New muon-nuclear physics in Geant4

Mikhail Kosov, G4Forum, 31.01.06

Main issues of the talk

- **Use cases of μ-nuclear interactions**
  - ☐ At rest: underground background
  - ☐ On flight: muon detectors in high energy physics

- **High energy muon-nuclear interactions**
  - ☐ Mean scattering angle & correlated background
  - ☐ Catastrophic energy loss of muons in matter

- **Nuclear muon capture at rest**
  - ☐ Production of neutrons and nuclear fragments
  - ☐ Comparison of neutron spectra with data

Development of CHIPS µ-nuclear

- CHIPS algorithm is published (**Eur.Phys.J.A14(2002)377**) for electron-nuclear reactions and generalized for μ and τ leptons

- Universal **G4QCollision** process is made for e, μ, τ, and γ:
  - □ e with G4QElectroNuclearCrossSection
  - □ μ with G4QMuonNuclearCrossSection
  - □ τ with G4QTauNuclearCrossSection
  - □ γ with G4QPhotoNuclearCrossSection

- **G4QCollision** CHIPS process can be used instead of
  - □ e: G4ElectronNuclearProcess/G4PositronNuclearProcess
  - □ μ: G4MuNuclearInteraction (where π^0 is used for nuclear reaction)
  - □ τ: *** **G4QCollision** is unique ***
  - □ γ: G4PhotoNuclearProcess(CHIPS for E<3GeV,QGSC for E>3GeV)

- **G4QCaptureAtRest** process for μ^- and τ^- nuclear capture can be used instead of **G4MuonMinusCaptureAtRest**
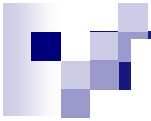
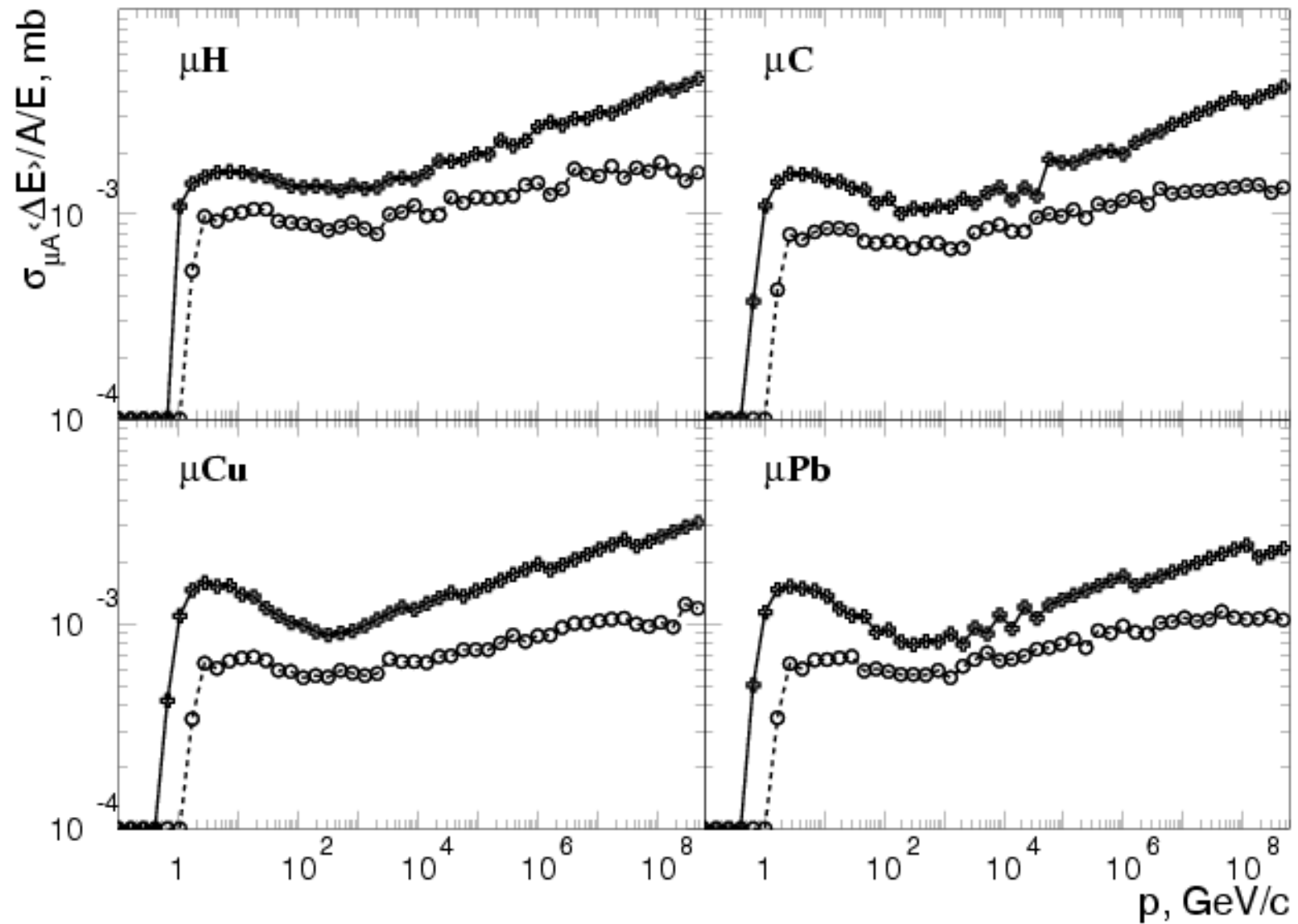## Quasi-real effective photons (dashed lines), all (a,b), high Q^2 (c,d) (solid lines)
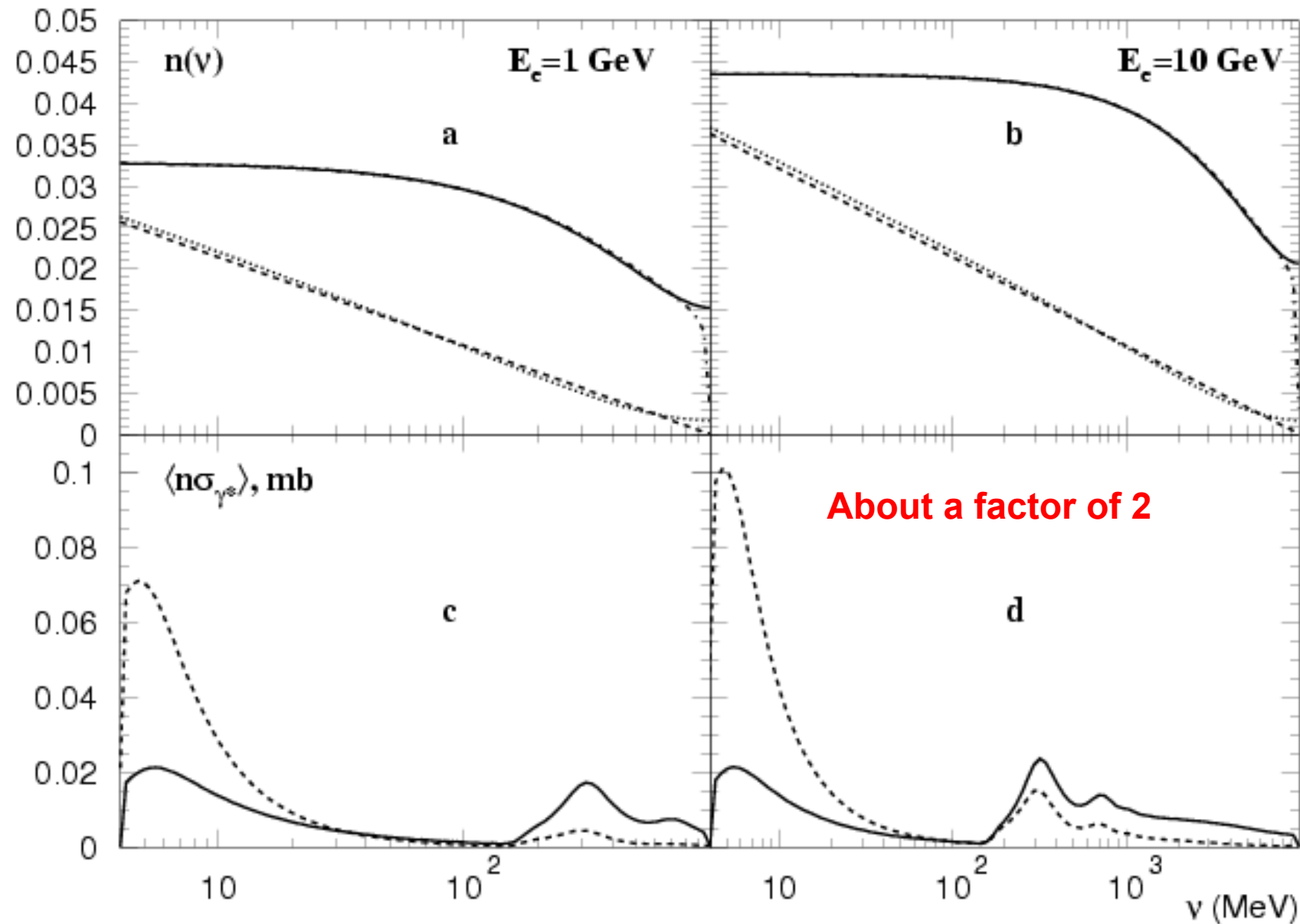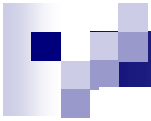
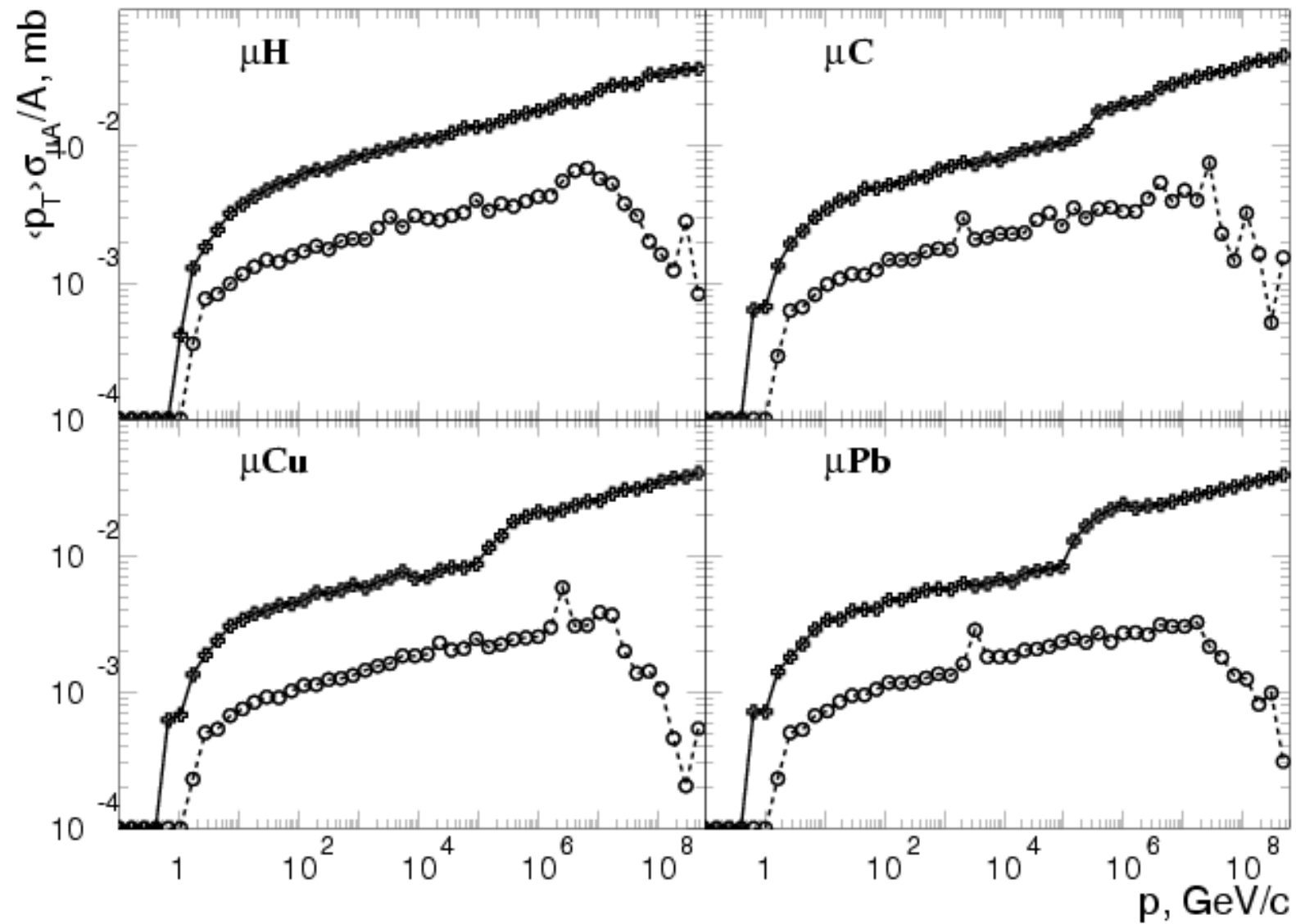p-dependence of μ-Nuclear: G4MuNuclearInteraction(o), G4QCollision(+)

Shadowing(o)=.22*A+.78*A$^{.89}$
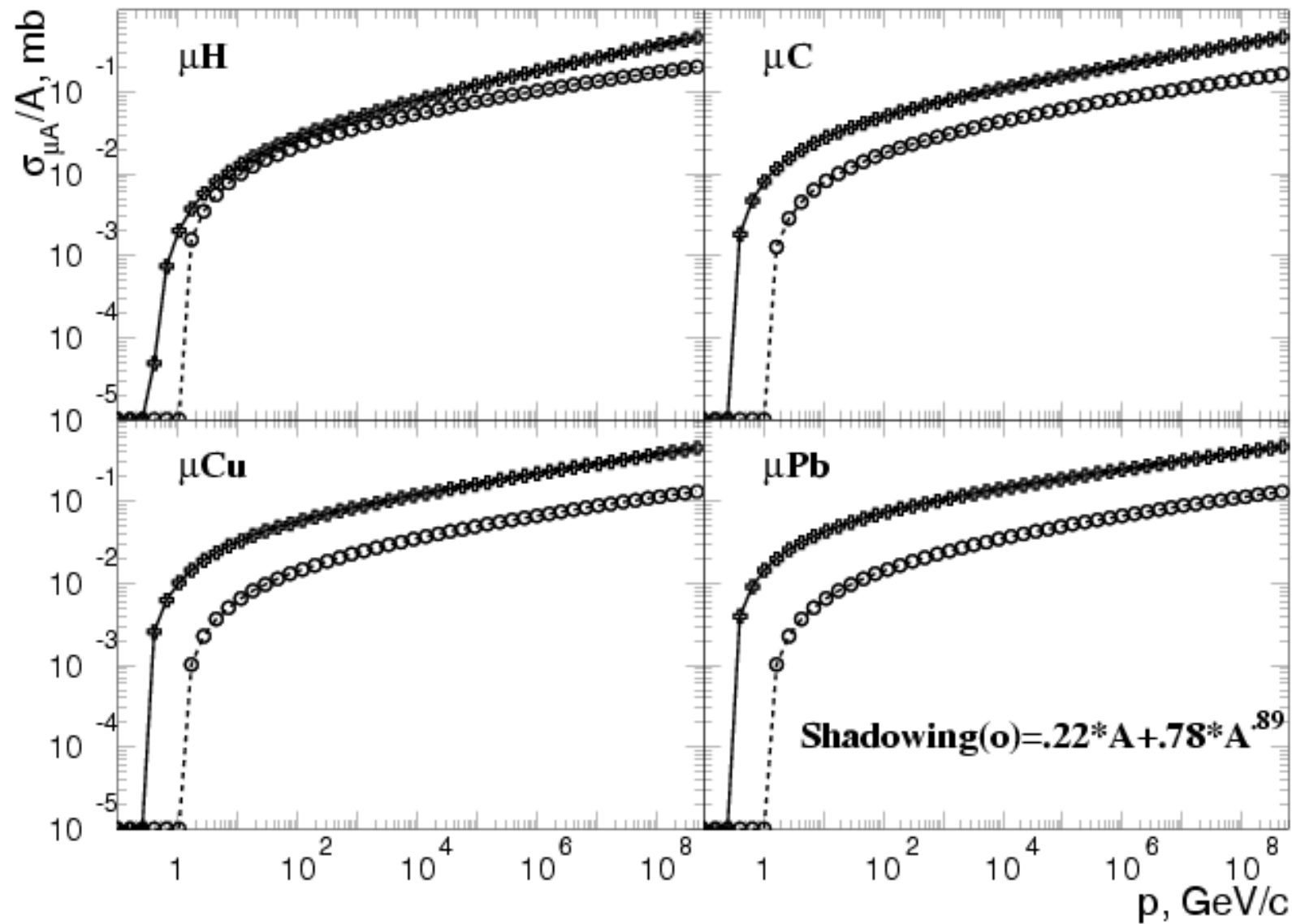
p-dep of σ‹ΔE›/A/E of μA: G4MuNuclearInteraction(o), G4QCollision(+)

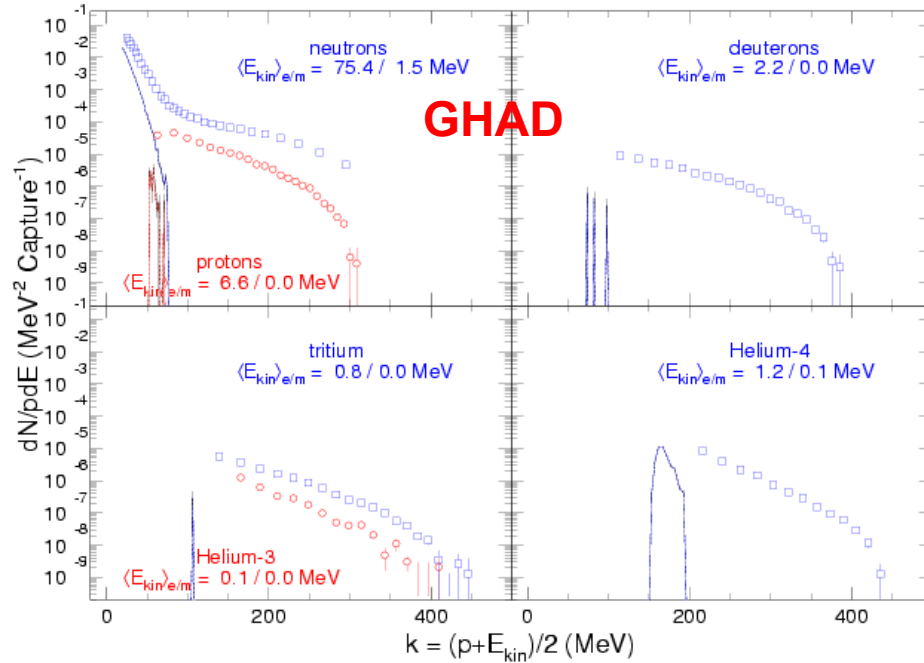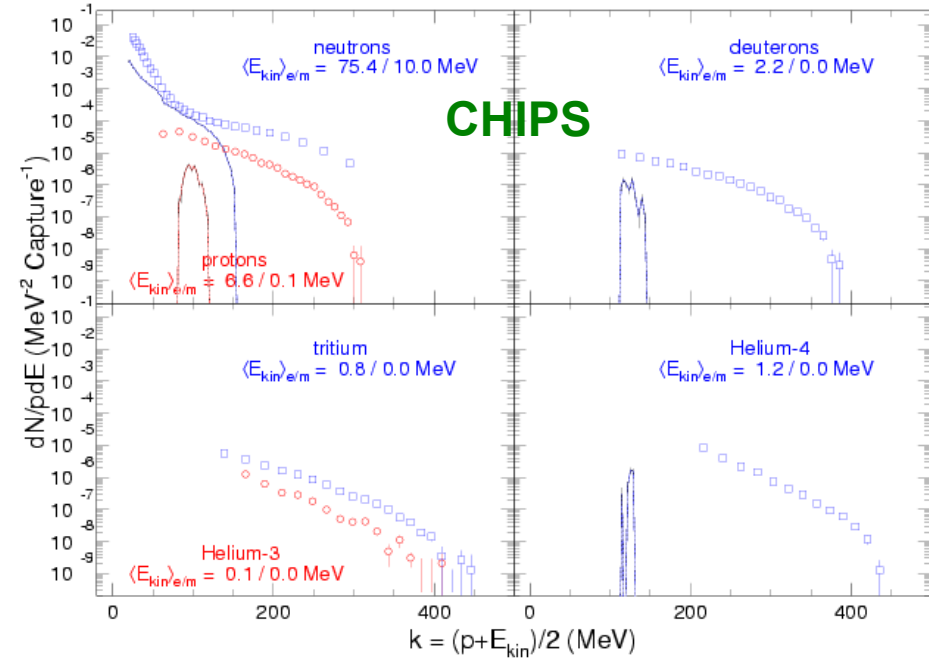p-dep of $\langle p_T \rangle \sigma/A$ of μA: G4MuNuclearInteraction(o), G4QCollision(+)

Nuclear muon capture at rest

- New approximation of Hoof factor Q (decay delay)
- New approximation of nuclear capture rate Λ_n.
- New total capture rate $\Lambda = 455.16 (ms^{-1}) + Q \cdot \Lambda_n$.
- New parameterization of decay of a bounded muon
- In **G4QCaptureAtRest** CHIPS fragmentation is used with initial $q + \mu \rightarrow q + \nu_\mu$ excitation.
- **G4MuonMinusCaptureAtRest** uses $p + \mu \rightarrow n + \nu_\mu$ reaction with following pre-compound deexcitation

Muon capture on ^{12}C nucleus (data for π^-)
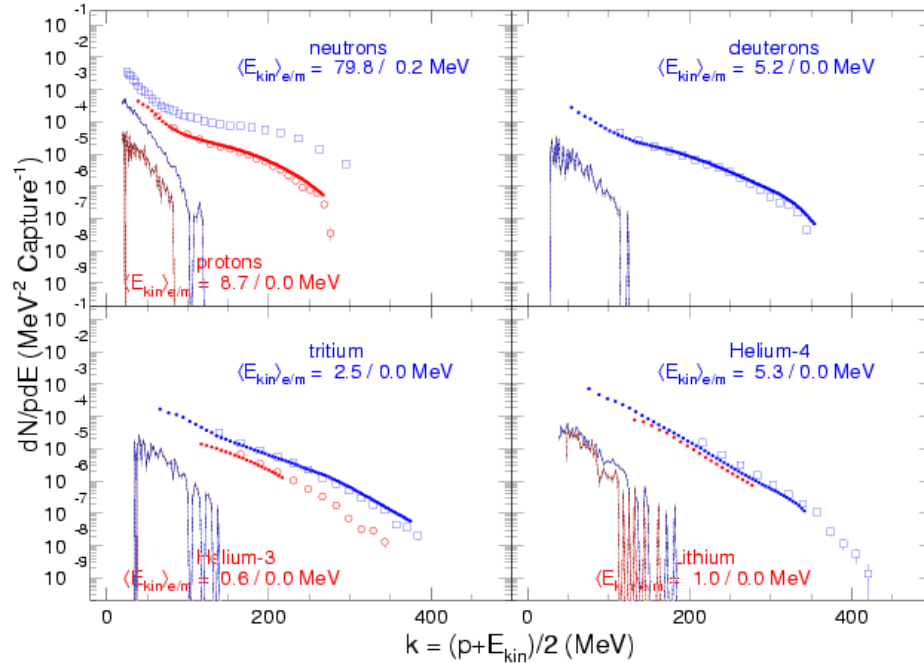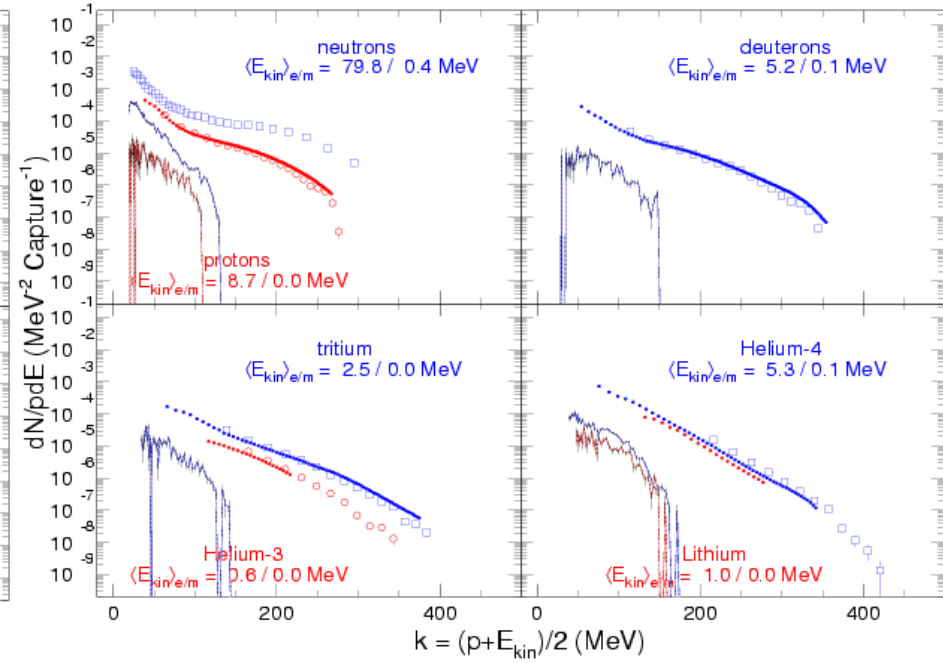
Muon capture on ^{12}C nucleus (data for π^-)

Muon capture on ^{181}Ta nucleus (data for π^-)

Muon capture on ^{181}Ta nucleus (data for π^-)

GHAD

CHIPS

Muon capture on ^{40}Ca nucleus

$m_\mu/2$

— CHIPS

— GHAD

Kinematic limit for $\mu=\pi\iota$ ($E_v=0$) capture on ^{40}Ca

$m_\mu/2$

CHIPS ($\mu=\pi$)

GHAD

dN/pdE (MeV^{-2} Capture^{-1})

$k = (p+E_{kin})/2$ (MeV)
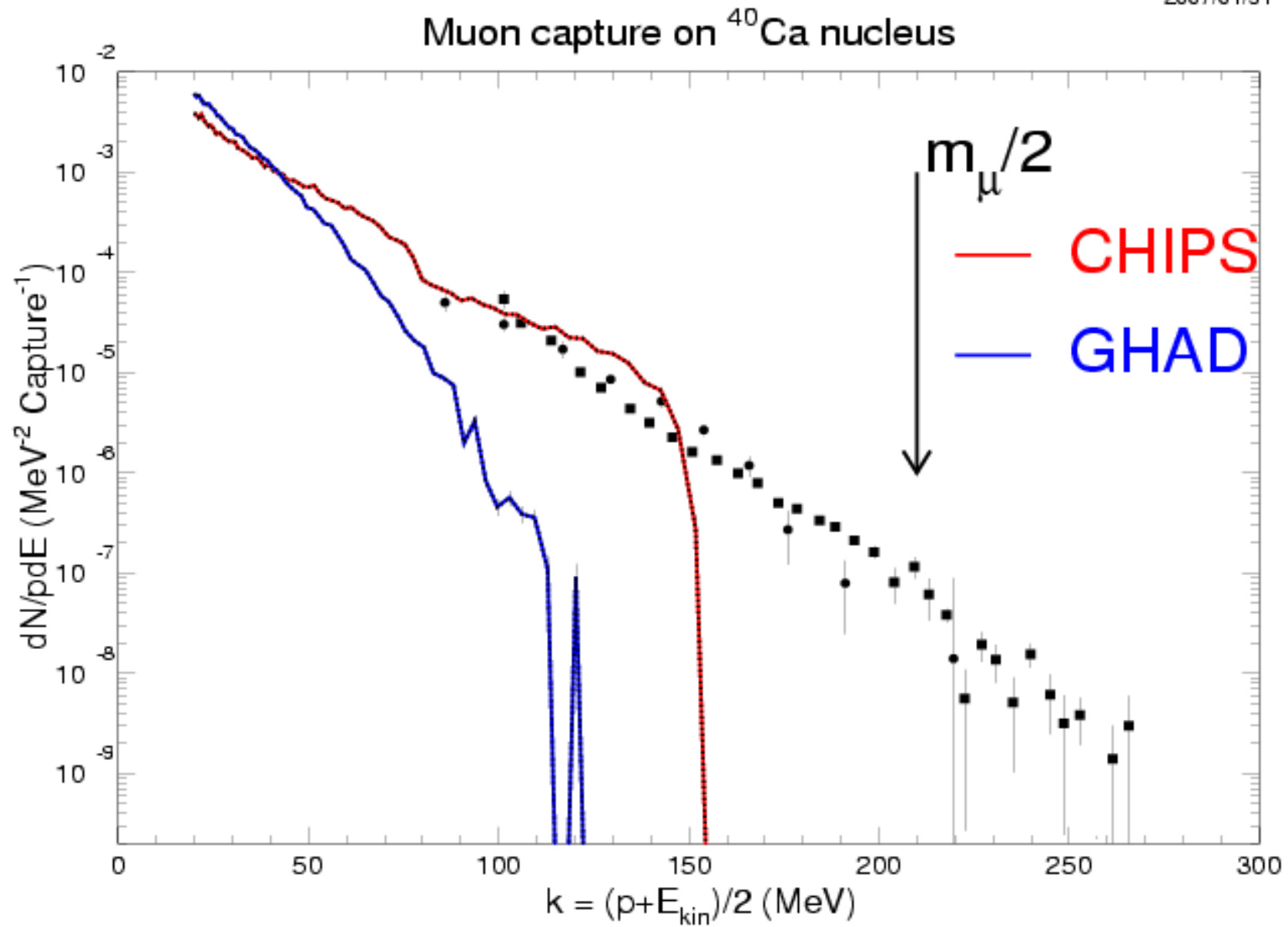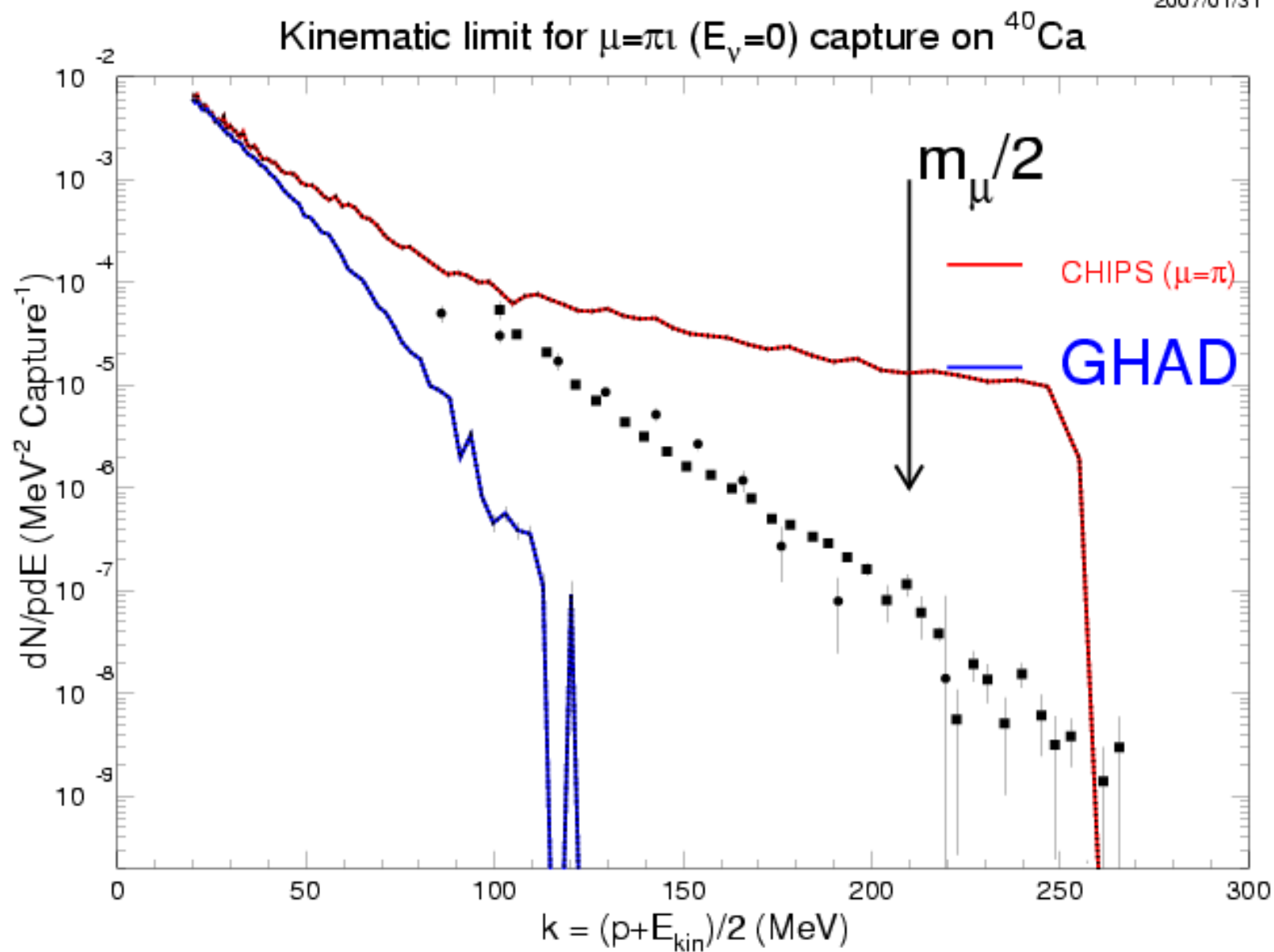
$\mu \rightarrow \pi + \nu$ hypothesis and kinematics limits

- In 1977 J.Bernabeu, T.E.O.Ericson and C.Jarlskog (Phys.Lett. B69, p.161) proposed a new $\mu \rightarrow \pi + \nu$ mechanism of the muon nuclear capture.

- In the extreme case it is possible that $m_{\pi*}=m_{\mu}$, $E_{\nu}=0$, and all energy of the muon's mass is transferred to the nucleus similar to the pion capture.

- Just to check the kinematics limit this extreme mechanism was used in CHIPS and it was found that the experimental data reach this limit, so they can be used for the tuning of the virtual $m_{\pi*}$ distribution.

Conclusion

- G4MuNuclearInteraction process gives nun's for cross-sections below T = 1 GeV. **G4QCollision** process does not produce nun's and doubles mean integrated deposited energy and mean p_T of μ's.

- A precise description of neutron spectra from muon nuclear capture at rest is a real challenge, but CHIPS (**G4QCaptureAtRest**) describes the spectra better then G4MuonMinusCaptureAtRest which is used in present Physics Lists.