Prediction for charm in CC in xFitter

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ZAF, 15 May 2018

(slides from xFitter developers meeting on 09 May 2018, with contributions from Valerio Bertone and Fred Olness)

Introduction

- In the old interface we had:
  - NC DIS inclusive
  - NC DIS charm
  - NC DIS beauty
  - CC DIS inclusive
- In the new interface it is straightforward to implement all possible variants:
  - reaction: NC DIS or CC DIS
  - final state: inclusive, charm or beauty (beauty is not of interest in CC)
  - cross section type: F_2, F_L, σ_{red}, $\frac{d^2\sigma}{dxdQ^2}$

```
TheoryType = 'expression'
TermName = 'R'
TermType = 'reaction'
!TermSource = 'use:hf_scheme_DISNC'
TermSource = 'use:hf_scheme_DISCC'
TermInfo = 'type=sigred:flav=c:echarge=+1:epolarity=0:energy=318.',
TheorExpr = 'R'
```

- However, the definition of charm CC cross sections seems to be not straightforward from theory point of view

Implementation

- Task is of practical interest for ongoing analysis in ZEUS
- Implementation will be done in the new interface only
- Branch `charm-CC-XFITTER-70` (JIRA task # 70)
- Implementation can be done for:
  - ZMVFNS (QCDNUM)
  - FFABM (OPENQCDRAD)
  - FONLL (APFEL)
  - RTOPT implementation in xFitter uses ZMVFNS for CC
  - ACOT? not yet in new interface
- Inclusive CC prediction verified vs old interface for 3 schemes: exact agreement
- Charm CC prediction:
  - depends on CKM matrix
  - for massless treatment, can be defined only in terms of couplings, not partonic processes [1001.2312, section 5]
    $\Rightarrow$ both $s \to c$, $c \to s$ need to included in FONLL and (?) ZMVFNS
    $\Rightarrow$ this does not apply to FFABM? only $s \to c$ included in OPENQCDRAD
  - paper [1001.2312] discusses the impact of different theoretical and experimental definition of charm contribution, but only for NC
    - ★ concluded that it is at (sub)percent level for HERA
    - ★ seems to be not the case for CC: differences appear at LO

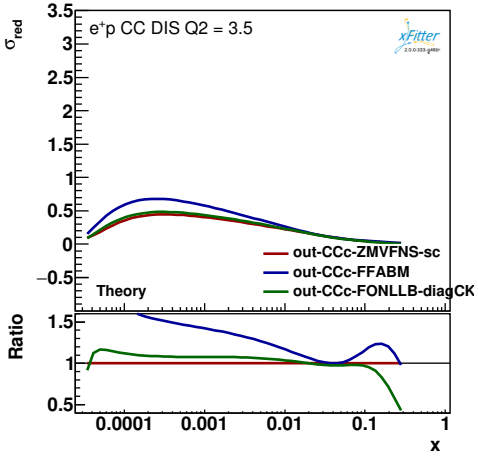
Implementation

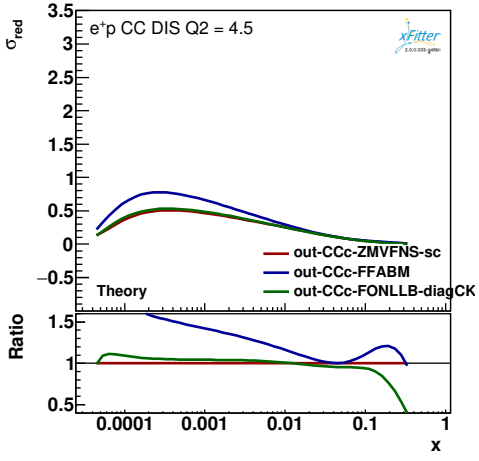
- Current status of charm CC implementation:
  - ZMVFNS (QCDNUM): implemented, but results are weird: to be checked with Michiel Botje
  - FFABM (OPENQCDRAD): straightforward to take from OPENQCDRAD (to be checked with Sergey Alekhin)
  - FONLL (APFEL): straightforward to take from APFEL, checked with Valerio
- Dependence on CKM matrix:
  - ZMVFNS so far uses diagonal CKM matrix
  - FFABM so far uses its own non-diagonal CKM matrix (setup inside OPENQCDRAD)
  - FONLL presently is the only reaction which preperly takes CKM matrix from parameters.yaml
    $\Rightarrow$ dependence on CKM checked by using diag. vs non-diag. CKM with FONLL
    $\Rightarrow$ setting of CKM from parameters.yaml to be implemented for ZMVFNS and FFABM
- Contribution from different processes:
  - checked in ZMVFNS by switching them on/off

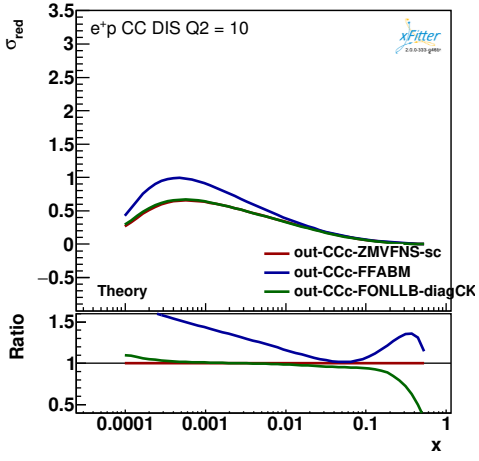
Tests

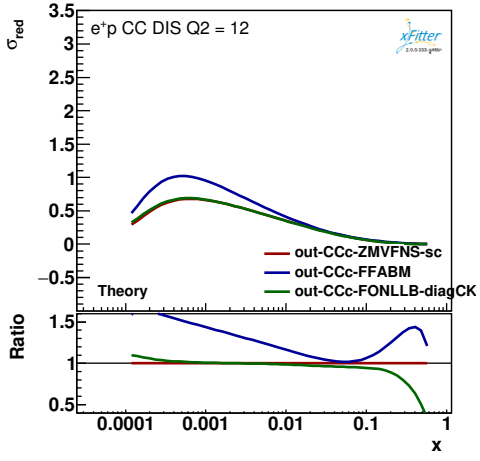
- Comparison of charm CC prediction done for ZMVFNS, FFABM and FONLL:
  - calculation at NLO
  - same PDFs at starting scale 1.9 GeV^2 (but different evolution, plots for PDFs in backup)
  - same charm mass (pole mass option in FFABM and FONLL)
  - FONLL-B with diagonal CKM (non-diag. CKM only in FFABM)
  - scales set to Q^2
  - pseudodata file used to provide predictions for $3.5 < Q^2 < 30000$ GeV^2 and full accesible x_{Bj} range
- Additionally, FONLL with diag. and non-diag. CKM compared
- Additionally, ZMVFNS with three sets of processes compared:
  - $c \to s$ only ('ZMFVNS-1')
  - $s \to c$ only ('ZMFVNS-2')
  - $s \to c$ and $c \to s$ ('ZMFVNS-3')

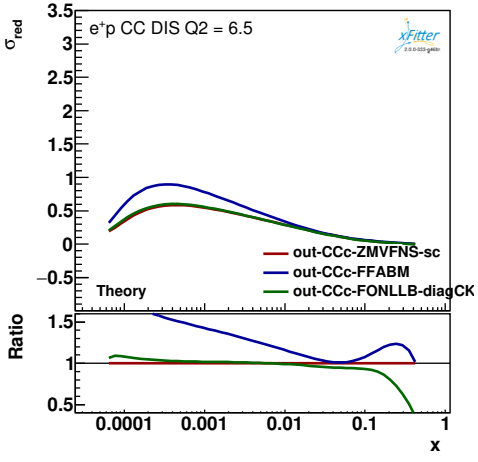
CC charm in three schemes (CC inclusive in backup)

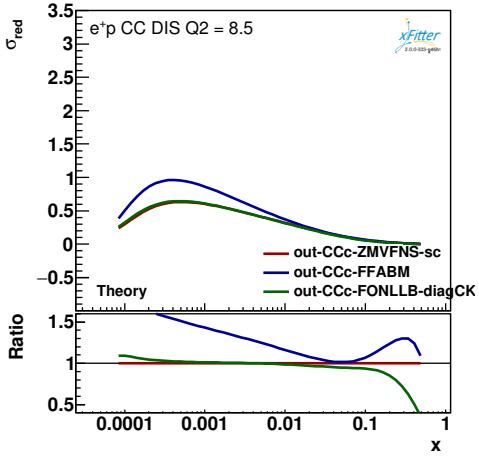

e+p CC DIS Q2 = 3.5
σred
Theory
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCK
Ratio
x

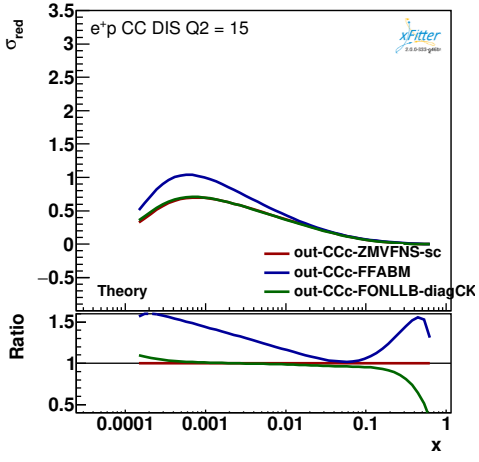

e+p CC DIS Q2 = 4.5
σred
Theory
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCK
Ratio
x

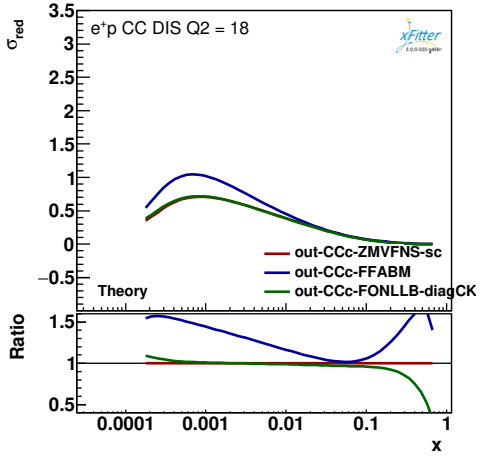

e+p CC DIS Q2 = 10
σred
Theory
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCK
Ratio
x


e+p CC DIS Q2 = 12
σred
Theory
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCK
Ratio
x


e+p CC DIS Q2 = 6.5
σred
Theory
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCK
Ratio
x


e+p CC DIS Q2 = 8.5
σred
Theory
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCK
Ratio
x


e+p CC DIS Q2 = 15
σred
Theory
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCK
Ratio
x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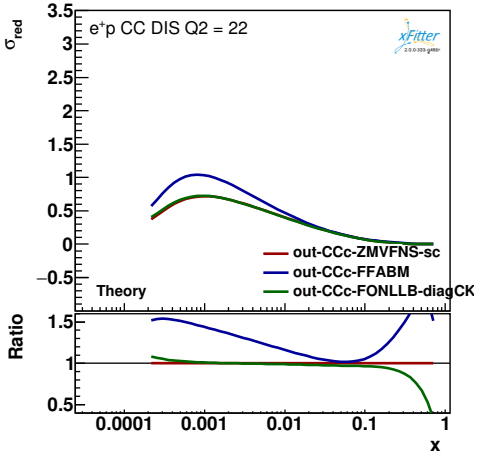
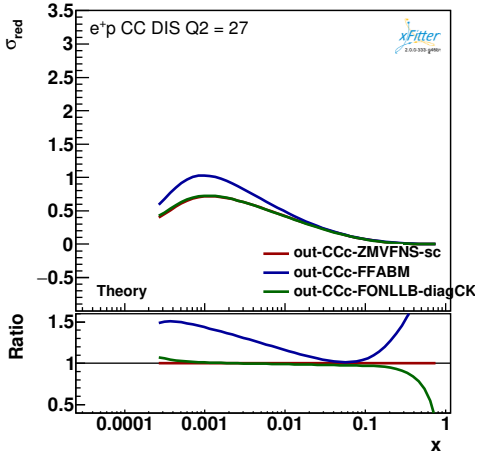
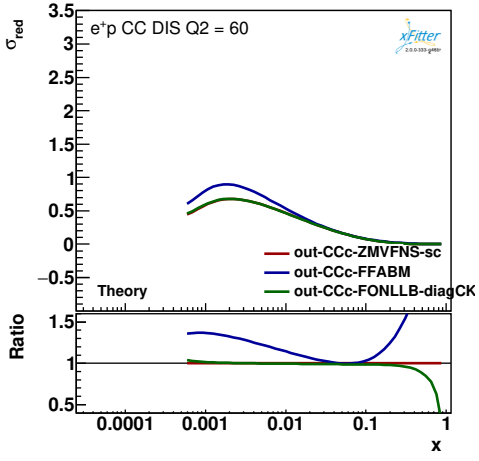
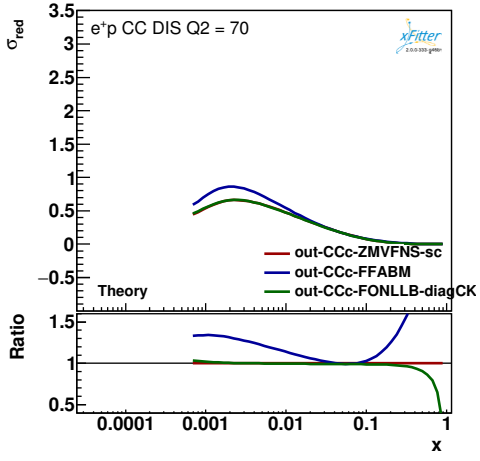
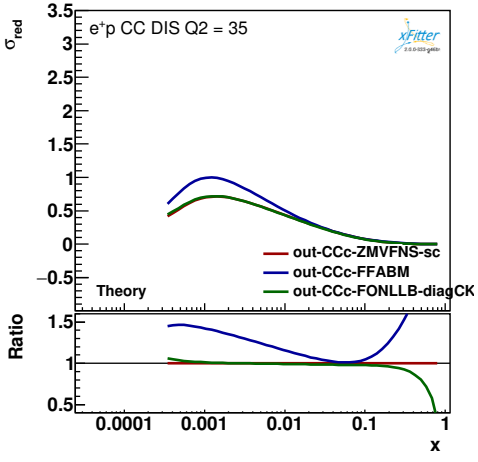
σred
Theory
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCK
Ratio
x

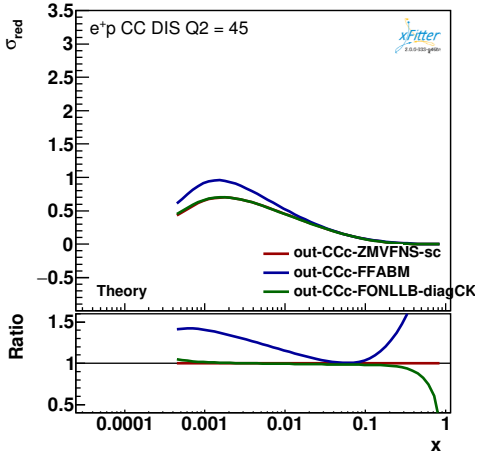

e+p CC DIS Q2 = 22
xFitter
σred
Theory
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCK
Ratio
x

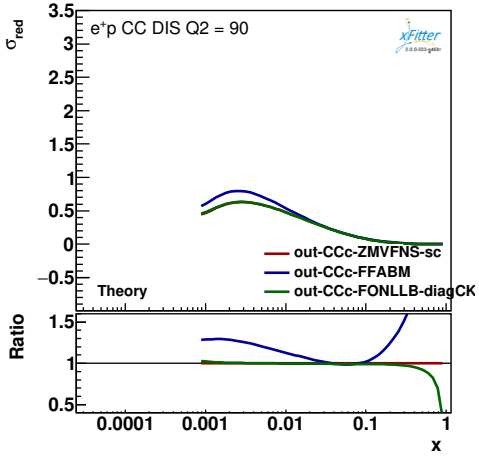

e+p CC DIS Q2 = 27
xFitter
σred
Theory
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCK
Ratio
x

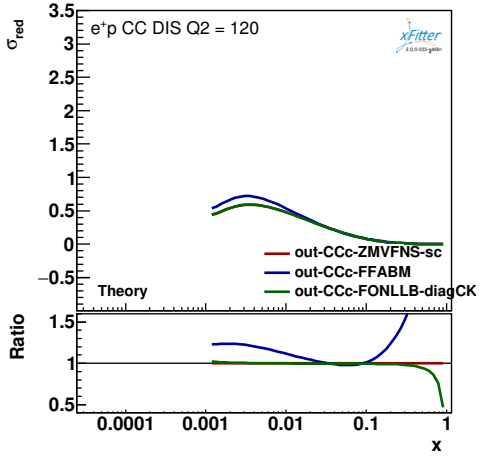

e+p CC DIS Q2 = 60
xFitter
σred
Theory
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCK
Ratio
x

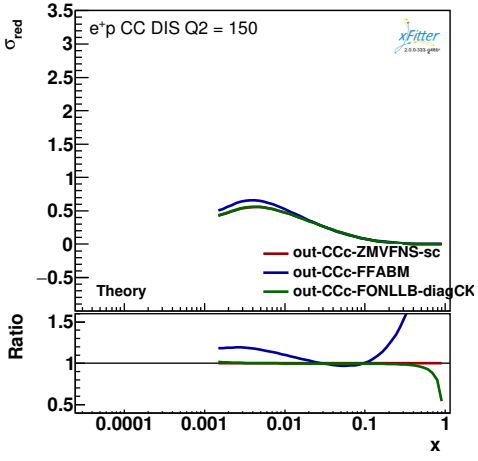

e+p CC DIS Q2 = 70
xFitter
σred
Theory
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCK
Ratio
x

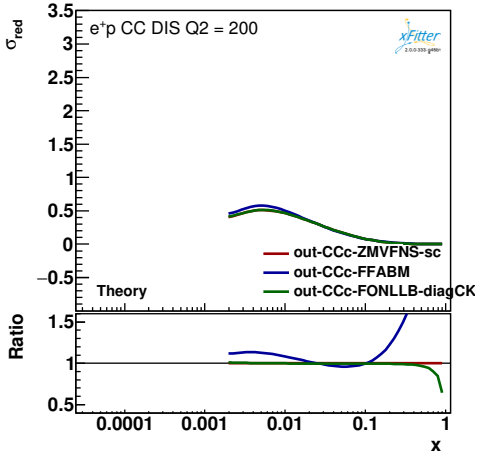

e+p CC DIS Q2 = 35
xFitter
σred
Theory
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCK
Ratio
x

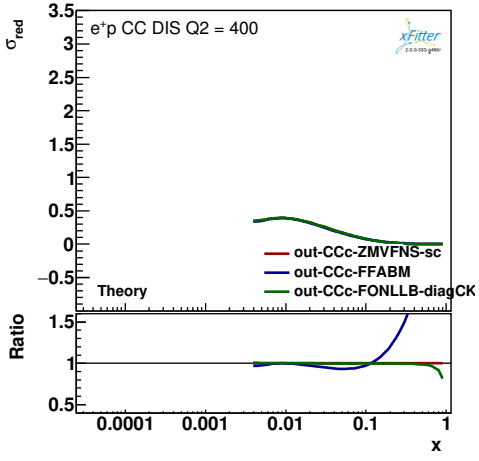

e+p CC DIS Q2 = 45
xFitter
σred
Theory
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCK
Ratio
x

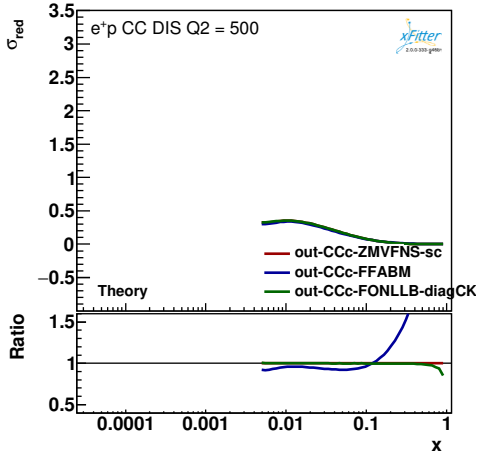

e+p CC DIS Q2 = 90
xFitter
σred
Theory
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCK
Ratio
x

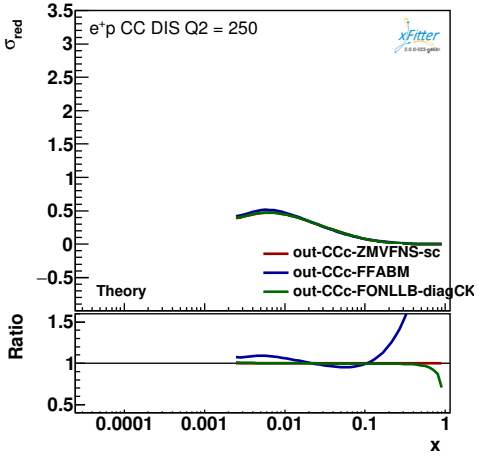

e+p CC DIS Q2 = 120
xFitter
σred
Theory
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCK
Ratio
x

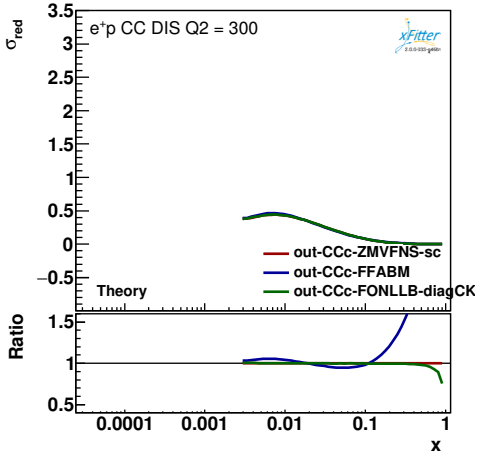

e+p CC DIS Q2 = 150
σred
Ratio
x
Theory
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCK

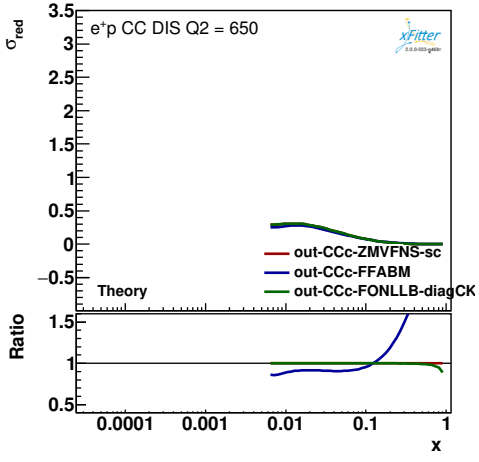

e+p CC DIS Q2 = 200
σred
Ratio
x
Theory
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCK

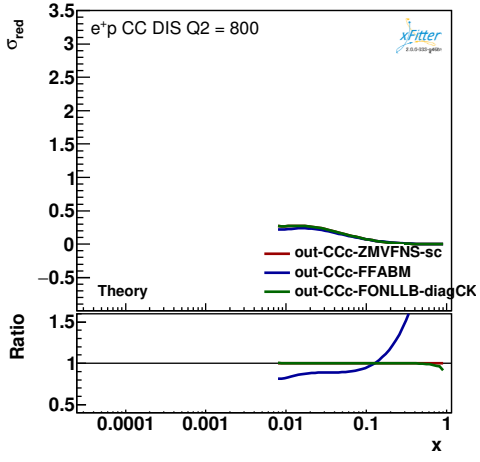

e+p CC DIS Q2 = 400
σred
Ratio
x
Theory
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCK

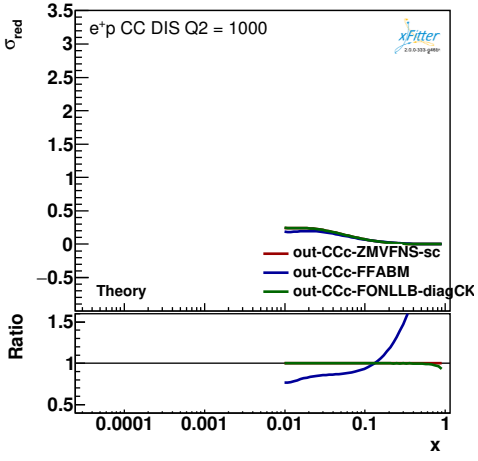

e+p CC DIS Q2 = 500
σred
Ratio
x
Theory
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCK

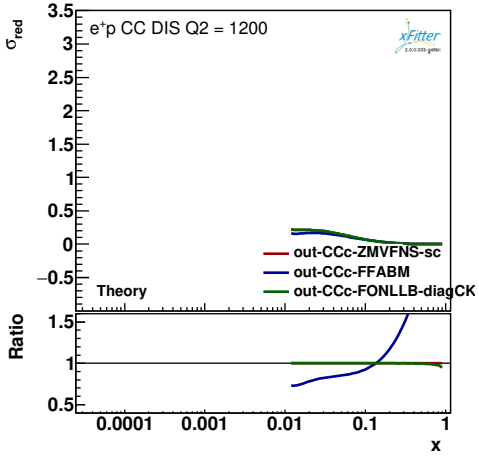

e+p CC DIS Q2 = 250
σred
Ratio
x
Theory
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCK

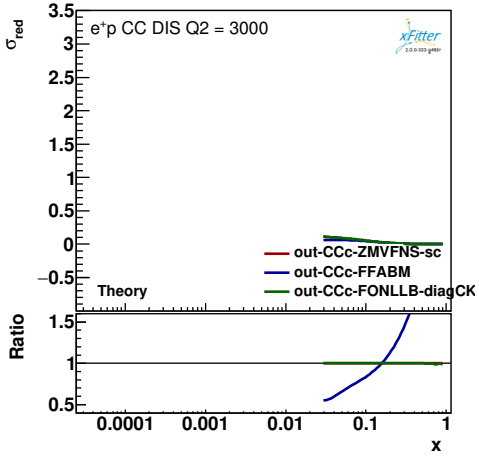

e+p CC DIS Q2 = 300
σred
Ratio
x
Theory
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCK

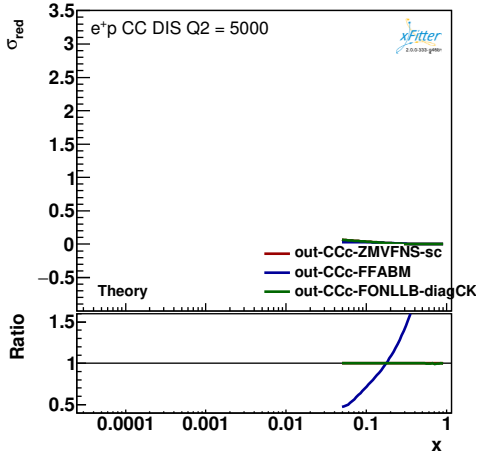

e+p CC DIS Q2 = 650
σred
Ratio
x
Theory
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCK


e+p CC DIS Q2 = 800
σred
Ratio
x
Theory
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCK


e+p CC DIS Q2 = 1000
σred
Ratio
x
Theory
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCK


e+p CC DIS Q2 = 1200
σred
Ratio
x
Theory
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCK


e+p CC DIS Q2 = 3000
σred
Ratio
x
Theory
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCK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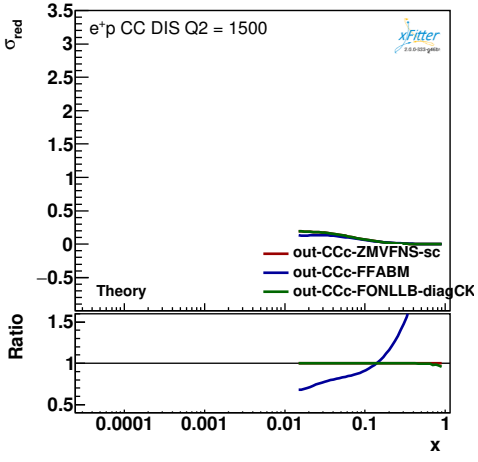
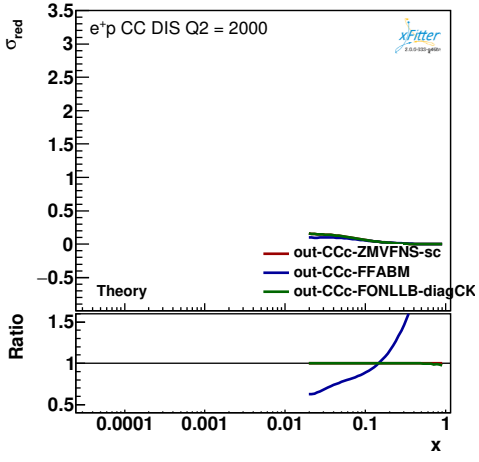
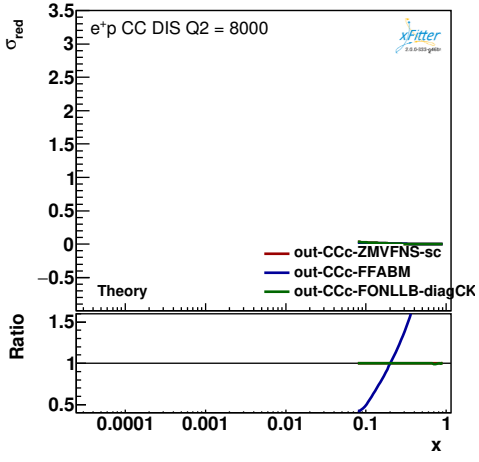
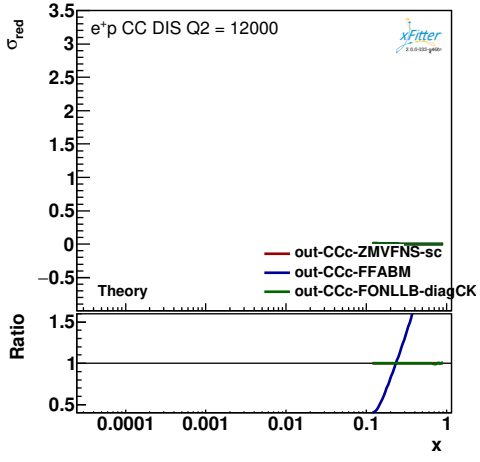
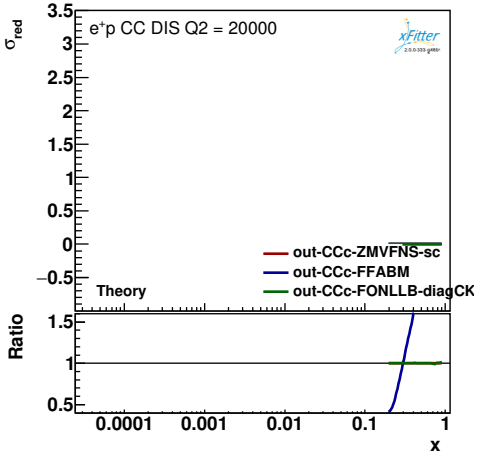
σred
Ratio
x
Theory
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCK

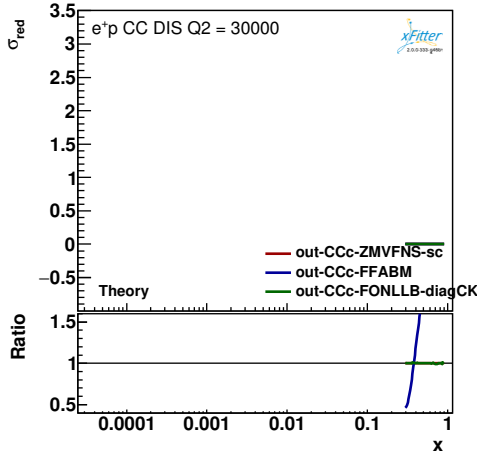

e+p CC DIS Q2 = 1500
σred
Ratio
x
Theory
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCK


e+p CC DIS Q2 = 2000
σred
Ratio
x
Theory
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCK

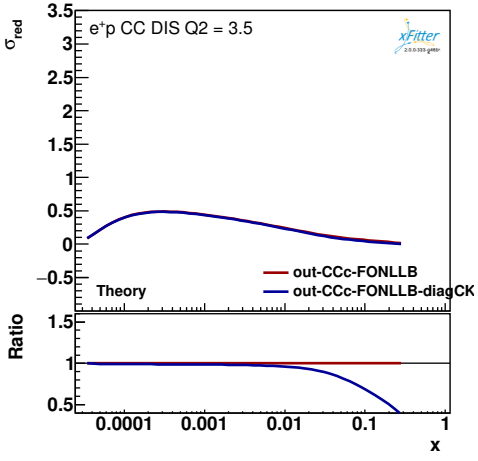

e+p CC DIS Q2 = 8000
σred
Ratio
x
Theory
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCK

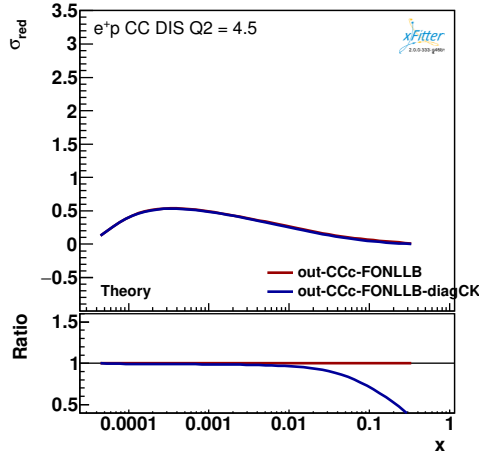

e+p CC DIS Q2 = 12000
σred
Ratio
x
Theory
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCK

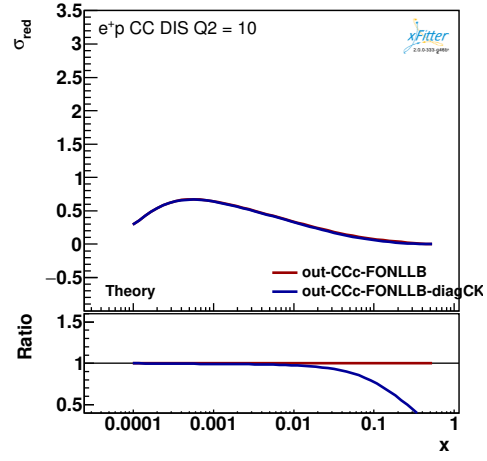

e+p CC DIS Q2 = 20000
σred
Ratio
x
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCK
Theory

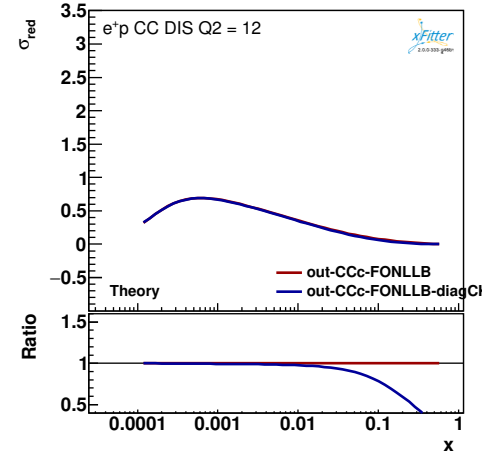

e+p CC DIS Q2 = 30000
σred
Ratio
x
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCK
Theory

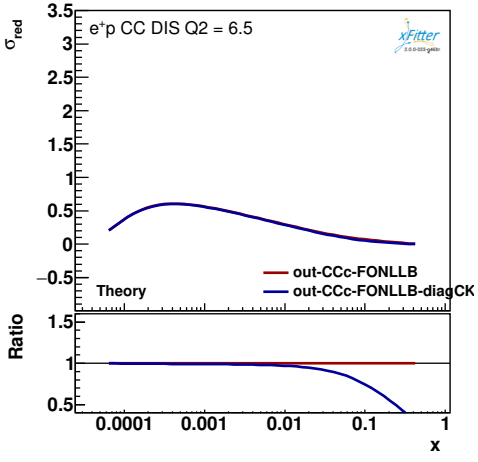
CC charm in FONLL, diag. vs non-diag. CKM

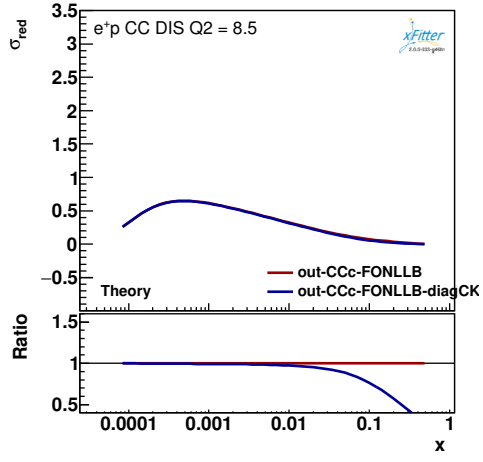

e+p CC DIS Q2 = 3.5
xFitter
σred
Theory
out-CCc-FONLLB
out-CCc-FONLLB-diagCK
Ratio
x

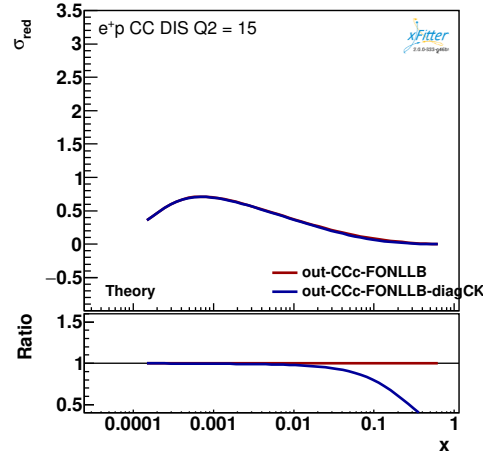

e+p CC DIS Q2 = 4.5
xFitter
σred
Theory
out-CCc-FONLLB
out-CCc-FONLLB-diagCK
Ratio
x

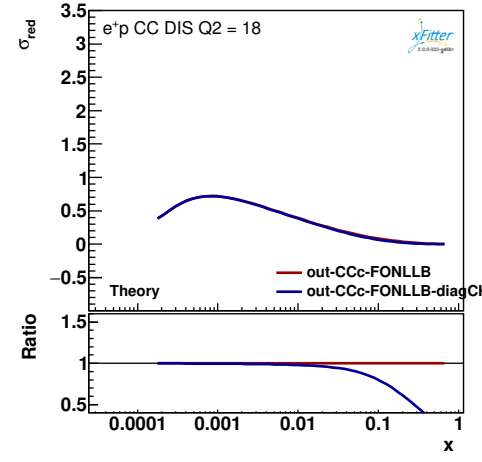

e+p CC DIS Q2 = 10
xFitter
σred
Theory
out-CCc-FONLLB
out-CCc-FONLLB-diagCK
Ratio
x

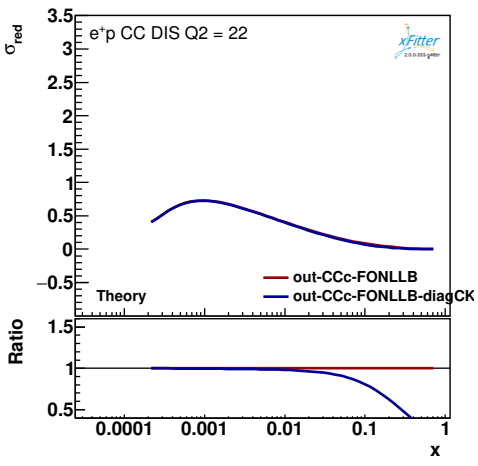

e+p CC DIS Q2 = 12
xFitter
σred
Theory
out-CCc-FONLLB
out-CCc-FONLLB-diagCK
Ratio
x

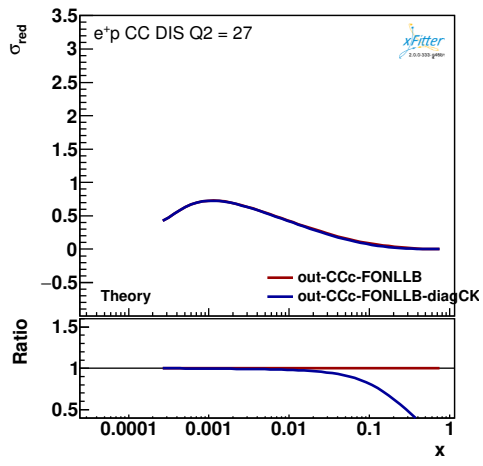

e+p CC DIS Q2 = 6.5
xFitter
σred
Theory
out-CCc-FONLLB
out-CCc-FONLLB-diagCK
Ratio
x

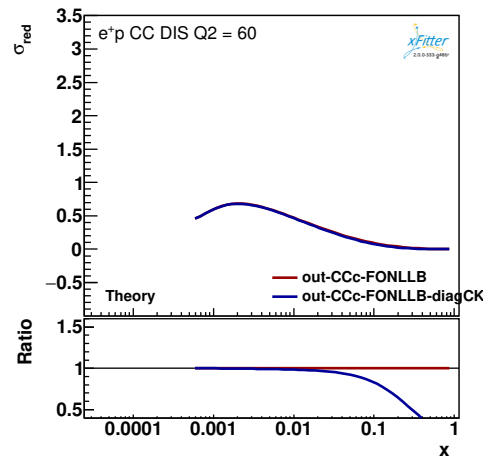

e+p CC DIS Q2 = 8.5
xFitter
σred
Theory
out-CCc-FONLLB
out-CCc-FONLLB-diagCK
Ratio
x

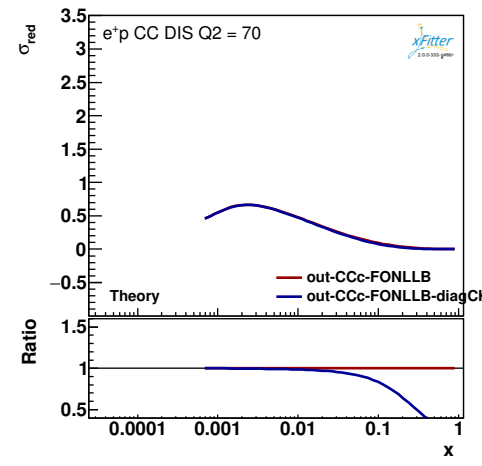

e+p CC DIS Q2 = 15
xFitter
σred
Theory
out-CCc-FONLLB
out-CCc-FONLLB-diagCK
Ratio
x

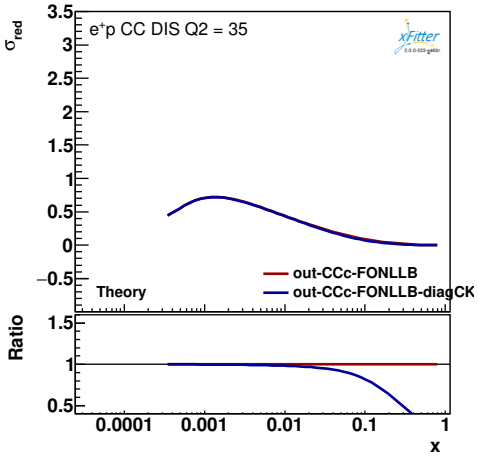

e+p CC DIS Q2 = 18
xFitter
σred
Theory
out-CCc-FONLLB
out-CCc-FONLLB-diagCK
Ratio
x

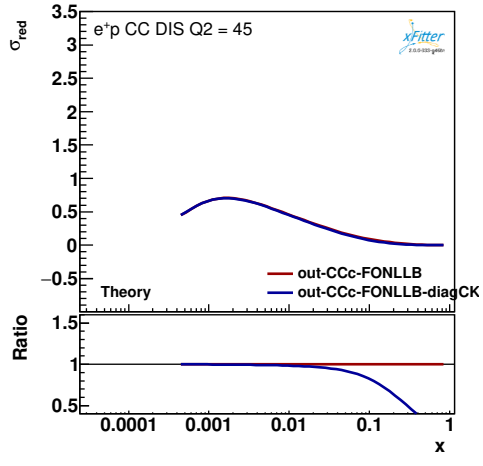

e+p CC DIS Q2 = 22
xFitter
σred
Theory
out-CCc-FONLLB
out-CCc-FONLLB-diagCK
Ratio
x

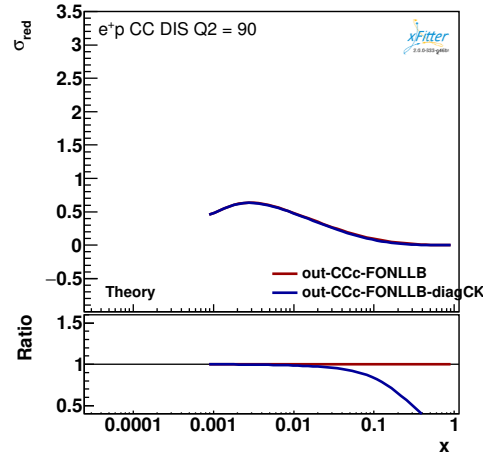

e+p CC DIS Q2 = 27
xFitter
σred
Theory
out-CCc-FONLLB
out-CCc-FONLLB-diagCK
Ratio
x

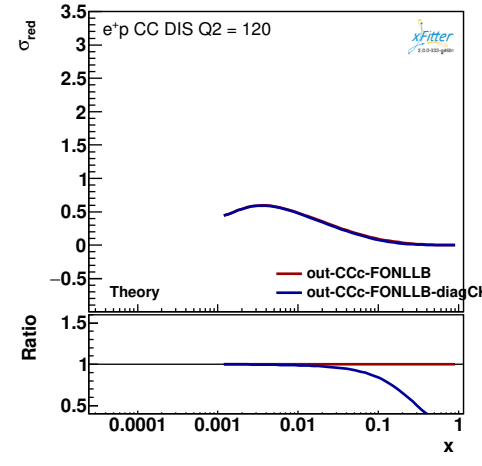

e+p CC DIS Q2 = 60
xFitter
σred
Theory
out-CCc-FONLLB
out-CCc-FONLLB-diagCK
Ratio
x

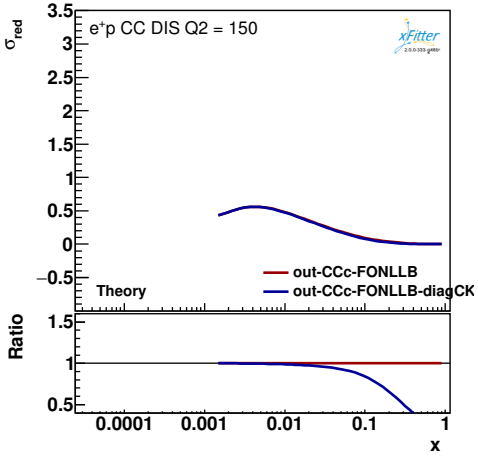

e+p CC DIS Q2 = 70
xFitter
σred
Theory
out-CCc-FONLLB
out-CCc-FONLLB-diagCK
Ratio
x

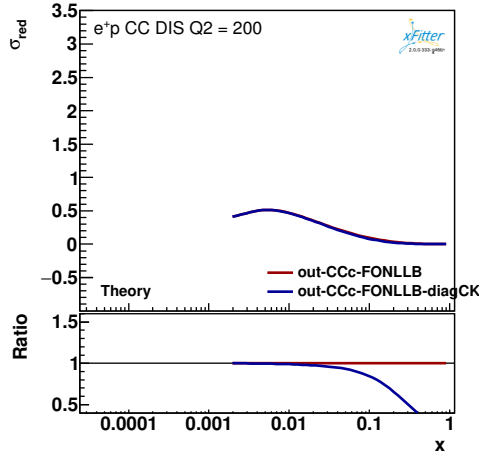

e+p CC DIS Q2 = 35
xFitter
σred
Theory
out-CCc-FONLLB
out-CCc-FONLLB-diagCK
Ratio
x

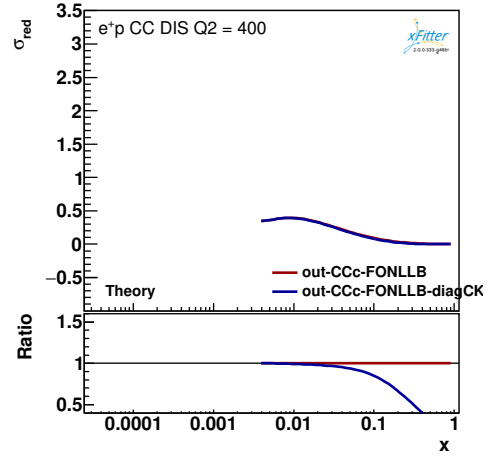

e+p CC DIS Q2 = 45
xFitter
σred
Theory
out-CCc-FONLLB
out-CCc-FONLLB-diagCK
Ratio
x

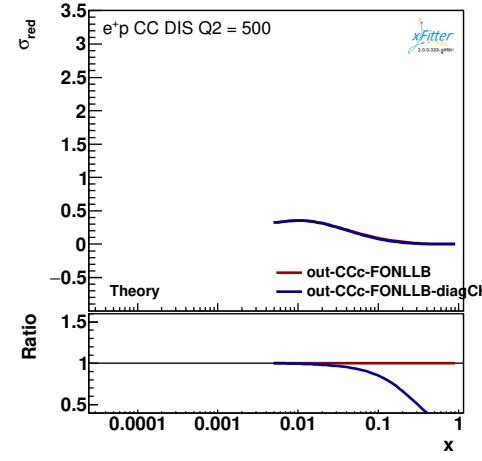

e+p CC DIS Q2 = 90
xFitter
σred
Theory
out-CCc-FONLLB
out-CCc-FONLLB-diagCK
Ratio
x

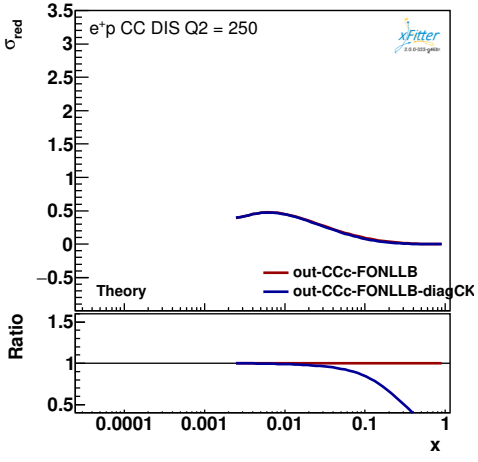

e+p CC DIS Q2 = 120
xFitter
σred
Theory
out-CCc-FONLLB
out-CCc-FONLLB-diagCK
Ratio
x

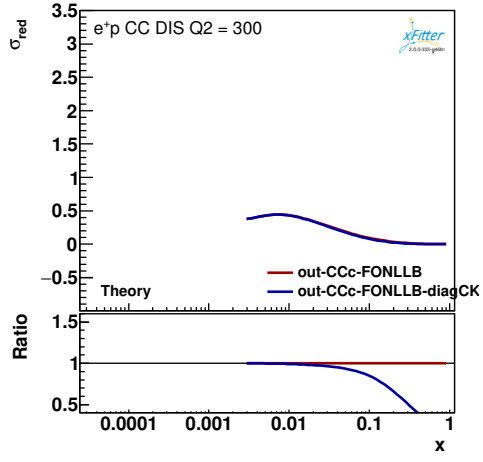

e+p CC DIS Q2 = 150
xFitter
σred
Theory
out-CCc-FONLLB
out-CCc-FONLLB-diagCK
Ratio
x

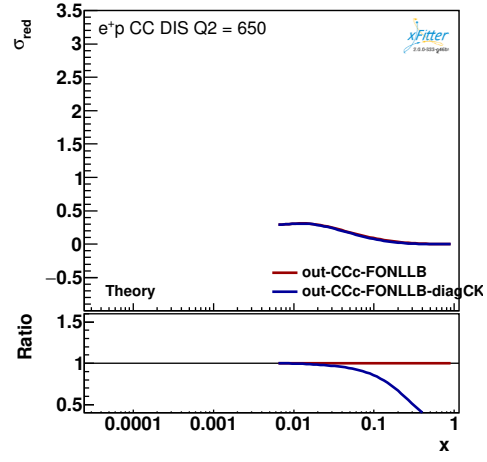

e+p CC DIS Q2 = 200
xFitter
σred
Theory
out-CCc-FONLLB
out-CCc-FONLLB-diagCK
Ratio
x

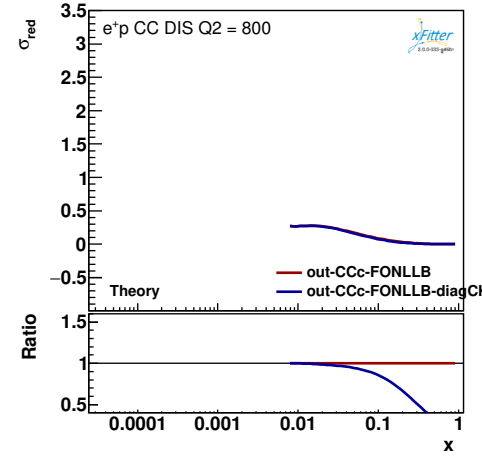

e+p CC DIS Q2 = 400
xFitter
σred
Theory
out-CCc-FONLLB
out-CCc-FONLLB-diagCK
Ratio
x

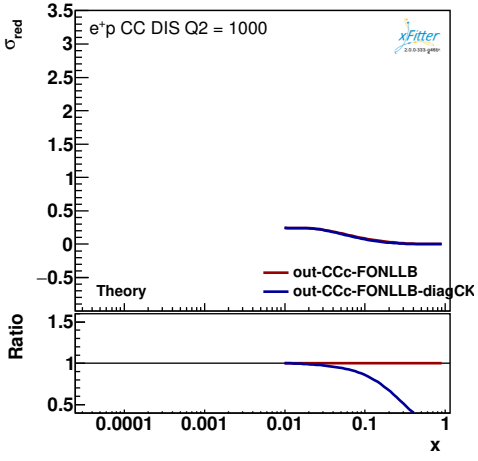

e+p CC DIS Q2 = 500
xFitter
σred
Theory
out-CCc-FONLLB
out-CCc-FONLLB-diagCK
Ratio
x

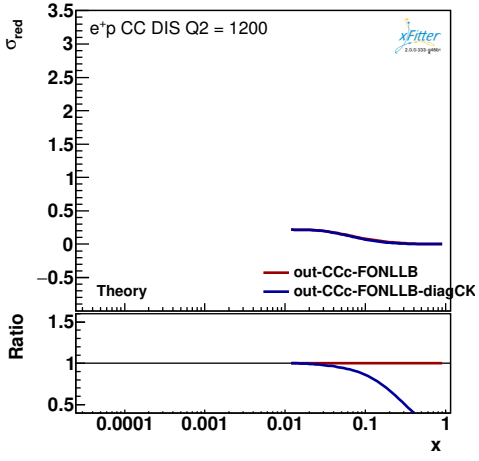

e+p CC DIS Q2 = 250
xFitter
σred
Theory
out-CCc-FONLLB
out-CCc-FONLLB-diagCK
Ratio
x

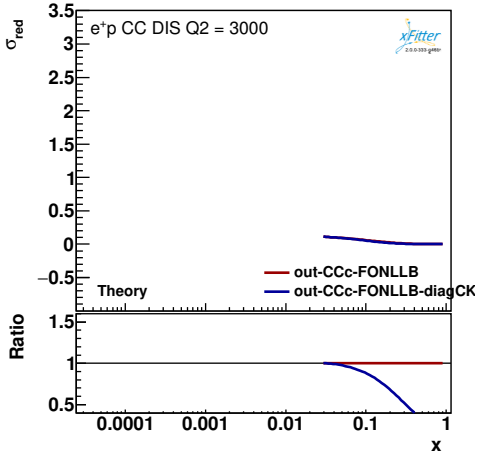

e+p CC DIS Q2 = 300
xFitter
σred
Theory
out-CCc-FONLLB
out-CCc-FONLLB-diagCK
Ratio
x

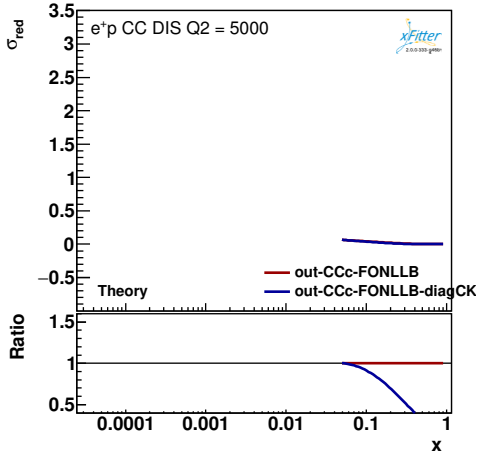

e+p CC DIS Q2 = 650
xFitter
σred
Theory
out-CCc-FONLLB
out-CCc-FONLLB-diagCK
Ratio
x

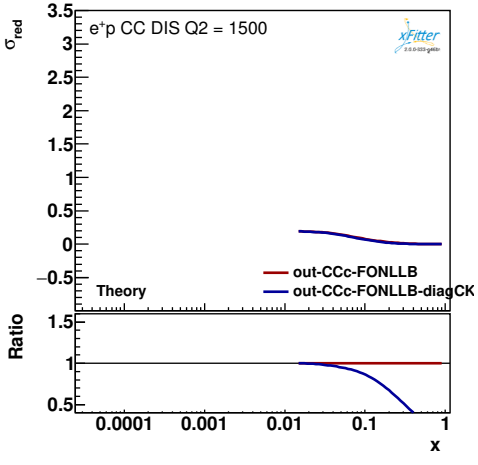

e+p CC DIS Q2 = 800
xFitter
σred
Theory
out-CCc-FONLLB
out-CCc-FONLLB-diagCK
Ratio
x

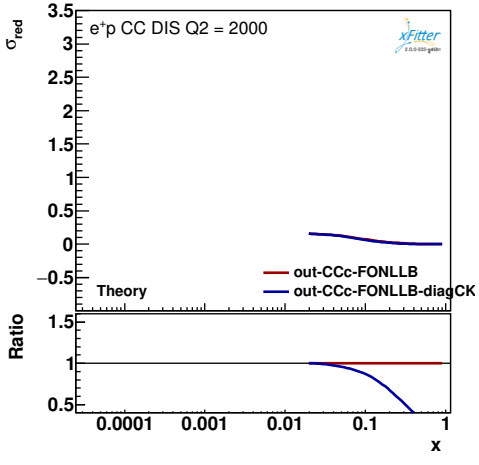

e+p CC DIS Q2 = 1000
σred
Theory
out-CCc-FONLLB
out-CCc-FONLLB-diagCK
Ratio
x

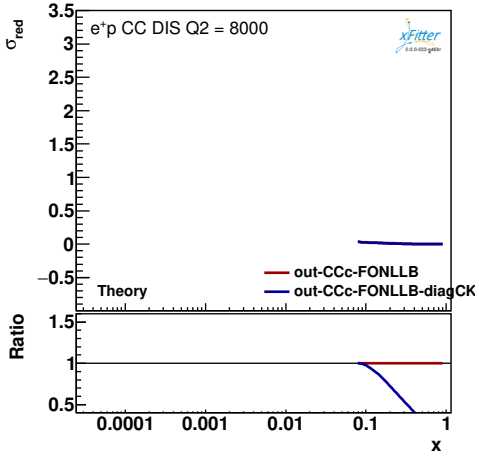

e+p CC DIS Q2 = 1200
σred
Theory
out-CCc-FONLLB
out-CCc-FONLLB-diagCK
Ratio
x

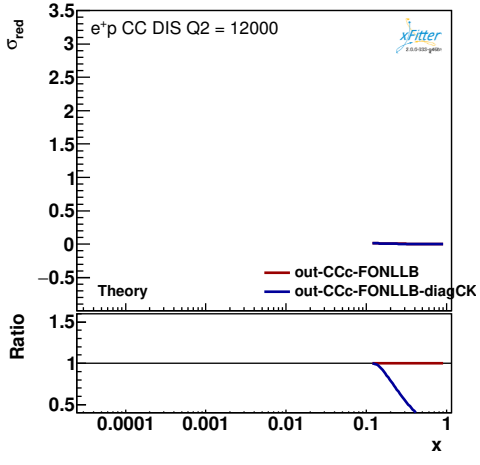

e+p CC DIS Q2 = 3000
σred
Theory
out-CCc-FONLLB
out-CCc-FONLLB-diagCK
Ratio
x

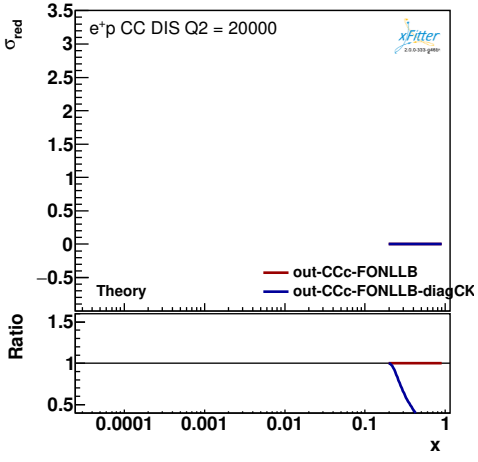

e+p CC DIS Q2 = 5000
σred
Theory
out-CCc-FONLLB
out-CCc-FONLLB-diagCK
Ratio
x

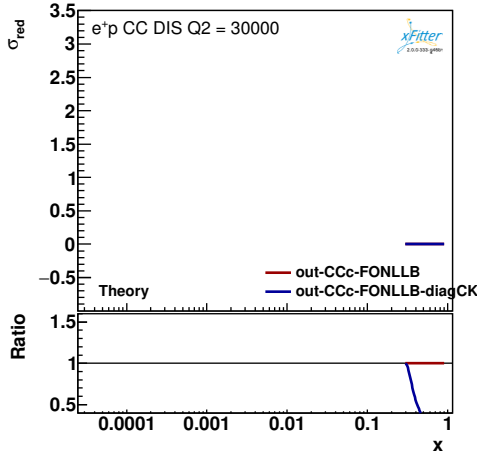

e+p CC DIS Q2 = 1500
σred
Theory
out-CCc-FONLLB
out-CCc-FONLLB-diagCK
Ratio
x


e+p CC DIS Q2 = 2000
σred
Theory
out-CCc-FONLLB
out-CCc-FONLLB-diagCK
Ratio
x


e+p CC DIS Q2 = 8000
σred
Theory
out-CCc-FONLLB
out-CCc-FONLLB-diagCK
Ratio
x

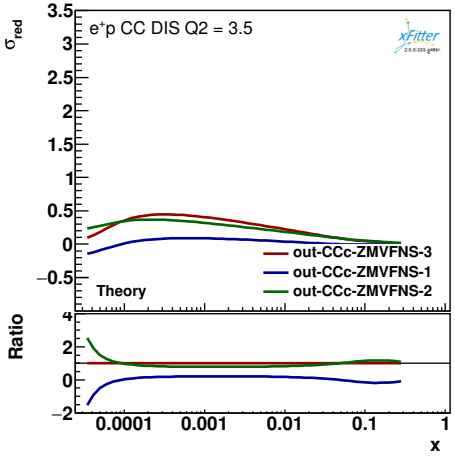

e+p CC DIS Q2 = 12000
σred
Theory
out-CCc-FONLLB
out-CCc-FONLLB-diagCK
Ratio
x

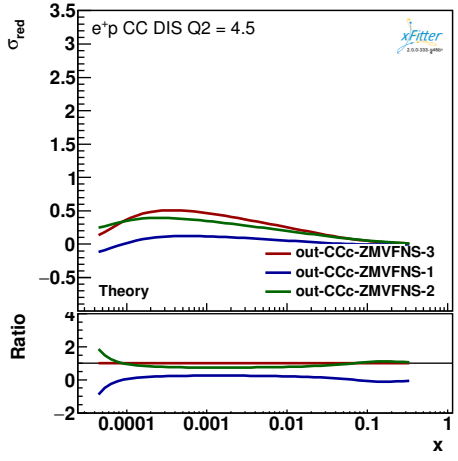

e+p CC DIS Q2 = 20000
σred
Theory
out-CCc-FONLLB
out-CCc-FONLLB-diagCK
Ratio
x

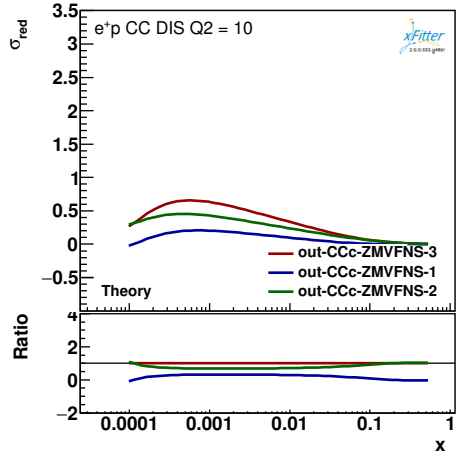

e+p CC DIS Q2 = 30000
σred
Theory
out-CCc-FONLLB
out-CCc-FONLLB-diagCK
Ratio
x

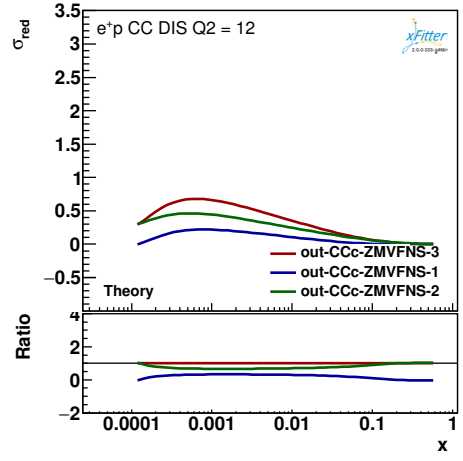
CC charm in ZMVFNS, different partonic processes:

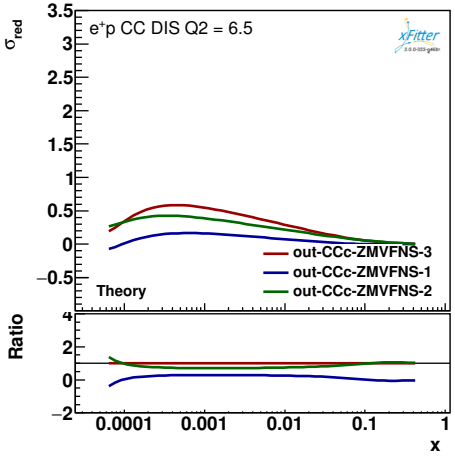
- $c \to s$ **only ('ZMFVNS-1')**
- $s \to c$ **only ('ZMFVNS-2')**
- $s \to c$ **and** $c \to s$ **('ZMFVNS-3')**

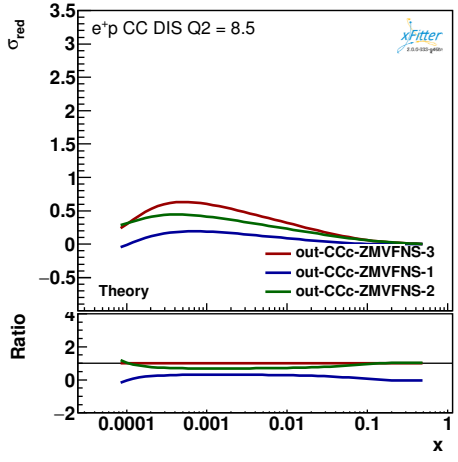

e+p CC DIS Q2 = 3.5
σred
Ratio
Theory
out-CCc-ZMVFNS-3
out-CCc-ZMVFNS-1
out-CCc-ZMVFNS-2
x

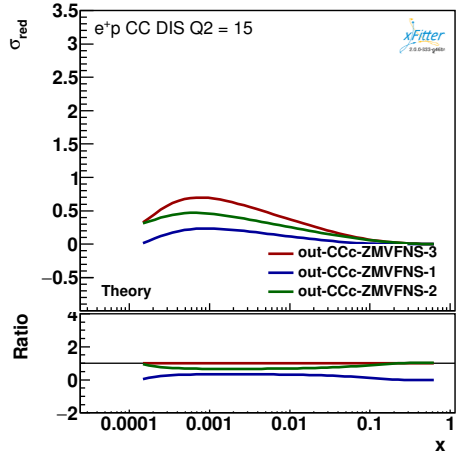

e+p CC DIS Q2 = 4.5
σred
Ratio
Theory
out-CCc-ZMVFNS-3
out-CCc-ZMVFNS-1
out-CCc-ZMVFNS-2
x

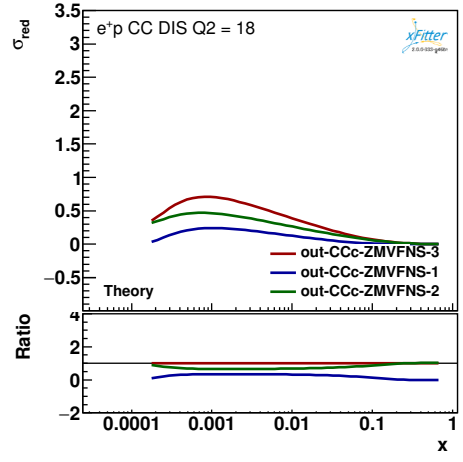

e+p CC DIS Q2 = 10
σred
Ratio
Theory
out-CCc-ZMVFNS-3
out-CCc-ZMVFNS-1
out-CCc-ZMVFNS-2
x

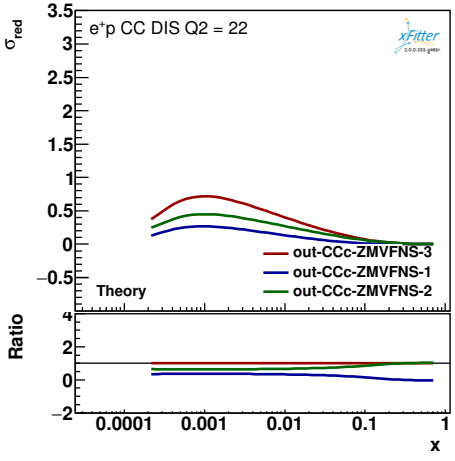

e+p CC DIS Q2 = 12
σred
Ratio
Theory
out-CCc-ZMVFNS-3
out-CCc-ZMVFNS-1
out-CCc-ZMVFNS-2
x

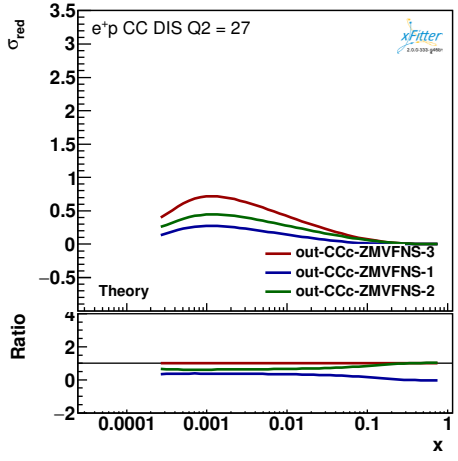

e+p CC DIS Q2 = 6.5
σred
Ratio
Theory
out-CCc-ZMVFNS-3
out-CCc-ZMVFNS-1
out-CCc-ZMVFNS-2
x

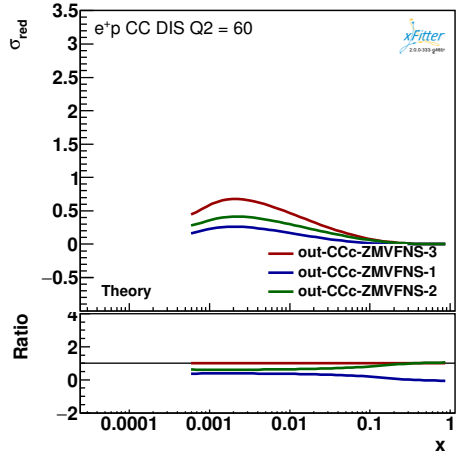

e+p CC DIS Q2 = 8.5
σred
Ratio
Theory
out-CCc-ZMVFNS-3
out-CCc-ZMVFNS-1
out-CCc-ZMVFNS-2
x

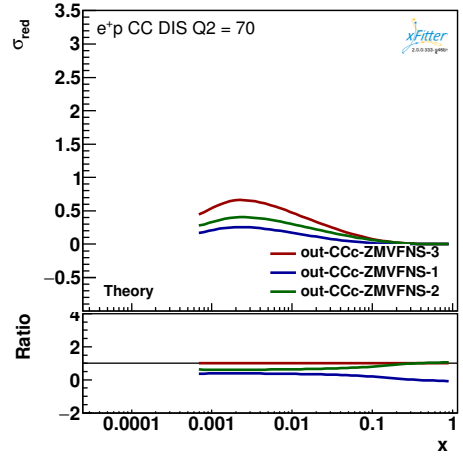

e+p CC DIS Q2 = 15
σred
Ratio
Theory
out-CCc-ZMVFNS-3
out-CCc-ZMVFNS-1
out-CCc-ZMVFNS-2
x

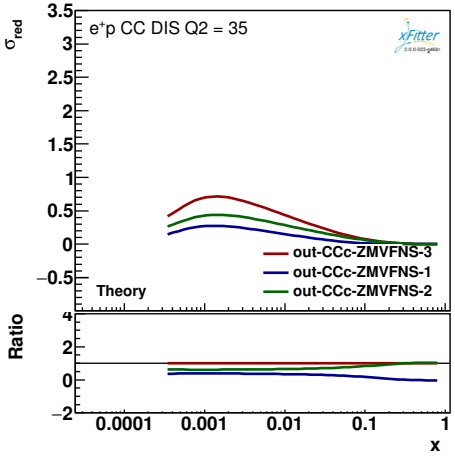

e+p CC DIS Q2 = 18
σred
Ratio
Theory
out-CCc-ZMVFNS-3
out-CCc-ZMVFNS-1
out-CCc-ZMVFNS-2
x

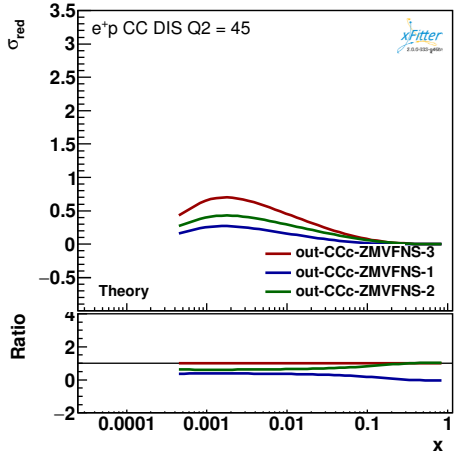

e+p CC DIS Q2 = 22
xFitter
σred
Theory
out-CCc-ZMVFNS-3
out-CCc-ZMVFNS-1
out-CCc-ZMVFNS-2
Ratio
x

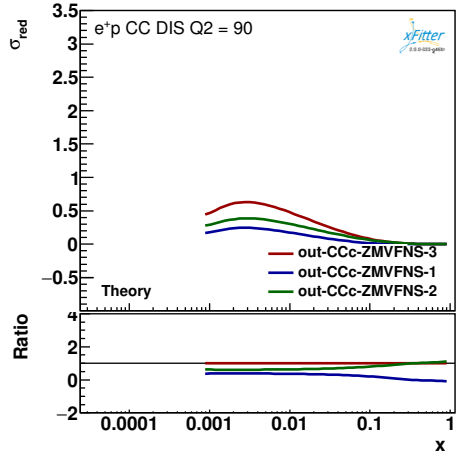

e+p CC DIS Q2 = 27
xFitter
σred
Theory
out-CCc-ZMVFNS-3
out-CCc-ZMVFNS-1
out-CCc-ZMVFNS-2
Ratio
x

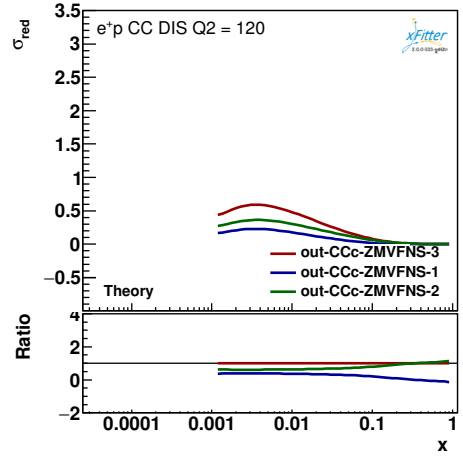

e+p CC DIS Q2 = 60
xFitter
σred
Theory
out-CCc-ZMVFNS-3
out-CCc-ZMVFNS-1
out-CCc-ZMVFNS-2
Ratio
x

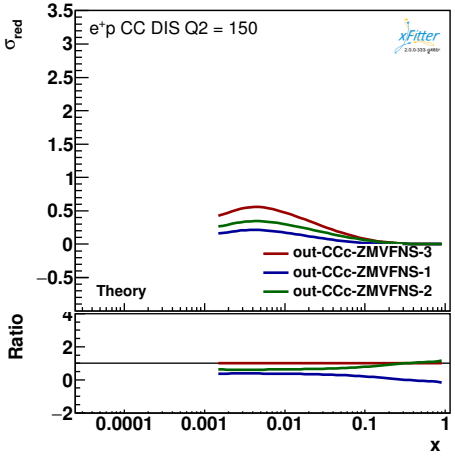

e+p CC DIS Q2 = 70
xFitter
σred
Theory
out-CCc-ZMVFNS-3
out-CCc-ZMVFNS-1
out-CCc-ZMVFNS-2
Ratio
x

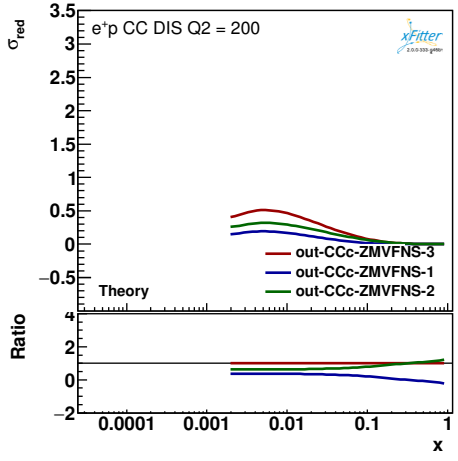

e+p CC DIS Q2 = 35
xFitter
σred
Theory
out-CCc-ZMVFNS-3
out-CCc-ZMVFNS-1
out-CCc-ZMVFNS-2
Ratio
x

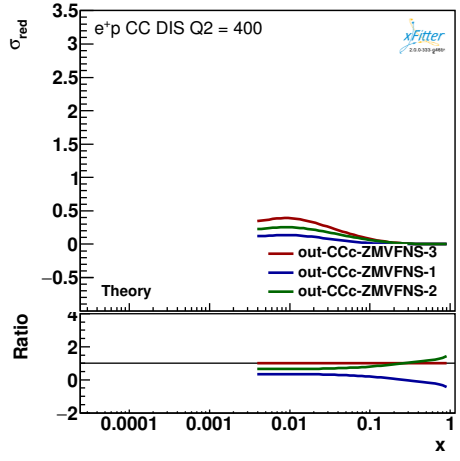

e+p CC DIS Q2 = 45
xFitter
σred
Theory
out-CCc-ZMVFNS-3
out-CCc-ZMVFNS-1
out-CCc-ZMVFNS-2
Ratio
x

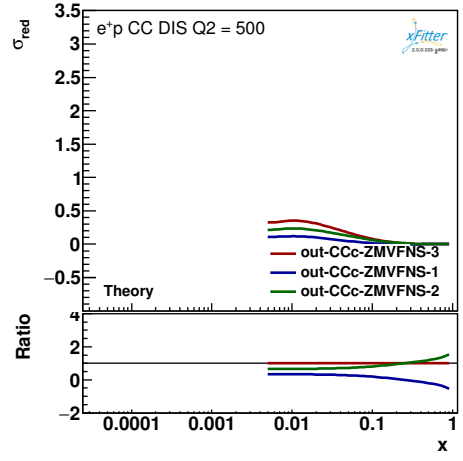

e+p CC DIS Q2 = 90
xFitter
σred
Theory
out-CCc-ZMVFNS-3
out-CCc-ZMVFNS-1
out-CCc-ZMVFNS-2
Ratio
x

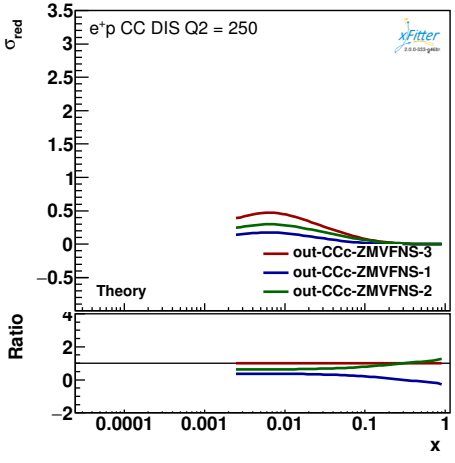

e+p CC DIS Q2 = 120
xFitter
σred
Theory
out-CCc-ZMVFNS-3
out-CCc-ZMVFNS-1
out-CCc-ZMVFNS-2
Ratio
x

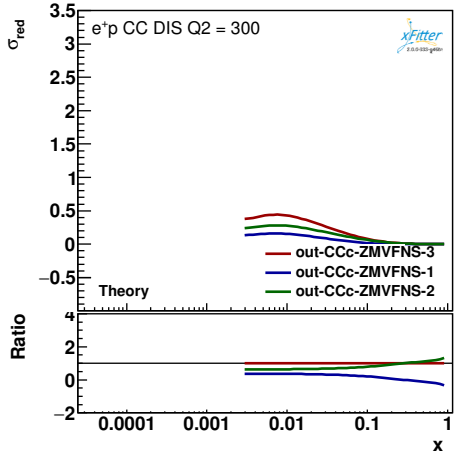

e+p CC DIS Q2 = 150
σred
Theory
out-CCc-ZMVFNS-3
out-CCc-ZMVFNS-1
out-CCc-ZMVFNS-2
Ratio
x

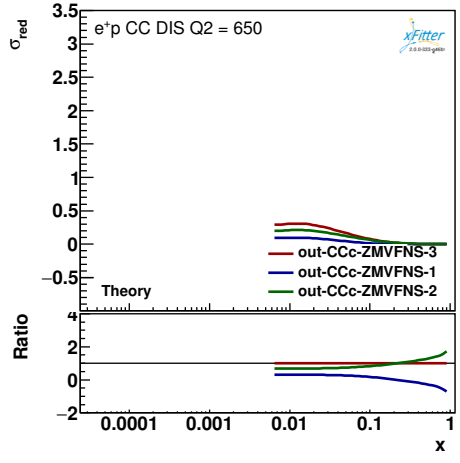

e+p CC DIS Q2 = 200
σred
Theory
out-CCc-ZMVFNS-3
out-CCc-ZMVFNS-1
out-CCc-ZMVFNS-2
Ratio
x

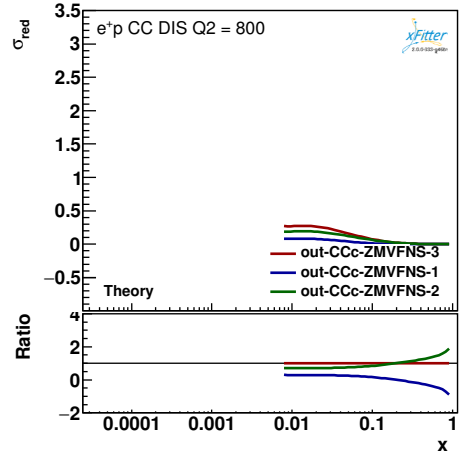

e+p CC DIS Q2 = 400
σred
Theory
out-CCc-ZMVFNS-3
out-CCc-ZMVFNS-1
out-CCc-ZMVFNS-2
Ratio
x

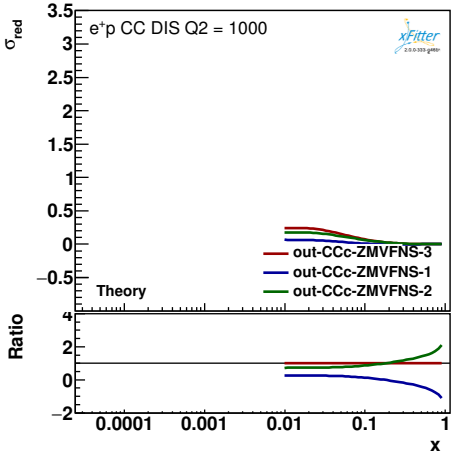

e+p CC DIS Q2 = 500
σred
Theory
out-CCc-ZMVFNS-3
out-CCc-ZMVFNS-1
out-CCc-ZMVFNS-2
Ratio
x

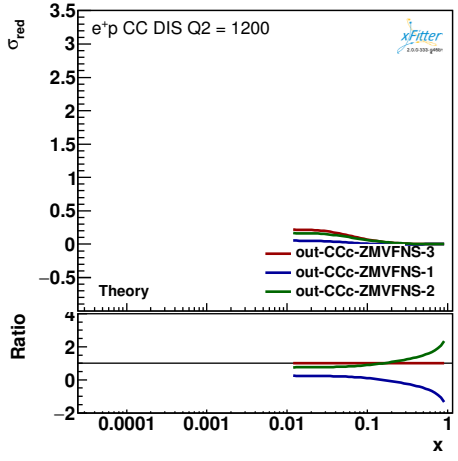

e+p CC DIS Q2 = 250
σred
Theory
out-CCc-ZMVFNS-3
out-CCc-ZMVFNS-1
out-CCc-ZMVFNS-2
Ratio
x

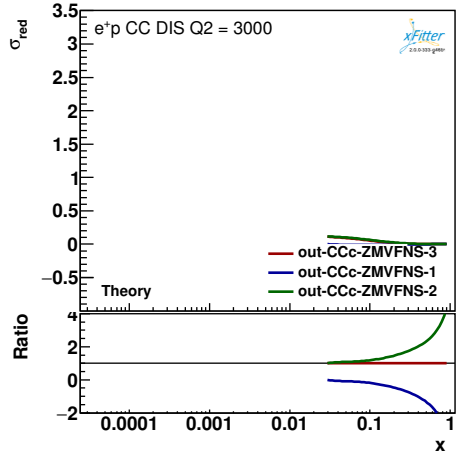

e+p CC DIS Q2 = 300
σred
Theory
out-CCc-ZMVFNS-3
out-CCc-ZMVFNS-1
out-CCc-ZMVFNS-2
Ratio
x

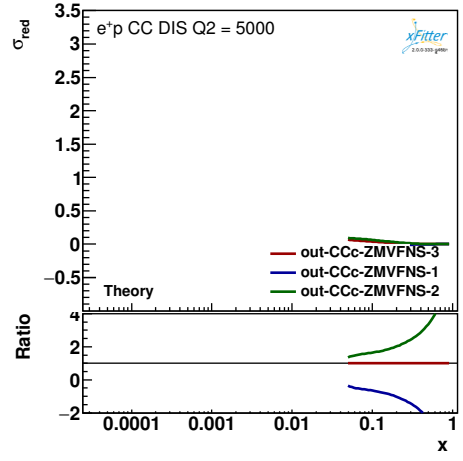

e+p CC DIS Q2 = 650
σred
Theory
out-CCc-ZMVFNS-3
out-CCc-ZMVFNS-1
out-CCc-ZMVFNS-2
Ratio
x

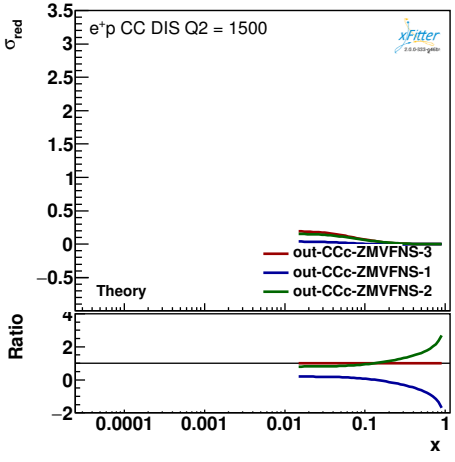

e+p CC DIS Q2 = 800
σred
Theory
out-CCc-ZMVFNS-3
out-CCc-ZMVFNS-1
out-CCc-ZMVFNS-2
Ratio
x

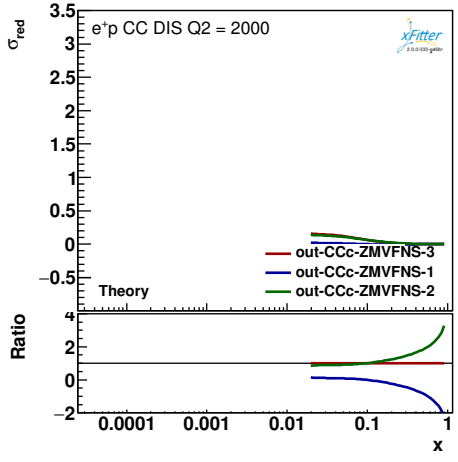

e+p CC DIS Q2 = 1000
σred
Ratio
x
Theory
out-CCc-ZMVFNS-3
out-CCc-ZMVFNS-1
out-CCc-ZMVFNS-2

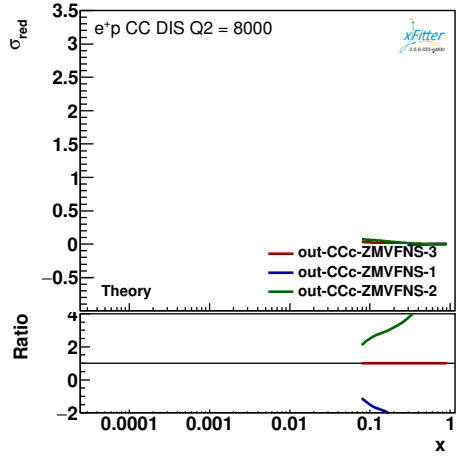

e+p CC DIS Q2 = 1200
σred
Ratio
x
Theory
out-CCc-ZMVFNS-3
out-CCc-ZMVFNS-1
out-CCc-ZMVFNS-2

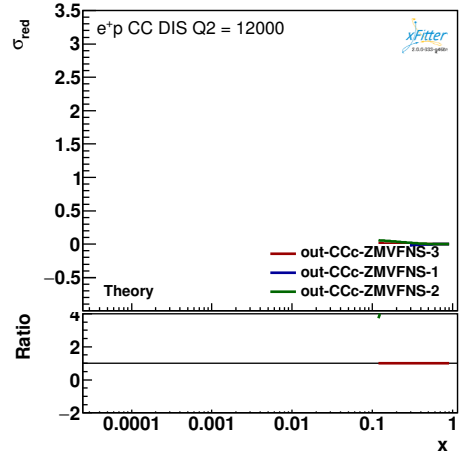

e+p CC DIS Q2 = 3000
σred
Ratio
x
Theory
out-CCc-ZMVFNS-3
out-CCc-ZMVFNS-1
out-CCc-ZMVFNS-2

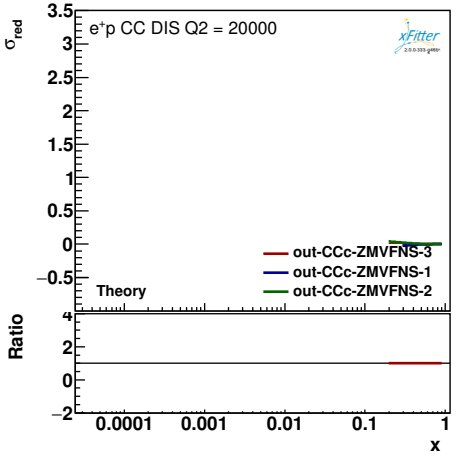

e+p CC DIS Q2 = 5000
σred
Ratio
x
Theory
out-CCc-ZMVFNS-3
out-CCc-ZMVFNS-1
out-CCc-ZMVFNS-2

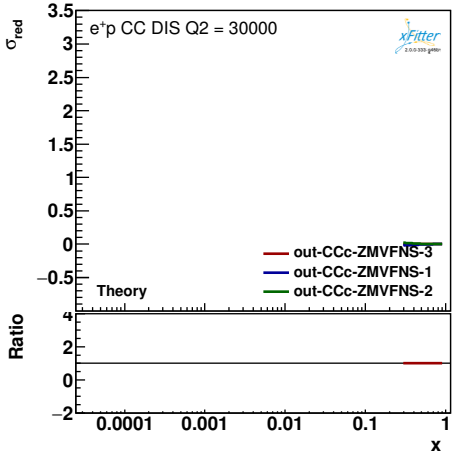

e+p CC DIS Q2 = 1500
σred
Ratio
x
Theory
out-CCc-ZMVFNS-3
out-CCc-ZMVFNS-1
out-CCc-ZMVFNS-2


e+p CC DIS Q2 = 2000
σred
Ratio
x
Theory
out-CCc-ZMVFNS-3
out-CCc-ZMVFNS-1
out-CCc-ZMVFNS-2


e+p CC DIS Q2 = 8000
σred
Ratio
x
Theory
out-CCc-ZMVFNS-3
out-CCc-ZMVFNS-1
out-CCc-ZMVFNS-2


e+p CC DIS Q2 = 12000
σred
Ratio
x
Theory
out-CCc-ZMVFNS-3
out-CCc-ZMVFNS-1
out-CCc-ZMVFNS-2


e+p CC DIS Q2 = 20000
xFitter
σred
out-CCc-ZMVFNS-3
out-CCc-ZMVFNS-1
out-CCc-ZMVFNS-2
Theory
Ratio
x


e+p CC DIS Q2 = 30000
xFitter
σred
out-CCc-ZMVFNS-3
out-CCc-ZMVFNS-1
out-CCc-ZMVFNS-2
Theory
Ratio
x

Summary

- Significant differences ($\sim$ 50% and larger at high Q^2) between schemes:
  - good agreement between ZMVFNS and FONLL
  - difference vs FFABM due to:
    - ★ massive vs massless treatment, number of flavours in PDF evolution
    - ★ different definition ($s \to c$ only vs $c \to s$, $s \to c$): perhaps dominant?
- Dependence on CKM becomes relevant for $x \gtrsim 0.05$
- If only $s \to c$ and $c \to s$ makes sense in ZMFVNS/VFNS, perhaps the difference from experimental definition ($s \to c$ only) **can not be ignored**
  - $\Rightarrow$ is ZMVFNS/VFNS prediction for charm CC usable?
- any advises/recommendations?

- Current plan:
  - we can have FFABM and FONLL inclusive predictions (function of Q^2, x_{Bj}) checked with the authors but defined differently
  - estimate contributions $s \to c$ and $c \to s$ at LO in ZMVFNS using QCDNUM (cannot be done in FFNS, VFNS or higher orders?)
    $\to$ might be useful in light of differences for s in global PDF analysis
    $\to$ so far weird results (negative $c \to s$), in contact with Michiel Botje

BACKUP

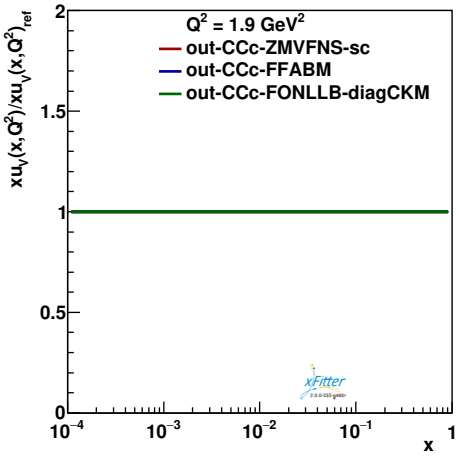
Implementation in ZMVFNS (QCDNUM)

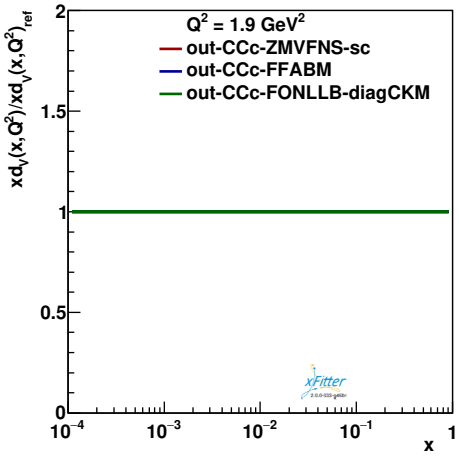
- Current status of charm CC implementation:
  - ZMVFNS (QCDNUM): seems to be straightforward once decided which processes to include

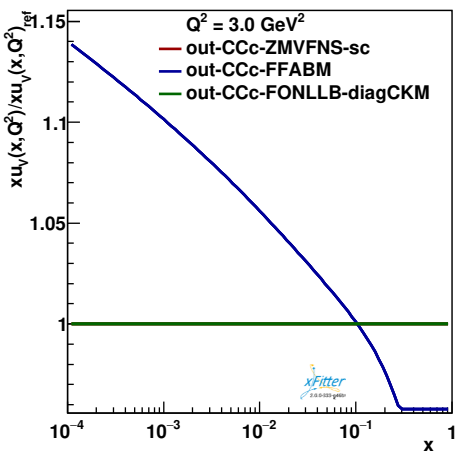
```
// Helpers for QCDNUM (CC):

//! full
const double  CCEP2F[] = {0.,0.,1.,0.,1.,0., 0. ,1.,0.,1.,0.,0.,0.} ;
const double  CCEM2F[] = {0.,0.,0.,1.,0.,1., 0. ,0.,1.,0.,1.,0.,0.} ;

const double  CCEP3F[] = {0.,0.,-1.,0.,-1.,0.,0.,1.,0.,1.,0.,0.,0.};
const double  CCEM3F[] = {0.,0. ,0.,-1.,0.,-1.,0.,0.,1.,0.,1.,0.,0.};

//! c
// work in progress: according to 1001.2312 section 5,
// in ZM only the sum of contributions s + c makes sense
// three different options are below for checks, uncommented one is for s + c
//
// only c
//const double  CCEP2Fc[] = {0.,0.,1.,0.,0.,0.,0.,0.,0.,0.,0.,0.,0.} ;
//const double  CCEM2Fc[] = {0.,0.,0.,0.,0.,0.,0.,0.,0.,0.,1.,0.,0.} ;
// only s
//const double  CCEP2Fc[] = {0.,0.,0.,0.,0.,0.,0.,0.,0.,1.,0.,0.,0.} ;
//const double  CCEM2Fc[] = {0.,0.,0.,1.,0.,0.,0.,0.,0.,0.,0.,0.,0.} ;
// only s,c
const double  CCEP2Fc[] = {0.,0.,1.,0.,0.,0.,0.,0.,0.,1.,0.,0.,0.} ;
const double  CCEM2Fc[] = {0.,0.,0.,1.,0.,0.,0.,0.,0.,0.,1.,0.,0.} ;
```

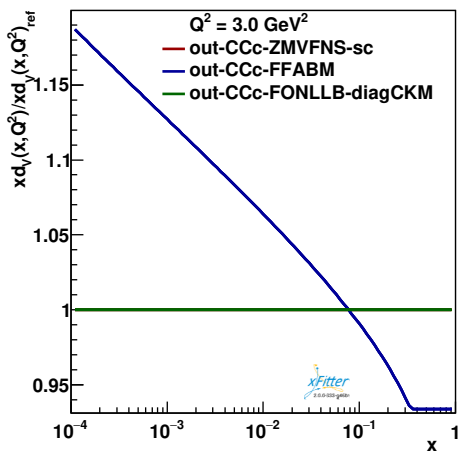
(same for `CCEM3F`,`CCEP3F`)

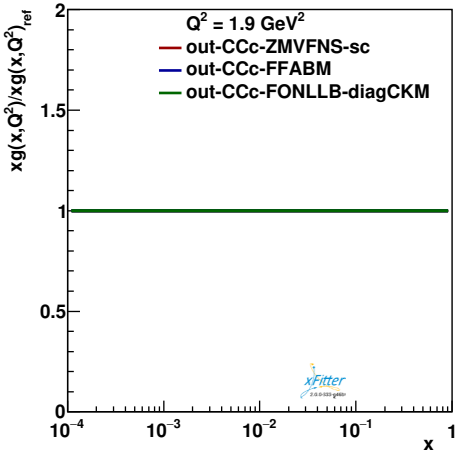
PDFs in three schemes

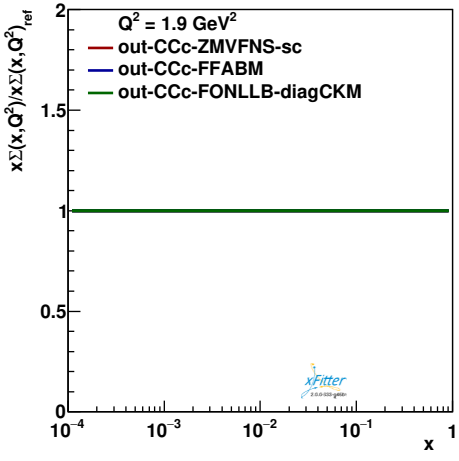

Q^2 = 1.9 GeV^2
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCKM
$xu_V(x,Q^2)/xu_V(x,Q^2)_{ref}$
x

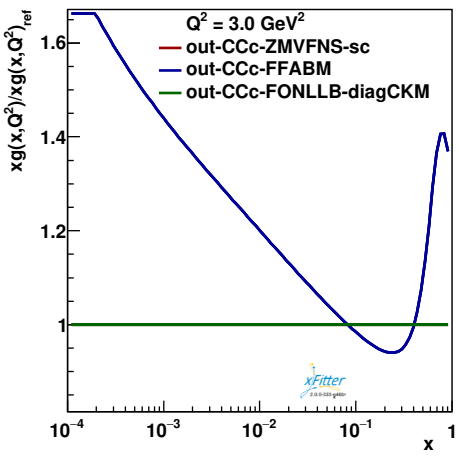

Q^2 = 1.9 GeV^2
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCKM
$xd_V(x,Q^2)/xd_V(x,Q^2)_{ref}$
x

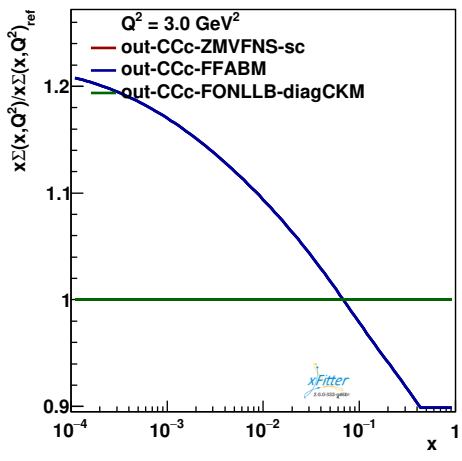

Q^2 = 3.0 GeV^2
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCKM
$xu_V(x,Q^2)/xu_V(x,Q^2)_{ref}$
x

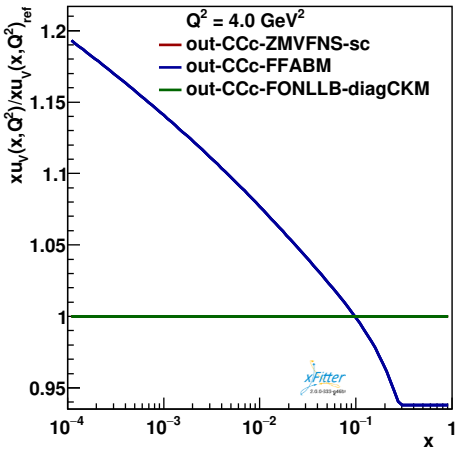

Q^2 = 3.0 GeV^2
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCKM
$xd_V(x,Q^2)/xd_V(x,Q^2)_{ref}$
x

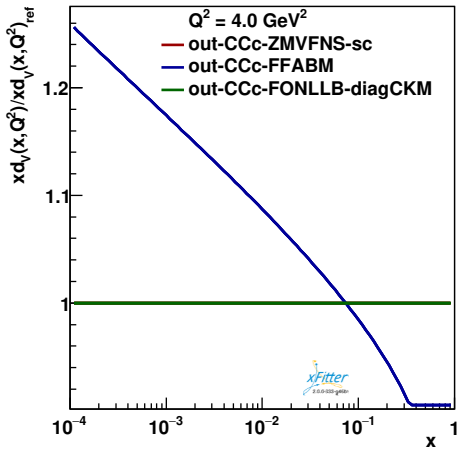

Q^2 = 1.9 GeV^2
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCKM
$xg(x,Q^2)/xg(x,Q^2)_{ref}$
x

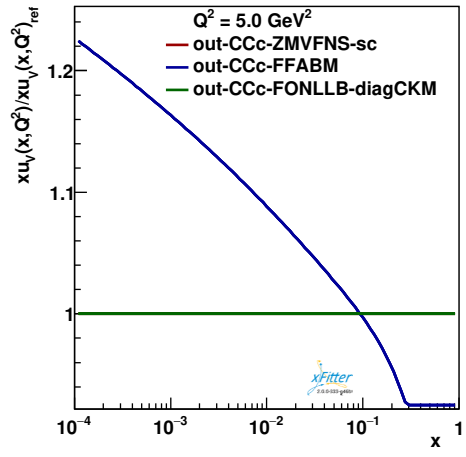

Q^2 = 1.9 GeV^2
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCKM
$x\Sigma(x,Q^2)/x\Sigma(x,Q^2)_{ref}$
x

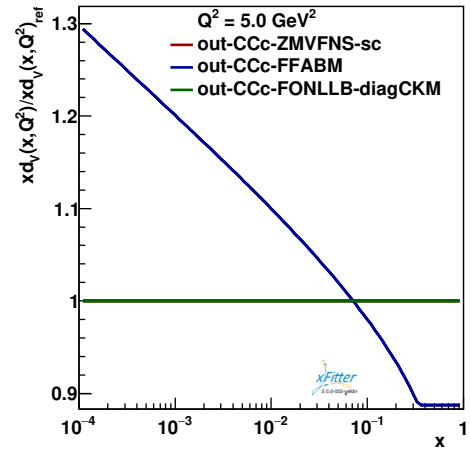

Q^2 = 3.0 GeV^2
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCKM
$xg(x,Q^2)/xg(x,Q^2)_{ref}$
x

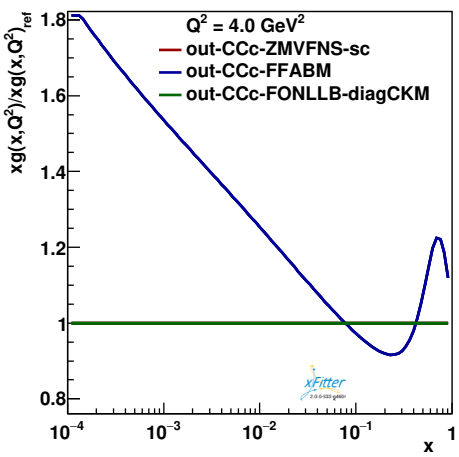

Q^2 = 3.0 GeV^2
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCKM
$x\Sigma(x,Q^2)/x\Sigma(x,Q^2)_{ref}$
x

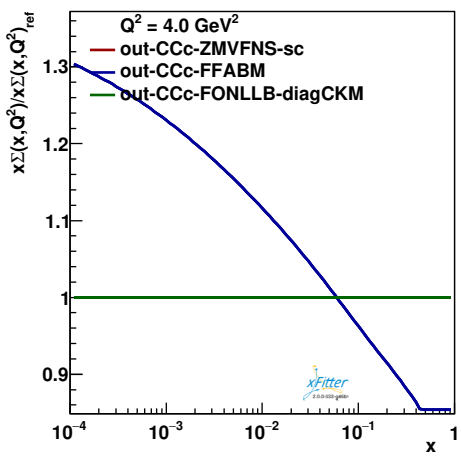

Q^2 = 4.0 GeV^2
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCKM
$xu_V(x,Q^2)/xu_V(x,Q^2)_{ref}$
x

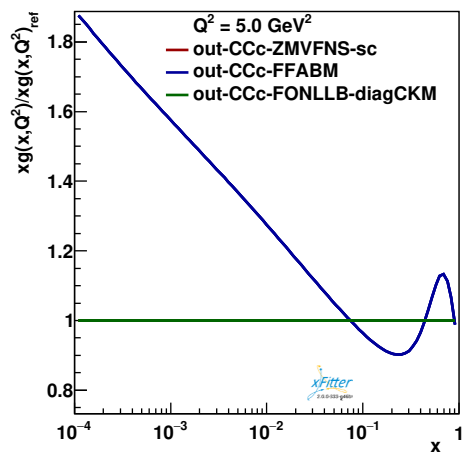

Q^2 = 4.0 GeV^2
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCKM
$xd_V(x,Q^2)/xd_V(x,Q^2)_{ref}$
x

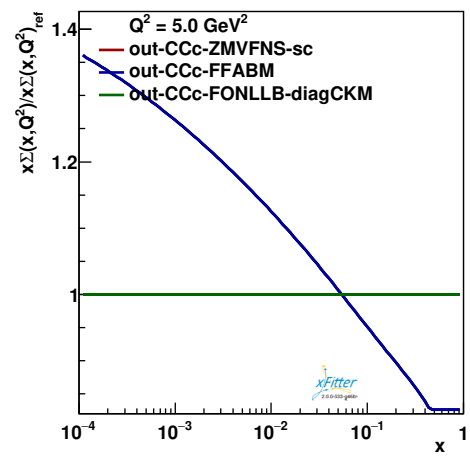

Q^2 = 5.0 GeV^2
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCKM
$xu_V(x,Q^2)/xu_V(x,Q^2)_{ref}$
x

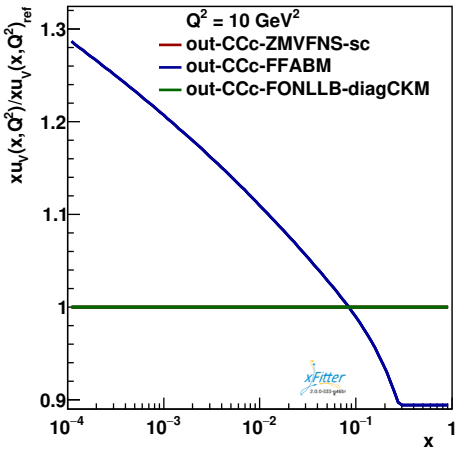

Q^2 = 5.0 GeV^2
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCKM
$xd_V(x,Q^2)/xd_V(x,Q^2)_{ref}$
x

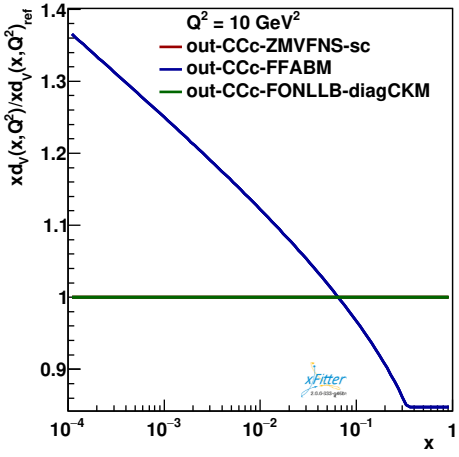

Q^2 = 4.0 GeV^2
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCKM
$xg(x,Q^2)/xg(x,Q^2)_{ref}$
x

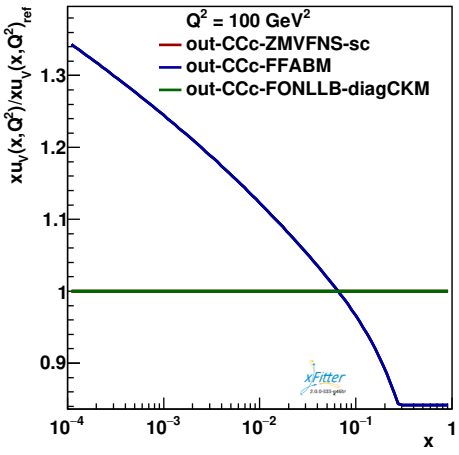

Q^2 = 4.0 GeV^2
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCKM
$x\Sigma(x,Q^2)/x\Sigma(x,Q^2)_{ref}$
x

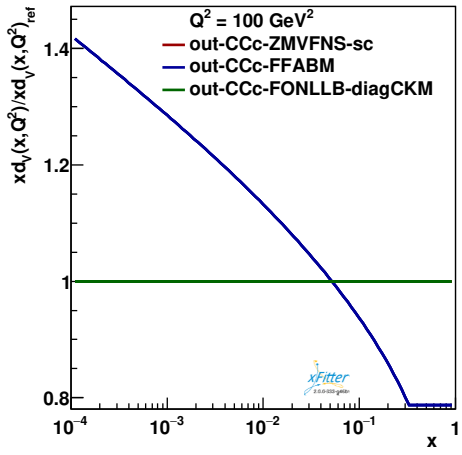

Q^2 = 5.0 GeV^2
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCKM
$xg(x,Q^2)/xg(x,Q^2)_{ref}$
x

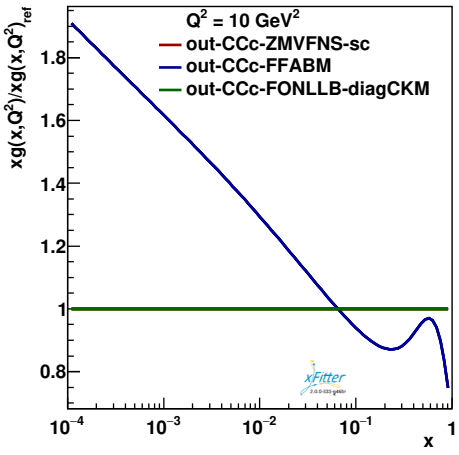

Q^2 = 5.0 GeV^2
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCKM
$x\Sigma(x,Q^2)/x\Sigma(x,Q^2)_{ref}$
x

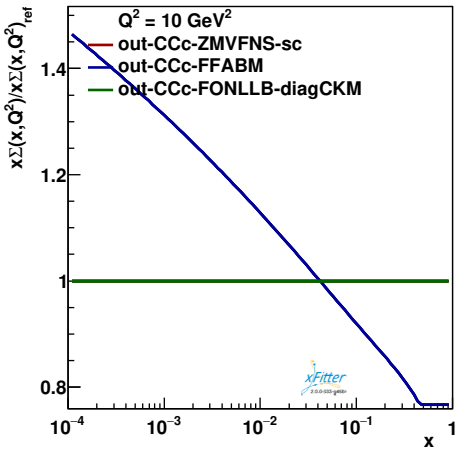

Q^2 = 10 GeV^2
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCKM
$xu_V(x,Q^2)/xu_V(x,Q^2)_{ref}$
x
xFitter

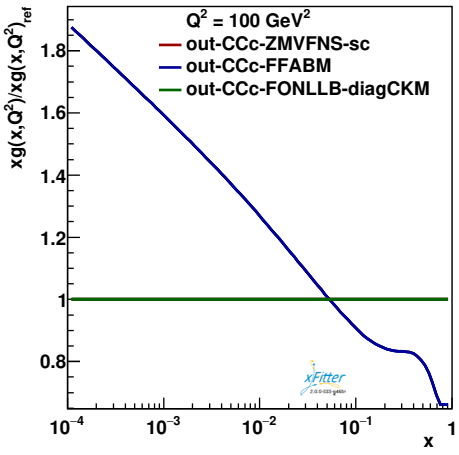

Q^2 = 10 GeV^2
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCKM
$xd_V(x,Q^2)/xd_V(x,Q^2)_{ref}$
x
xFitter

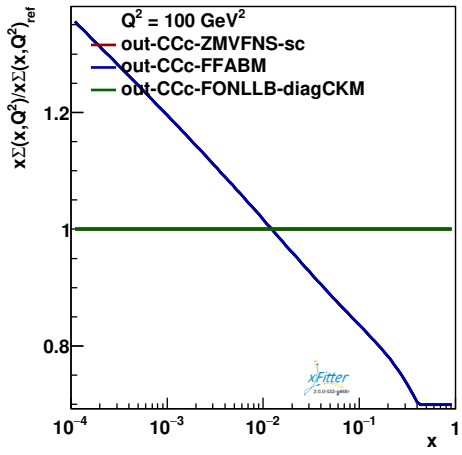

Q^2 = 100 GeV^2
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCKM
$xu_V(x,Q^2)/xu_V(x,Q^2)_{ref}$
x
xFitter

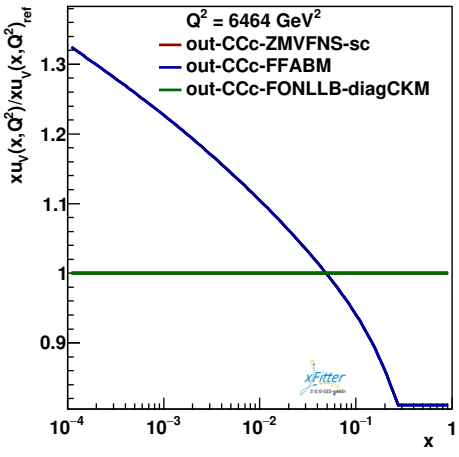

Q^2 = 100 GeV^2
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCKM
$xd_V(x,Q^2)/xd_V(x,Q^2)_{ref}$
x
xFitter

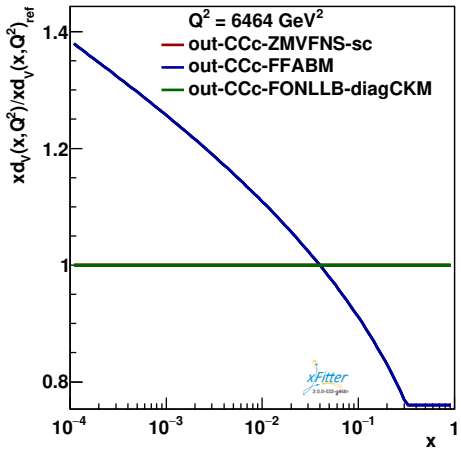

Q^2 = 10 GeV^2
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCKM
$xg(x,Q^2)/xg(x,Q^2)_{ref}$
x
xFitter

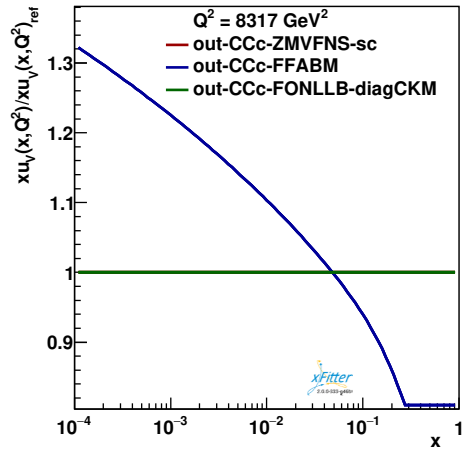

Q^2 = 10 GeV^2
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCKM
$x\Sigma(x,Q^2)/x\Sigma(x,Q^2)_{ref}$
x
xFitter

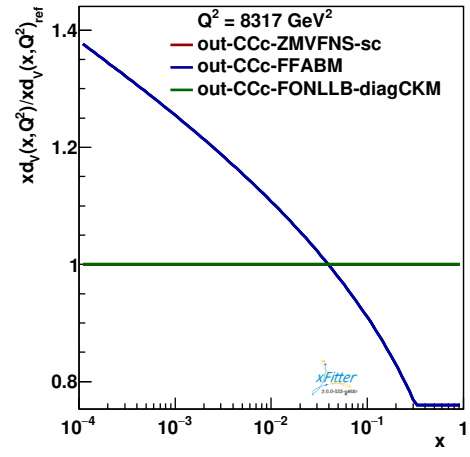

Q^2 = 100 GeV^2
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCKM
$xg(x,Q^2)/xg(x,Q^2)_{ref}$
x
xFitter

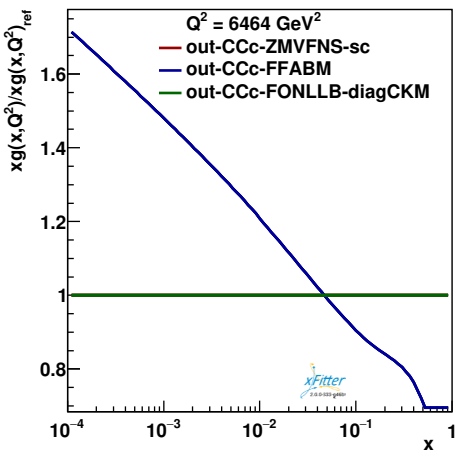

Q^2 = 100 GeV^2
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCKM
$x\Sigma(x,Q^2)/x\Sigma(x,Q^2)_{ref}$
x
xFitter

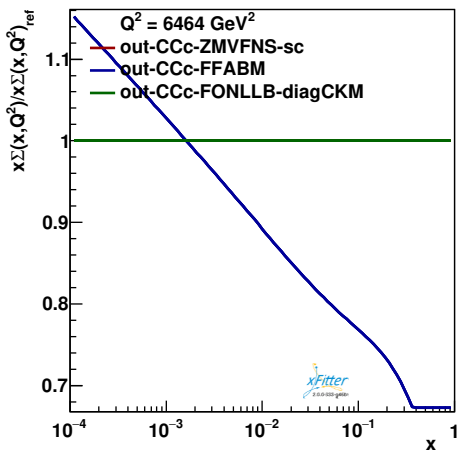

Q^2 = 6464 GeV^2
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCKM
$xu_V(x,Q^2)/xu_V(x,Q^2)_{ref}$
x

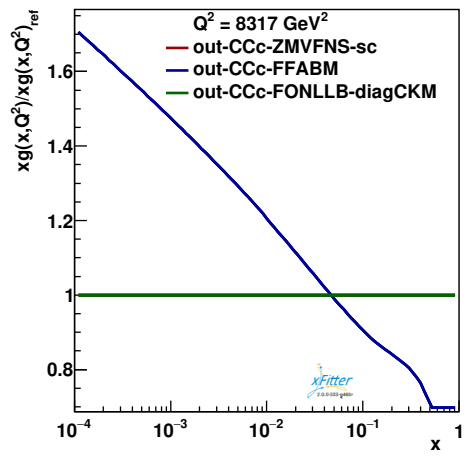

Q^2 = 6464 GeV^2
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCKM
$xd_V(x,Q^2)/xd_V(x,Q^2)_{ref}$
x

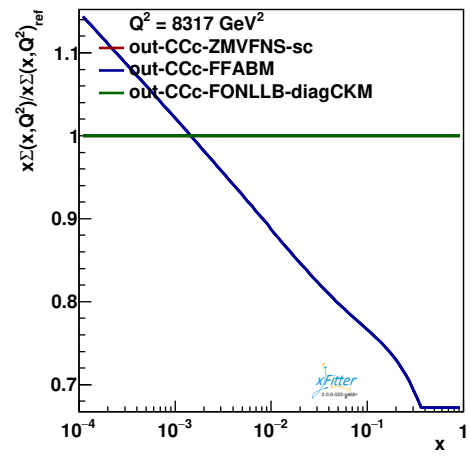

Q^2 = 8317 GeV^2
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCKM
$xu_V(x,Q^2)/xu_V(x,Q^2)_{ref}$
x


Q^2 = 8317 GeV^2
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCKM
$xd_V(x,Q^2)/xd_V(x,Q^2)_{ref}$
x

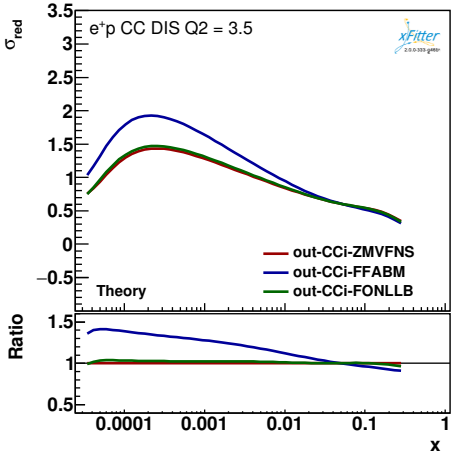

Q^2 = 6464 GeV^2
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCKM
$xg(x,Q^2)/xg(x,Q^2)_{ref}$
x

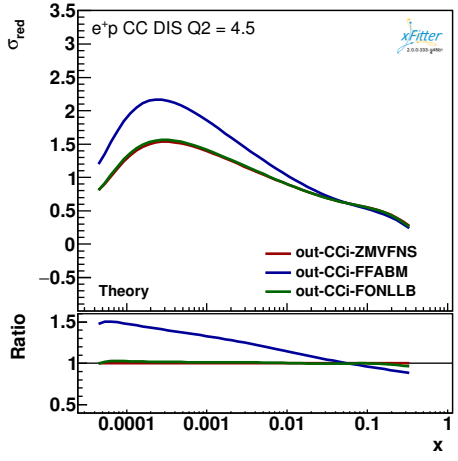

Q^2 = 6464 GeV^2
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCKM
$x\Sigma(x,Q^2)/x\Sigma(x,Q^2)_{ref}$
x

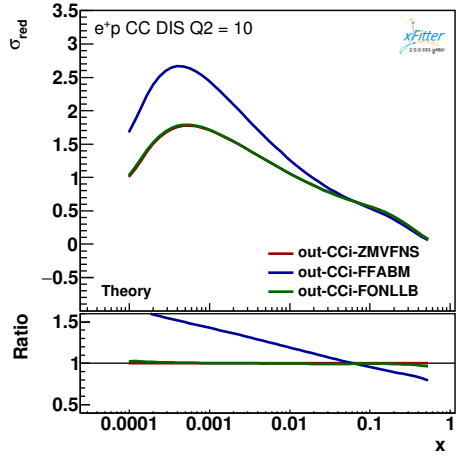

Q^2 = 8317 GeV^2
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCKM
$xg(x,Q^2)/xg(x,Q^2)_{ref}$
x

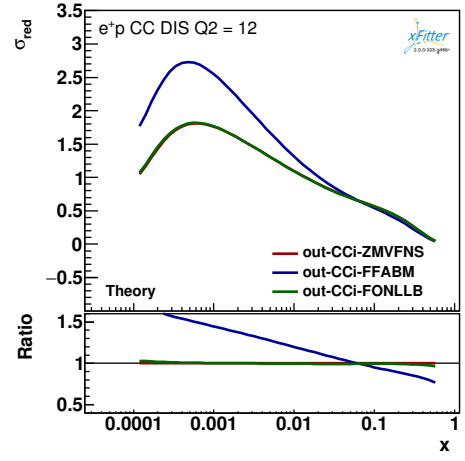

Q^2 = 8317 GeV^2
out-CCc-ZMVFNS-sc
out-CCc-FFABM
out-CCc-FONLLB-diagCKM
$x\Sigma(x,Q^2)/x\Sigma(x,Q^2)_{ref}$
x

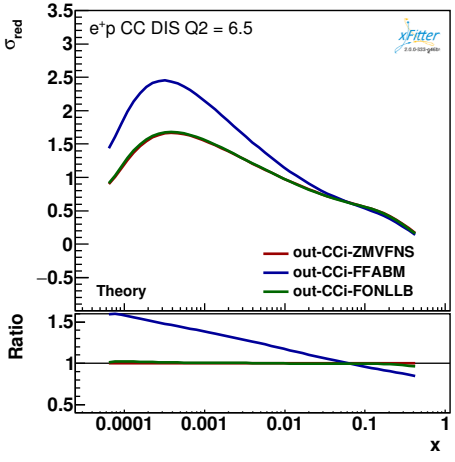
CC inclusive in three schemes

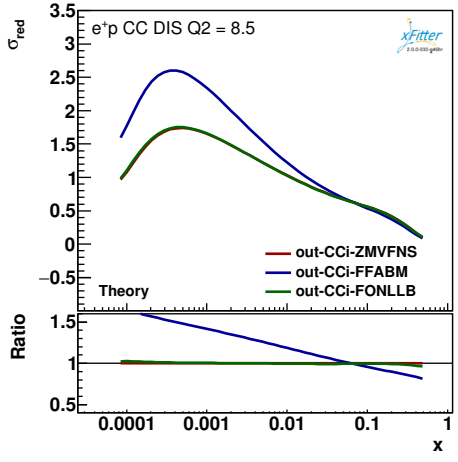

e+p CC DIS Q2 = 3.5
σred
Theory
out-CCi-ZMVFNS
out-CCi-FFABM
out-CCi-FONLLB
Ratio
x

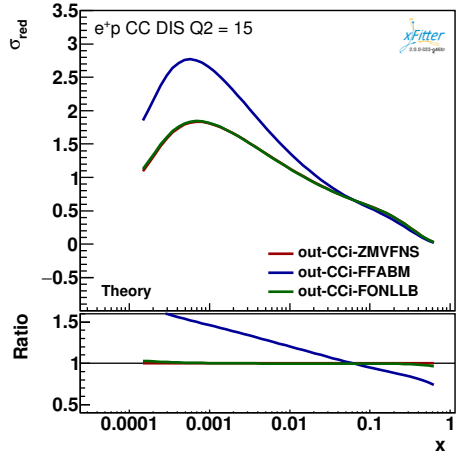

e+p CC DIS Q2 = 4.5
σred
Theory
out-CCi-ZMVFNS
out-CCi-FFABM
out-CCi-FONLLB
Ratio
x

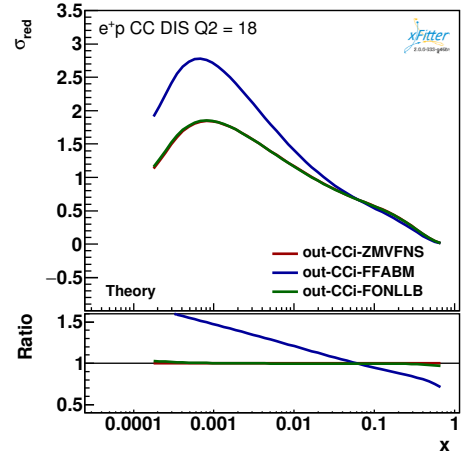

e+p CC DIS Q2 = 10
σred
Theory
out-CCi-ZMVFNS
out-CCi-FFABM
out-CCi-FONLLB
Ratio
x

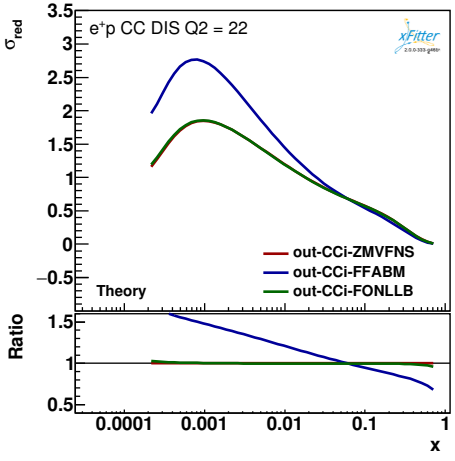

e+p CC DIS Q2 = 12
σred
Theory
out-CCi-ZMVFNS
out-CCi-FFABM
out-CCi-FONLLB
Ratio
x

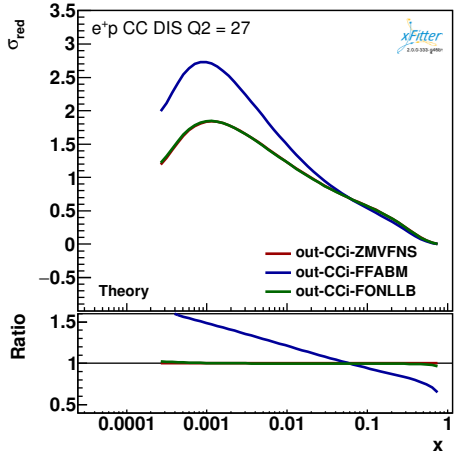

e+p CC DIS Q2 = 6.5
σred
Theory
out-CCi-ZMVFNS
out-CCi-FFABM
out-CCi-FONLLB
Ratio
x

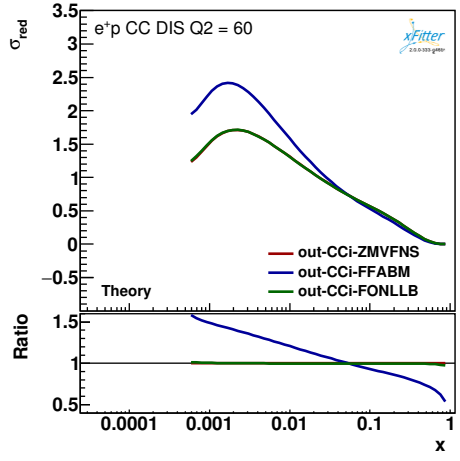

e+p CC DIS Q2 = 8.5
σred
Theory
out-CCi-ZMVFNS
out-CCi-FFABM
out-CCi-FONLLB
Ratio
x

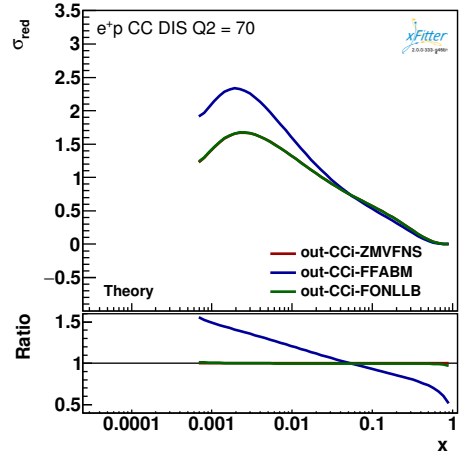

e+p CC DIS Q2 = 15
σred
Theory
out-CCi-ZMVFNS
out-CCi-FFABM
out-CCi-FONLLB
Ratio
x

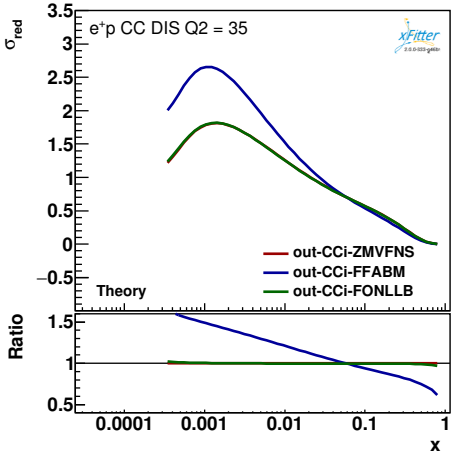

e+p CC DIS Q2 = 18
σred
Theory
out-CCi-ZMVFNS
out-CCi-FFABM
out-CCi-FONLLB
Ratio
x

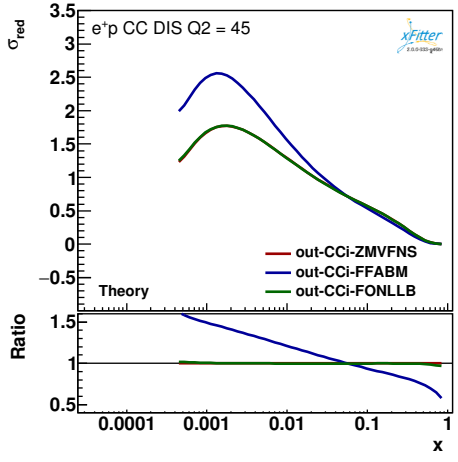

e+p CC DIS Q2 = 22
σred
Theory
out-CCi-ZMVFNS
out-CCi-FFABM
out-CCi-FONLLB
Ratio
x

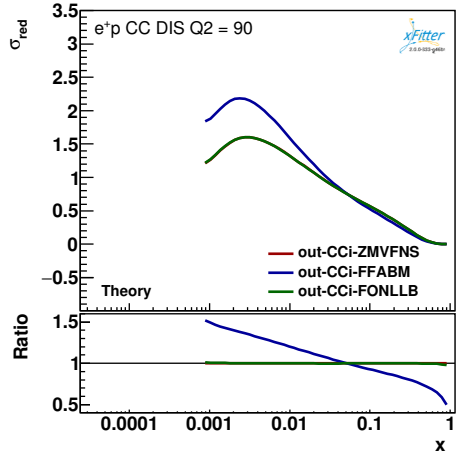

e+p CC DIS Q2 = 27
σred
Theory
out-CCi-ZMVFNS
out-CCi-FFABM
out-CCi-FONLLB
Ratio
x

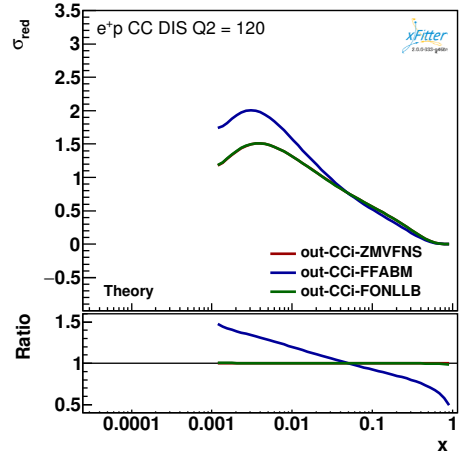

e+p CC DIS Q2 = 60
σred
Theory
out-CCi-ZMVFNS
out-CCi-FFABM
out-CCi-FONLLB
Ratio
x

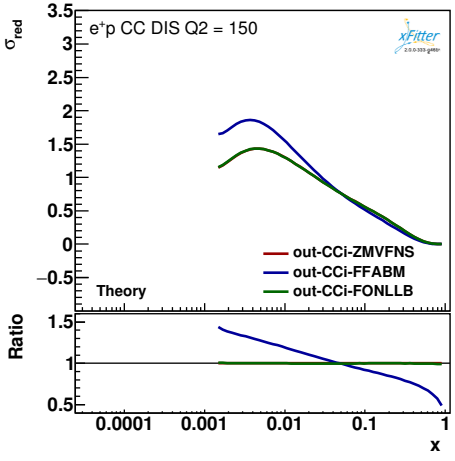

e+p CC DIS Q2 = 70
σred
Theory
out-CCi-ZMVFNS
out-CCi-FFABM
out-CCi-FONLLB
Ratio
x

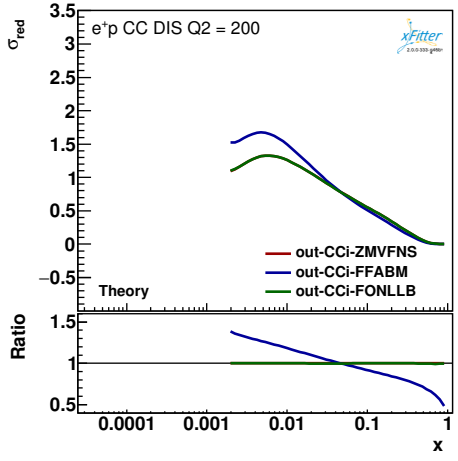

e+p CC DIS Q2 = 35
σred
Theory
out-CCi-ZMVFNS
out-CCi-FFABM
out-CCi-FONLLB
Ratio
x

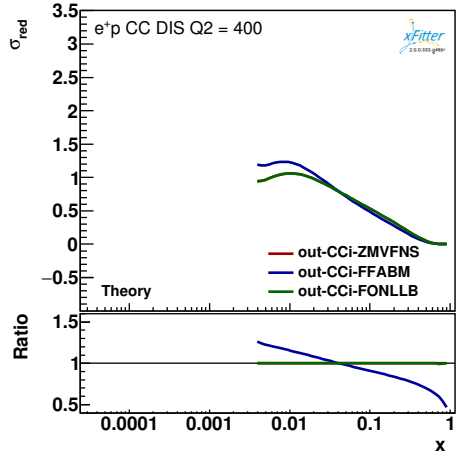

e+p CC DIS Q2 = 45
σred
Theory
out-CCi-ZMVFNS
out-CCi-FFABM
out-CCi-FONLLB
Ratio
x

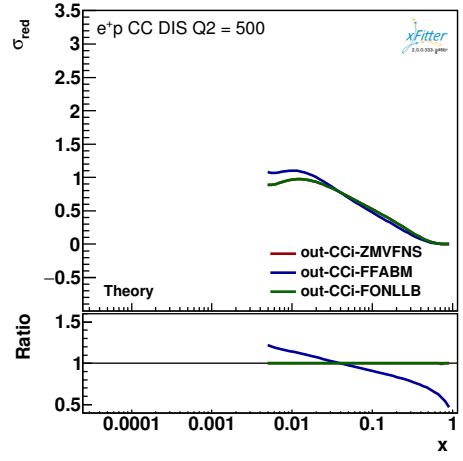

e+p CC DIS Q2 = 90
σred
Theory
out-CCi-ZMVFNS
out-CCi-FFABM
out-CCi-FONLLB
Ratio
x

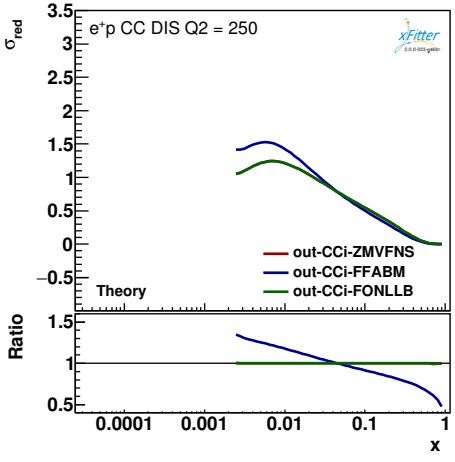

e+p CC DIS Q2 = 120
σred
Theory
out-CCi-ZMVFNS
out-CCi-FFABM
out-CCi-FONLLB
Ratio
x

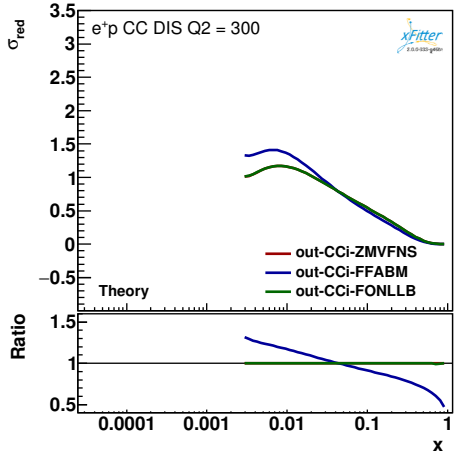

e+p CC DIS Q2 = 150
σred
Ratio
x
Theory
out-CCi-ZMVFNS
out-CCi-FFABM
out-CCi-FONLLB

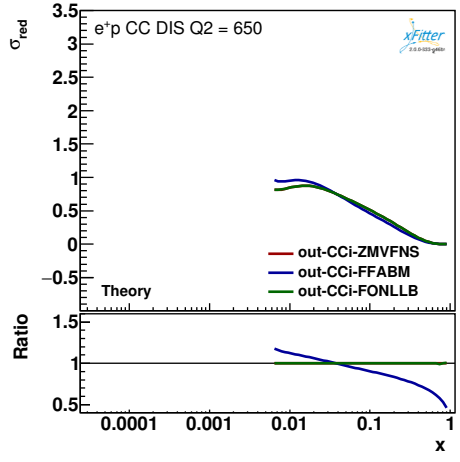

e+p CC DIS Q2 = 200
σred
Ratio
x
Theory
out-CCi-ZMVFNS
out-CCi-FFABM
out-CCi-FONLLB

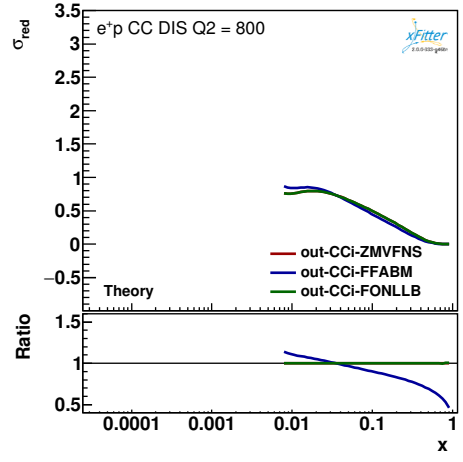

e+p CC DIS Q2 = 400
σred
Ratio
x
Theory
out-CCi-ZMVFNS
out-CCi-FFABM
out-CCi-FONLLB


e+p CC DIS Q2 = 500
σred
Ratio
x
Theory
out-CCi-ZMVFNS
out-CCi-FFABM
out-CCi-FONLLB


e+p CC DIS Q2 = 250
σred
Ratio
x
Theory
out-CCi-ZMVFNS
out-CCi-FFABM
out-CCi-FONLLB


e+p CC DIS Q2 = 300
σred
Ratio
x
Theory
out-CCi-ZMVFNS
out-CCi-FFABM
out-CCi-FONLLB


e+p CC DIS Q2 = 650
σred
Ratio
x
Theory
out-CCi-ZMVFNS
out-CCi-FFABM
out-CCi-FONLLB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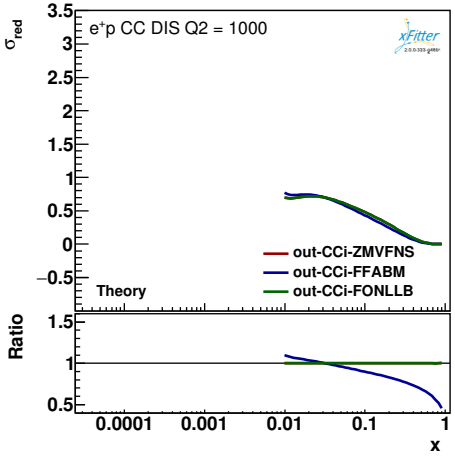
σred
Ratio
x
Theory
out-CCi-ZMVFNS
out-CCi-FFABM
out-CCi-FONLLB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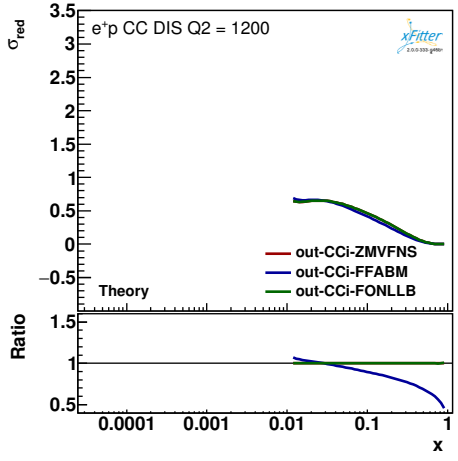
σred
Theory
out-CCi-ZMVFNS
out-CCi-FFABM
out-CCi-FONLLB
Ratio
x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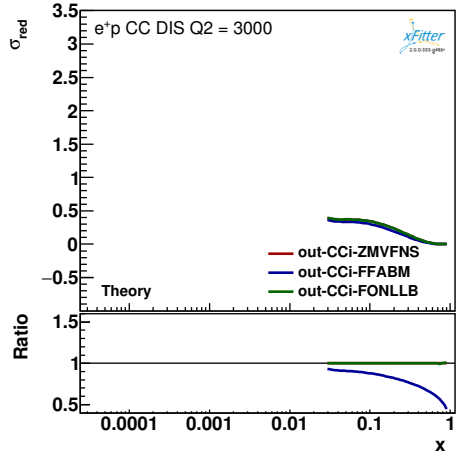
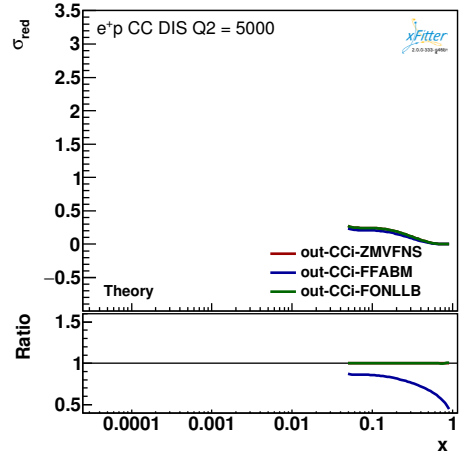
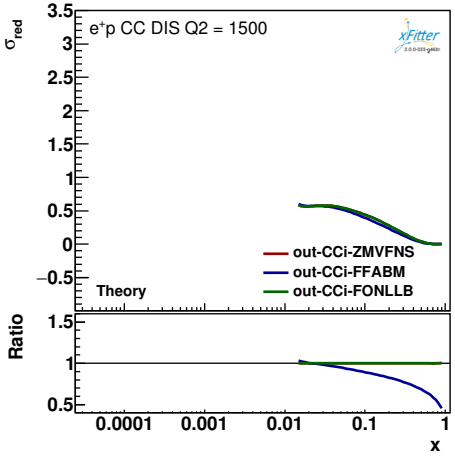
σred
Theory
out-CCi-ZMVFNS
out-CCi-FFABM
out-CCi-FONLLB
Ratio
x


e+p CC DIS Q2 = 3000
σred
Theory
out-CCi-ZMVFNS
out-CCi-FFABM
out-CCi-FONLLB
Ratio
x


e+p CC DIS Q2 = 5000
σred
Theory
out-CCi-ZMVFNS
out-CCi-FFABM
out-CCi-FONLLB
Ratio
x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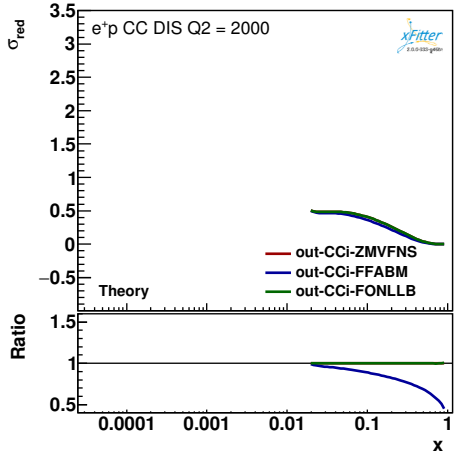
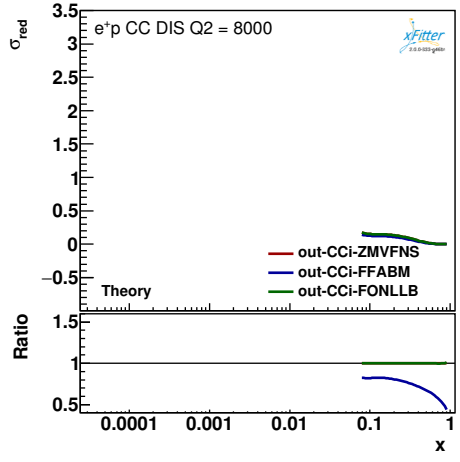
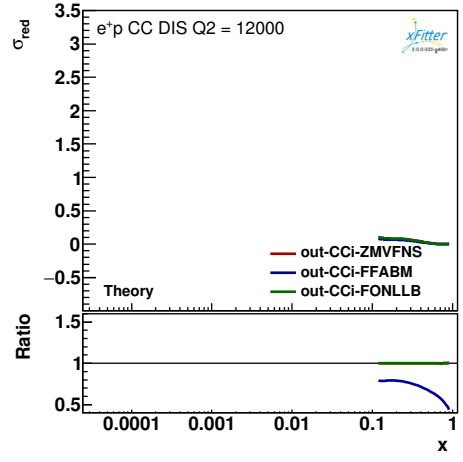
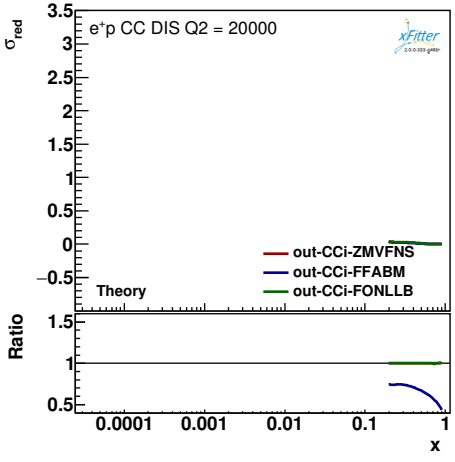
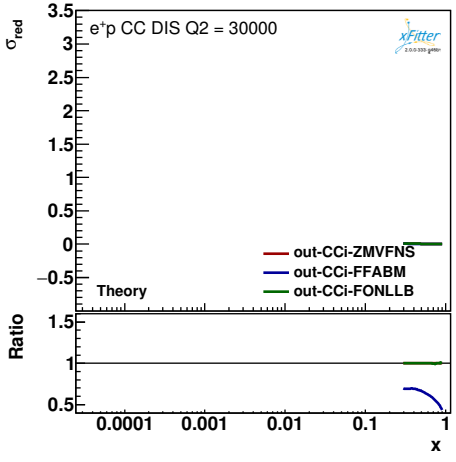
σred
Theory
out-CCi-ZMVFNS
out-CCi-FFABM
out-CCi-FONLLB
Ratio
x


e+p CC DIS Q2 = 2000
σred
Theory
out-CCi-ZMVFNS
out-CCi-FFABM
out-CCi-FONLLB
Ratio
x


e+p CC DIS Q2 = 8000
σred
Theory
out-CCi-ZMVFNS
out-CCi-FFABM
out-CCi-FONLLB
Ratio
x


e+p CC DIS Q2 = 12000
σred
Theory
out-CCi-ZMVFNS
out-CCi-FFABM
out-CCi-FONLLB
Ratio
x


e+p CC DIS Q2 = 20000
σred
Ratio
Theory
out-CCi-ZMVFNS
out-CCi-FFABM
out-CCi-FONLLB
x
0.0001
0.001
0.01
0.1
1


e+p CC DIS Q2 = 30000
σred
Ratio
Theory
out-CCi-ZMVFNS
out-CCi-FFABM
out-CCi-FONLLB
x
0.0001
0.001
0.01
0.1
1

Notes from Fred Olness

A. Very Rough Notes on charged current with Variable Flavor Number Scheme.

I've attached some diagrams to illustrate the problem.

Suppose we want to compute the inclusive F_2^{charm} with Charged Current (CC) charm production at NLO. The obvious LO diagram is ($sW^+ \to c$).

What is not so obvious is we also need ($\bar{c}W^+ \to \bar{s}$). This is because the $\bar{c}$ comes from a gluon splitting to $c\bar{c}$, and the c goes down the beam pipe. Experimentally, this is unobservable, but if you want to do a consistent truly "inclusive" F_2^{charm}, this is essential. If you ignore it, the problems will appear with the NLO terms. [More precisely, a truly "inclusive" F_2^{charm} is ill-defined; Collins proof of factorization for heavy quarks specifically focused on a totally inclusive F_2 for this reason.]

Note, if you make a "non-inclusive" F_2^{charm} (or "exclusive") measurement, this can be well defined; however, you must add a resolution scale (or regulator) to define how close to the beam fragments your charm can be.

To keep things simple, we'll focus on just the NLO gluon-initiated diagrams. The arguments follow through in a similar manner for the quark-initiated graphs.

1. *t-channel at NLO*

The t-channel at NLO is straightforward. We add the ($gW^+ \to c\bar{s}$) diagram. This exchanges an s quark in the t-channel, and thus will have a $\ln(m_s^2/Q^2)$ divergence for large Q. This is resolved by the subtraction term $f_g \otimes \mathcal{P}_{g\to s} \otimes \sigma_{sW^+\to c}$ where the $\mathcal{P}_{g\to s}$ represents a perturbative splitting of $g \to s$ and will cancel the double counting between the LO and NLO graphs in the limit where the exchanged s quark becomes collinear. At NLO, the SUB term is proportional to $\mathcal{P}_{g\to s} \sim \frac{\alpha_S}{2\pi} P^{(1)}_{g\to s} \ln(m_s^2/Q^2)$. The logarithmic divergence will cancel between the NLO and SUB terms as $Q^2 \to \infty$, resulting in a finite result for the NLO t-channel contribution.

2. *u-channel at NLO*

The u-channel at NLO is more subtle. We add the ($gW^+ \to c\bar{s}$) diagram with a $\bar{c}$ quark in the u-channel, and thus will have a $\ln(m_c^2/Q^2)$ divergence for large Q. This is resolved by the subtraction term $f_g \otimes \mathcal{P}_{g\to\bar{c}} \otimes \sigma_{\bar{c}W^+\to\bar{s}}$ where the $\mathcal{P}_{g\to\bar{c}}$ represents a perturbative splitting of $g \to \bar{c}$ and will cancel the double counting between the LO and NLO graphs in the limit where the exchanged $\bar{c}$ quark becomes collinear. At NLO, the SUB term is proportional to $\mathcal{P}_{g\to\bar{c}} \sim \frac{\alpha_S}{2\pi} P^{(1)}_{g\to\bar{c}} \ln(m_c^2/Q^2)$. The logarithmic divergence will cancel between the NLO and SUB terms as $Q^2 \to \infty$, resulting in a finite result for the NLO u-channel contribution.

The above description parallels the t-channel analysis.

Why do we need the LO ($\bar{c}W^+ \to \bar{s}$)?

The SUB term: It is essential we include the subtraction term $f_g \otimes \mathcal{P}_{g\to\bar{c}} \otimes \sigma_{\bar{c}W^+\to\bar{s}}$ so that we get a finite answer at large energies.

But, what if we did NOT include the LO ($\bar{c}W^+ \to \bar{s}$)?

At energy scales $Q \sim m_c$, the LO and SUB terms remove the double counting between the LO and NLO processes. This is most apparent when you plot the individual terms versus the Q scale (or more properly, it is the μ scale). [See Figure]

In the region of $Q \sim m_c$, the charm PDF f_c (and hence, the LO contribution) rises very quickly as it is driven by the very large gluon, and coupled with a large $\alpha_S(m_c)$.

The SUB subtraction also rises quickly as this is driven by the logarithmic term $\ln(m_c^2/Q^2)$.

The difference LO-SUB is the physical contribution to the total (TOT=LO+NLO-SUB), and it is this combination which is smooth across the "turn on" of the charm PDF.

We now see that if we neglect the LO ($\bar{c}W^+ \to \bar{s}$) we loose the cancellation between LO and SUB in the $Q \sim m_c$ and our structure function (or cross section) would have an anomalous rise at the location where we arbitrarily turn on the charm PDF.

B. The bottom line:

A truly "inclusive" F_2^{charm} is ill-defined. Instead, we necessarily must an "experimentally" defined F_2^{charm} where we specify conditions so that the final state charm is isolated from the hadron remnants.

We can talk about a fully inclusive F_2 where we include all flavors; this was the subject of Collins' proof.

If we compute a "pseudo-inclusive" F_2^{charm} in the Variable Flavor Number Scheme, we do need to include the LO ($\bar{c}W^+ \to \bar{s}$) and the associated SUB ($gW^+ \to c\bar{s}$).

We can compute in the Fixed Flavor Number Scheme, but in the large energy limit, we encounter $\ln(m_c^2/Q^2)$ divergences. In practice, our Q scales are not large enough to generate infinities, but they are large enough where we see the resummed logs included in the VFNS charm PDF become important.

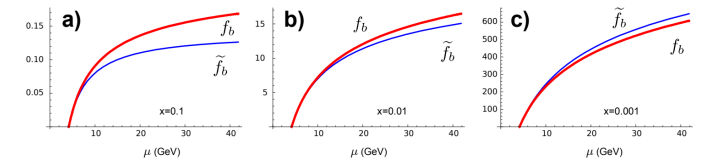


Fig. 2 The comparison of the DGLAP evolved PDF $f_b(x,\mu)$ and the perturbatively calculated $\tilde{f}_b(x,\mu)$ as a function of μ for selected x values. For $\mu \to m_b$ we find the functions match precisely: $\tilde{f}_b(x,\mu) \to f_b(x,\mu)$. We have used NNPDF30_lo_as_118_nf_6 as the base PDF set.

Figure 1. Figure taken from our xFitter paper "Impact of the heavy quark matching scales in PDF fits." The LO contributions correspond to f_b, and the SUB to $\tilde{f}_b$. The cancelation (LO-SUB) is quite precise. If we were to remove LO or SUB, our TOT result would have anomalous contributions in the region $Q \sim m$.

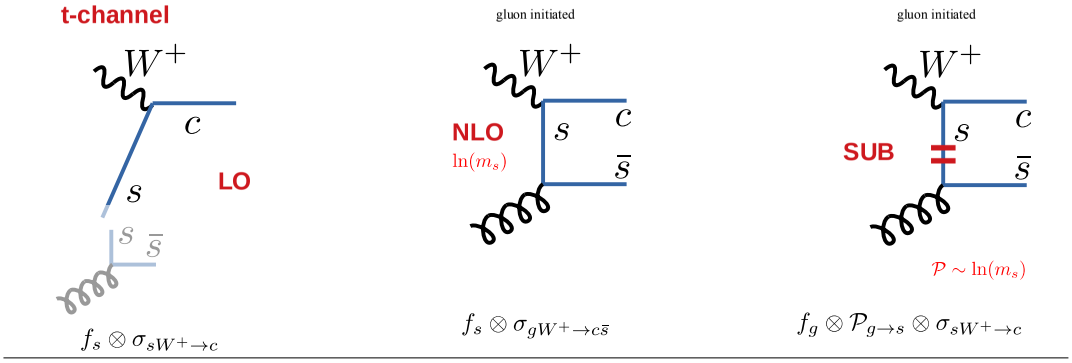


Figure 2. Gluon NLO processes

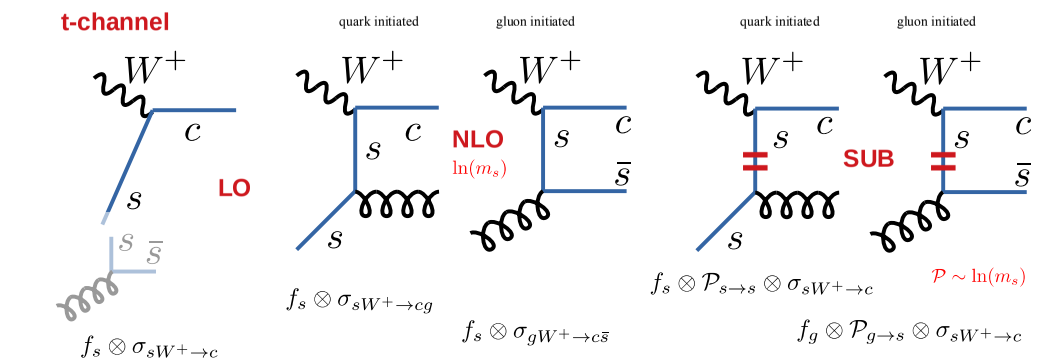


Figure 3. Gluon & Quark NLO processes