# High Energy Neutrino Cross Sections

Neutrino 2004, 18 June 2004

The University of Iowa

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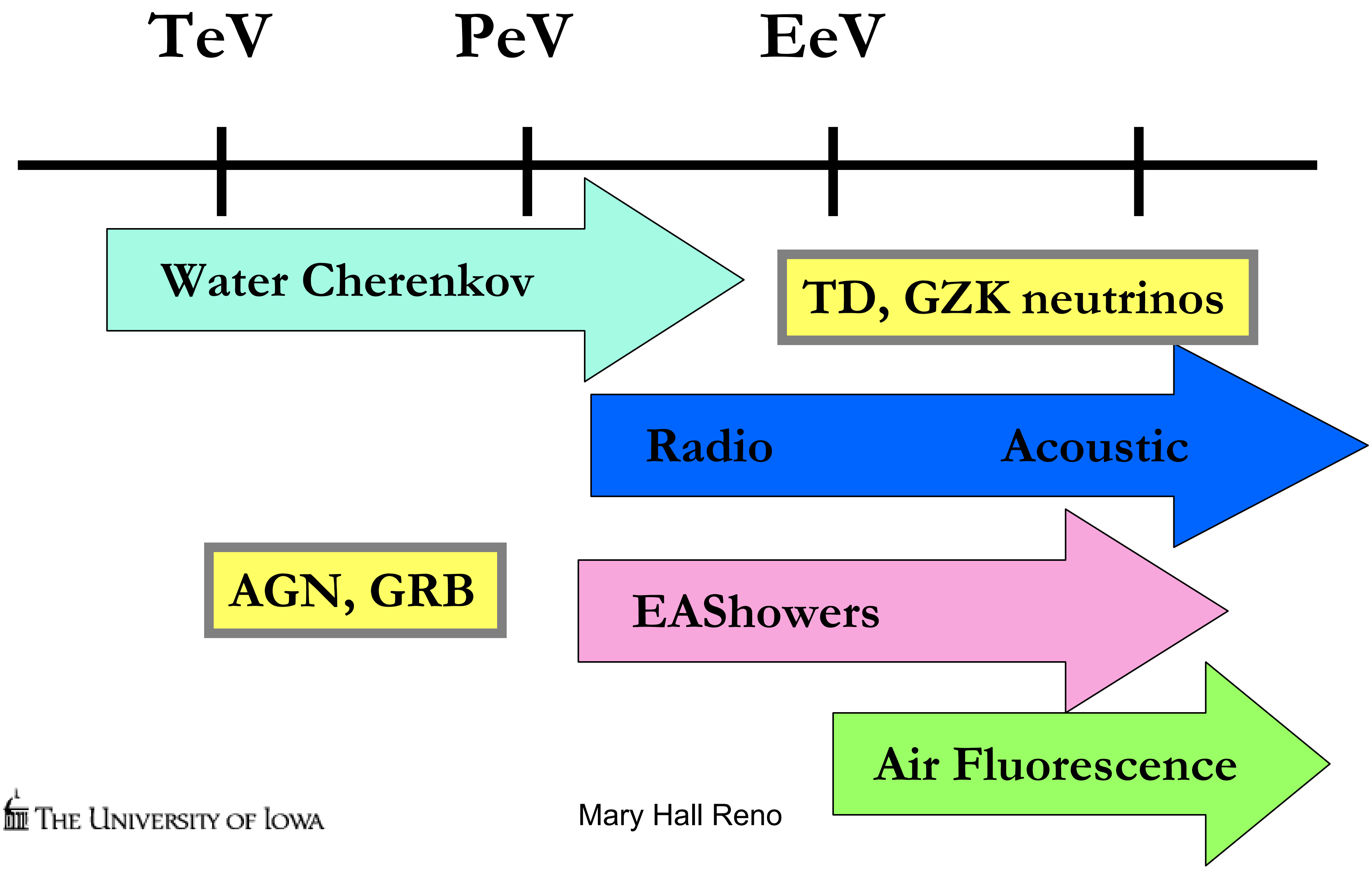
# Energy Ranges



# Outline

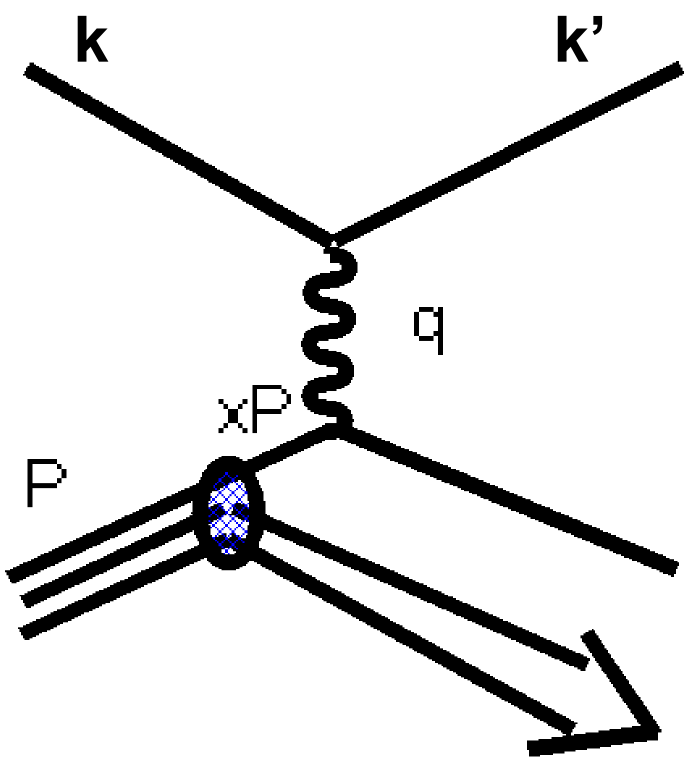
- Ultrahigh energy neutrino cross sections in the standard model:
  - DGLAP evolution,
  - Small x issues (when Q~mass of W)
- Other contributions to the cross sections: non-perturbative effects
- Non-standard model cross sections
- Implications: attenuation/interaction rates

# Ultrahigh energy neutrino cross section

- Ultrahigh energy neutrino nucleon cross section depends on parton distribution functions outside the measured

$$q = (k - k'),\ q^2 = -Q^2$$

$$x = \frac{Q^2}{P \cdot q}$$



# Charged Current Scattering

$$\frac{d^2\sigma}{dx\,dy} = \frac{2G_F^2 M E_\nu}{\pi}\left(\frac{M_W^2}{Q^2 + M_W^2}\right)^2 \left[xq(x,Q) + x\bar{q}(x,Q)(1-y)^2\right]$$

Q increases, propagator decreases

Q increases, PDFs increase

Propagator wins:

$$Q^2 \sim M_W^2 \;\; and \;\; x \sim \frac{M_W^2}{M_N E_\nu}$$

# Issues-Measurements

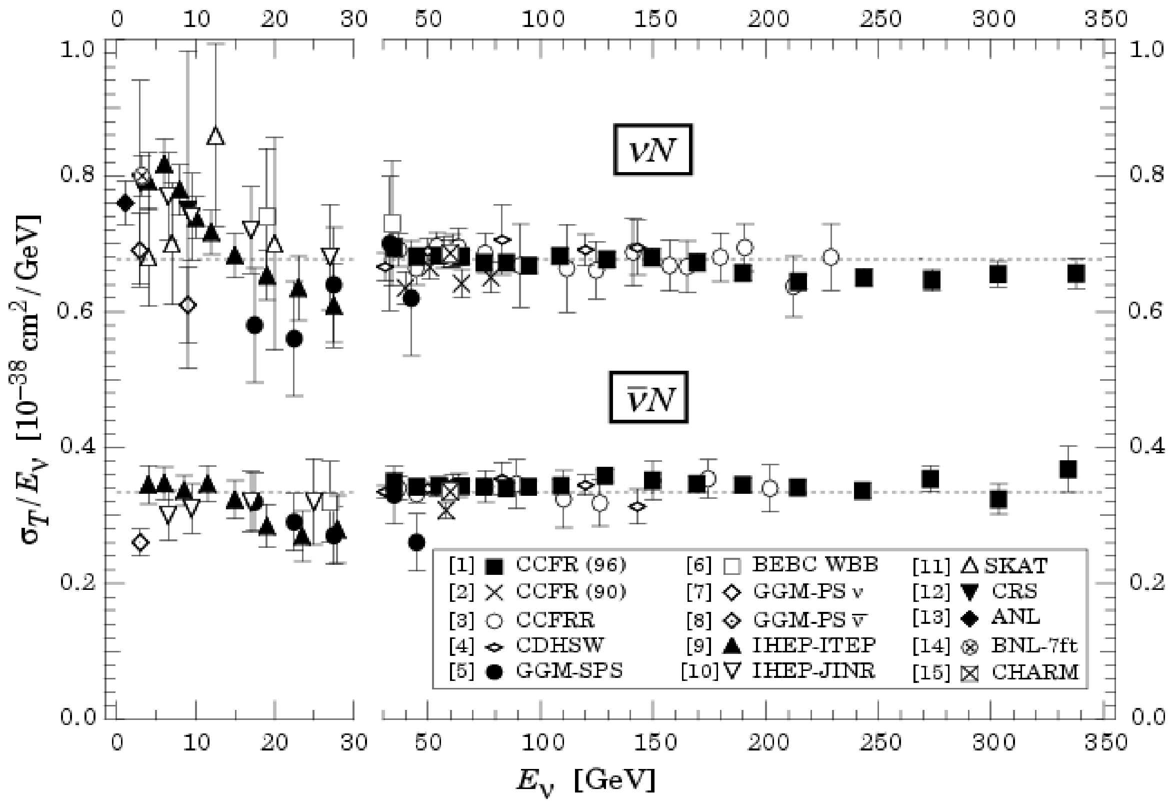
Energy of incident particle: neutrino energies up to 350 GeV, HERA ep scattering, equivalent energy of ~54 TeV.

(x,Q) relevant for ultrahigh-energy neutrino scattering are not measured.

# Muon neutrino and antineutrino CC cross section

[0 30 || 50 GeV 350]

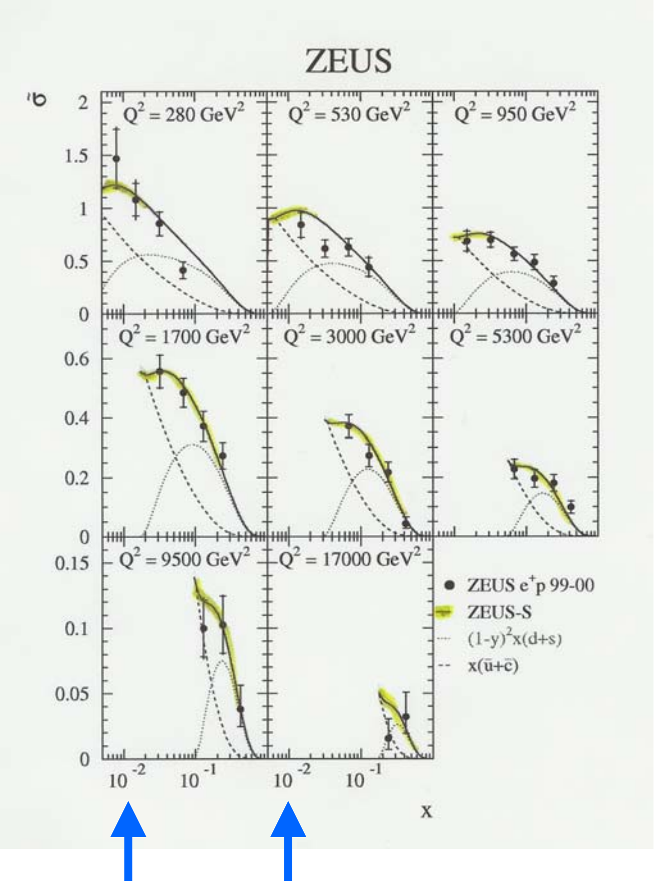
$$\frac{\sigma_{CC}}{E}$$
$[\mathrm{cm}^2/\mathrm{GeV}]$



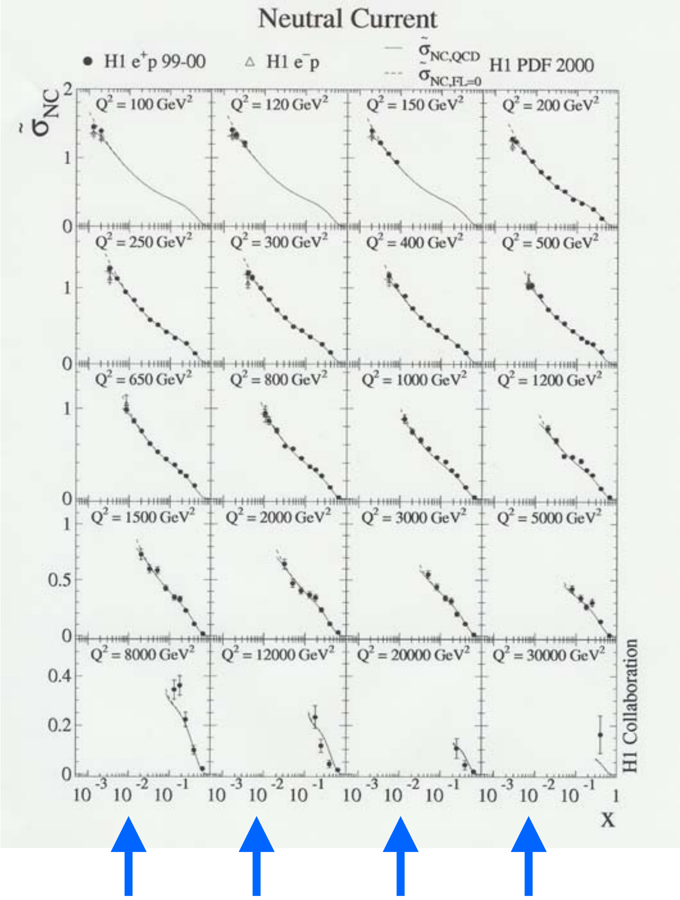

PDG, Hagiwara et al, Phys Rev D66 (2002)

# HERA CC and NC Measurements

Zeus Collab, Eur. Phys. J. C 32, 1 (2003)

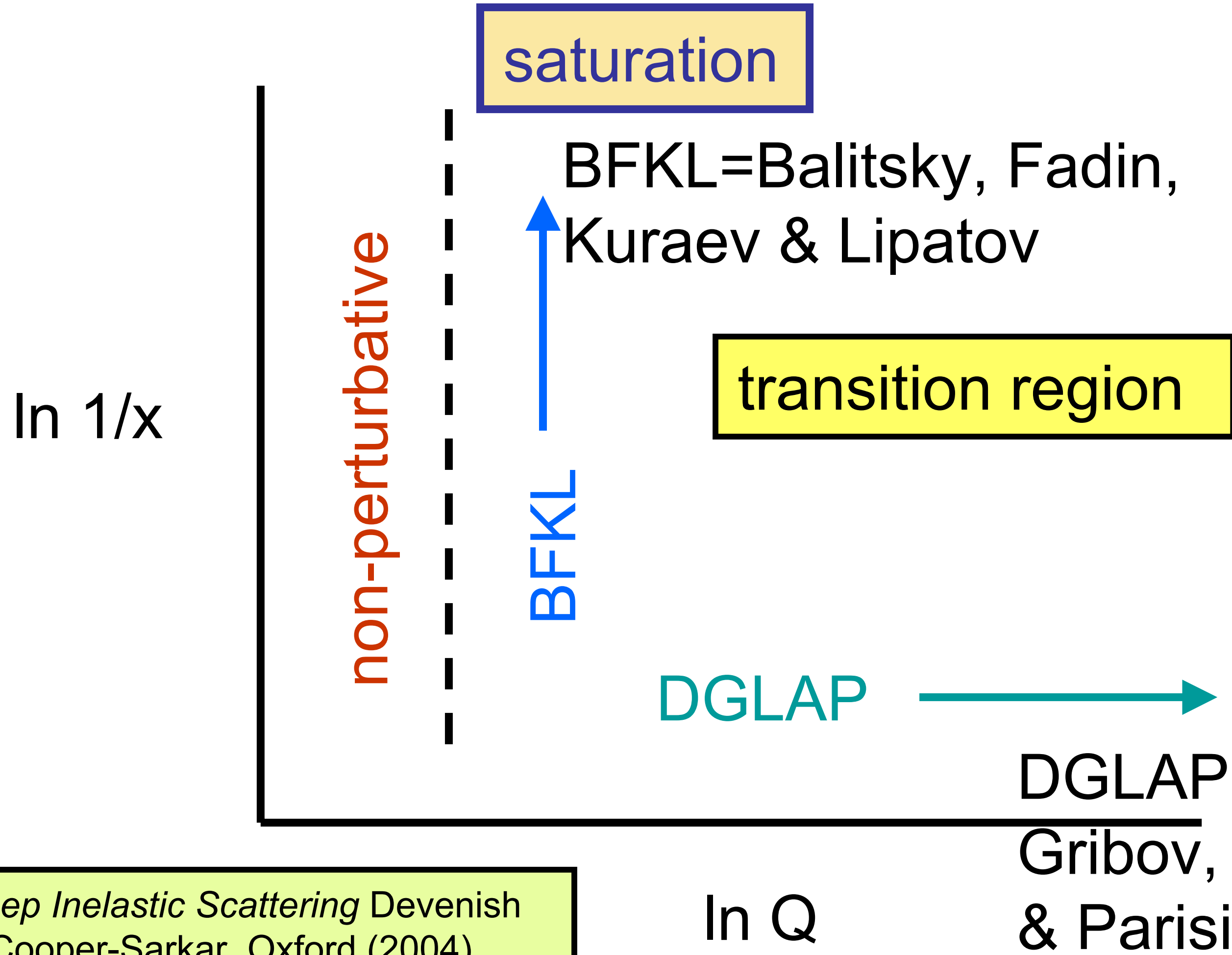



H1 Collab, Eur. Phys. J. C 30, 1 (2003)




$$x = 10^{-2}$$

# Issues-Theory




BFKL=Balitsky, Fadin, Kuraev & Lipatov

DGLAP=Dokshitzer, Gribov, Lipatov, Altarelli & Parisi

*Deep Inelastic Scattering* Devenish & Cooper-Sarkar, Oxford (2004)

# Small-x extrapolations

DGLAP evolution of parton distribution functions: small-x evolution dominated by gluon

$$g \to q\,\bar{q}$$

Sea quarks dominate the cross section.

$$xg(x,Q_0) \sim A\ x^{-\lambda}$$

$$\Rightarrow\ \ xg(x,Q) \sim x^{-\lambda},\ \lambda \geq (\sim 0.2)$$

e.g.,Ellis, Kunszt & Levin (1994)

# Extrapolations-DGLAP

## for $\lambda \sim 0$

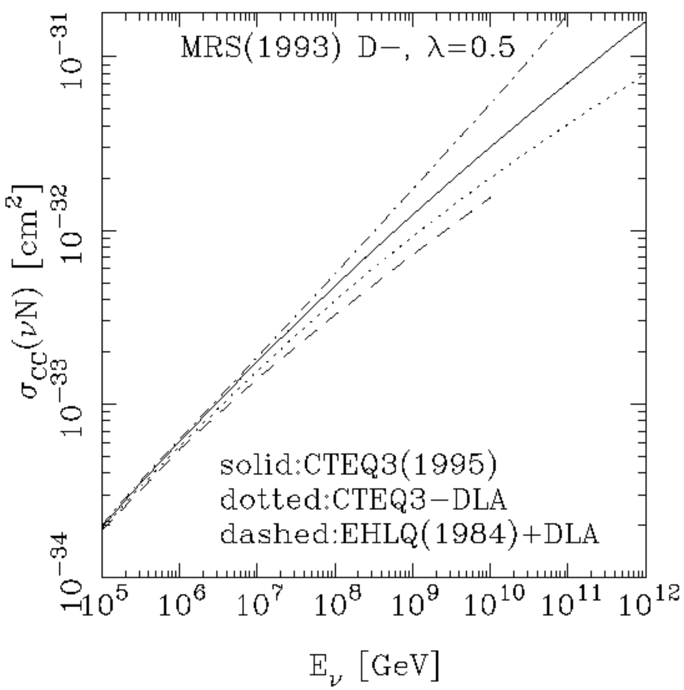
Double leading log approximation:

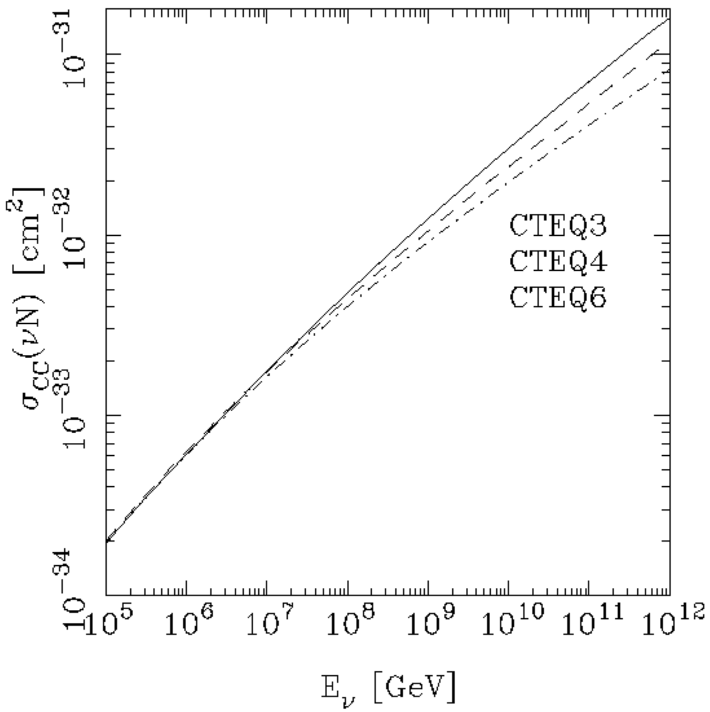
$$xg(x,Q^2) \sim A \exp\left[ B(\ln(Q^2/Q_0^2)\ln(x_0/x))^{1/2} \right]$$

Gribov, Levin & Ryskin, Phys. Rep. 100 (1983)

# CC Cross Sections

## DGLAP extrapolations: power law and double leading log approx.




Numerous calculations: Quigg, Reno & Walker (1986), McKay & Ralston (1986), Frichter, McKay & Ralston (1995), Gandhi et al. (1996,1998), Gluck, Kretzer & Reya (1999)

# More small-x extrapolations

LO BFKL, sum leading ln(1/x)   (LL(1/x))

Multiple gluon emissions at small-x predict $\lambda$

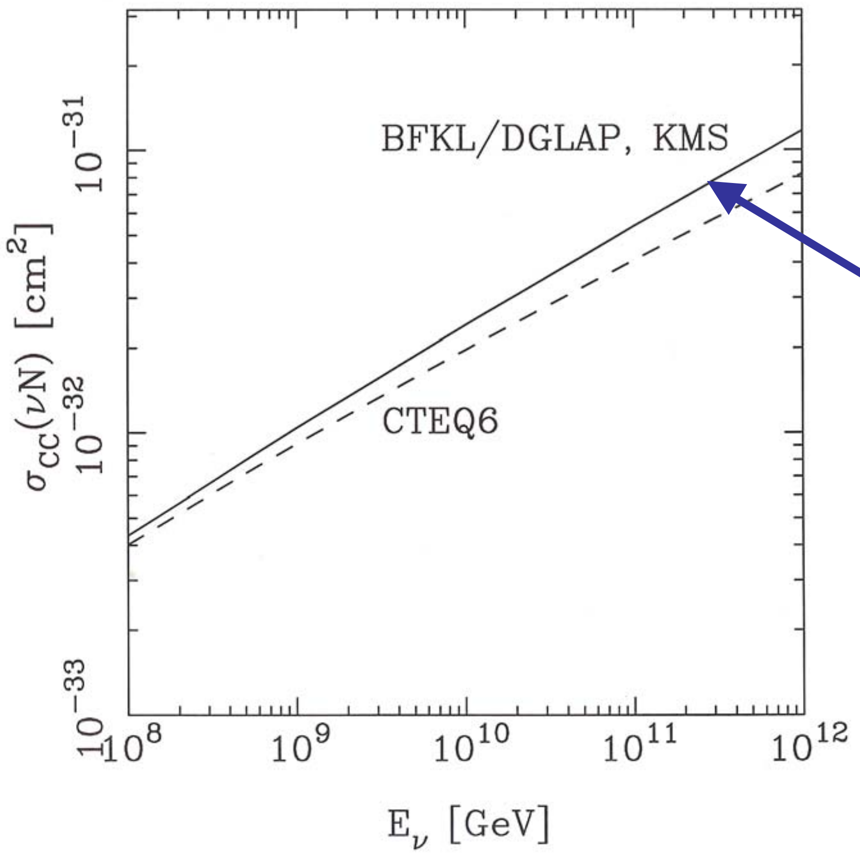
$$xf(x,Q) \sim x^{-\lambda}$$

LL(1/x): OK,  NLL(1/x): wrong sign,  for fixed $\bar{\alpha}_s$

Fadin & Lipatov, Camici & Ciafaloni

Recent work by Altarelli, Ball & Forte; Ciafaloni, Colferai, Salam & Stasto on ln(1/x) resummation with running coupling.

# BFKL/DGLAP vs DGLAP




BFKL evolution matched to DGLAP accounting for some subleading ln(1/x), running coupling constant,matched to GRV parton distribution functions

Kwiecinski, Martin & Stasto, PRD 59 (1999)093002

# Saturation effects

Saturation due to high gluon density at small x (recombination effects)

**gluons/unit rapidity**

**g-g cross section**

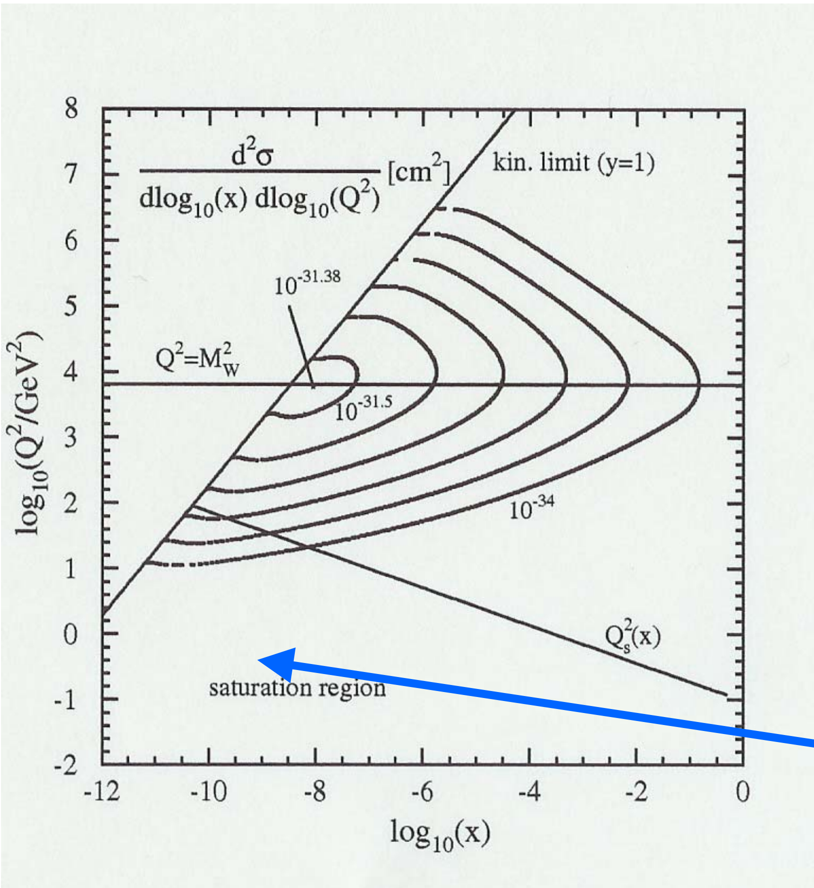
**size of proton disk**

$$\frac{\alpha_s}{Q^2} xg(x,Q^2) \sim \pi R^2$$

Estimate of scale: $Q_s^{\,2} \sim 1\ GeV^2 \cdot (10^{-4}/x)^{0.3}$

$Q_s \sim M_W$ for $x \sim 10^{-17}$

# First Guess



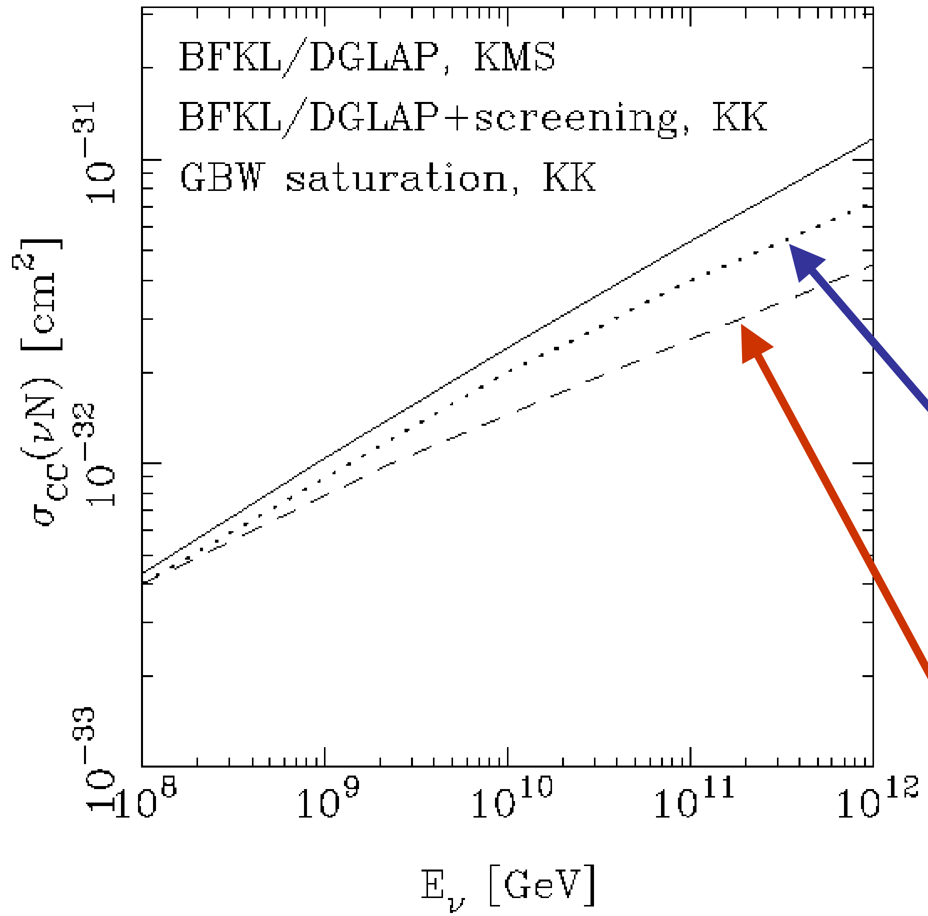

Contours of constant cross section for

$$E_\nu = 10^{12}\ GeV$$

saturation region

MHR, Sarcevic, Sterman, Stratmann & Vogelsang, hep-ph/0110235

# CC Cross Sections




KMS: Kwiecinski, Martin & Stasto, PRD56(1997)3991;

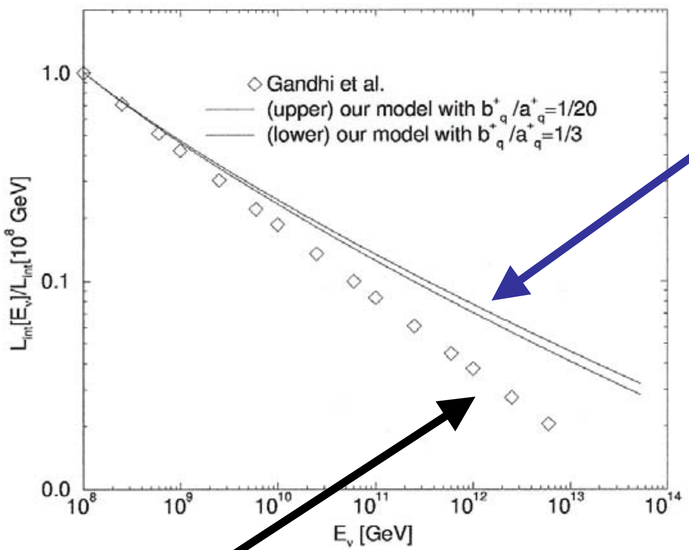
KK: Kutak & Kwiecinski, EPJ,C29(2003)521

more realistic screening, incl. QCD evolution

Golec-Biernat & Wusthoff model (1999), color dipole interactions, alternative to BFKL for low Q

# Other results

$$L = (\sigma_{\nu N} N_A)^{-1}$$




Fiore et al. PRD68 (2003), with a soft non-perturbative model and approx QCD evolution.

Note: J. Jalilan-Marian, PRD68 (2003) suggests that there are enhancements to the cross section due to high gluon density effects; enhancements also in Gazizov et al. astro-ph/0112244.

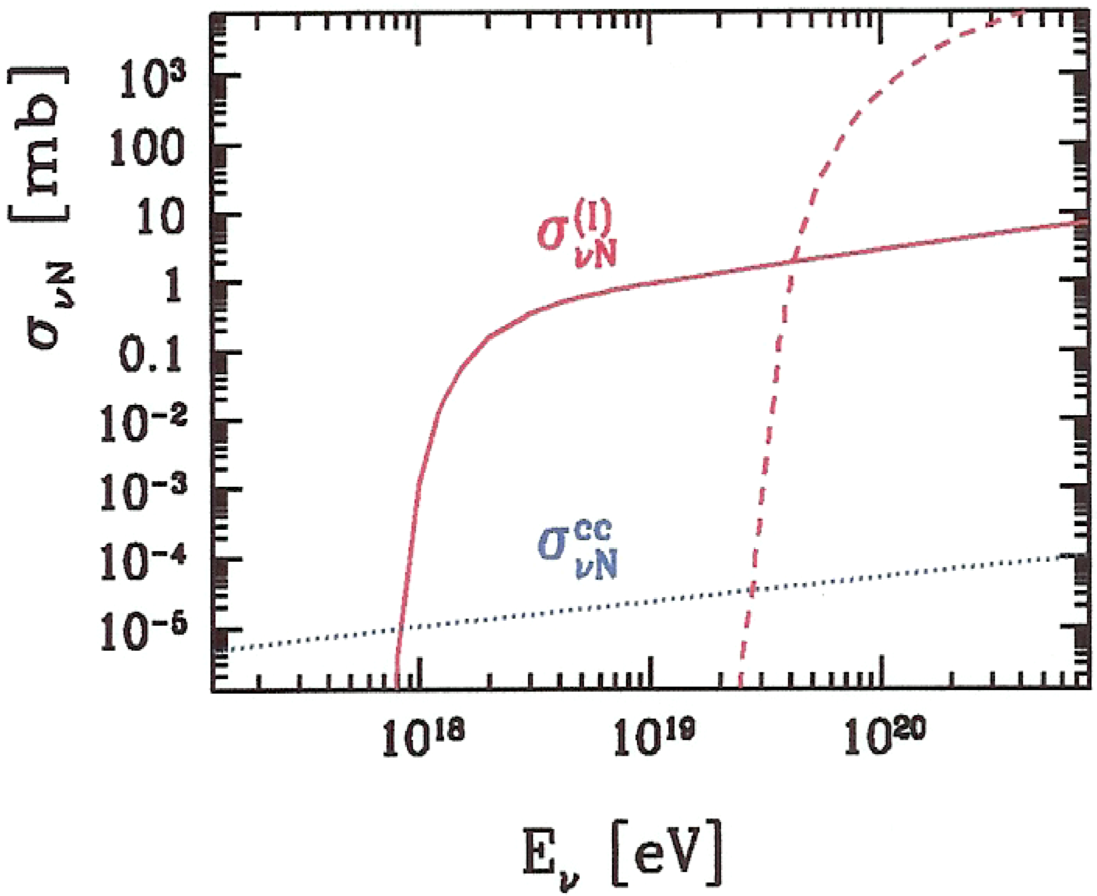
factor ~2

Machado, hep-ph/0311281, color dipole with BFKL/DGLAP; poster by Henley & Huang.

# Electroweak Instantons

- Close analogy to QCD, parton scattering amplitude using perturbation theory in instanton background.
- Ringwald, PLB 555(2003) and Fodor, Katz, Ringwald & Tu PLB 561 (2003) – rapid rise in cross section at high energies.
- Han and Hooper, PLB 582 (2004), exponential factor with constant prefactor a la Bezrukov et al.
- Effect should be there, but precisely how big, we don't know.

# EW Instanton Cross Sections

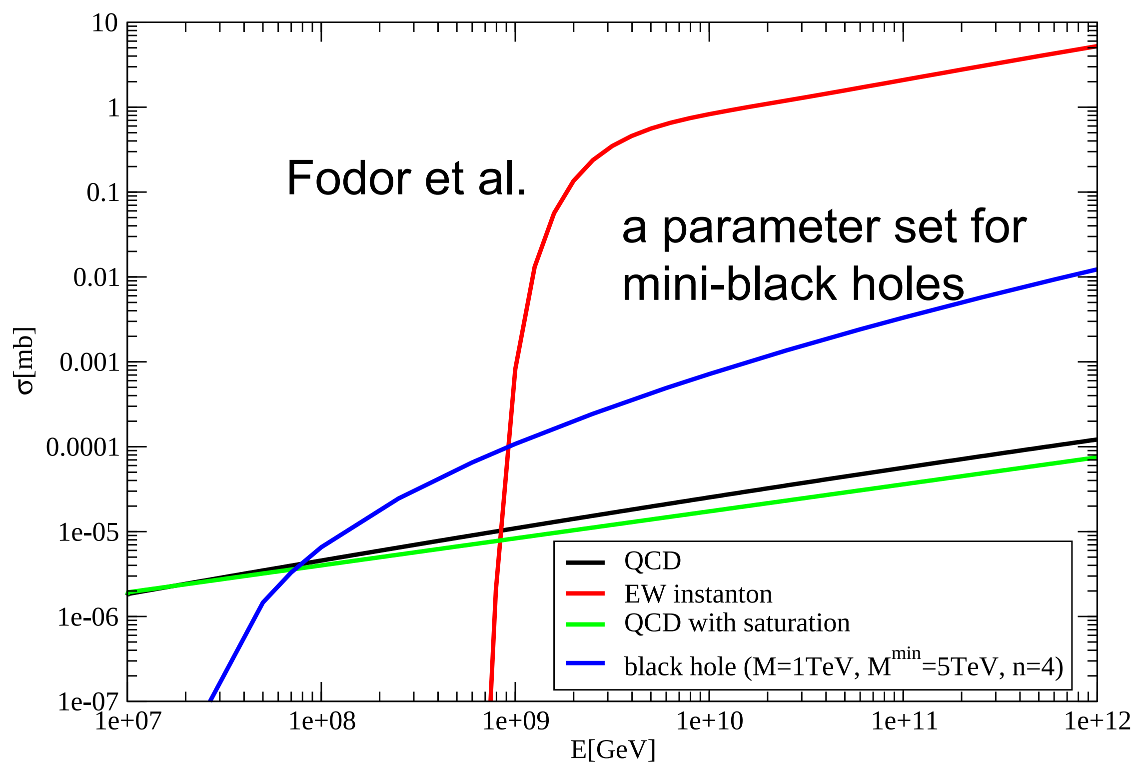



Hooper and Han

Fodor et al.

Strongly interacting neutrinos responsible for highest energy “cosmic rays”?

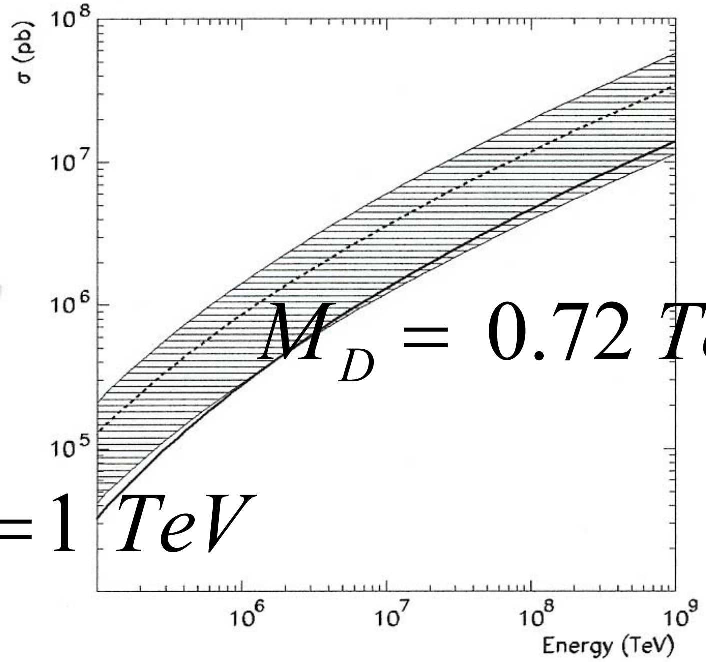
# Non-Standard Model Physics, e.g., extra dimensions and mini-blackholes




- TeV scale modifications of gravity, 4D Newton's constant related to higher dimensional gravitational constant.
- Depends on scale of extra-dimensions, number of extra-dimensions.

Many papers on subject: e.g., Feng & Shapere (2002), Anchordoqui et al. (2002,2003), Emparan et al. (2002), Ringwald & Tu (2002), Kowalski et al. (2002), Dutta et al. (2002), Alvarez-Muniz et al. (2002)

# Uncertainties




$M_D = 0.72\ TeV$

$M_D = 1\ TeV$

Examples:

- Semiclassical description of mini-blackhole production
- Unknown form factor (F) in cross section
- Approximation of momentum transfer in events.

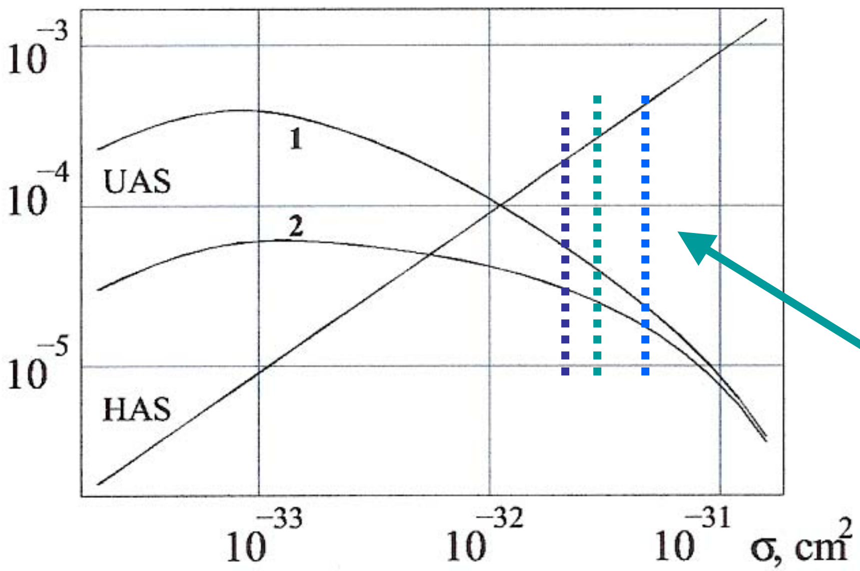
Shaded band in Fig:

$$F = 1 \pm 2/3$$

Ahn, Cavaglia & Olinto, hep-ph/0312249

# Cross Sections-Std. Model Uncertainties and their observational implications

$10^{11} GeV$




Kusenko & Weiler, PRL 88(2002)

air shower probability per incident tau neutrino: Upward Air Showers (UAS) with different energy thresholds, and Horizontal Air Showers (HAS)

KMS and KK cross sections shown earlier

# Standard Model Physics

- Small-x: learn from ultrahigh energy interaction rates
- Instanton – how big?

# Enhanced Neutrino Cross Sections

- Possibility for discovery of new physics, e.g. extradimensions – the beams are free(!) but not well known.
- Potential to explain the puzzle of the post-GZK cosmic ray events.

We look forward to the UHE neutrino results from astrophysical and cosmic sources!