Parton Distributions at High Energy Colliders

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In collaboration with
CTEQ-TEA

9th Workshop of TeV Physics WG
May 15-18, 2014@ Sun Yat-sen Univ., Guangzhou, China

CTEQ-TEA group

- CTEQ – Tung et al. (TEA)

  in memory of Prof. Wu-Ki Tung, who established CTEQ Collaboration in early 90's

- Current members:

Sayipjamal Dulat (Xinjiang Univ.)

Tie-Jiun Hou (Academia Sinica, Taipei)

Southern Methodist Univ. -- Pavel Nadolsky, Jun Gao, Marco Guzzi

Michigan State Univ. -- Joey Huston, Jon Pumplin, Dan Stump, Carl Schmidt, CPY

Back to 2012

- March 8, 2012: Daya Bay Neutrino Experiment; θ_{13}

- July 4: Higgs Discovery at LHC

- November 12-15: 7th TeV Workshop

清華大學
Tsinghua University

Center for High Energy Physics Tsinghua University

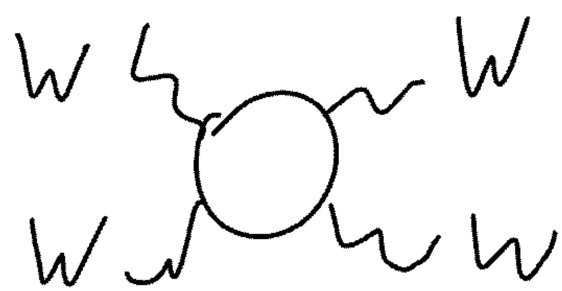
7th Workshop on TeV Physics

In honor of Prof Yu-Ping Kuang

2012 November (12-15th)

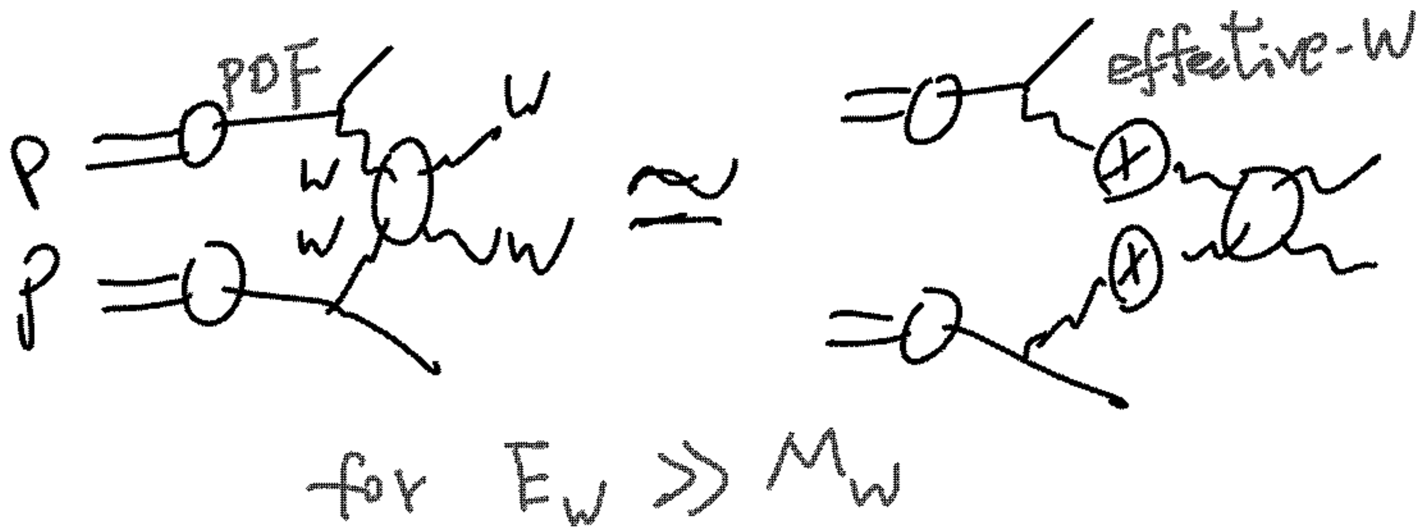
A Long Time Ago

- 1984-1985: Prof. Gordy Kane asked me to compare parton luminosities at various pp or p-pbar collider energies; to compare their physics potential, particularly, on probing the Electroweak Symmetry Breaking sector via studying



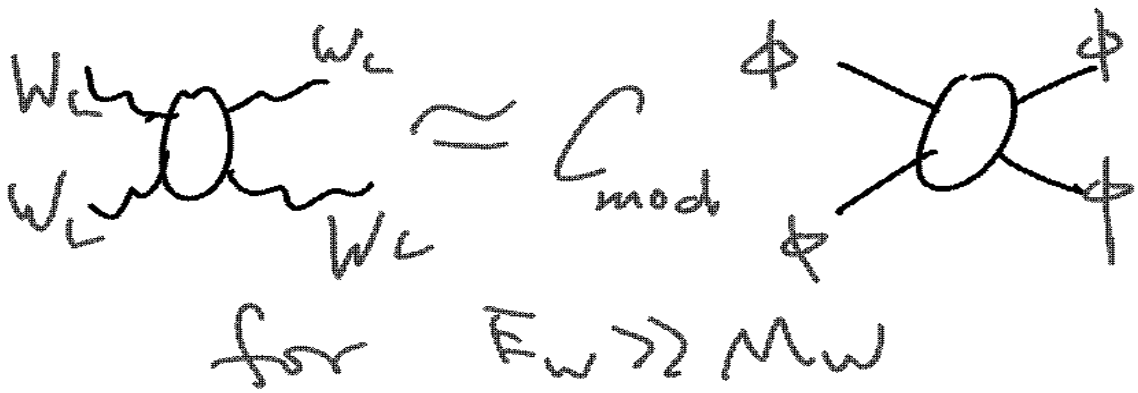
Need to know

- Parton Distribution Functions
- Effective W approximation



Another important ingredient

- Goldstone Boson Equivalence Theorem



- In general, the modification factor C(mod) is not 1 beyond the tree level.

York-Peng Yao and CPY; PRD 38 (1988) 2237

J. Bagger and C. Schmidt; PRD 41 (1990) 264

- C(mod) can be made to be 1 in a special renormalization scheme. (See next slide.)

Prof. Yu-Ping Kuang and me

- 1992: referee of PRL 69 (1992) 2619

"On the precise formulation of equivalence theorem", by

Hong-Jian He, Yu-Ping Kuang and Xiao-Yuan Li

- 1993: my first trip to China (CCAST); followed by many collaborations on studying the Electroweak Symmetry Breaking sector.
- 1997-2000: Hong-Jian He joined MSU, as a postdoc; initiating further collaborations.

WW -> WW

- In the SM, Higgs boson ensures its unitarity.
- If the coupling of H-W-W deviates from the SM, then unitarity is violated.

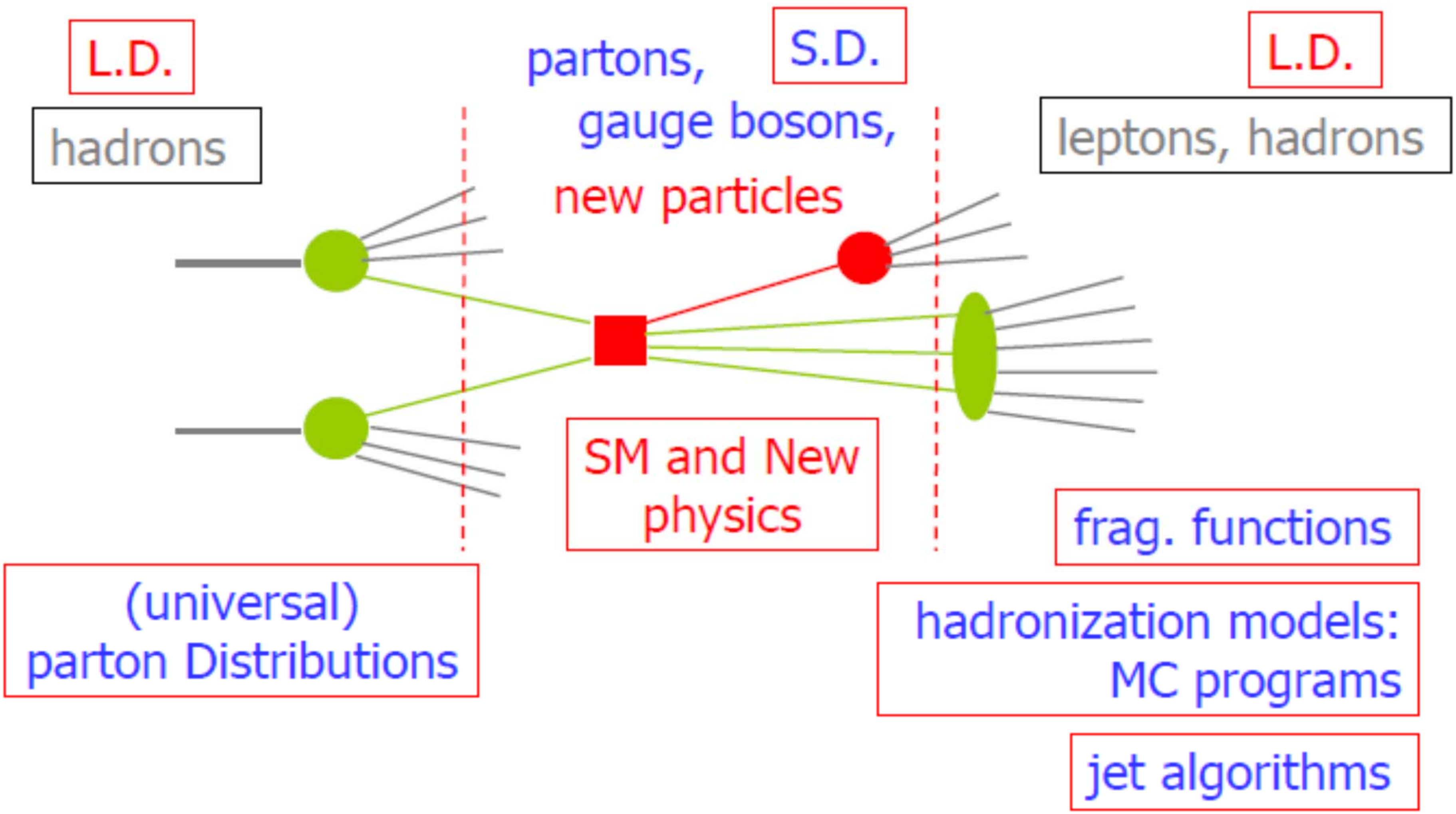
Bin Zhang, Yu-Ping Kuang, Hong-Jian He, CPY; PRD 67 (2003) 114024

- Require New Physics to restore unitarity up to some higher energy scale. It generally implies new resonance states, such as scalar, vector, tensor, or fermion states.

Parton Distribution Functions

Needed for making theoretical calculations to compare with experimental data

Hadron Collider Physics



CT10 NNLO update and QED effects in PDFs

Carl Schmidt

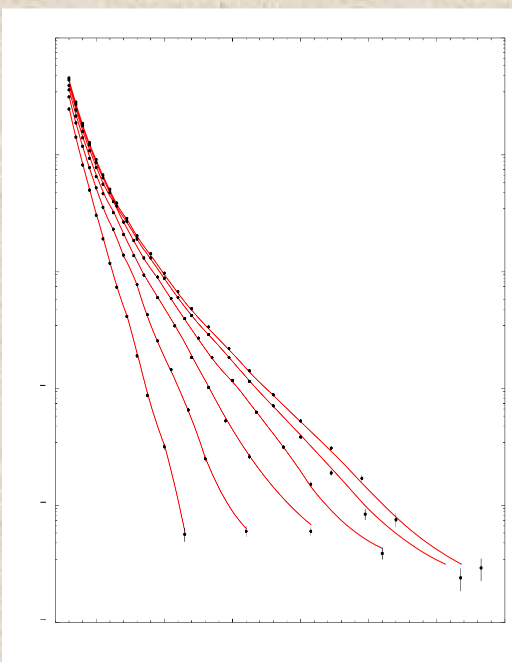
Michigan State University

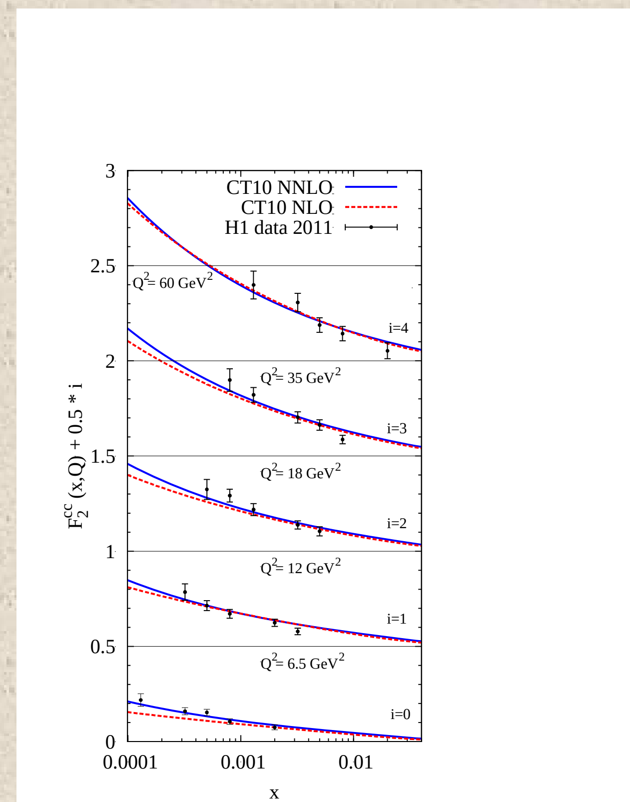
On behalf of CTEQ-TEA group

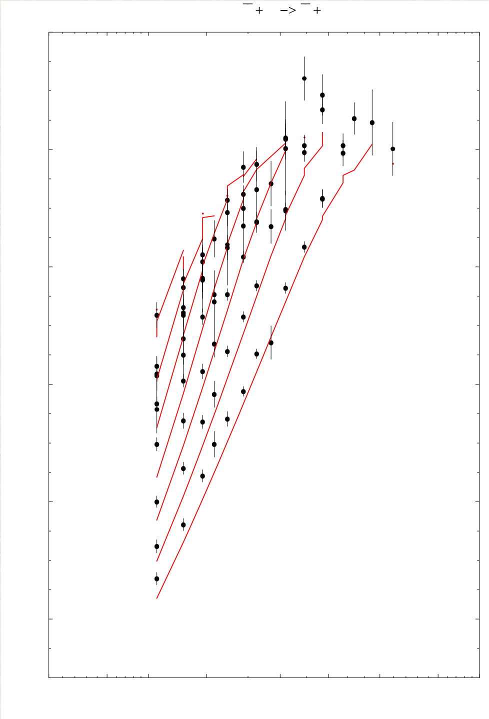
April 29, 2014

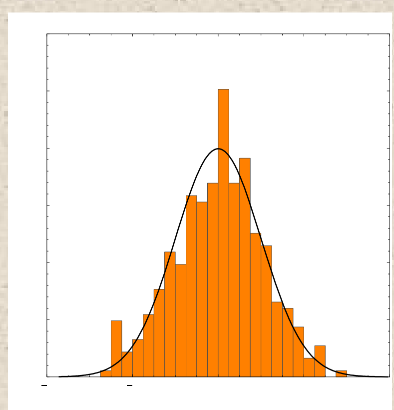
DIS2014, Warsaw, Poland

CT10NNLO vs. fitted data





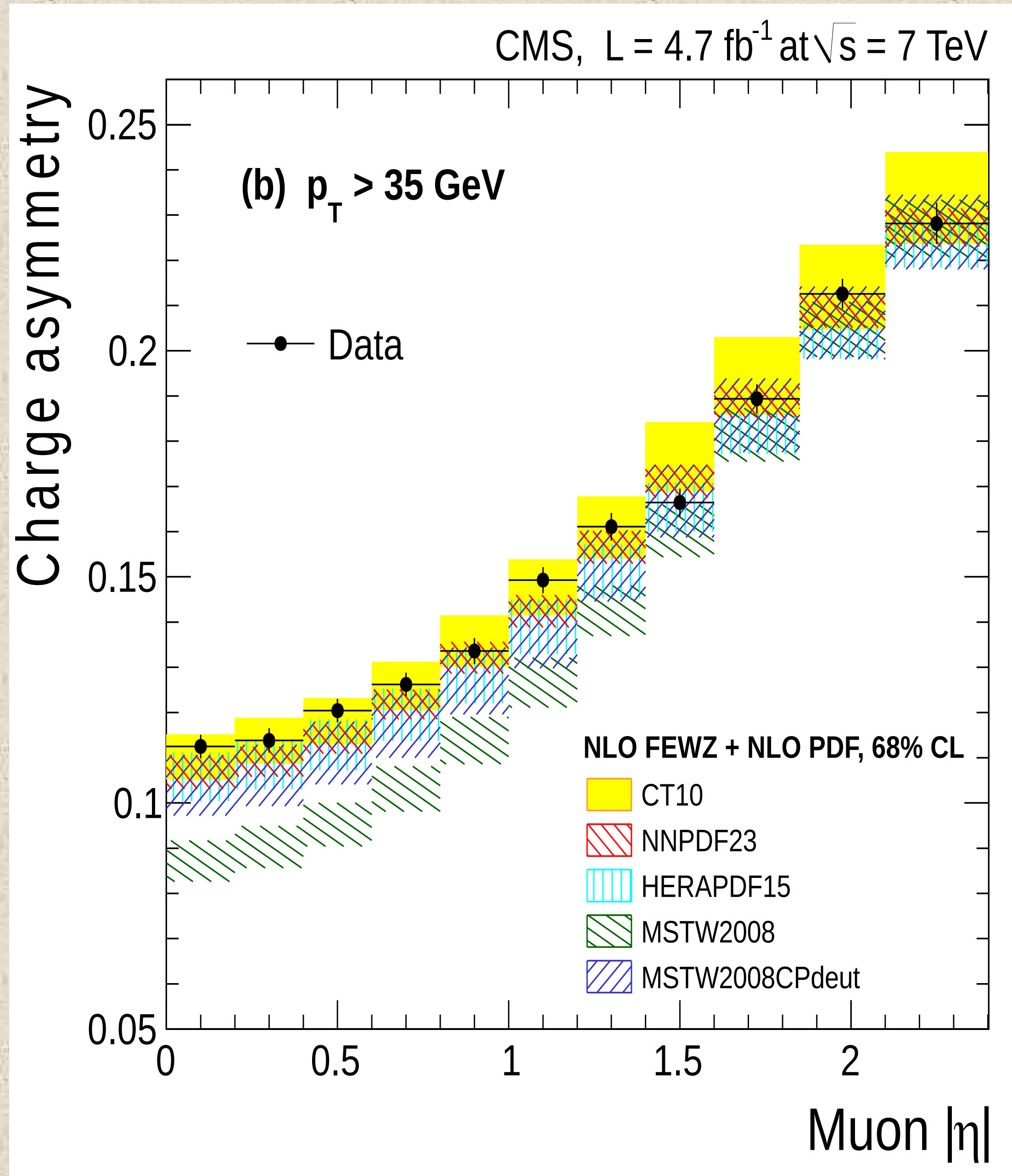




Fits well: $\chi^2 / N_{pt} = 2950/2641 = 1.11$

CT10, CT1X, and LHC data

- We have since included early (7 TeV) LHC data: Atlas W/Z production and asymmetry at 7 TeV, Atlas single jet inclusive, CMS W asymmetry, HERA F_L and F_2^c
- More flexible parametrization – gluon, d/u at large x and both, d/u and dbar/ubar at small x, strangeness, and s - sbar.
- Improvements modest so far, but expectation from ttbar, W/Z, Higgs, etc.

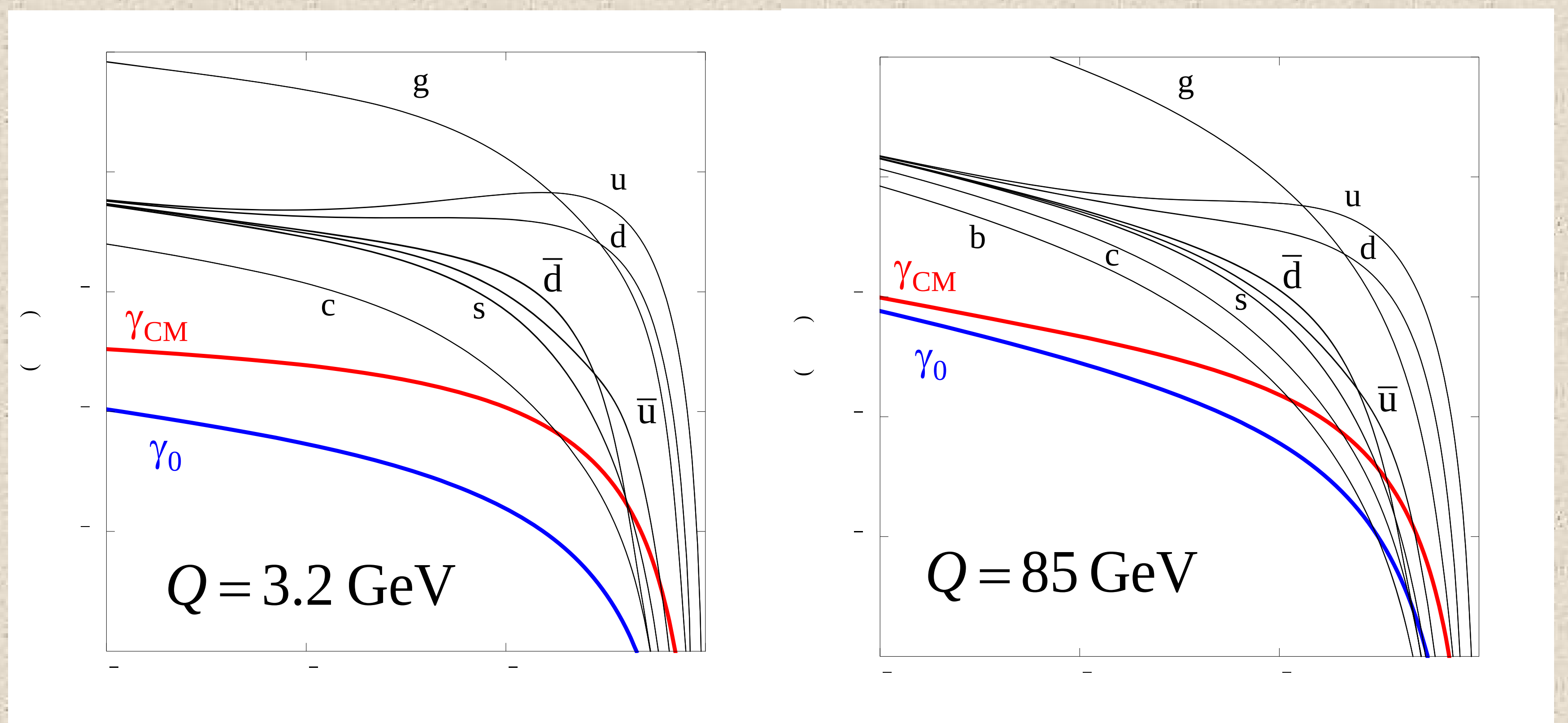


Data is already more precise than current PDF uncertainty.

Will help to determine PDFs in small x region.

Most useful for determining dbar/ubar.

Photon PDFs (in proton)



γ momentum fraction:

$p^{\gamma}(Q)$	$\gamma(x,Q_0)=0$	$\gamma(x,Q_0)_{CM}$
Q = 3.2 GeV	0.05%	0.34%
Q = 85 GeV	0.22%	0.51%

Photon PDF can be larger than sea quarks at large x!

Initial Photon PDF still
← significant at large Q.

Uncertainties on H and ttbar Predictions at the LHC

(and update on Intrinsic Charm)

Carl Schmidt

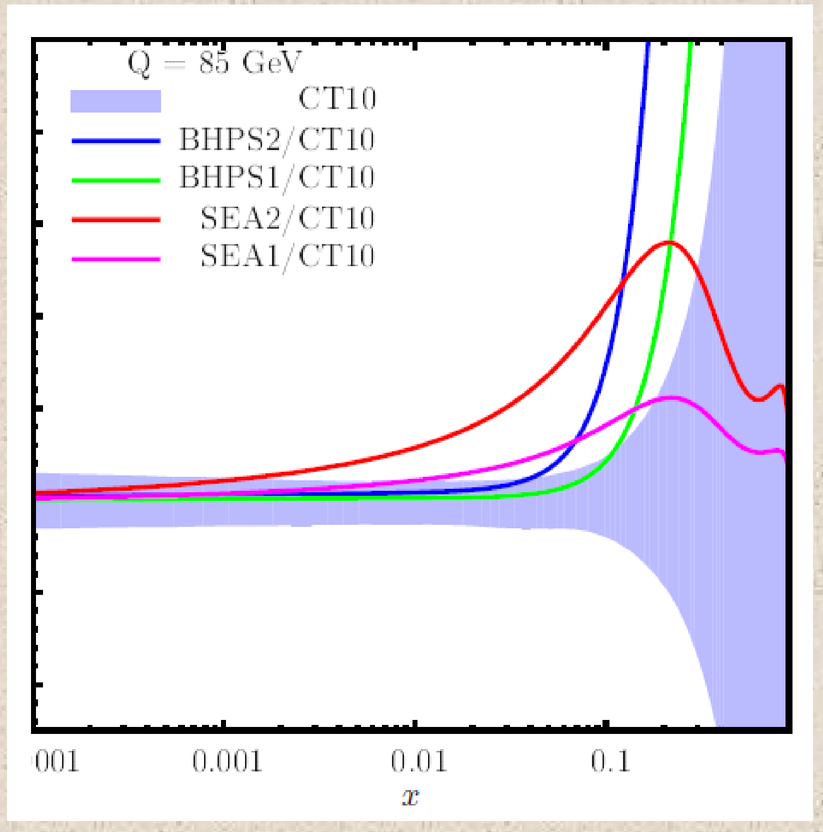
Michigan State University

On behalf of CTEQ-TEA group

April 29, 2014

DIS2014, Warsaw, Poland

Intrinsic Charm at LHC

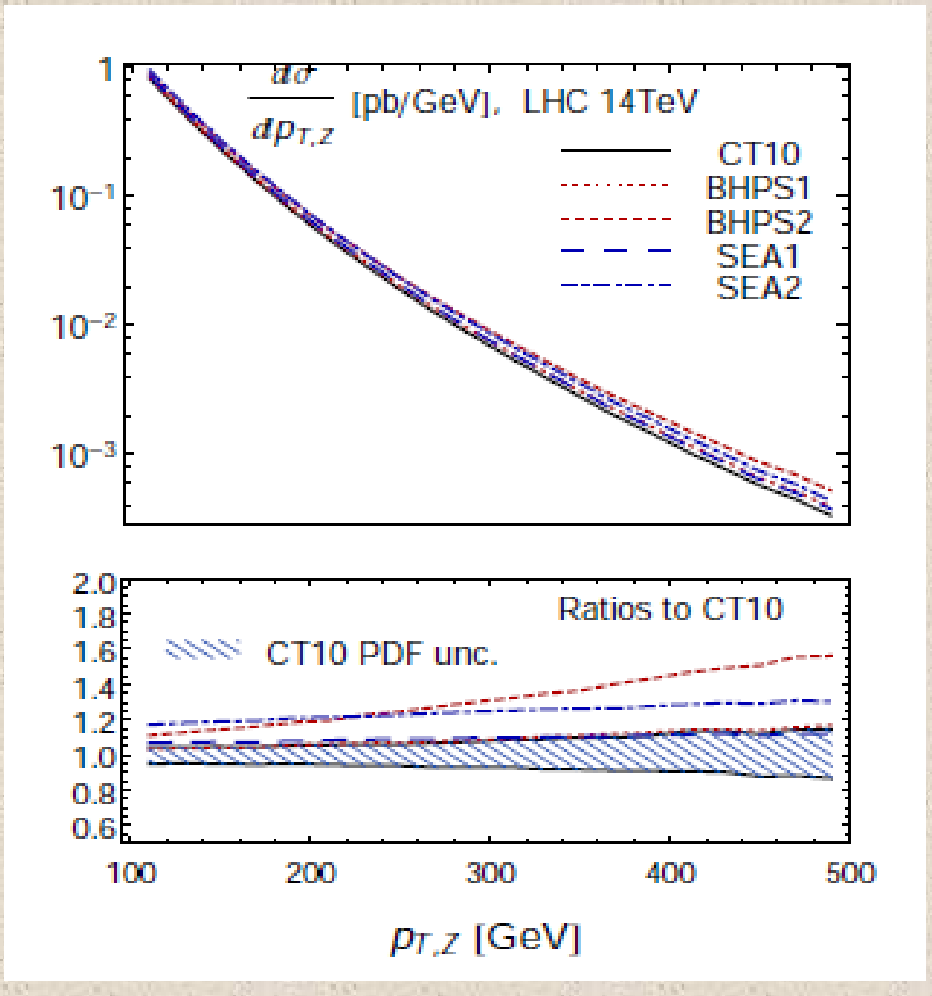


IC vs CT10 charm PDF

SEA1/BHPS1: $\langle x \rangle_{\mathrm{IC}} = 0.57\%$

SEA2: $\langle x \rangle_{\mathrm{IC}} = 1.5\%$

BHPS2: $\langle x \rangle_{\mathrm{IC}} = 2.0\%$



$pp \rightarrow Zc$ at LHC may further constrain valence-like model

Some basics about PDFs

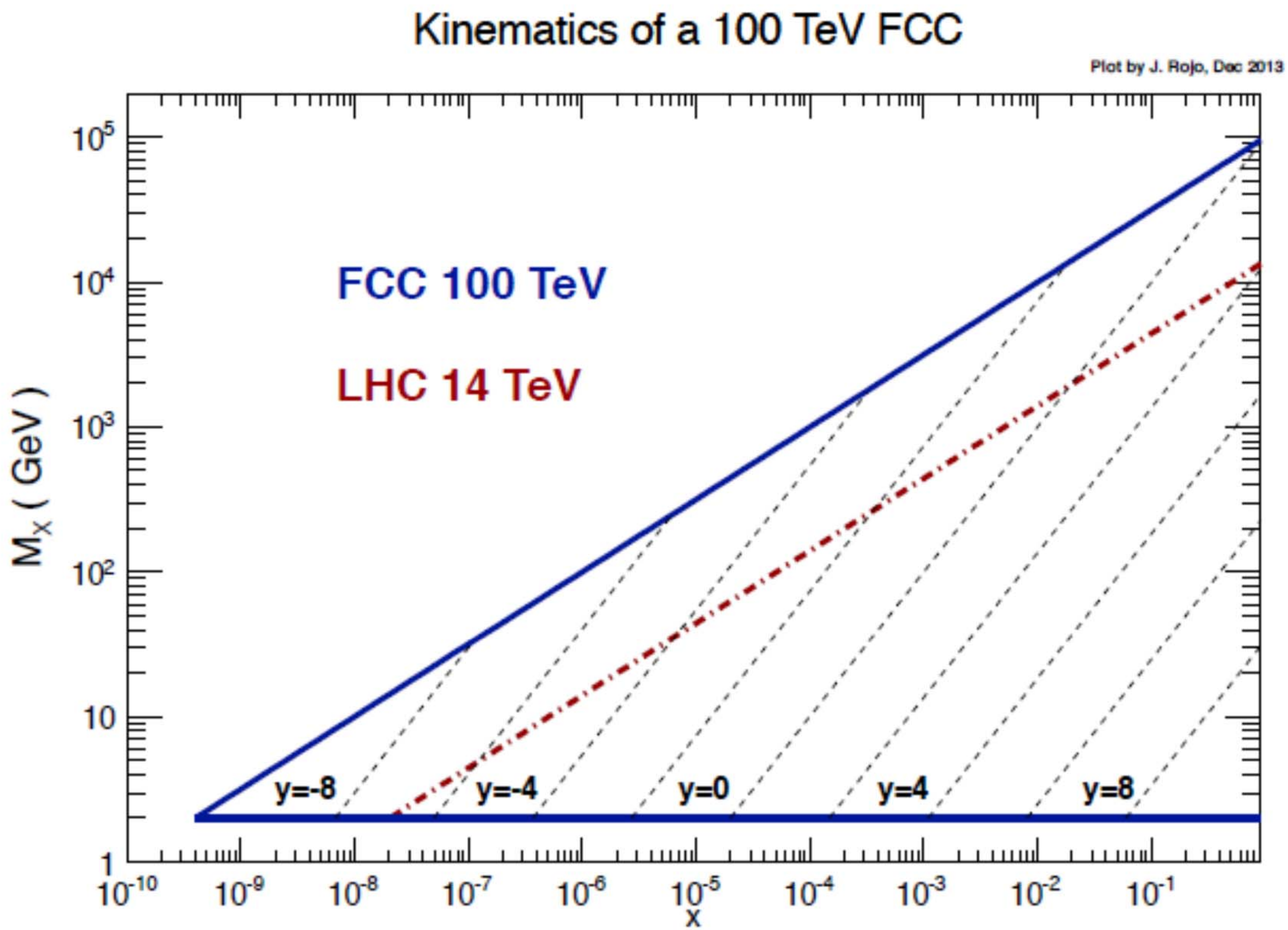
- Parton Distribution Function $f(x, \mathrm{Q})$
- Given a heavy resonance with mass Q produced at hadron collider with c.m. energy $\sqrt{S}$
- What's the typical x value?

$$<x> = \frac{Q}{\sqrt{S}}$$ at central rapidity (y=0)

- Generally, $x_1 = \frac{Q}{\sqrt{S}} e^{y} \quad and \quad x_2 = \frac{Q}{\sqrt{S}} e^{-y}$

$$x_1 + x_2 = 2\frac{Q}{\sqrt{S}} \cosh(\mathrm{y}) \Longrightarrow y_{\max} : \; x_1 + x_2 = 1$$

Kinematics of a 100 TeV SppC



- J. Rojo: kickoff meeting for FCC at CERN, Feb. 2014

On to a 100 TeV SppC

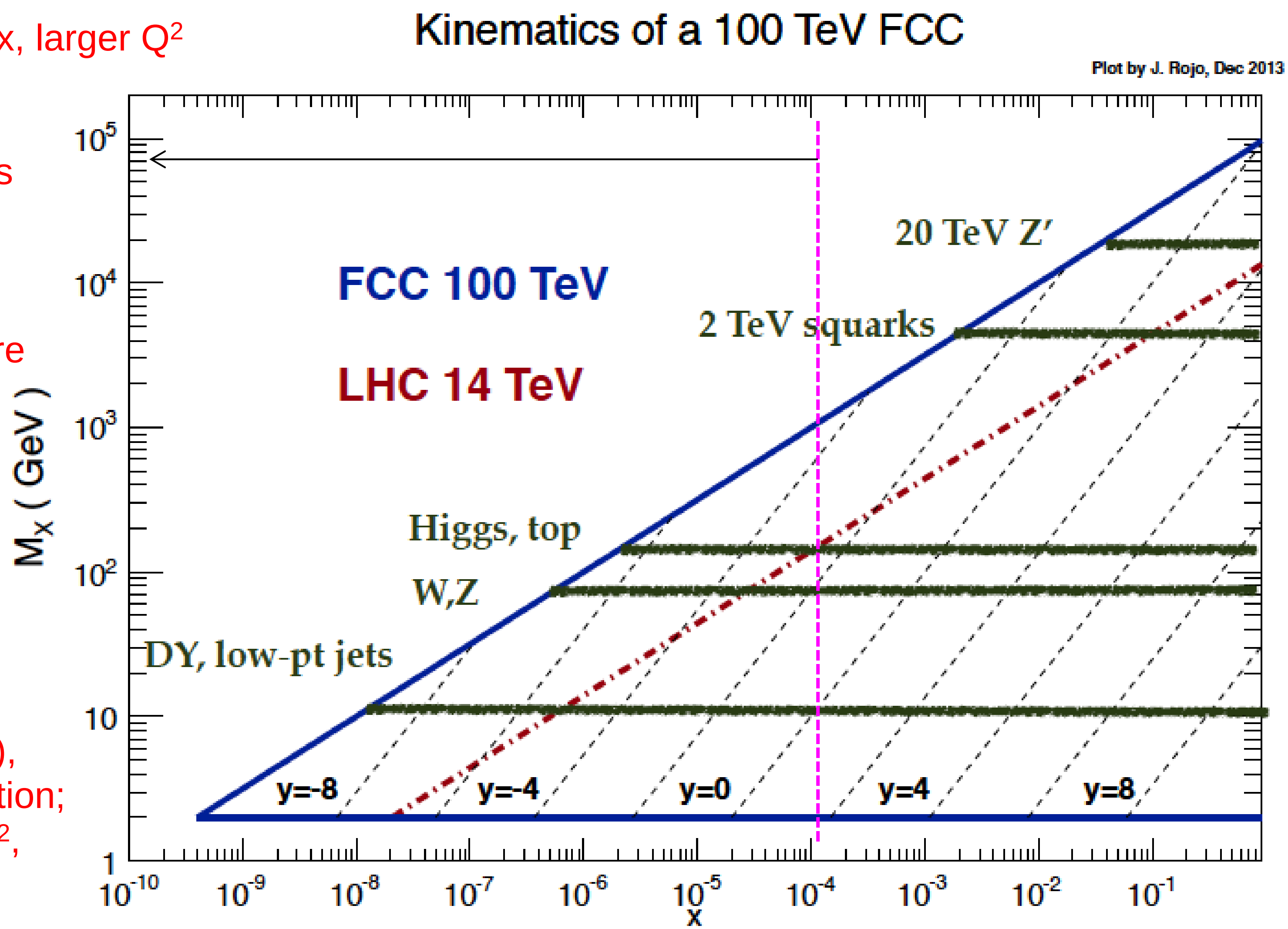
will access smaller x, larger Q^2

currently have no constraints on PDFs for x values below 1E-4

we don't know where at low x, BFKL effects start to become important

poor constraints (still) as well for high x PDFs

at high masses (Q^2), rely on DLAP evolution; we know at large Q^2, EW effects also become important



CT10 NNLO PDFs

- PDF error bands
  - u and d PDFs are best known
  - currently no constraint for x below 1E-4
  - large error for x above 0.3
  - larger sea (e.g., ubar and dbar) quark uncertainties in large x region
  - with non-perturbative parametrization form dependence in small and large x regions
- PDF eigensets
  - useful for calculating PDF induced uncertainty
  - sensitive to some special (combination of) parton flavor(s).

  (e.g., eigenset 7 is sensitive to d/u or dbar/ubar; hence, W asymmetry data at Tevatron and LHC.)

CT10 NNLO PDFs

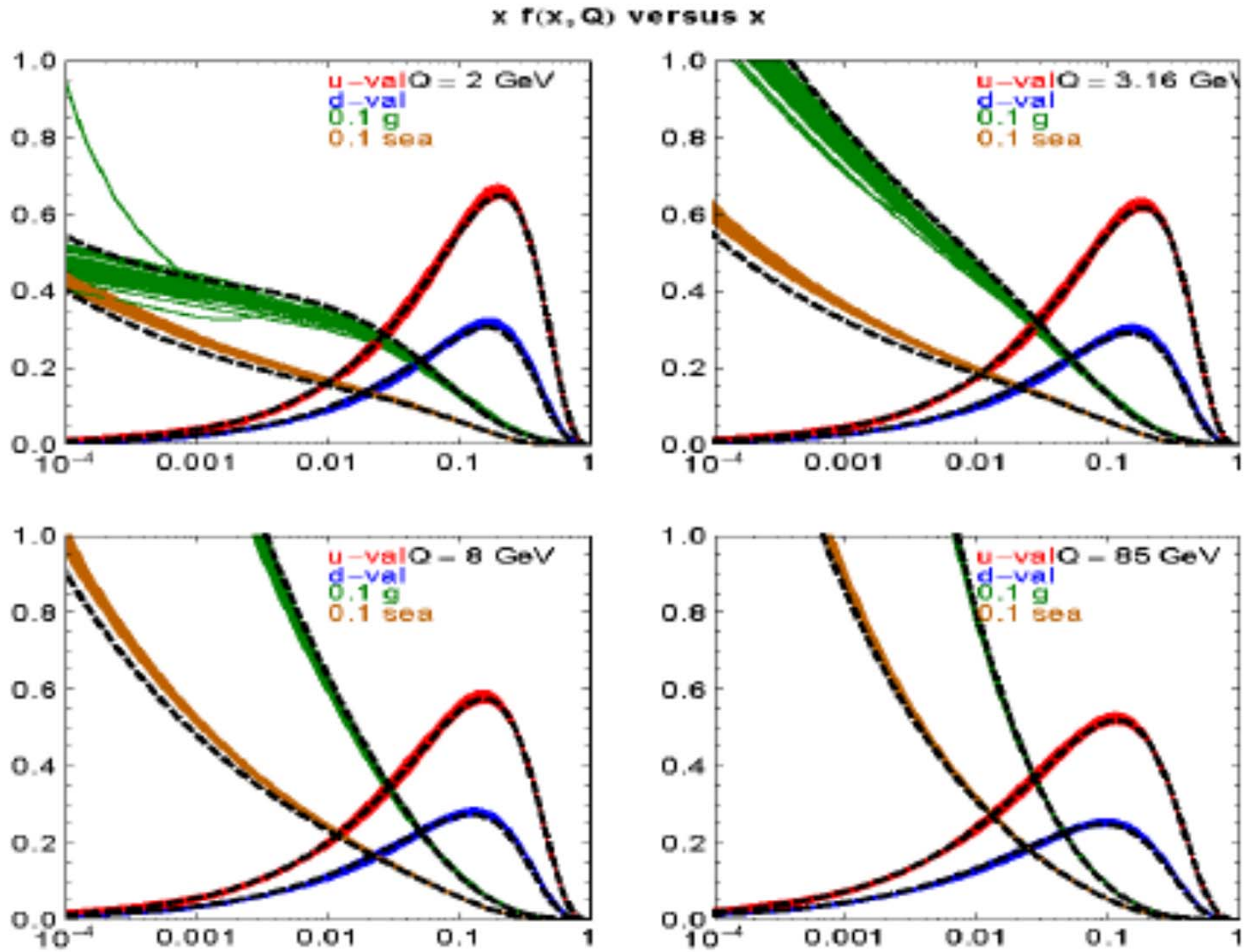
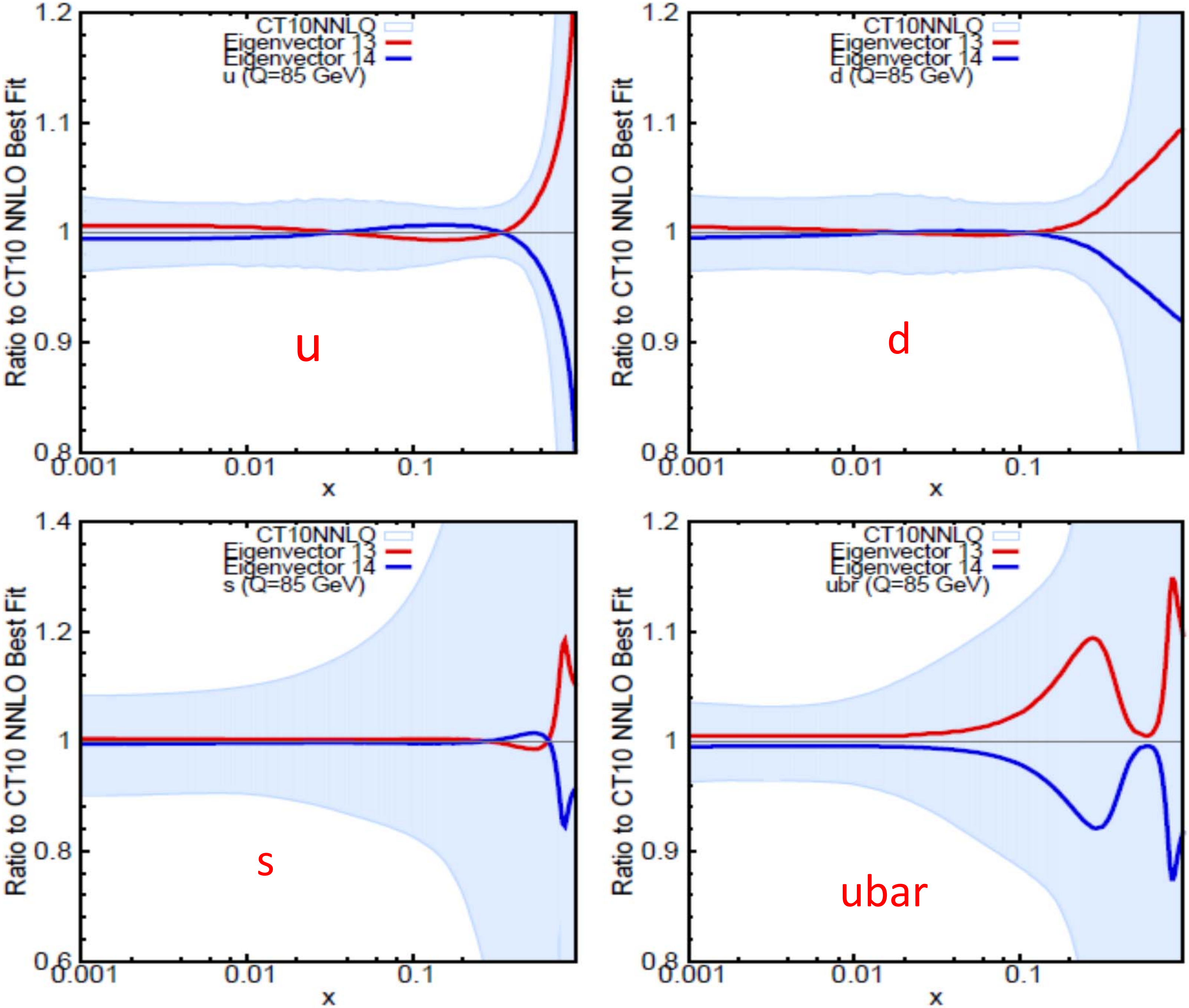
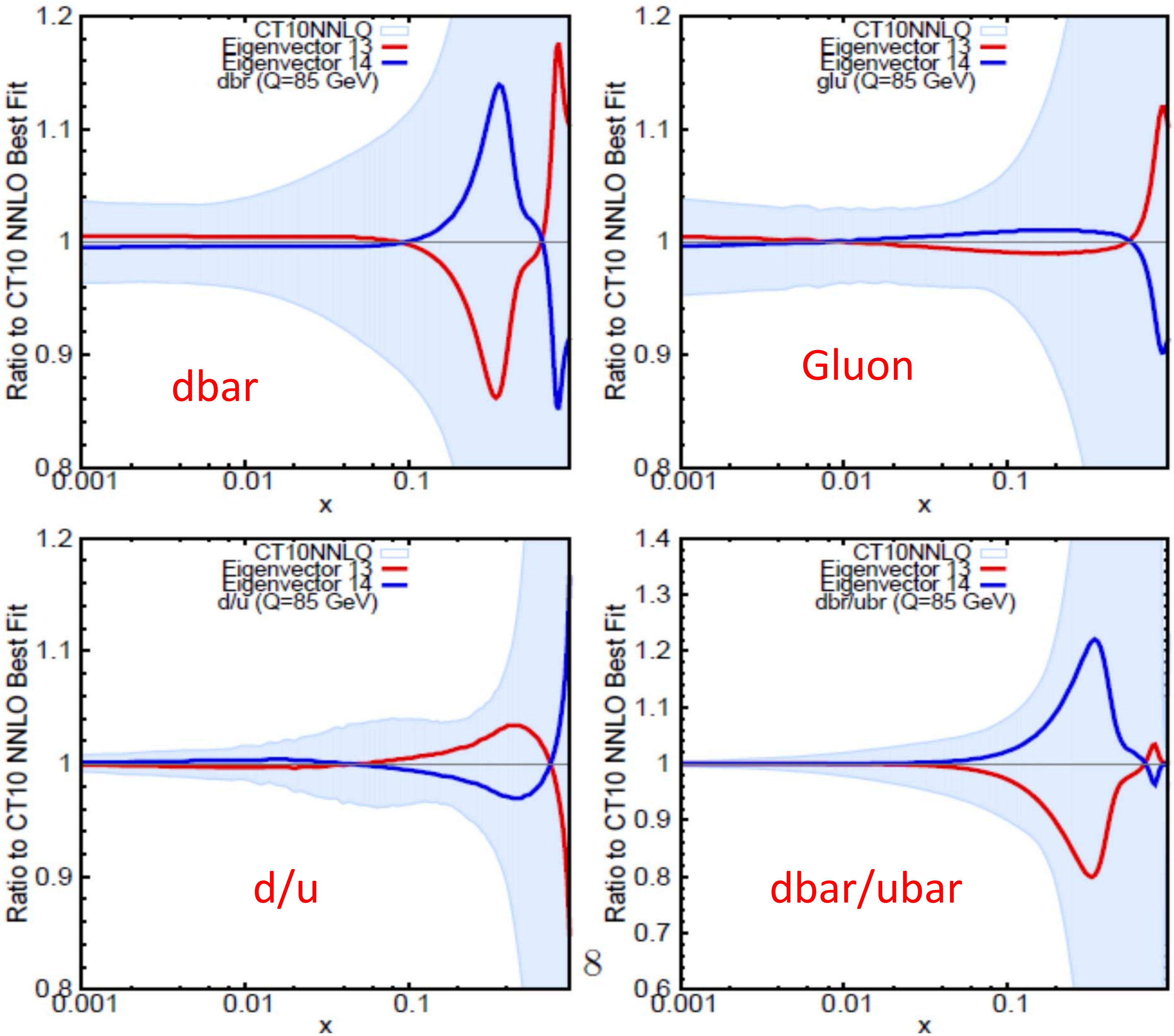


Figure 3: CT10-NNLO parton distribution functions. These figures show the *alternate fits* for the CT10-NNLO analysis. Each graph shows $x\,u_{\text{valence}} = x(u - \overline{u}), x\,d_{\text{valence}} = x(d - \overline{d}), 0.10\,x\,g$ and $0.10\,x\,\overline{q}$sea as functions of x for a fixed value of Q. The values of Q are $2, 3.16, 8, 85$ GeV. Sea $= 2(\overline{d} + \overline{u} + \overline{s})$. The dashed curves are the central NLO fit, CT10.

7th CT10 Eigenset



7th CT10 Eigenset



PDF luminosities

$$\sigma = \int dx_1 dx_2 \; g(x_1, M) g(x_2, M) \hat{\sigma}(M)$$

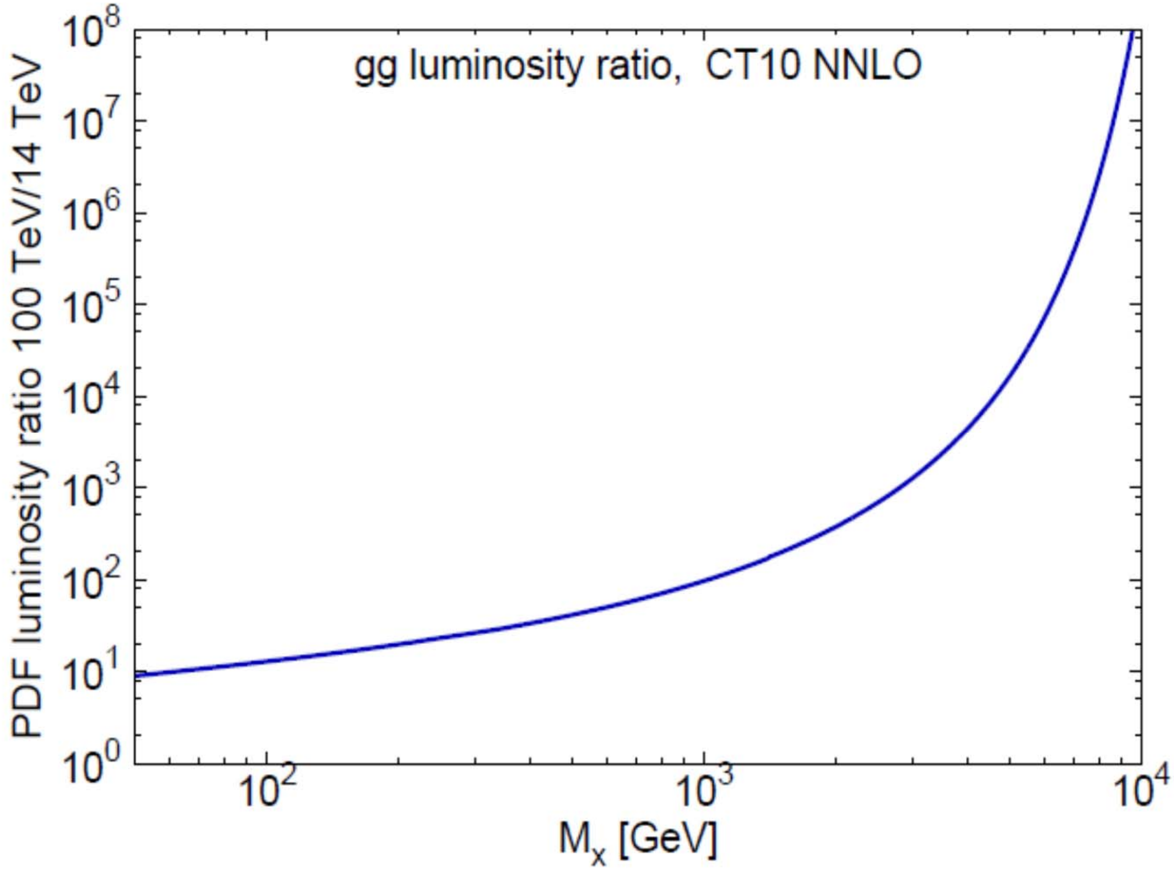
$$= \int d\tau dy \; g(x_1, M) g(x_2, M) \hat{\sigma}(M)$$

$$\equiv \int dM^2 \frac{dL}{dM^2} \hat{\sigma}(M)$$

PDF Luminosity

$$\tau = x_1 x_2$$

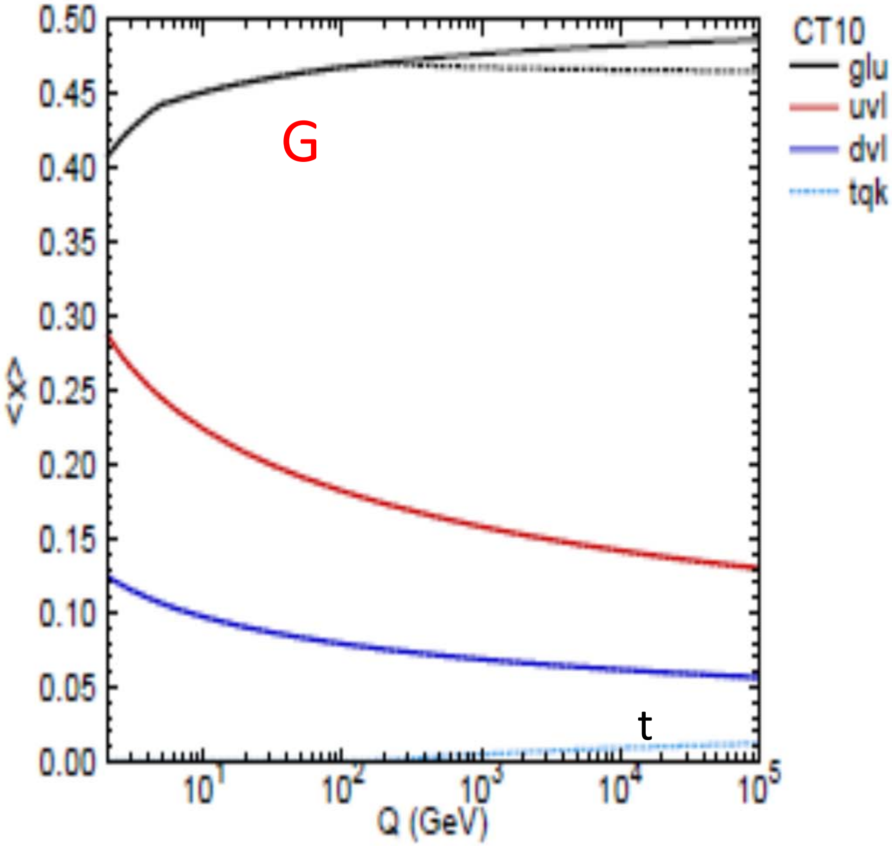
$$y = \frac{1}{2} \ln\left(\frac{x_1}{x_2}\right)$$

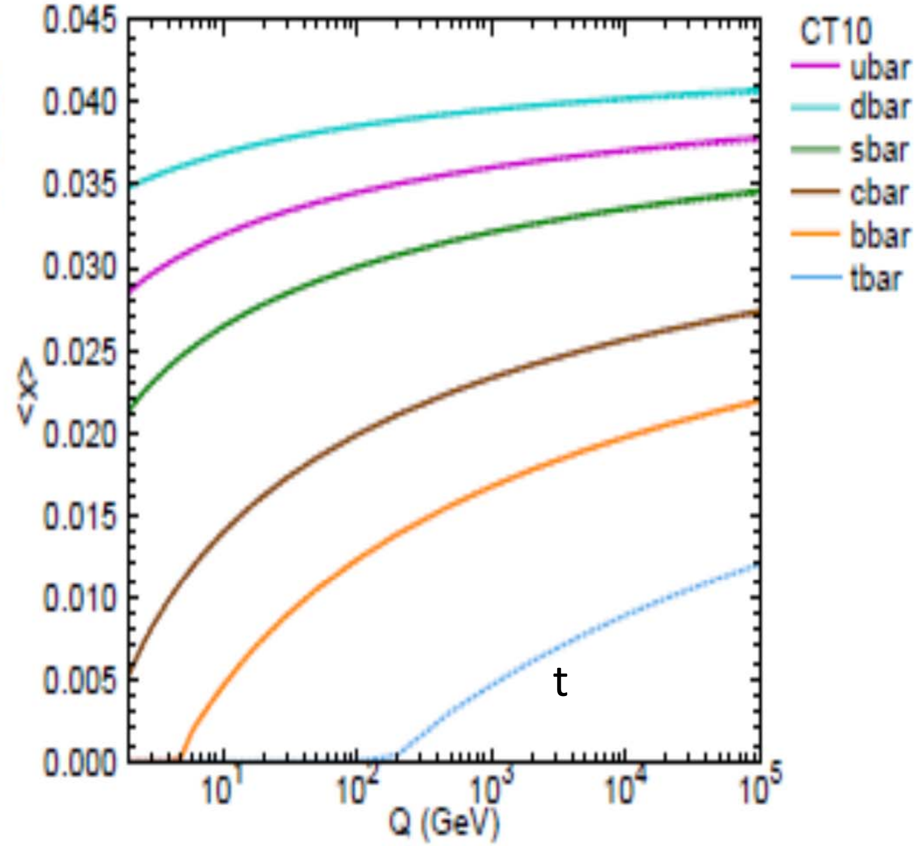


Top quark as a parton

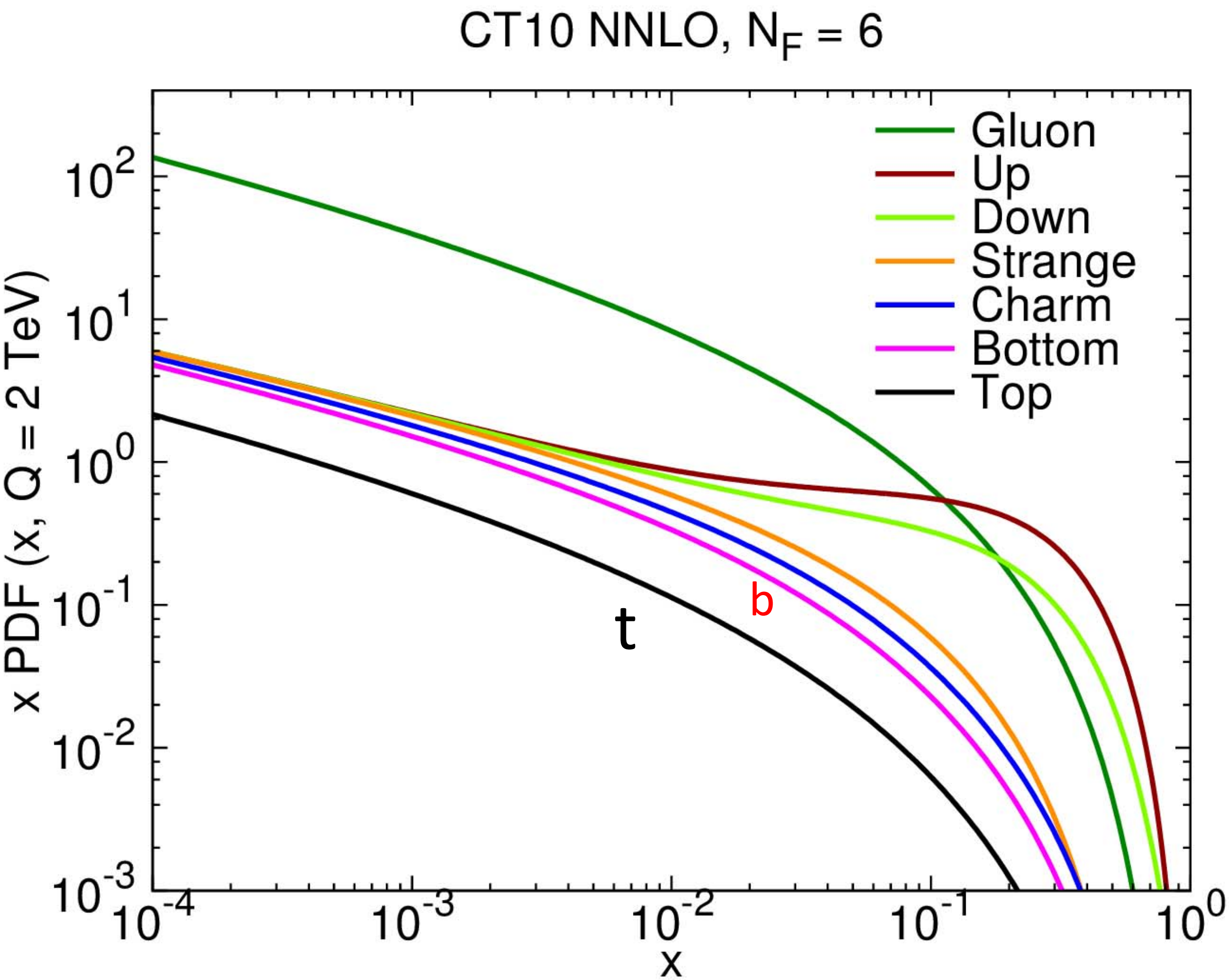
- For a 100 TeV SppC, top mass (172 GeV) can be ignored; top quark, just like bottom quark, can be a parton of proton.
- Top parton will take away some of the momentum of proton, mostly, from gluon (at NLO).
- Need to use s-ACOT scheme to calculate hard part matrix elements, to be consistent with CT10 PDFs.

Momentum fraction inside proton



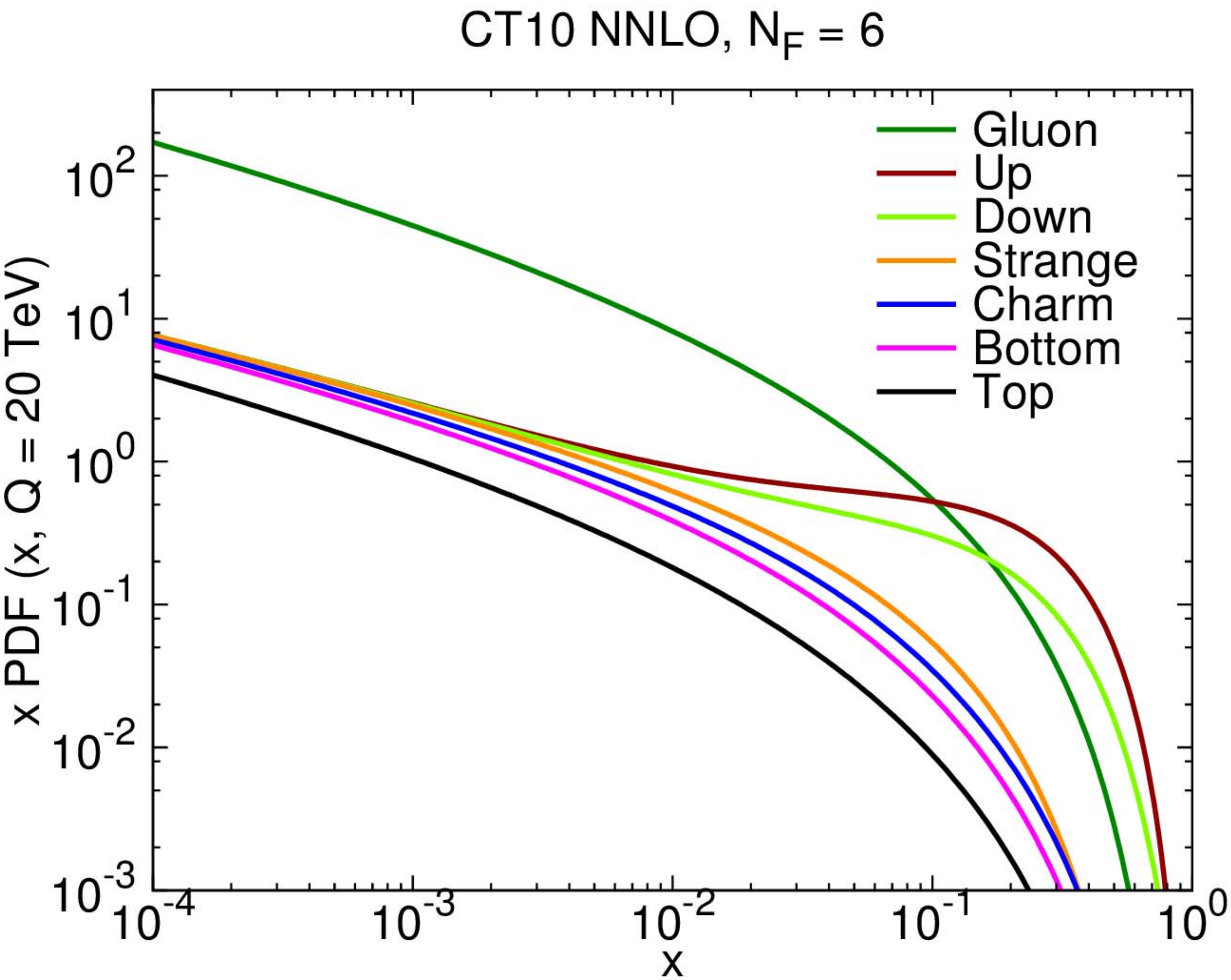


CT10 Top PDFs (Q=2 TeV)

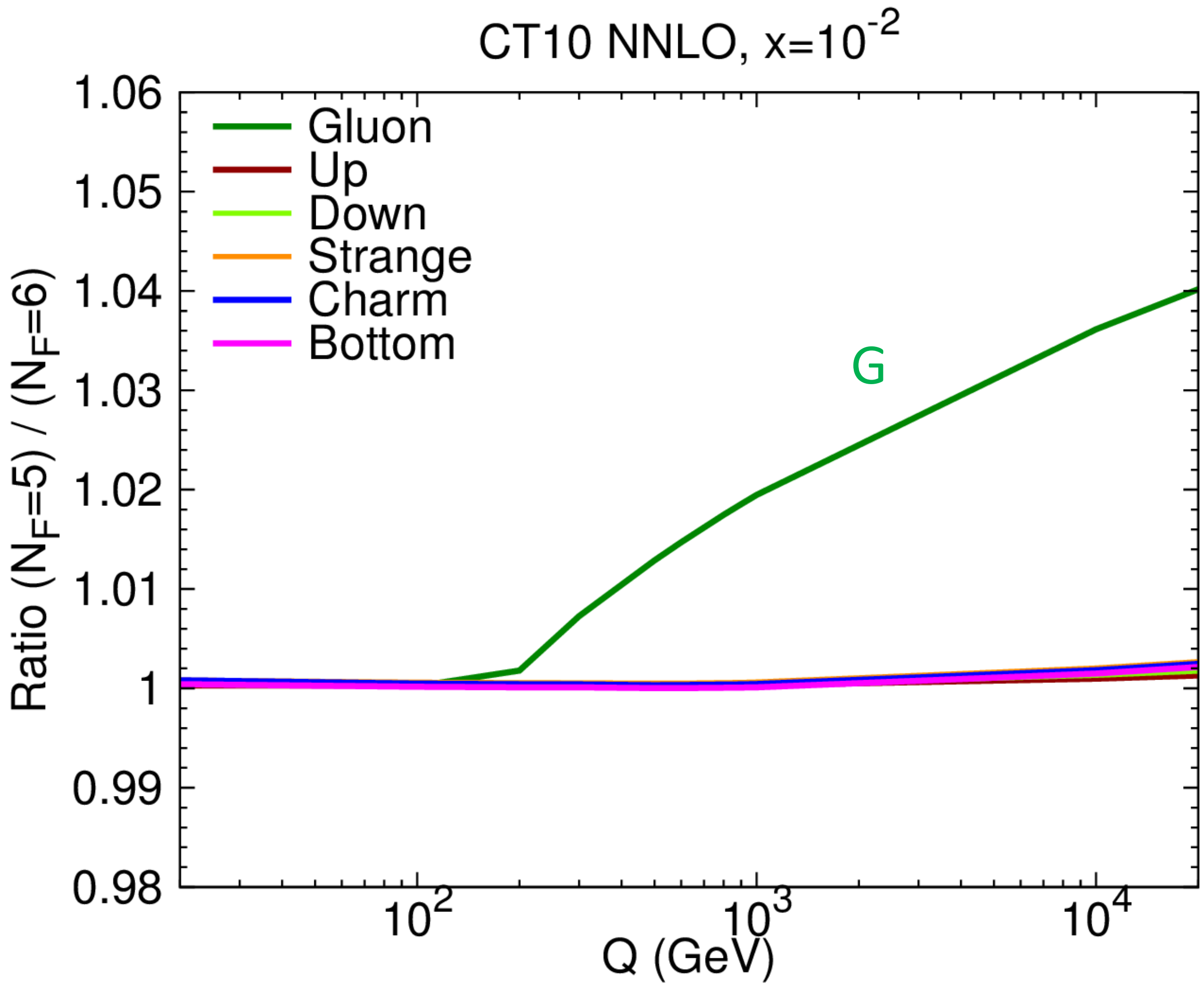


Top PDF is only a factor of 2 smaller than b PDF

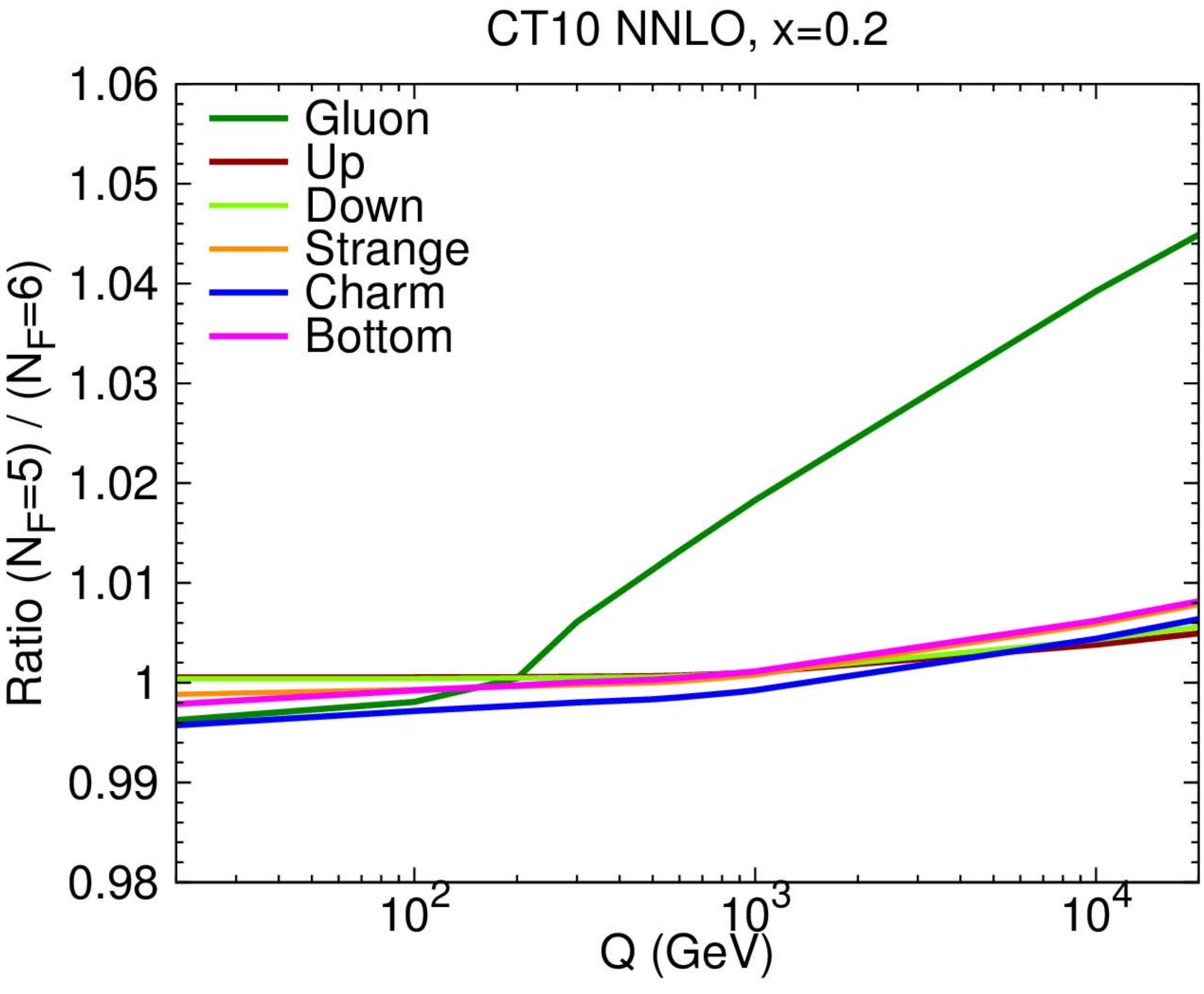
CT10 Top PDFs
(Q=20 TeV)



CT10Top PDFs

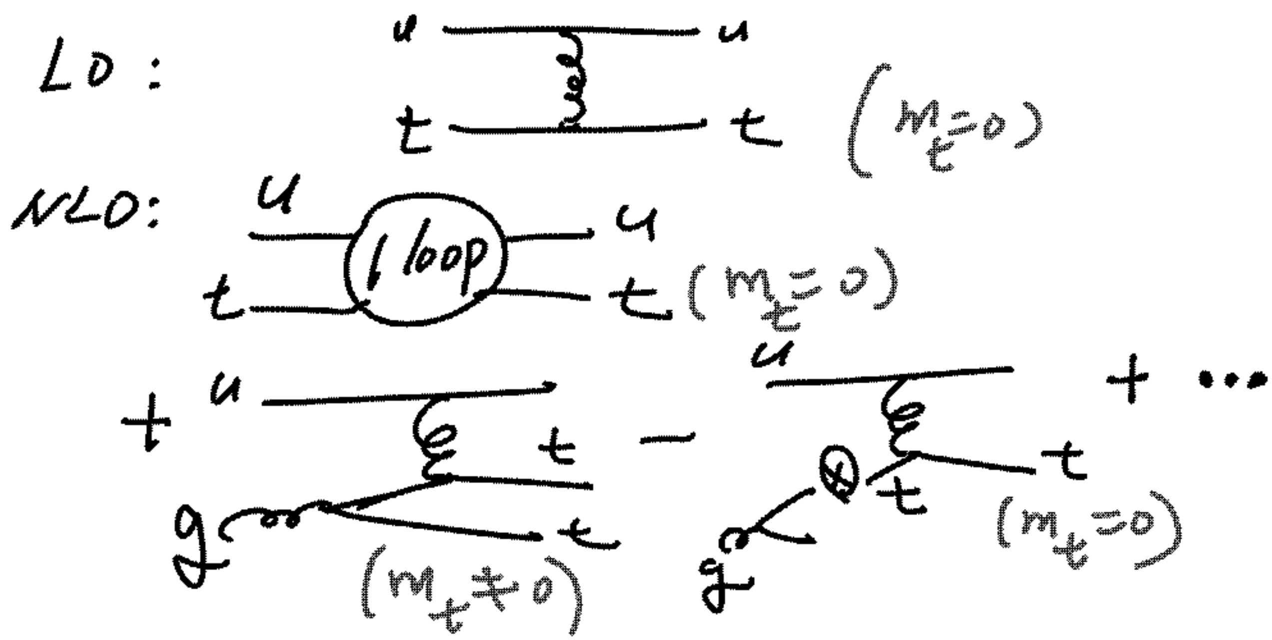


CT10Top PDFs



Hard part calculation

- S-ACOT scheme
- Example: single-top production



Summary

- PDFs have larger uncertainties in both small x and large x regions.
- PDFs will be further determined by LHC data.
- Photon can be treated as a parton inside proton.
- In a 100TeV SppC, top quark can be a parton of proton, consistent hard part calculations are needed.