# Global QCD Analysis and Collider Phenomenology — CTEQ

DIS07 SF-2 Tung

# Progress in CTEQ Global Analysis

New PDFs (CTEQ6.5M,S,C) from better treatment of heavy quark mass effects and more complete data input;

- Predictions on parton luminosities and SM phenomenology at the LHC; (for BSM apps., cf. Yuan: EW-5)
- First examination of an *independent strange sector* of the nucleon structure: s(x) and sbar(x);
- First look at an *independent charm sector* of the nucleon structure (intrinsic charm); (wkt: HFL-2)
- Examination of controversial E866, NuTeV data sets and large-x behavior of PDFs;
- Combined $p_T$ resummation and PDF global QCD analysis — new constraints on PDFs, better predictions for precision W/Z, Top, and Higgs physics at the Tevatron & LHC. (Yuan: SF-8)

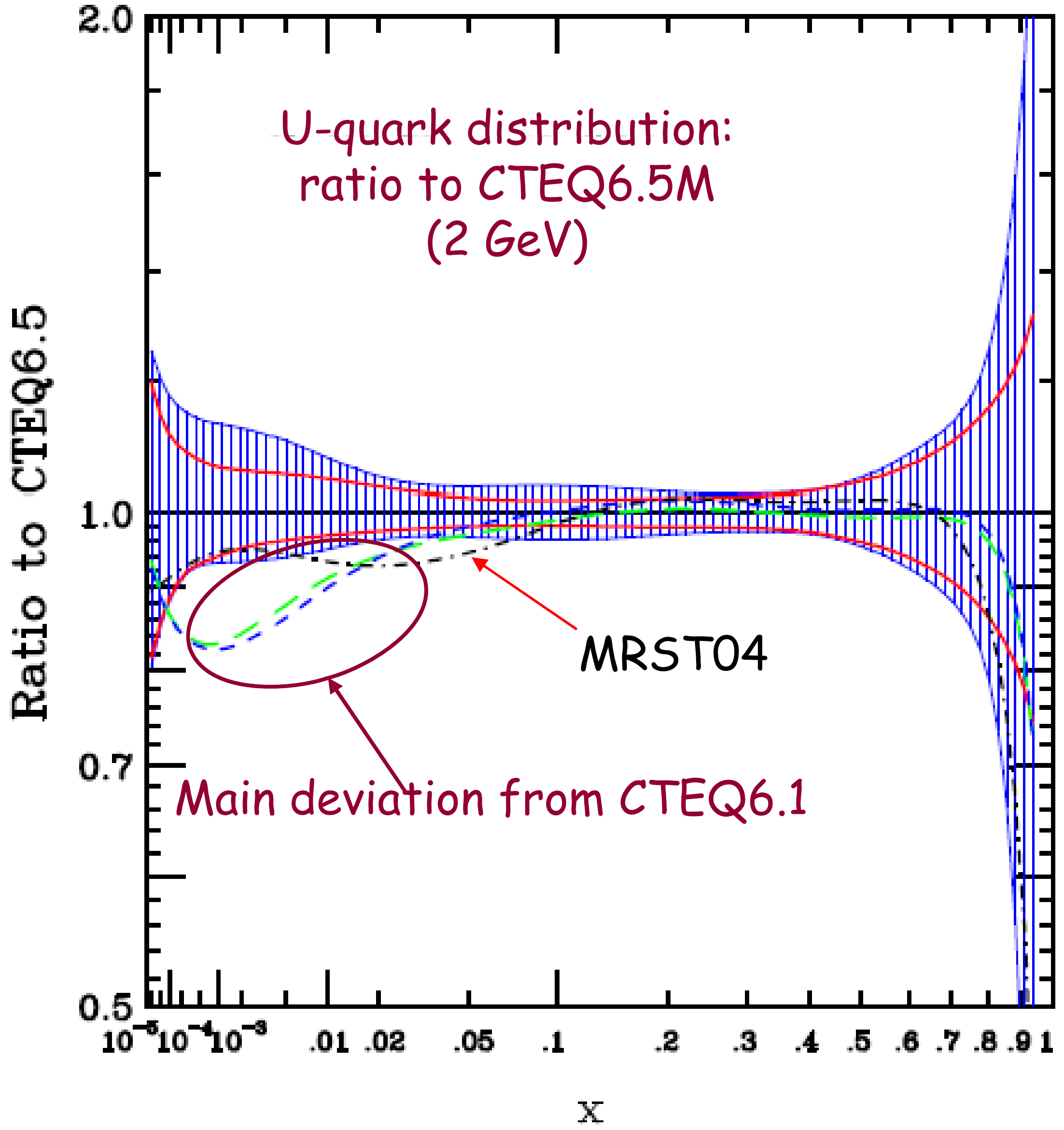
# Impact of new CTEQ6.5 (M,S,C) PDFs on Collider Phenomenology

CTEQ6.1 → CTEQ6.5:

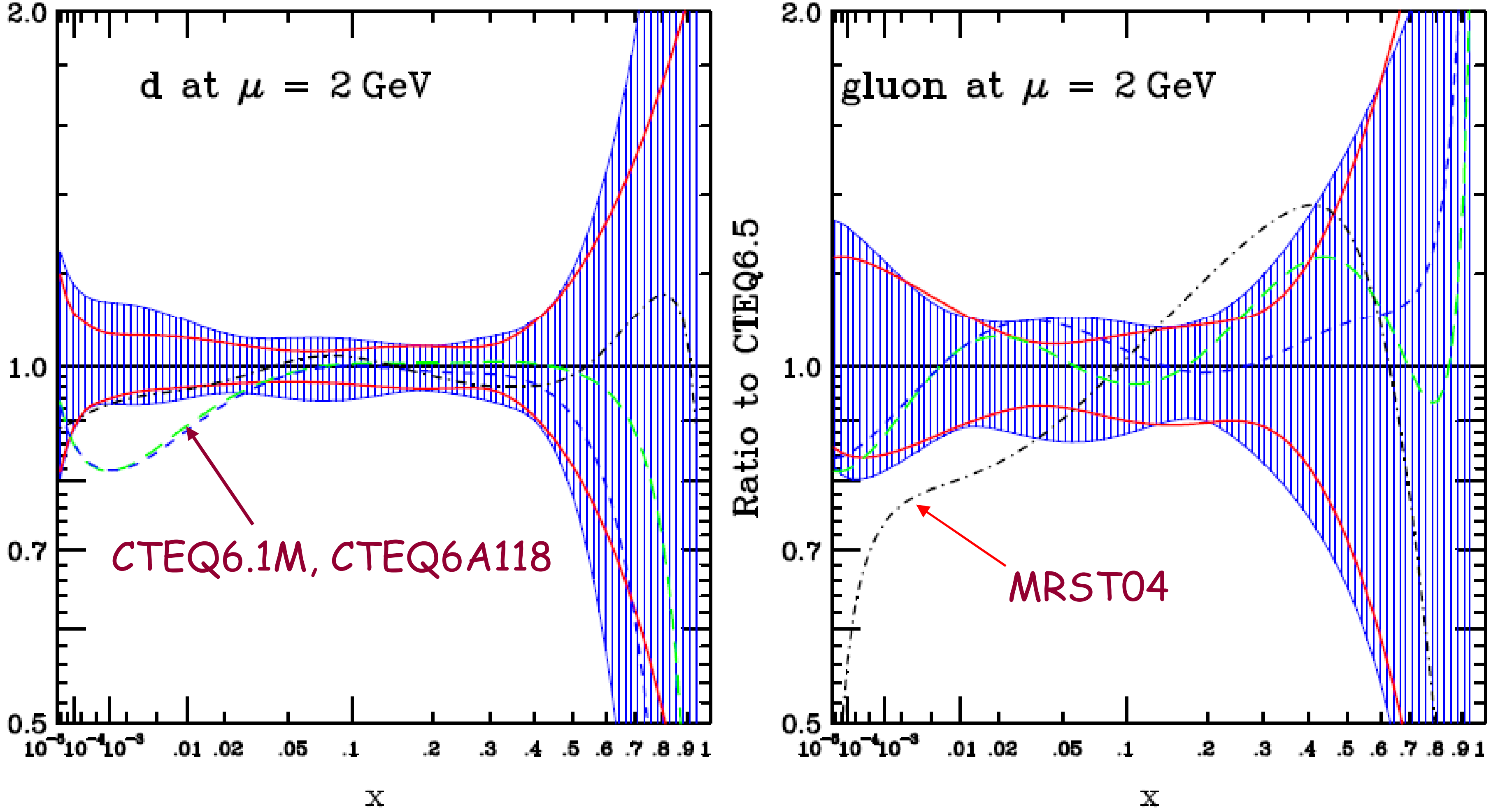
- better treatment of heavy quark mass effects;
- more complete data input;

(DIS2006; hep-ph/0611254, HFL-2)

# Shift of PDFs from CTEQ6.1M to CTEQ6.5M

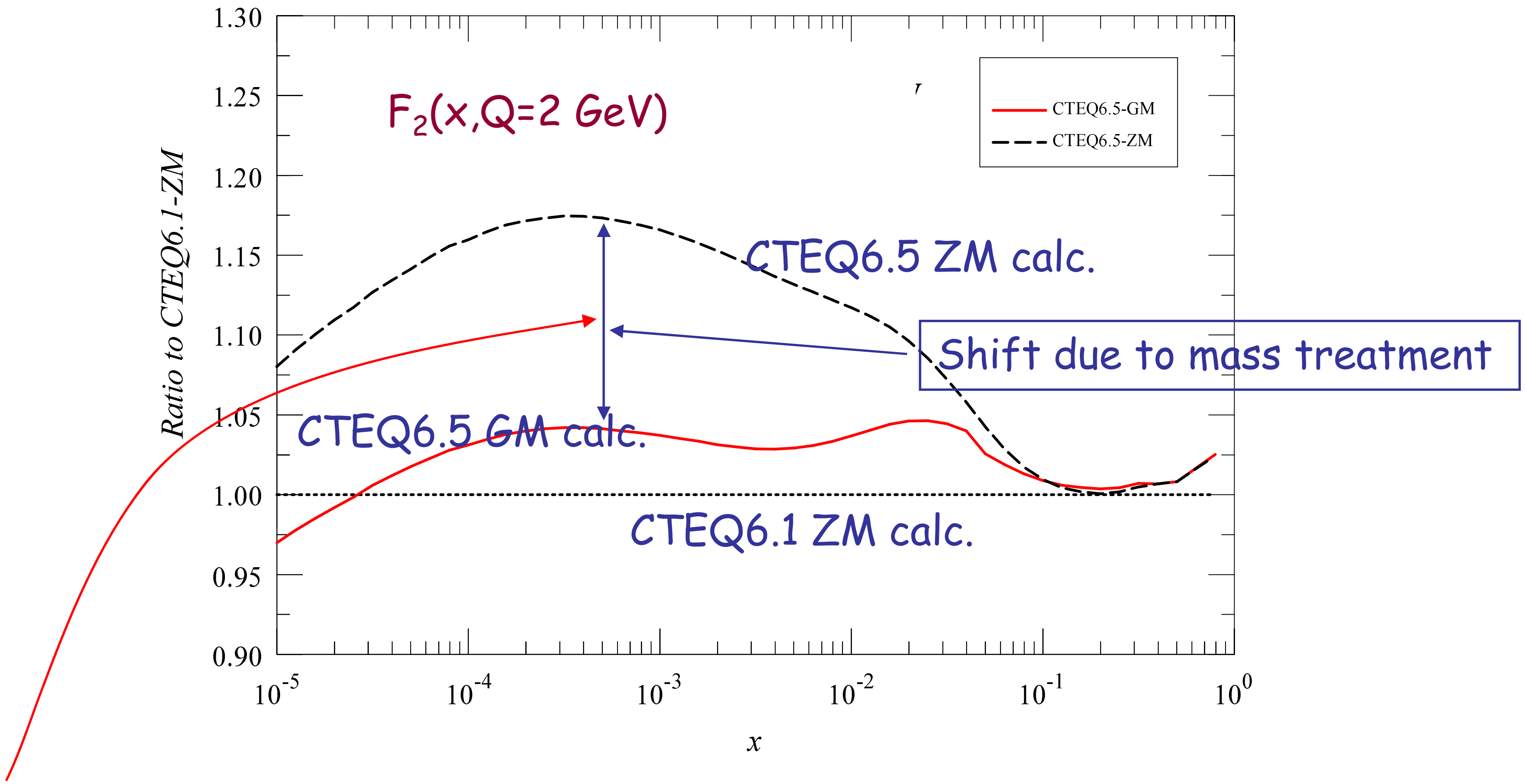


# Shift of PDFs from CTEQ6.1M to CTEQ6.5M



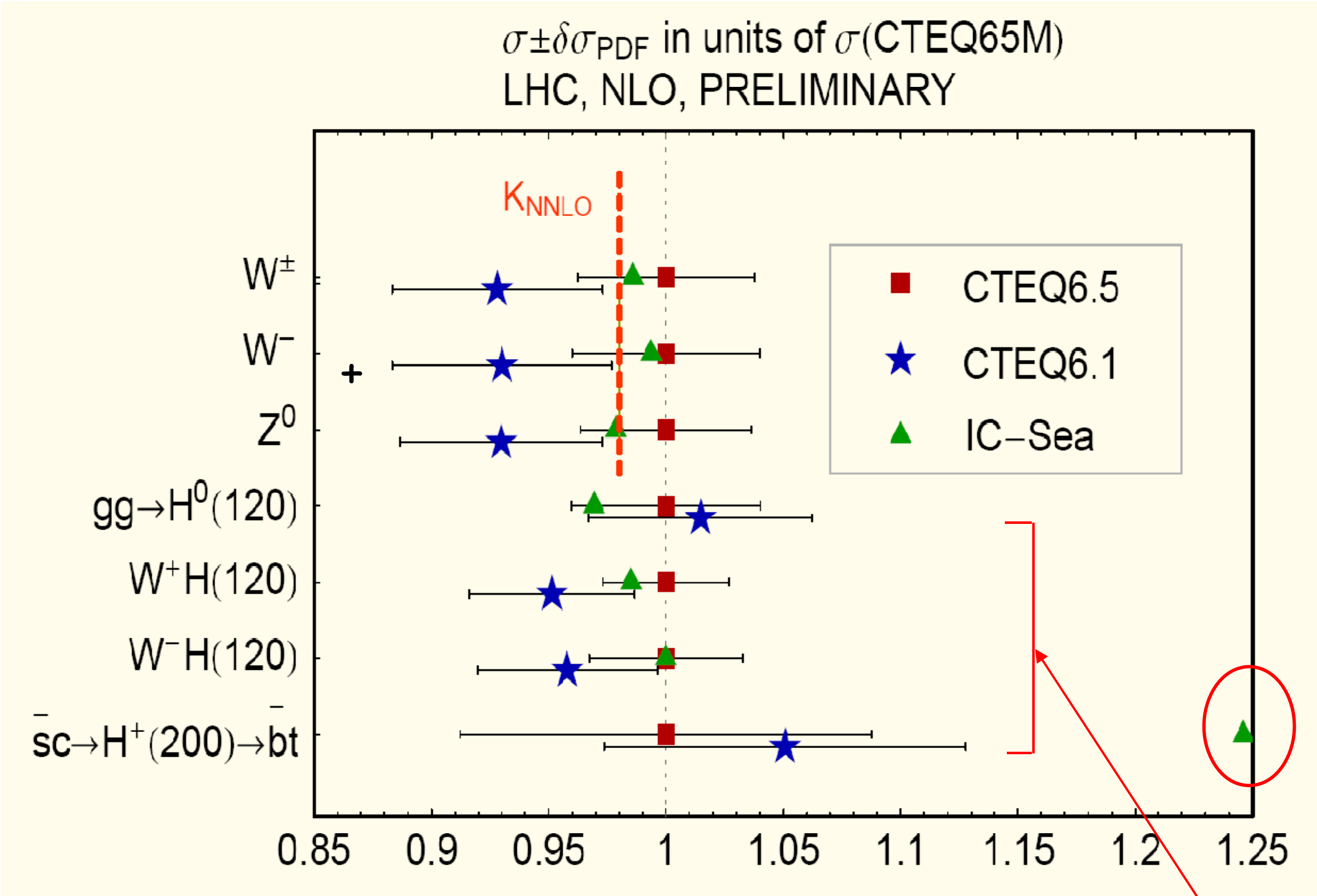
Origin of CTEQ6.1 → CTEQ6.5 shift:
mass effects (Wilson coefficients + Kinematics)

(Details in wkt: HFL-2)



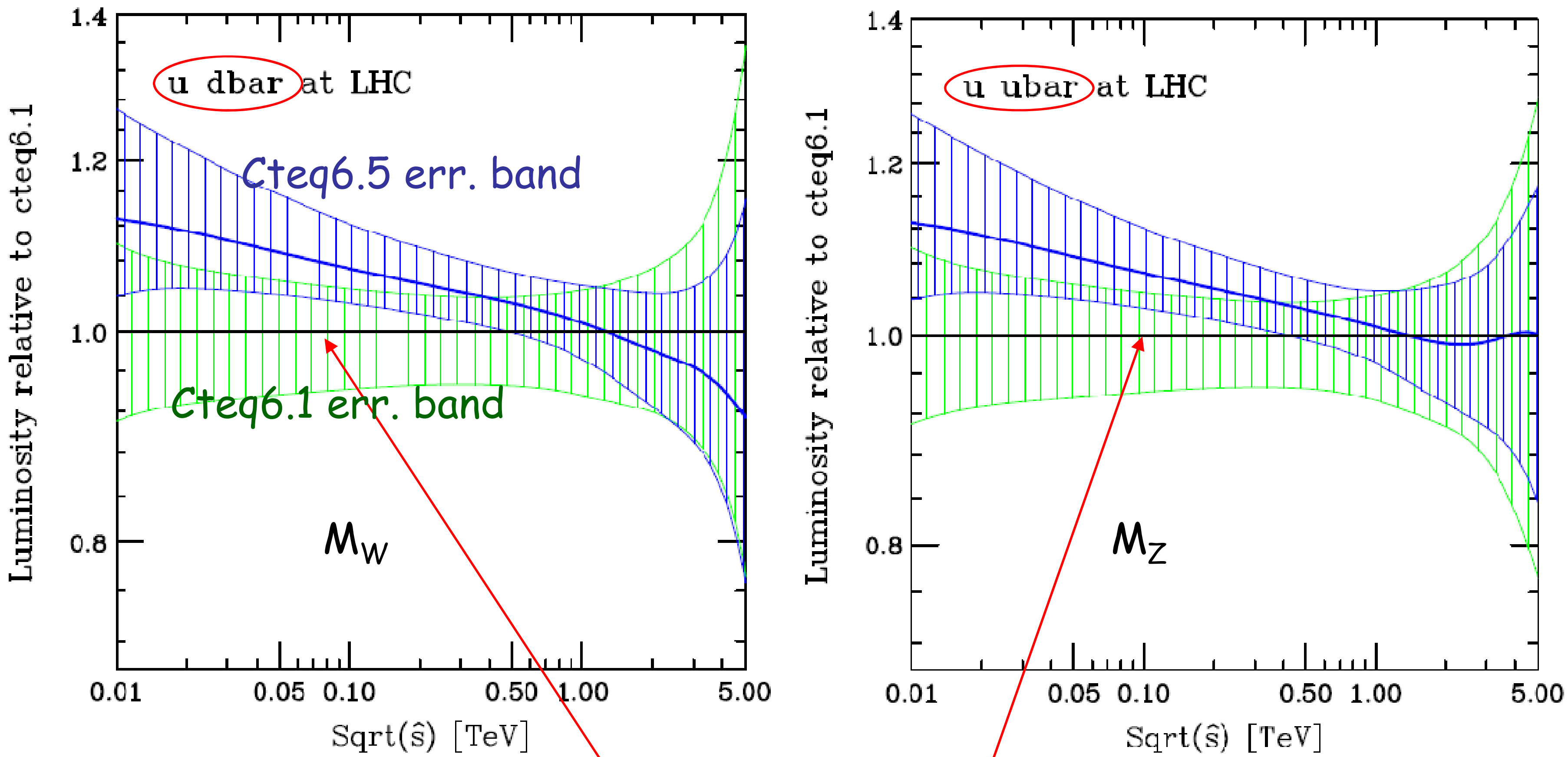

This shift must be compensated by shifts of PDFs in a global analysis of experimental data.

# Impact of CTEQ6.5M,S,C PDF's on $\sigma_{tot}$'s at LHC



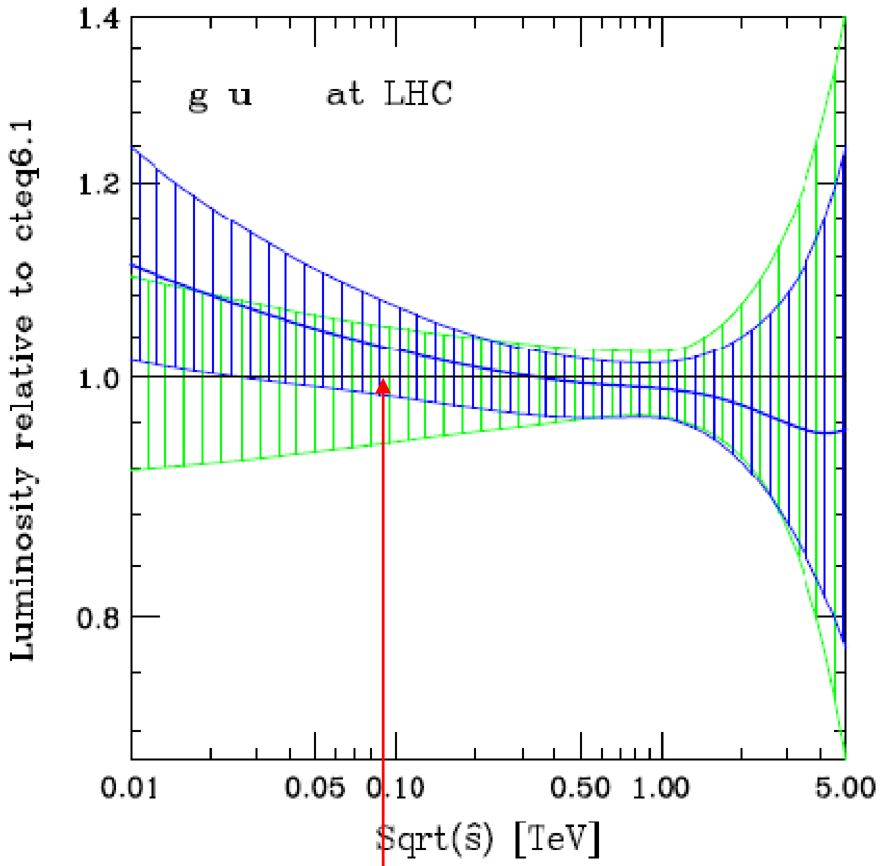

Yuan: EW-5

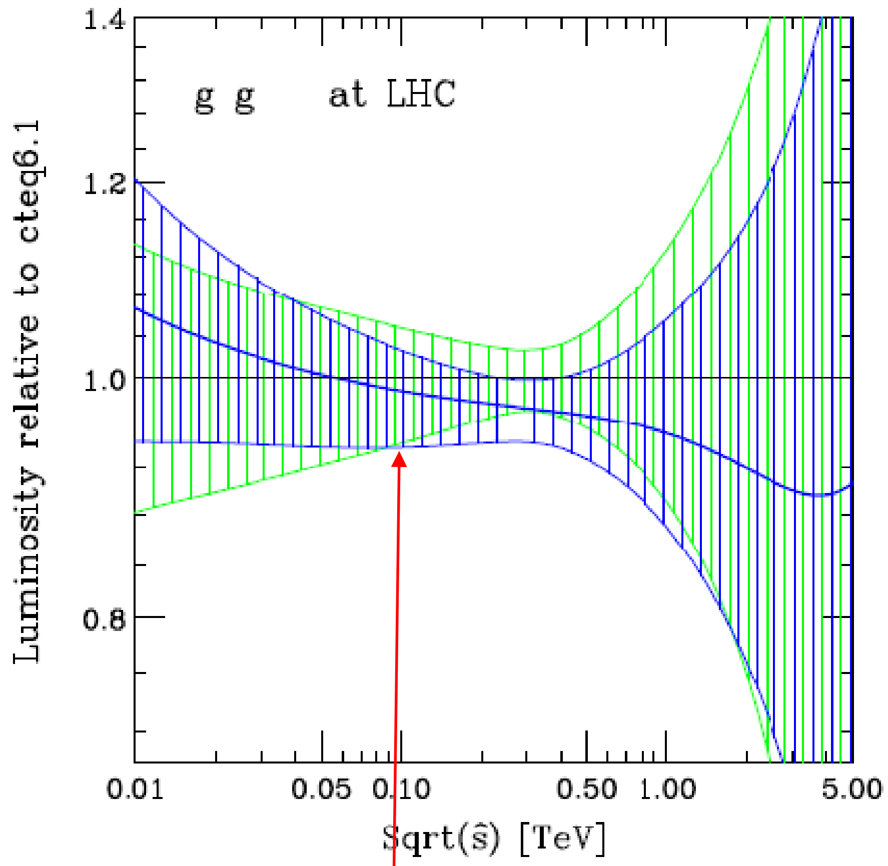
# Useful general results: LHC Luminosities




$\Delta$ ~7%,
(outside error band)

# Implications: LHC Luminosities




Δ ~3%,
(in error band)

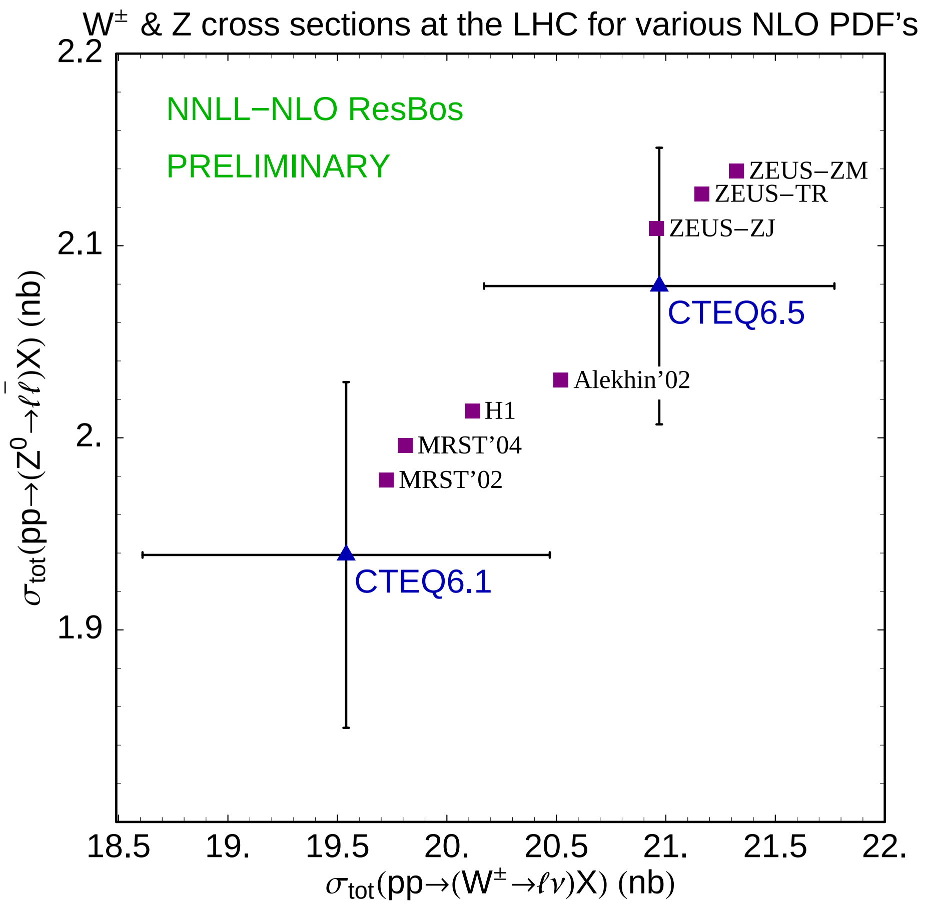
Δ ~0,
(error bands overlap)

# W/Z Production xSec @ LHC

The shift cteq6.1 → 6.5 is well understood as due to the improved theory treatment ZM → GM QCD. (earlier slide & wkt: HFL-2)

ZEUS PDFs seem to be insensitive to the mass treatment. (MRST mass treatment has evolved, but prediction has not changed.)

Could the difference in H1 and ZEUS predictions due to subtle differences in data?



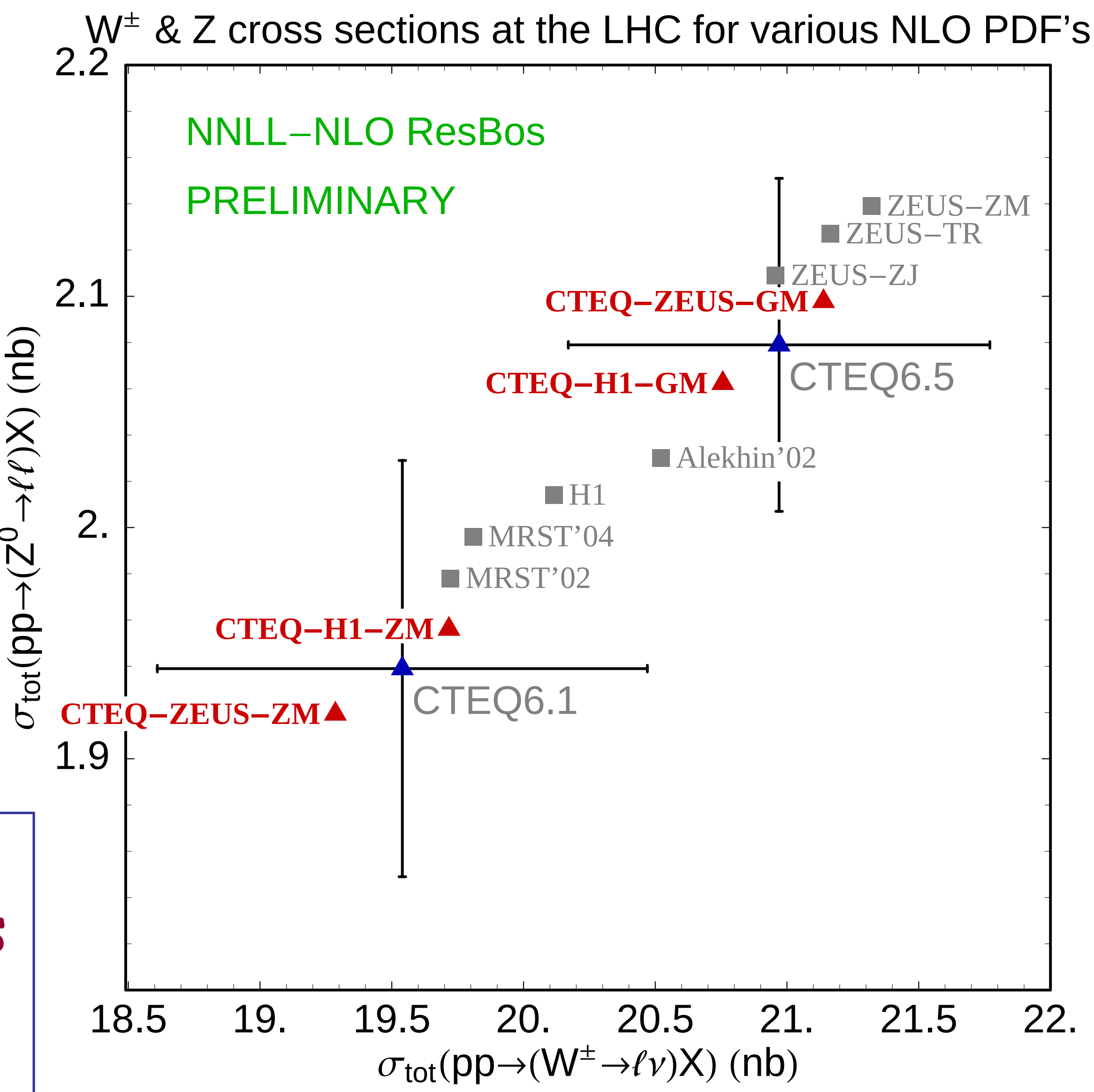

Will take a closer look …

CTEQ-H1/ZEUS-GM/ZM:

CTEQ GM/ZM fits, using H1/ZEUS data (along with other non-Hera data).

Results sensitive to mass treatment, but insensitive to H1 vs. ZEUS.

Why ZEUS PDFs are insensitive to the mass treatment is puzzling to us.




It is important to resolve this issue for the LHC physics program!

# Strange Parton Structure of the Nucleon

# Strange parton content of the nucleon

- Surprisingly little is known so far about the strangeness sector of the parton structure of the nucleon:
  - generally assume $s(x) = \bar{s}(x) = r(\bar{u}(x) + \bar{d}(x))/2$
  - it is known that *r ~ 0.5*, with large uncertainties.
- Inputs that can improve our knowledge of this sector:
  - NuTeV CC dimuon prod. data (sensitive to charm prod.)
  - Precise GM QCD calculation of HQ processes.
- dedicated study of the strangeness sector: CTEQ6.5S:
  - Can $s_+(x) = s(x) + \bar{s}(x)$ now be determined? What is it like?
  - What can we say about the strangeness asymmetry $s_-(x) = s(x) - \bar{s}(x)$ ?

(Lai, Pumplin, wkt, … hep-ph/0702268)

## Symmetric strange distribution $s_+(x) = s(x) + \bar{s}(x)$

- New global analysis disfavors

$$s_+(x) \propto \bar{u}(x) + \bar{d}(x)$$ ;

- it suggests that, with current experimental constraints, we need independent new shape parameters for $s_+(x)$.

| change of goodness-of-fit | # strange shape parameters | | |
|---|---|---|---|
| | 2 | 3 | 4 |
| $-\Delta\chi^2_{\text{global}}$ (3542 pts.) | 65 | 68 | 69 |
| $-\Delta\chi^2_{\mu^+\mu^-}$ (149 pts.) | 46 | 48 | 50 |

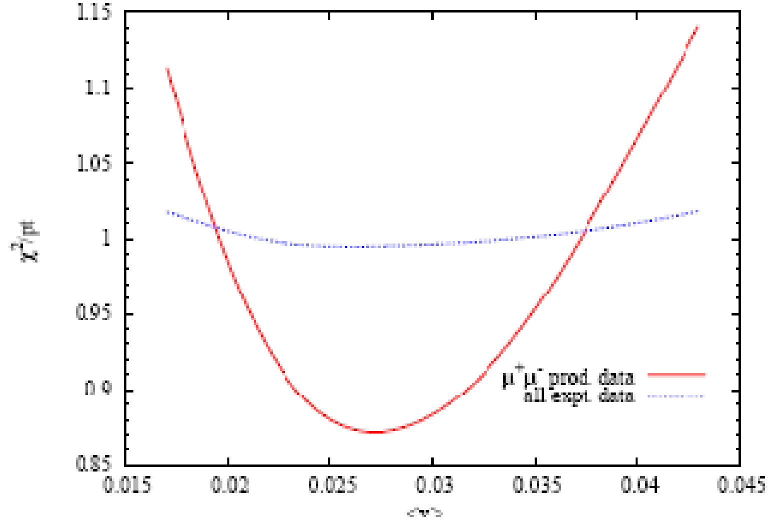
- Only two shape parameters are needed for current analysis; more may be needed with further experimental constraints in the future.

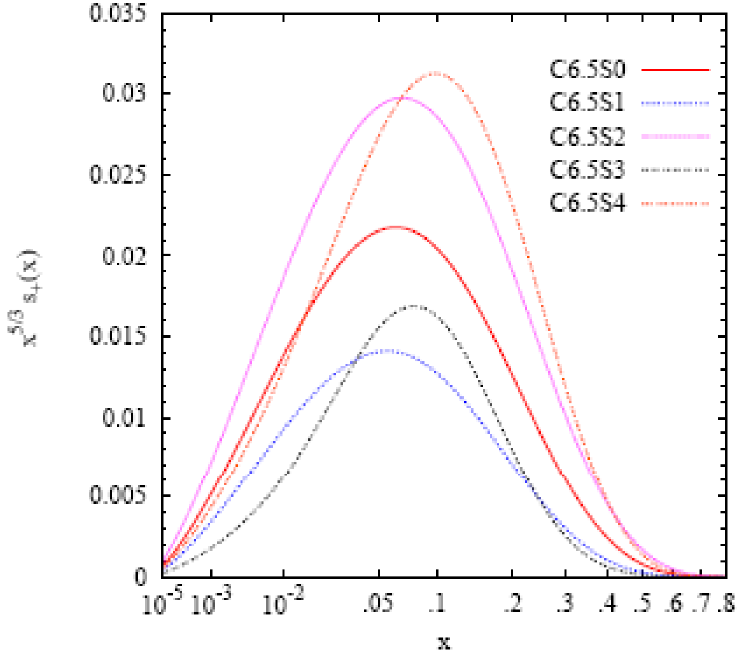
# Bounds on the Symmetric strange distribution

$$s_+(x) = s(x) + \bar{s}(x)$$

- We obtain
  bounds on the magnitude of $s_+$:

$$0.27 < r = \frac{\langle x \rangle_{s+\bar{s}}}{\langle x \rangle_{\bar{u}+\bar{d}}} < 0.67$$




- We obtain a range of shape variation of $s_+(x)$.

Strange Asymmetry $s_-(x) = s(x) - \bar{s}(x)$

- Non-perturbative models of nucleon structure suggest possible strangeness asymmetry;
- $S_-(x)$ was first studied in the global analysis context in 2003 as a possible explanation of the "NuTeV anomaly". The results were suggestive, but not conclusive.
- Has the situation improved, due to recent advances?

# Results on Strange Asymmetry $s_-(x) = s(x) - \bar{s}(x)$

- Current global analysis does not *require* a non-zero $s_-(x)$.

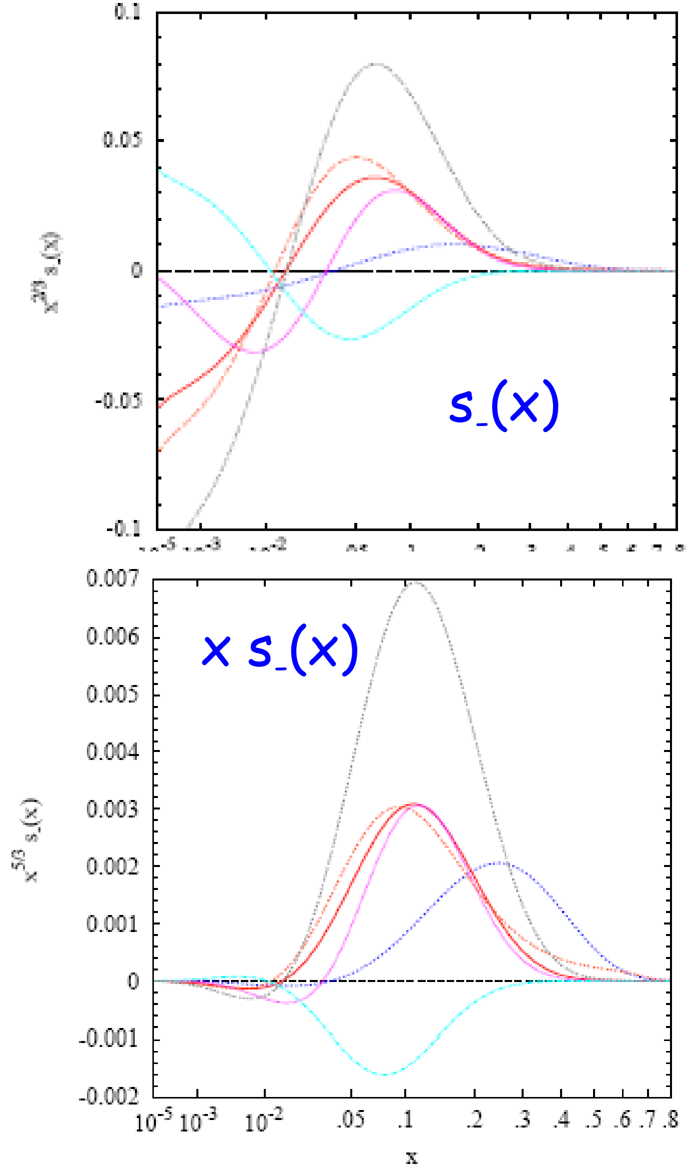
- It can be non-zero. The range of its magnitude as determined by current experimental constraints:

$$-0.001 < \langle x \rangle_{s_-} < 0.005$$

—the same as in the 2003 study.

$$\left( \langle x \rangle_{s_-} \equiv \int_0^1 x\, s_-(x)\, dx \right)$$

- *A* range on its shape is found ➔➔



# The Charm Content of the Nucleon

Is the charm sector of the nucleon structure completely generated perturbatively by the light-flavor sector—the (unspoken) conventional assumption?

If so, what is the starting scale?
(It matters quite a lot in precise global analysis.)

Models of nucleon structure strongly suggest a non-perturbative component of charm at the scale ~ $m_c$.

It is time to study this question phenomenologically: do current data support independent charm degrees of freedom in the global QCD analysis of PDFs?

(wkt: HFL-2)

# Outlook

- Frontiers for Global QCD Analysis are continuously been expanded in new directions;
- Evolutionary, but significant, advances have been made in analysis methodology; while many revolutionary new methods are being proposed and tried;
- These developments go very well with the demand of ever higher reliability and accuracy of PDFs for the Tevatron RunII and the LHC physics programs.

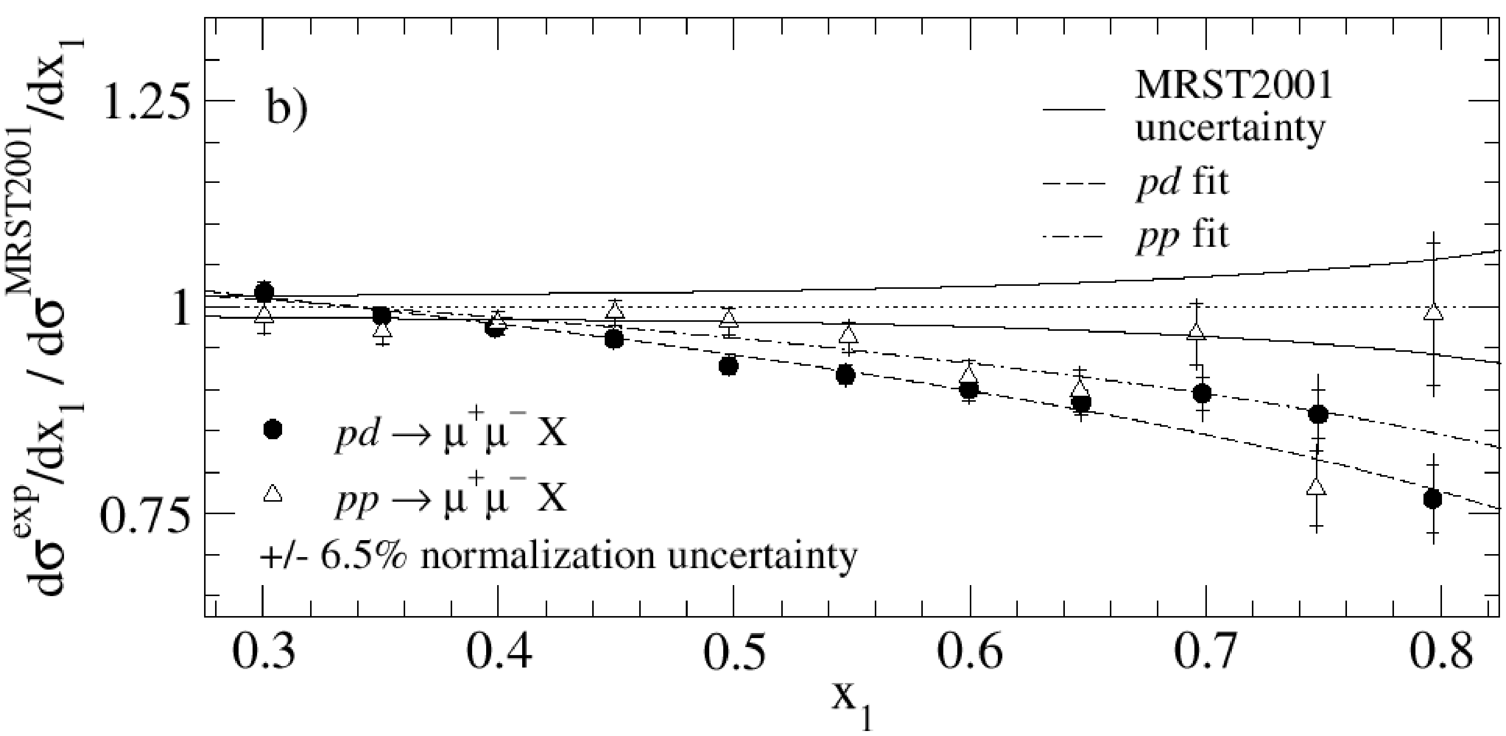
- There are a lot to look forward to!

- There are also nagging unresolved problems, e.g. recent NuTeV total cross section and E866 pd data …

# Study of Large-x Behavior of PDFs

(Owens, Huston, Keppel, Kuhlmann, Morfin, Olness, Pumplin, Stump)

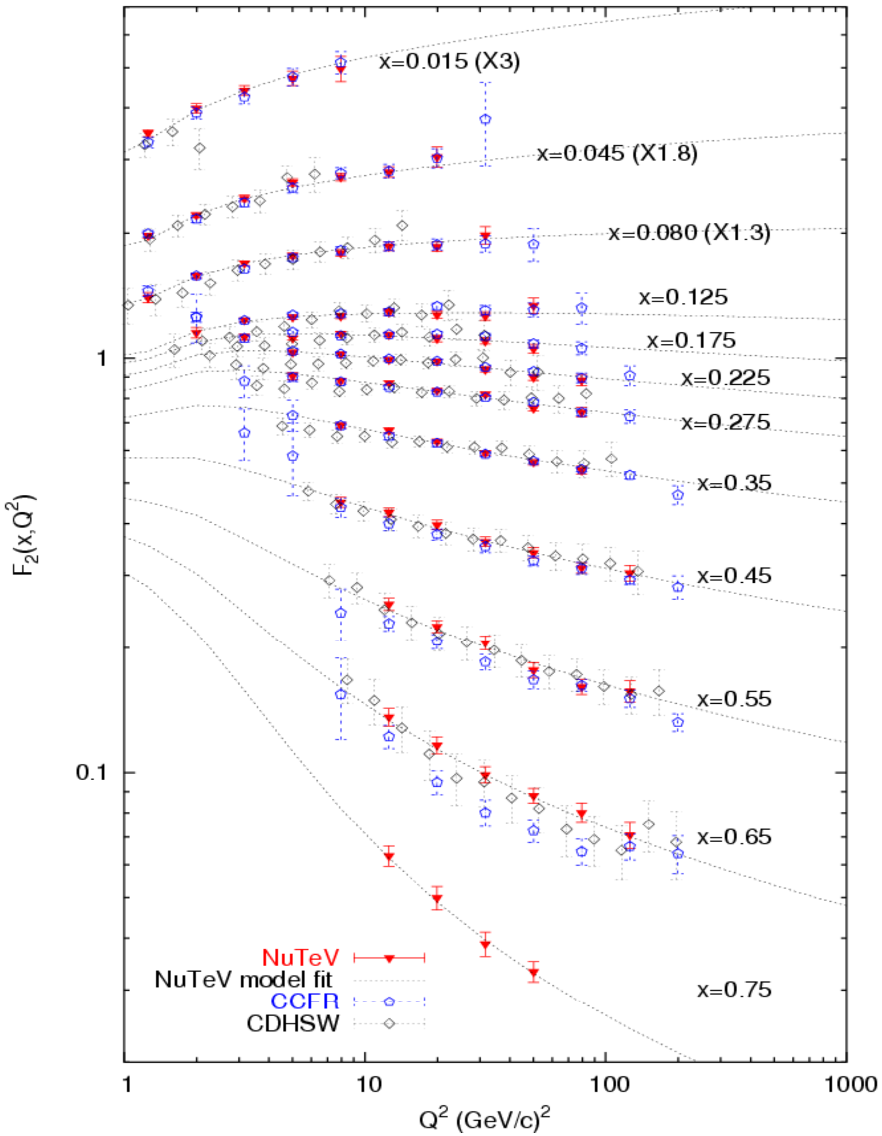
- E866 pp and pd cross sections
  - Preliminary results (hep-ex/0302019)



# NuTeV Results

Tzanov, DIS2005

## $F_2$ Measurement



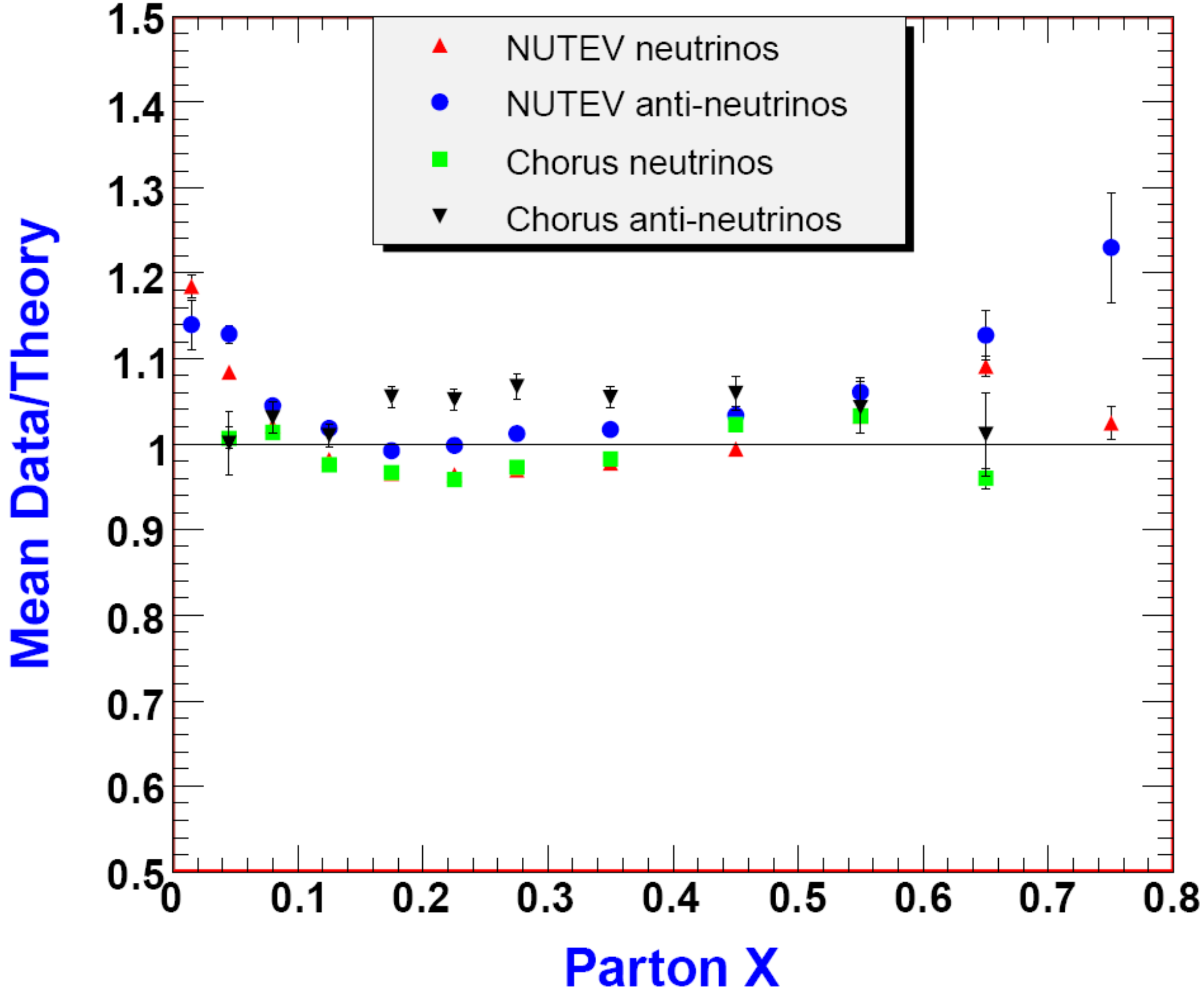

- Isoscalar ν-Fe $F_2$
- NuTeV $F_2$ is compared with CCFR and CDHSW results
  - the line is a fit to NuTeV data
- All systematic uncertainties are included
- All data sets agree for $x<0.4$.
- At $x>0.4$ NuTeV agrees with CDHSW
- At $x>0.4$ NuTeV is systematically above CCFR

M. Tzanov et al., PRD 74, 012008 (2006)

# Attempts to Incorporate the NuTeV and E866 *data* in the Global Analysis

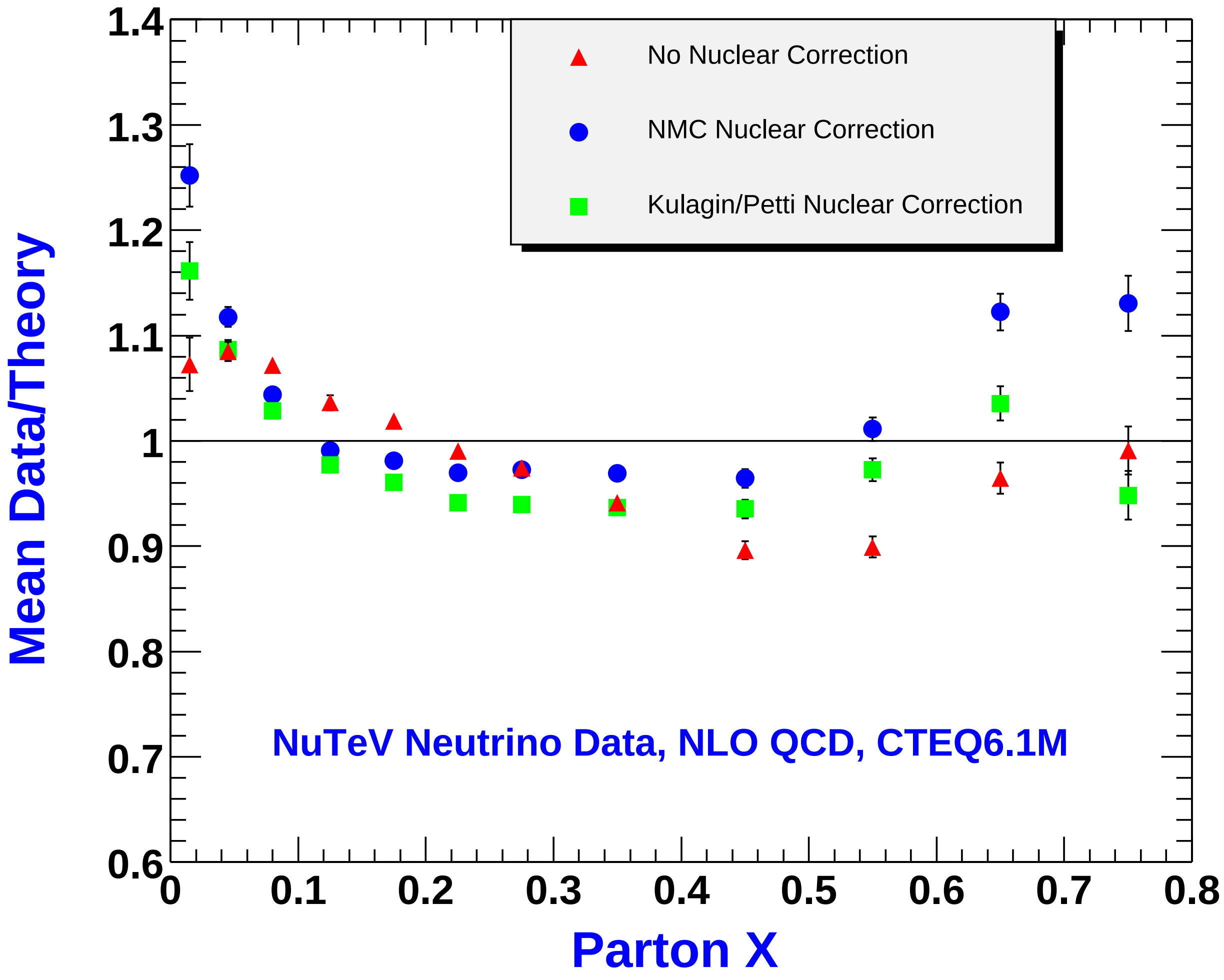
- NuTeV data set pulls against several of the other data sets, notably the E-866 and the BCDMS and NMC. Nuclear corrections (heavy target) do not improve the situation. (In fact, no nuclear correction lessens, but does not remove, the problem.)
- Effects are most pronounced when one examines the d/u ratio. Adding NuTeV and E-866 simultaneously in the global analysis causes the d/u ratio to flatten out substantially, resulting in worsened fits to other precision DIS data.
- E866 pp data is more comparable with precision DIS data sets than the pd data.

Comparison of NuTeV and Chorus data to Standard Global fit results (dominated by NC DIS)

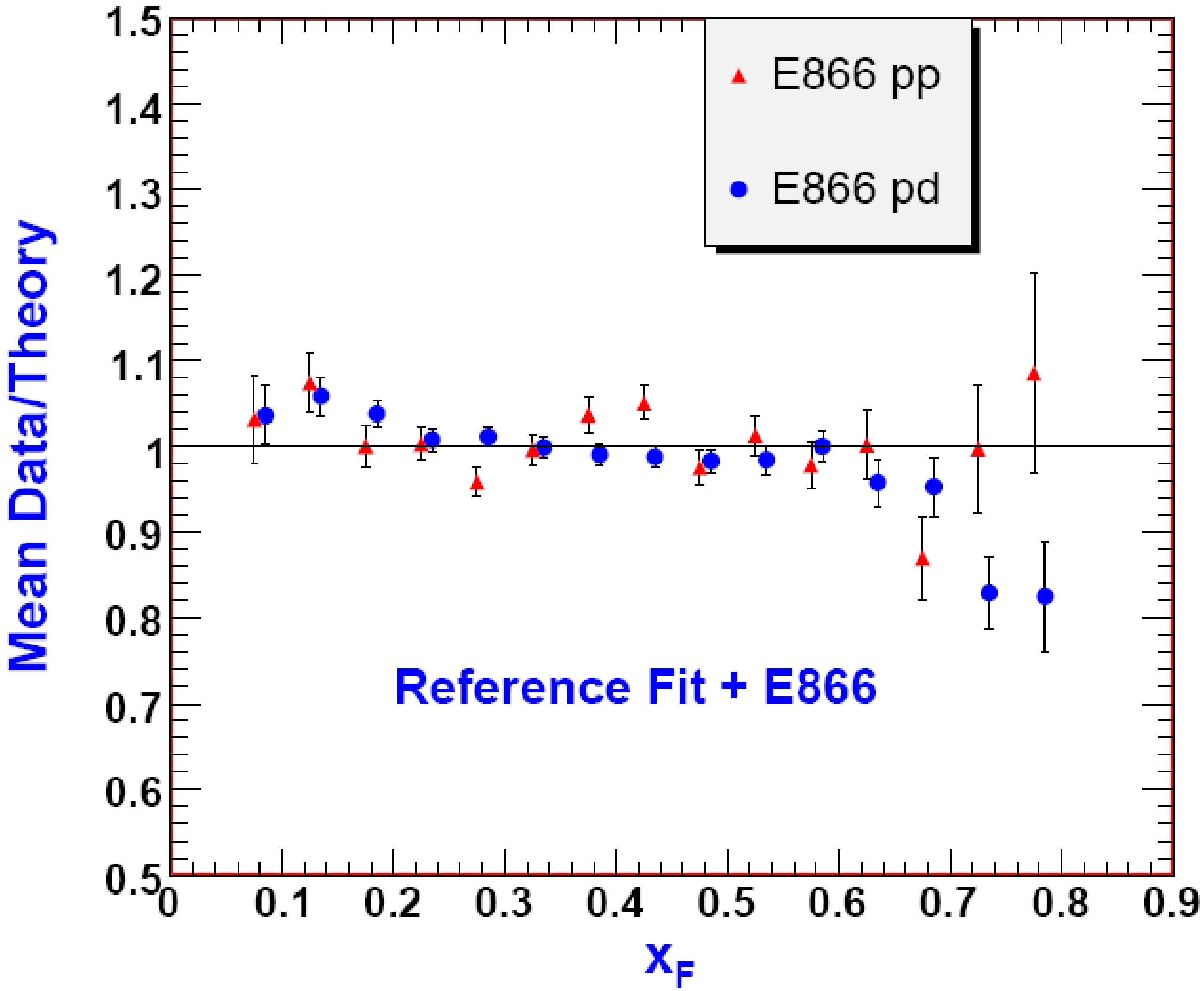


# Can Nuclear Corrections Help?

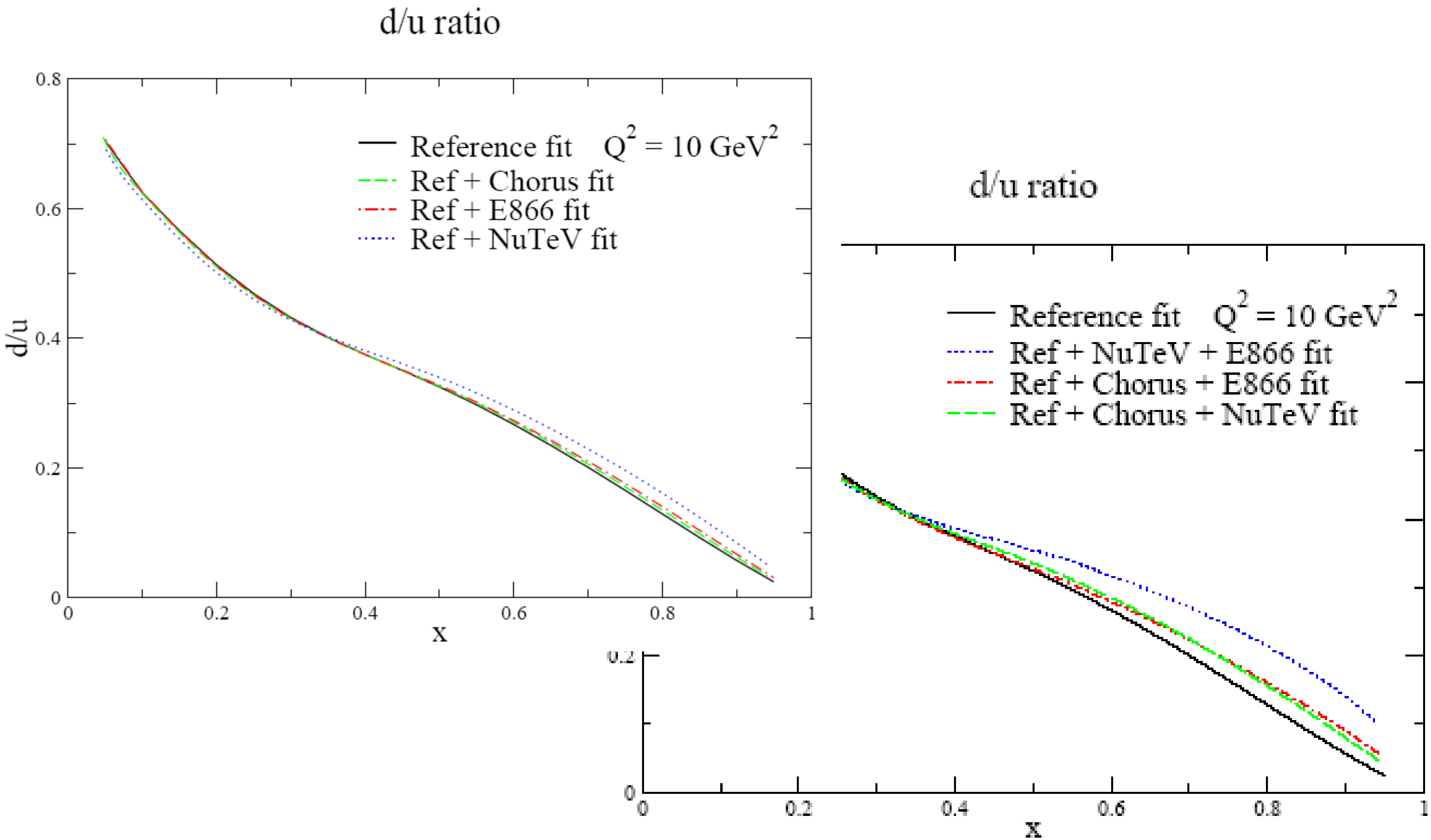
- For each x, data are combined and errors are weighted;
- See a systematic x-dependent deviation that cannot be reduced substantially by nuclear correction models.



# Comparison of the global fit including E-866, with the E-866 data.



# Tension between NuTeV and E866 data, manifested through the d/u ratio



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