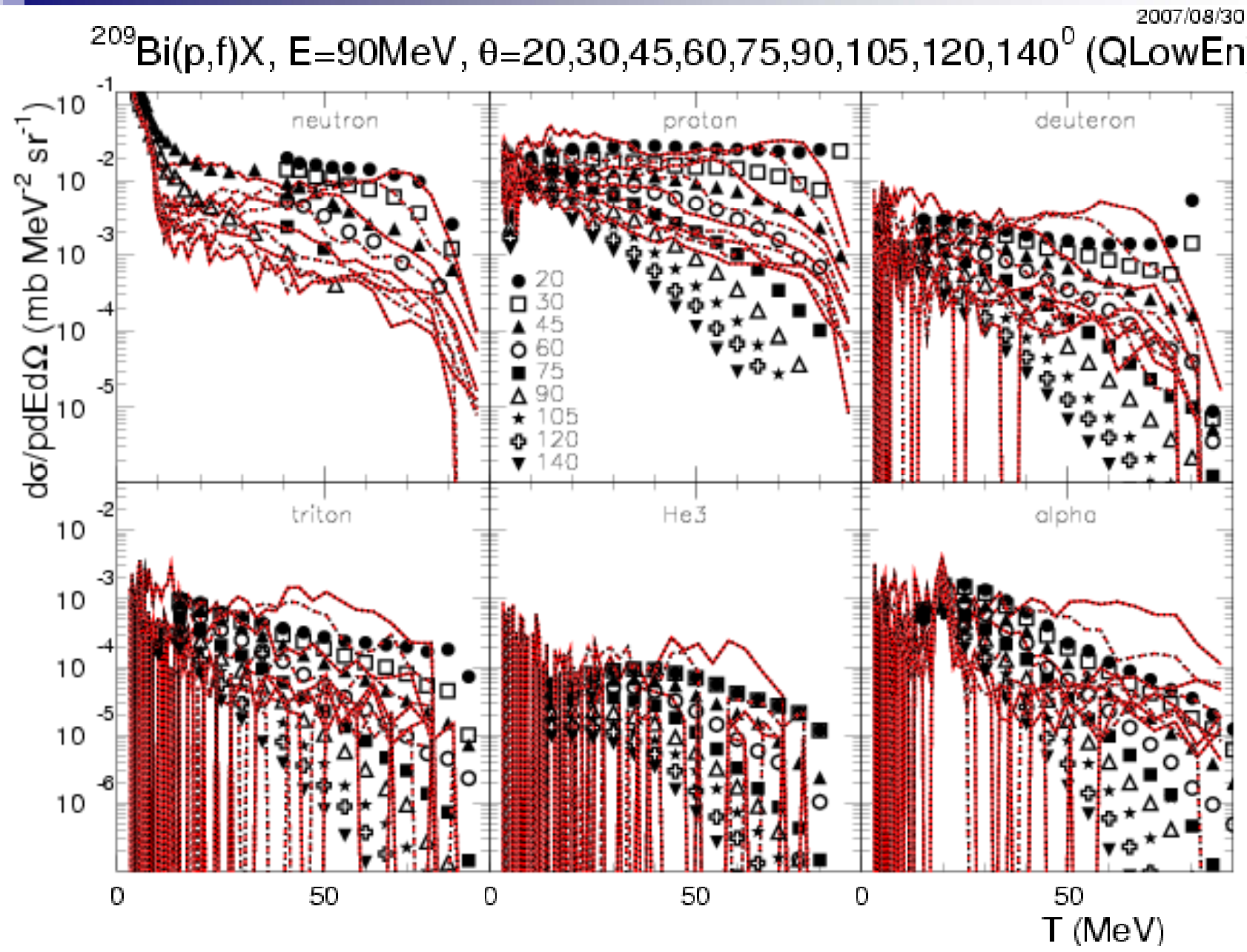

2007/08/17
^{27}Al(p,f)X, E=90MeV, θ=20,30,45,60,75,90,105,120,140^{0} (CHIPS)
dσ/pdEdΩ (mb MeV^{-2} sr^{-1})
neutron
proton
deuteron
triton
He3
alpha
20
30
45
60
75
90
105
120
140
T (MeV)


2007/08/17
209Bi(p,f)X, E = 90MeV, θ = 20,30,45,60,75,90,105,120,140^0 (CHIPS)
neutron
proton
deuteron
triton
He3
alpha
20
30
45
60
75
90
105
120
140
dσ/pdEdΩ (mb MeV^-2 sr^-1)
T (MeV)


2007/08/18
^{27}Al(p,f)X, E=90MeV, θ=20,30,45,60,75,90,105,120,140^{0} (CHIPS+QE)
neutron
proton
deuteron
triton
He3
alpha
dσ/pdEdΩ (mb MeV^{-2} sr^{-1})
20
30
45
60
75
90
105
120
140
T (MeV)


2007/08/21 01
209Bi(p,f)X, E=90MeV, θ=20,30,45,60,75,90,105,120,140^0 (CHIPS+QE)
dσ/pdEdΩ (mb MeV^-2 sr^-1)
neutron
proton
deuteron
triton
He3
alpha
20
30
45
60
75
90
105
120
140
T (MeV)


2007/08/30
27Al(p,f)X, E=90MeV, θ=20,30,45,60,75,90,105,120,140° (QLowEn)
neutron
proton
deuteron
triton
He3
alpha
dσ/pdEdΩ (mb MeV-2 sr-1)
20
30
45
60
75
90
105
120
140
T (MeV)


2007/08/30
209Bi(p,f)X, E=90MeV, θ=20,30,45,60,75,90,105,120,140^0 (QLowEn)
neutron
proton
deuteron
triton
He3
alpha
dσ/pdEdΩ (mb MeV^-2 sr^-1)
20
30
45
60
75
90
105
120
140
0
50
T (MeV)

Conclusion for Low Energy CHIPS models

- Old generators do not fit the fragment spectra
- LHEP does not produce He^3 at all
- Bertini does not have a Coulomb Barrier for fragments and spends too much energy to γ
- G4PreCompoundModel produces too many α
- New CHIPS models produce reasonable spectra for nucleons **and fragments**
- The G4QLowEnergy model is as fast as LHEP, produces fragments and conserves En/Mom.

Importance of Quasi-Elastic Scattering

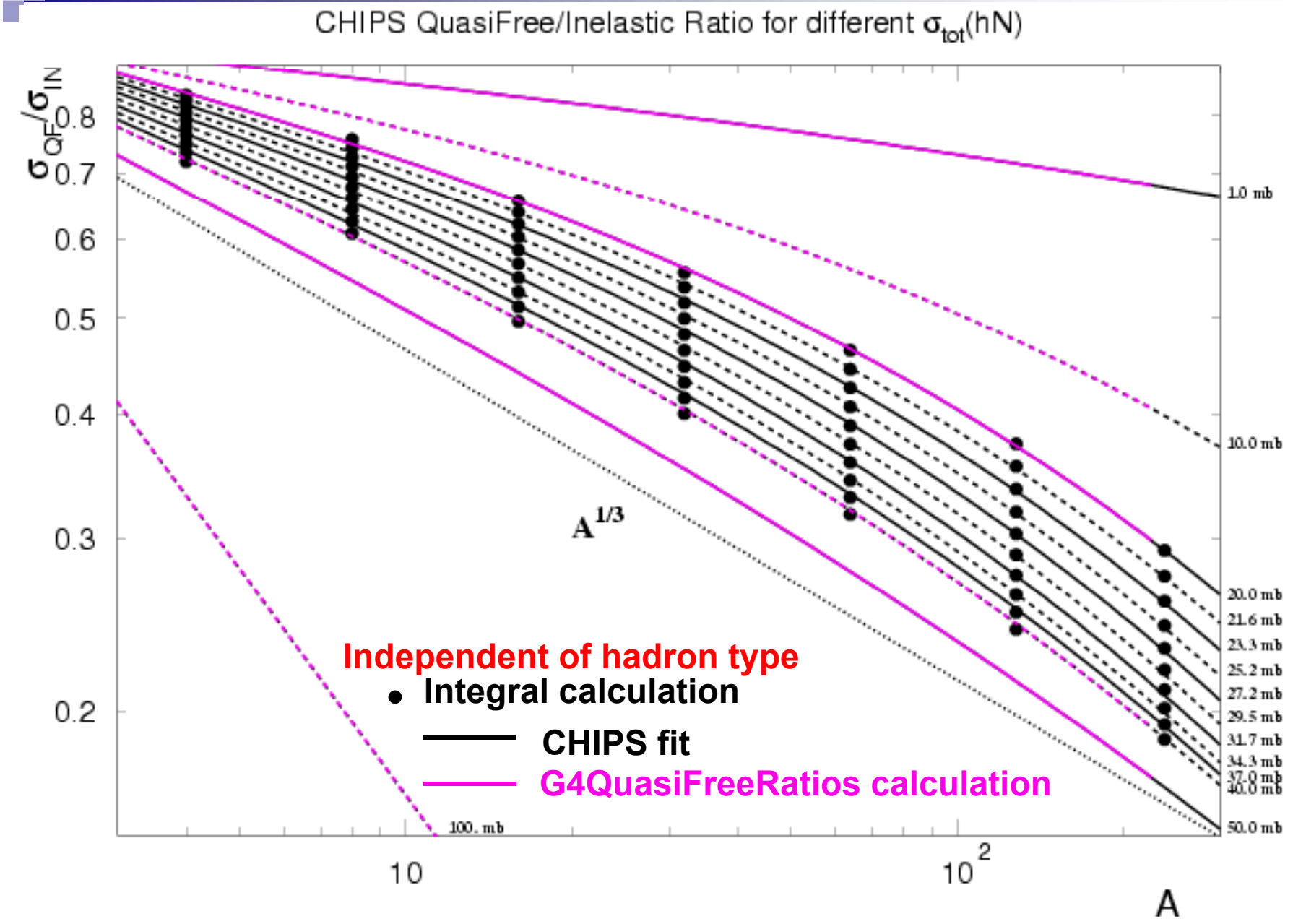
- Compensation of double counting in “elastic”
  - G4LElastic and G4HadronElastic include QES
  - G4QElastic doesn’t include QES, needs new QES
- Subtraction of QE from inelastic cross-section
  - Production cross-sections become smaller and the longitudinal shower shape becomes longer
  - Impossible for cascade models (they include QES)
- Includes QE charge exchange for nucleons
- Independent Quasi-Free process can be made

CHIPS method of QE calculation

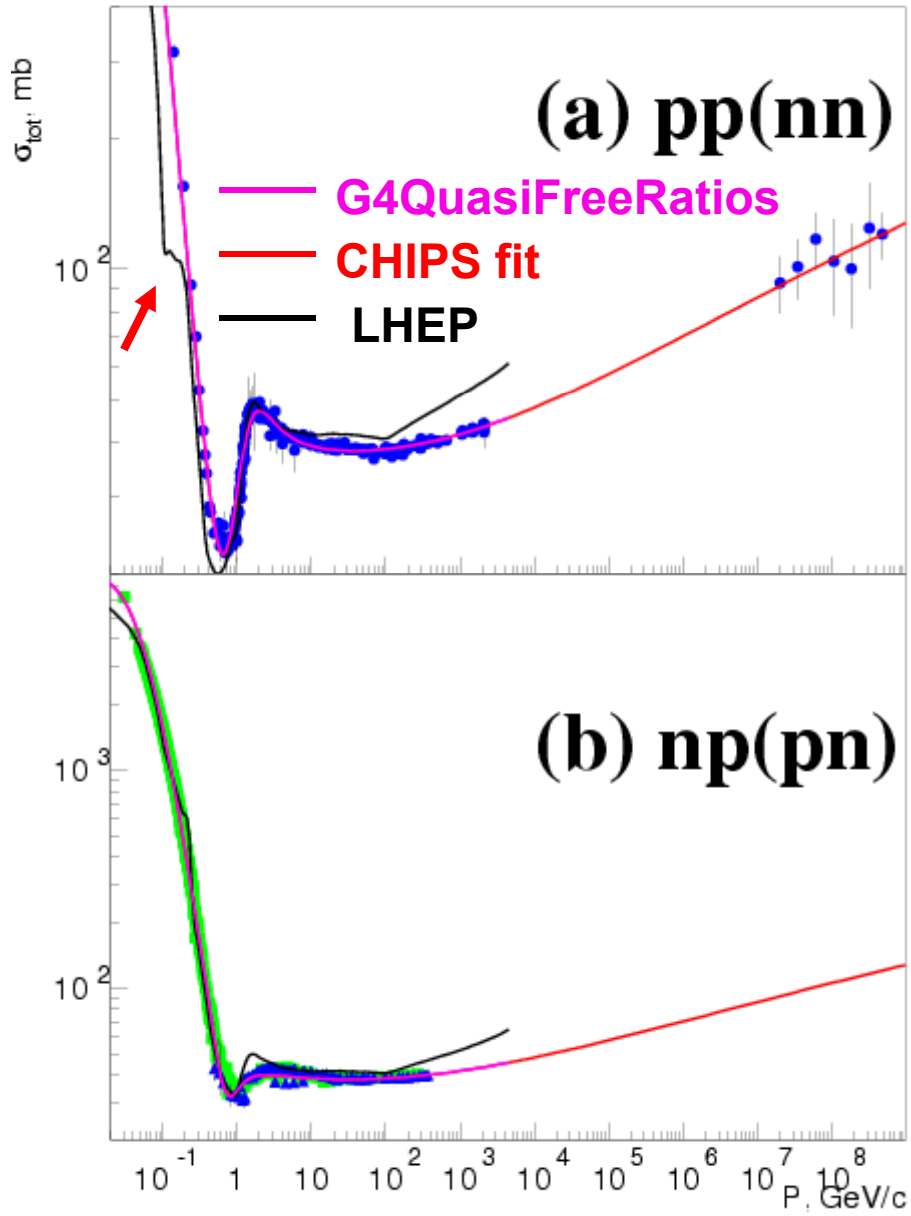
- Calculate and approximate QE/Inelastic
  - Probability of any interaction (Inelastic): $1-e^{-\sigma \cdot T(b)}$
  - Probability to interact only once (QE): $\sigma \cdot T(b) \cdot e^{-\sigma \cdot T(b)}$
- Precize approximation of $\sigma^{el}(hN)$ & $\sigma^{tot}(hN)$
  - nn/pp and np/pn interactions
  - $\bar{N}$-N and Hyperon-N interactions
  - π^-p/π^+n and π^+p/π^-n interactions
  - K^-N/K^0N and $K^+N/\bar{K}^0N$ interactions

8 groups

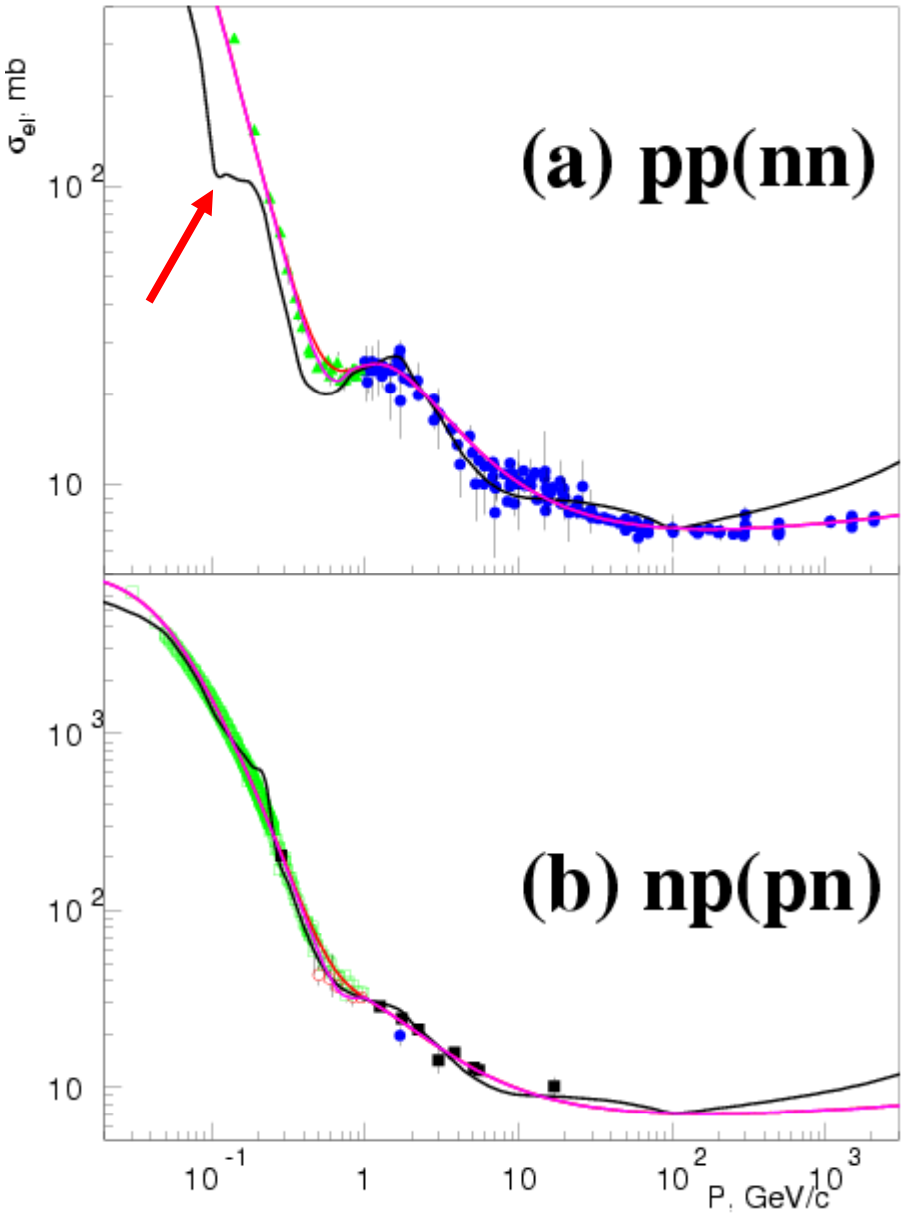
- Calculation of QElastic/In & QFree/In ratios


CHIPS QuasiFree/Inelastic Ratio for different σtot(hN)
σQF/σIN
0.8
0.7
0.6
0.5
0.4
0.3
0.2
A1/3
1.0 mb
10.0 mb
20.0 mb
21.6 mb
23.3 mb
25.2 mb
27.2 mb
29.5 mb
31.7 mb
34.3 mb
37.0 mb
40.0 mb
50.0 mb
100. mb
Independent of hadron type
Integral calculation
CHIPS fit
G4QuasiFreeRatios calculation
10
10 2
A

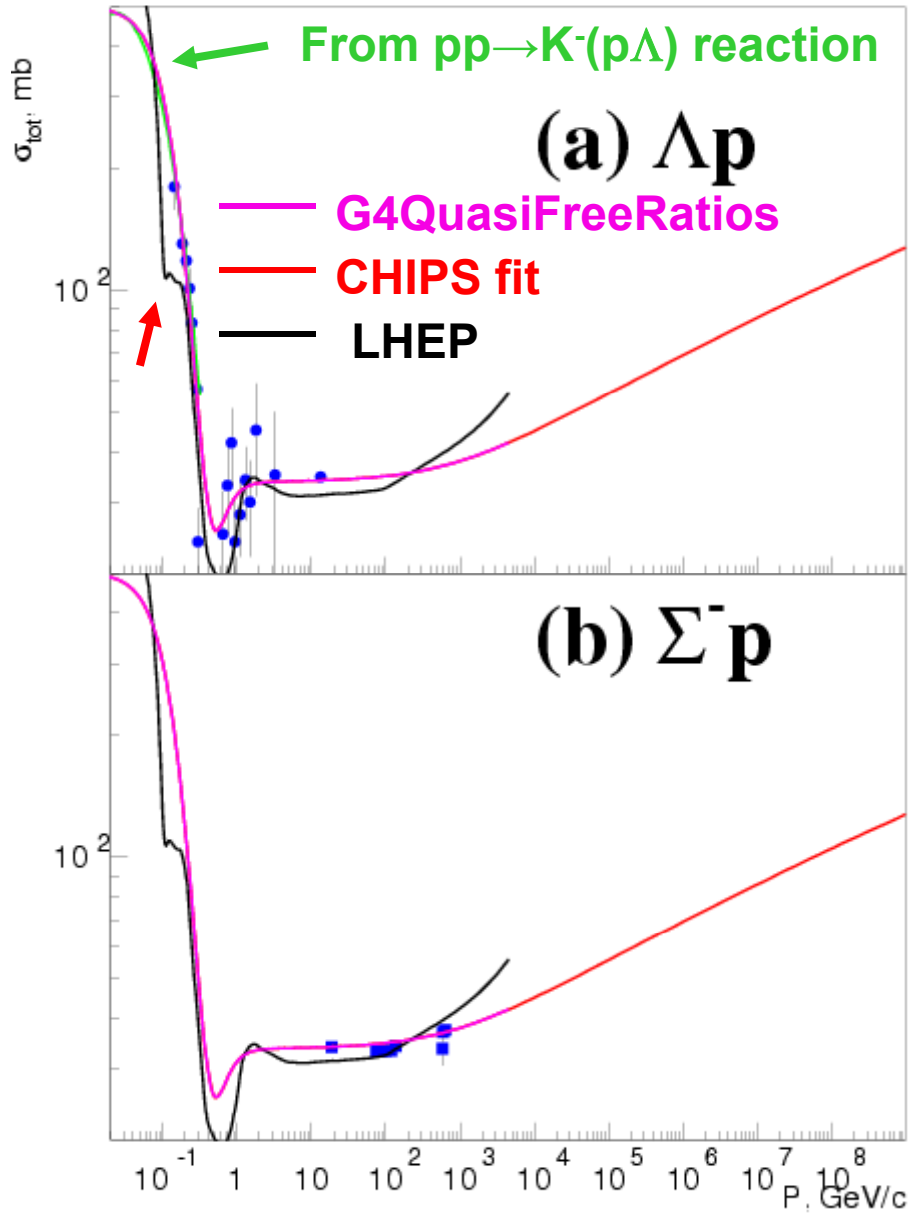
CHIPS improvement of NN total cross-section



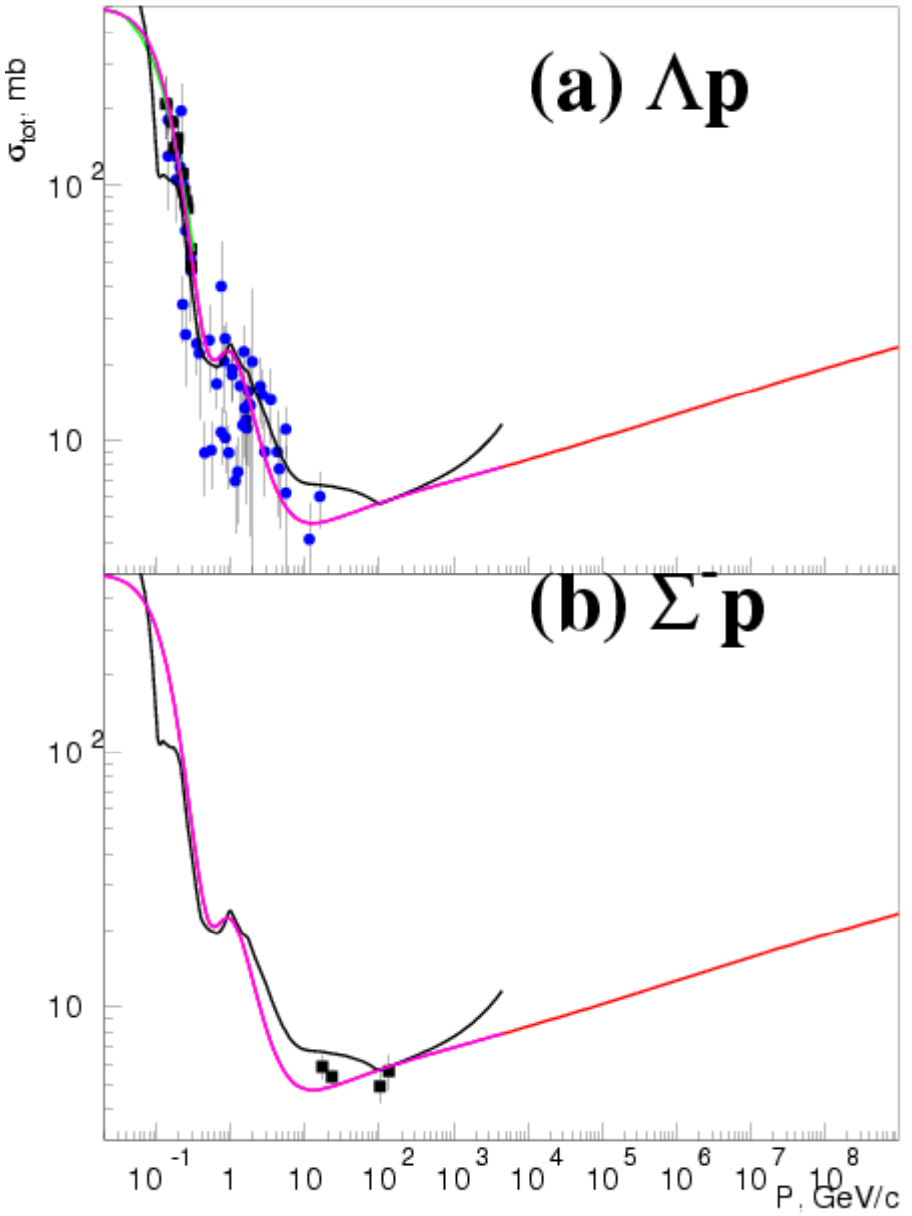
CHIPS improvement of NN elastic cross-section

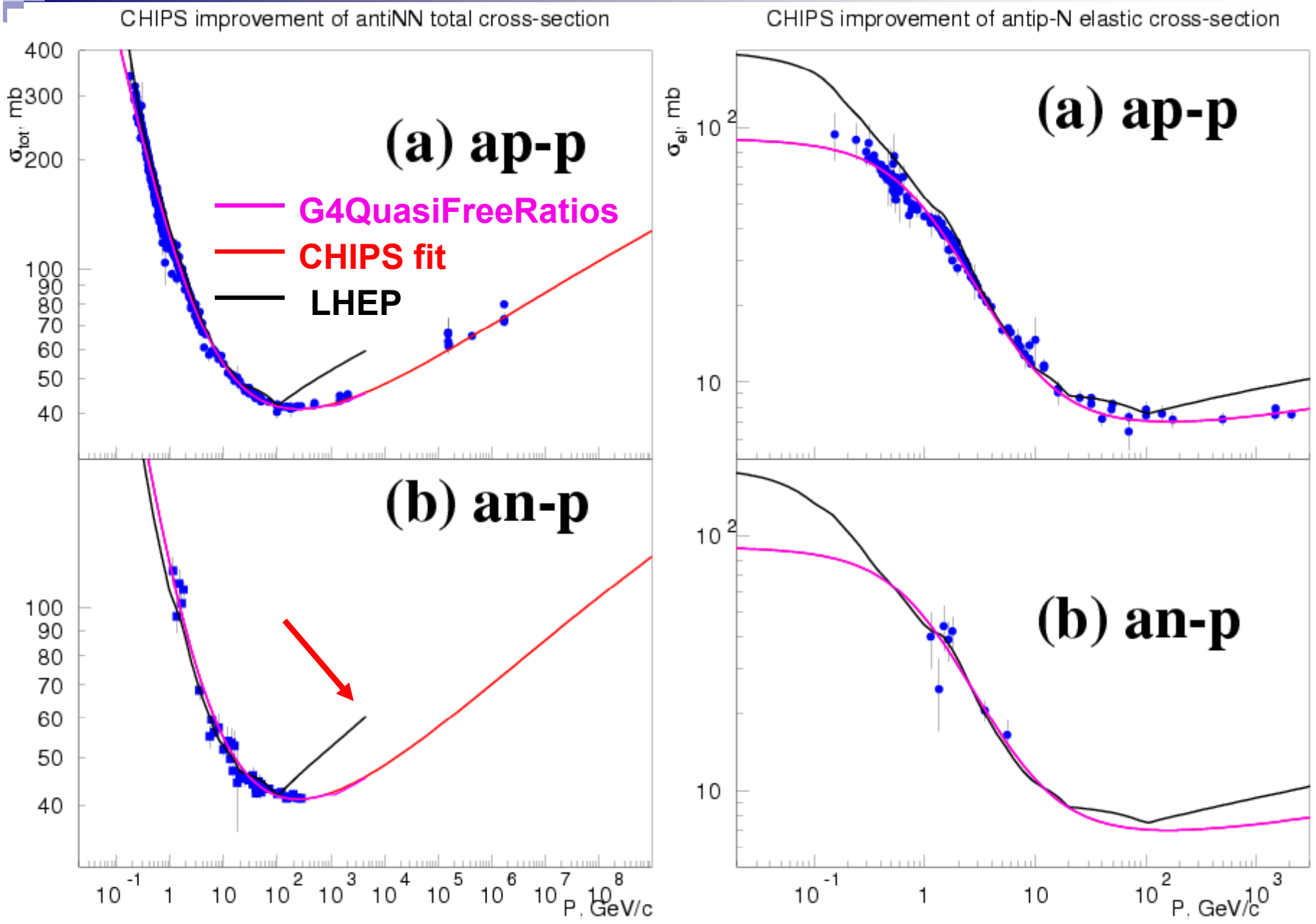


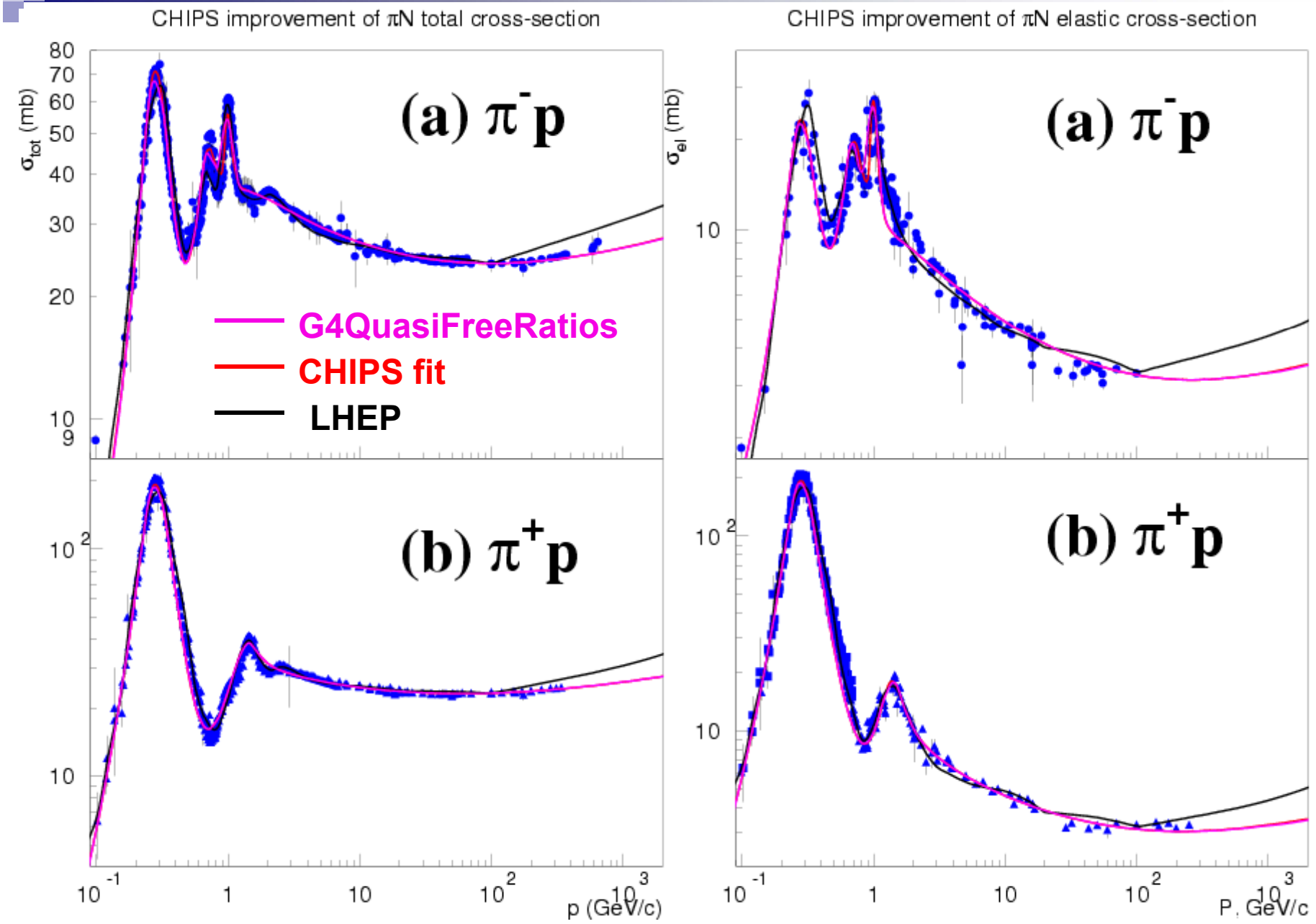
CHIPS improvement of Lambda/Sigma-N total cross-section

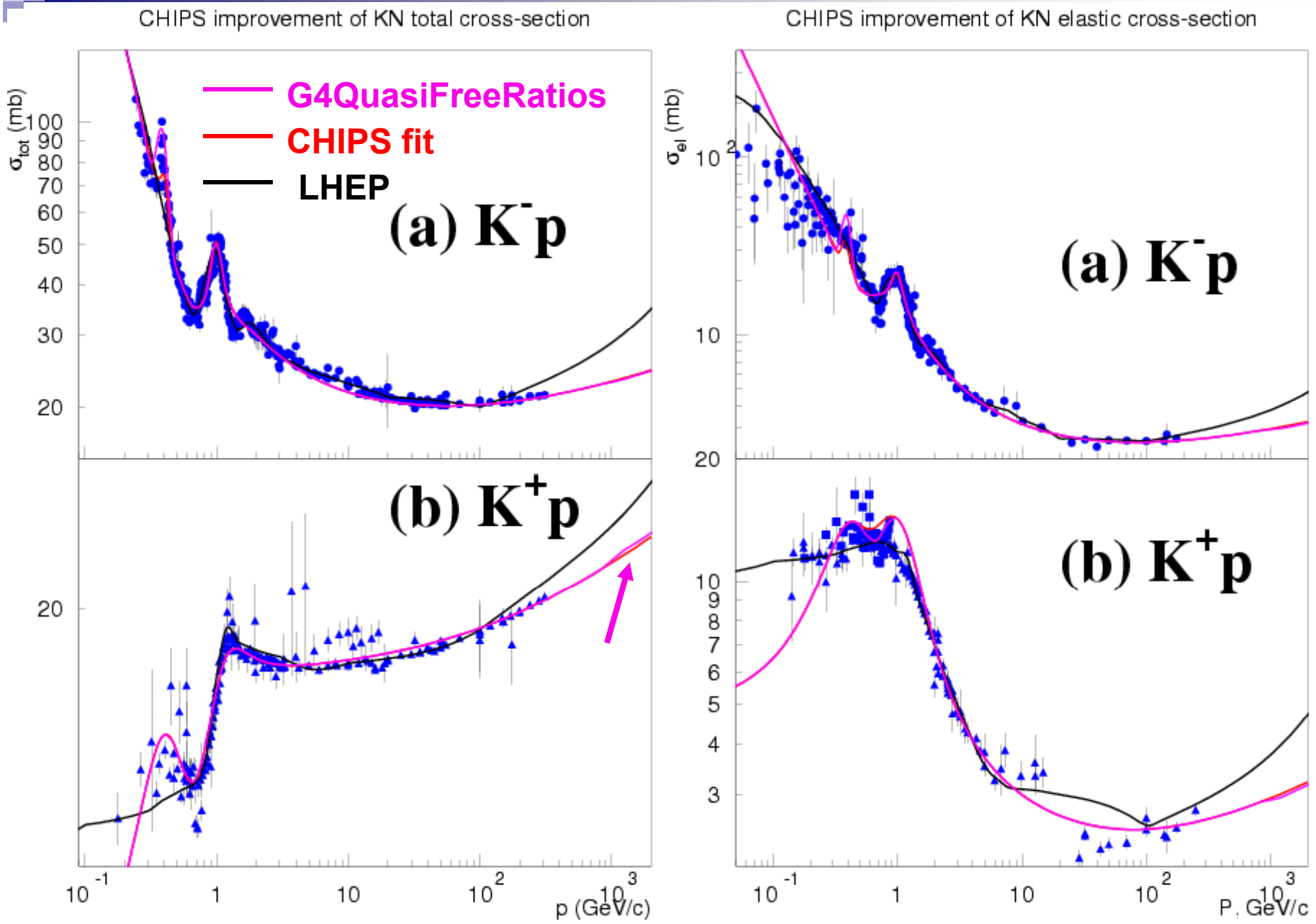


CHIPS improvement of Lambda/Sigma-N elastic cross-section

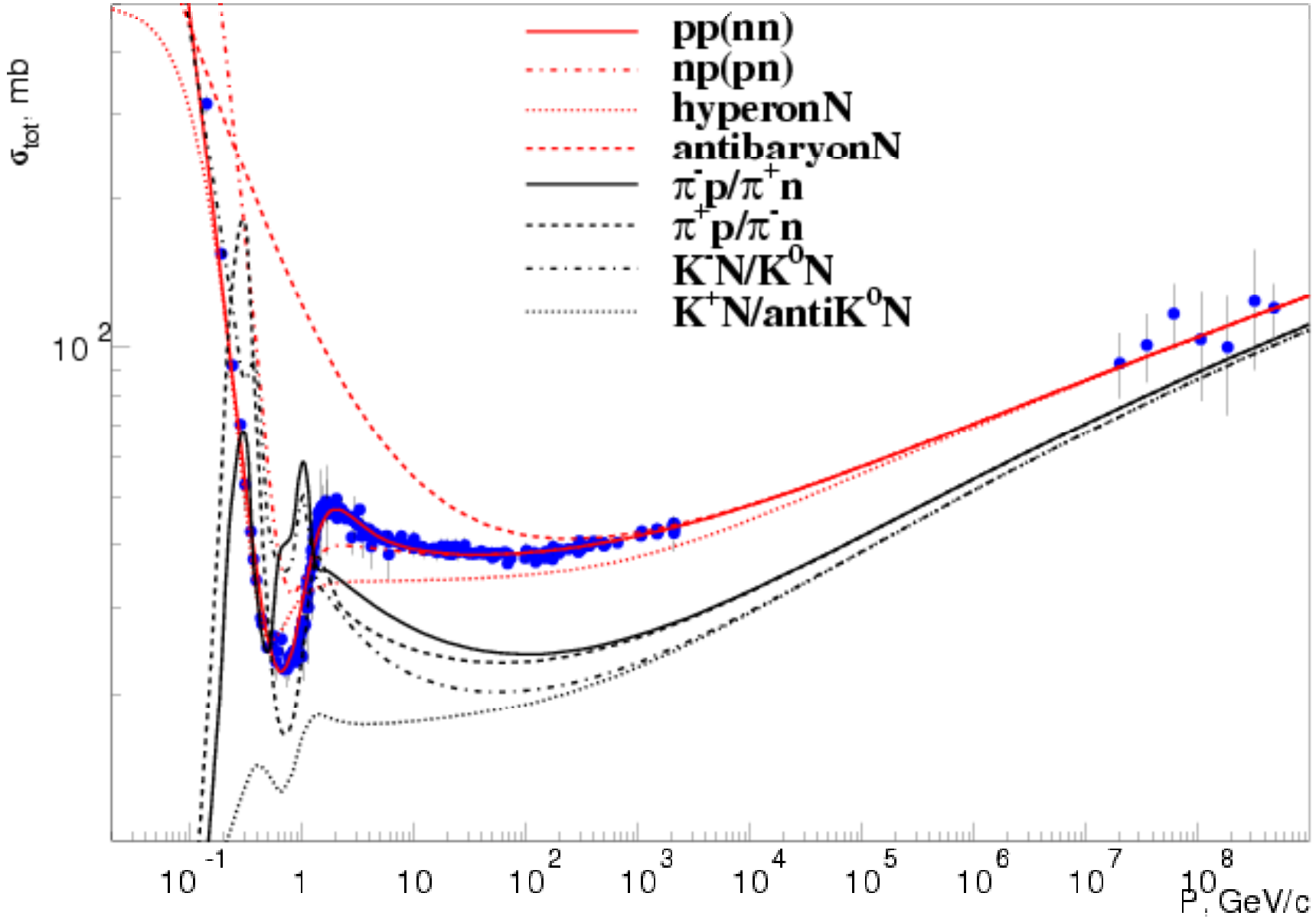



CHIPS improvement of antiNN total cross-section
CHIPS improvement of antip-N elastic cross-section
(a) ap-p
G4QuasiFreeRatios
CHIPS fit
LHEP
(b) an-p
σtot, mb
σel, mb
P, GeV/c

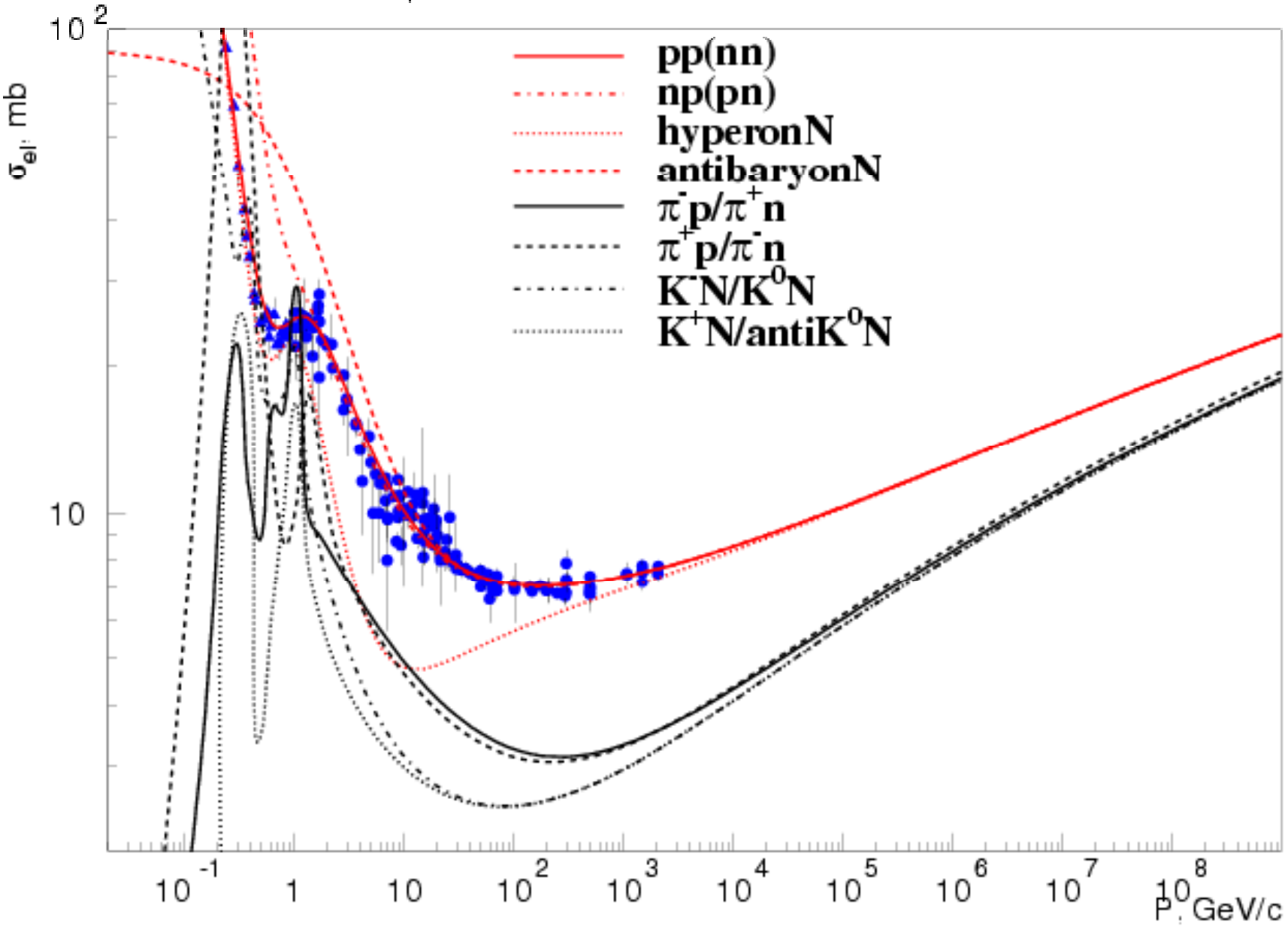

CHIPS improvement of πN total cross-section
CHIPS improvement of πN elastic cross-section
(a) π⁻p
(b) π⁺p
G4QuasiFreeRatios
CHIPS fit
LHEP
σtot (mb)
σel (mb)
p (GeV/c)
P, GeV/c

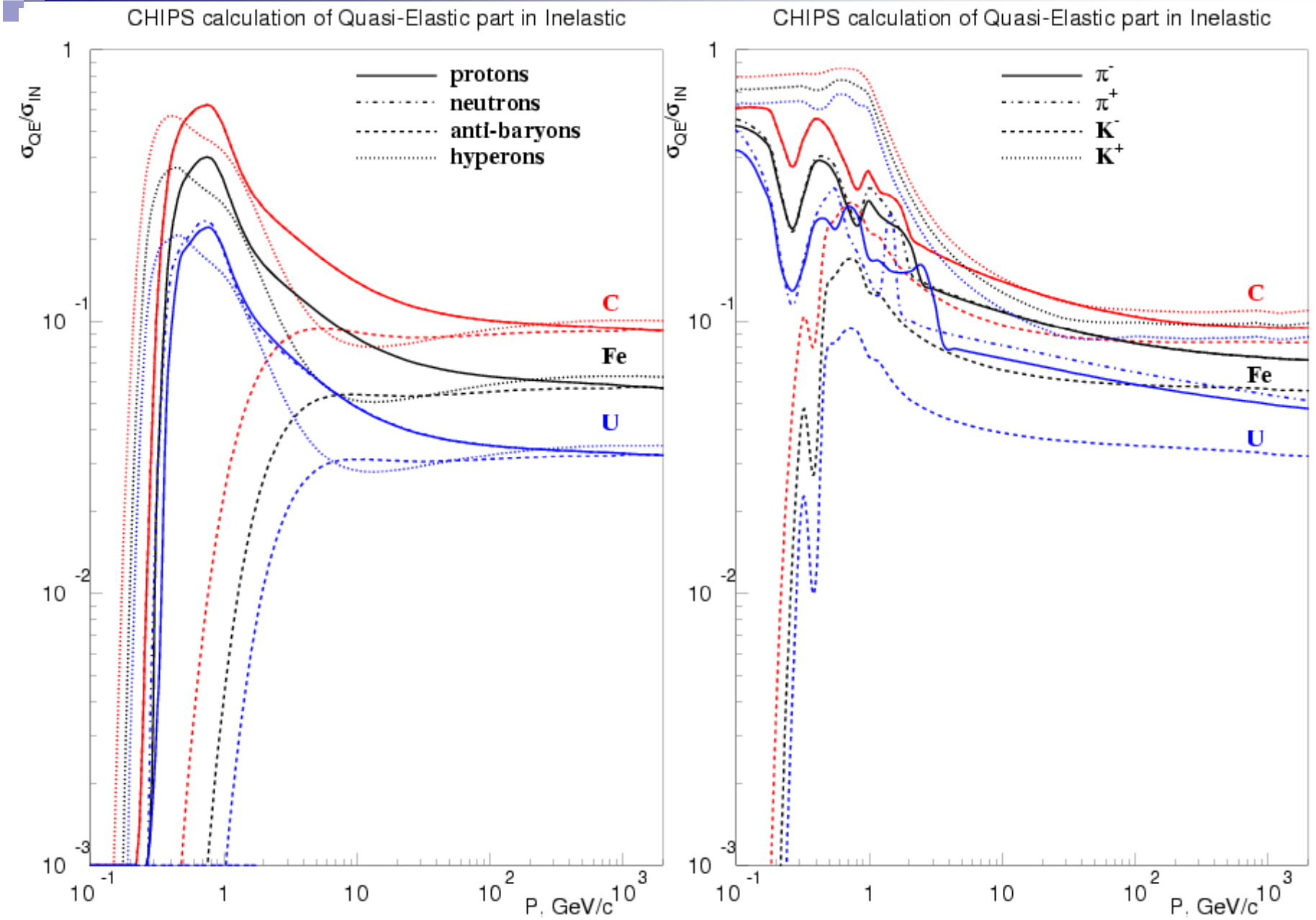

CHIPS improvement of KN total cross-section
CHIPS improvement of KN elastic cross-section
G4QuasiFreeRatios
CHIPS fit
LHEP
(a) K⁻p
(b) K⁺p
σtot (mb)
σel (mb)
p (GeV/c)
P, GeV/c

CHIPS improvement of hadron-nucleon total cross-section



CHIPS improvement of hadron-nucleon elastic cross-section




CHIPS calculation of Quasi-Elastic part in Inelastic
protons
neutrons
anti-baryons
hyperons
C
Fe
U
σQE/σIN
P, GeV/c
CHIPS calculation of Quasi-Elastic part in Inelastic
π-
π+
K-
K+
C
Fe
U
σQE/σIN
P, GeV/c

Conclusion for CHIPS quasi-elastic

- Total & elastic hN cross-sections are updated
- Calculation and approximation of $R=\sigma_{QF}/\sigma_{IN}$
- G4QuasiFreeRatios class provides a pair of $(\sigma_{QF}/\sigma_{IN}, \sigma_{QE}/\sigma_{QF})$ for inelastic processes
- Scattering on quasi-free clusters is possible
- G4QuasiFreeRatios is used in G4QCollision
- G4QuasiFreeRatios is used in QGS/FTF. It improves the longitudinal Shower Shape.