Charged Current Charm Consortium(C^4)

Demonstration of xFitter with FFNS/VFNS and multi-scale predictions

Fred Olness
SMU

Thanks for substantial input
from my friends & colleagues

Probing the strange content of the proton with charm production in charged current at LHeC

In development

Xfitter Development Team: ...

Some observations on Charm CC:
... based on work by Fred & Aleksander (Olek) Kusina et al.,
arXiv:1306.6553 Phys.Rev. D88 (2013) no.7, 074032

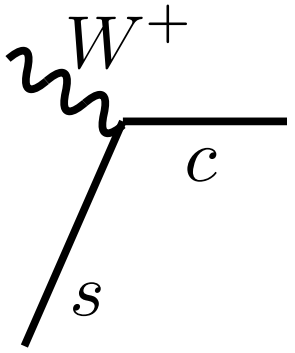
xFitter Workshop
Minsk
18-20 March 2019

Contents

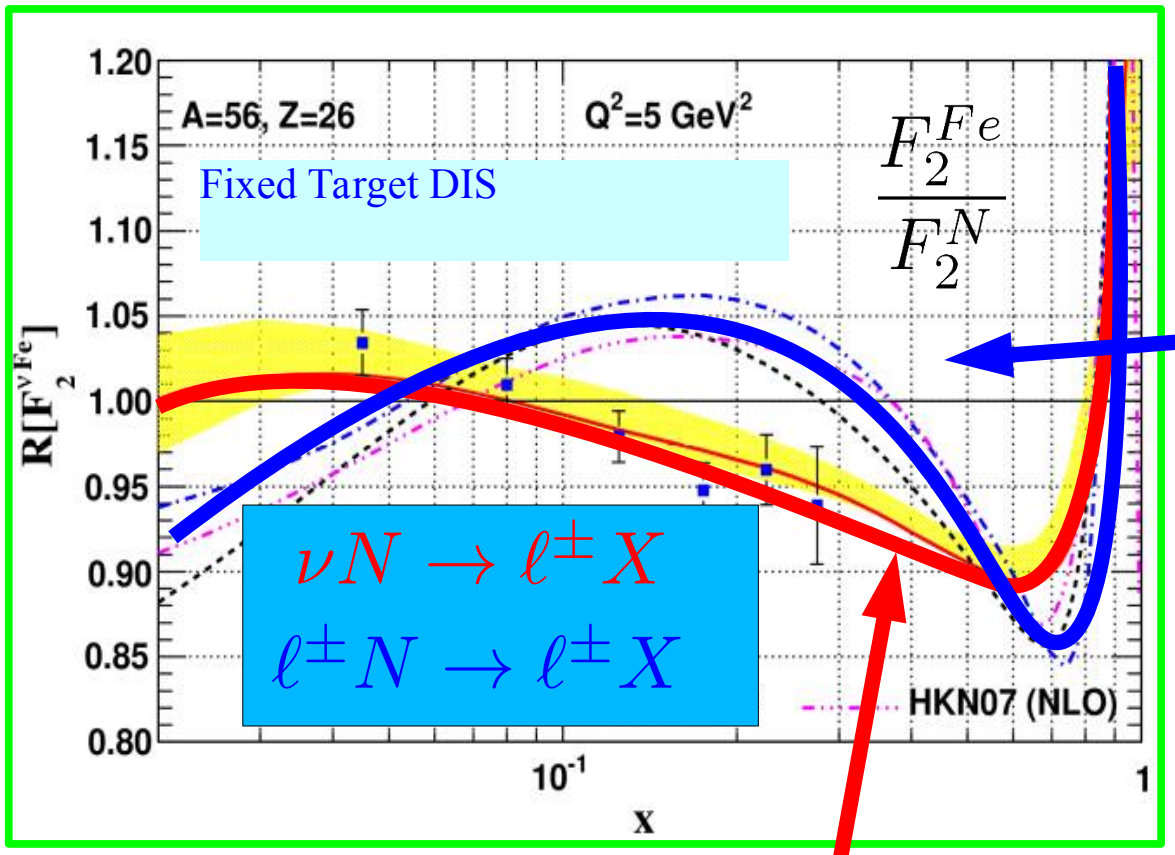
The CC Charm Production at the LHeC

A way to get to s(x)

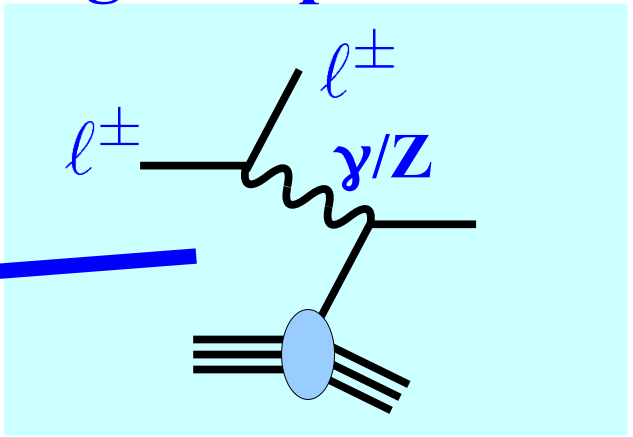
A multi-scale problem {m_s,m_c}



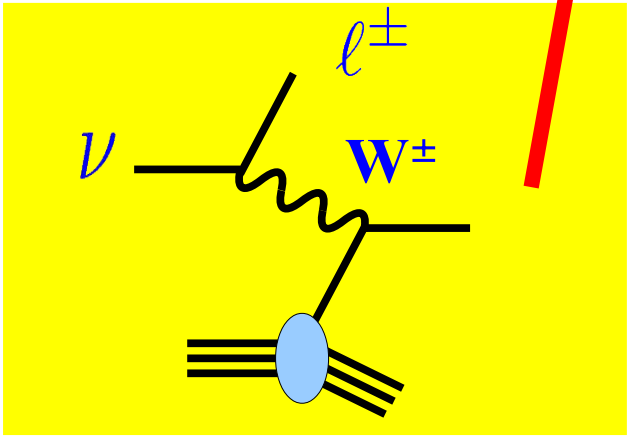
Age Old Puzzle: What is the strange quark PDF ???



Charged Lepton DIS

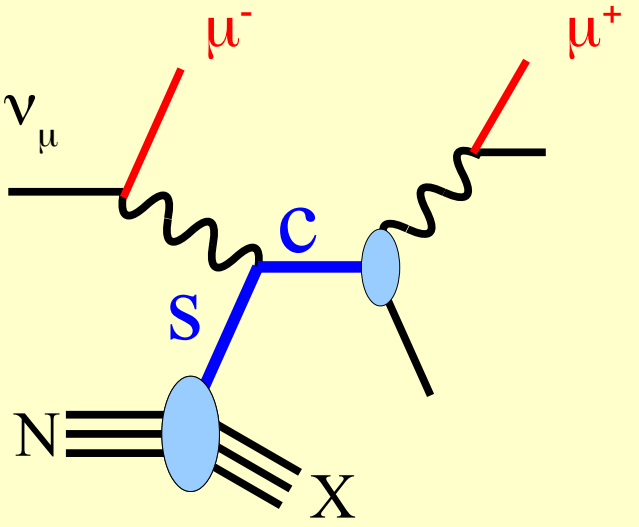


some caveats
... correlated errors

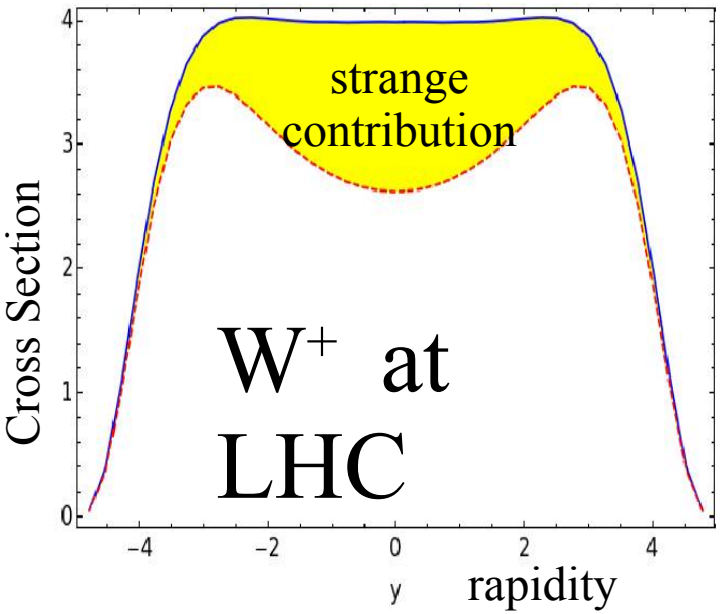


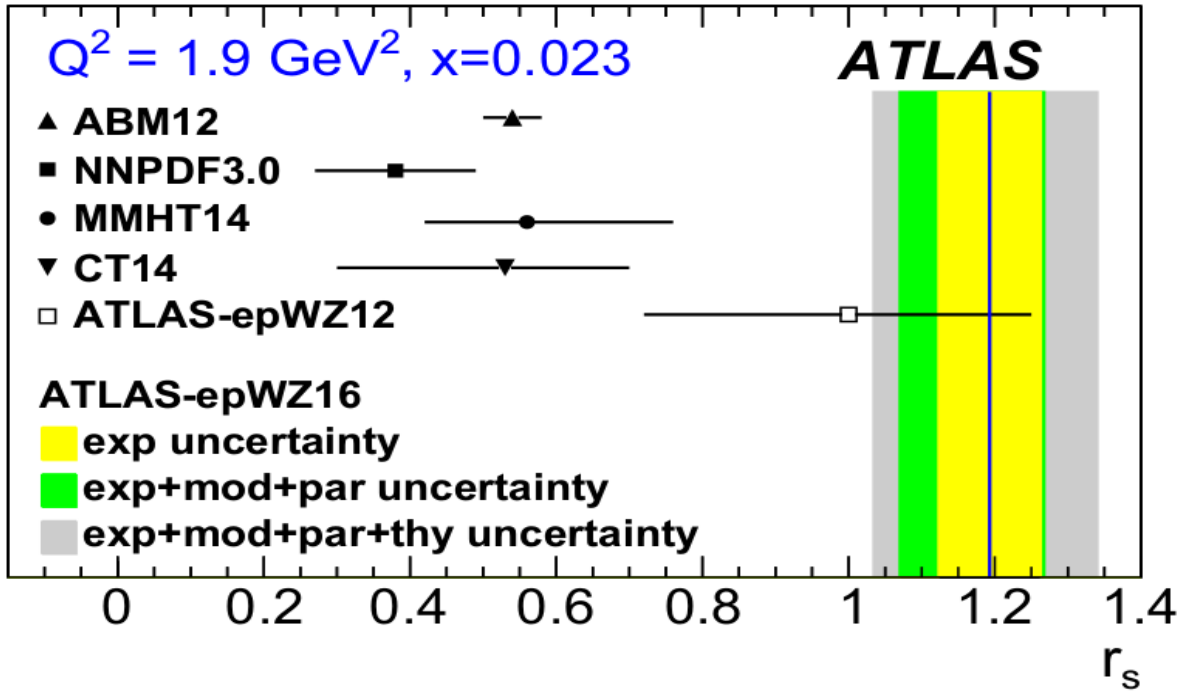
Neutrino DIS

Extract s(x)



$$u\bar{d} + u\bar{\mathbf{s}} + \mathbf{c}\bar{d} + \mathbf{c}\bar{\mathbf{s}} \rightarrow W^+$$
$$\bar{u}d + \bar{u}\mathbf{s} + \bar{\mathbf{c}}d + \bar{\mathbf{c}}\mathbf{s} \rightarrow W^-$$
$$u\bar{u} + d\bar{d} + \mathbf{s}\bar{\mathbf{s}} + \mathbf{c}\bar{\mathbf{c}} \rightarrow Z$$





$$r^s(x,Q) = \frac{\bar{s}(x,Q) + s(x,Q)}{2\bar{d}(x,Q)}$$

Do it yourself!!!
Try **xFitter**

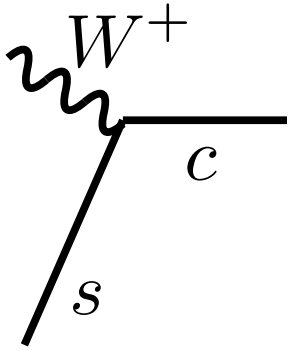
ATLAS: Eur. Phys. J. C 77 (2017) 367

2018 CTEQ School Tutorial

The CC Charm Production at the LHeC

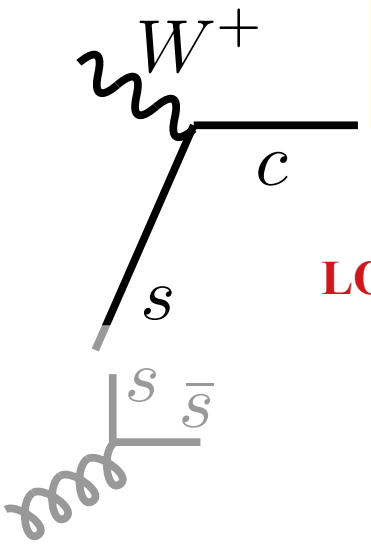
How do we compute it ???

Contrast FFNS vs. VFNS



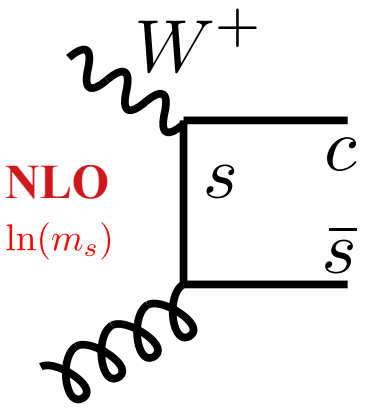
t-channel

VFNS



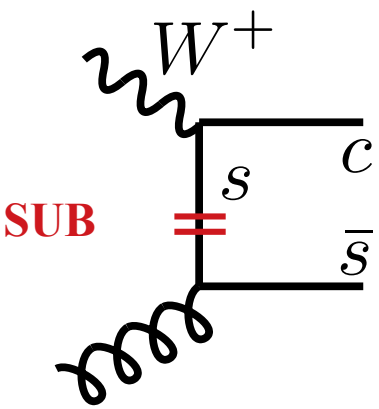
$f_s \otimes \sigma_{sW^+ \to c}$

gluon initiated



$f_s \otimes \sigma_{gW^+ \to c\bar{s}}$

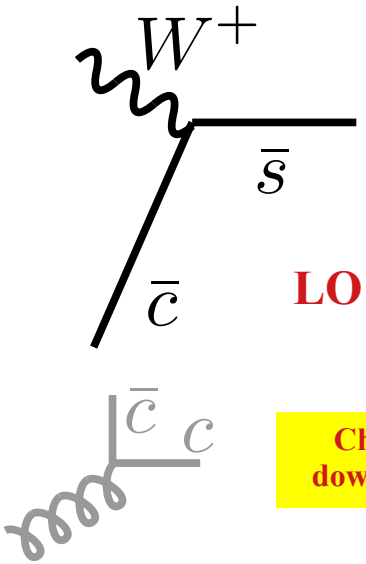
gluon initiated



$\mathcal{P} \sim \ln(m_s)$

$f_g \otimes \mathcal{P}_{g \to s} \otimes \sigma_{sW^+ \to c}$

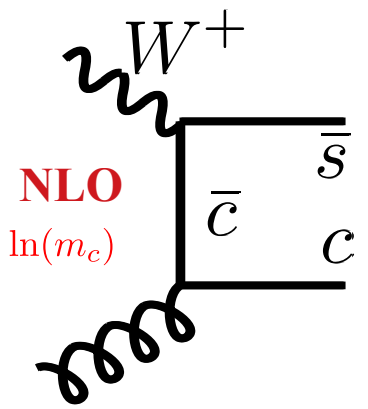
u-channel



Charm goes down beampipe

$f_{\bar{c}} \otimes \sigma_{\bar{c}W^+ \to \bar{s}}$

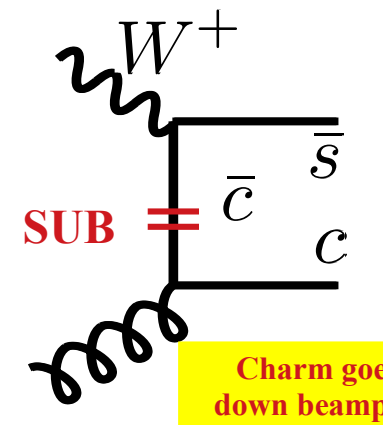
gluon initiated



F_2^c define carefully

$f_g \otimes \sigma_{gW^+ \to \bar{s}c}$

gluon initiated

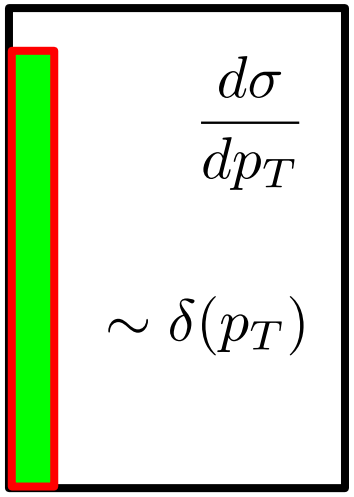


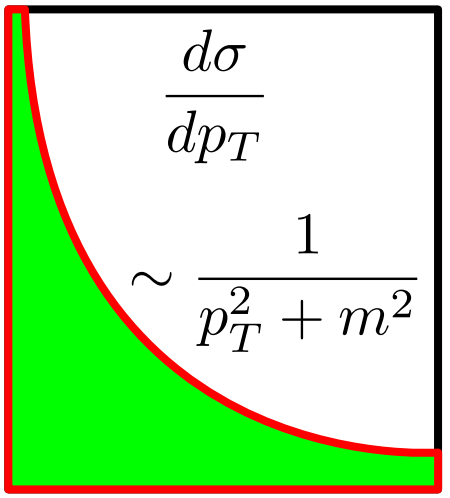
Charm goes down beampipe

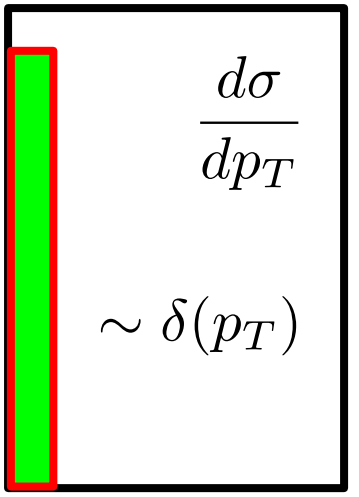
$\mathcal{P} \sim \ln(m_c)$

$f_g \otimes \mathcal{P}_{g \to \bar{c}} \otimes \sigma_{\bar{c}W^+ \to \bar{s}}$

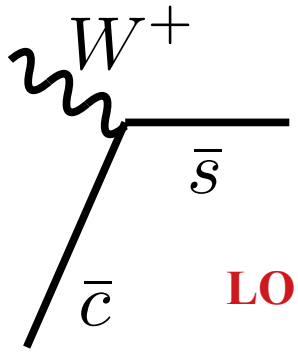
Look in P_T Space



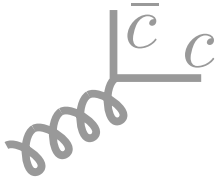




u-channel



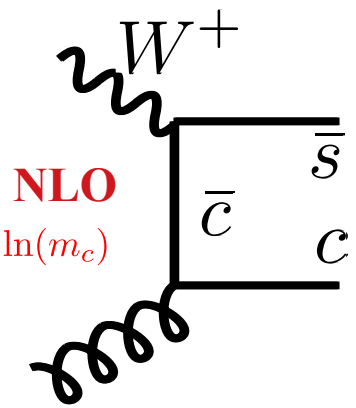
LO



Charm goes down beampipe

$f_{\bar{c}} \otimes \sigma_{\bar{c}W^+ \to \bar{s}}$

gluon initiated



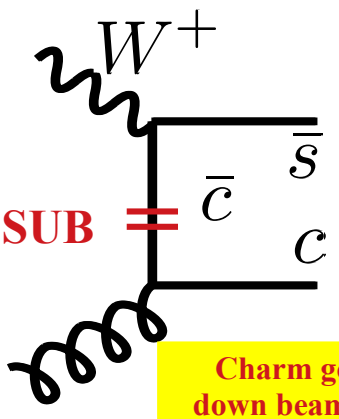
NLO

$\ln(m_c)$

F_2^c **define carefully**

$f_g \otimes \sigma_{gW^+ \to \bar{s}c}$

gluon initiated



SUB

Charm goes down beampipe

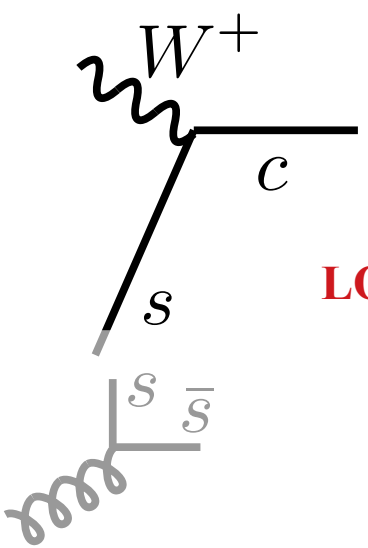
$\mathcal{P} \sim \ln(m_c)$

$f_g \otimes \mathcal{P}_{g \to \bar{c}} \otimes \sigma_{\bar{c}W^+ \to \bar{s}}$

What if there is no Charm PDF ???

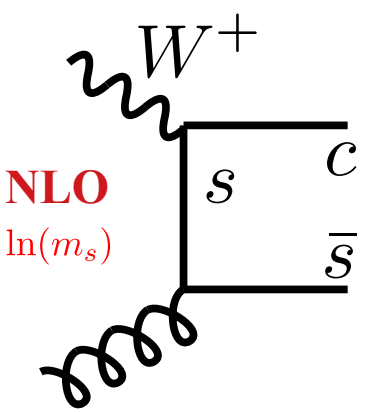
t-channel

FFNS



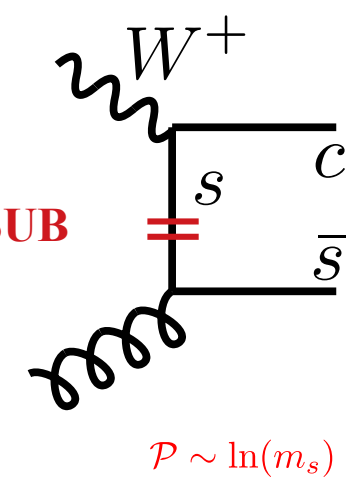
$f_s \otimes \sigma_{sW^+ \to c}$

gluon initiated



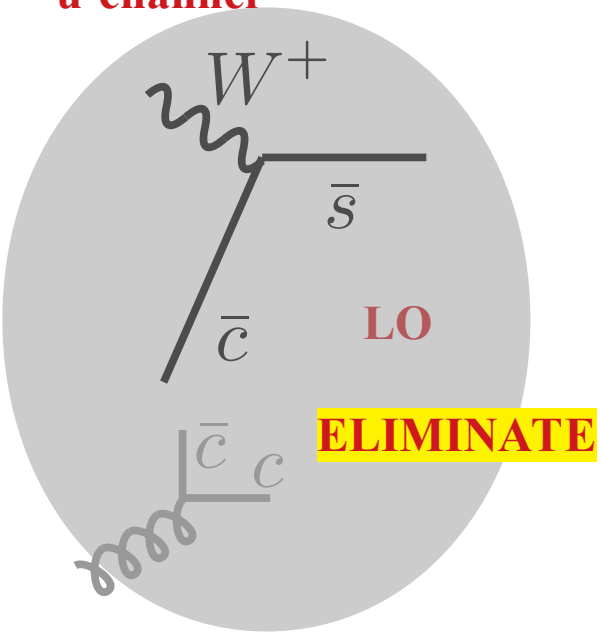
$f_s \otimes \sigma_{gW^+ \to c\bar{s}}$

gluon initiated



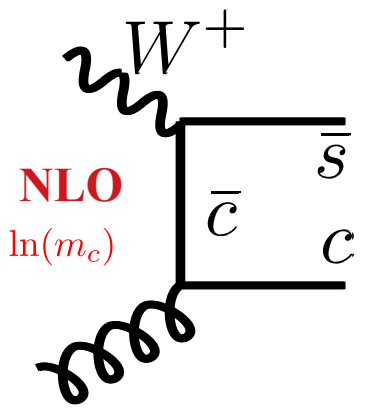
$f_g \otimes \mathcal{P}_{g \to s} \otimes \sigma_{sW^+ \to c}$

u-channel



$f_{\bar{c}} \otimes \sigma_{\bar{c}W^+ \to \bar{s}}$

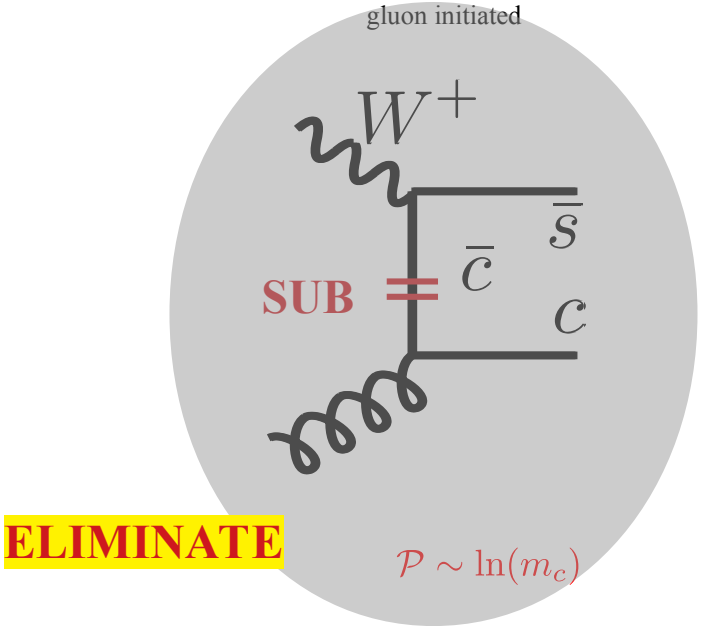
gluon initiated



Divergent
$\alpha_s \ln(m/\mu)$

$f_g \otimes \sigma_{gW^+ \to \bar{s}c}$

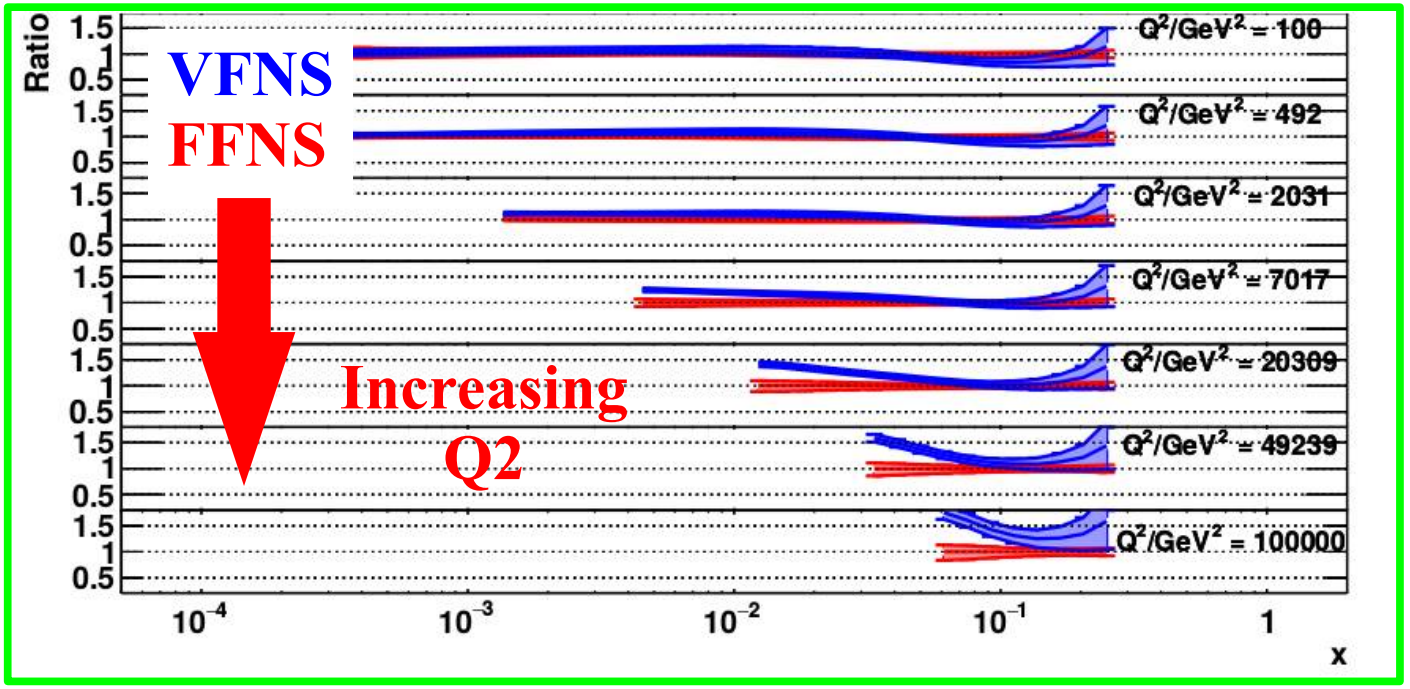
gluon initiated

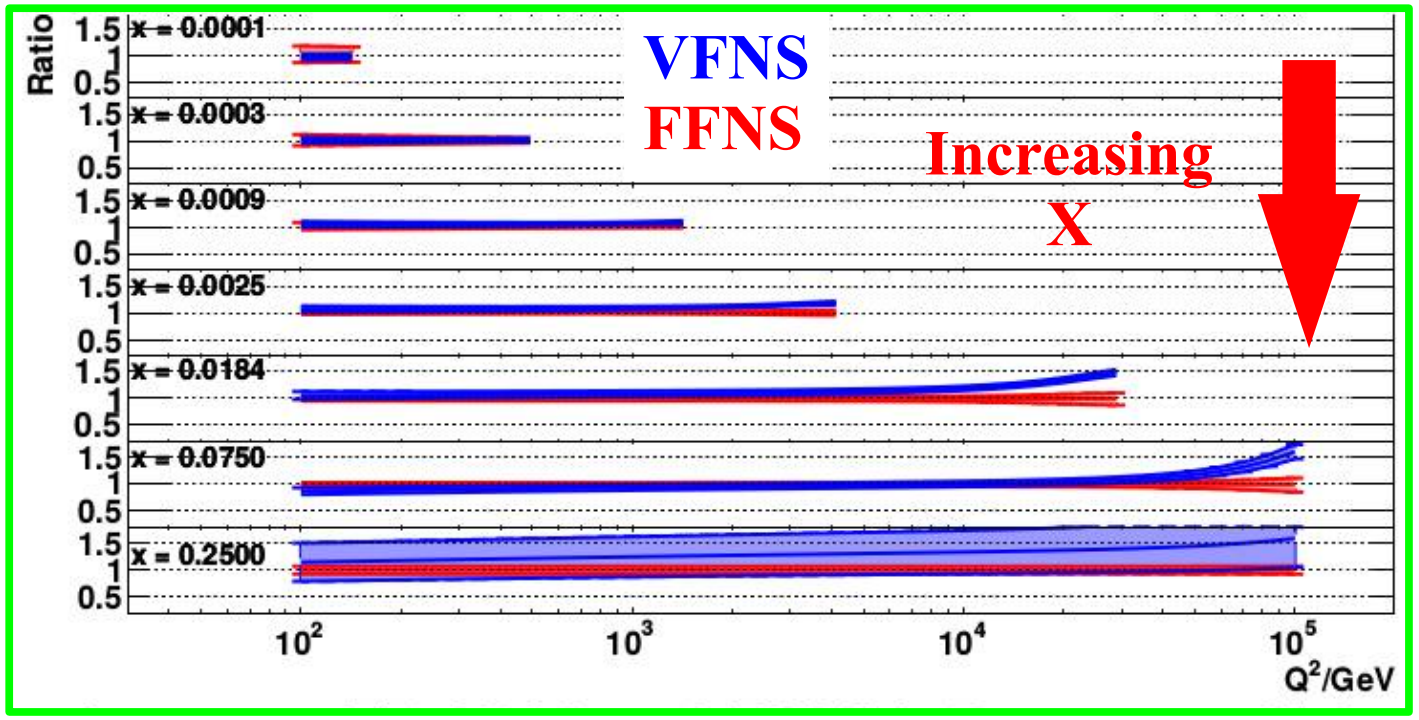


$f_g \otimes \mathcal{P}_{g \to \bar{c}} \otimes \sigma_{\bar{c}W^+ \to \bar{s}}$

Let's look at some limits…

Hi Q^2, Hi x





Ratio Plot:
VFNS
FFNS

Observations:

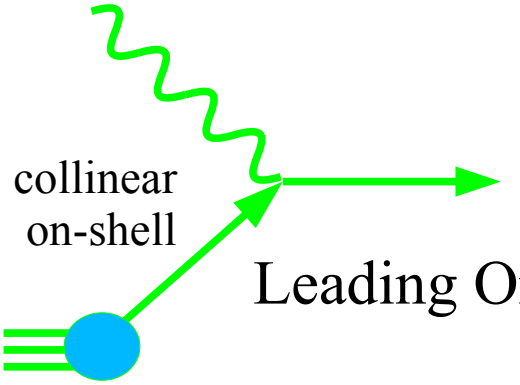
They differ at

i) large Q^2

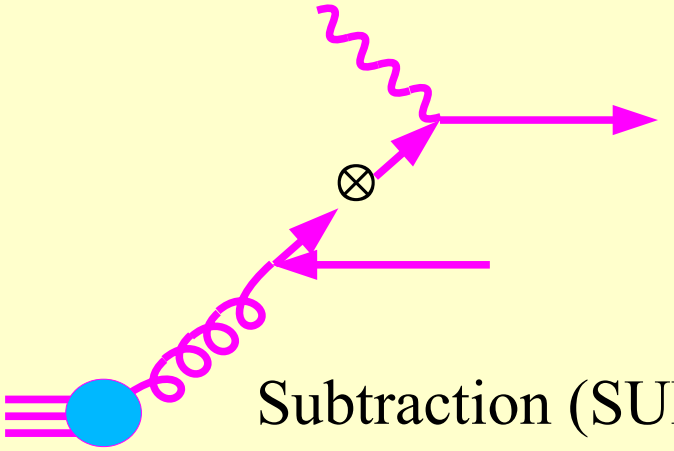
ii) large X

Source of the large Q difference

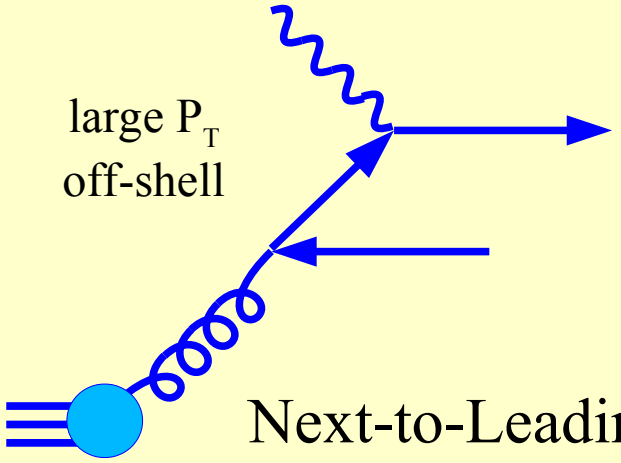
TOT = LO + NLO - SUB



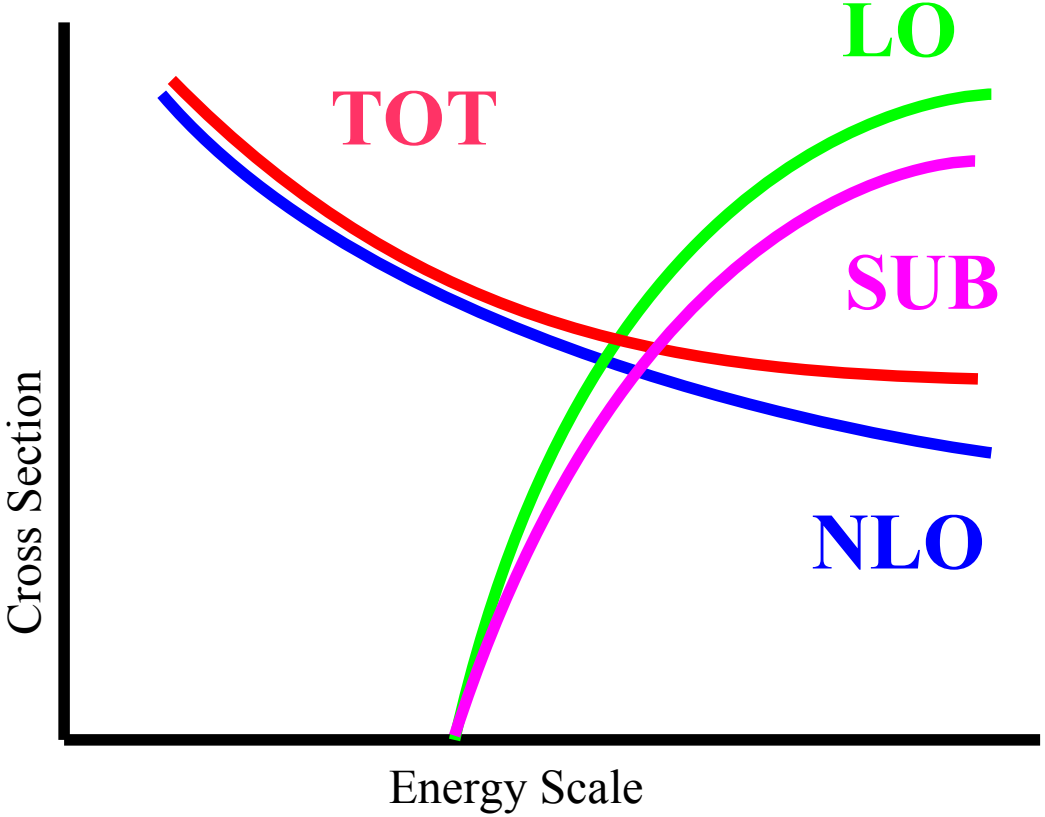
Leading Order (LO)



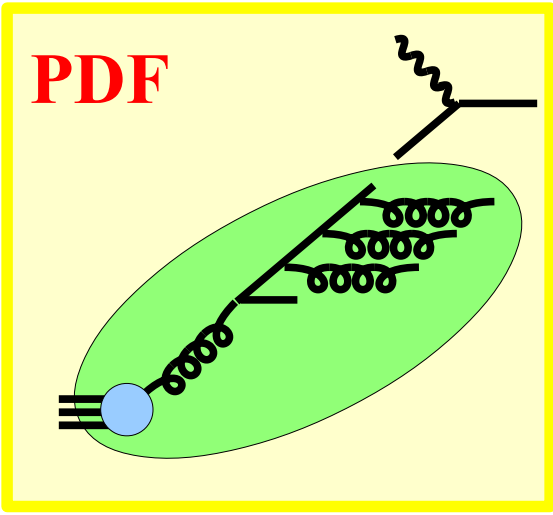
Subtraction (SUB)



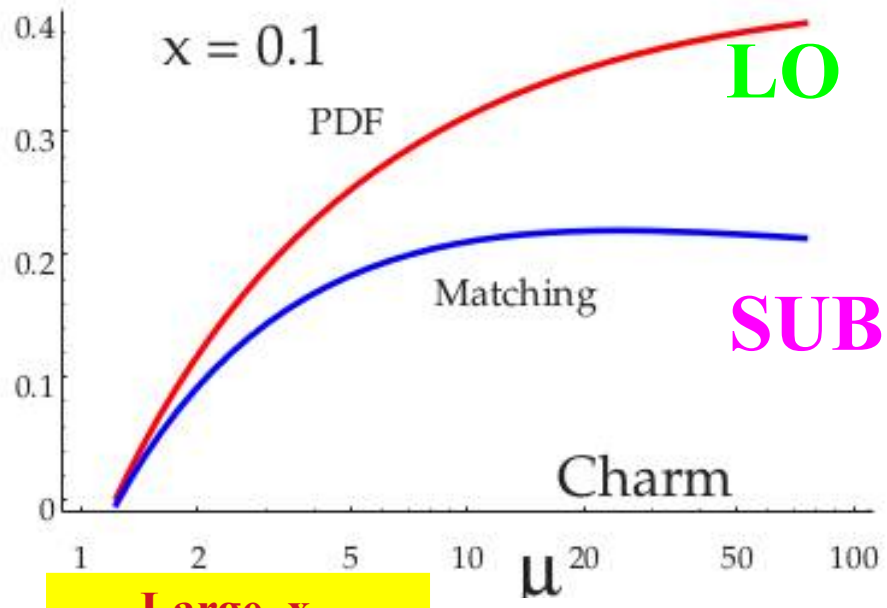
Next-to-Leading Order (NLO)

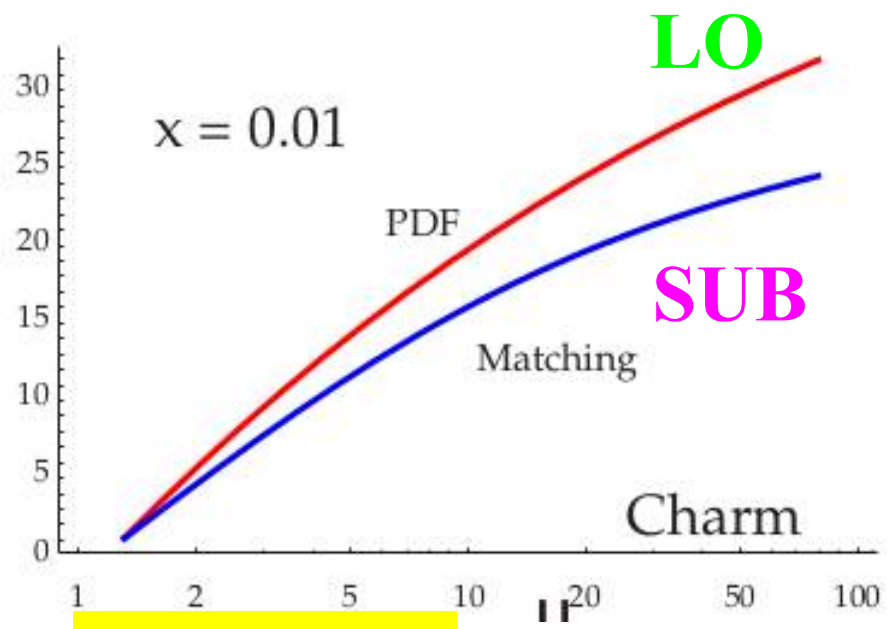


At large scales, PDF resummation becomes important!!!

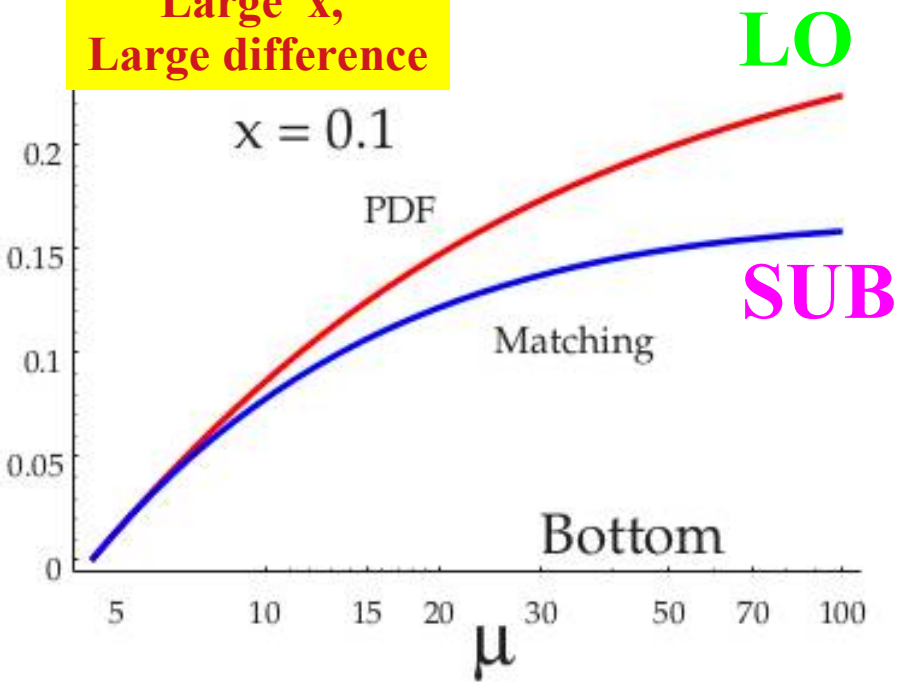


Source of the large X difference

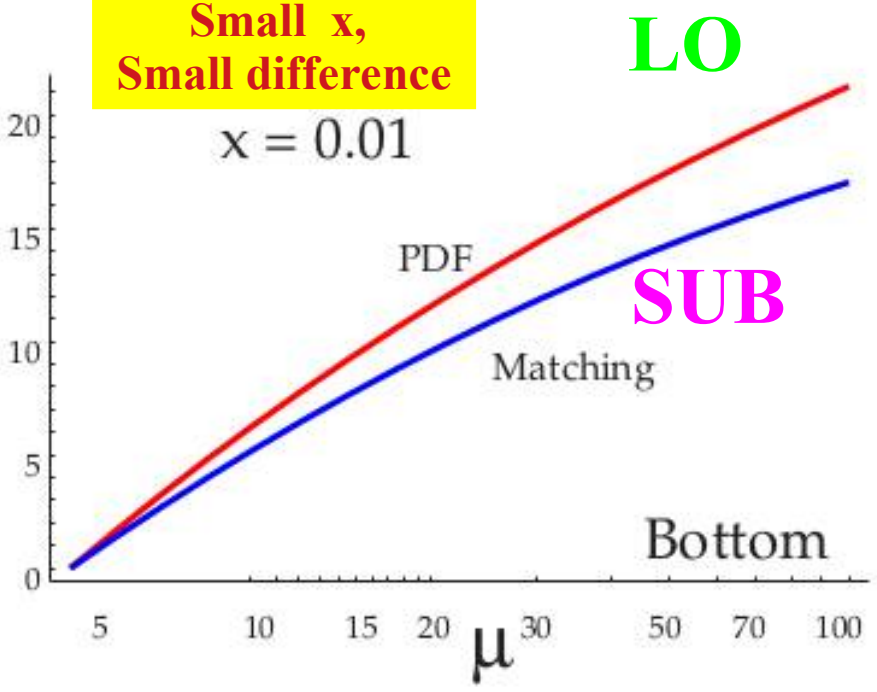




Large x, Large difference



Small x, Small difference

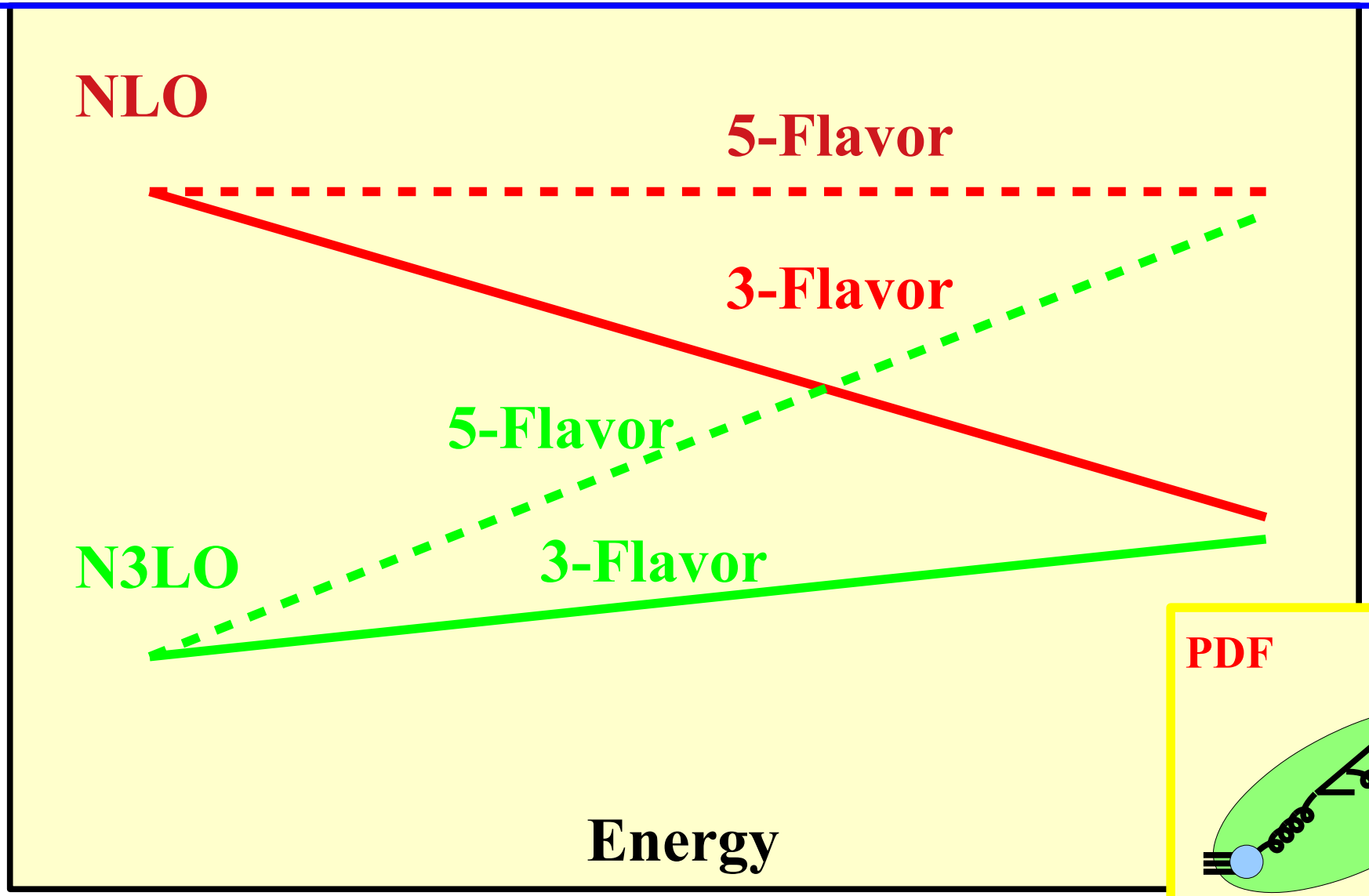


When must we switch to VFNS?

One measure, when the difference between FFNS and VFNS is larger than the higher order correction.

Some observations on Charm CC:
... based on work by Fred & Aleksander (Olek) Kusina et al.,
arXiv:1306.6553 Phys.Rev. D88 (2013) no.7, 074032

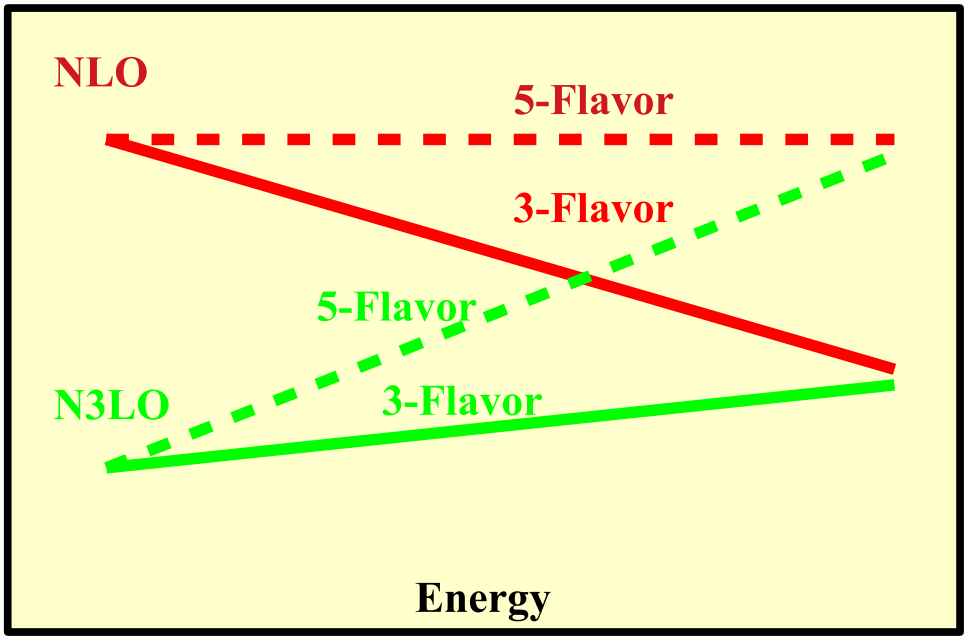
Limits: from low to high scales



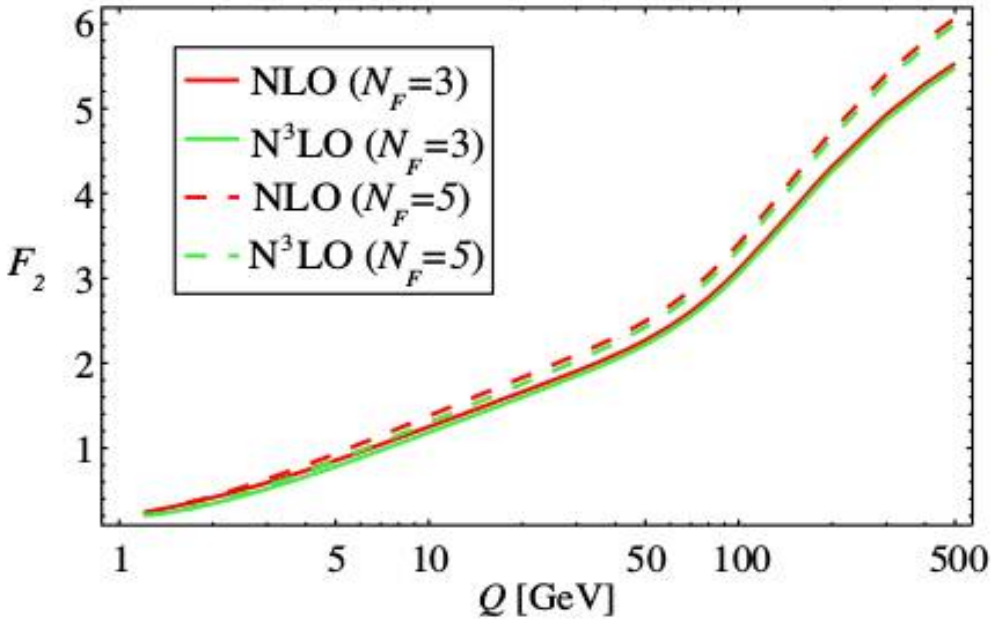
Low Energy:
3 & 5 Flavor match
(c & b PDFs = 0)

Hi Energy:
NLO & N3LO match
($\alpha_s \sim 0$)

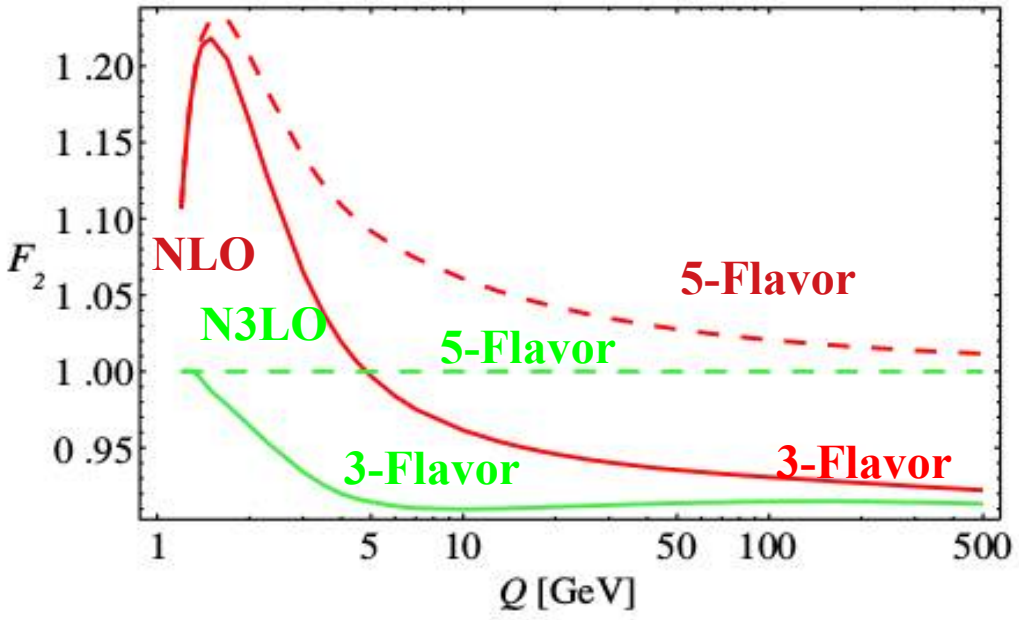
Low Energy:
3 & 5 Flavor match
(c & b PDFs = 0)

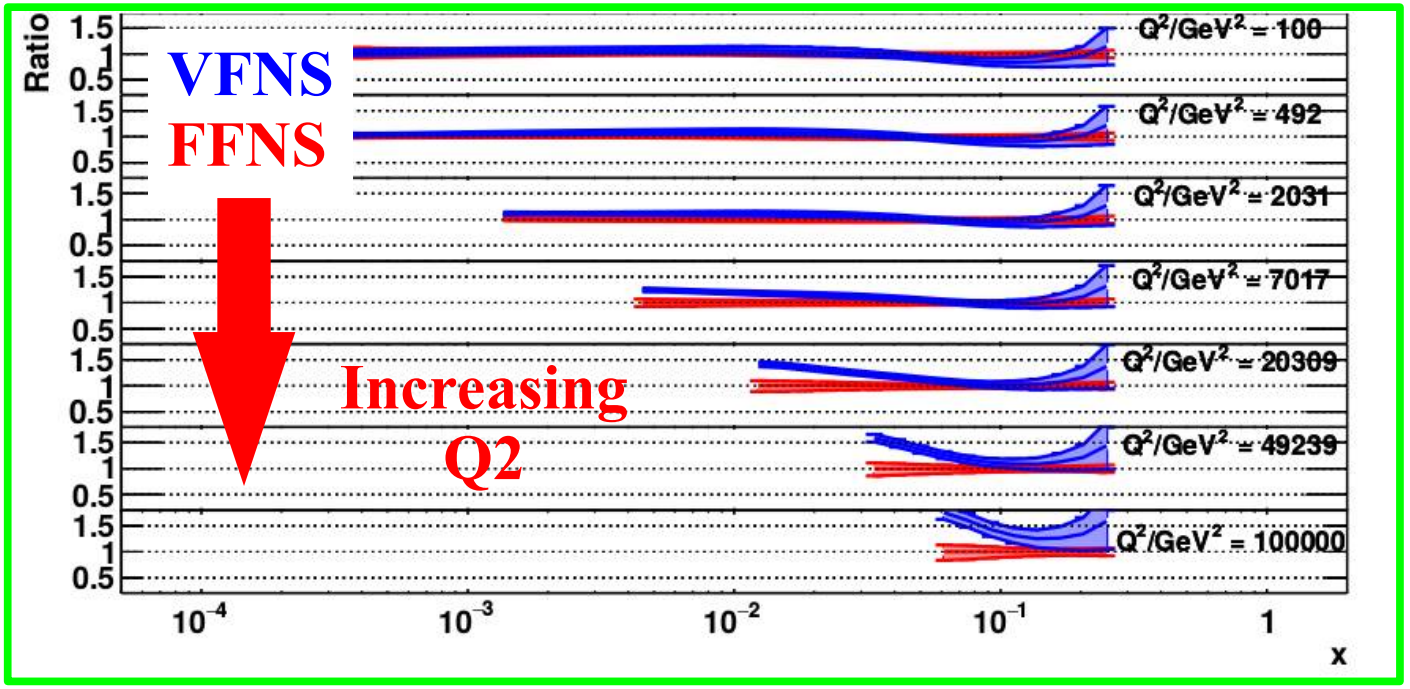


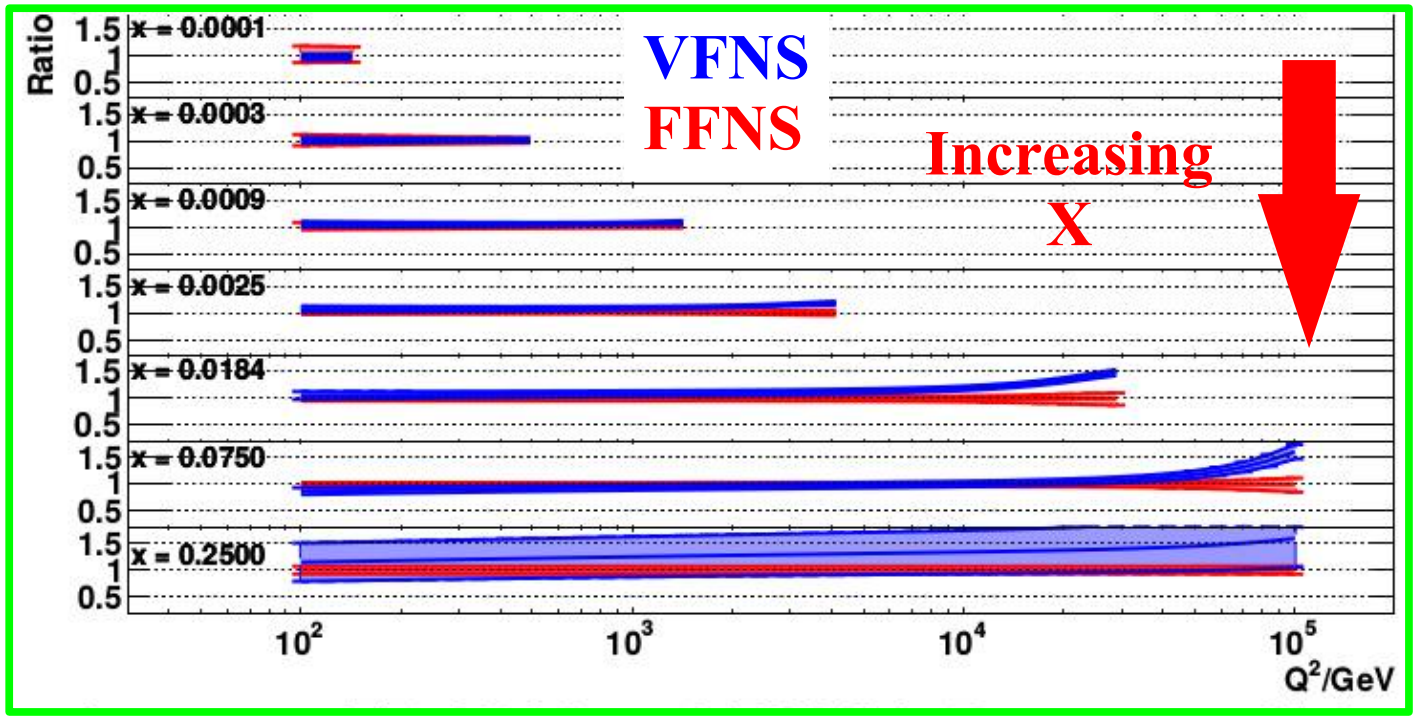
Hi Energy:
NLO & N3LO match
($\alpha_s \sim 0$)



Hybrid scheme for heavy flavors: Merging the fixed flavor number scheme and variable flavor number scheme
A. Kusina, [arXiv:1306.6553] Phys.Rev. D88 (2013) no.7, 074032







Ratio Plot:
VFNS
FFNS

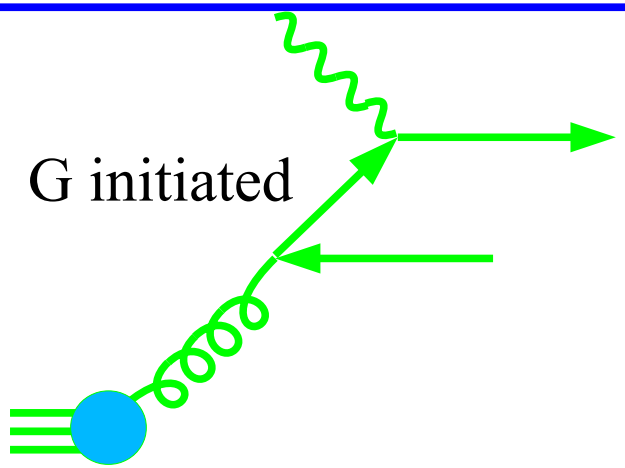
Observations:

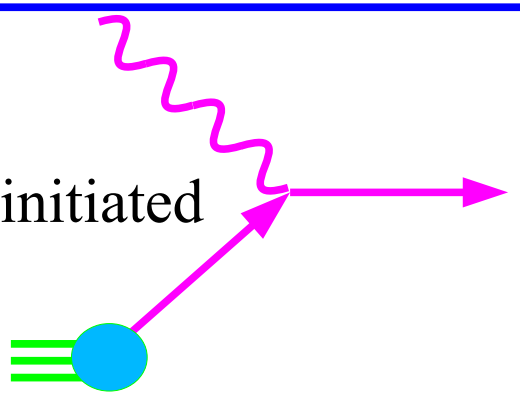
They differ at

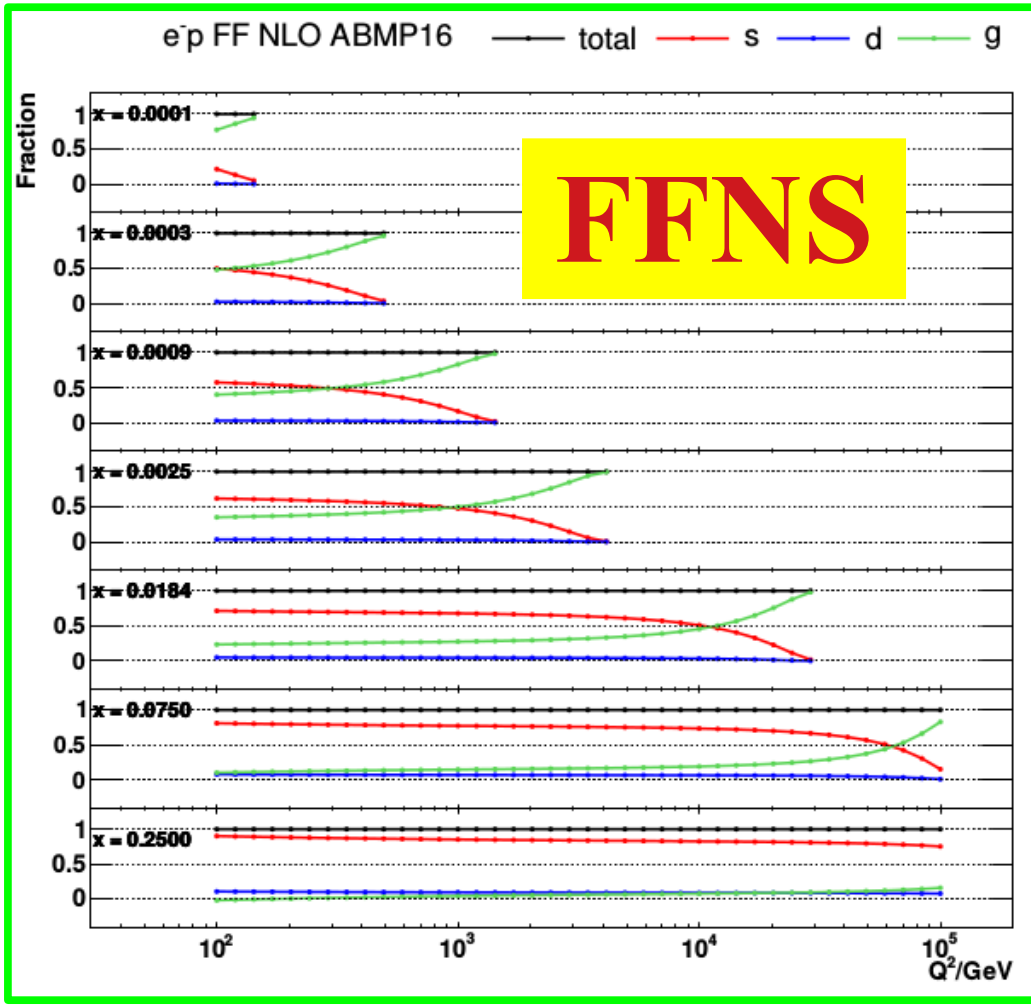
i) large Q^2

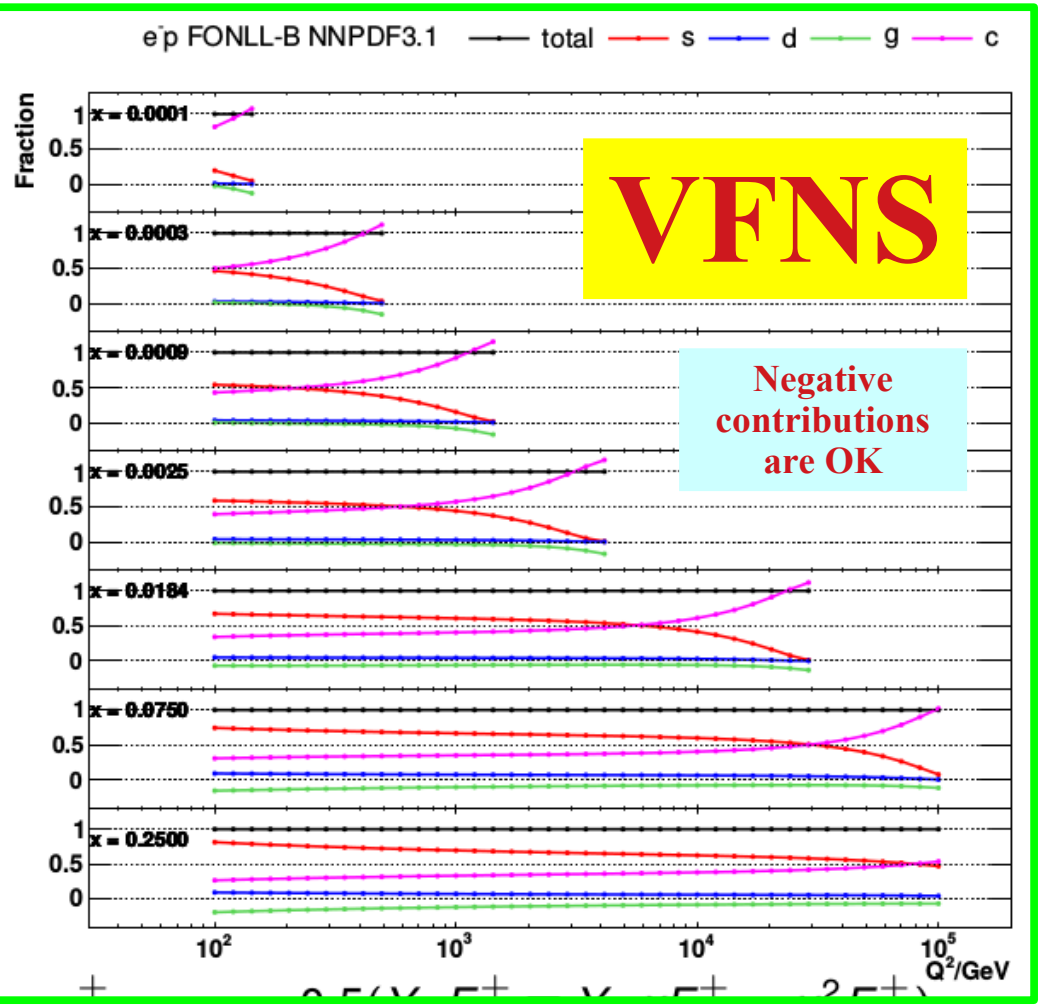
ii) large X

Gluon & Charm Initiated Contributions


G initiated


C initiated

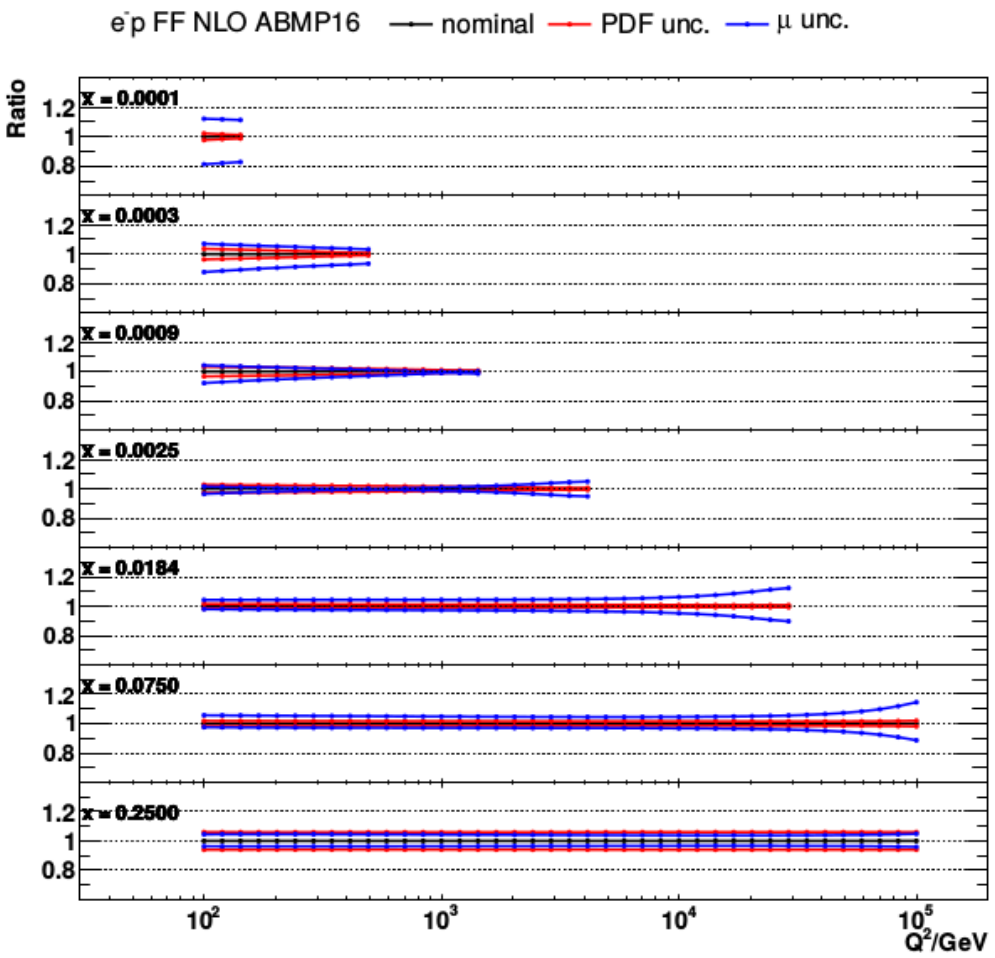

e⁻p FF NLO ABMP16
total
s
d
g
Fraction
x = 0.0001
x = 0.0003
x = 0.0009
x = 0.0025
x = 0.0184
x = 0.0750
x = 0.2500
FFNS
10²
10³
10⁴
10⁵
Q²/GeV

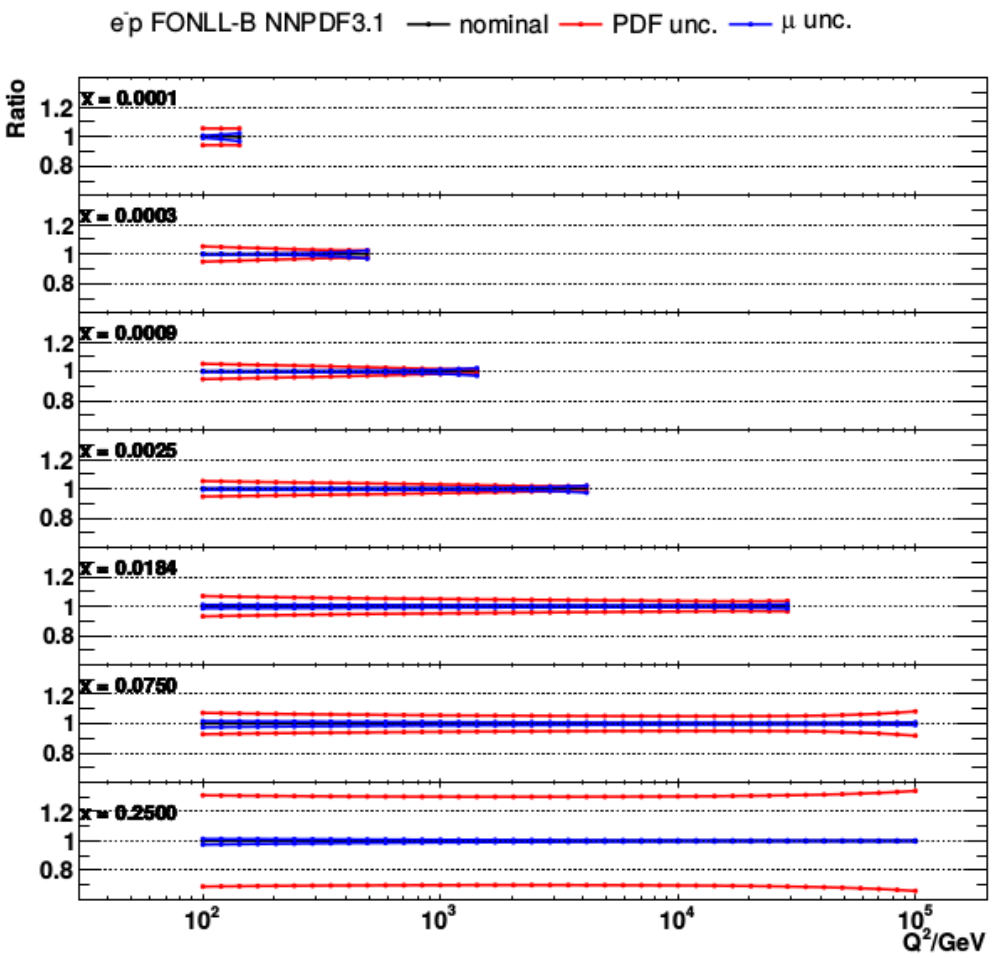

e⁻p FONLL-B NNPDF3.1
total
s
d
g
c
Fraction
x = 0.0001
x = 0.0003
x = 0.0009
x = 0.0025
x = 0.0184
x = 0.0750
x = 0.2500
VFNS
Negative contributions are OK
10²
10³
10⁴
10⁵
Q²/GeV

Uncertainties: PDF & μ

variations

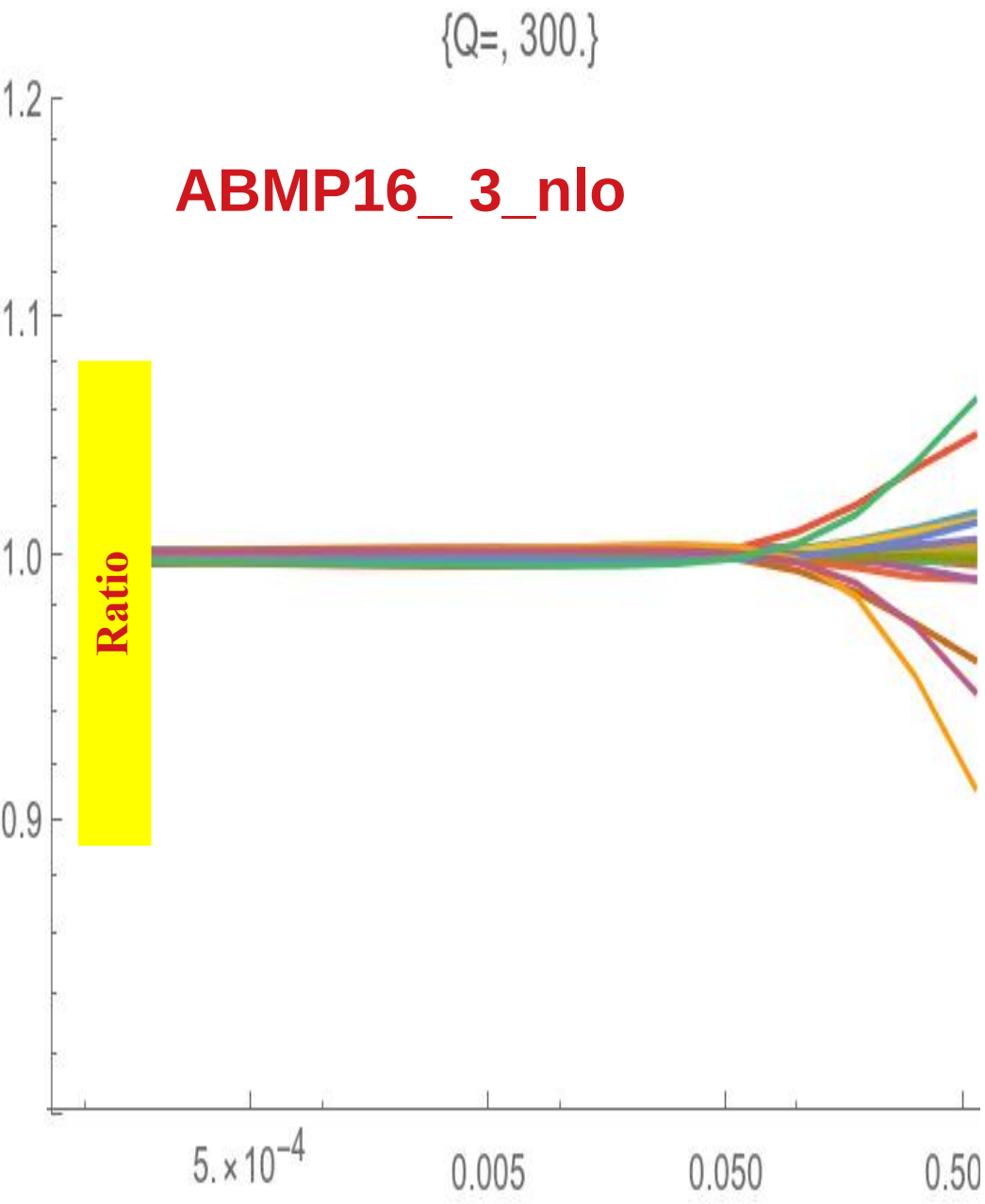
Theoretical uncertainties: Q^2

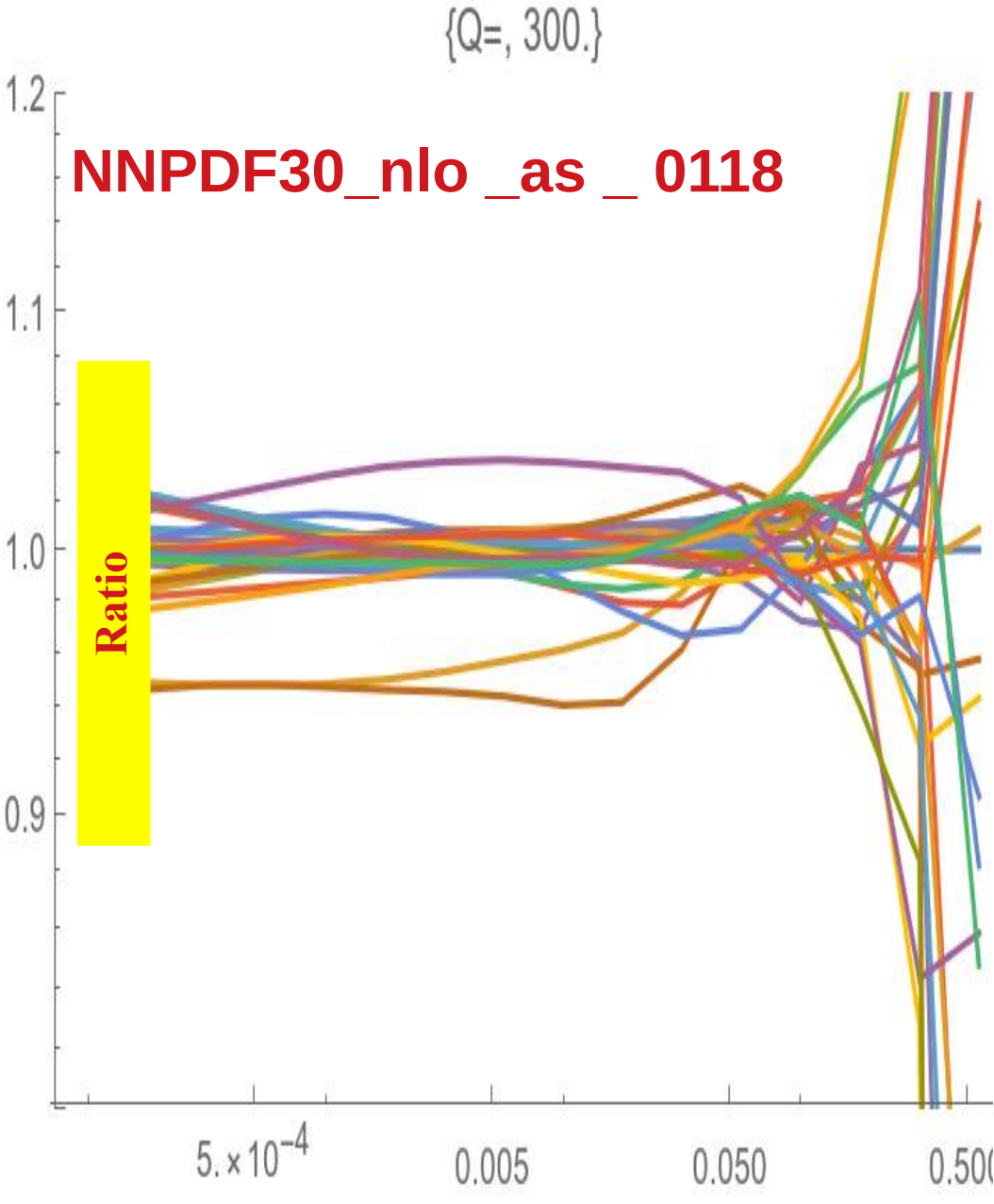




- Scale uncertainties: FF ABM > FONLL-B [to be checked]
- PDF uncertainties: FONLL-B [NNPDF] > FF ABM [ABMP16], especially at low y (s contribution)

Q=300

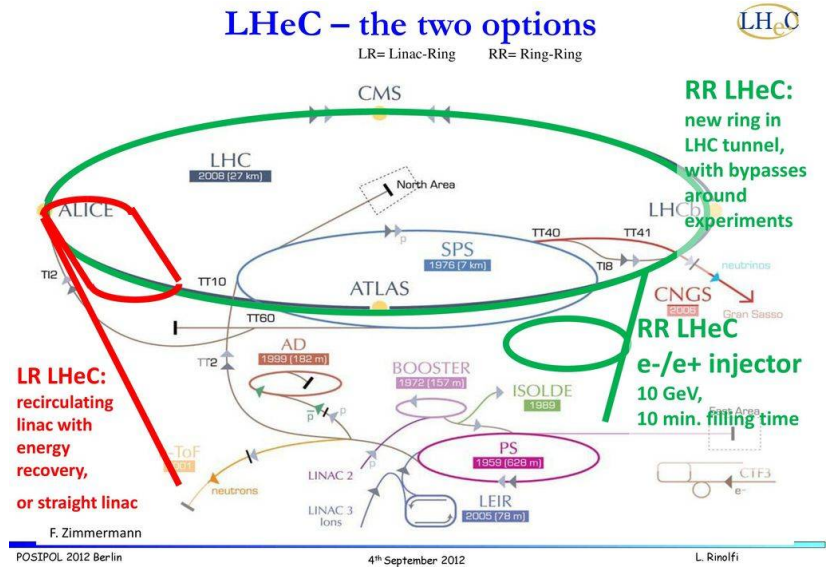

{Q=, 300.}
ABMP16_ 3_nlo
Ratio
1.2
1.1
1.0
0.9
5. x 10^-4
0.005
0.050
0.50

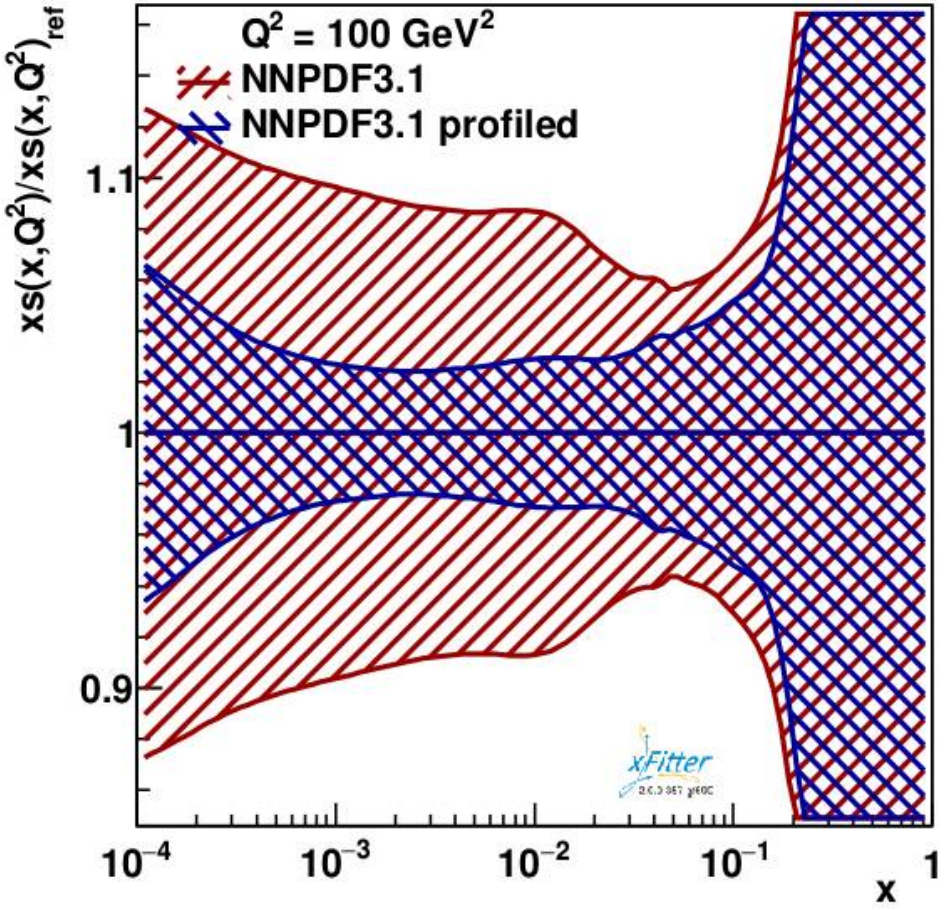

{Q=, 300.}
NNPDF30_nlo _as _ 0118
Ratio
1.2
1.1
1.0
0.9
5. x 10^-4
0.005
0.050
0.500

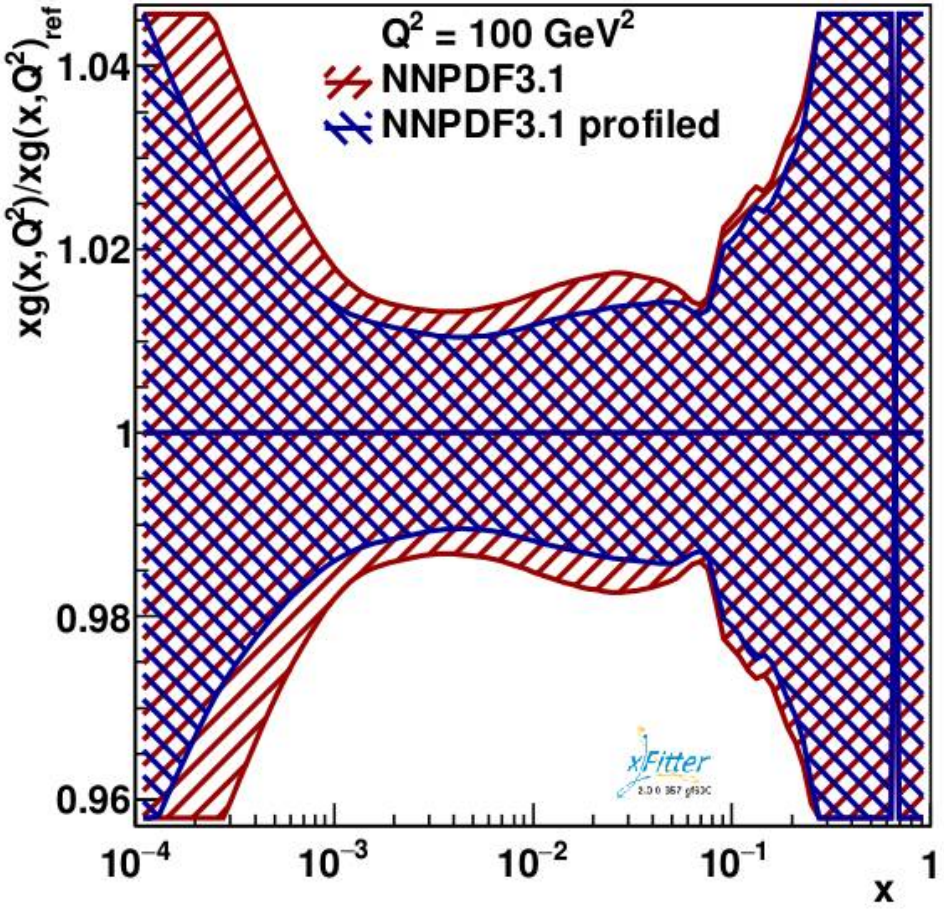
The bottom line:

Can we improve the PDFs???

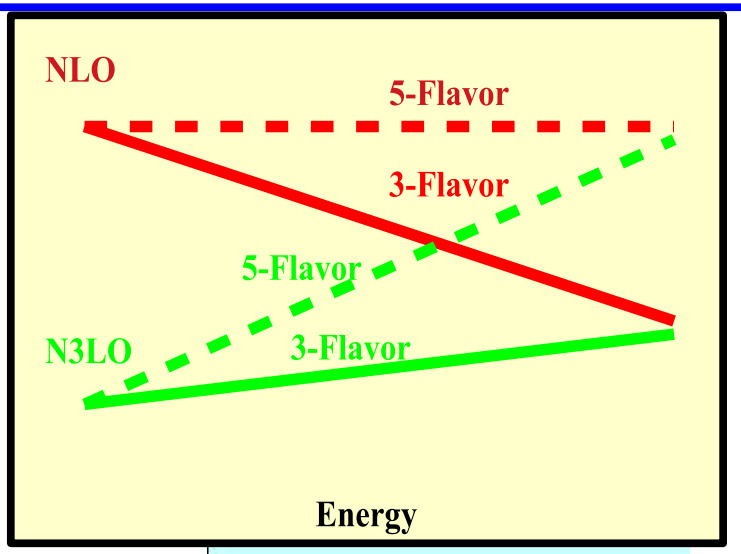
Excellent improvement on s(x)
Additional improvement on g(x)
***Note**: This is just one LHeC channel*

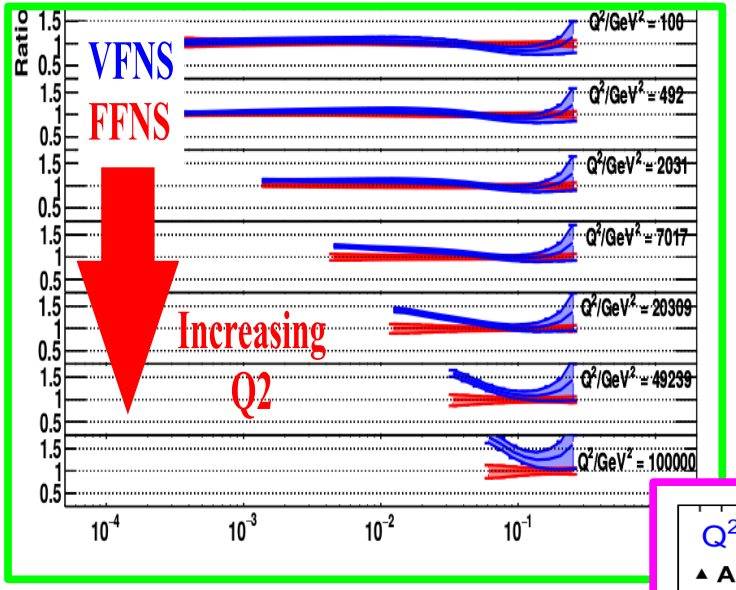




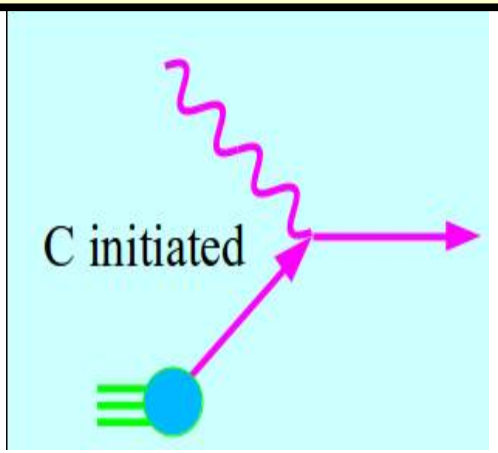


Summary: Versatility of xFitter

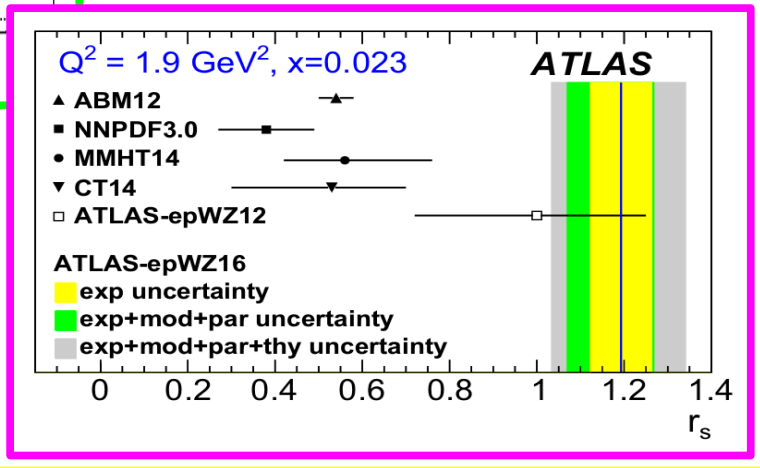


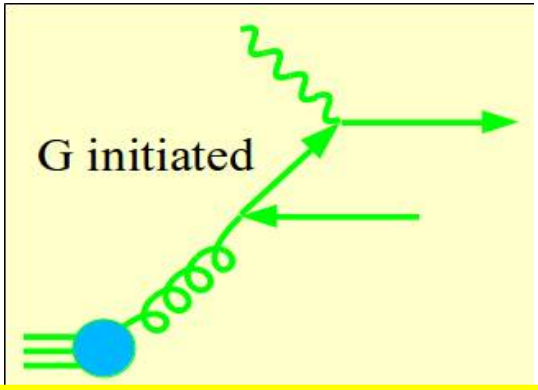


xFitter



LHeC





PDF Uncertainty, heavy quarks, FFNS & VFNS, C & G initiated, s(x) extraction, resummation...

LEFTOVERS

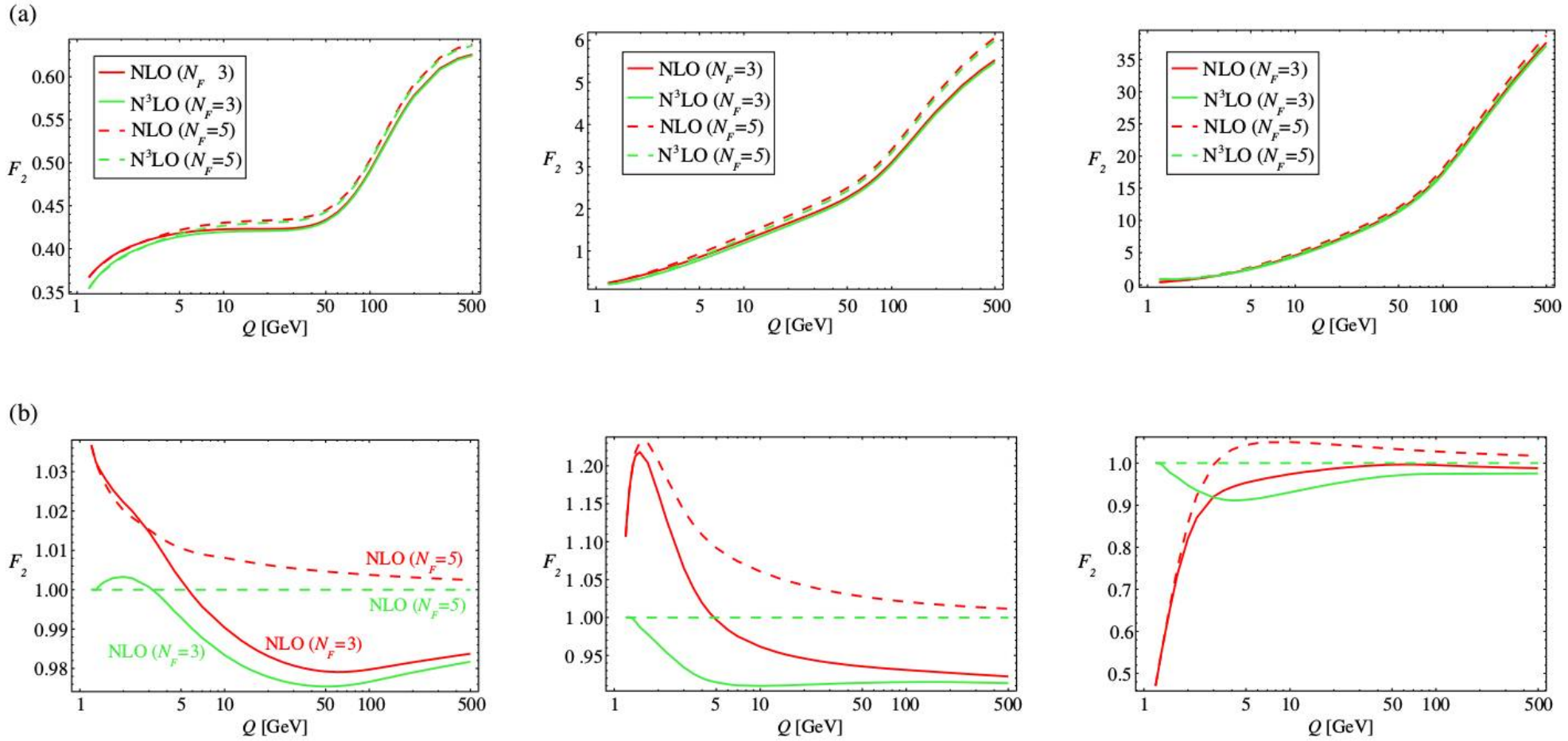


FIG. 7 (color online). (a) Inclusive F_2, (b) Ratio of inclusive F_2 as a function of Q [GeV] for different values of x : 10^{-1} (left), 10^{-3} (middle) and 10^{-5} (right). In these calculations we have chosen $\mu = Q$.

Hybrid scheme for heavy flavors: Merging the fixed flavor number scheme and variable flavor number scheme
A. Kusina, [arXiv:1306.6553] Phys.Rev. D88 (2013) no.7, 074032

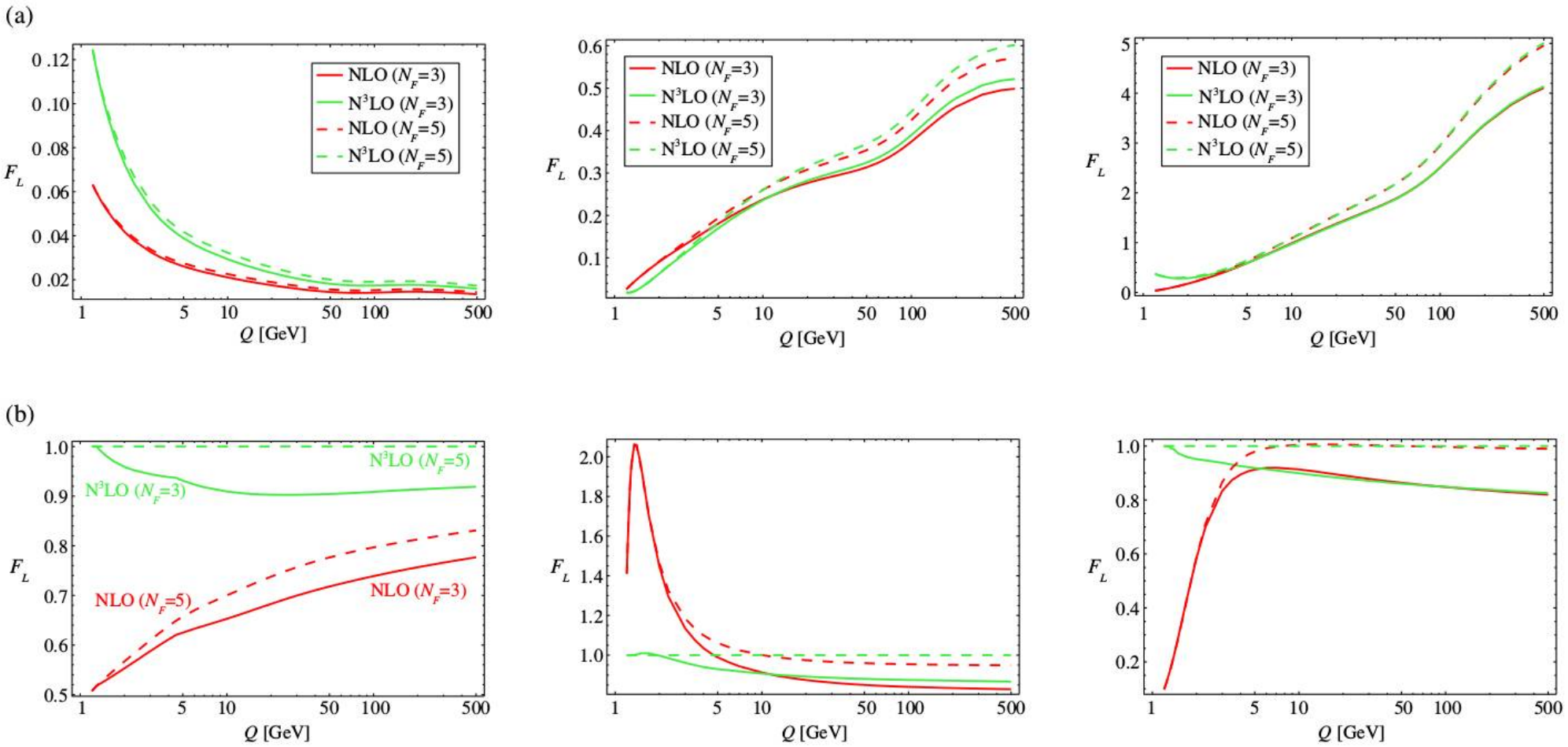


FIG. 8 (color online). (a) Inclusive F_L, (b) Ratio of inclusive F_L as a function of Q [GeV] for different values of x : 10^{-1} (left), 10^{-3} (middle) and 10^{-5} (right). In these calculations we have chosen $\mu = Q$.

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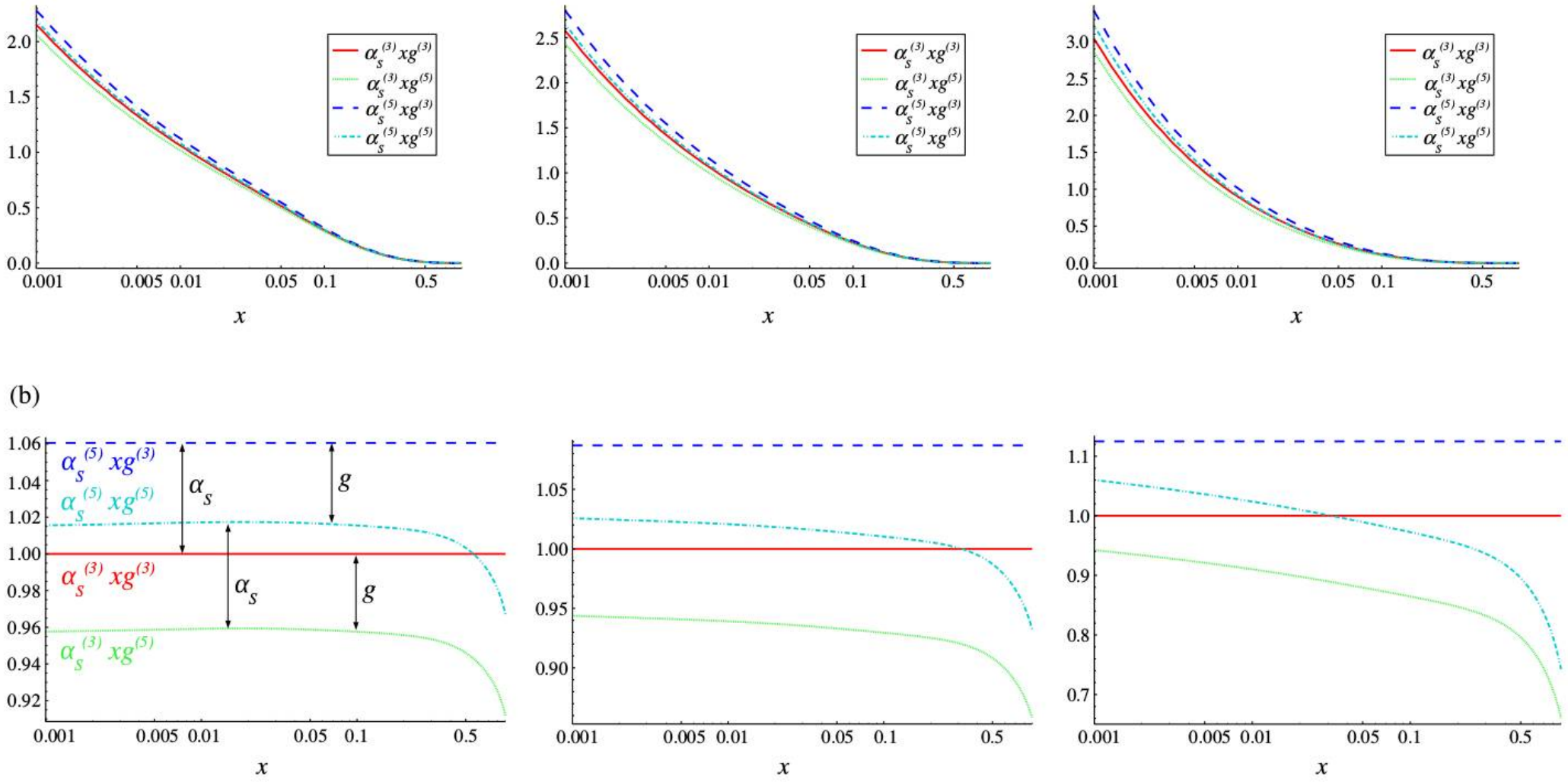

FIG. 5 (color online). ${\alpha_S}^{(N_R)} xg^{(N_F)}(x)$ as a function of x, for different values of μ. The curves are labeled ${\alpha_S}^{(N_R)} xg^{(N_F)}(x) = \{N_R, N_F\}$ where the first term in braces indicates the N_R for the α_s and the second indicates the N_F for g. (a) Different combinations of 3- and 5-flavor ${\alpha_S}^{(N_R)} xg^{(N_F)}(x)$ as a function of x, for different values of μ: 5 (left), 10 (middle) and 100 (right) GeV. (b) Ratio of different combination of 3- and 5-flavor ${\alpha_S}^{(N_R)} xg^{(N_F)}(x)$ and ${\alpha_S}^{(3)} xg^{(3)}(x)$ as a function of x, for different values of μ: 5 (left), 10 (middle) and 100 (right) GeV.

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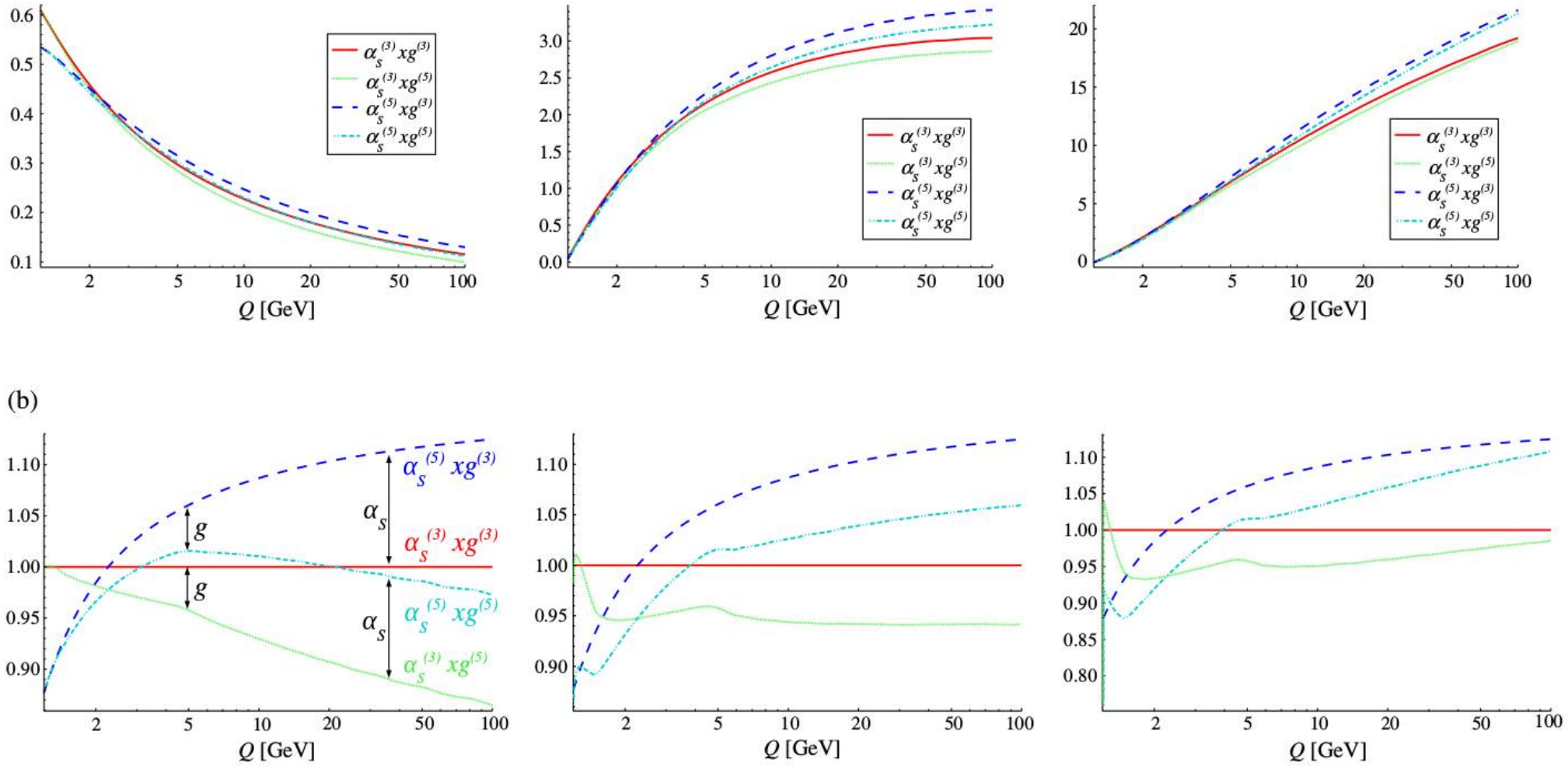

FIG. 6 (color online). ${\alpha_S}^{(N_R)} xg^{(N_F)}(x)$ as a function of μ, for different values of x. The curves are labeled ${\alpha_S}^{(N_R)} g^{(N_F)}(x) = \{N_R, N_F\}$ where the first term in braces indicates the N_R for the α_s and the second indicates the N_F for g. (a) Different combinations of 3- and 5-flavor ${\alpha_S}^{(N_R)} xg^{(N_F)}(x)$ as a function of μ, for different values of x : 10^{-1} (left), 10^{-3} (middle) and 10^{-5} (right). (b) Ratio of different combination of 3- and 5-flavor ${\alpha_S}^{(N_R)} xg^{(N_F)}(x)$ vs ${\alpha_S}^{(3)} xg^{(3)}(x)$ as a function of μ, for different values of x : 10^{-1} (left), 10^{-3} (middle) and 10^{-5} (right).

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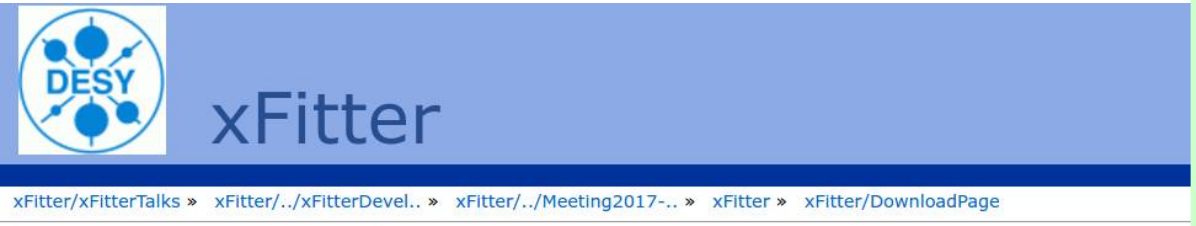
xFitter release xfitter-2.0.0

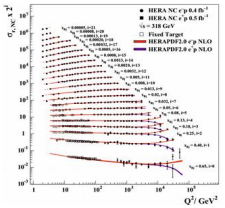
www.xFitter.org



Sample data files:

LHC: ATLAS, CMS, LHCb
Tevatron: CDF, D0
HERA: H1, ZEUS, Combined
Fixed Target: …
User Supplied: ...

Experimental Data



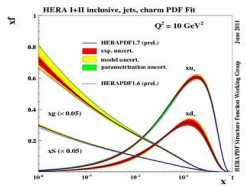
Data: HERA, Tevatron, LHC, fixed target experiments

Processes:
Inclusive DIS, Jets, Drell-Yan, Diffraction, Top production
W and Z production

Theory Calculations

HQ Schemes:	MSTW, NNPDF, ABM, ACOT
Jets, W, Z:	FastNLO, ApplGrid
Top:	Hathor
Evolution:	QCDNUM, APFEL, k_T
Other:	NNPDF reweighting TMDs, Dipole Model, ...

xFitter



Parton Distribution Functions:
PDF, Updf, TMD

$\alpha_S(M_Z)$, m_c,m_b,m_t ...

Theoretical Cross Sections

Comparisons to other PDFs (LHAPDF)

xFitter 2.0.0 FrozenFrog

Features & Recent Updates:

Photon PDF & QED
Pole & MS-bar masses
Profiling and Re-Weighting

Heavy Quark Variable Treshold
Improvements in χ^2 and correlations
TMD PDFs (uPDFs)
... and many other