Small-x Physics

*and the **detection** of*

Ultra-High Energy Neutrinos

G. Parente

Universidade de Santiago de Compostela

work done in coll. with N.Armesto, C.Merino and E.Zas

XLIIIrd Rencontres de Moriond

QCD and High Energy Interactions

La Thuile, 8-15 March

Outline

- The search for UHE cosmic neutrinos: ν_τ
- τ energy loss at UHE
- νN DIS CC x-section

Detection of UHE neutrinos

- Neutrino-induced muons or showers in ice/water

  IceCube, Antares, Nestor, Baikal

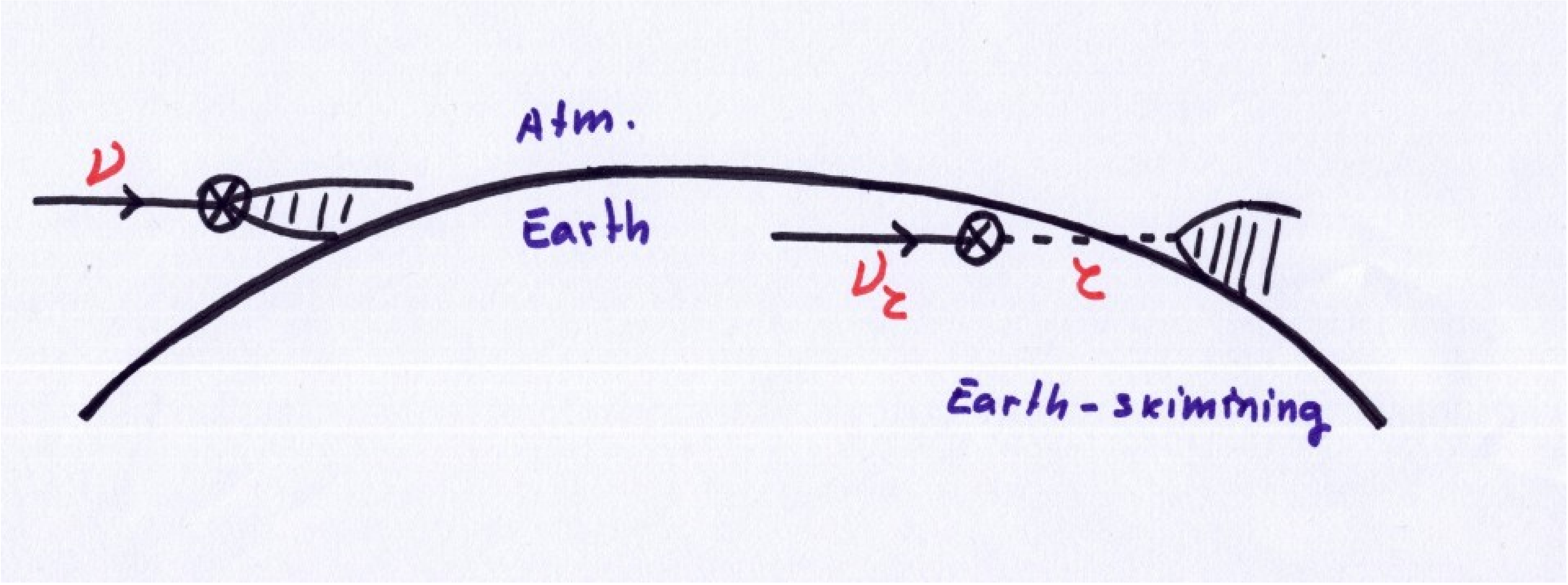
- Neutrino-induced showers in air shower arrays

  Pierre Auger

  - Down-going neutrinos (inclined showers)
  - **Up-going tau-neutrinos (Earth-skimming)**

Earth-skimming neutrinos

- ν_τ conversion into τ through **D.I.S.**
- τ energy loss (mostly **photonuclear**)
- τ emerges from the ground and decays in fly producing an extensive air shower



Event rate

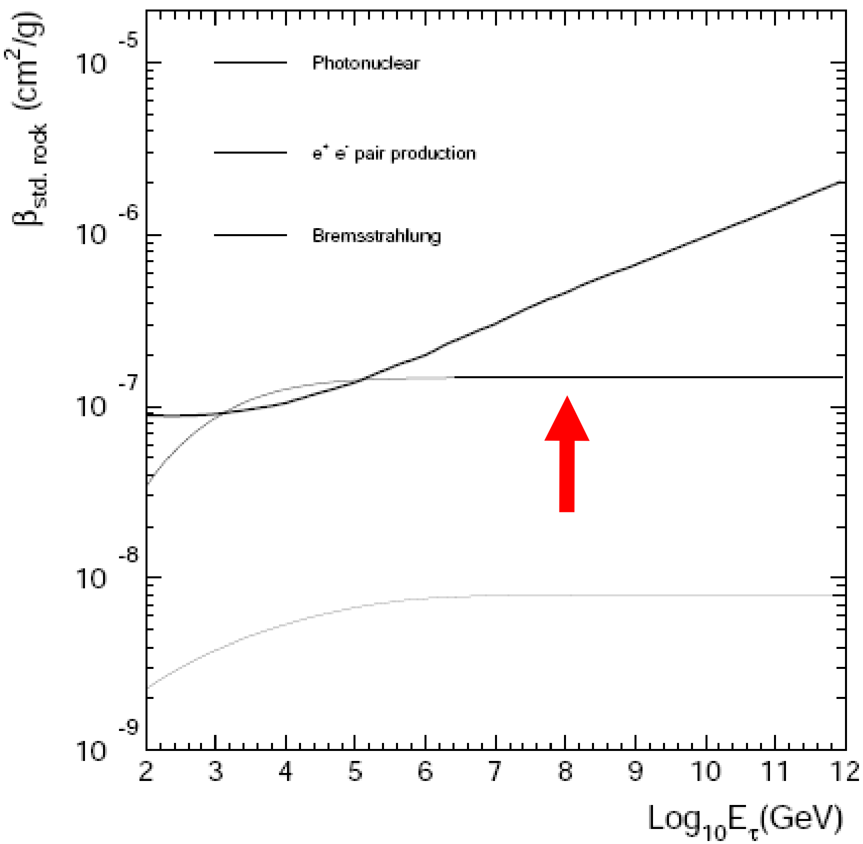
- tau neutrino flux
- **νN x-section (CC DIS)**
- **τN x-section (photonuclear)**
- τ decay probability
- Detector acceptance

τ energy loss

$$-\left\langle \frac{dE}{dX} \right\rangle = a(E) + b(E)E$$

b(E)

[g/cm^2]$^{-1}$



photonuclear

pair production

bremsstrahlung

From Aramo et al Astrop.Phys. 23 (2005) 65

(Standard Rock: A=22, Z=11, density=2.65 g/cm3)

τ energy loss: photonuclear

$$b(E) = \frac{N_A}{A} \int dy\, y \int dQ^2 \frac{d\sigma^{lA}}{dQ^2 dy}$$

$$Q^2_{min} = \frac{y^2 m_l^2}{1-y}\ , \qquad Q^2_{max} = 2m_p E y - 2m_\pi m_p - m_\pi^2\ ,$$

$$y_{min} = \frac{2m_\pi m_p + m_\pi^2}{2m_p E}\ , \qquad y_{max} = 1 - \frac{m_l}{E}\ ,$$

$$\frac{d\sigma^{lA}}{dQ^2 dy} = \frac{4\pi\alpha^2}{Q^4} \frac{F_2^A}{y} \left[1 - y - \frac{Q^2}{4E^2} + \left(1 - 2\frac{m_l^2}{Q^2}\right) \frac{y^2 + Q^2/E^2}{2(1+R^A)}\right]$$

Calculations of b(E)

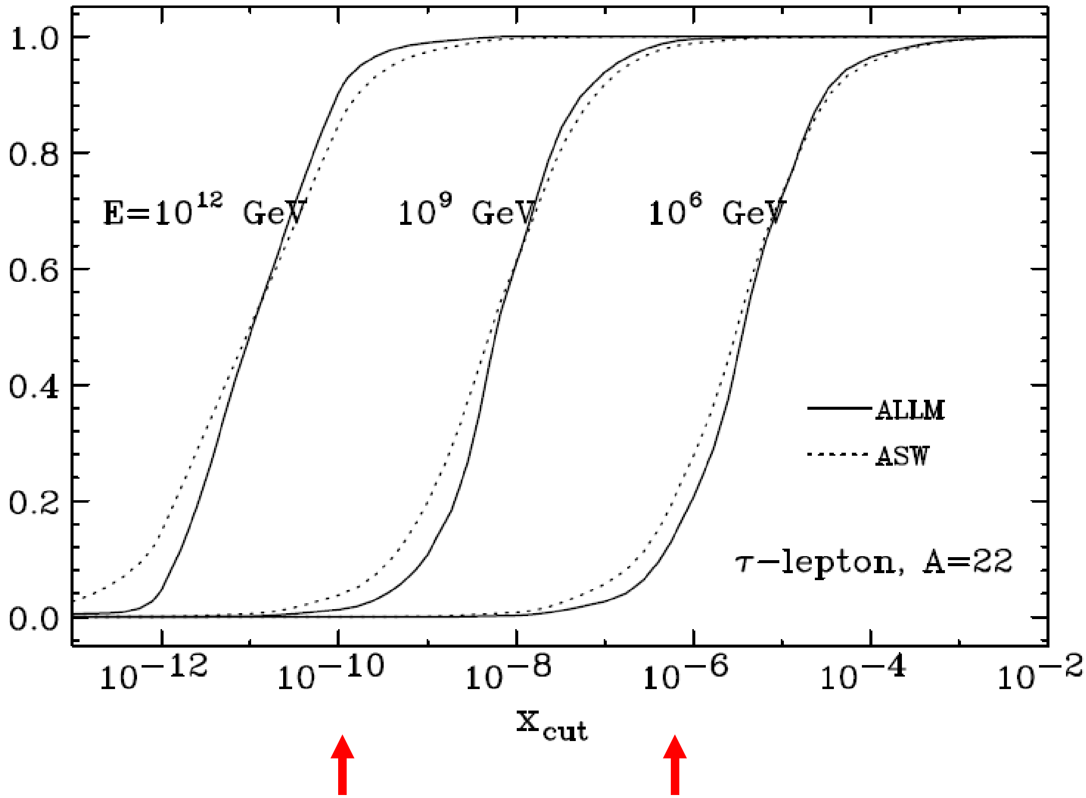
- Generalized Vector Dominance (soft) Bezrukov, Bugaev 1981
  + Color Dipole (hard) Bugaev, Shlepin 2003

- Regge theory (pomeron + reggeon) Dutta et al. 2001 (ALLM)
  + pQCD (hard)
  Butkevich, Mikheyev 2002 (CKMT)
  Kuzmin et al 2004 (CKMT)
  Petrukhin, Timashkov 2005

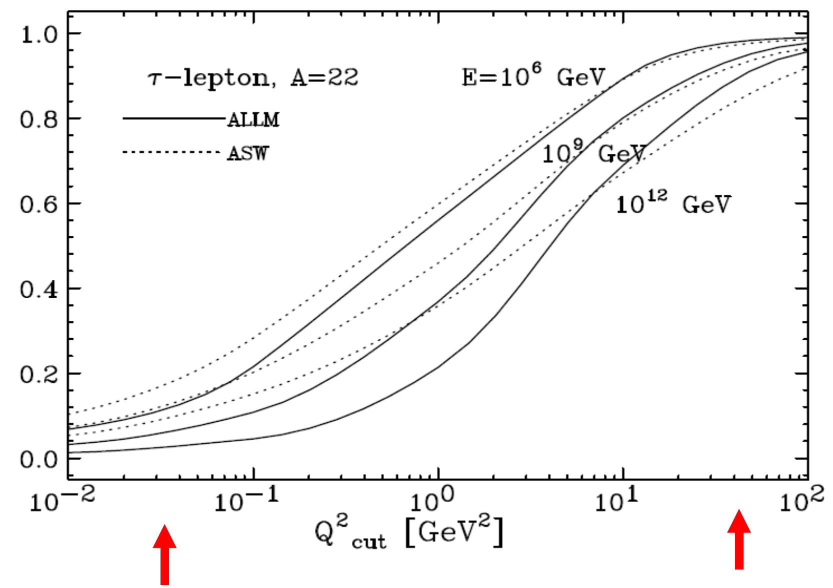
- Geometric scaling property found in γ^*p and γ^*N x-section data (saturation) Armesto, Merino, Parente, Zas 2008
  (ASW: Armesto, Salgado, Wiedemann 2005)

The τ energy loss from different X and Q^2 regions

b(E) [$x < x_{cut}$]

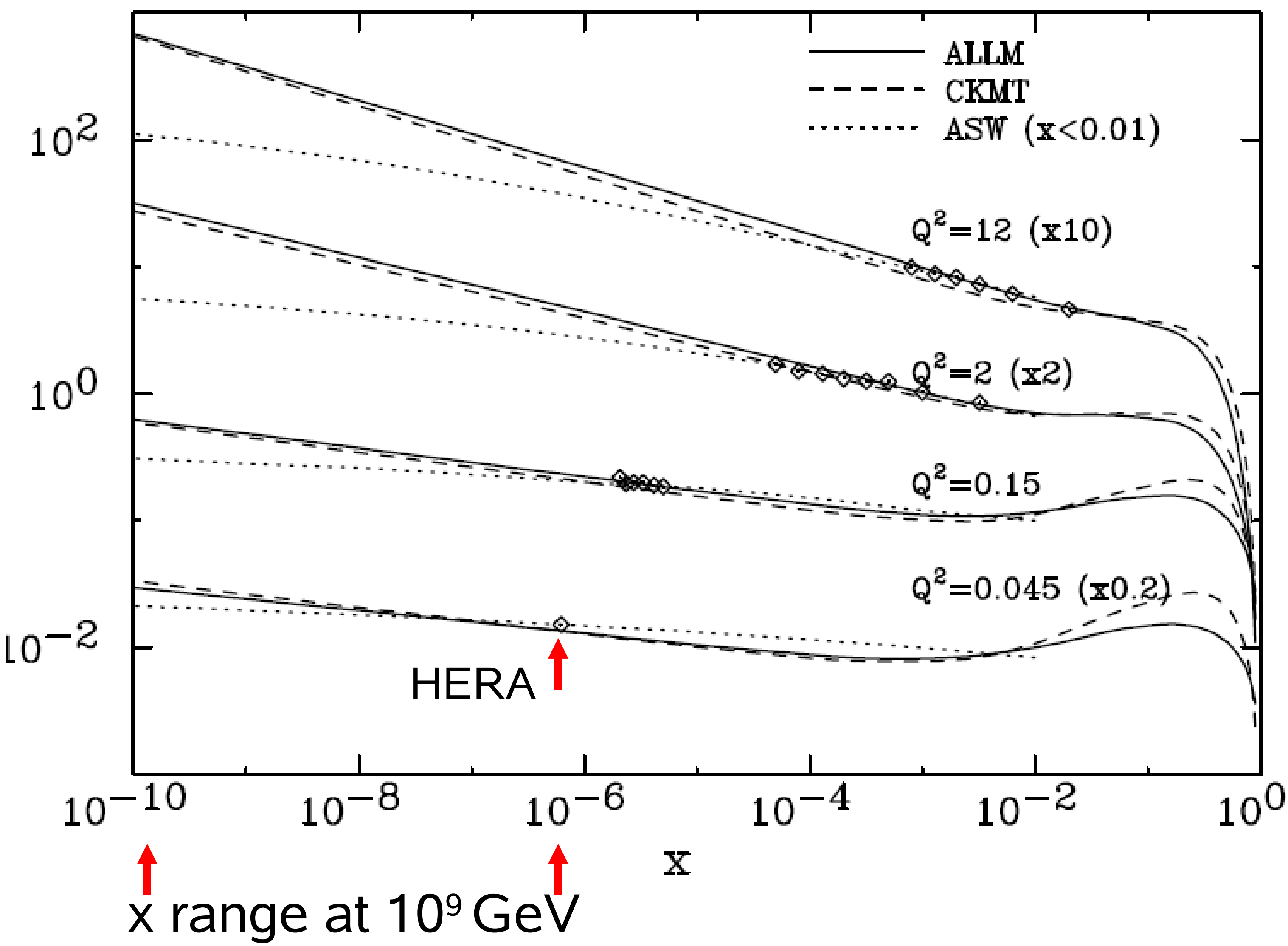


b(E) [$Q^2<Q^2_{cut}$]



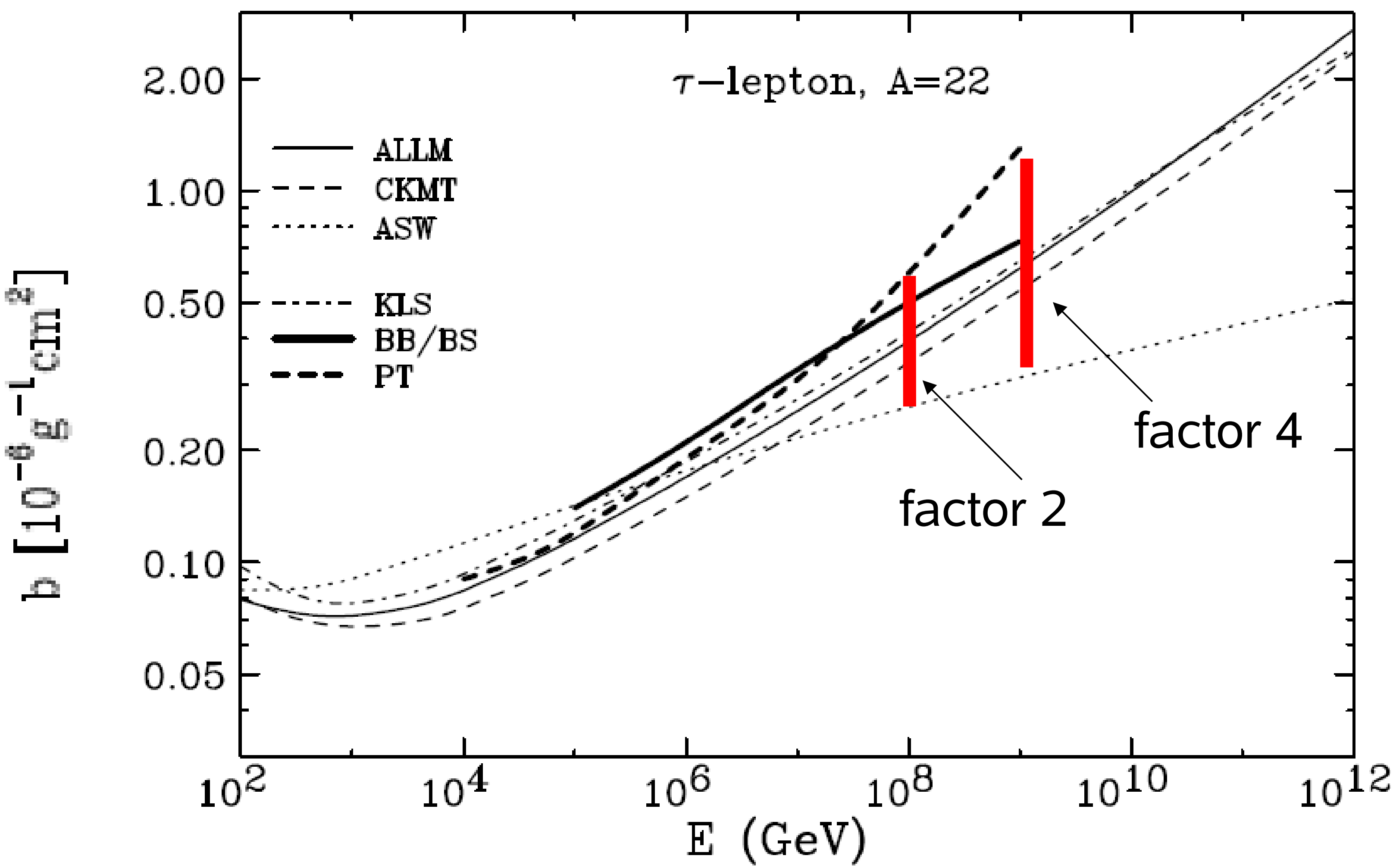
x range at 10^9 GeV

F_2 proton at low and moderate Q^2



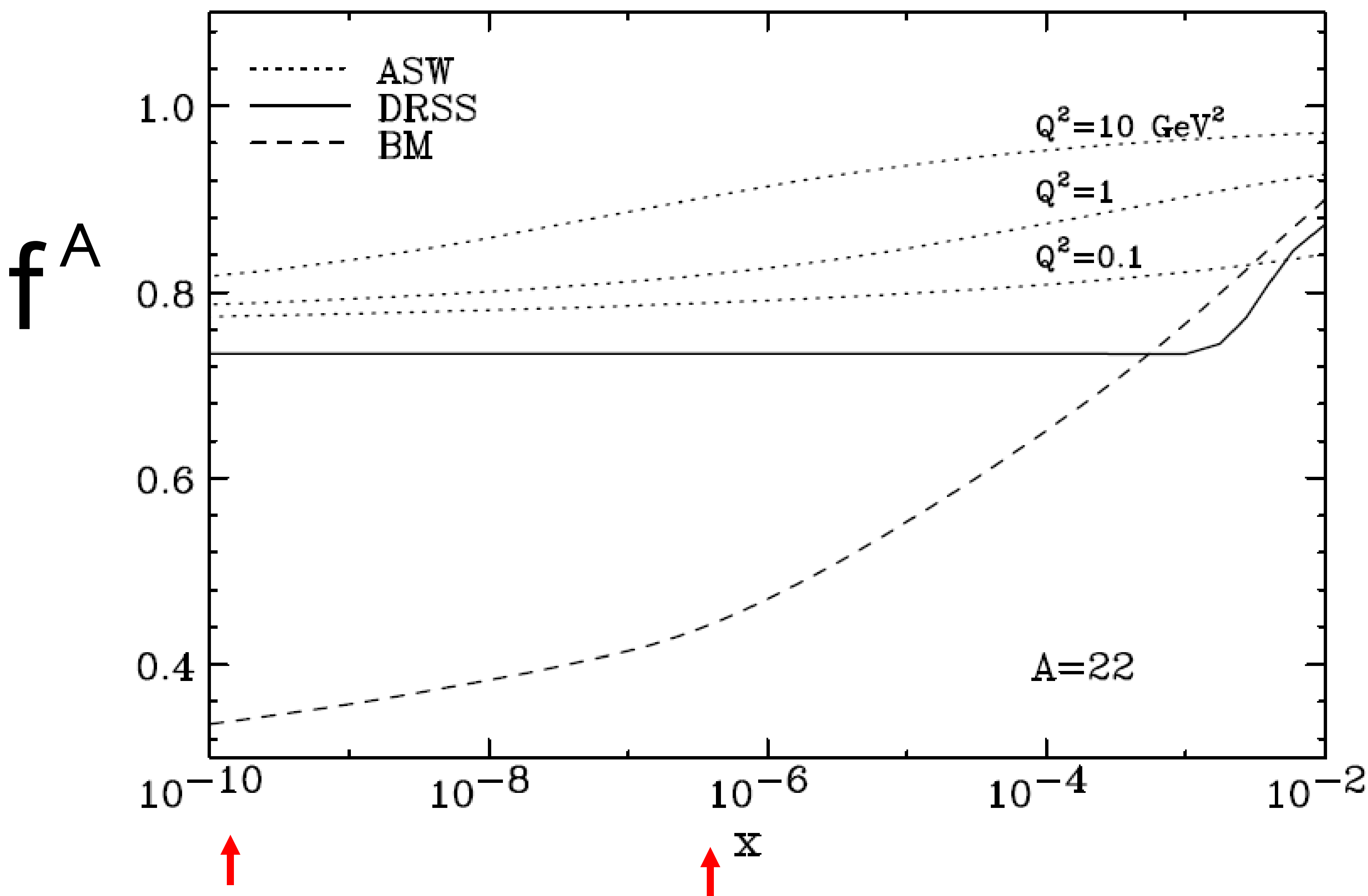
τ energy loss

$$b(E) = -\frac{1}{E}\left\langle\frac{dE}{dX}\right\rangle = \frac{N_A}{A}\int dyy\int dQ^2\frac{d\sigma^{lA}}{dQ^2dy}\,, \quad (1)$$



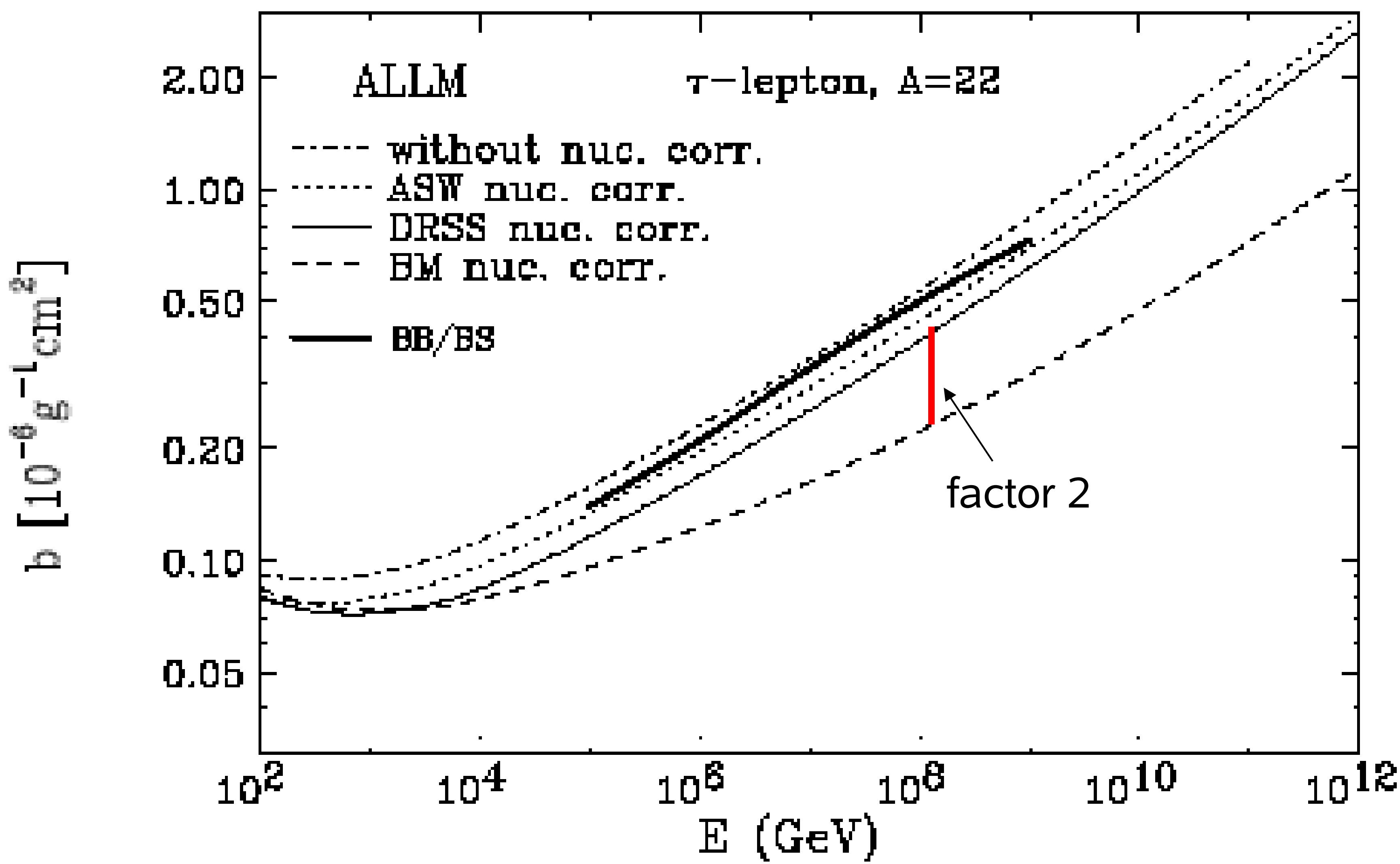
f^A

Nuclear correction factor $F_2^A = f^A A F_2^p$



x range at 10^9 GeV

The effect of nuclear corrections

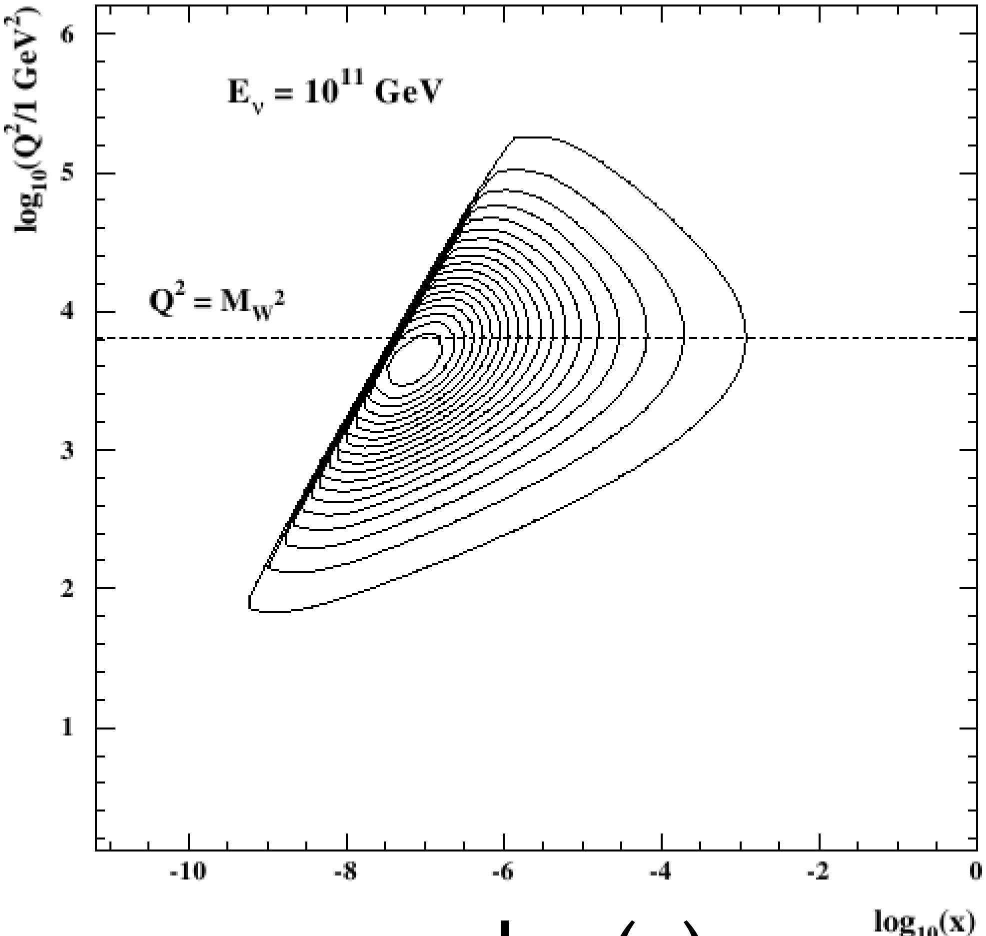


Neutrino-nucleon CC DIS x-section

$$\frac{d\sigma_{CC}^{\nu N}}{dQ^2 dy} = \frac{G_F^2}{4\pi}\left(\frac{M_W^2}{M_W^2 + Q^2}\right)^2 \frac{F_2^{\nu N}}{y}[1 + (1-y)^2]$$

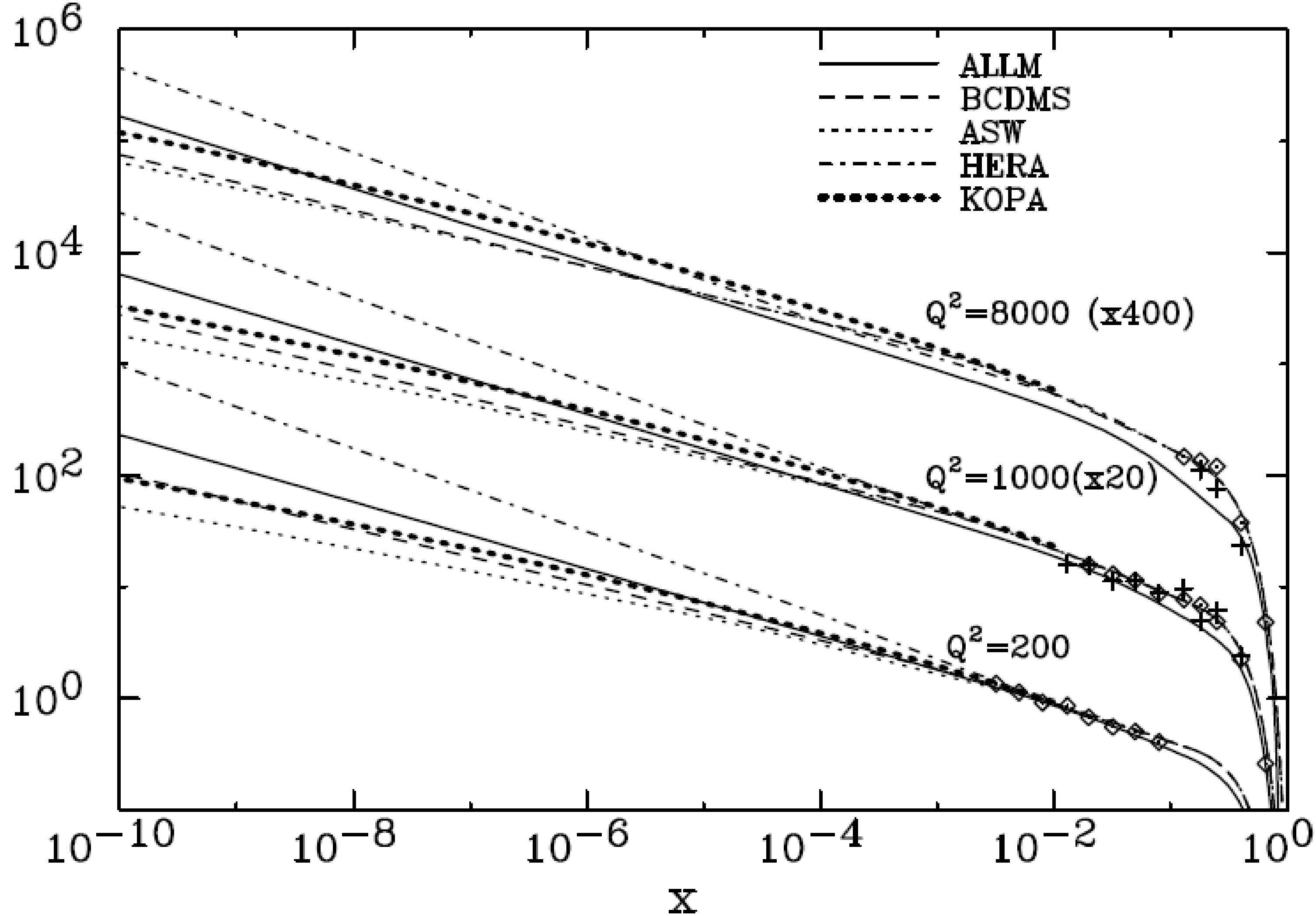
A.M. Stasto astro-ph/0310636

log(Q^2)

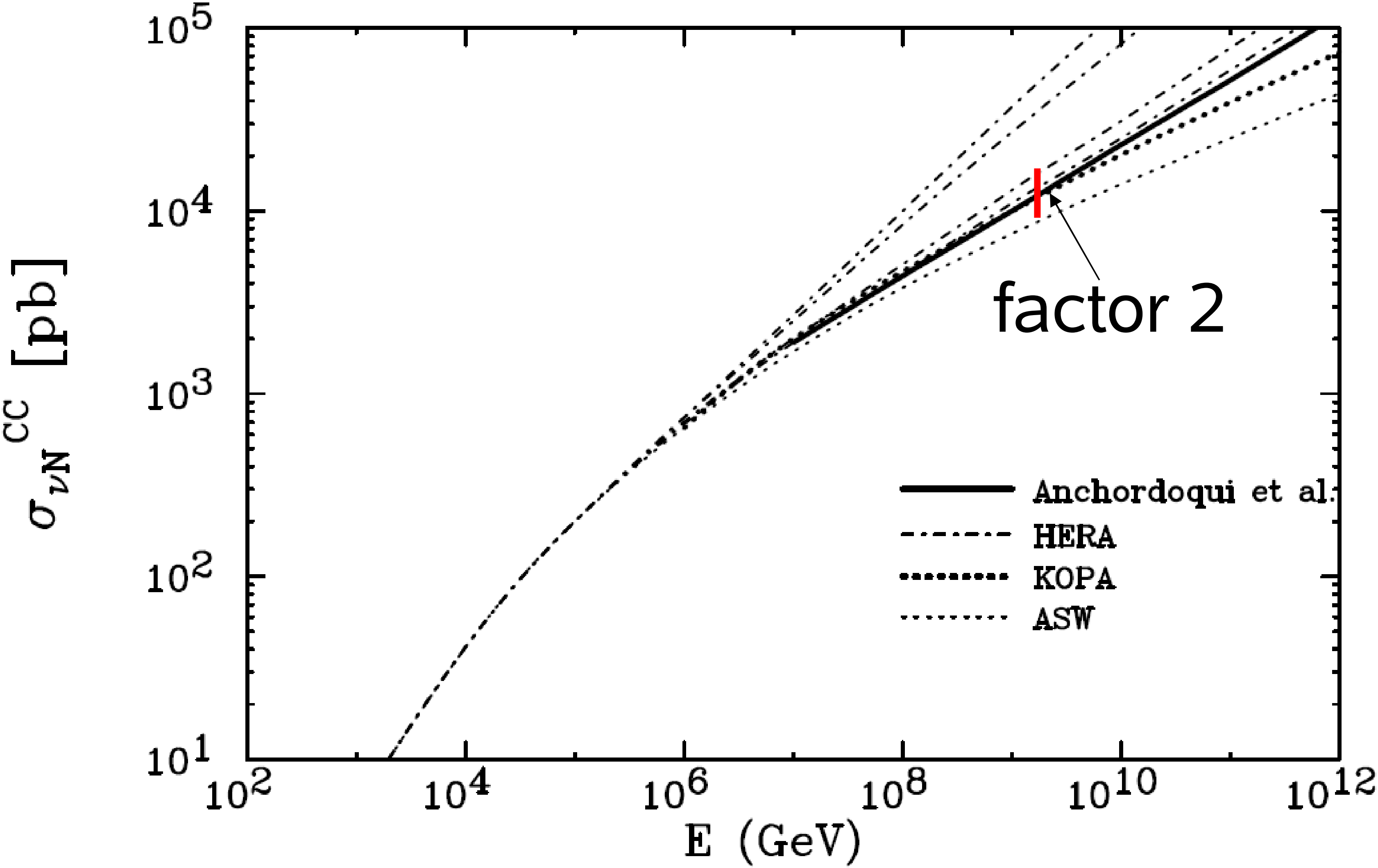


log(x)

F_2 at high Q^2



ALLM
BCDMS
ASW
HERA
KOPA
Q²=8000 (x400)
Q²=1000(x20)
Q²=200
10⁶
10⁴
10²
10⁰
10⁻¹⁰
10⁻⁸
10⁻⁶
10⁻⁴
10⁻²
10⁰
x


10^5
10^4
10^3
10^2
10^1
$\sigma_{\nu N}^{CC}$ [pb]
10^2
10^4
10^6
10^8
10^{10}
10^{12}
E (GeV)
factor 2
Anchordoqui et al.
HERA
KOPA
ASW

Summary

- **The stablishment of a tau neutrino bound from air shower data is affected by important systematic effects due to the uncertainty in F_2 at low x.**

- **Several F_2 models have been explored in the low x range. For the neutrino-nucleon interaction at high Q^2 and for the tau interaction at low and moderate Q^2.**

- **For the tau energy loss at 10^9 GeV the difference between the two extreme predictions reaches a factor 4. For the neutrino cross section it is a factor 2.**

- **GVD and Regge based (+ hard pQCD component) calculations of the tau energy loss agree within a 30% and go parallel to all energies.**

- **A much stronger nuclear shadowing at small x lower b(E) by a factor up to 2 but is not expected to affect the neutrino cross section.**