CHIPS improvement of Elastic Scattering in Geant4

Mikhail Kosov, Lisbon, 2006

Plan

- **Neutron-proton elastic scattering**
  - Elastic and low energy inelastic np reactions
  - Comparison with G4LElastic and SAID (G4Lnp)

- **Proton-proton elastic scattering**
  - Energy dependence of reaction cross-sections
  - Differential cross-sections (+ electromagnetic)
  - Comparison with G4LElastic and SAID (G4Lpp)

- **Proton-nuclear elastic scattering**
  - Comparison with G4LElastic/G4HadronElastic

CHIPS improvement of nH elastic

- **Importance of nH elastic scattering**
  - ☐ Scintillation detectors in High Energy Physics
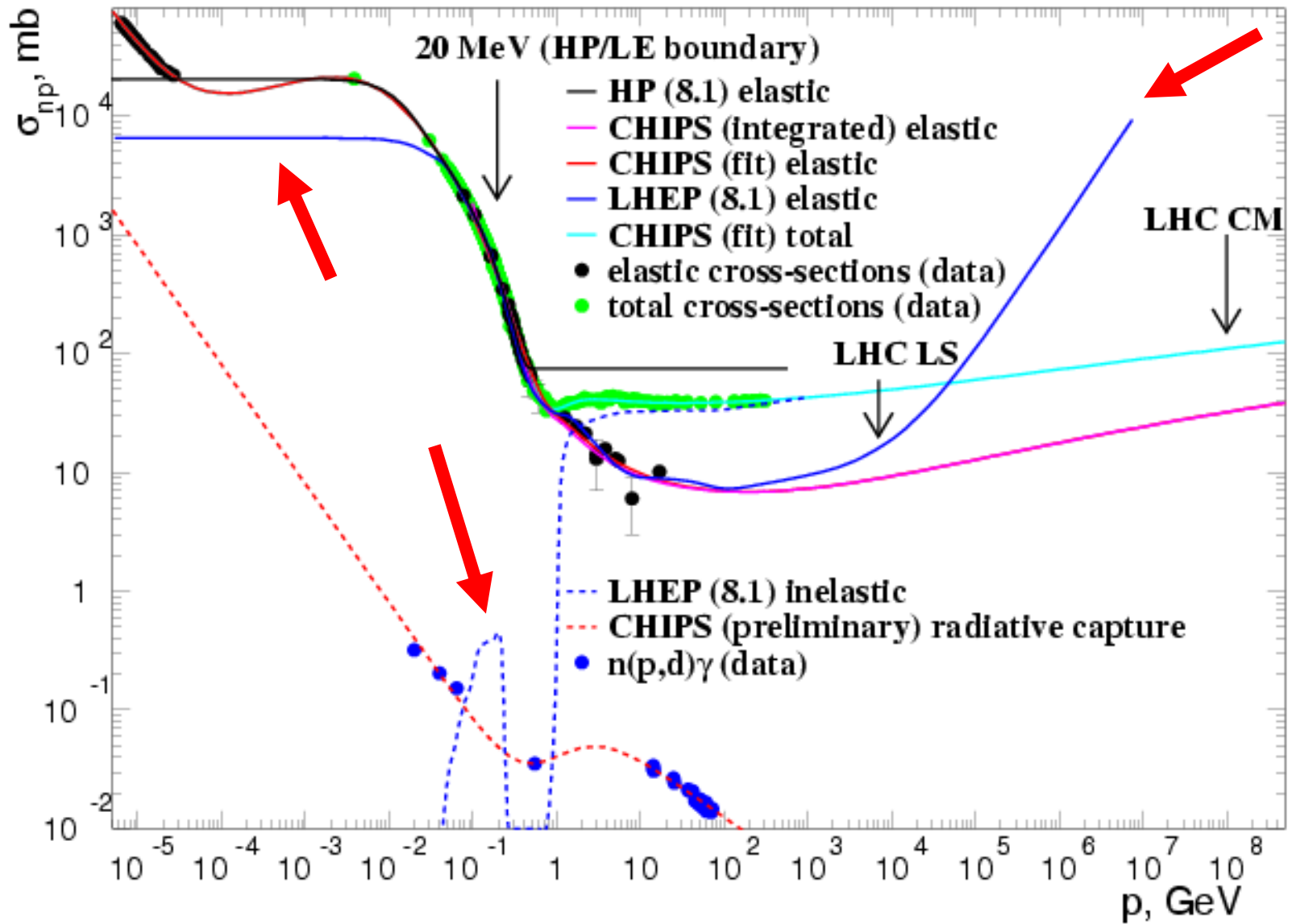 - ☐ Hydrogen as an element of water for medicine
- **nH interaction at low energies**
  - ☐ Large elastic scattering with charge exchange
  - ☐ Binary n(p,d)γ reaction (radiative capture)
  - ☐ Hard bremsstraglung of neutrons: n(p,np)γ
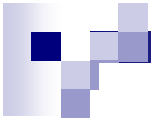- **High Energy: elastic is ~15% of inelastic**
  - ☐ Weak energy dependence of parameters
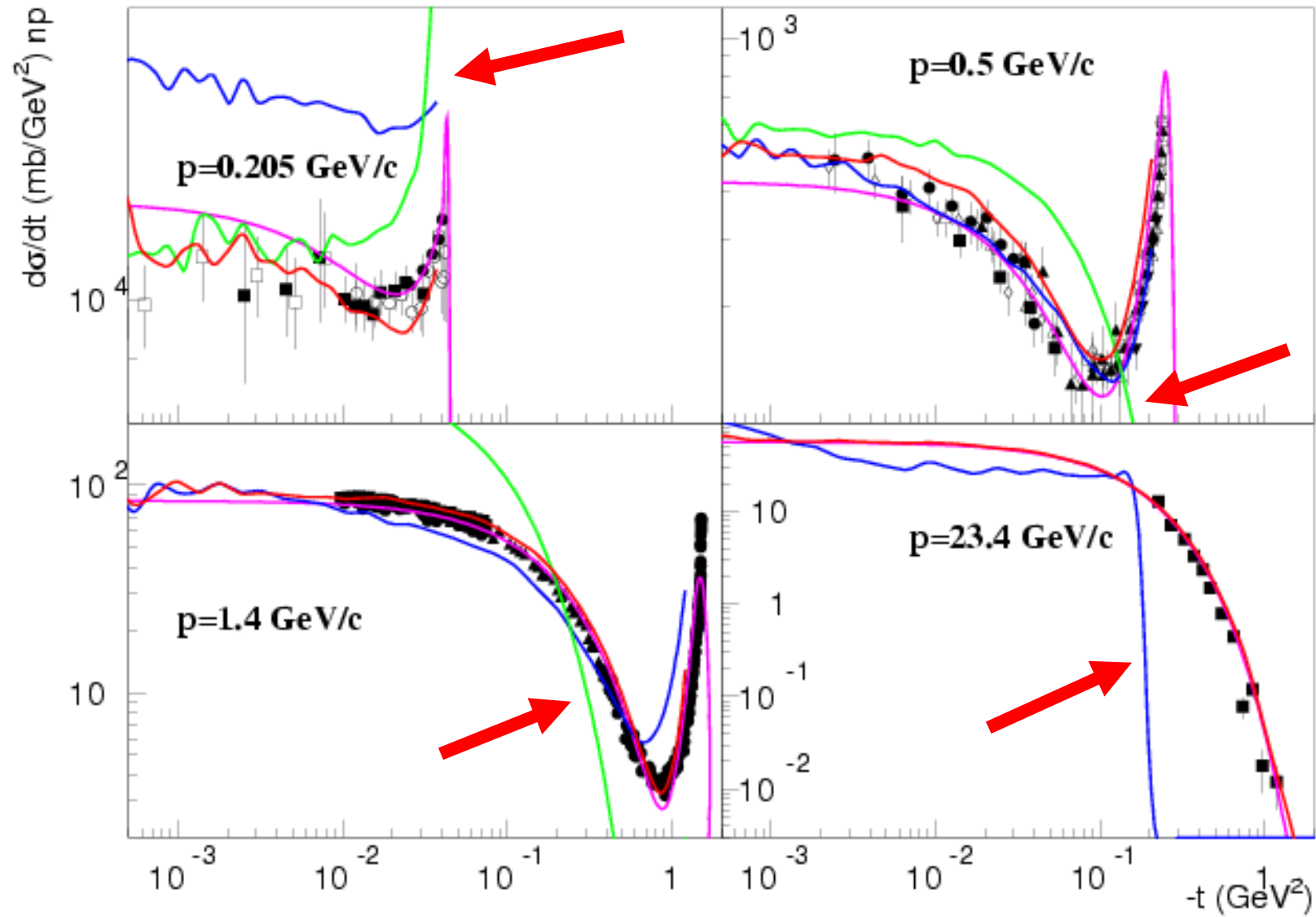
CHIPS improvement of neutron-proton interaction

CHIPS approximation of nH elastic

- Approximation formula for differential cross-section: $d\sigma/dt = A(p)e^{B(p)t} + C(p)e^{D(p)u}$

- Contributing processes:
  - A(p) includes π^0 and Pomeron exchange
  - C(p) includes π^- exchange (small at high E)

- CHIPS (pink lines are approximation, red lines are simulation) compared with
  - G4LElastic (8.1) process (green lines)
  - SAID (PWA) Geant4 version G4Lnp (blue lines)

CHIPS improvement of np elastic scattering

M.Kosov. Elastic scattering

CHIPS improvement of pH elastic

■ **Importance of pH elastic scattering**

  ☐ Breeding of protons in scintillation detectors (plastic cancer in High Energy Physics)
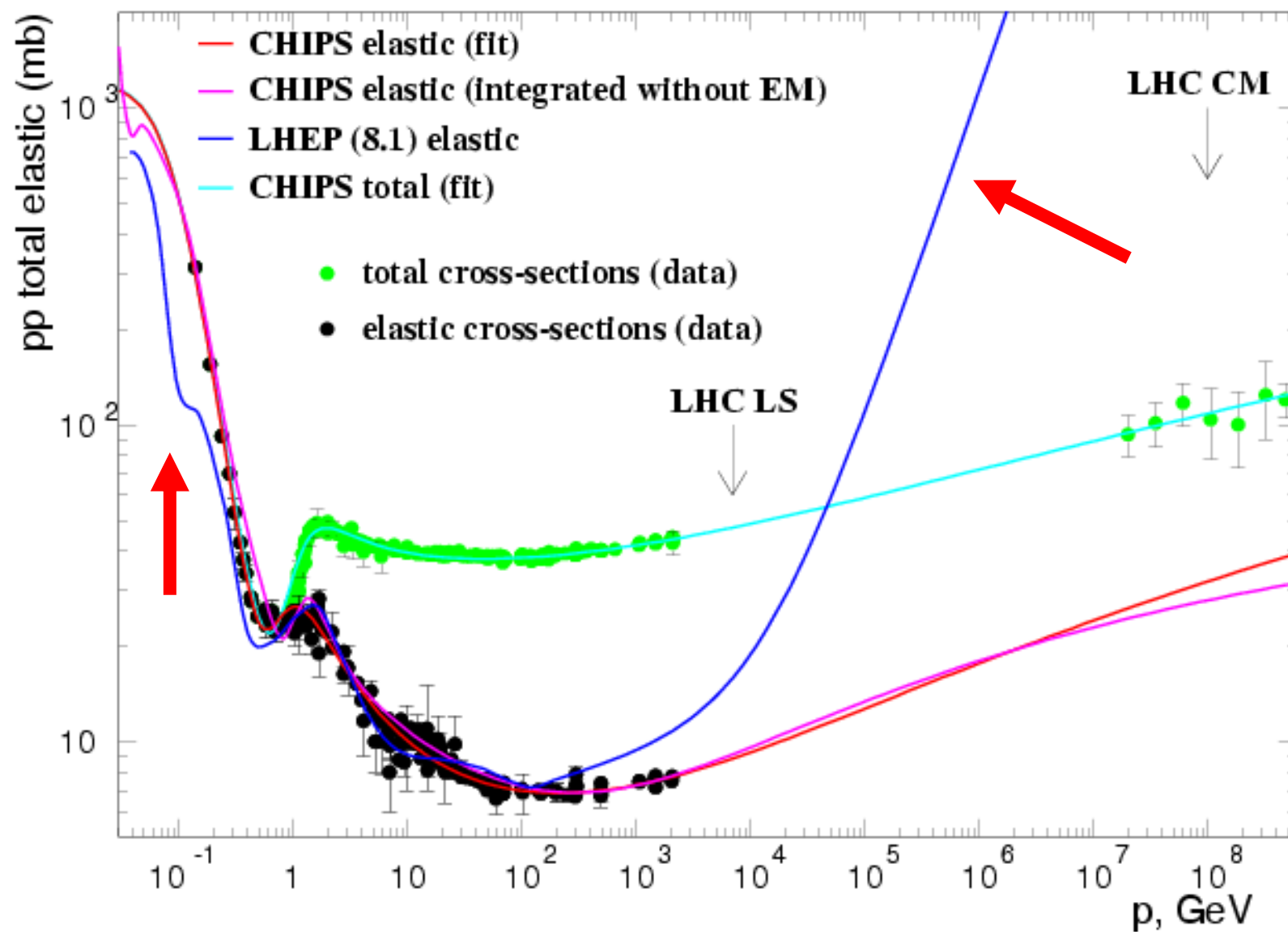
  ☐ Lateral widening of proton's Bragg peak in water

■ **pH interaction at low energies**

  ☐ There is no "HP" package for low energy protons

  ☐ CHIPS reaction cross section is too big and can make a calculation time problem (continuous?)

■ **High Energy: elastic is ~15% of inelastic**

  ☐ Weak energy dependence of parameters

CHIPS improvement of proton-proton interactions

CHIPS approximation of pH elastic

- Formula for differential cross-section ($T=|t|^{n-1}$):

    $ds/d|t| = E(p) \cdot e^{-F(p)\sqrt{|t|}} / \sqrt{|t|} + A(p) \cdot e^{B(p) \cdot t} + C(p) \cdot T \cdot e^{D(p) \cdot t \cdot T} + G(p) \cdot e^{H(p) \cdot t}$

    - E(p) is Electromagnetic pp scattering (EM below)

- Only π^0 and Pomeron exchange

    - Symmetric in respect to 90^0 in center of mass

- CHIPS (pink lines are approximation, red lines are simulation) compared with

    - G4LElastic (8.1) process (green lines)

    - SAID (PWA) Geant4 version G4Lpp (blue lines)
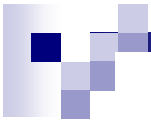
CHIPS improvement of pp elastic scattering
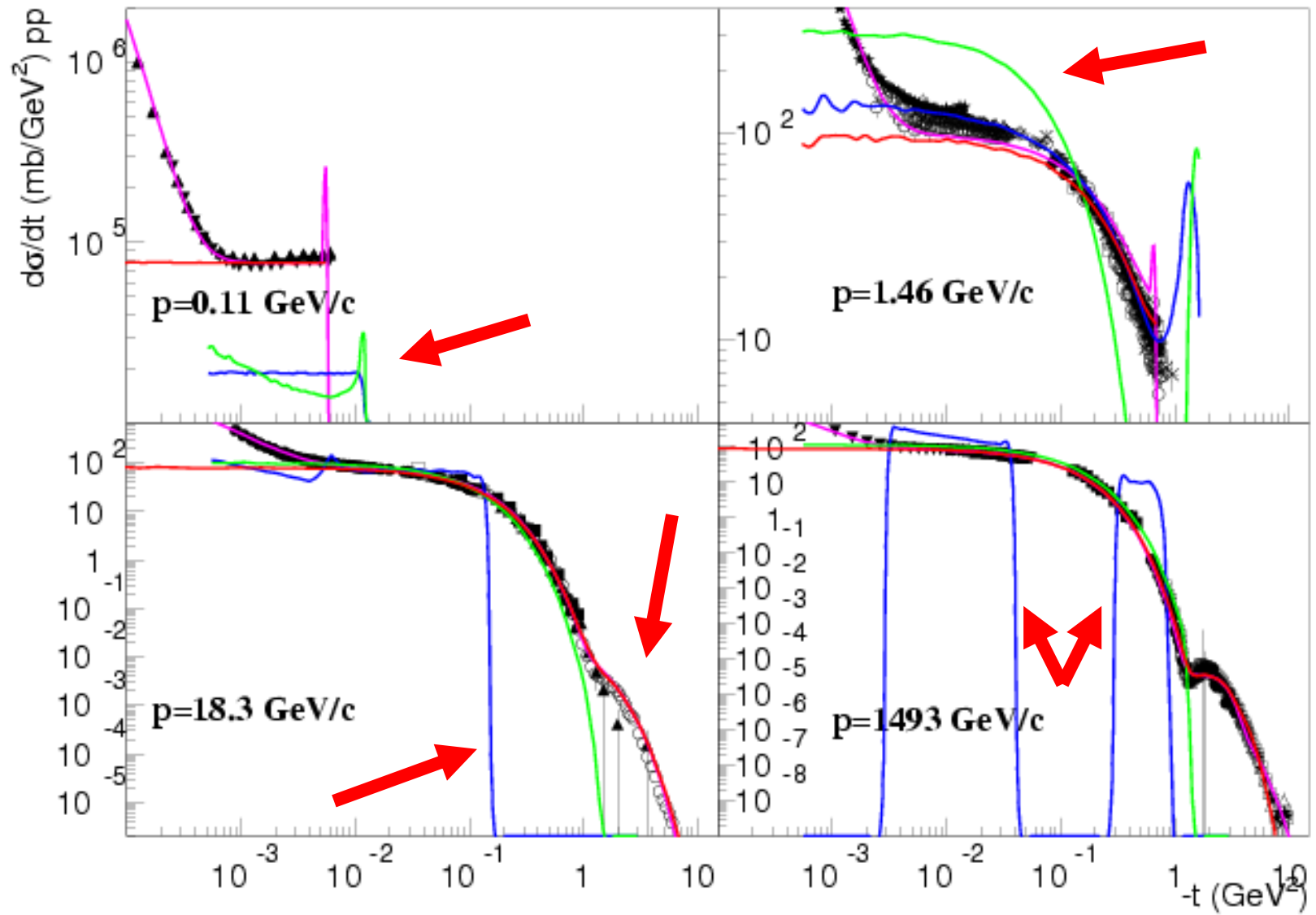
CHIPS approximation of pA elastic

- Formula for differential cross-section ($T=t^2$):

  - $A<7$ (d,^{3}He,^{4}He,^{6}Li) with nuclear gloria:

    $ds/d|t|=EM+N\cdot(B+2C\cdot t)e^{t\cdot(B-C\cdot t)}+D\cdot T\cdot e^{H\cdot t\cdot T}+R\cdot e^{K\cdot t}+G\cdot e^{S\cdot u}$

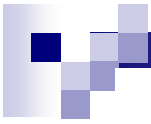 - $A>6$ (^{7}Li, Be, C, Al, Cu, Sn, Pb) ($V=t^4$, $W=t^6$)

    $ds/d|t|=EM+N\cdot(B+2C\cdot t)e^{t\cdot(B-C\cdot t)}+D\cdot V\cdot e^{H\cdot t\cdot V}+G\cdot W\cdot e^{S\cdot t\cdot W}+R\cdot e^{K\cdot t}$

  - **N, B, C, D, G, H, K, R, S are functions of p and A**

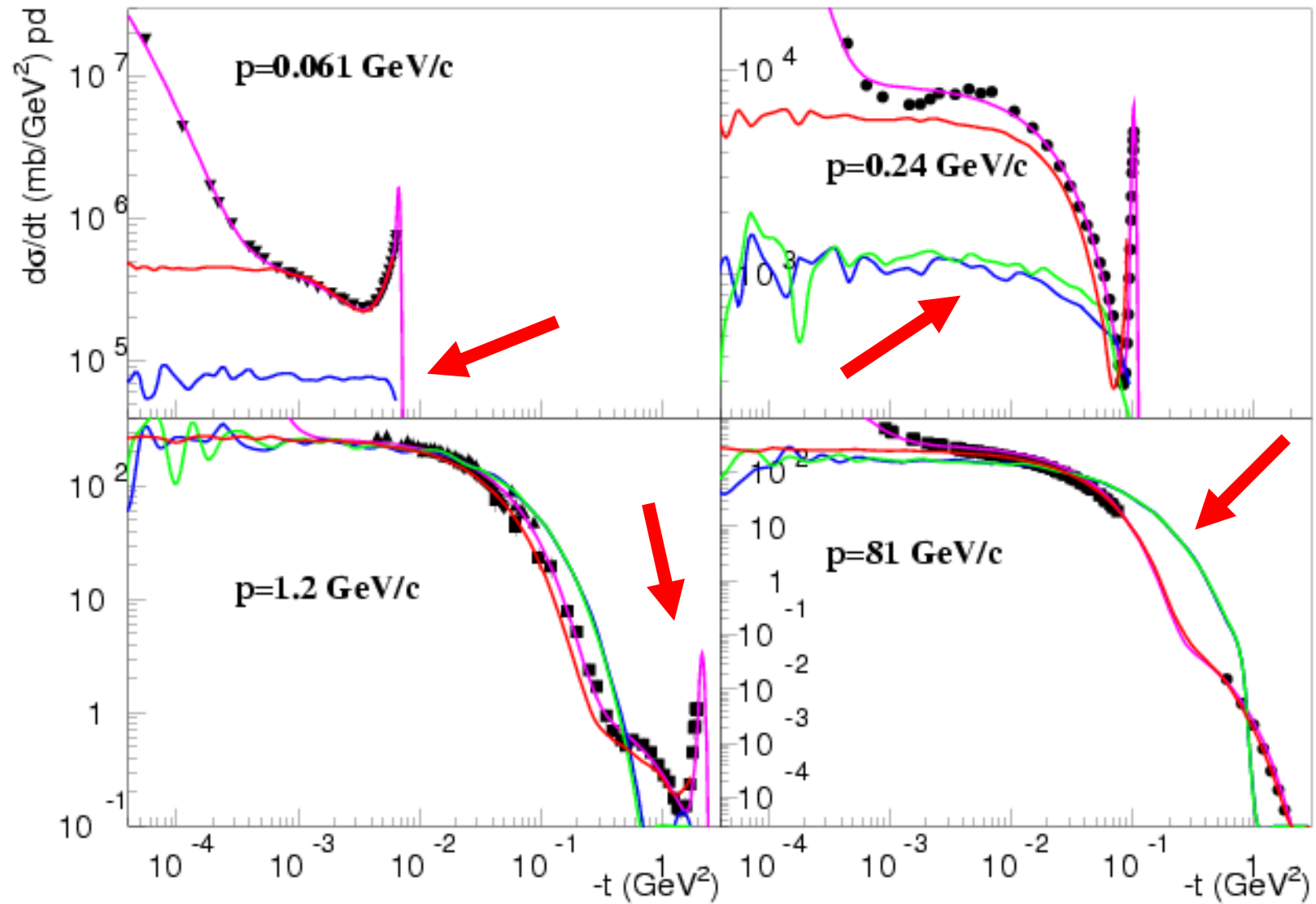- CHIPS (pink lines is approximation, red lines is old simulation – d,^{4}He) compared with

  - G4LElastic (8.1) process (green lines)

  - G4HadronElastic (8.1-V.Ivanchenko) (blue lines)
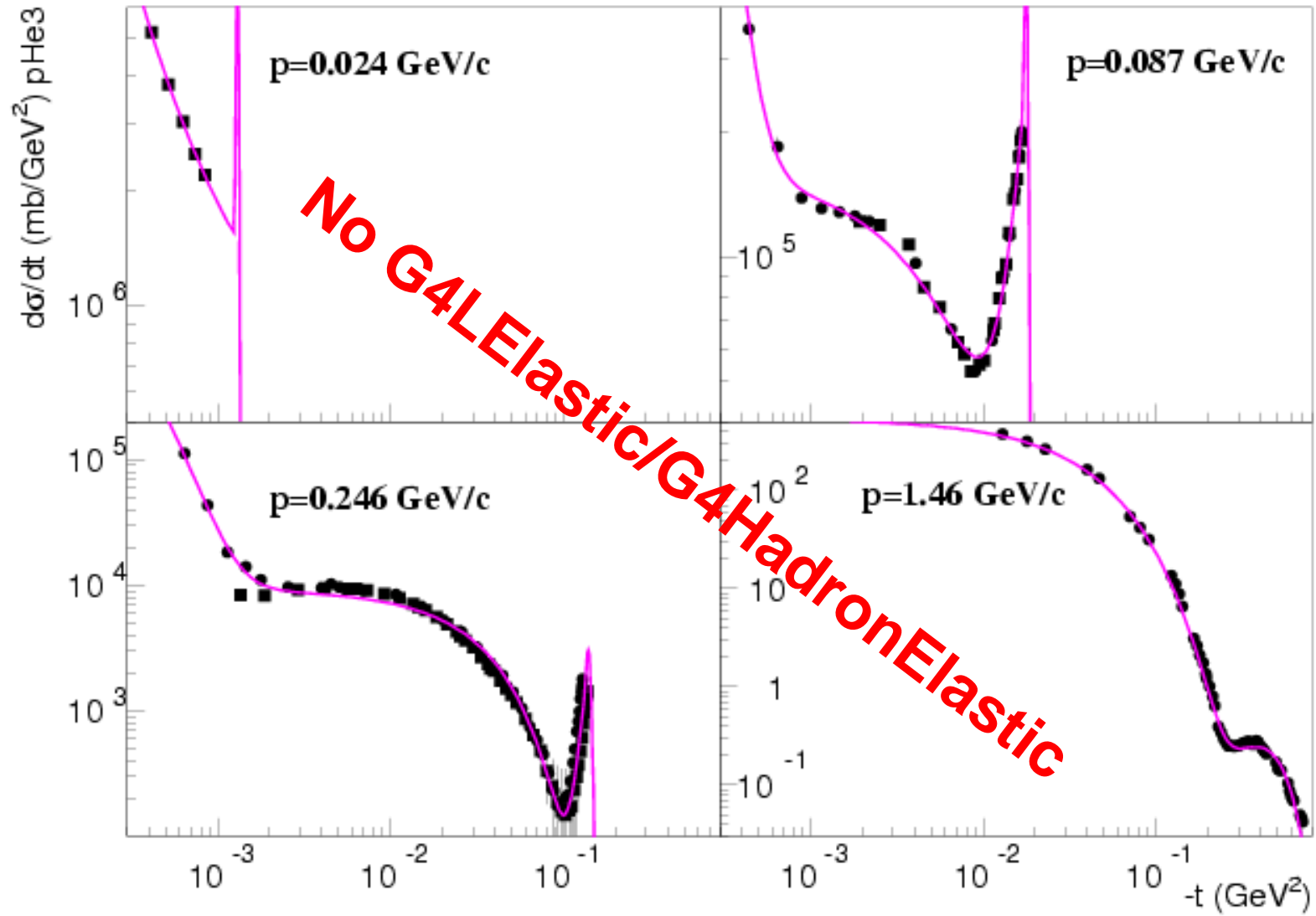
CHIPS improvement of pd elastic scattering

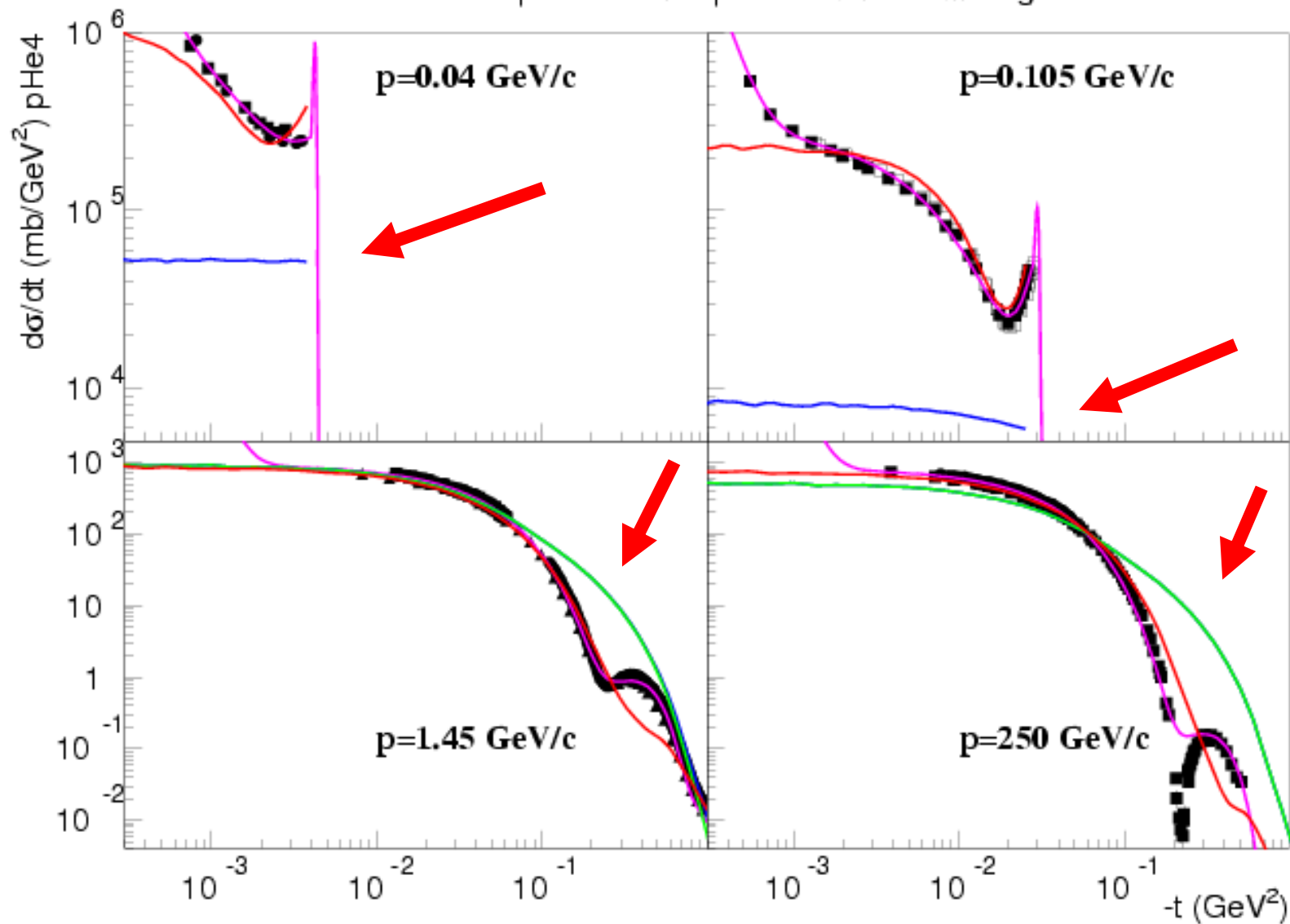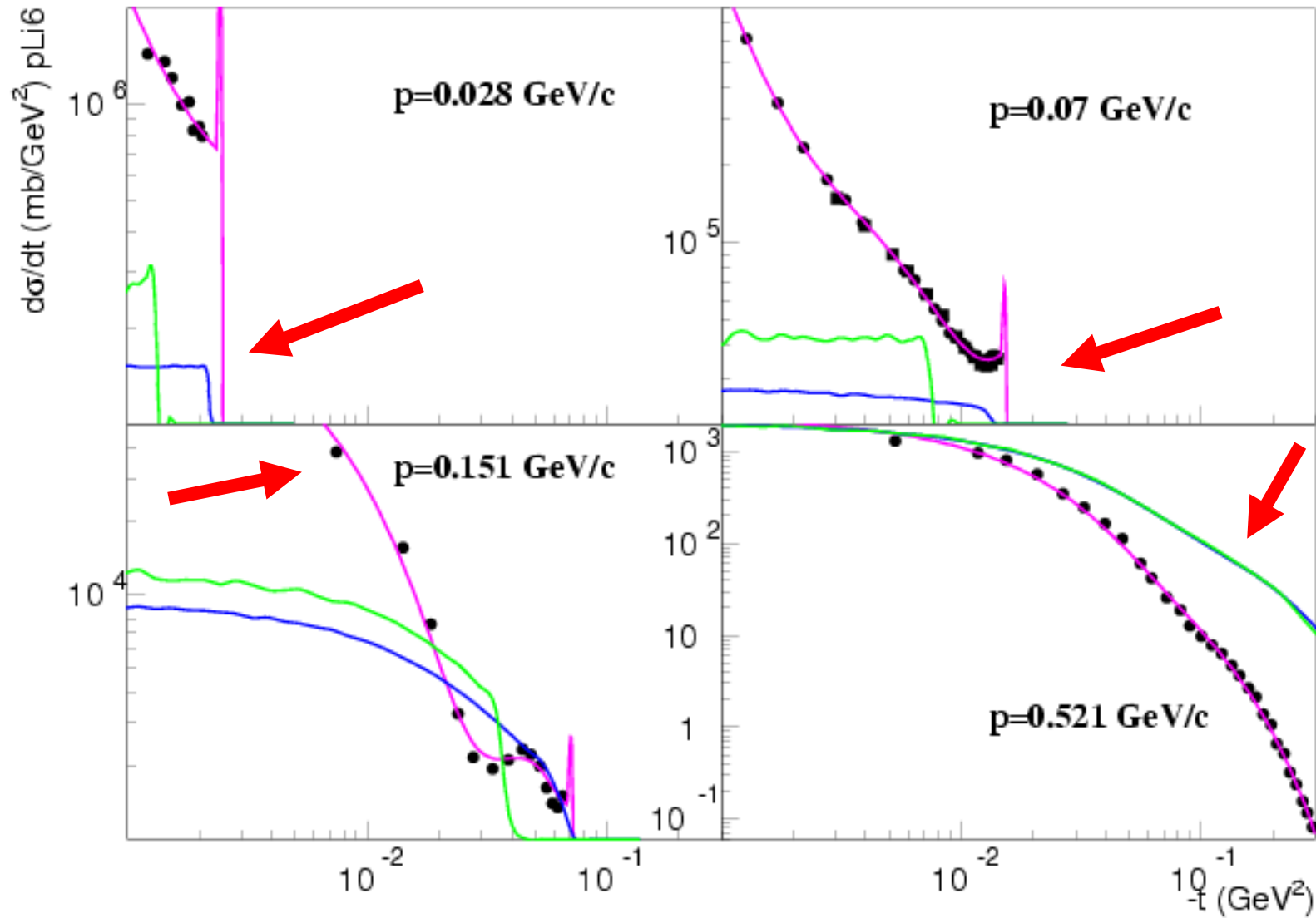CHIPS improvement of pHe3 elastic scattering

M.Kosov. Elastic scattering

CHIPS improvement of pHe4 elastic scattering

M.Kosov. Elastic scattering

CHIPS improvement of pLi6 elastic scattering

p=0.028 GeV/c

p=0.07 GeV/c

p=0.151 GeV/c

p=0.521 GeV/c

$d\sigma/dt$ (mb/GeV^2) pLi6
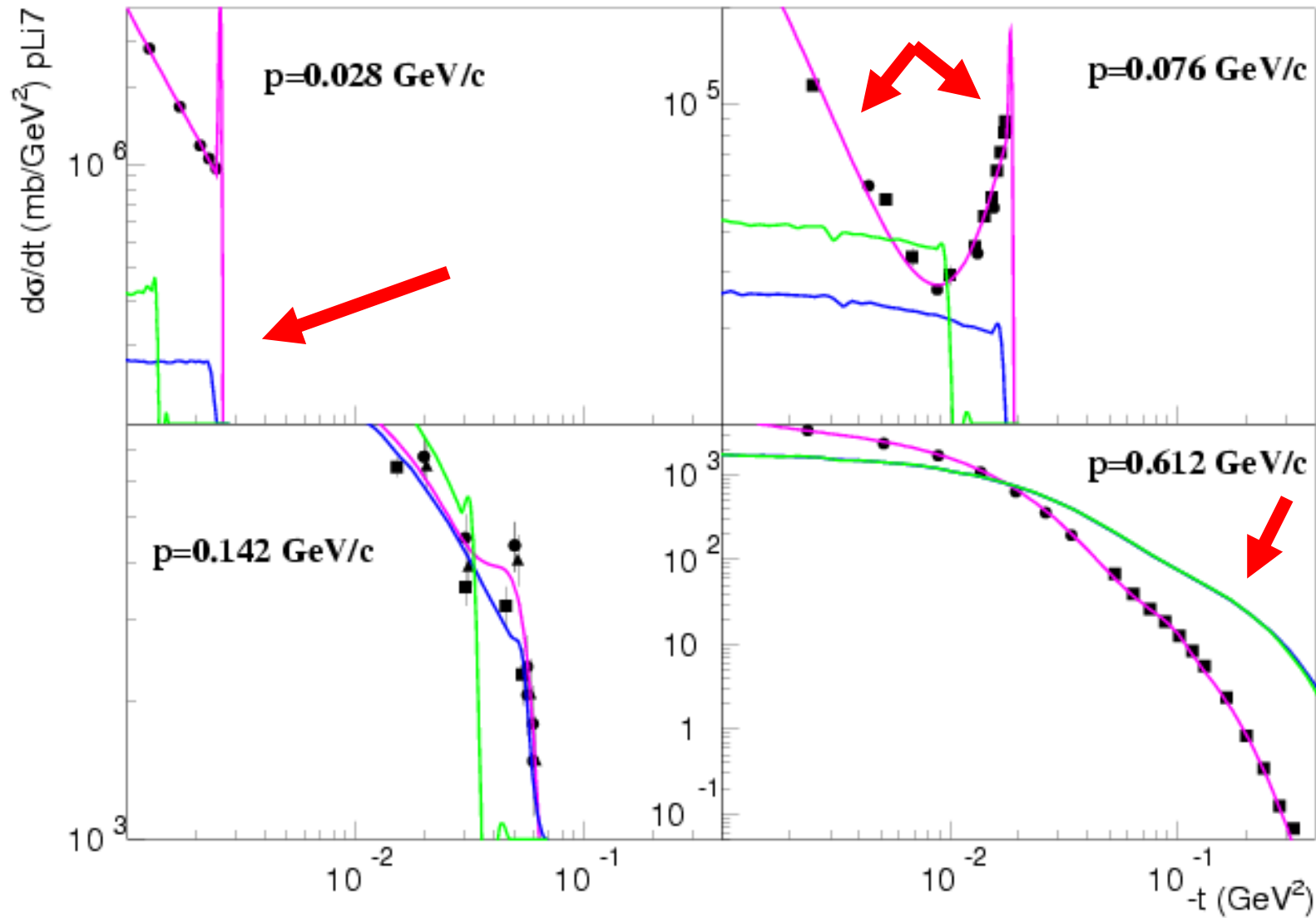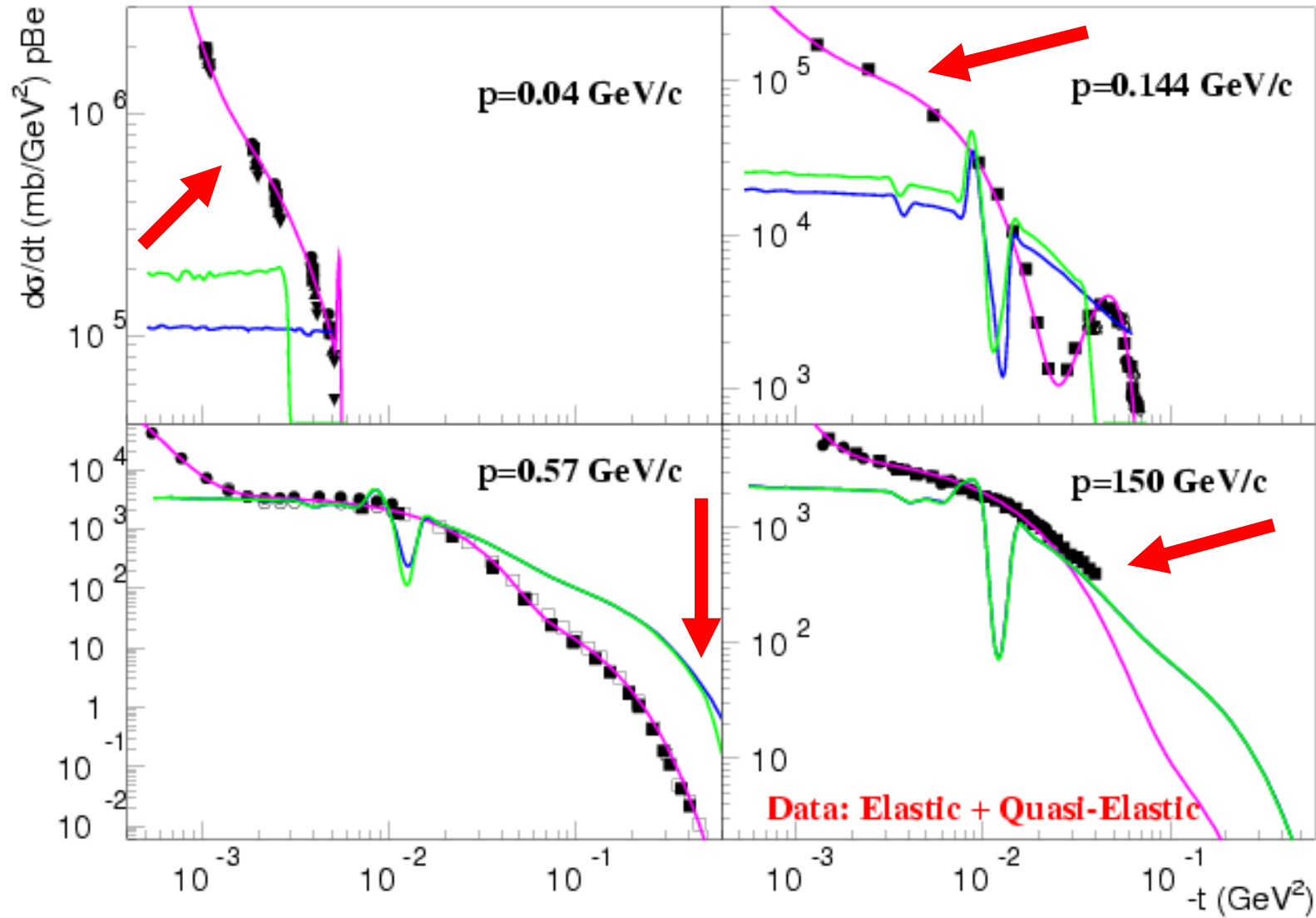
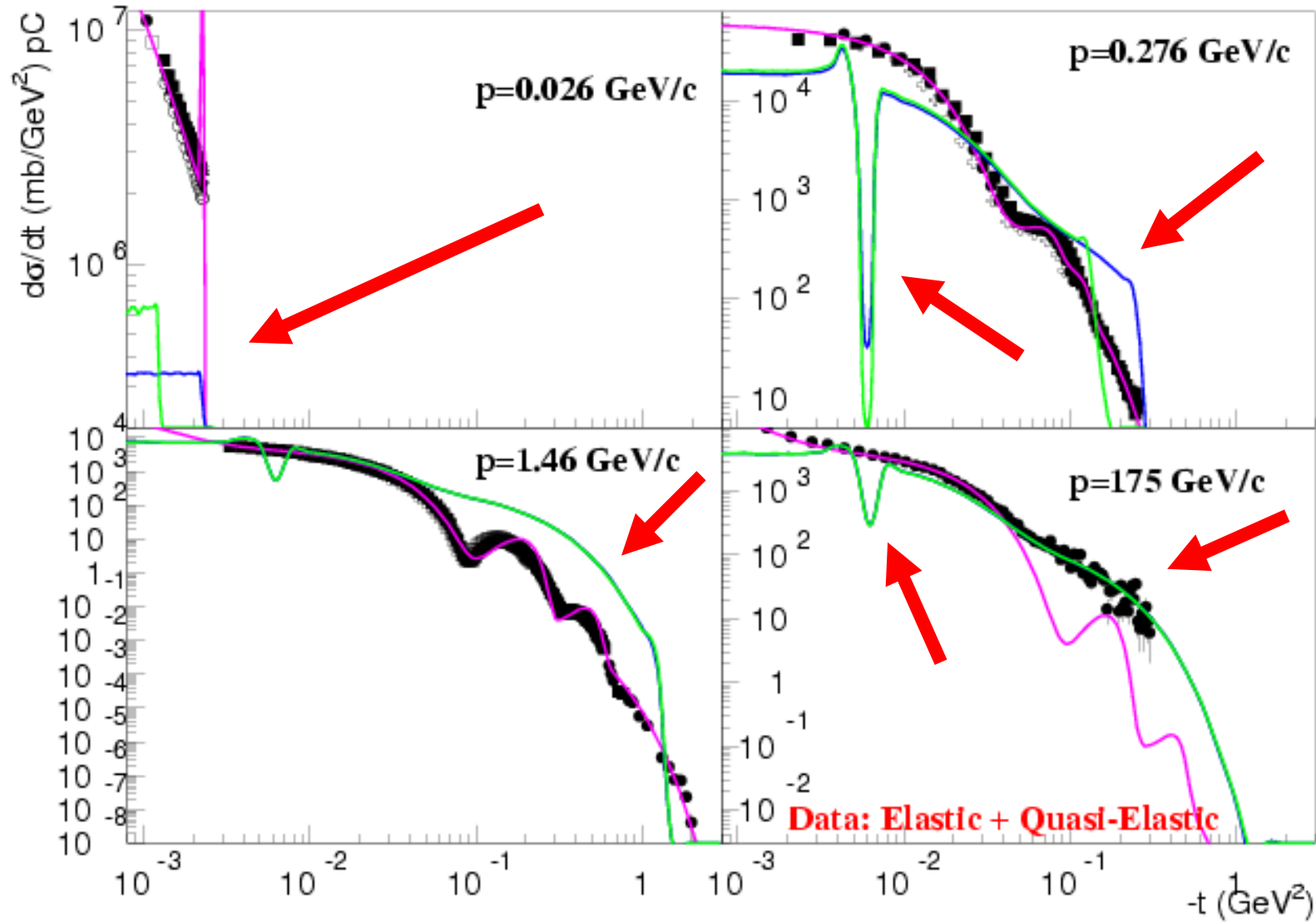$-t$ (GeV^2)

CHIPS improvement of pLi7 elastic scattering

CHIPS improvement of pBe elastic scattering

CHIPS improvement of pC elastic scattering

CHIPS improvement of pAl elastic scattering

M.Kosov. Elastic scattering
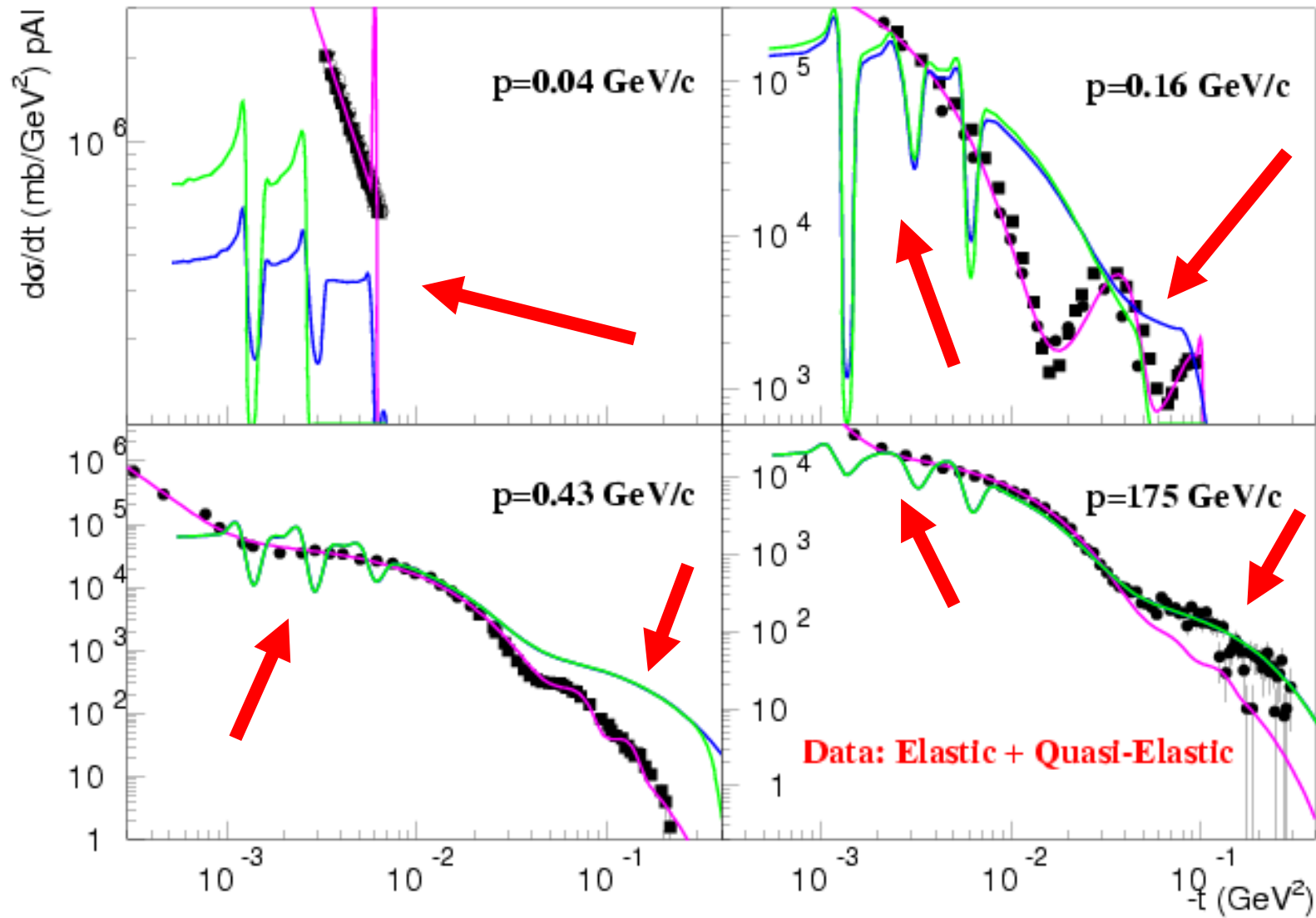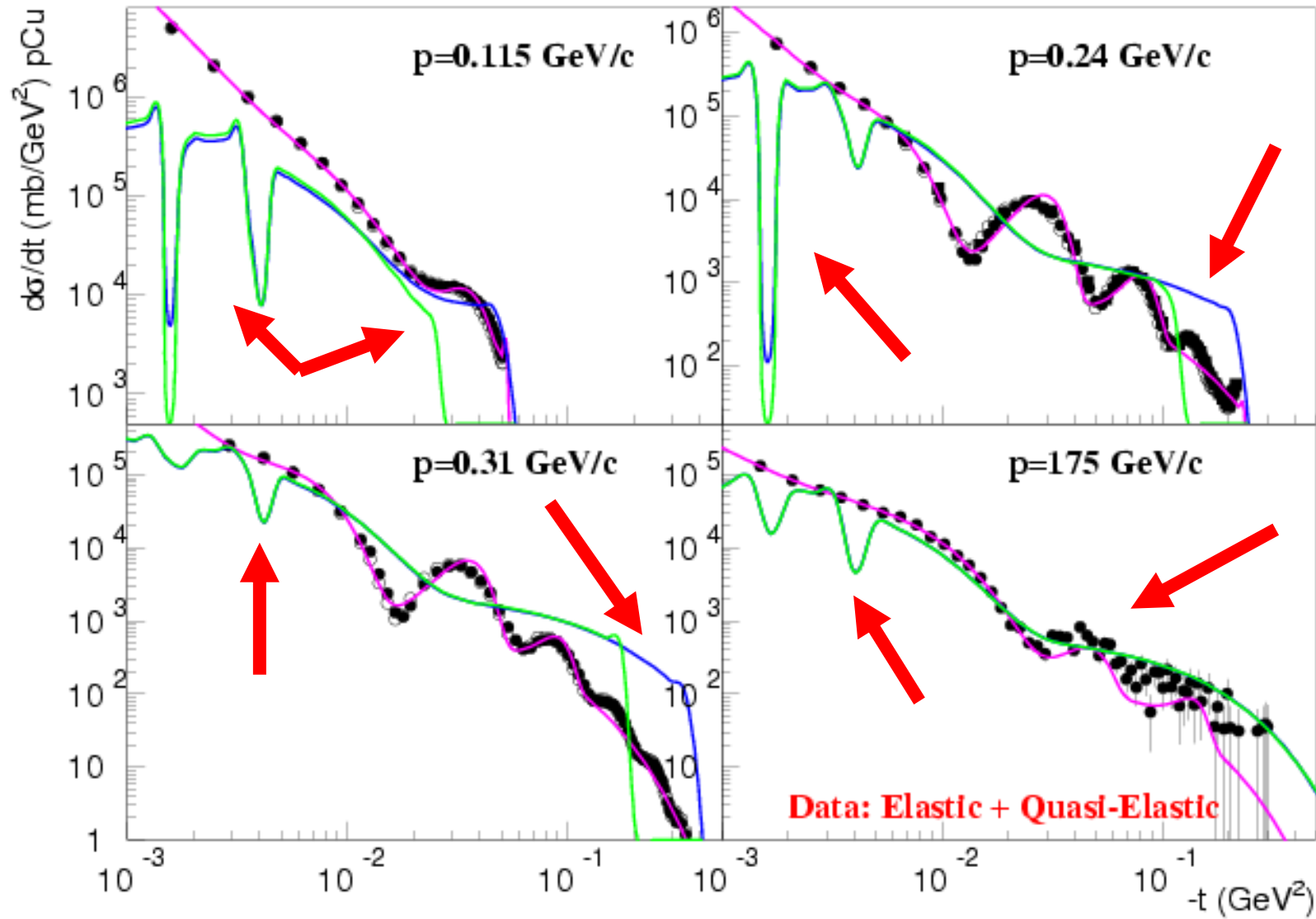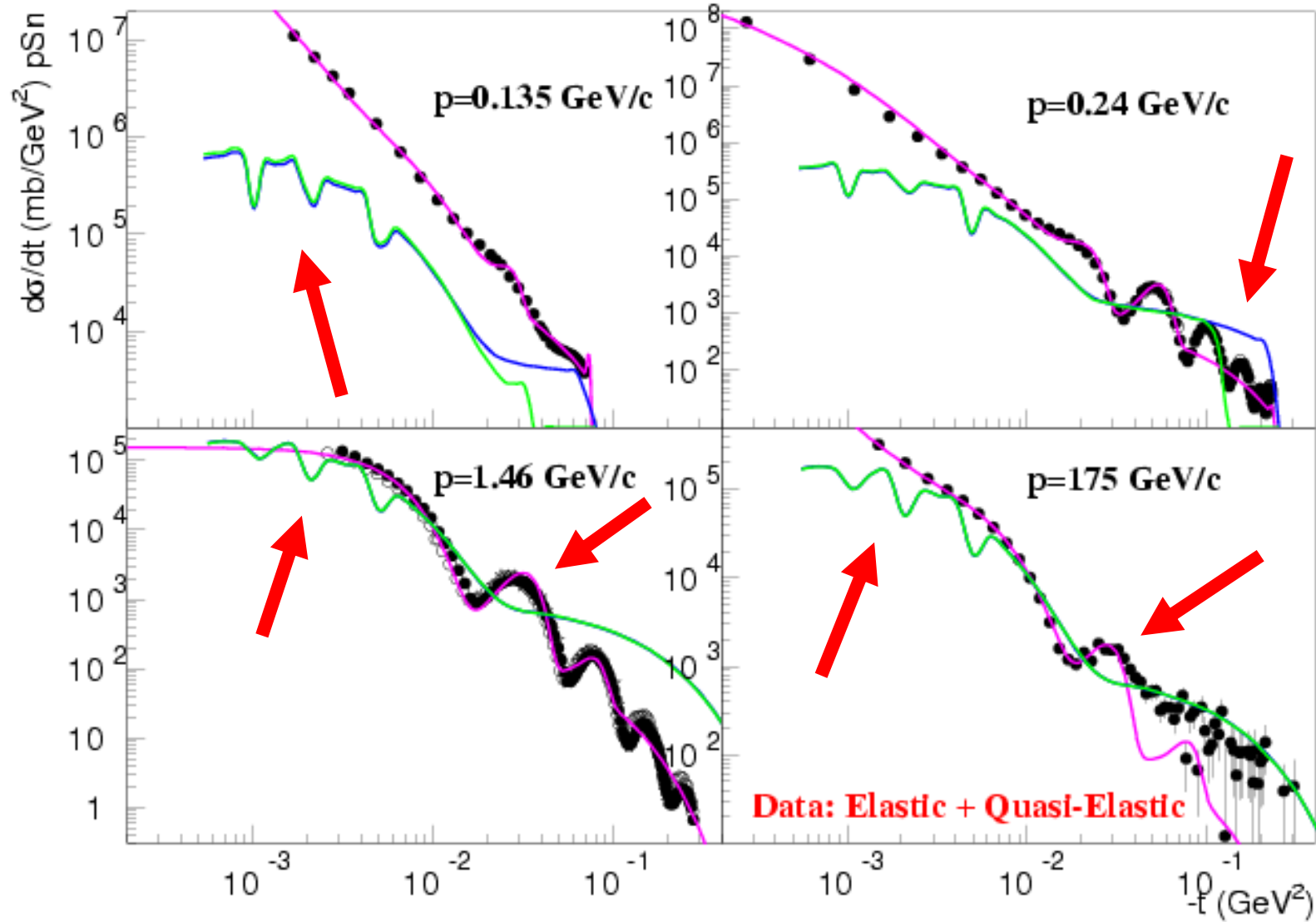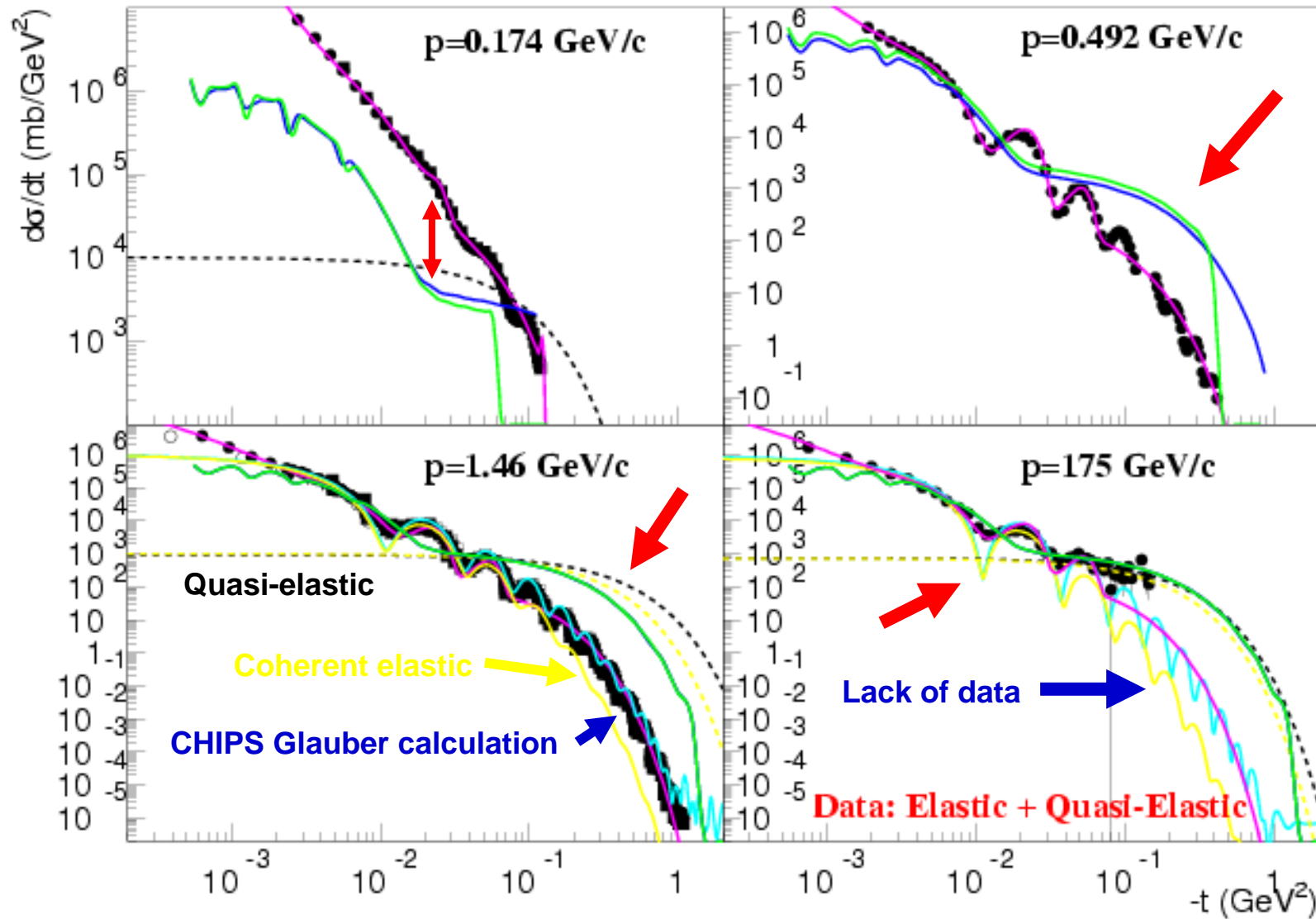
CHIPS improvement of pCu elastic scattering

CHIPS improvement of pSn elastic scattering

CHIPS improvement of pPb elastic scattering

Conclusion

- **Review of existing Geant4 elastic models**
  - ☐ G4LElasic(8.1) is used in LHEP (stops at 90^0 c.m. – nothing above)
    - ▪ bad at low energies (E < 30 MeV) – bad reaction cross-sections
    - ▪ double counting of quasi-elastic scattering at high energies
    - ▪ no isotope dependency (independent internal isotope choice)
    - ▪ frequently 1 particles in final state, no energy/momentum conservation
  - ☐ G4HadronElastic(8.1) (G4QElastic for np and pp) is used in QGSP
    - ▪ the same bad at low energies with arbitrary extrapolation to 180^0 c.m.
    - ▪ redouble the double counting of quasi-elastic (extend from 90^0 to 180^0)
    - ▪ lets to make the isotope choice, but does not have e.g. ^{3}He isotope
    - ▪ produces 2 particles in final state and conserves energy/momentum
  - ☐ G4np/G4pp (SAID) is not used in physics lists (only inside Binary)
    - ▪ The same bad at low energies (because of the wrong reaction XS)
    - ▪ Not applicable above 3 GeV (drops down at |t|>0.1 Gev^2 etc.)
  - ☐ G4QElastic (CHIPS) – good, but made only for np, pp, and pA now
  - ☐ G4ElasticHadrNucleusHE/G4ElasticCascadeInterface don't work