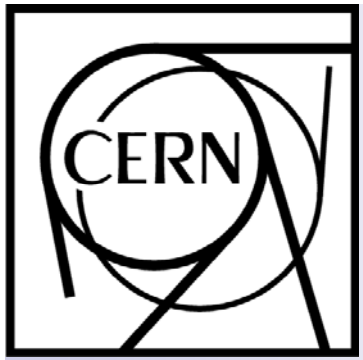


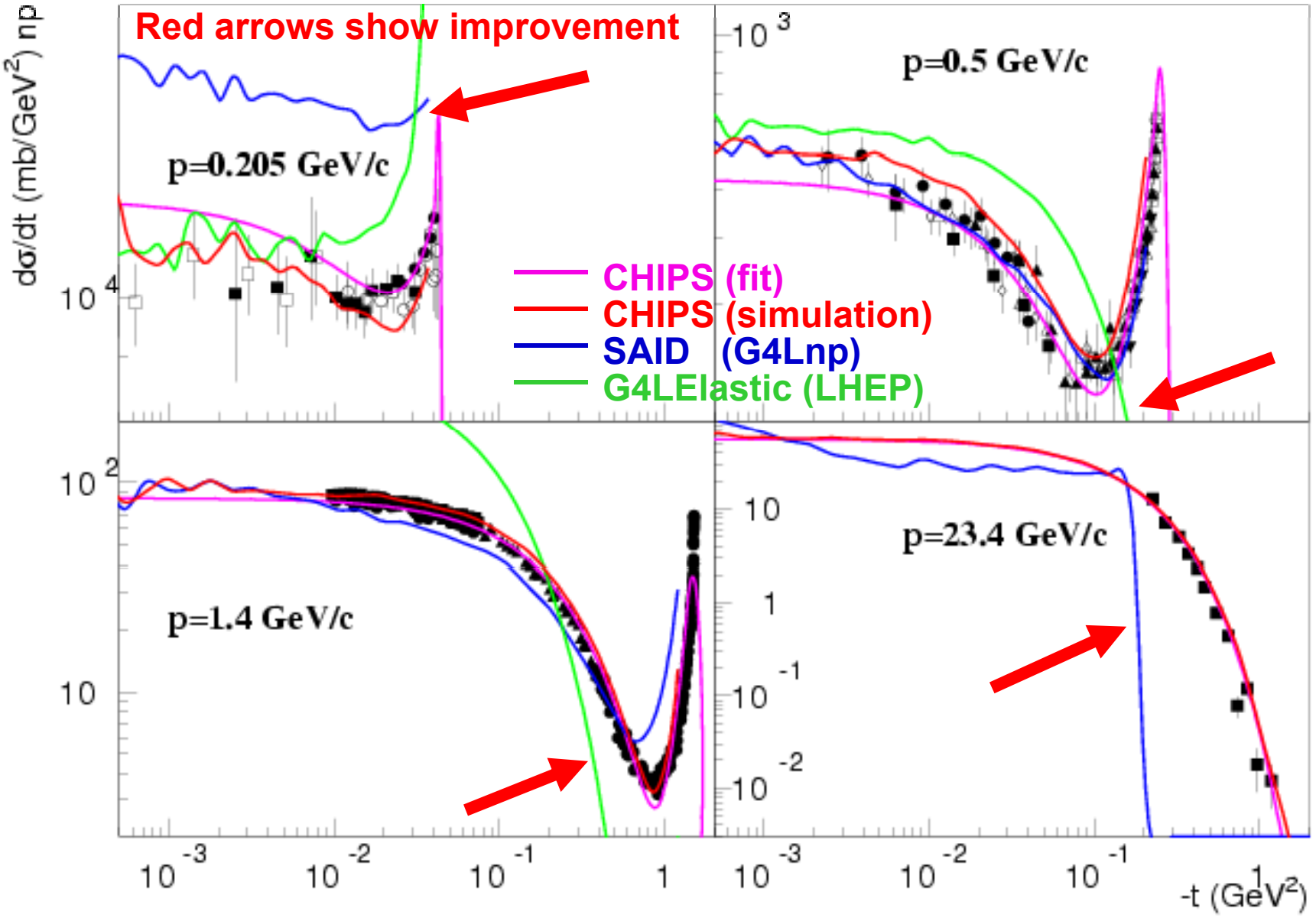
Recent CHIPS implementations

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

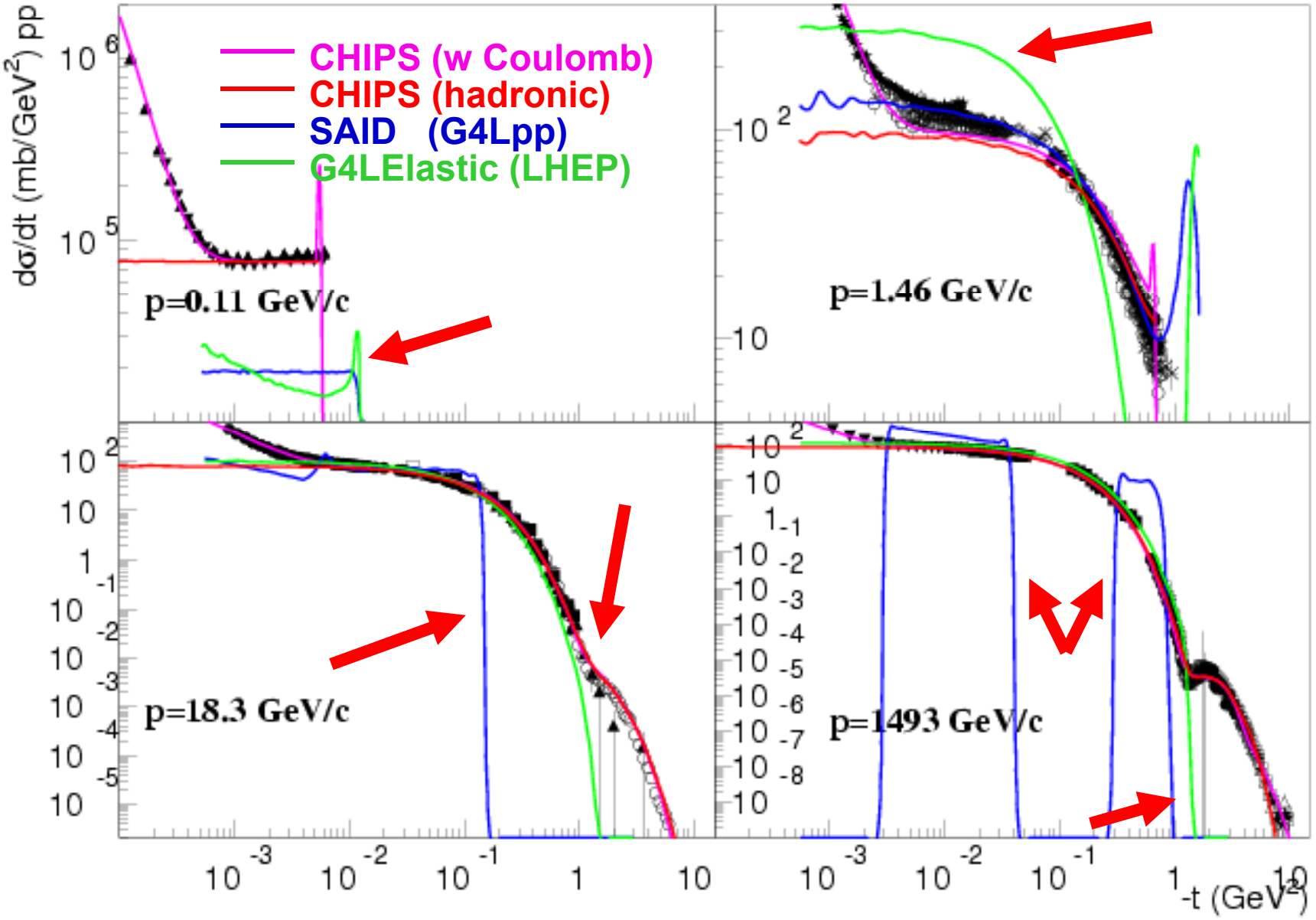
Plan

- New default CHIPS physics in Geant4 8.3/9.0
  - **G4QElastic** for protons and neutrons
  - Quasi-Elastic (**G4QuasiFreeRatios**) in **FTF/QGS**
  - New muon-capture (**G4QCaptureAtRest**)
- New processes not yet in the default physics
  - Muon-nuclear interaction process (**G4QCollision**)
  - Tau-nuclear interaction process (**G4QCollision**)
  - A(ν,μ): neutrino-nuclear interaction process (**G4QCollision**)
  - **G4QLowEnergy** process for inelastic interactions of fragments (including p & n) and hyper-fragments with nuclei
  - Detailed CHIPS process for pA interactions below 150 MeV

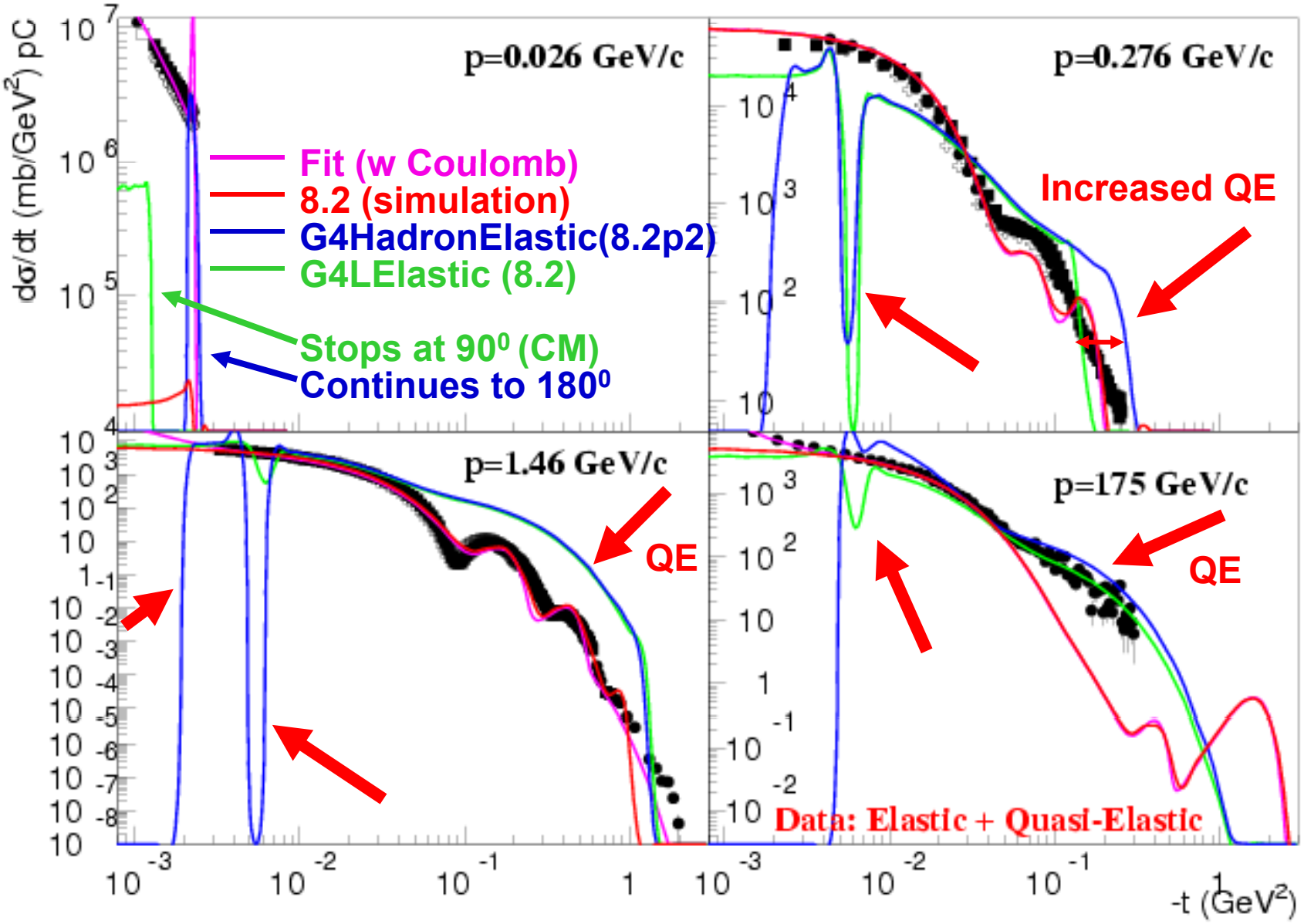
CHIPS improvement of np elastic scattering



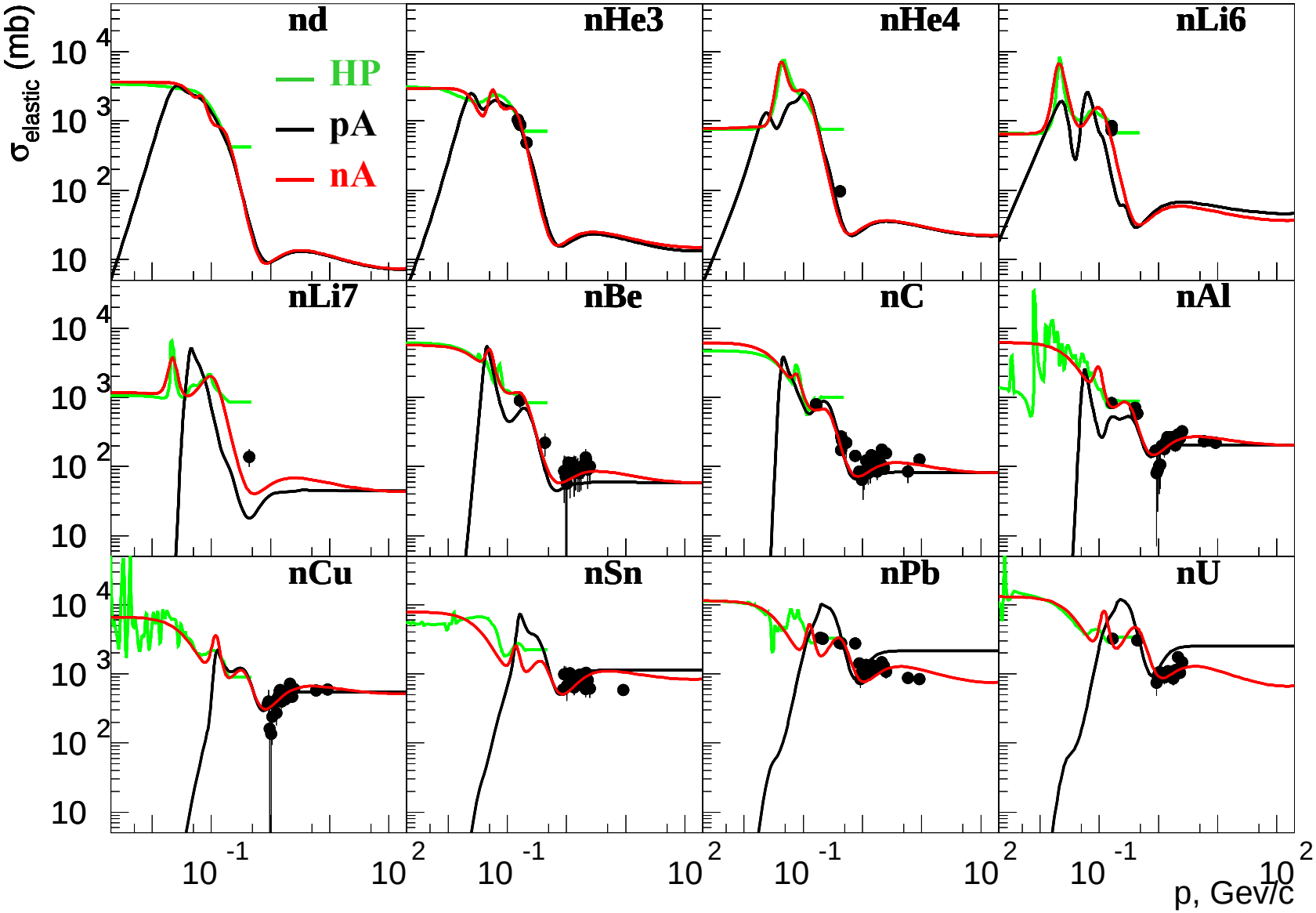
CHIPS improvement of pp elastic scattering



CHIPS improvement of pC elastic scattering

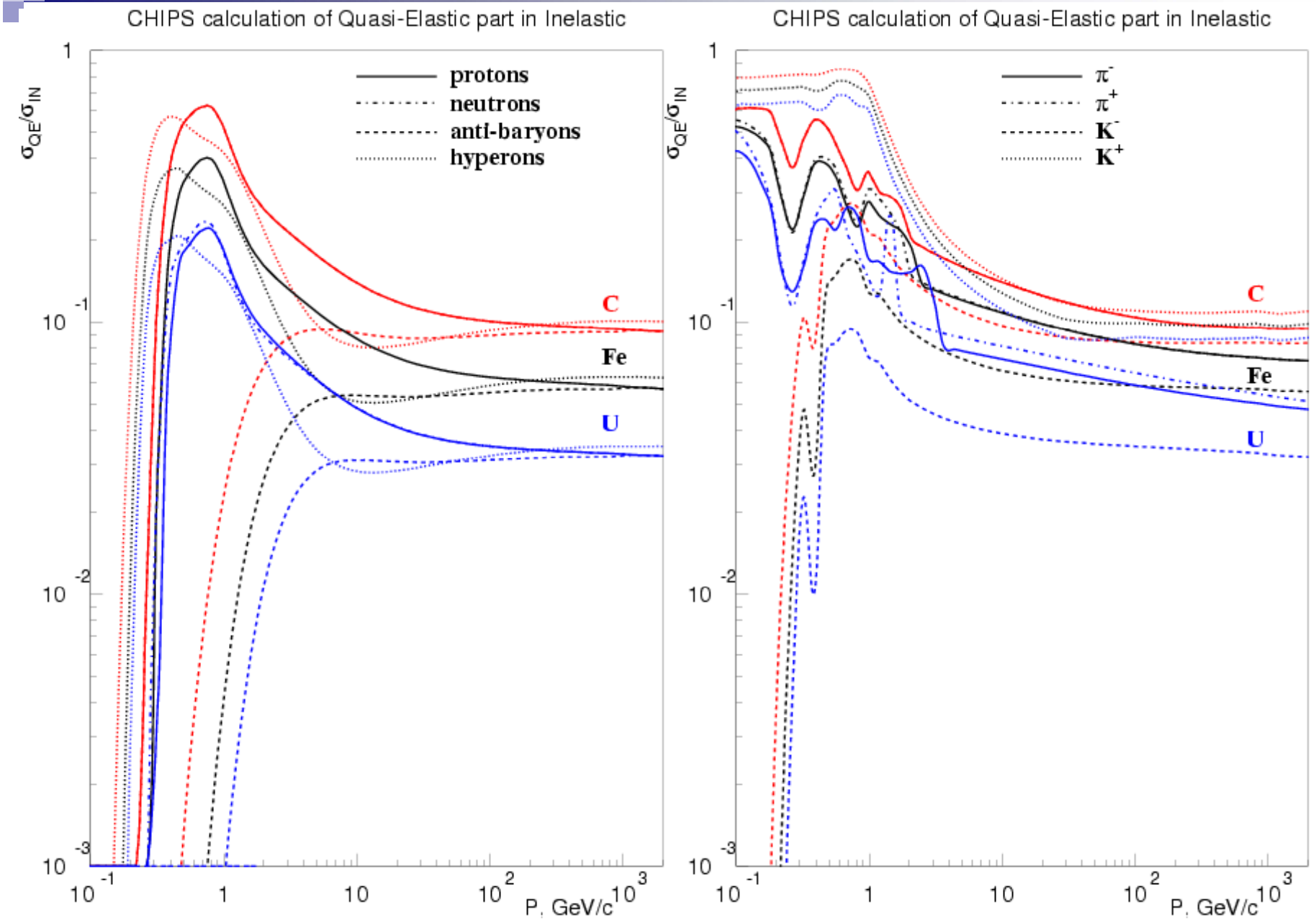


Improvement of nA elastic (red) over integrated pA elastic and data fit of elastic (red) over integrated (black) cross sections



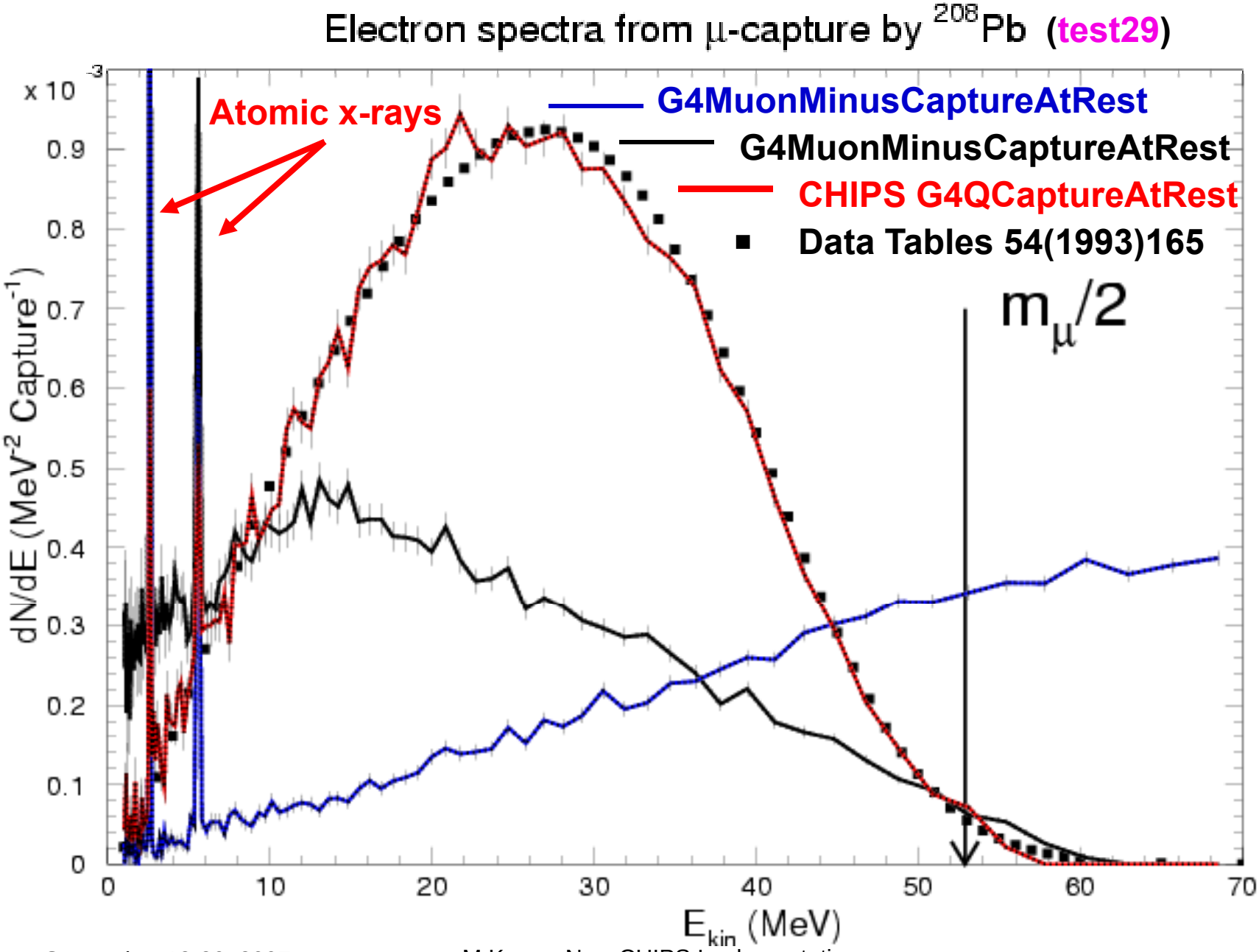
Quasi-Elastic at high energies

- A part of inelastic cross-section is a quasi-elastic scattering (elastic scattering of the projectile on a quasi-free nucleon of nuclei)
- G4QuasiFreeRatios class provides a part of the quasi-elastic in the inelastic cross-section
- The Scatter member function provides the quasi-elastic scattering on the basis of Elastic
- The CHIPS quasi-elastic is implemented in all 8.3/9.0 FTF/QGS Physics Lists (default)

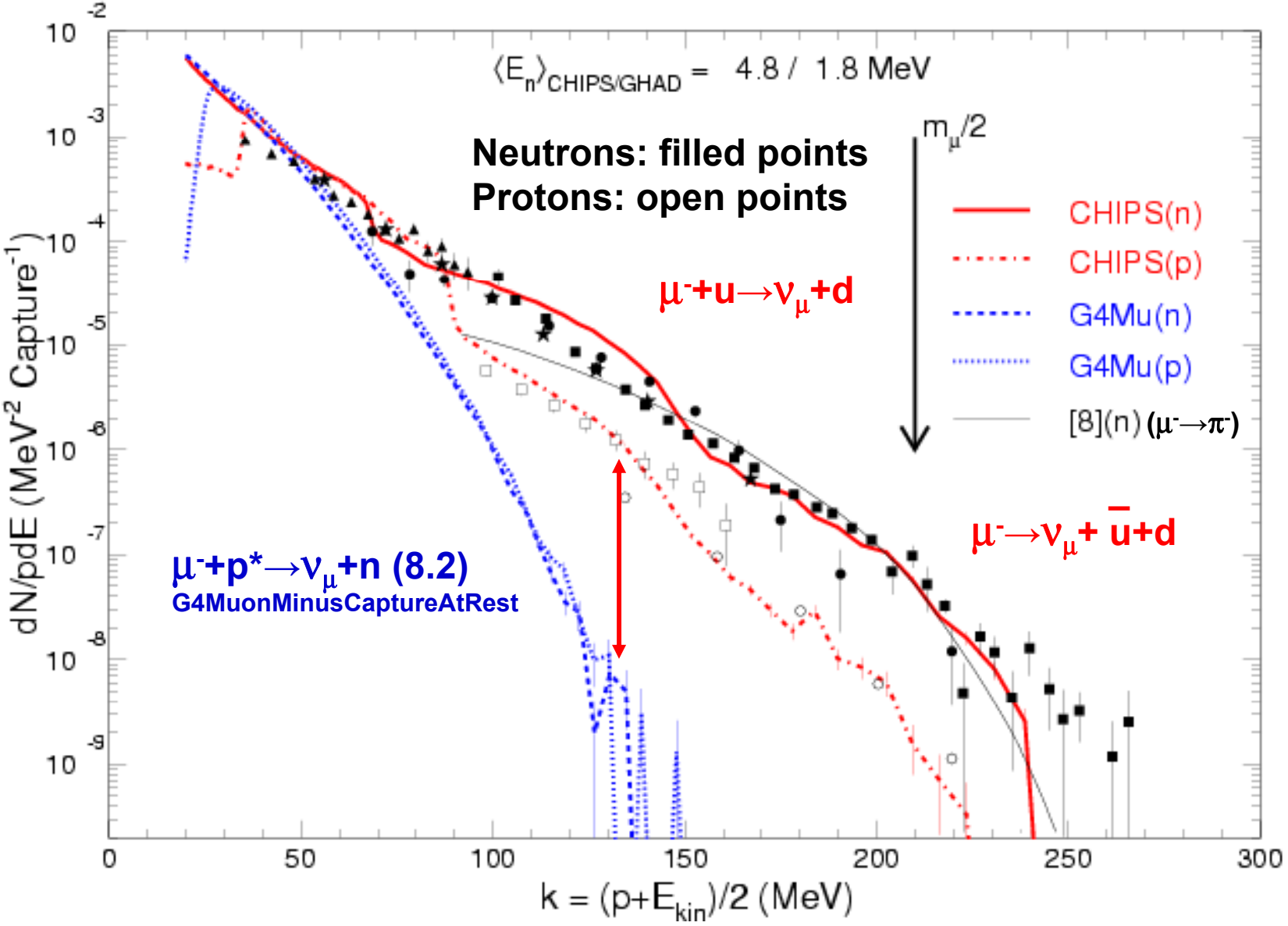

CHIPS calculation of Quasi-Elastic part in Inelastic
σQE/σIN
protons
neutrons
anti-baryons
hyperons
C
Fe
U
P, GeV/c
CHIPS calculation of Quasi-Elastic part in Inelastic
σQE/σIN
π-
π+
K-
K+
C
Fe
U
P, GeV/c

New muon capture at rest

- The atomic muon decay is improved, using the recent calculations (Nuclear Data Tables)
- A precise approximation of the decay rate and the capture rate are provided
- Atomic e^-/γ cascade is simulated
- Spectra of protons, neutrons and fragments in the nuclear muon capture reaction are fitted using the $\mu^- \rightarrow du\nu_\mu$ CHIPS decay [Published in M.Kossov, EPJ A33 (2007) 7]

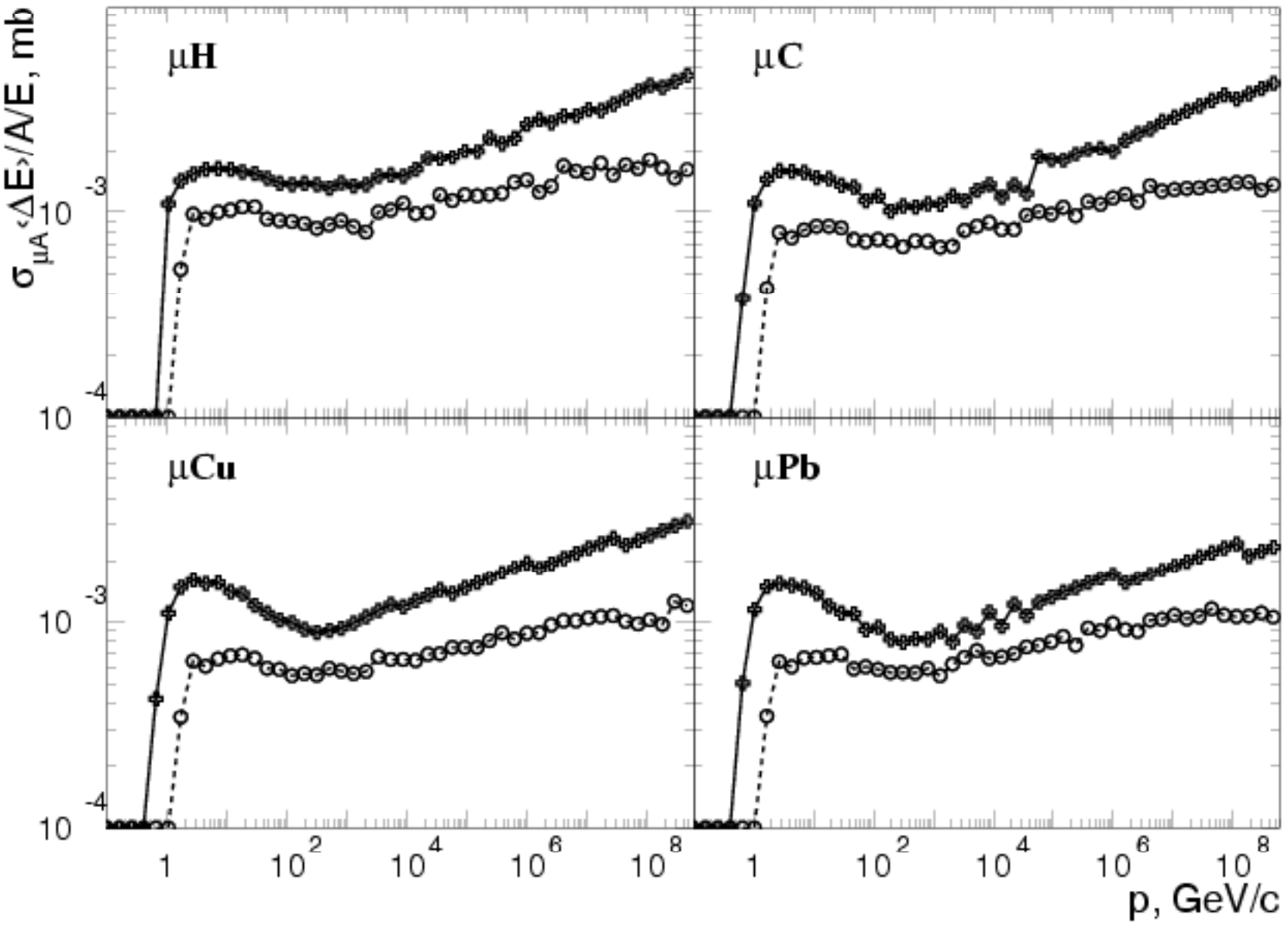

Electron spectra from μ-capture by ^{208}Pb (test29)
Atomic x-rays
G4MuonMinusCaptureAtRest
G4MuonMinusCaptureAtRest
CHIPS G4QCaptureAtRest
Data Tables 54(1993)165
$m_\mu/2$
x 10^{-3}
dN/dE (MeV^{-2} Capture^{-1})
E_{kin} (MeV)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0
10
20
30
40
50
60
70

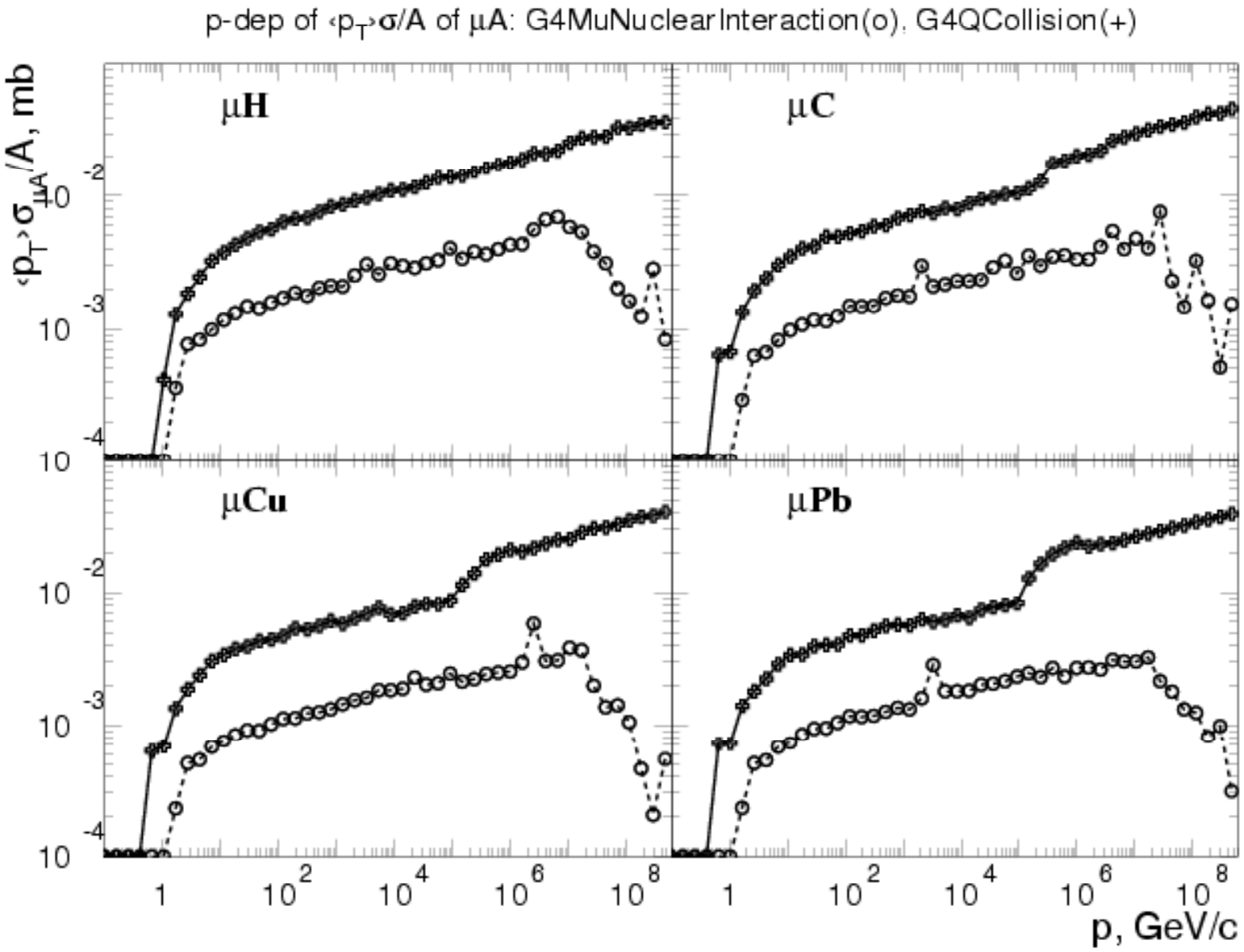
CHIPS:G4QCaptureAtRest(test29,μ^-Ca)



New process for muon-nuclear reactions

- CHIPS μ-nuclear process is G4QCollision
- It is based on the generalized theory of lepto-nuclear interactions [**M.Kossov, EPJ A14 (2002) 377**]
- With respect to the old model it doubles the scattering angle of muons on nuclei and the energy transferred to the nucleus. As a result the number of produced neutrons is doubled.
- Simulates secondary $\pi \rightarrow \mu$ penetrating muons

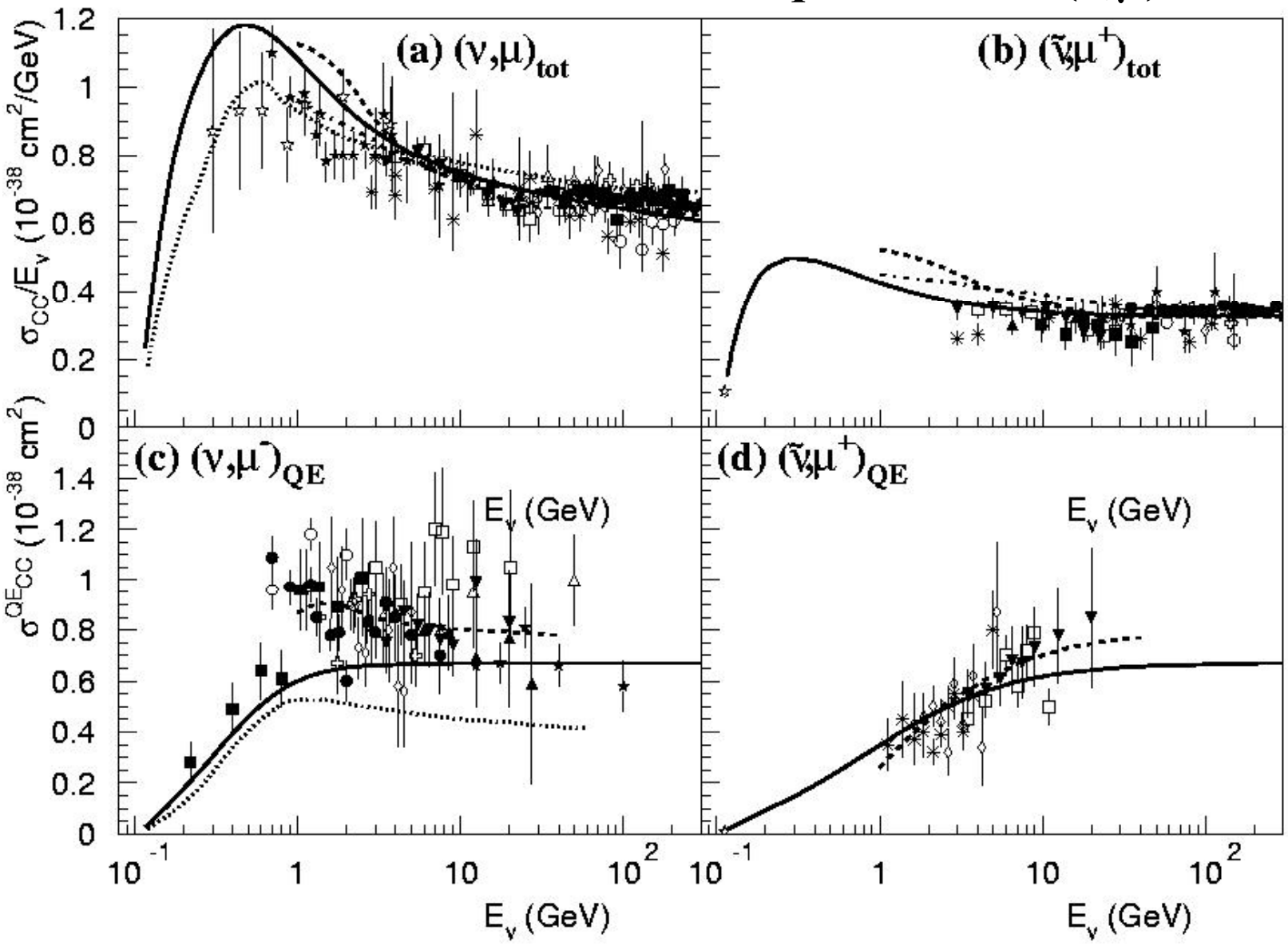

p-dep of σ‹ΔE›/A/E of μA: G4MuNuclearInteraction(o), G4QCollision(+)
σμA‹ΔE›/A/E, mb
μH
μC
μCu
μPb
10^-3
10^-4
1
10^2
10^4
10^6
10^8
p, GeV/c


p-dep of ‹p_T›σ/A of μA: G4MuNuclearInteraction(o), G4QCollision(+)
‹p_T›σ_μA/A, mb
μH
μC
μCu
μPb
p, GeV/c

(ν,μ)-nuclear and τ-nuclear interactions

- The neutrino-nuclear interactions are not very important for the LHC physics simulation, but can be important for simulation of neutrino detectors. The small cross-section of νA interaction can be biased.
- The τ-nuclear interactions can be important for calculation of the τ-efficiency on 1% level

CHIPS calculation of total and quasi-elastic (ν,μ) reactions



R&D of hadronic CHIPS processes

- First steps of the hadronic CHIPS project have been done:
  - **G4QEvaporation** class making an isotropic final evaporation of excited residual nuclei
  - It was used in the **G4QLowEnergy** class, which can be applied for inelastic interactions of low energy fragments and hyper-fragments
  - CHIPS cross-sections for nucleon-nuclear and nuclear-nuclear interactions have been fitted
  - Hadronic **G4QCollision** inelastic process is made for **pA and nA** interactions in the pre-compound energy range ($E<m_{\pi}$)