Heavy Flavors:

Working with heavy quarks at High Scales & High Orders

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SMU

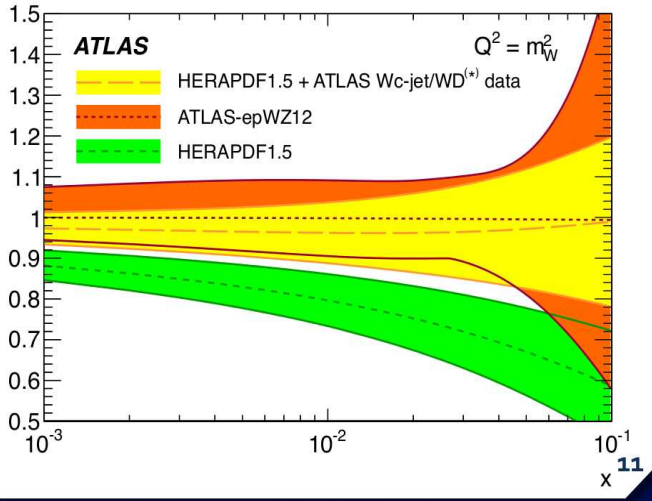
… informal discussion topics

xFitter Workshop - Dubna
19 February 2016

W + c / D production

JHEP 05 (2014) 068

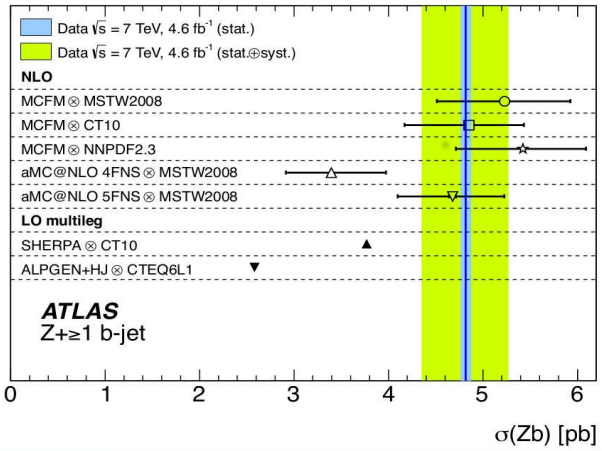
- Further sensitivity to s-quark content of the PDF from W+c studies
- Two measurements strategies: tag the c-jet vs reconstruct D-meson
- Consistently with W/Z inclusive measurements, ATLAS data favor s-quark enhancement against ½ suppression wrt d-quark PDF
  - Substantial reductions of uncertainty

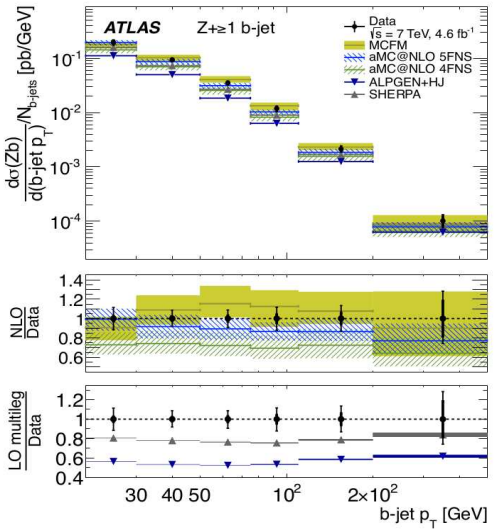


Heavy flavor: Z+b-jets

JHEP 10 (2014) 141

- Good agreement with NLO MCFM and aMC@NLO
  - Seems to favor scheme where b-quark is taken from PDF (5 FNS)
  - LO+PS generators are underestimating the cross section
  - Can't constrain PDF yet due to too large uncertainty
- Good description of b-jet p_T shape
  - Normalization is off





The ACOT Scheme for heavy quarks PDFs

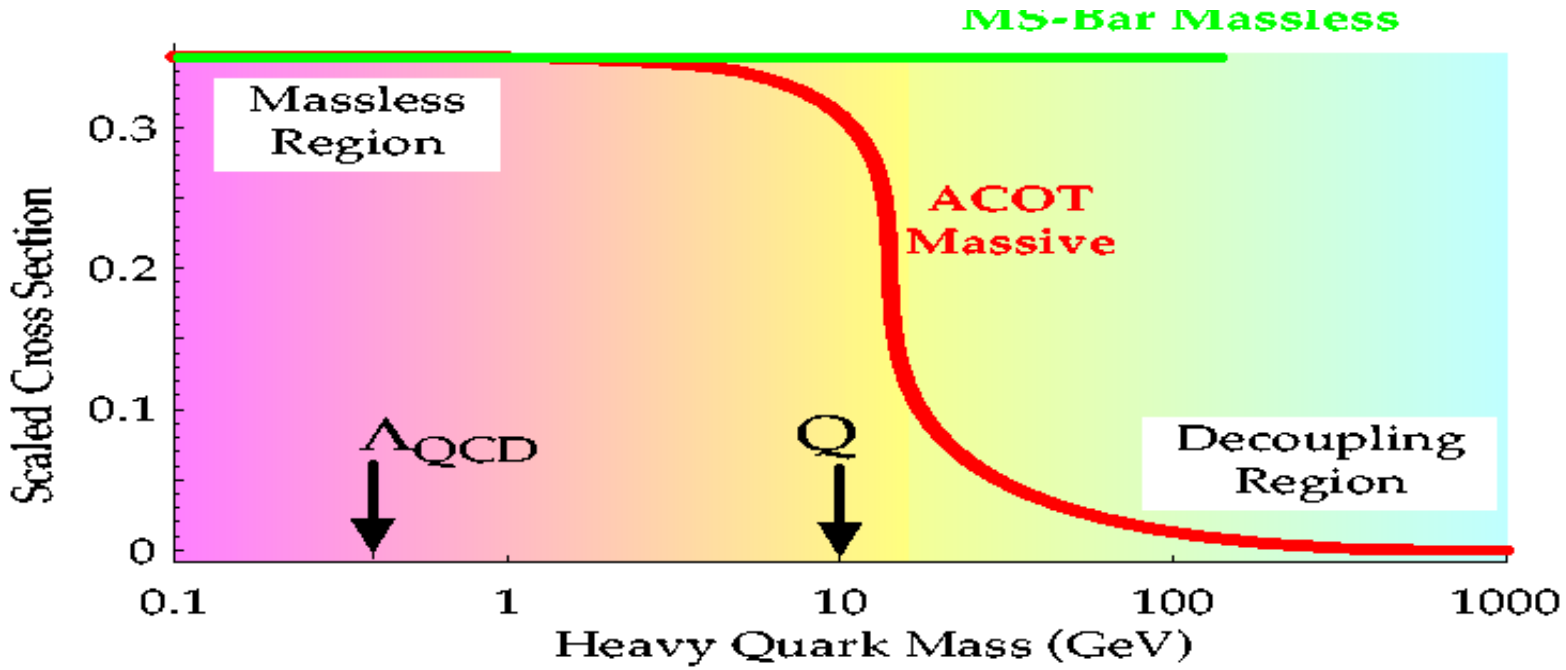
Theorists would much prefer that quark masses only come in 2 varieties:

m = 0: Massless case.

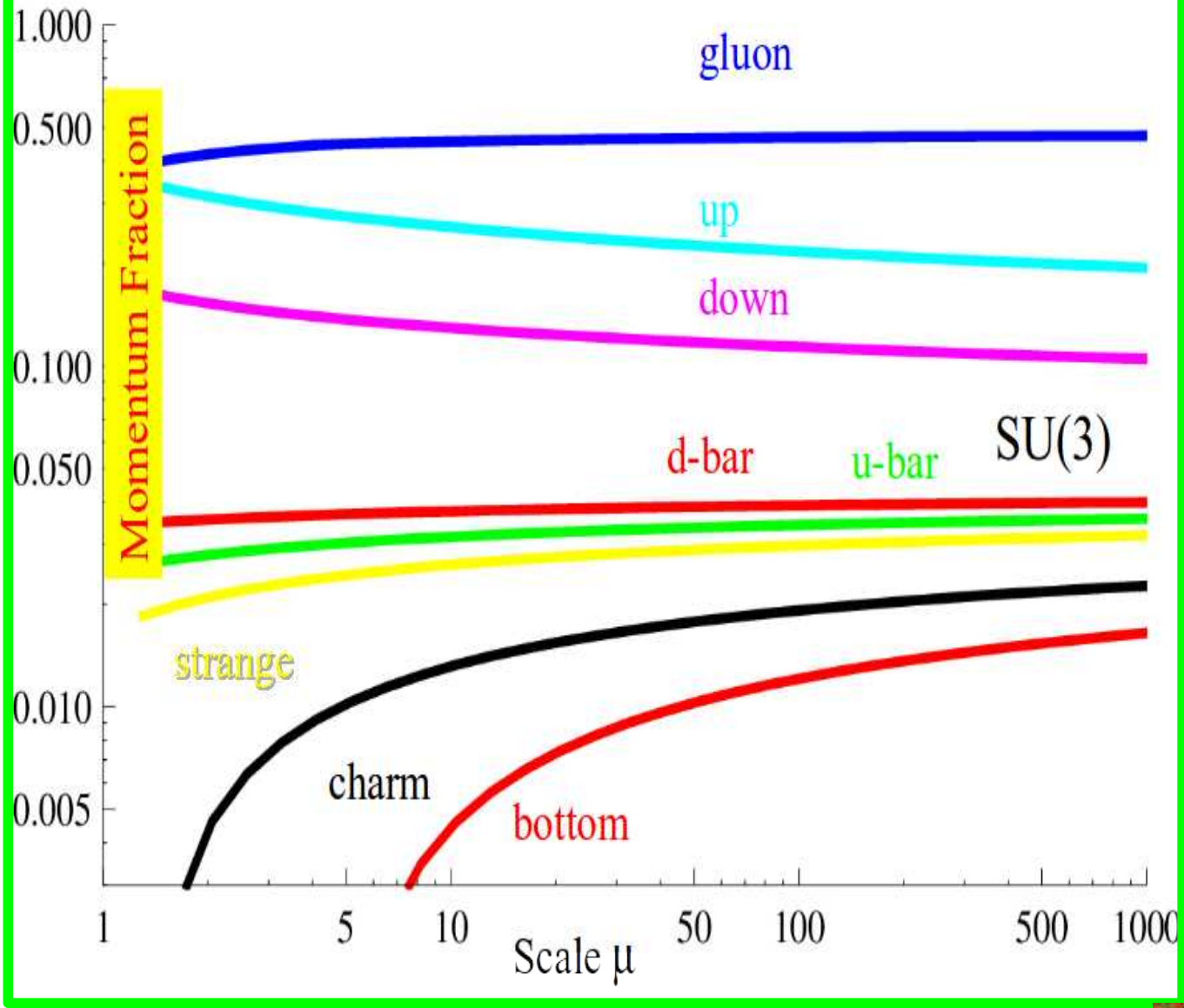
Mass plays no dynamic role
Well understood.

m = ∞: Infinite case.

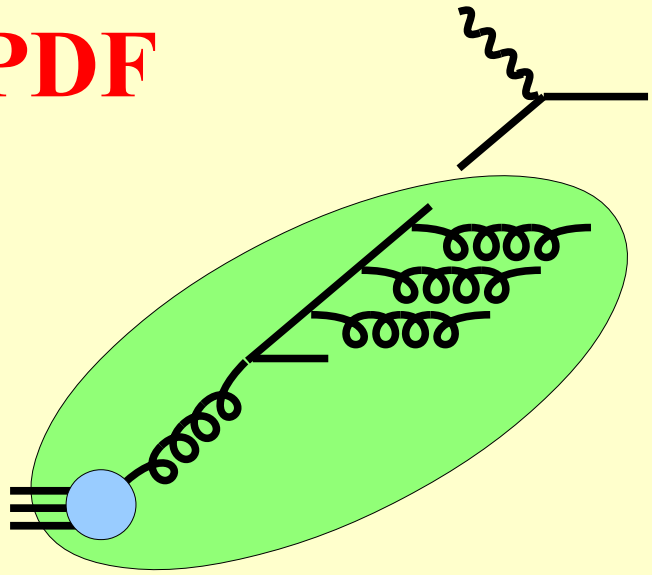
Mass Decouples.
We can forget about this object

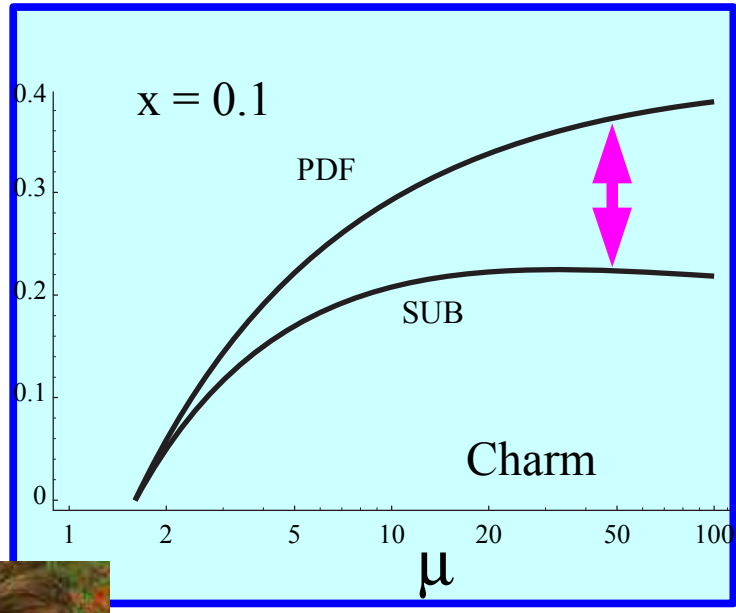


Resum $\alpha_s \ln(m/Q)$

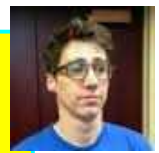


PDF

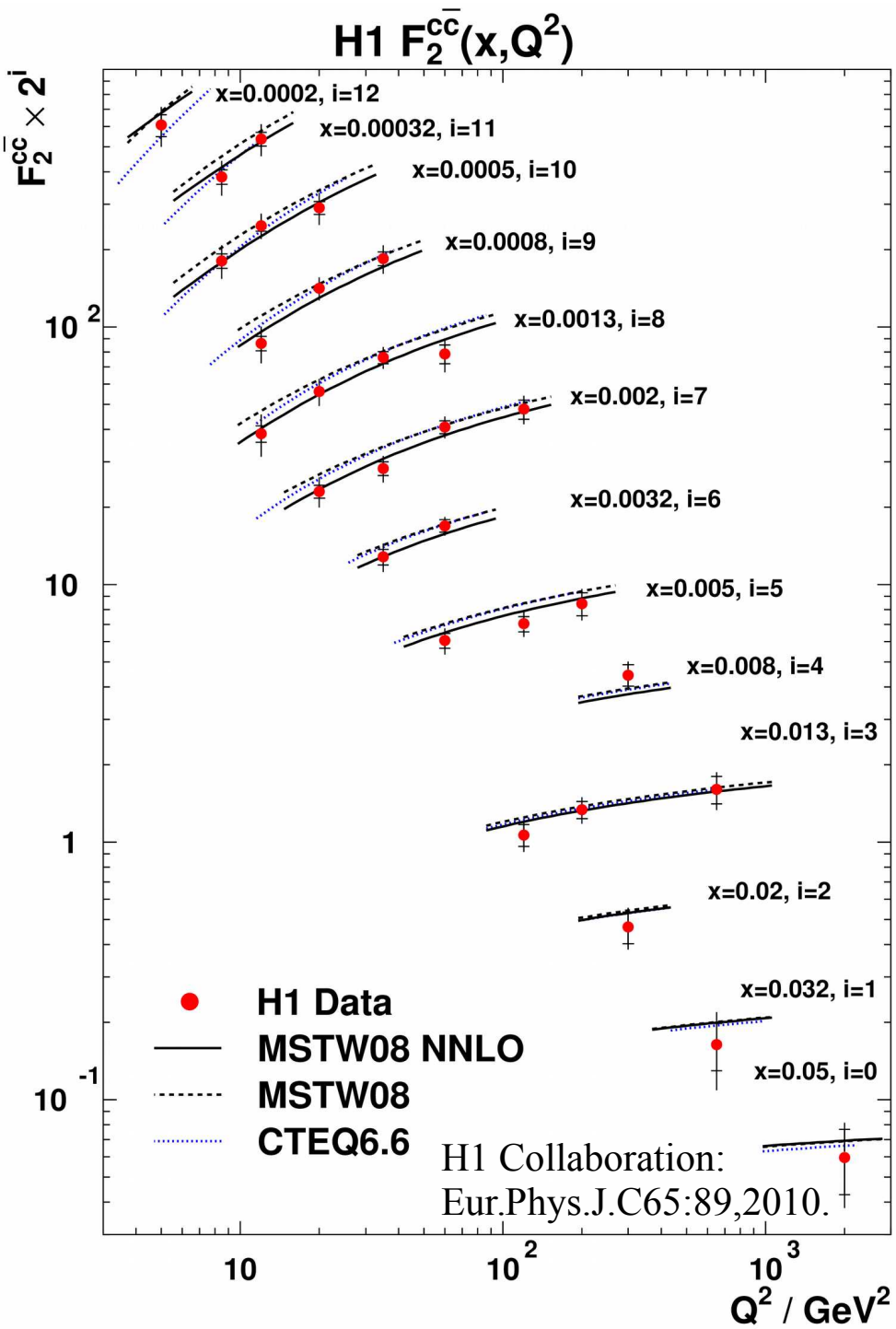




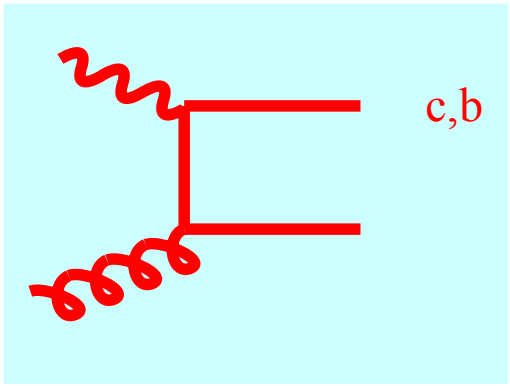
Plots made with ManeParse Mathematica package

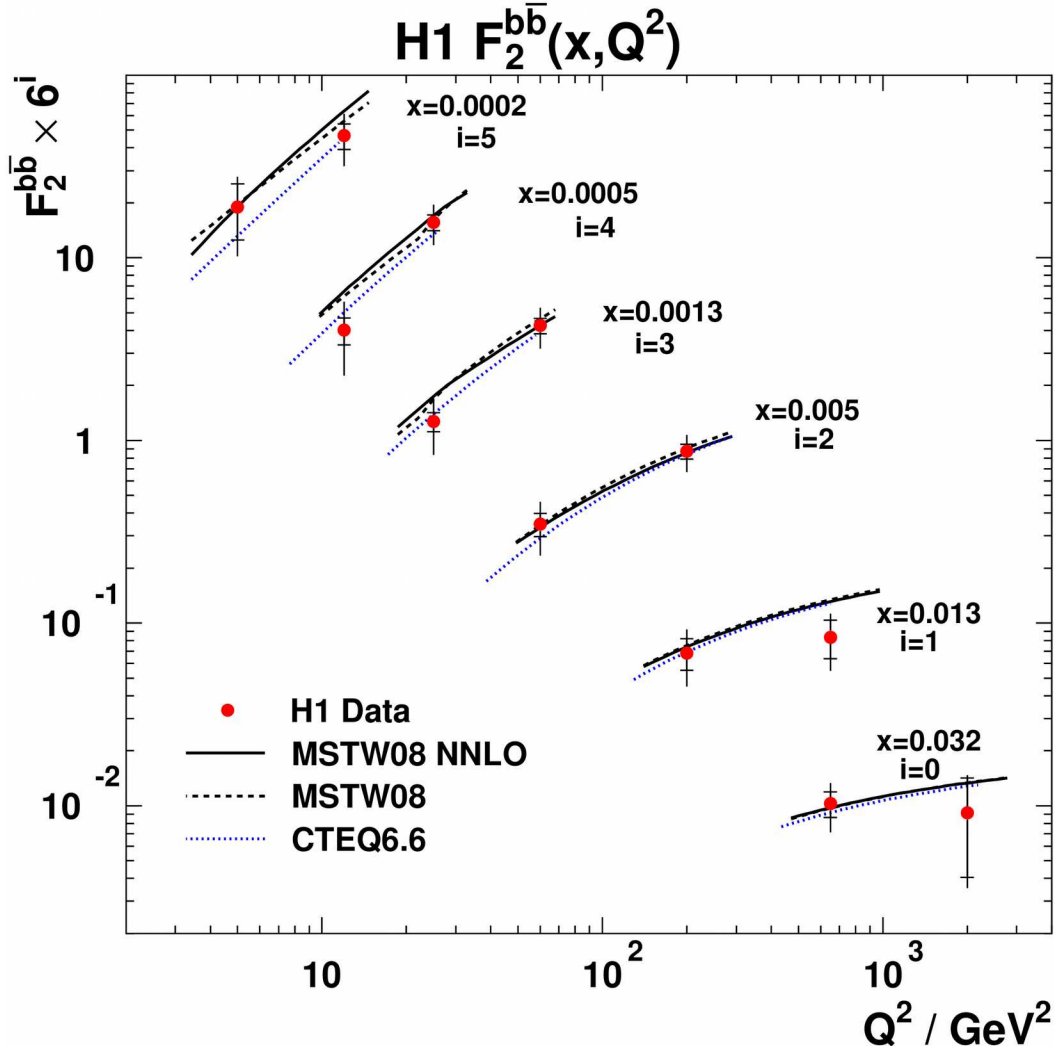


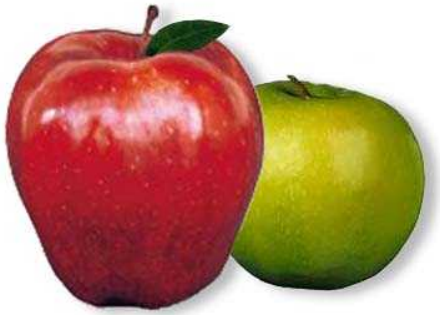
Heavy Flavor Components will play a MORE prominent role at LHC



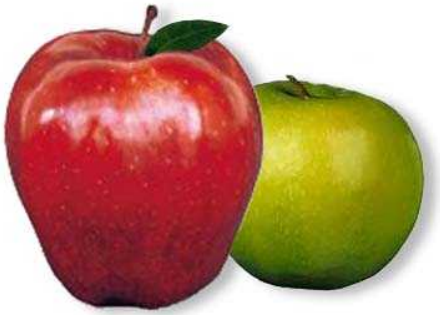
c & b tied to gluon PDFs



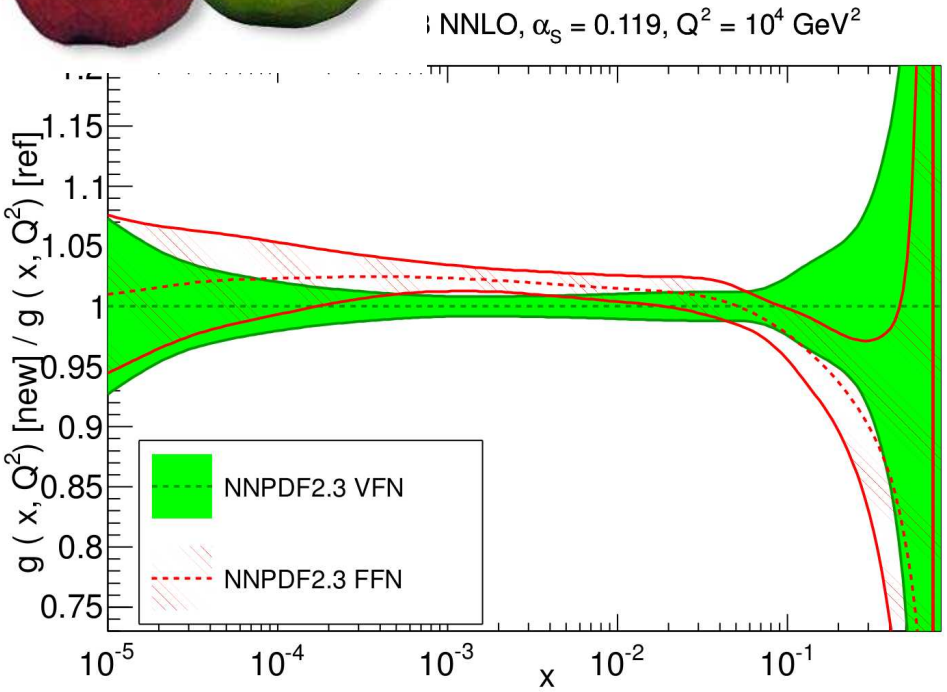


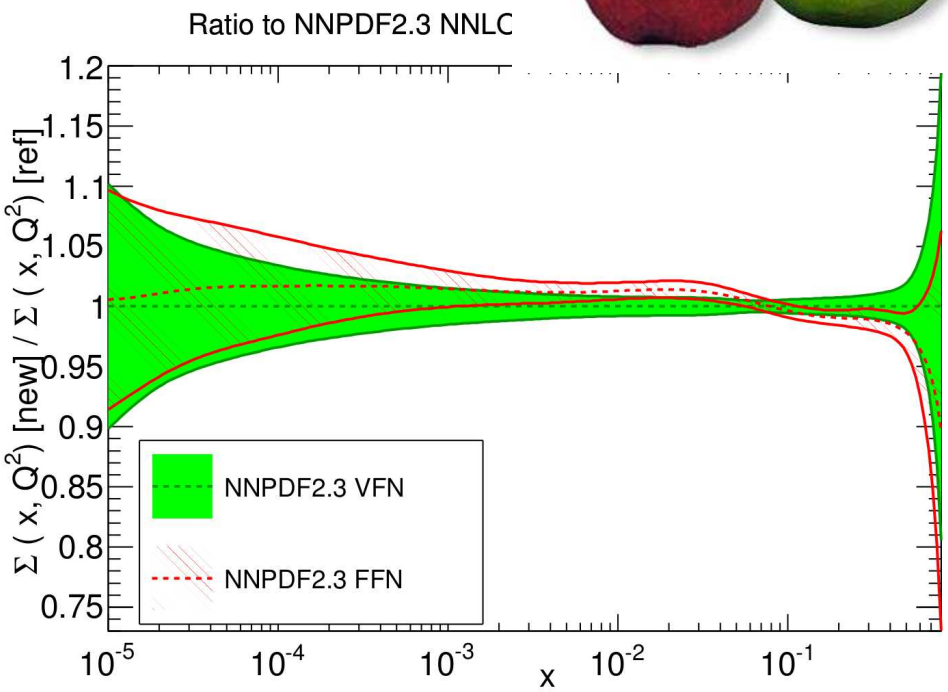


Compare VFN & FFN Schemes



Resum: $\alpha \ln(m/Q)$





$$\Delta\chi^2 \equiv \chi^2_{FFN} - \chi^2_{VFN} > 0$$

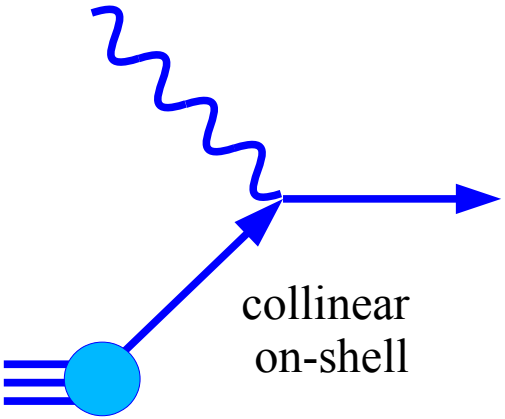
$x_{\min}$	$x_{\max}$	$Q^2_{\min}$ (GeV)	$Q^2_{\max}$ (GeV)	$\Delta\chi^2$ (DIS)	$N_{\rm dat}^{\rm DIS}$	$\Delta\chi^2$ (HERA-I)	$N_{\rm dat}^{\rm hera-I}$
$4\cdot10^{-5}$	1	3	10^6	72.2	2936	77.1	592
$4\cdot10^{-5}$	0.1	3	10^6	87.1	1055	67.8	405
$4\cdot10^{-5}$	0.01	3	10^6	40.9	422	17.8	202
$4\cdot10^{-5}$	1	10	10^6	53.6	2109	76.4	537
$4\cdot10^{-5}$	1	100	10^6	91.4	620	97.7	412
$4\cdot10^{-5}$	0.1	10	10^6	84.9	583	67.4	350
$4\cdot10^{-5}$	0.1	100	10^6	87.7	321	87.1	227

The NNPDF Collaboration, PLB723 (2013) 330

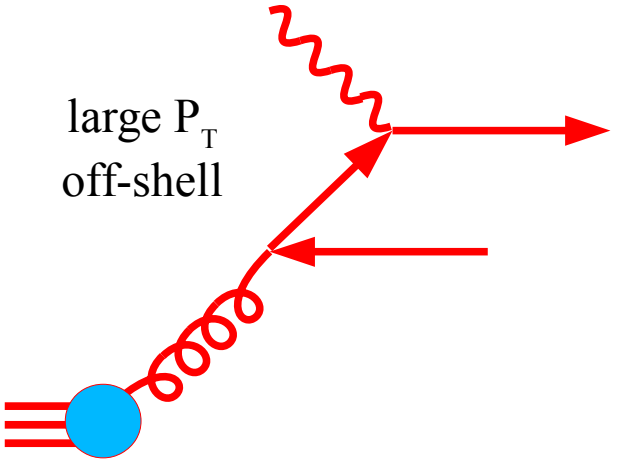
General ideas & assumptions behind heavy quark PDF, ACOT, and VFNS

```
 Order  = 'NLO'       ! 'LO', 'NLO' or 'NNLO', used for DGLAP evolution.

 Q02     = 1.9 ! Evolution starting scale

! --- Scheme for heavy flavors
! ---  HF_SCHEME = 'ZMVFNS'           : ZM-VFNS (massless) from QCDNUM,
! ---  HF_SCHEME = 'ZMVFNS MELA'      : ZM-VFNS (massless) from MELA (N-space),
! ---  HF_SCHEME = 'RT'               : Thorne-Roberts VFNS (massive)
! ---  HF_SCHEME = 'RT FAST'          : Fast approximate TR VFNS scheme, usign k-factor
! ---  HF_SCHEME = 'RT OPT'           : Thorne-Roberts VFNS (massive)
! ---  HF_SCHEME = 'RT OPT FAST'      : Fast approximate TR VFNS scheme, usign k-factor
! ---  HF_SCHEME = 'ACOT Full'        : ACOT - F.Olness Version (massive), using k-factors
! ---  HF_SCHEME = 'ACOT Chi'         : ACOT - F.Olness Version (massive), using k-factors
! ---  HF_SCHEME = 'ACOT ZM'          : ACOT - F.Olness Version (massless), using k-factors
! ---  HF_SCHEME = 'FF'               : Fixed Flavour Number Scheme (qcdnum)
! ---  HF_SCHEME = 'FF ABM'           : Fixed Flavour Number Scheme (ABM)
! ---  HF_SCHEME = 'FF ABM RUNM'      : Fixed Flavour Number Scheme (ABM) using run mass def
! ---  HF_SCHEME = 'FONLL-A'          : FONLL-A mass scheme provided by APFEL with pole masses (available only at NLO)
! ---  HF_SCHEME = 'FONLL-A RUNM OFF' : FONLL-A mass scheme provided by APFEL with MSbar masses running OFF (available only at NLO)
! ---  HF_SCHEME = 'FONLL-A RUNM ON'  : FONLL-A mass scheme provided by APFEL with MSbar masses running ON (available only at NLO)
! ---  HF_SCHEME = 'FONLL-B'          : FONLL-B mass scheme provided by APFEL with pole masses (available only at NLO)
! ---  HF_SCHEME = 'FONLL-B RUNM OFF' : FONLL-B mass scheme provided by APFEL with MSbar masses running OFF (available only at NLO)
! ---  HF_SCHEME = 'FONLL-B RUNM ON'  : FONLL-B mass scheme provided by APFEL with MSbar masses running ON (available only at NLO)
! ---  HF_SCHEME = 'FONLL-C'          : FONLL-C mass scheme provided by APFEL with pole masses (available only at NNLO)
! ---  HF_SCHEME = 'FONLL-C RUNM OFF' : FONLL-C mass scheme provided by APFEL with MSbar masses running OFF (available only at NNLO)
! ---  HF_SCHEME = 'FONLL-C RUNM ON'  : FONLL-C mass scheme provided by APFEL with MSbar masses running ON (available only at NNLO)
                                      ! (Any of the FONLL schemes at LO is equivalent to the ZM-VFNS)

 HF_SCHEME = 'RT FAST'
```

Wait a minute!
Since the heavy quark originally came from a gluon splitting, these diagrams are
Double Counting

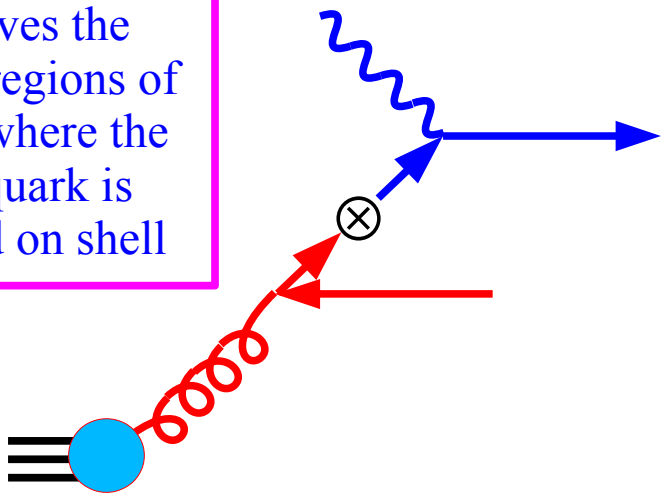


Leading Order (LO)



Next-to-Leading Order (NLO)

SUB removes the overlapping regions of phase space where the t-channel quark is collinear and on shell



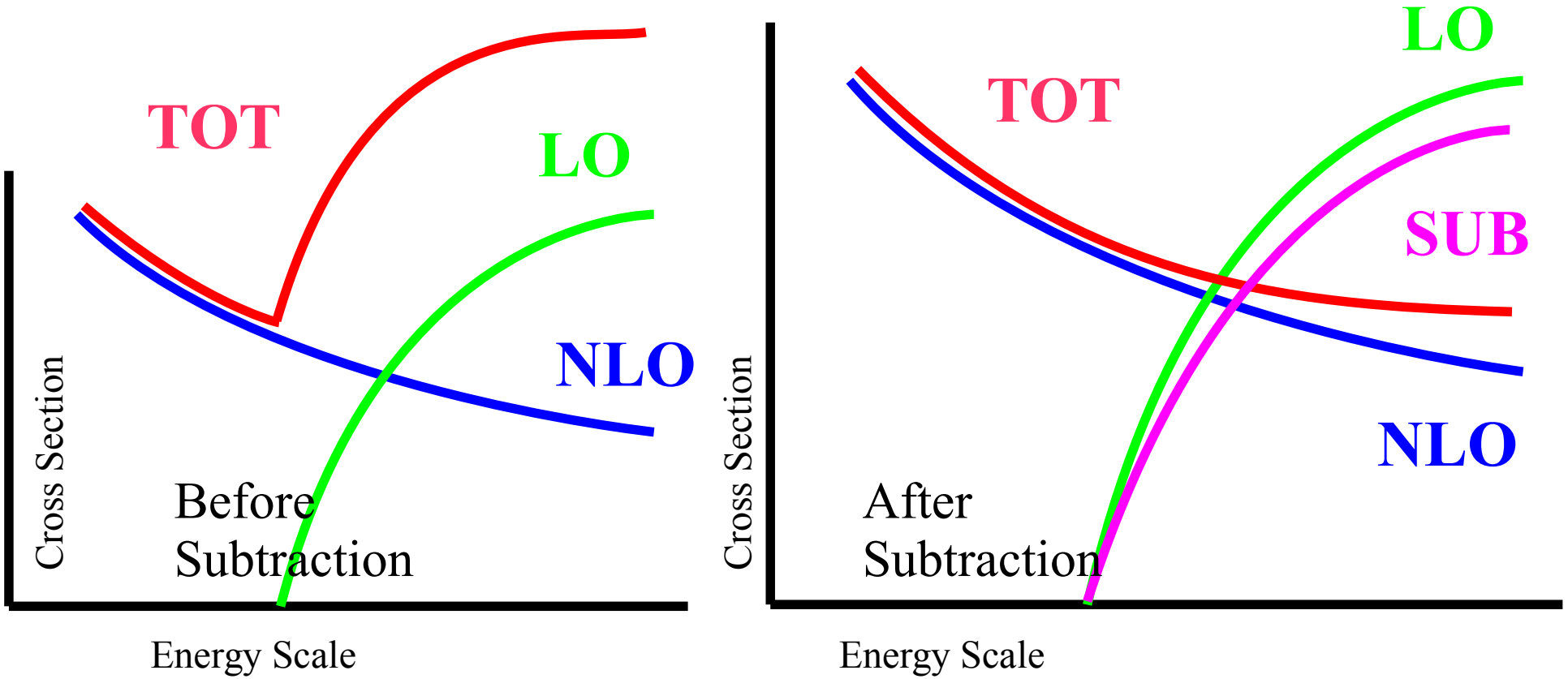
Subtraction (SUB)

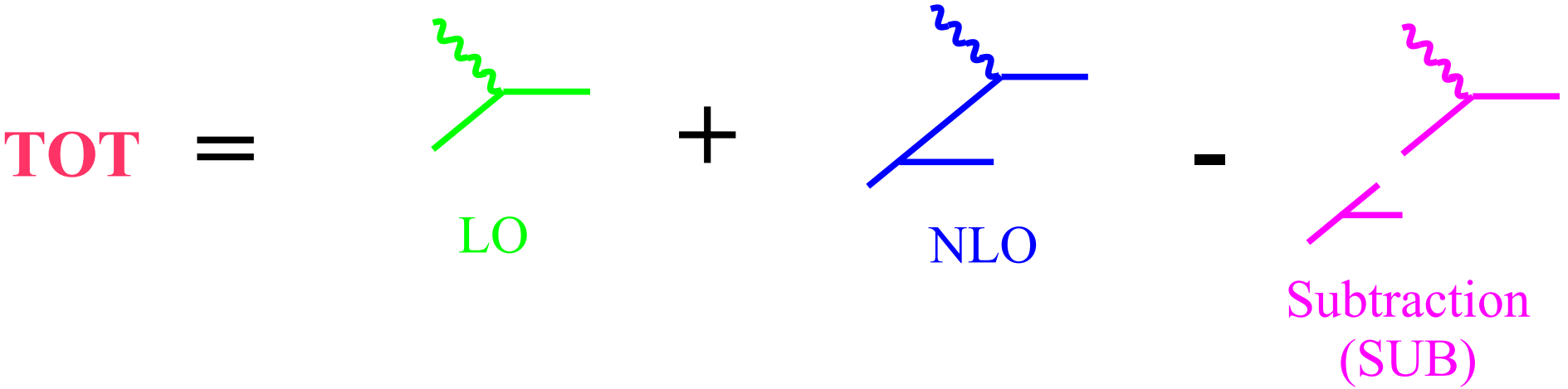
TOT = LO + (NLO – SUB)

Formally, NLO

Interaction of the separate contributions vs. energy scale

Note, we'll see this again ...



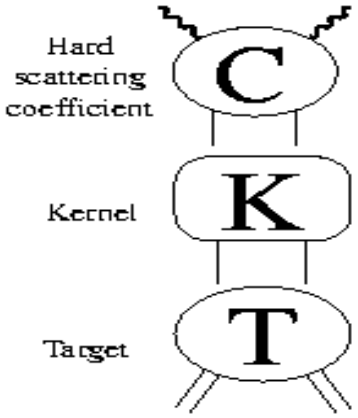


There is a rigorous factorization proof ...

Ingredients of Factorization

Decompose into (t-channel) 2PI amplitudes:

$$\sigma = \Sigma_{N=1}^{\infty} \; C \; (K)^N \; T \; + \textit{Non-leading}$$



Collins, Sopet, Sterman. Perturbative QCD, World Scientific (1989). Collins, in preparation

After reorganization of the infinite sum:

$$\sigma \approx \overbrace{C\,[1-(1-Z)\,K]^{-1}\,Z}^{\text{Parton Model}}\;\overbrace{[1-K]^{-1}\,T}^{\text{Parton Distribution}} + \overbrace{C\,[1-(1-Z)\,K]^{-1}\,(1-Z)T}^{\text{Remainder}}$$

Wilson Coefficient (Hard Scatt. $\hat{\sigma}$)

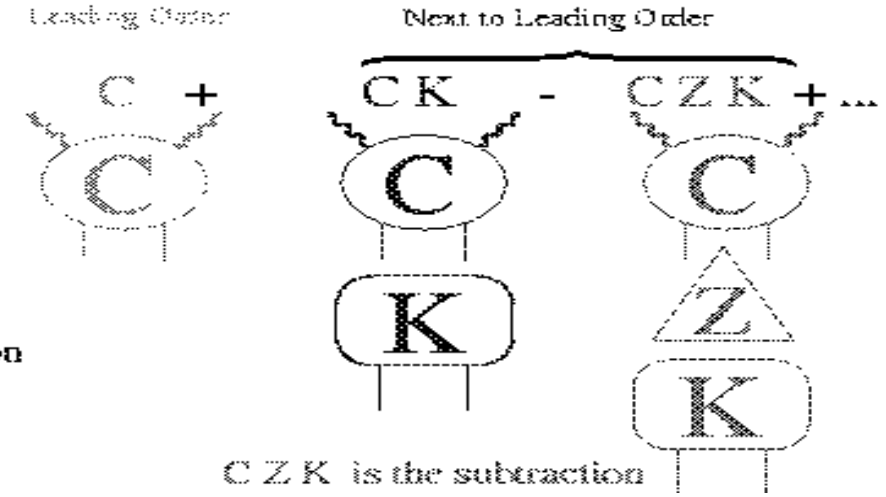
Z: collinear projection

Power Suppressed

Wilson Coefficient:

$$C\,[1-(1-Z)\,K]^{-1} \approx$$

All orders result



Wilson Coefficient: IR safe "hard" scattering cross section

C Z K is the subtraction

A formal proof was constructed by numerous groups.

This proof was explicitly extended to the case of massive quarks

(Collins,1998)

THOUGH EXPERIMENT
To keep things simple, let's consider scattering off a parton target.

Application of Factorization Formula at Leading Order (LO)

Basic Factorization Formula

$$\sigma = f \otimes \omega + O(\Lambda^2/Q^2)$$

At Zeroth Order:

$$\sigma^0 = f^0 \otimes \omega^0 + O(\Lambda^2/Q^2)$$

f^0 f^1

for parton target

Use: $f^0 = \delta$ for a parton target.

Therefore:

$$\sigma^0 = f^0 \otimes \omega^0 = \delta \otimes \omega^0 = \omega^0$$

$$\sigma^0 = \omega^0$$

Warning: This trivial result leads to many misconceptions at higher orders

Application of Factorization Formula at Next to Leading Order (NLO)

Basic Factorization Formula

$$\sigma = f \otimes \omega + O(\Lambda^2/Q^2)$$

At First Order:

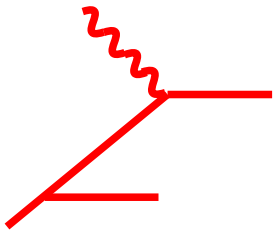
$$\sigma^1 = f^1 \otimes \omega^0 + f^0 \otimes \omega^1 +$$
$$\sigma^1 = f^1 \otimes \omega^0 + \omega^1$$

f^0 f^1

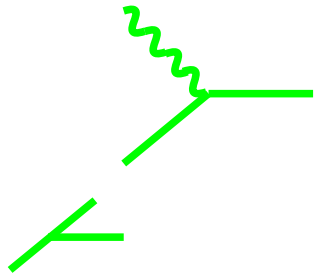
We used: $f^0 = \delta$ and $d^0 = \delta$ for a parton target.

Therefore:

$$\omega^1 = \sigma^1 - f^1 \otimes \omega^0$$



σ^1



$f^1 \otimes \sigma^0$

An Example: How the separate pieces can conspire

Expand f(x)=x in Taylor Series about x_0.

For x_0=0: $f(\varepsilon) = 0 + (\varepsilon - 0) + \ldots = \varepsilon$

For x_0=1: $f(\varepsilon) = 1 + (\varepsilon - 1) + \ldots = \varepsilon$

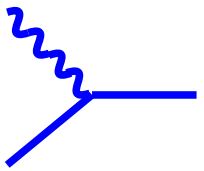
TOT

LO

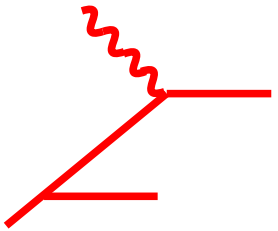
NLO

SUB

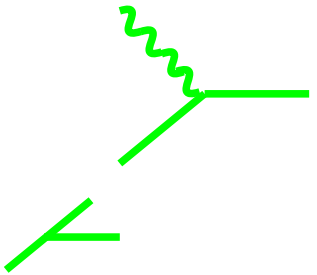
Subtraction



σ^0



σ^1



$f^1 \otimes \sigma^0$

TOT = LO + NLO – SUB

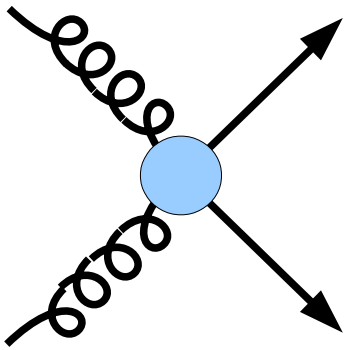
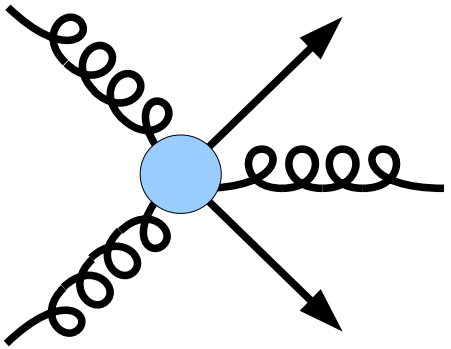
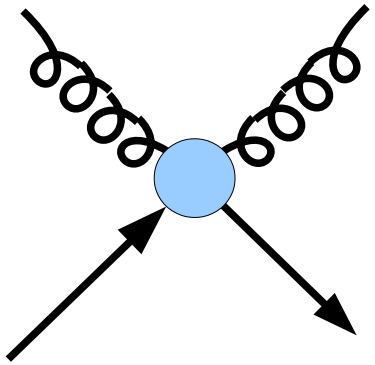
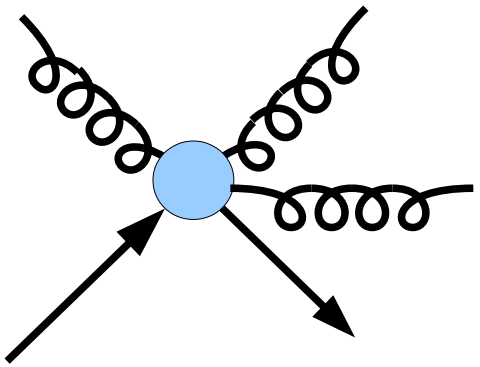
The Moral

It doesn't matter which expansion point you use; QCD will compensate (if you go to high enough order).

In practice ...

we are often limited to low-order calculations, so it is wise to choose your expansion point carefully.

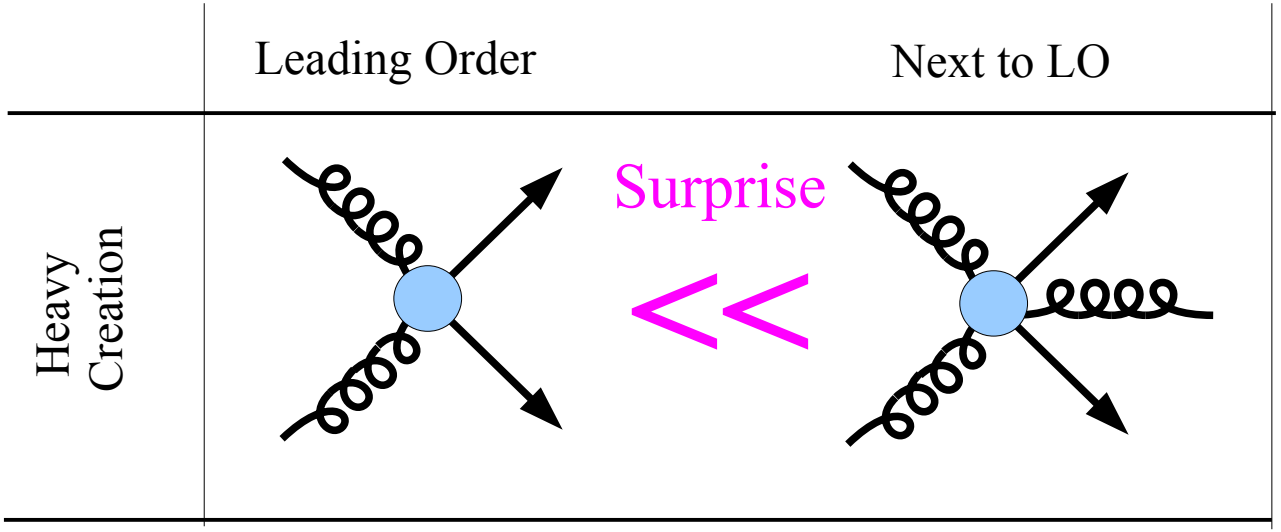
The Basic Contributions to Heavy Flavor Production

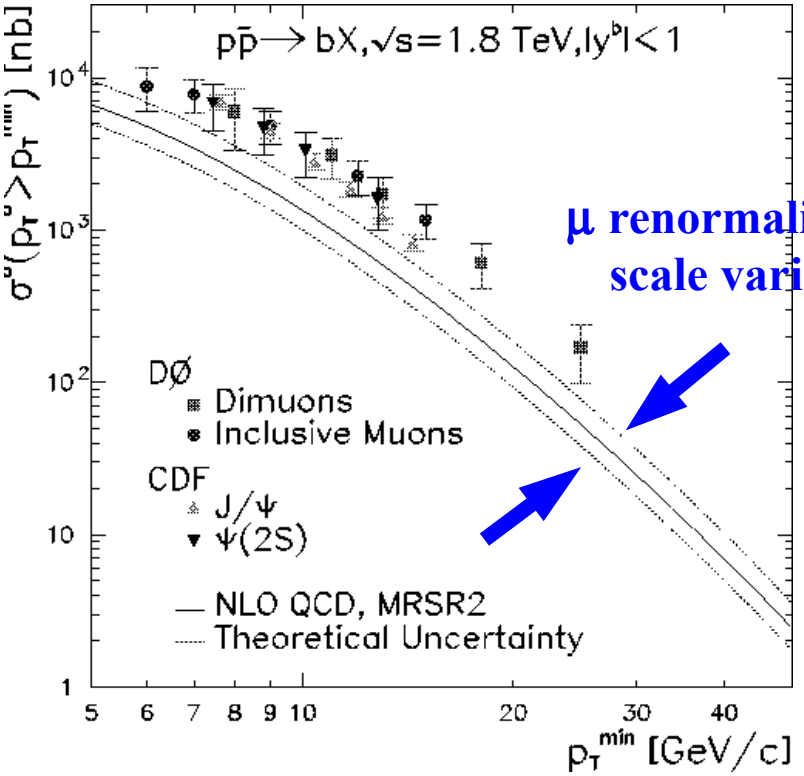
	Leading Order	Next to LO
Heavy Creation		
Heavy Excitation		

Fixed-Flavor Scheme

Variable-Flavor Scheme

NLO Fixed-Flavor Scheme





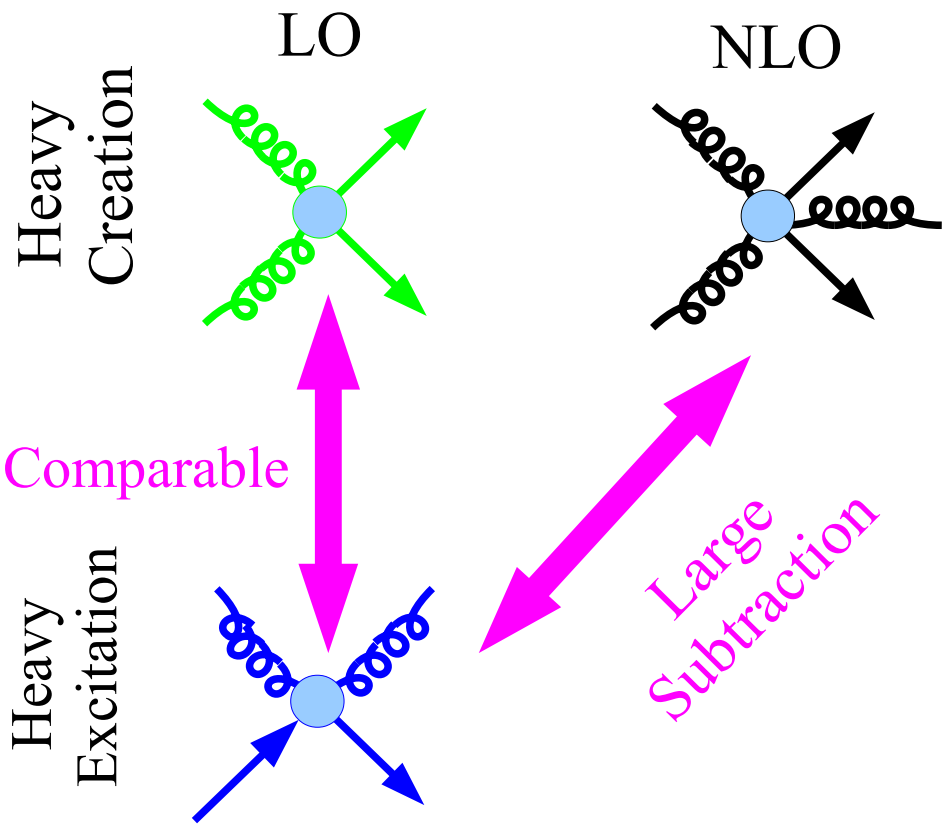
μ renormalization scale variation

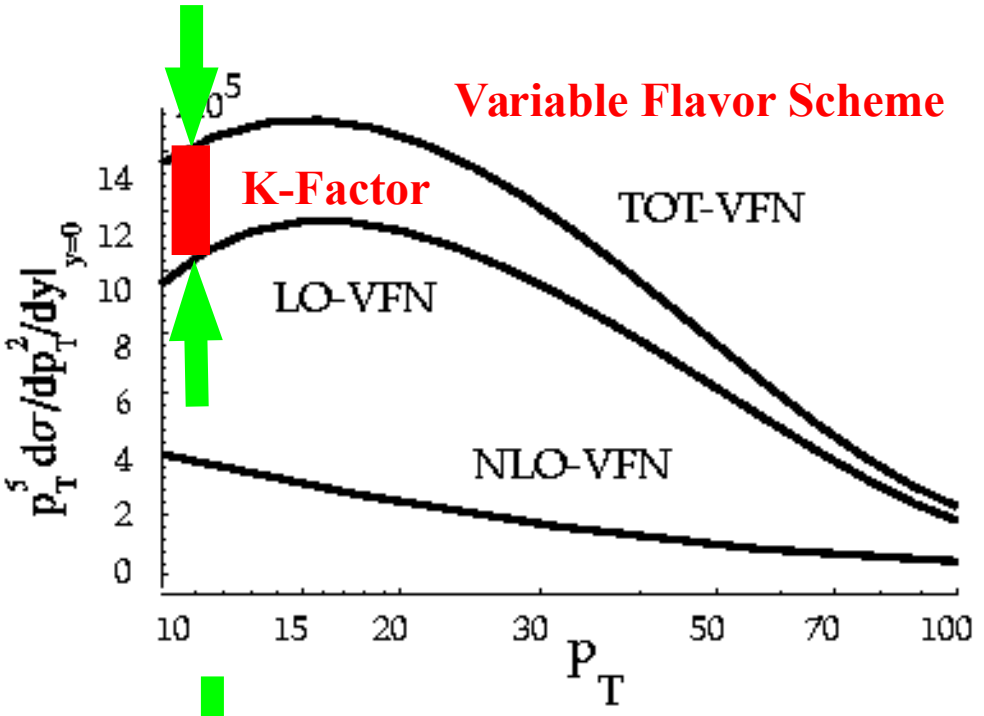
Surprise: NLO / LO ~ 2

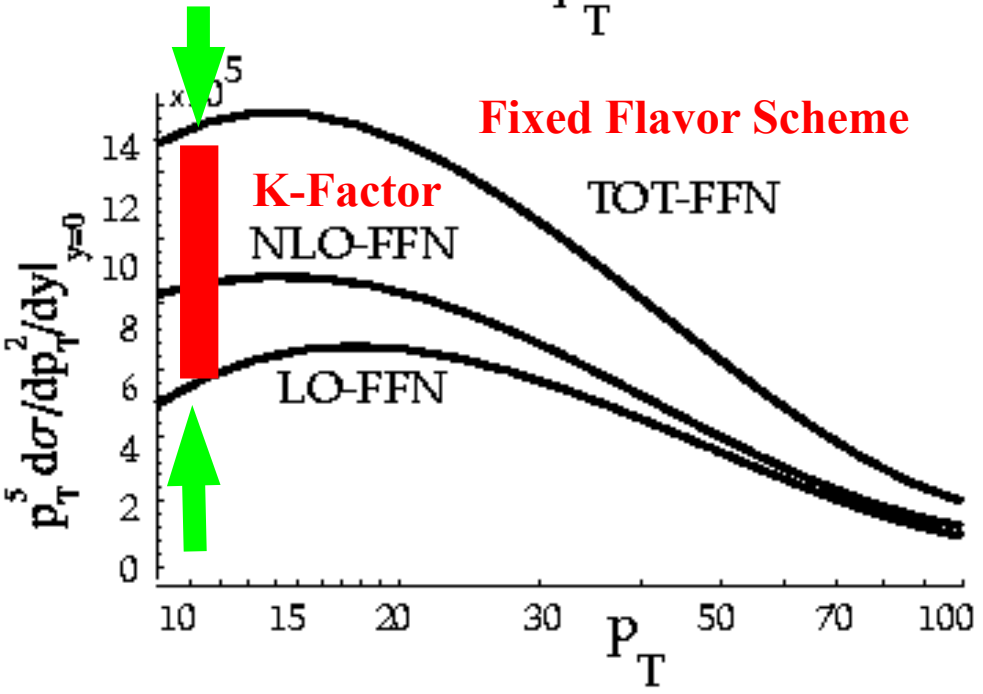
But, theory still below data

Nason, Dawson, Ellis
Beenakker, Kuijf, Van Neerven, Smith

NLO Variable Flavor Scheme







Net result:

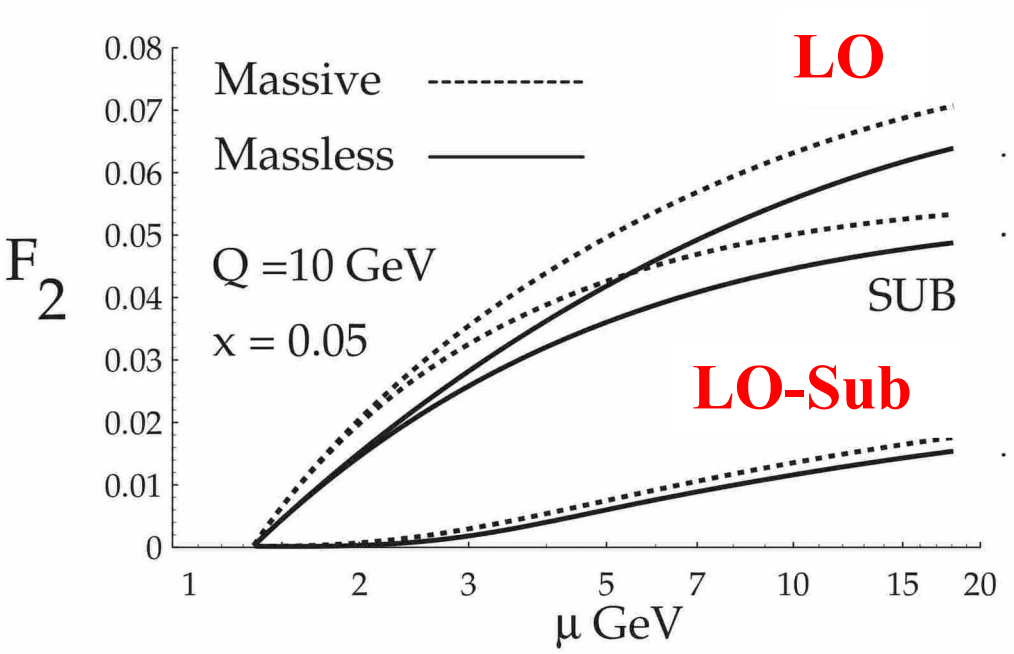
- Reduction of μ-dependence
- 30% to 50% increase in σ

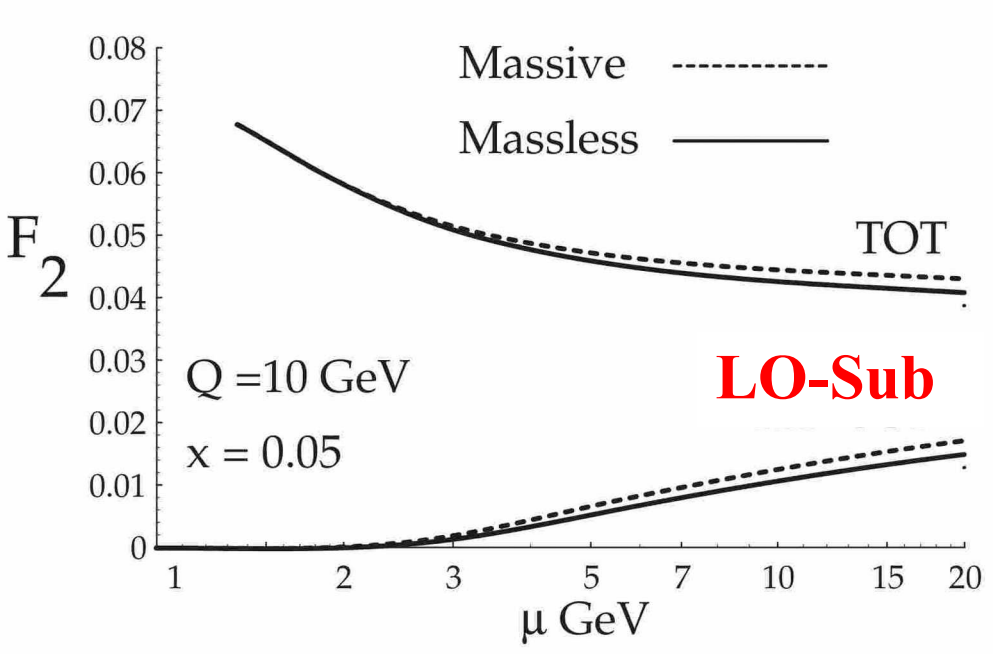
Aivazis, Collins, Olness, Tung
Olness, Scalise, Tung

Mass-Independent Evolution.

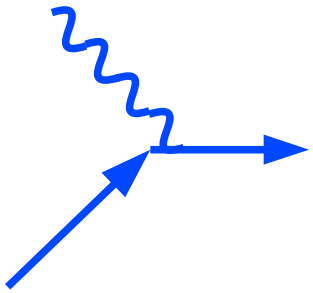
Why is it valid?

Effect of Heavy Quark Mass in the Calculation is Trivial

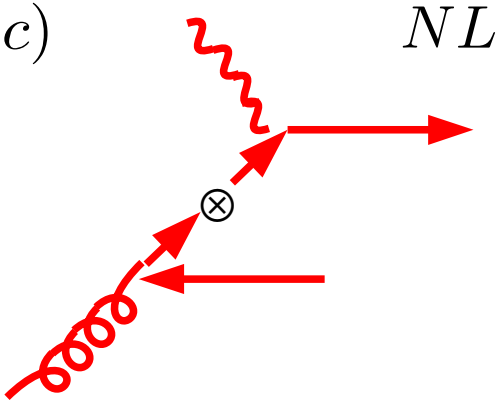


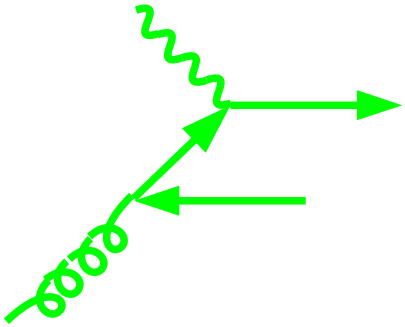


$$LO = \int f(P \to a) \otimes \sigma(a \to c)$$



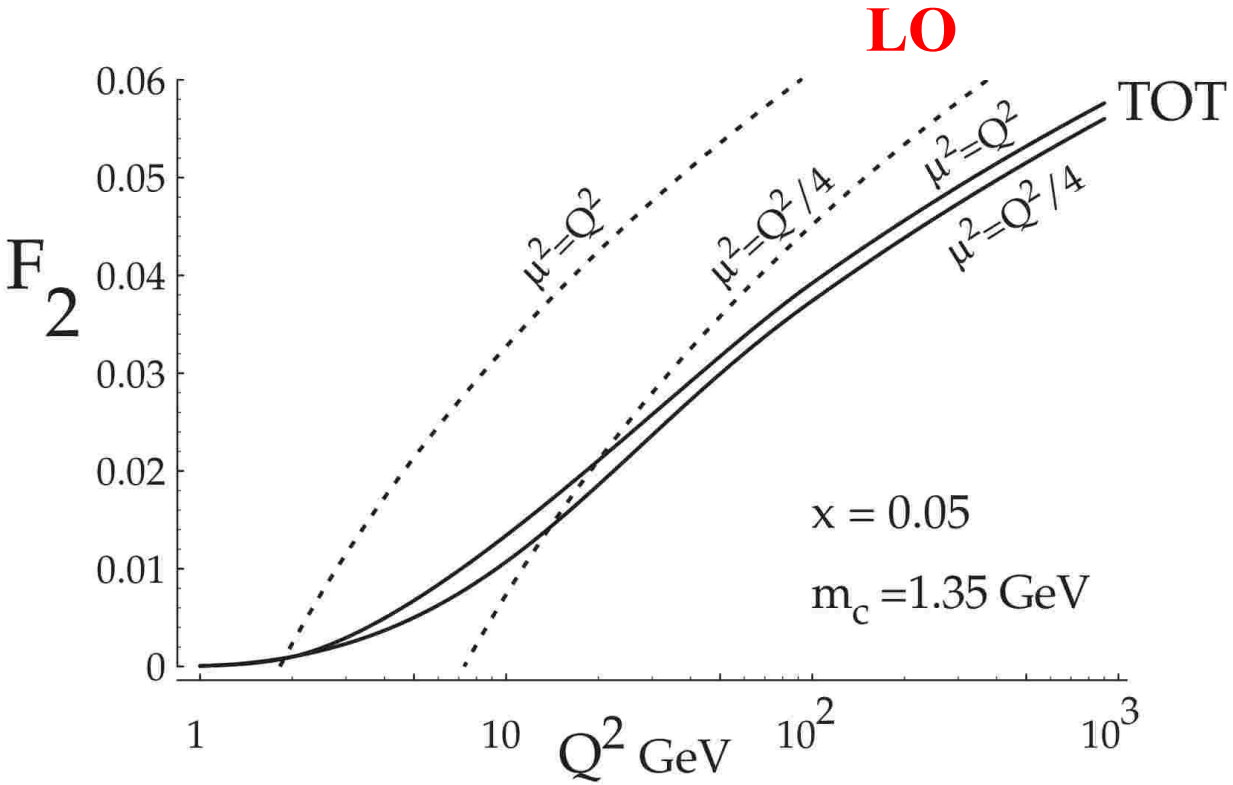
$$NLO = \int f(P \to g) \otimes \sigma(g \to c)$$





$$SUB = \int f(P \to g) \otimes {}^{1}P(g \to a) \otimes \sigma(a \to c)$$

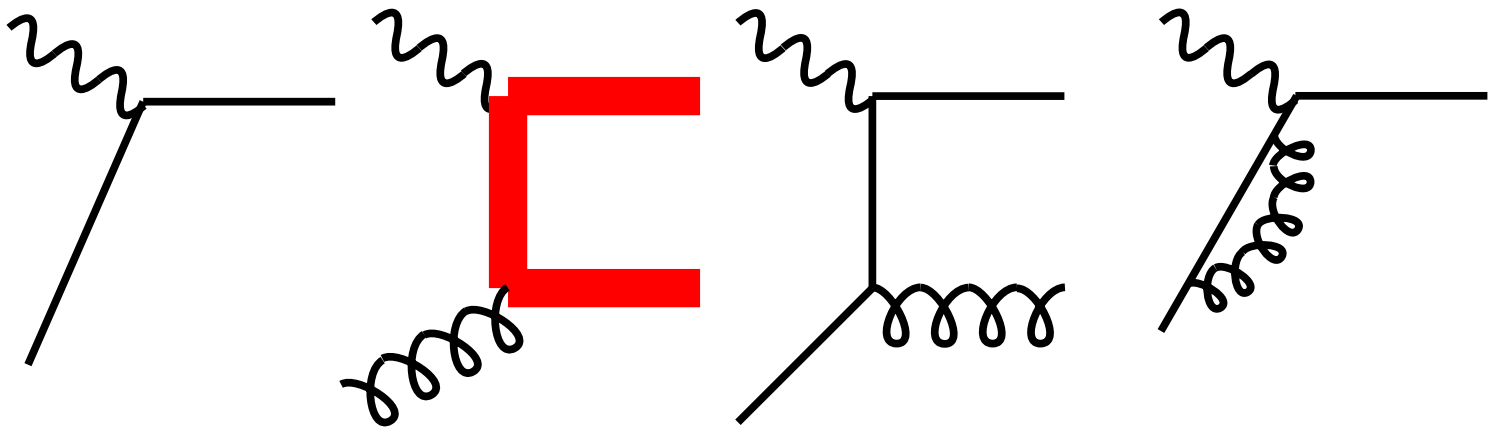
Variation of σ vs. renormalization scale μ

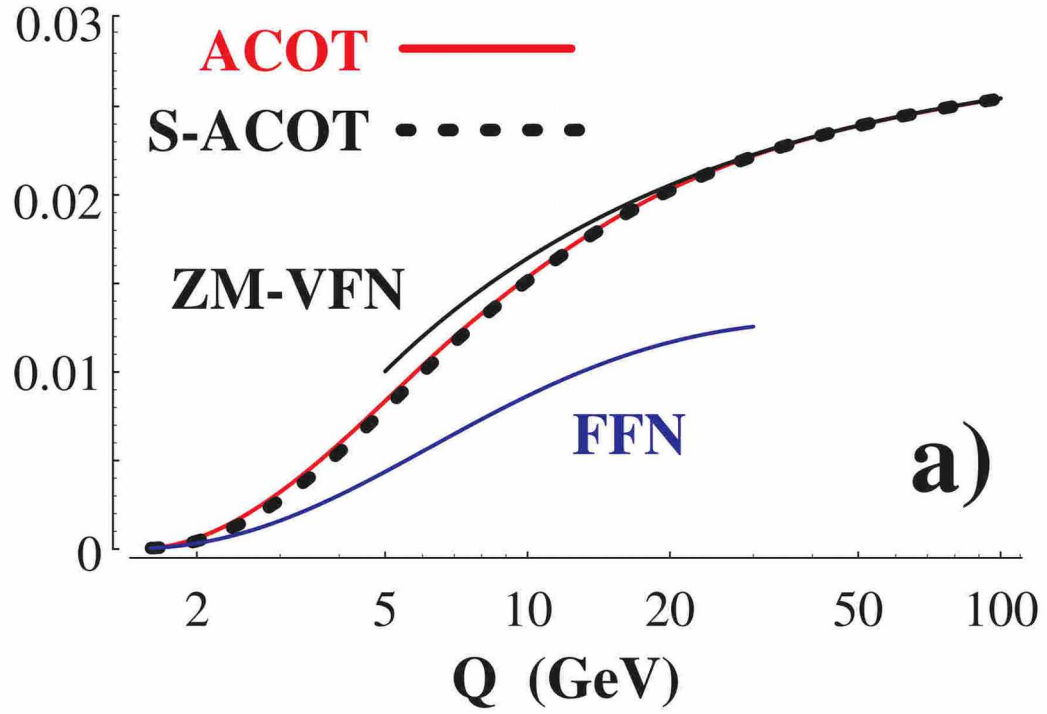


LO = HE result is very sensitive to the choice of scale (i.e., $\mu^2=Q^2$ or $Q^2/4$)
TOT result (higher order) is stable w.r.t. the choice of scale

An accurate calculation must be stable as the renormalization scale varies

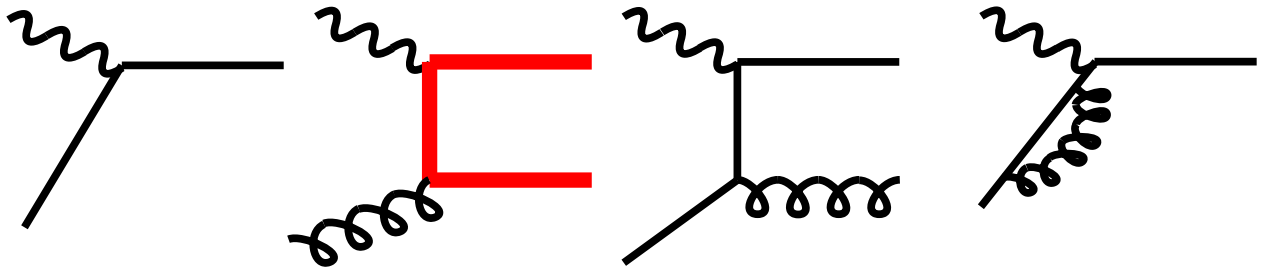
Simplified ACOT

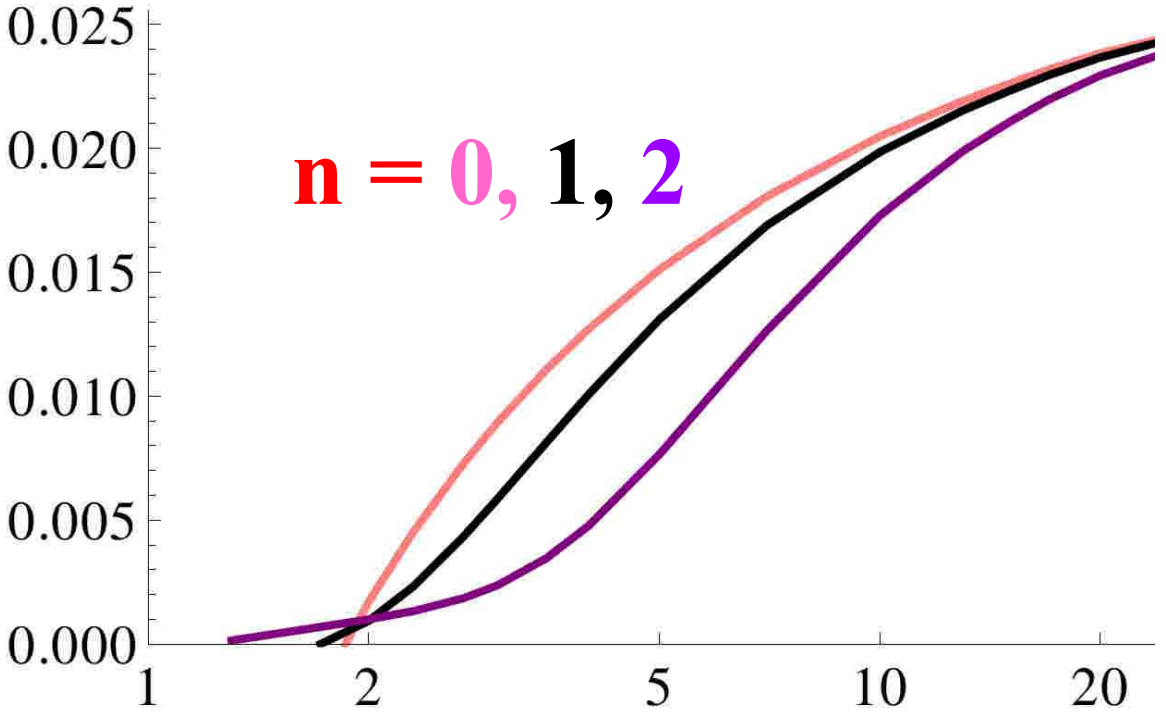




χ -Prescription

rescaling: $$x \to \chi = x \left[1 + \frac{(n\,m)^2}{Q^2} \right]$$





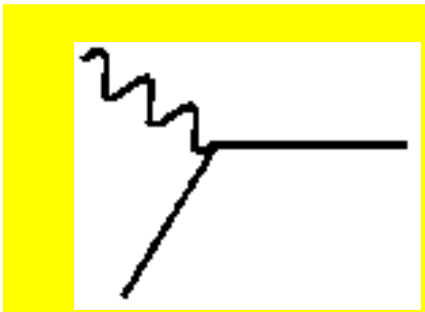
Higher Orders

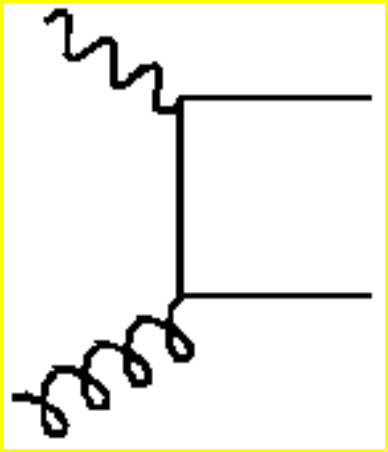
An example...

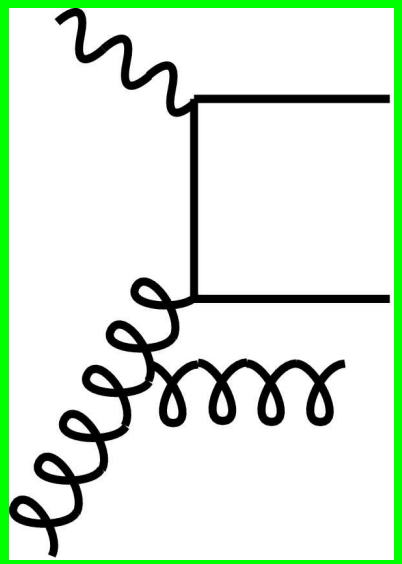
ACOT@ NNLO + N^3LO

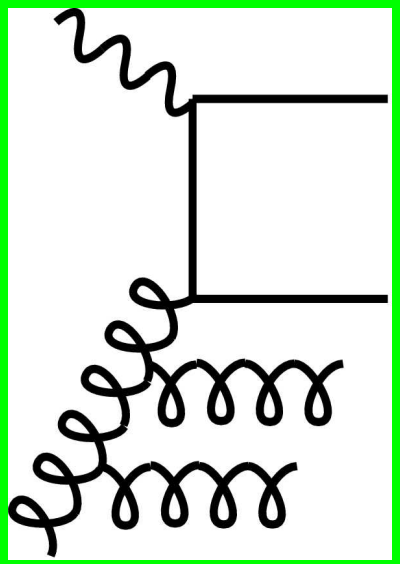
Stavreva, Olness, Schienbein, Jezo, Kusina, Kovarik, Yu
Phys.Rev. D85 (2012) 114014

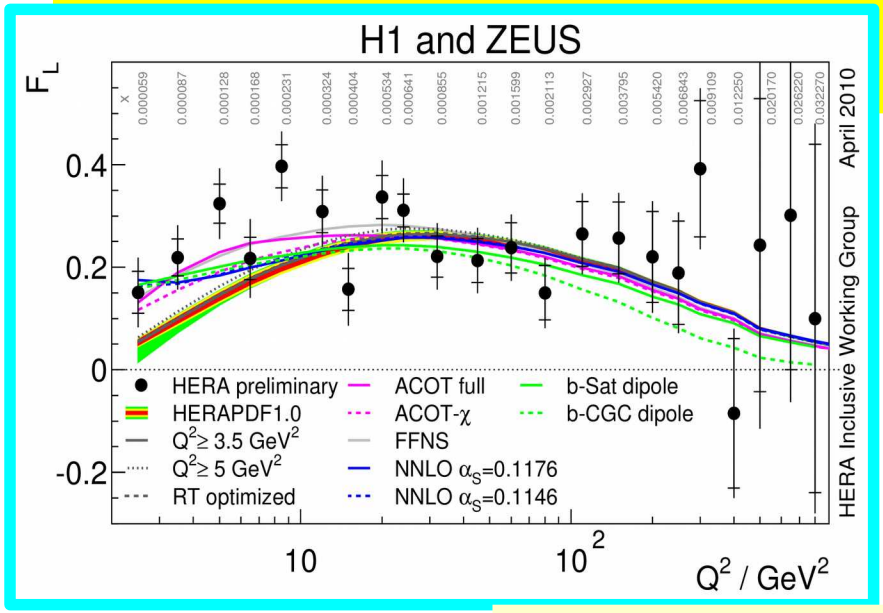
LO **NLO** **N2LO** **N3LO**









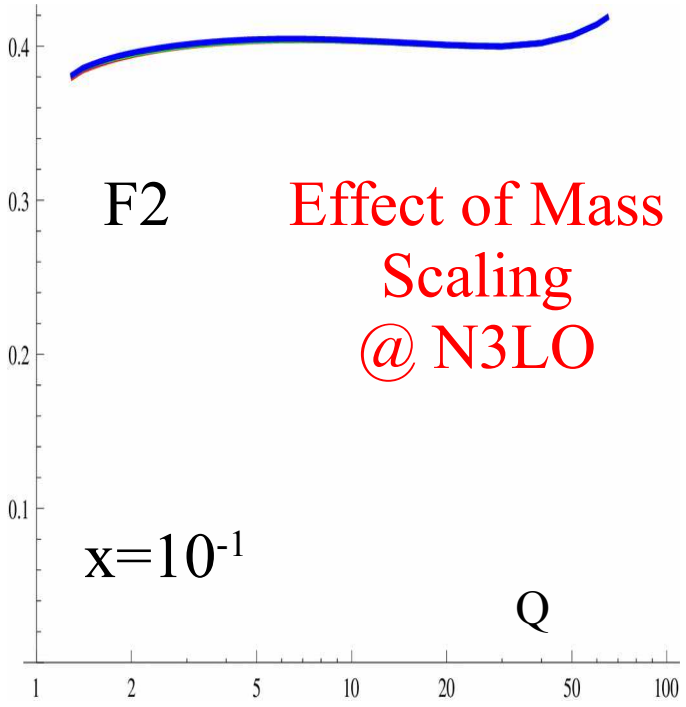


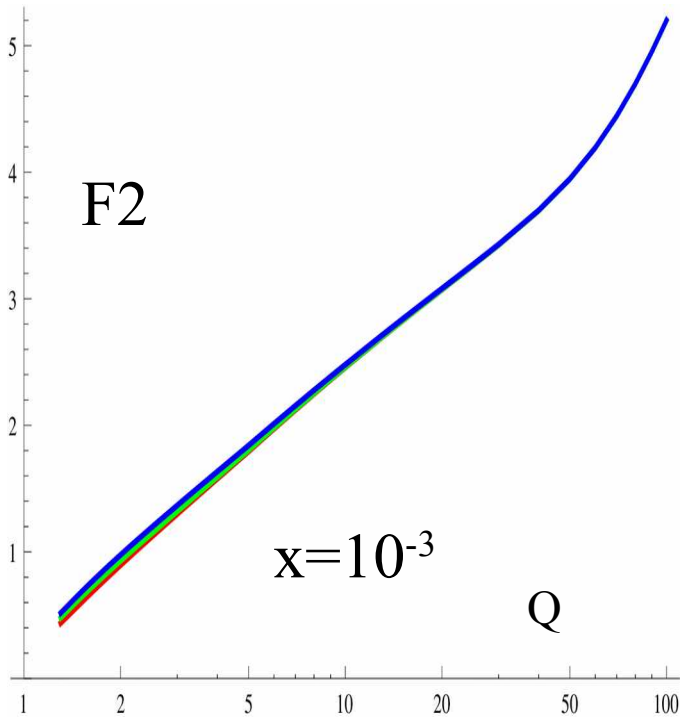
Masses are important

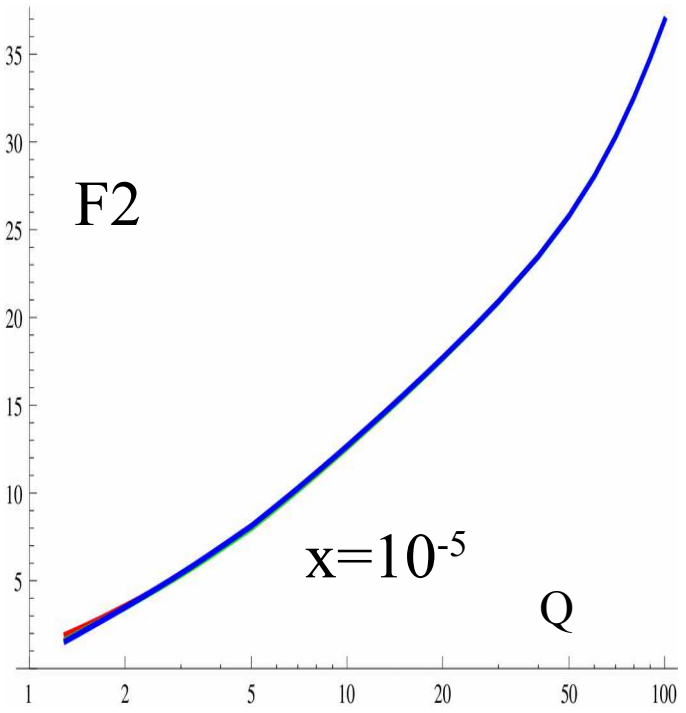
Higher Orders are important

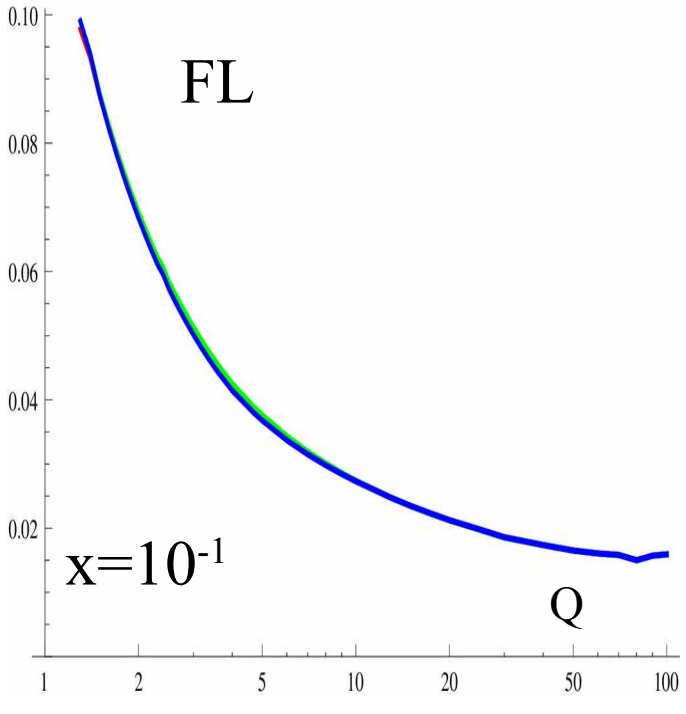
$$F_L \sim \frac{m^2}{Q^2} q(x) + \alpha_S \{c_g \otimes g(x) + c_q \otimes q(x)\}$$

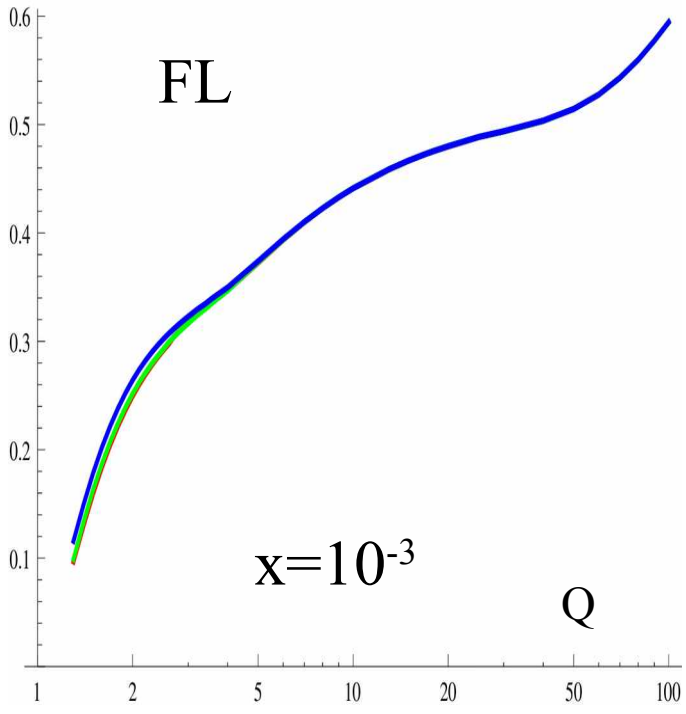
EFFECT OF MASS SCALING @ N3LO (Phase Space Mass)

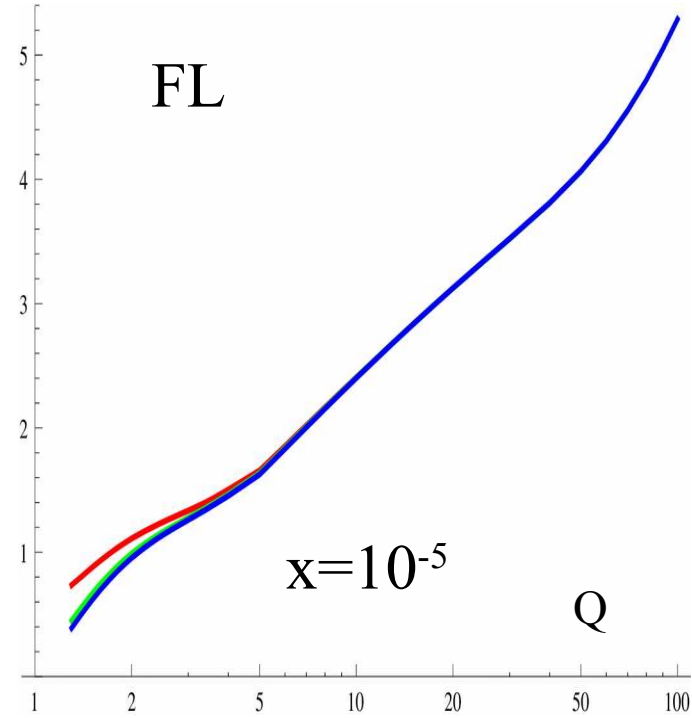




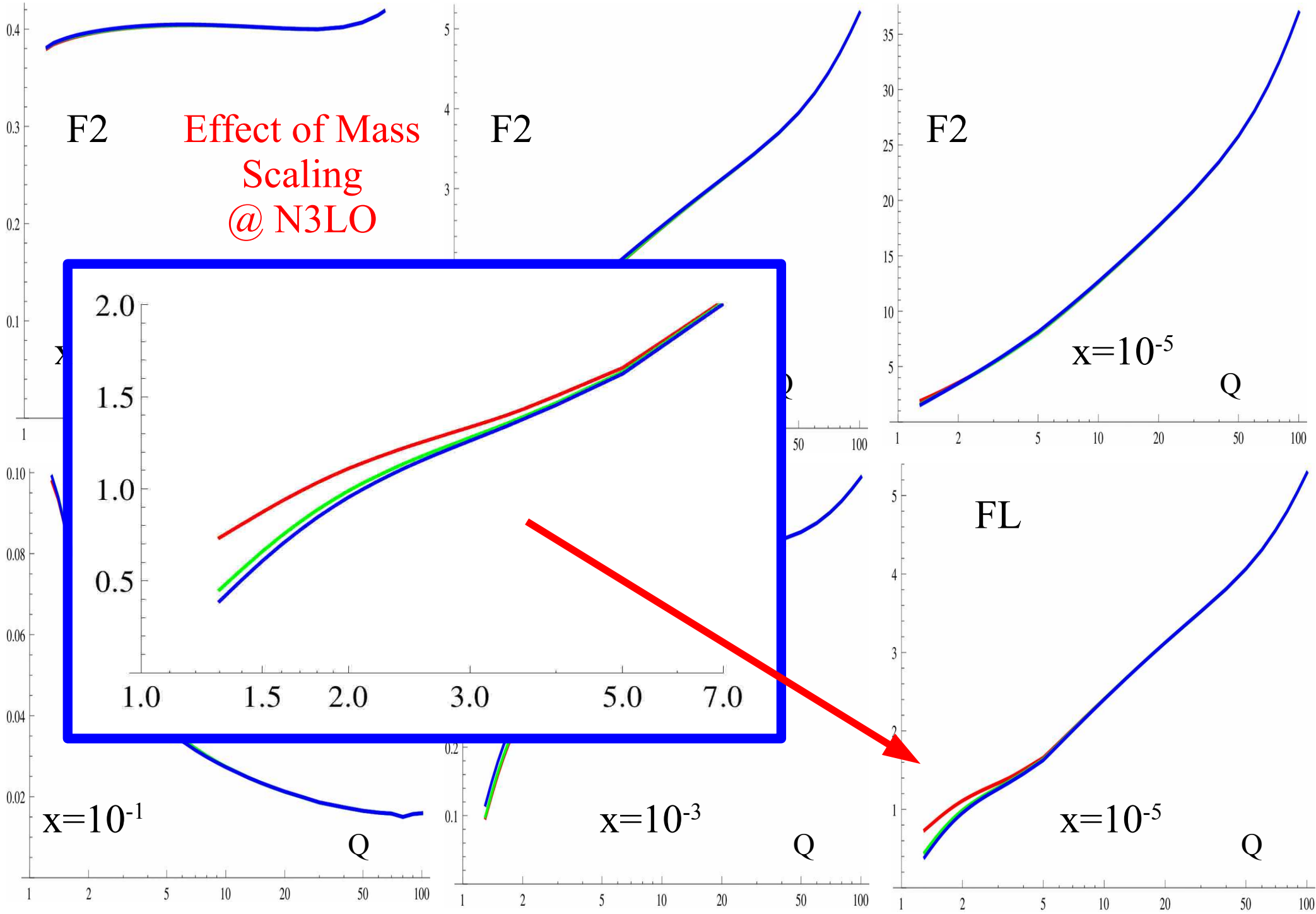




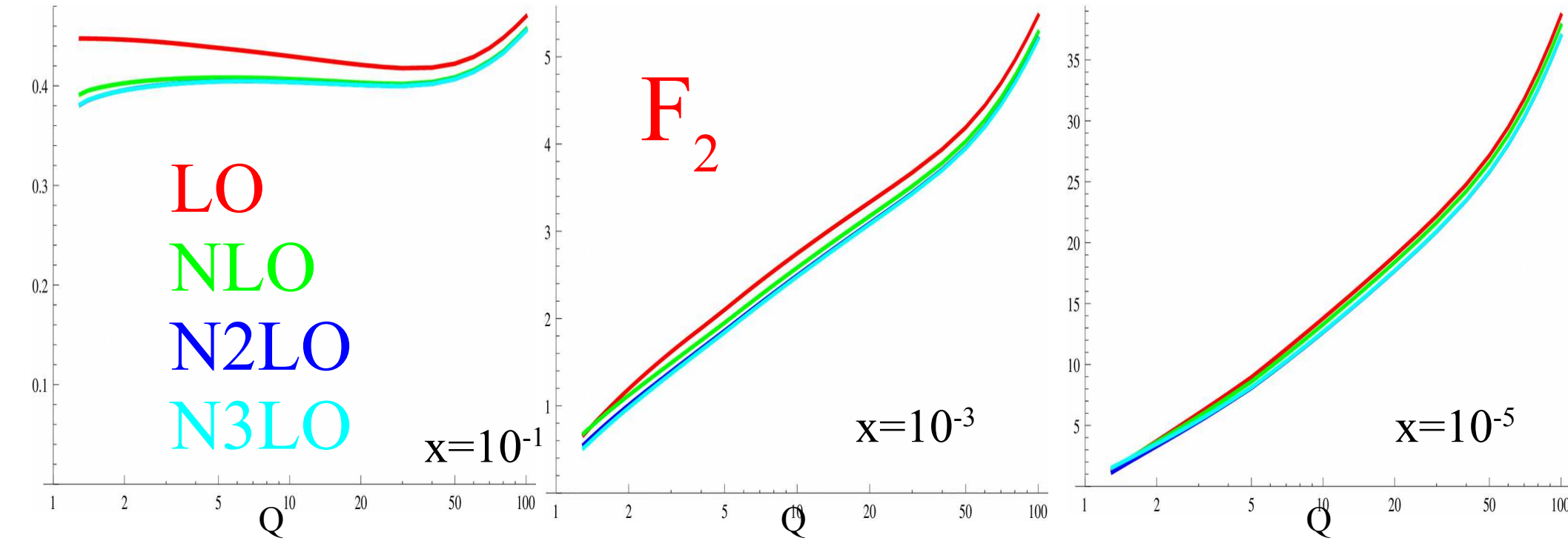


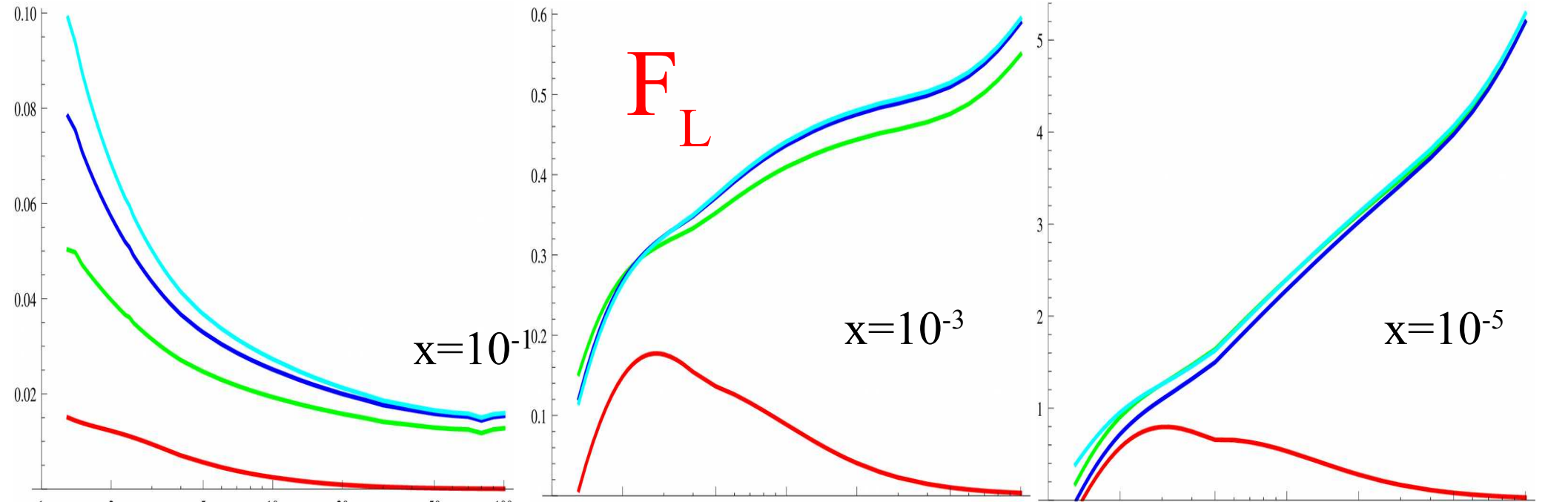


EFFECT OF MASS SCALING @ N3LO (Phase Space Mass)



$F_{2,L}$ @ N3LO





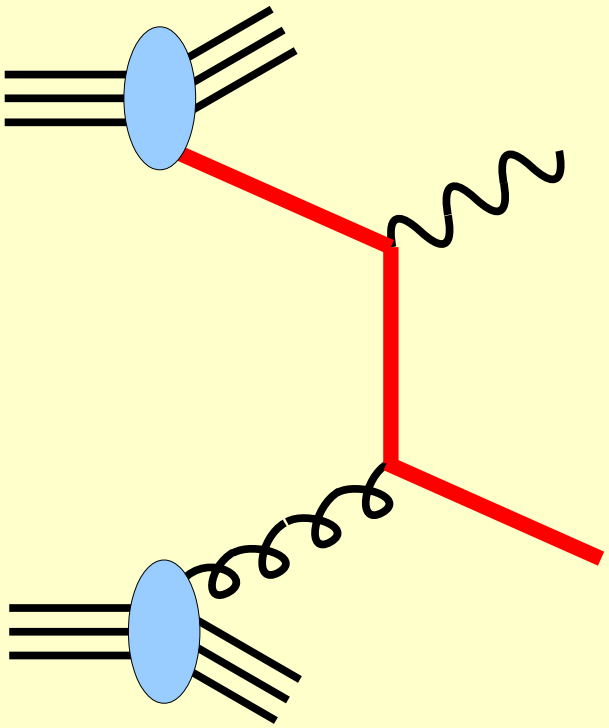
... what about the

Heavy Quarks

at high energies

Tevatron & LHC

Tevatron & LHC can Access Heavy Flavor Components Directly



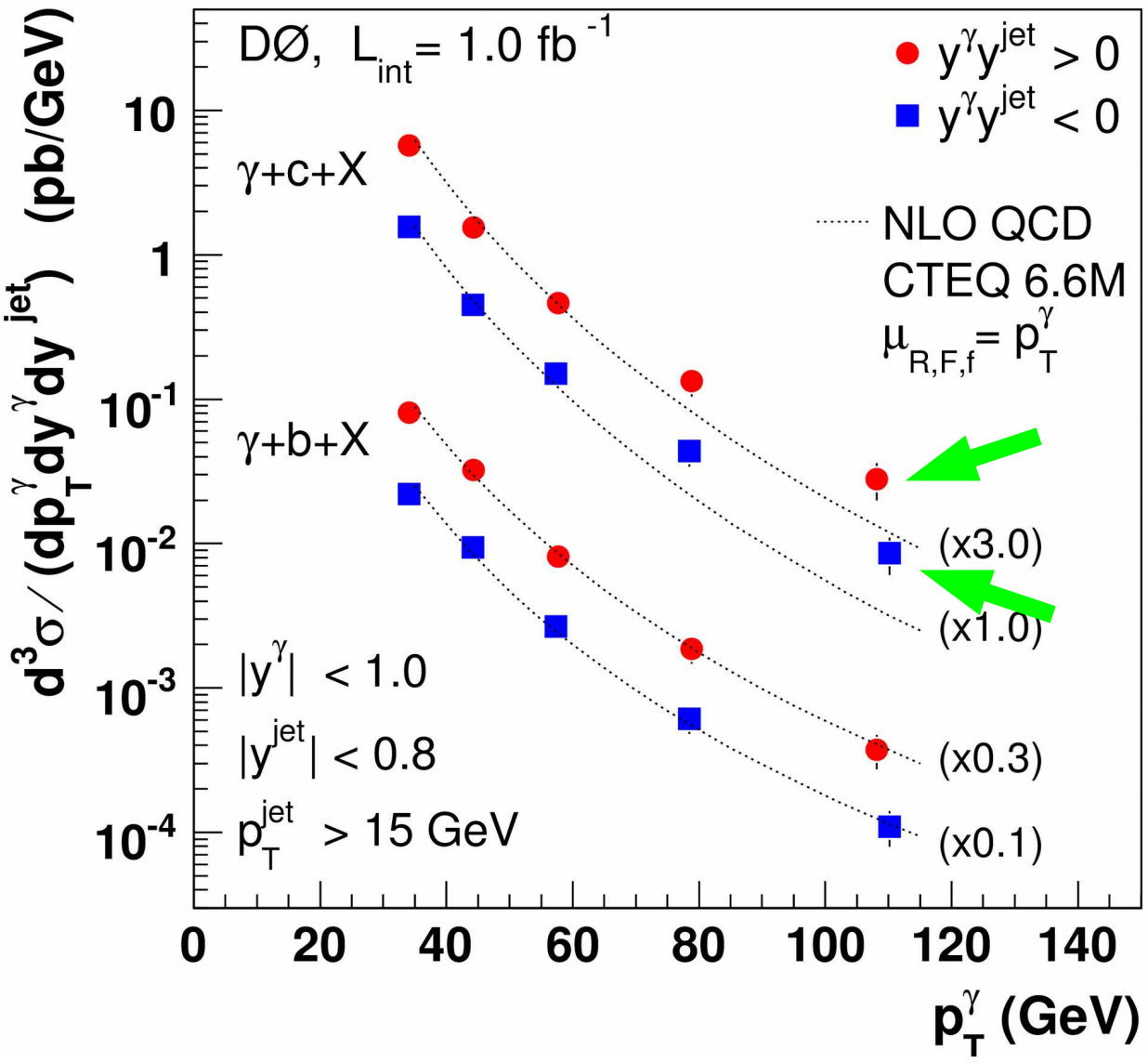
$$c\ g \rightarrow c\ \gamma$$

$$b\ g \rightarrow b\ \gamma$$

$$s\ g \rightarrow c\ W$$

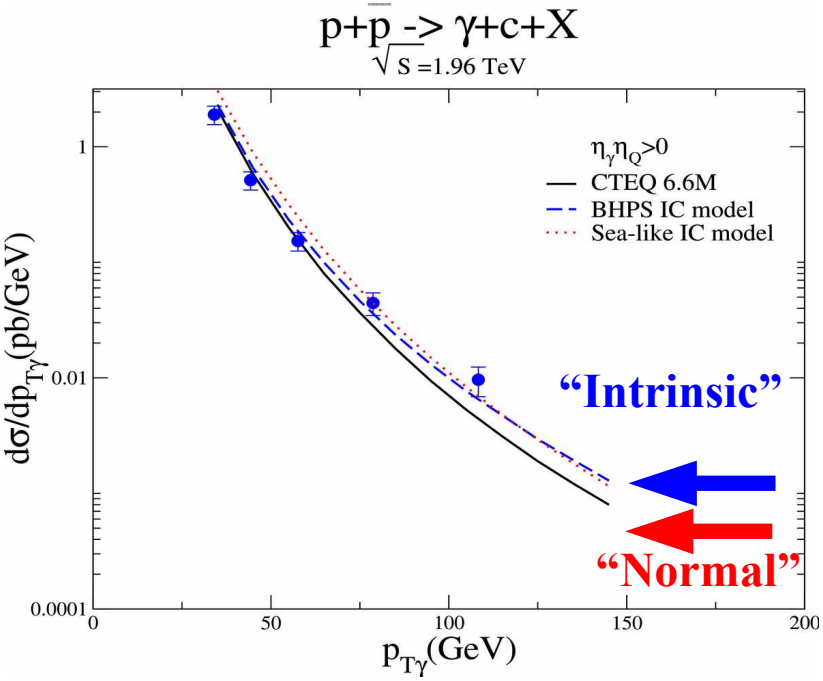
$$c\ g \rightarrow b\ W$$

Heavy Quarks at the Tevatron: … "intrinsic" charm???



Excess in Charm,
NOT Bottom

only at high PT



D. Duggan (D0) arXiv:0906.0136

T. Stavreva, I. Schienbein, F. Arleo, K. Kovarik, F. Olness, J.Y. Yu, J.F. Owens, JHEP 1101 (2011) 152

Heavy Quarks at the Tevatron: … "intrinsic" charm???

DGLAP Evolution equations …
including **ordinary Q_0** and **intrinsic Q_1** heavy quark

$$\dot{g} = P_{gg} \otimes g + P_{gq} \otimes q + P_{gQ} \otimes Q_0 + \cancel{P_{gQ} \otimes Q_1},$$
$$\dot{q} = P_{qg} \otimes g + P_{qq} \otimes q + P_{qQ} \otimes Q_0 + \cancel{P_{qQ} \otimes Q_1},$$
$$\dot{Q}_0 + \dot{Q}_1 = P_{Qg} \otimes g + P_{Qq} \otimes q + P_{QQ} \otimes Q_0 + P_{QQ} \otimes Q_1 .$$

neglect

Equations decouple:
- Intrinsic component evolves independently
- Scale set by m_Q
- Adjust normalization by simple rescaling

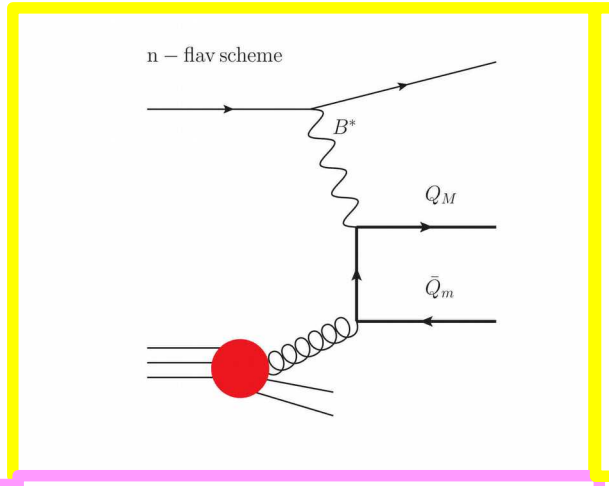
$$\dot{Q}_1 = P_{QQ} \otimes Q_1 .$$

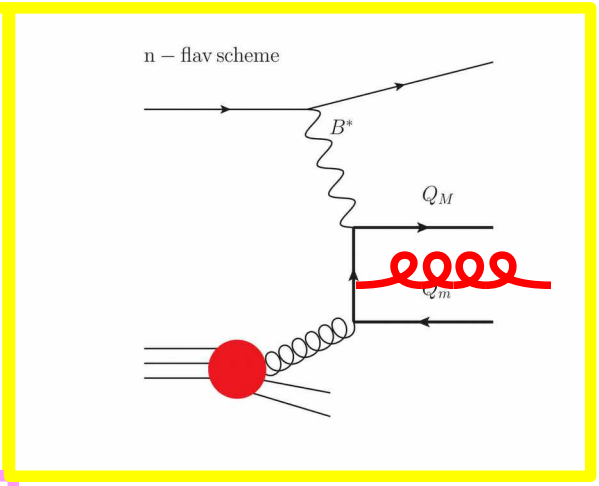
$$c_1(x) = \bar{c}_1(x) \propto x^2[6x(1+x)\ln x + (1-x)(1+10x+x^2)]$$

arXiv:1504.05156: On the intrinsic bottom content of the nucleon and its impact on heavy new physics at the LHC
F. Lyonnet, A. Kusina, T. Ježo, K. Kovařík, F. Olness, I. Schienbein, J.Y. Yu

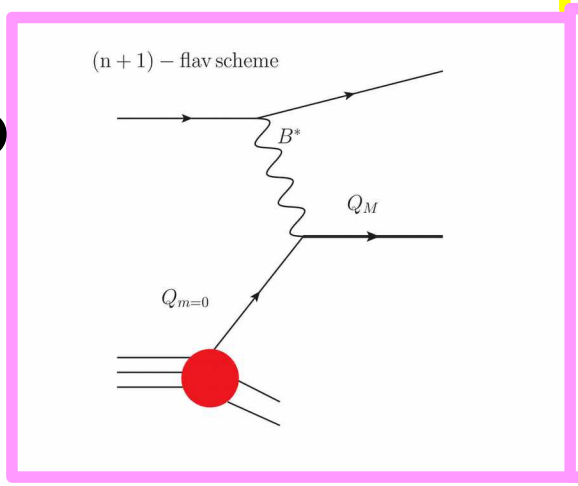
Thoughts

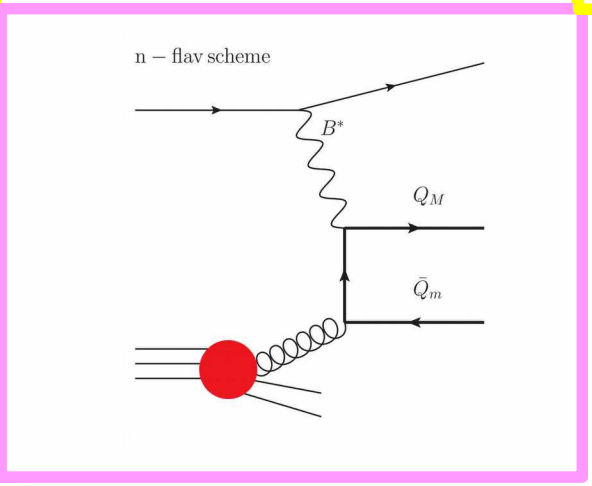
4 Flavor NLO

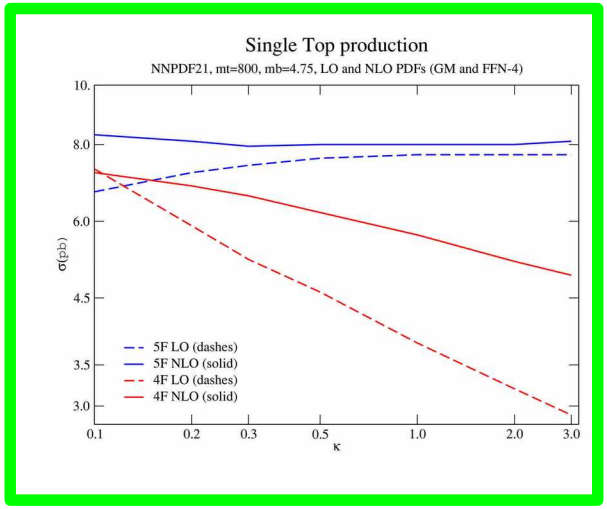


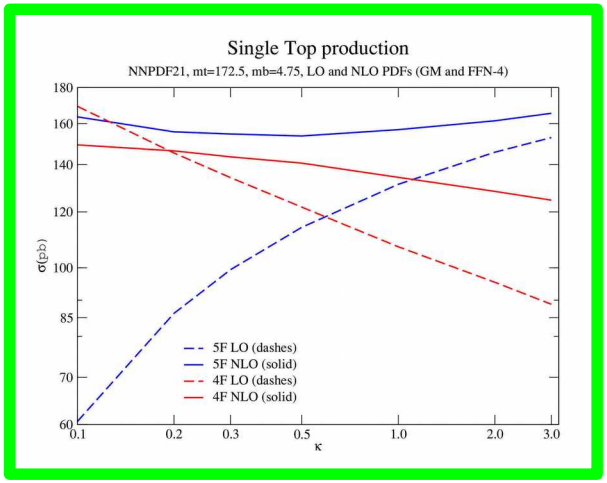


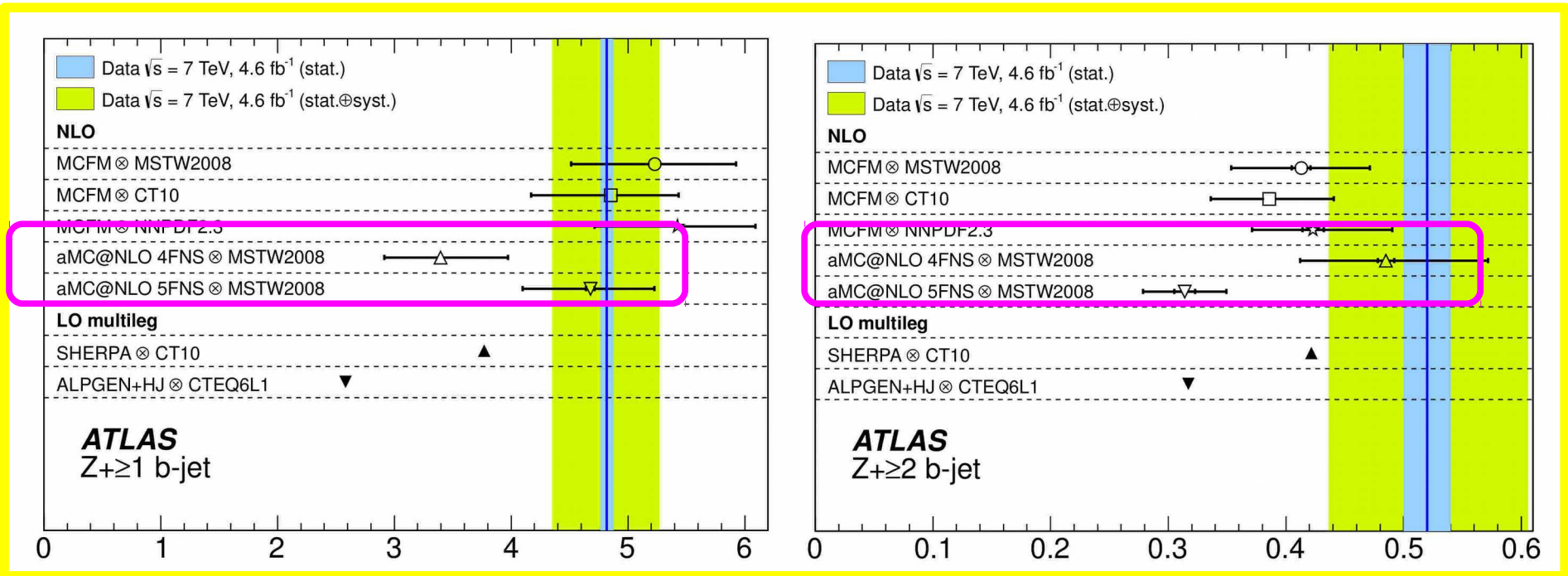
5 Flavor NLO











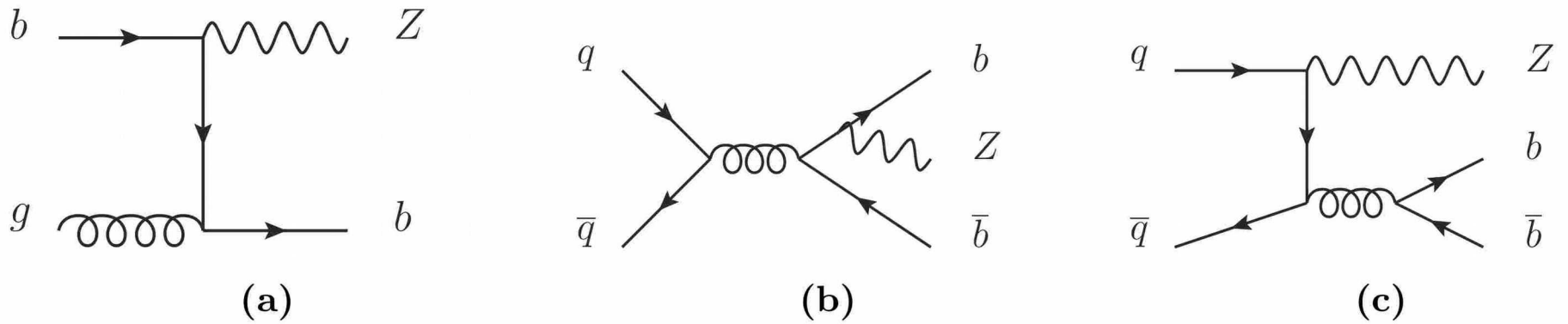


Figure 1. Leading order Feynman diagrams contributing to Z+b-jets production. Process 1a is only present in a 5FNS calculation, while 1b and 1c are present in both the 4FNS and 5FNS calculations.

Conclusions

* ACOT (& variations) allow full mass dependence

  based on CWZ renormalization scheme

  systematically applied to all orders

* Massless Evolution (MS-bar): no loss of information

* S-ACOT: can eliminate SOME masses WITHOUT loss of information

* χ -presription: rescaling: $x \rightarrow \chi = x(1+\mathrm{n}\ m^2/Q^2)$

  … helps at threshold; ALTERNATE: turn on at 2m or 4m, ...

  … use rescaling to estimate higher order contributions: N2LO, N3LO

* 5-Flavor Scheme encompasses 4-Flavor Scheme

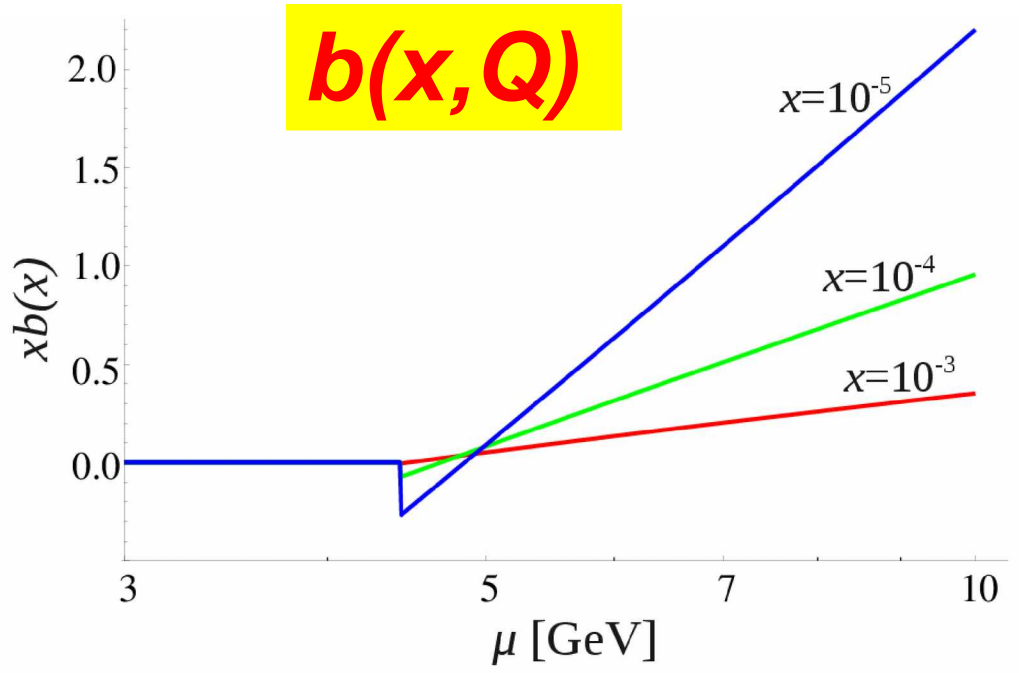
  … beware how higher-orders are “counted”

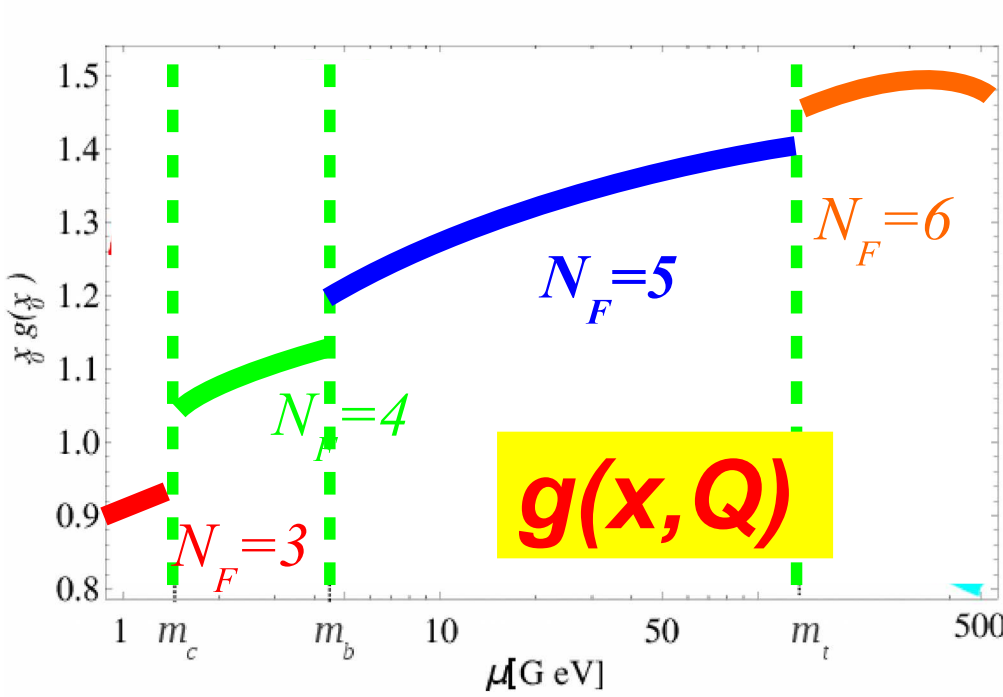
  … requires care when “truncated”: e.g. Z+b vs Z+bb

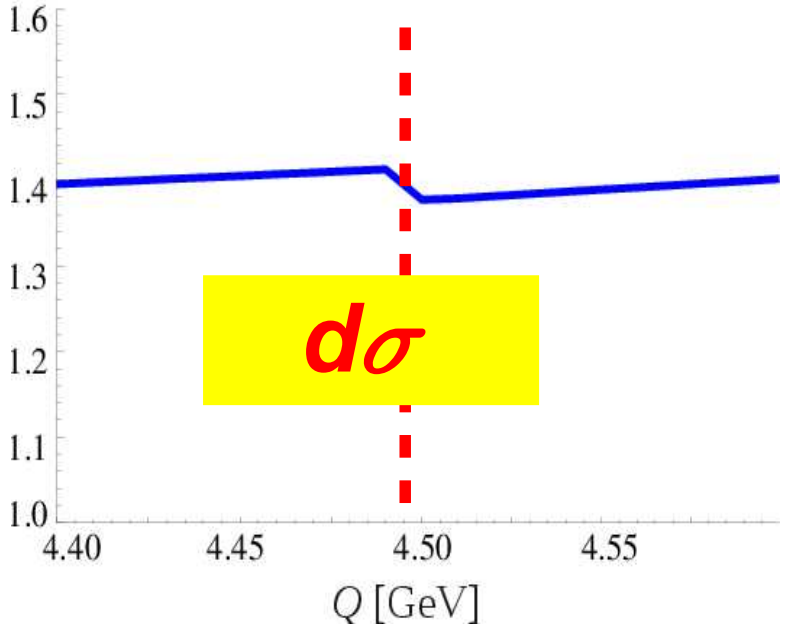
Lots of progress, in part due to xFitter. We'll need it for Precisions LHC

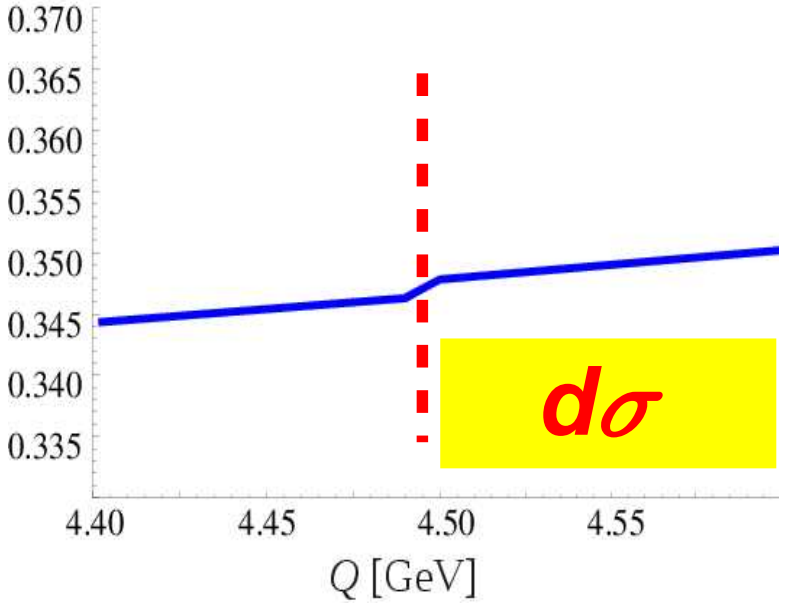
Leftover

At higher orders: f(x,Q) & $\alpha_s(Q)$ are discontinuous

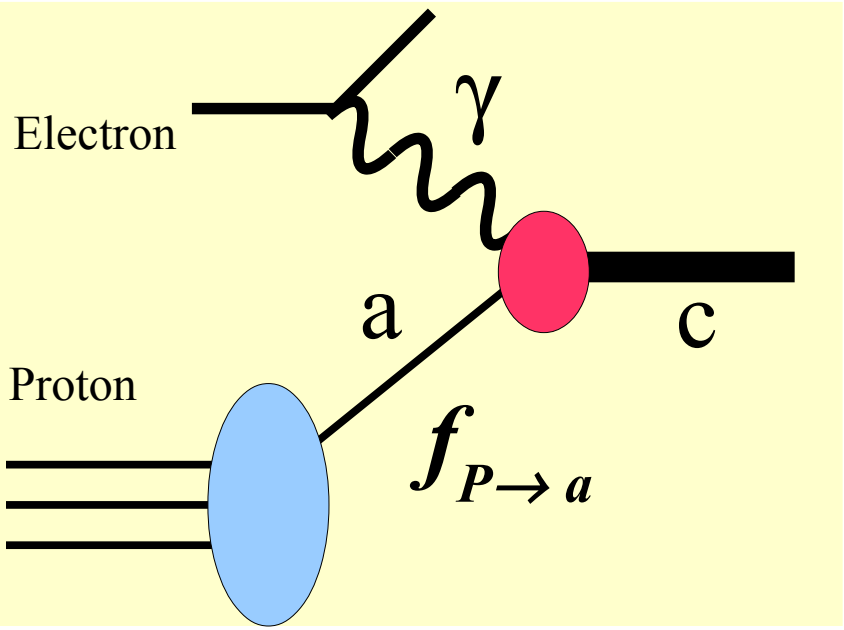








Pictorial Demonstration of Scheme Consistency

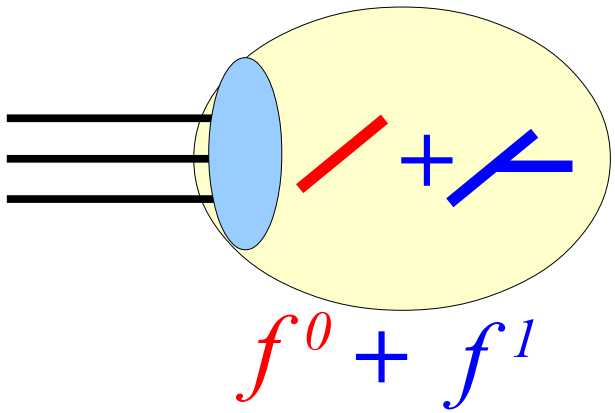


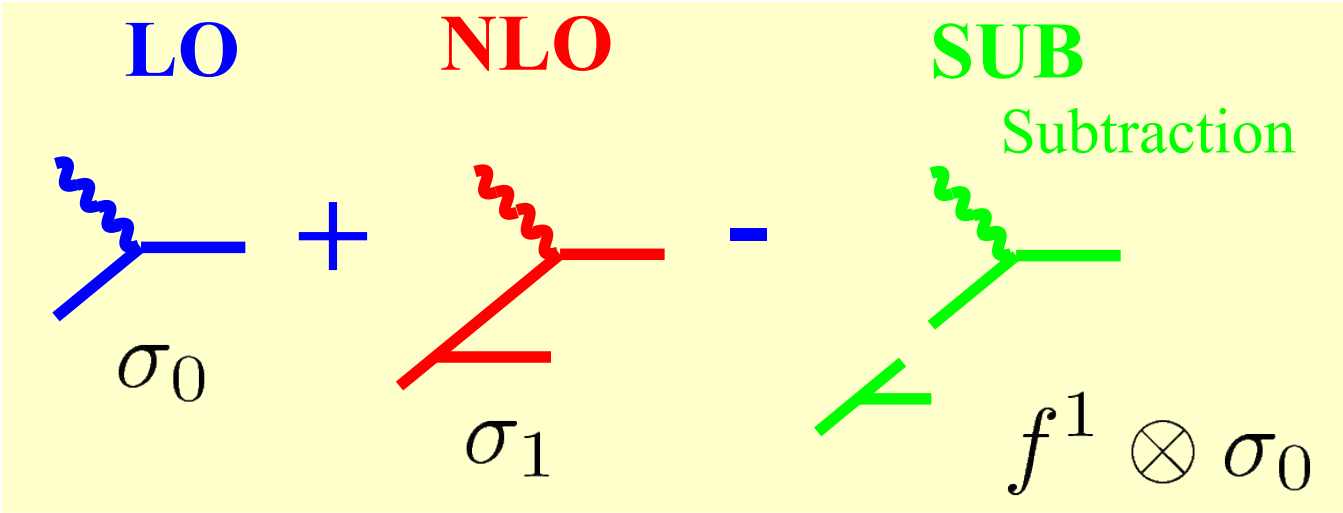
Parton Model

$$\sigma(Q^2) = f(\mu, \alpha_s) \otimes \widehat{\omega}(Q^2, \mu^2, \alpha_s)$$

Evolution Equation

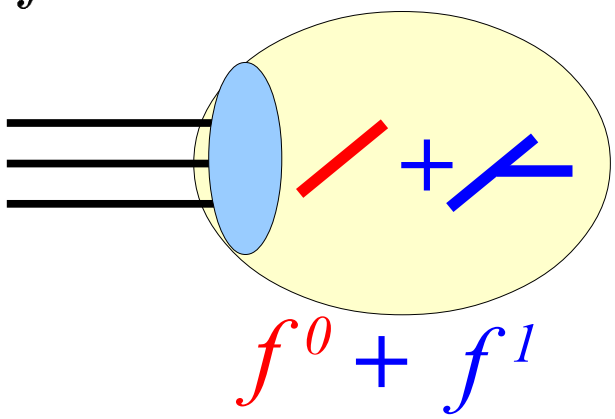
$$\frac{df}{\ln[\mu^2]} = P \otimes f$$





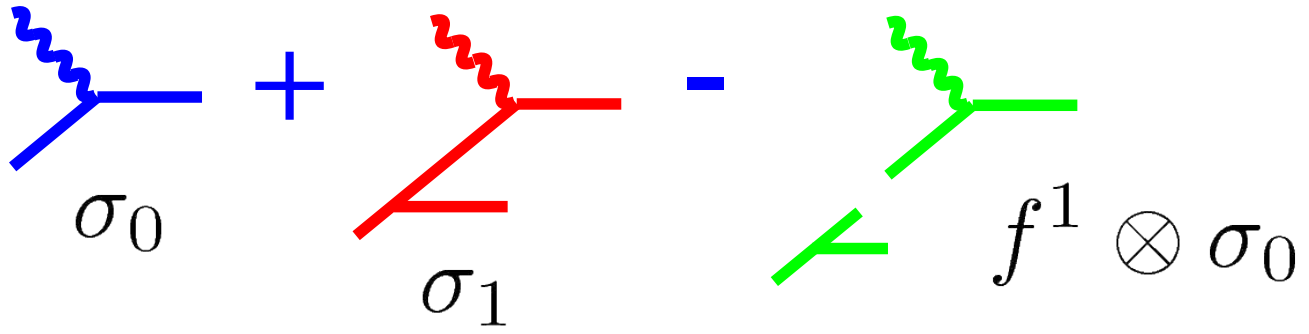
Pictorial Demonstration of Scheme Consistency

$f^0 \equiv \delta$



LO **NLO** **SUB**

Subtraction



Complete NLO Term

$$\left[\delta + f^1\right] \otimes \left[\sigma_0 + \sigma_1 - f^1 \otimes \sigma_0\right]$$

$$f^1 \sim \frac{\alpha_s}{2\pi} P^{(1)}$$

P(1) defined by scheme choice

$$\sigma_0 + \sigma_1 + f^1 \otimes \sigma_0 - f^1 \otimes \sigma_0 + \mathcal{O}(\alpha_s^2)$$

Contains BOTH collinear and non-collinear region

From PDF Evolution

From NLO Subtraction

QCD is Bullet-proof

Multi-Scale Problems are Challenging

Two-Loop Total Cross Section: One Scale

$$\sigma(Q^2)=\sigma_0\left\{1+\frac{\alpha_s(Q^2)}{4\pi}(3C_F)+\left[\frac{\alpha_s(Q^2)}{4\pi}\right]^2\left[-C_F^2\left[\frac{3}{2}\right]+C_FC_A\left[\frac{123}{2}-44\zeta(3)\right]+C_FTn_f(-22+16\zeta(3))\right]\right.$$

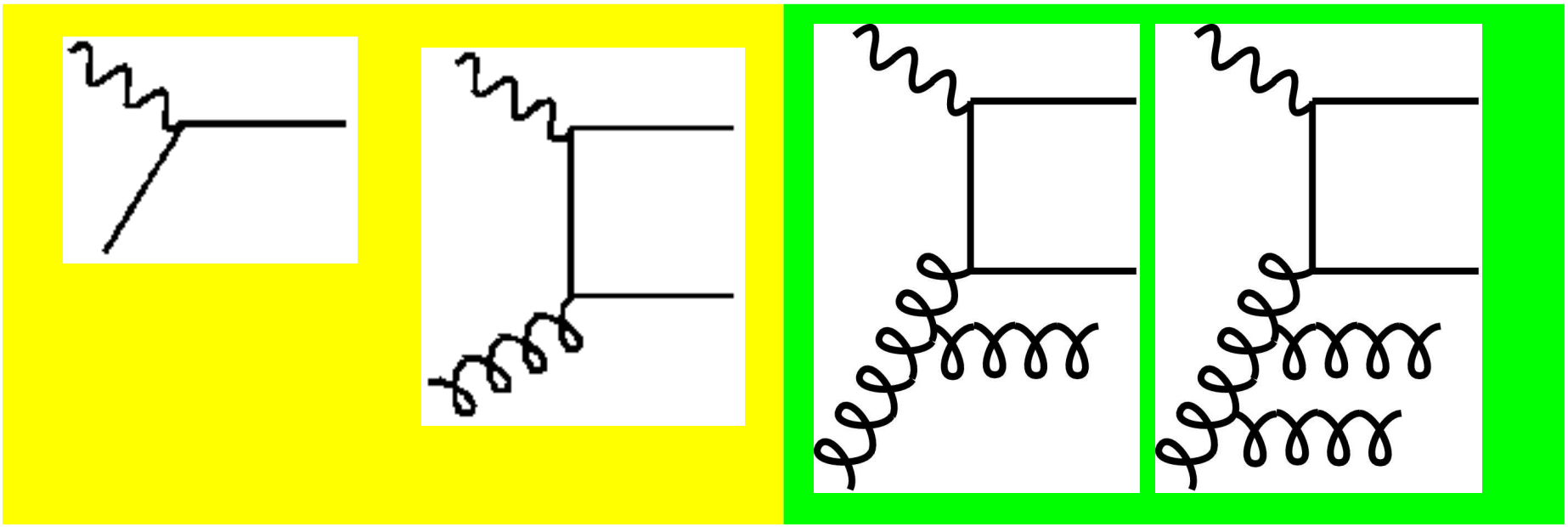
Two-Loop Drell-Yan Cross Section: Two Scales

$$\begin{aligned}
H_{q\bar{q}}^{(2),S+V}(z)=&\left[\frac{\alpha_s}{4\pi}\right]^2\delta(1-z)\left\{C_AC_F\left[\left[\tfrac{193}{3}-24\zeta(3)\right]\ln\left[\frac{Q^2}{M^2}\right]-11\ln^2\left[\frac{Q^2}{M^2}\right]-\tfrac{12}{5}\zeta(2)^2+\tfrac{592}{9}\zeta(2)+28\zeta(3)-\tfrac{1535}{12}\right]\right.\\
&+C_F^2\left[[18-32\zeta(2)]\ln^2\left[\frac{Q^2}{M^2}\right]+[24\zeta(2)+176\zeta(3)-93]\ln\left[\frac{Q^2}{M^2}\right]\right.\\
&\left.\left.+\tfrac{8}{5}\zeta(2)^2-70\zeta(2)-60\zeta(3)+\tfrac{511}{4}\right]\right.\\
&\left.+n_fC_F\left[2\ln^2\left[\frac{Q^2}{M^2}\right]-\tfrac{34}{3}\ln\left[\frac{Q^2}{M^2}\right]+8\zeta(3)-\tfrac{112}{9}\zeta(2)+\tfrac{127}{6}\right]\right\}\\
&+C_AC_F\left[-\tfrac{44}{3}\mathcal{D}_0(z)\ln^2\left[\frac{Q^2}{M^2}\right]+\{[\tfrac{536}{9}-16\zeta(2)]\mathcal{D}_0(z)-\tfrac{176}{3}\mathcal{D}_1(z)\}\ln\left[\frac{Q^2}{M^2}\right]\right.\\
&\left.-\tfrac{176}{3}\mathcal{D}_2(z)+[\tfrac{1072}{9}-32\zeta(2)]\mathcal{D}_1(z)+[56\zeta(3)+\tfrac{176}{3}\zeta(2)-\tfrac{1616}{27}]\mathcal{D}_0(z)\right]\\
&+C_F^2\left[[64\mathcal{D}_1(z)+48\mathcal{D}_0(z)]\ln^2\left[\frac{Q^2}{M^2}\right]+\{192\mathcal{D}_2(z)+96\mathcal{D}_1(z)-[128+64\zeta(2)]\mathcal{D}_0(z)\}\ln\left[\frac{Q^2}{M^2}\right]\right.\\
&\left.+128\mathcal{D}_3(z)-(128\zeta(2)+256)\mathcal{D}_1(z)+256\zeta(3)\mathcal{D}_0(z)\right]\\
&+n_fC_F\left[\tfrac{8}{3}\mathcal{D}_0(z)\ln^2\left[\frac{Q^2}{M^2}\right]+[\tfrac{32}{3}\mathcal{D}_1(z)-\tfrac{80}{9}\mathcal{D}_0(z)]\ln\left[\frac{Q^2}{M^2}\right]+\tfrac{32}{3}\mathcal{D}_2(z)-\tfrac{160}{9}\mathcal{D}_1(z)+[\tfrac{224}{27}-\tfrac{32}{3}\zeta(2)]\mathcal{D}_0(z)\right].
\end{aligned}$$

Ref: CTEQ Handbook

ACOT Extension to Higher Orders

LO **NLO** **N2LO** **N3LO**



Full ACOT

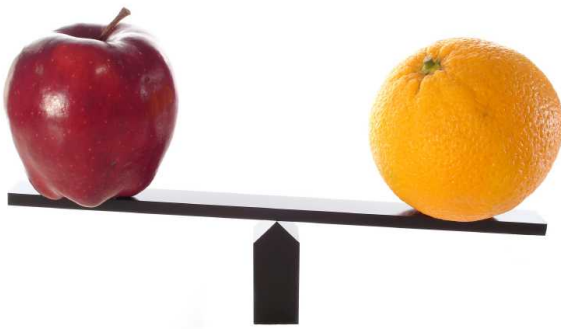
Based on the Collins-Wilczek-Zee (CWZ) Renormalization Scheme
... hence, extensible to all orders

DGLAP kernels & PDF evolution are pure MS-Bar
Subtractions are MS-Bar

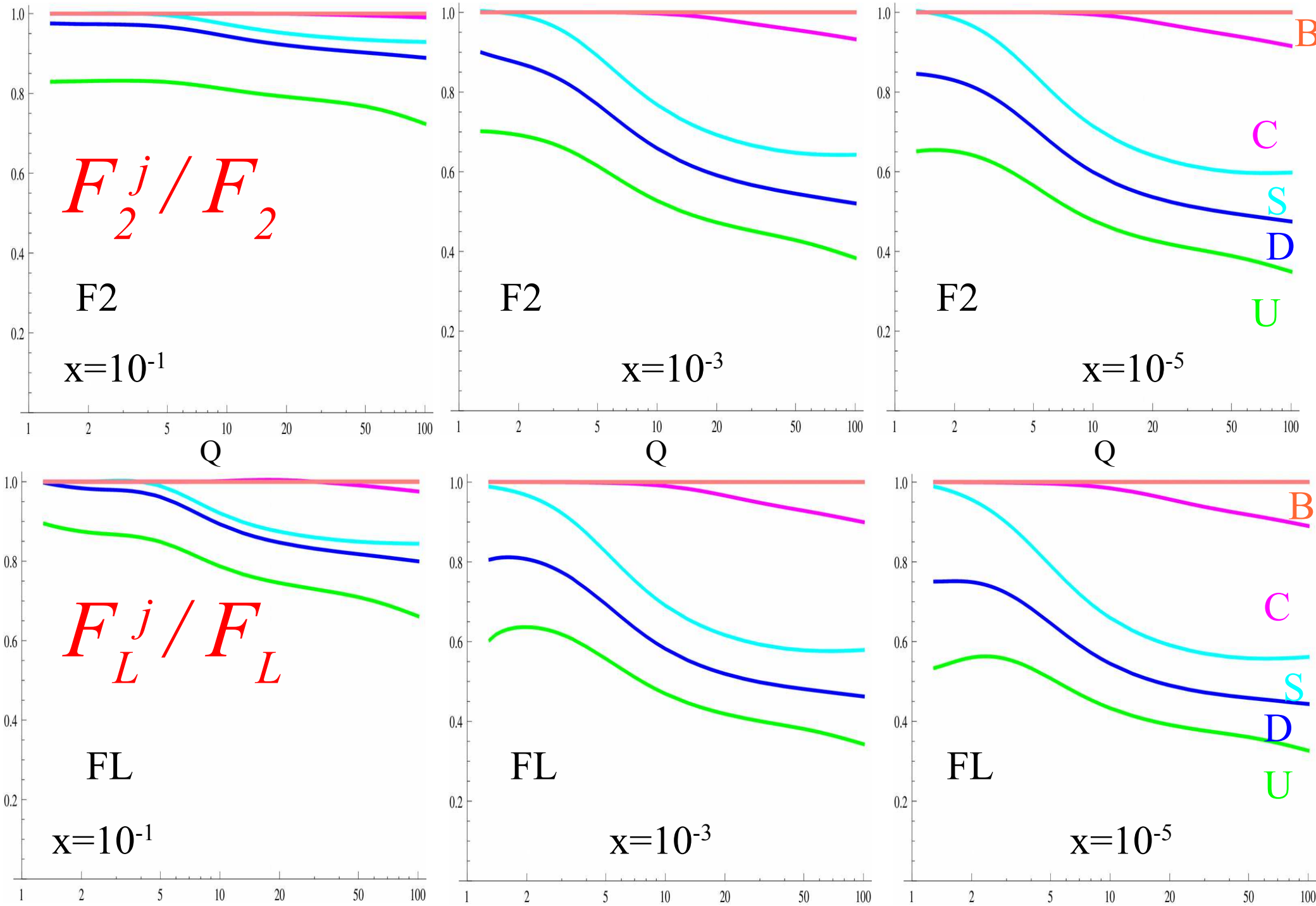
ACOT: $m \to 0$ limit yields MS-Bar
with no finite renormalization

PDFs Discontinuous at N2LO

α_s Discontinuous at α_s^3



FLAVOR DECOMPOSITION: Final State Quark:

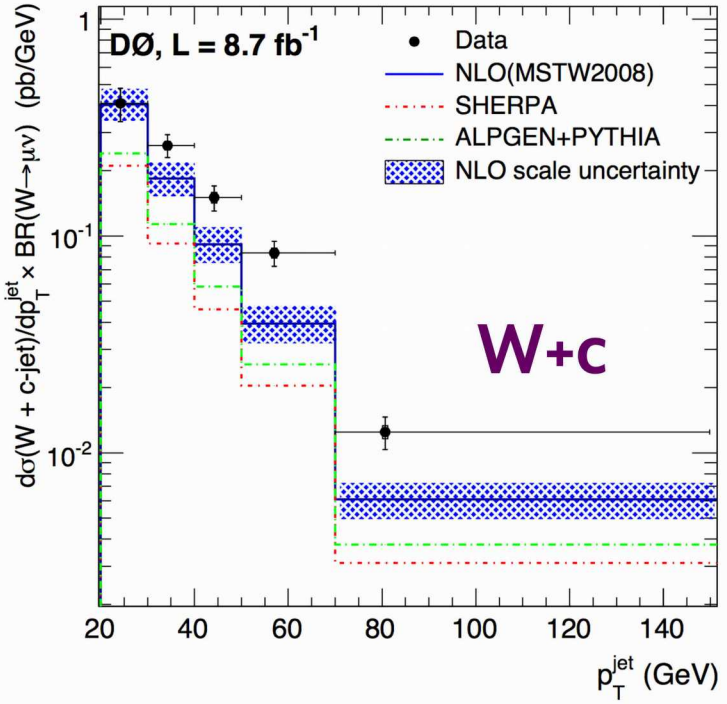


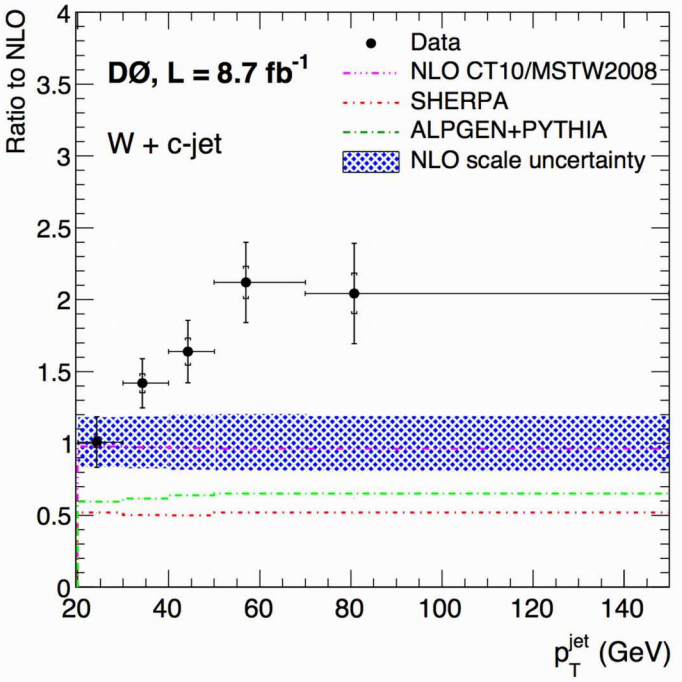
W+c production

Phys. Lett. B 743 (2015) 6; arXiv:1412.5315

Extracted W+c production rates corrected for efficiency and acceptance:

4–7% statistical and 12–17% systematic uncertainties, dominantly from c/b-jet ID, selection efficiency, and luminosity





Cross-section compared to predictions from NLO pQCD (corrected for non-perturbative effects), and Sherpa/Alpgen+Pythia MC models.

Unlike W+b, see a clear trend developing to higher jet p_T

High p_T range where gluon splitting becomes increasingly important.

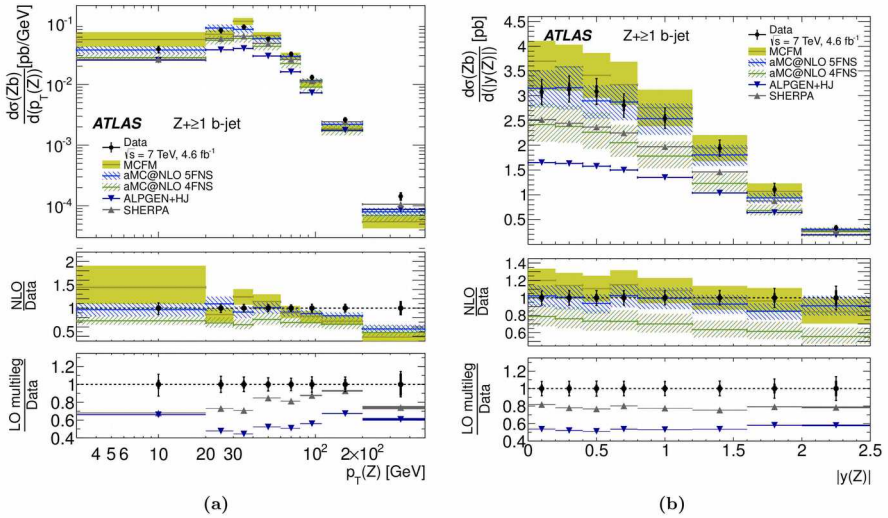


Figure 8. The cross-section $\sigma(Zb)$ as a function of Z boson p_{T} (a) and $|y|$ (b). The top panels show measured differential cross-sections as filled circles with statistical (inner) and total (outer bar) uncertainties. Overlayed for comparison are the NLO predictions from MCFM and aMC@NLO both using the MSTW2008 PDF set. The shaded bands represents the total theoretical uncertainty for MCFM and the uncertainty bands on aMC@NLO points represent the dominant theoretical scale uncertainty only. Also overlaid are LO multi-legged predictions for ALPGEN+HERWIG+JIMMY and SHERPA. The middle panels show the ratio of NLO predictions to data, and the lower panels show the ratio of LO predictions to data.

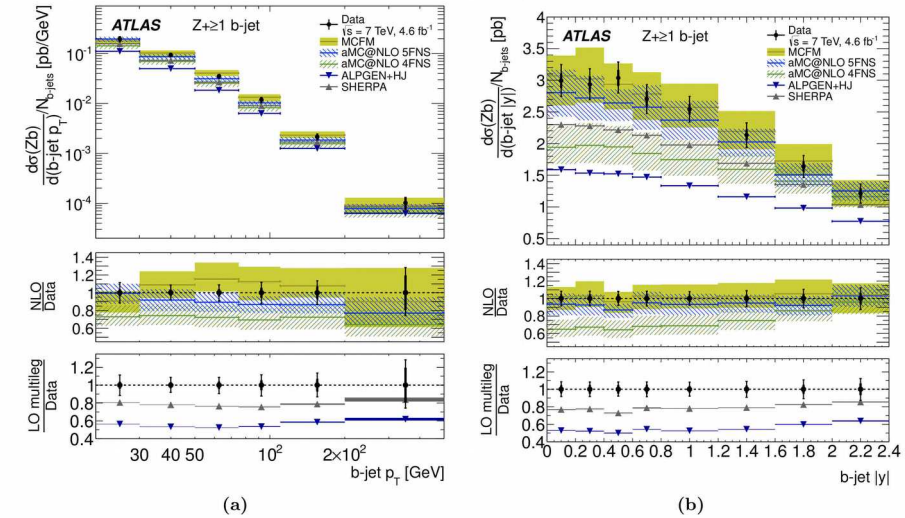


Figure 7. The inclusive b-jet cross-section $\sigma(Zb) \times N_{b\text{-jet}}$ as a function of b-jet p_{T} (a) and $|y|$ (b). The top panels show measured differential cross-sections as filled circles with statistical (inner) and total (outer bar) uncertainties. Overlayed for comparison are the NLO predictions from MCFM and aMC@NLO both using the MSTW2008 PDF set. The shaded bands represents the total theoretical uncertainty for MCFM and the uncertainty bands on aMC@NLO points represent

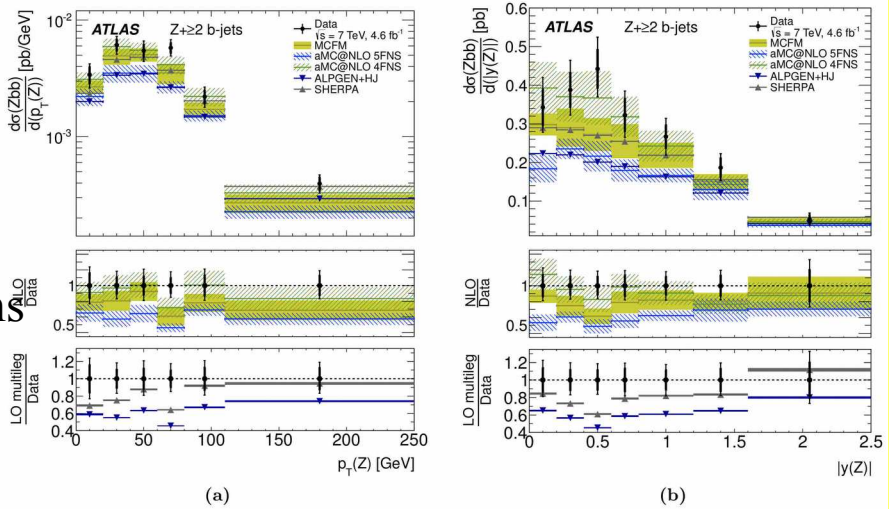


Figure 11. The cross-section $\sigma(Zbb)$ as a function of Z boson p_{T} (a), and $|y|$ (b). The top panels show measured differential cross-sections as filled circles with statistical (inner) and total (outer bar) uncertainties. Overlayed for comparison are the NLO predictions from MCFM and aMC@NLO both using the MSTW2008 PDF set. The shaded bands represents the total theoretical uncertainty for MCFM and the uncertainty bands on aMC@NLO points represent the dominant theoretical scale uncertainty only. Also overlaid are LO multi-legged predictions for ALPGEN+HERWIG+JIMMY and SHERPA. The middle panels show the ratio of NLO predictions to data, and the lower panels show the ratio of LO predictions to data.

ArXiv ePrint: 1407.3643

Measurement of differential production cross-sections for a Z boson in association with b-jets in 7 TeV proton-proton collisions with the ATLAS detector

Measurement of the cross-section for W boson production in association with b-jets in pp collisions at
√s = 7 TeV with the ATLAS detector

JHEP 06 (2013) 084

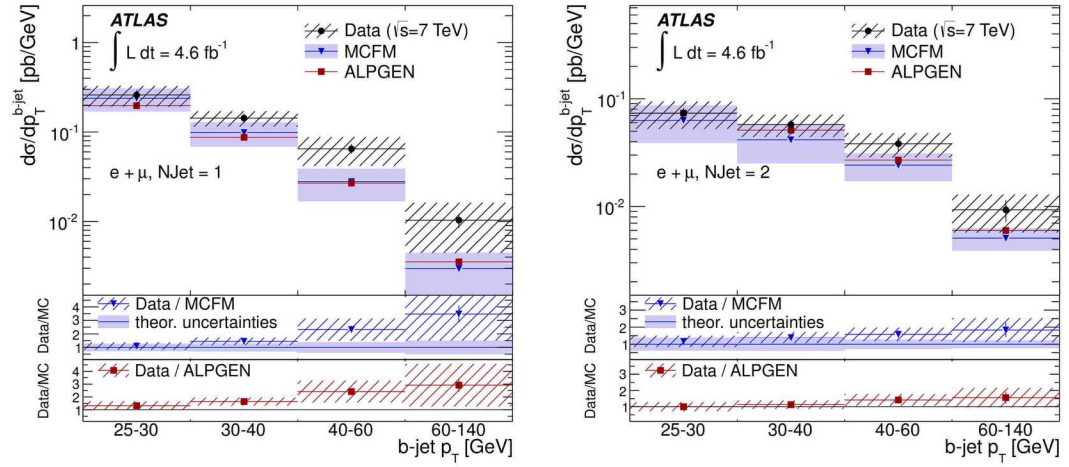


Figure 8. Measured differential $W+b$-jets cross-sections with the statistical plus systematic uncertainties as a function of $p_{\mathrm{T}}^{b\text{-jet}}$ in the 1-jet (left) and 2-jet (right) fiducial regions, obtained by combining the muon and electron channel results. The measurements are compared to the MCFM predictions and to the ALPGEN predictions interfaced to HERWIG and JIMMY and scaled by the NNLO inclusive W normalization factor. The ratios between measured and predicted cross-sections are also shown.

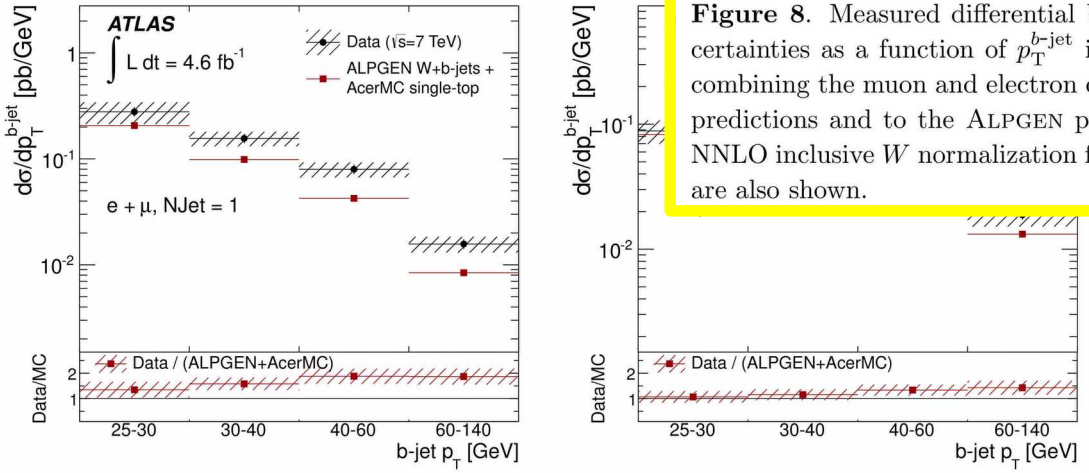


Figure 9. Measured differential $W+b$-jets cross-section without single-top subtraction as a function of $p_{\mathrm{T}}^{b\text{-jet}}$ in the 1-jet (left) and 2-jet (right) samples, obtained by combining the electron and muon channels. The measurements are compared to the $W+b$-jets plus single-top predictions obtained using ALPGEN interfaced to HERWIG and JIMMY and scaled by the NNLO inclusive W normalization factor plus ACERMC interfaced to PYTHIA and scaled to the NLO single-top cross-section. The ratios between measured and predicted cross-sections are also shown.

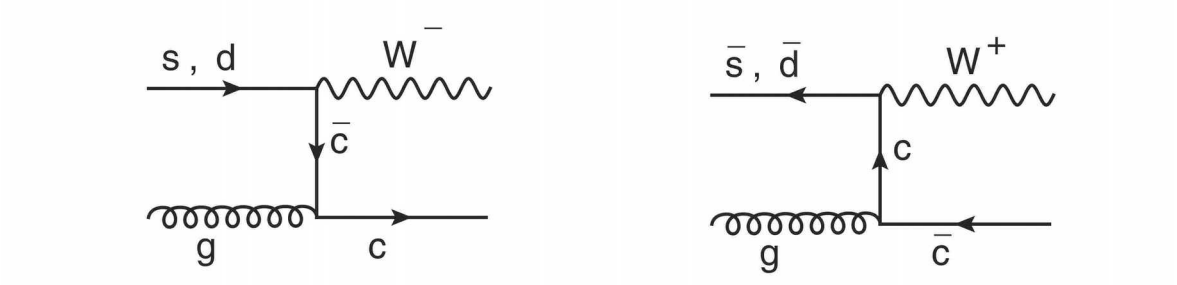
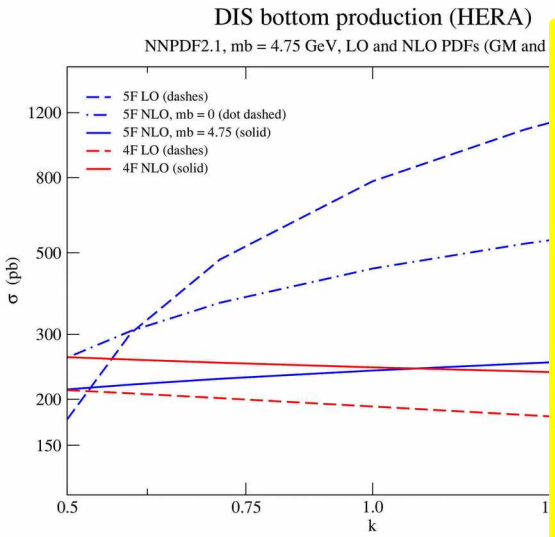


Figure 1. Main diagrams at the hard-scattering level for associated W + c production at the LHC.



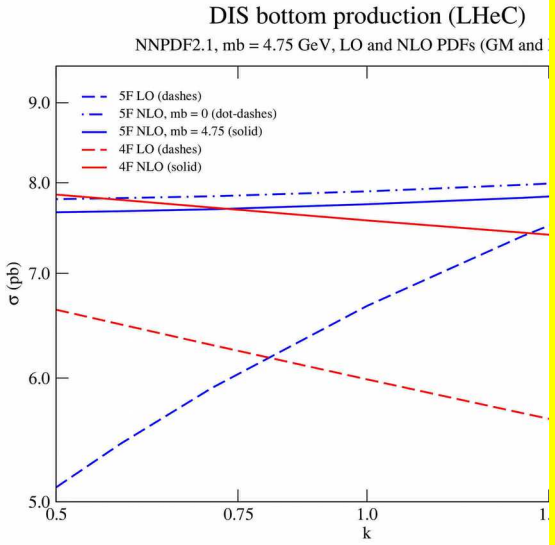
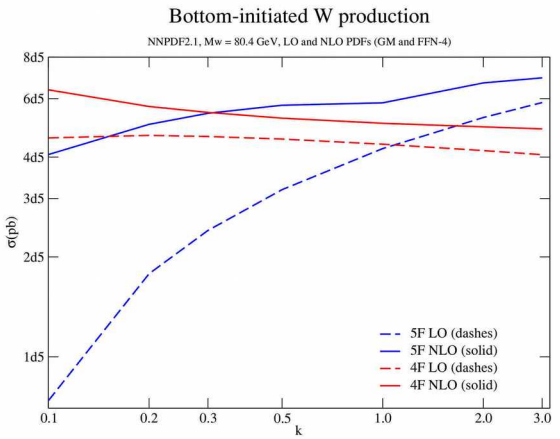
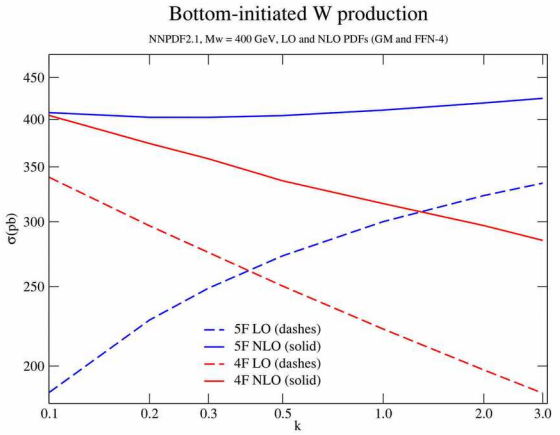


Figure 3. Comparison between 4F and 5F production for $b\bar{b}$ pr
and LHeC (bottom). Input PDFs: `NNPDF2.1_FFN_NF4` (LO and NL
HVQDIS) and `NNPDF2.1` (LO and NLO) for the 5F scheme (run w
$m_b = 4.75\,\text{GeV}$, $k = \mu/\sqrt{Q^2 + 4m_b^2}$, with $\mu = \mu_F = \mu_R$.





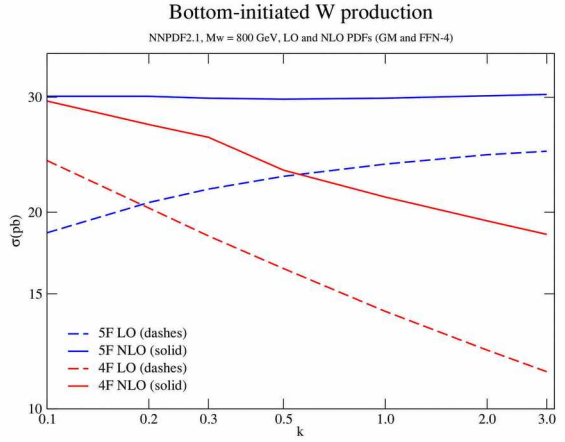


Figure 6. Comparison between 4F and 5F production for b-initiated W production at LHC 14 TeV,