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THEORY UNCERTAINTIES ON PDFS

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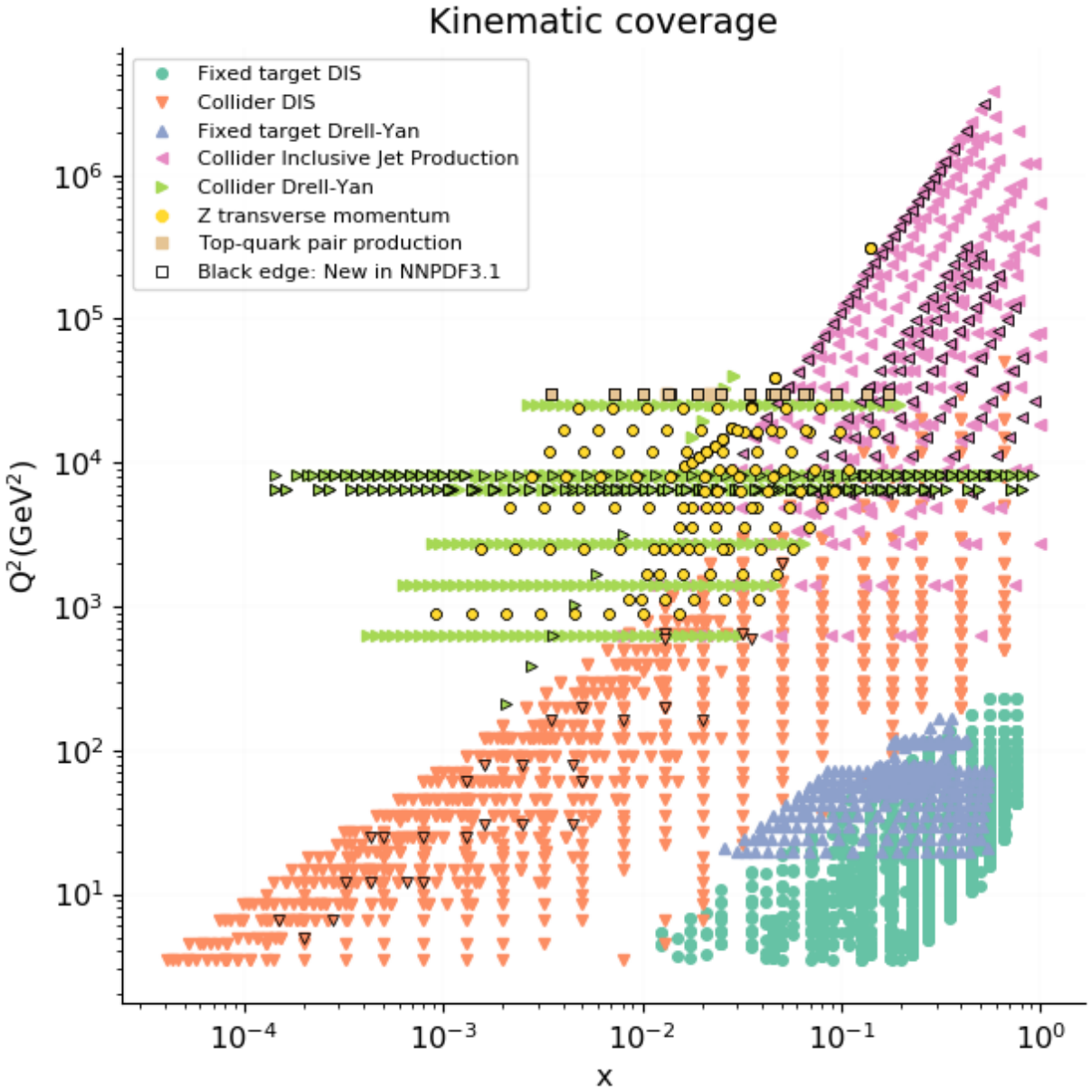
THEORY INSTITUTE

CERN, JULY 17 2018

PDF DATASET
LHC DATA!: NNPDF3.0 vs NNPDF3.1

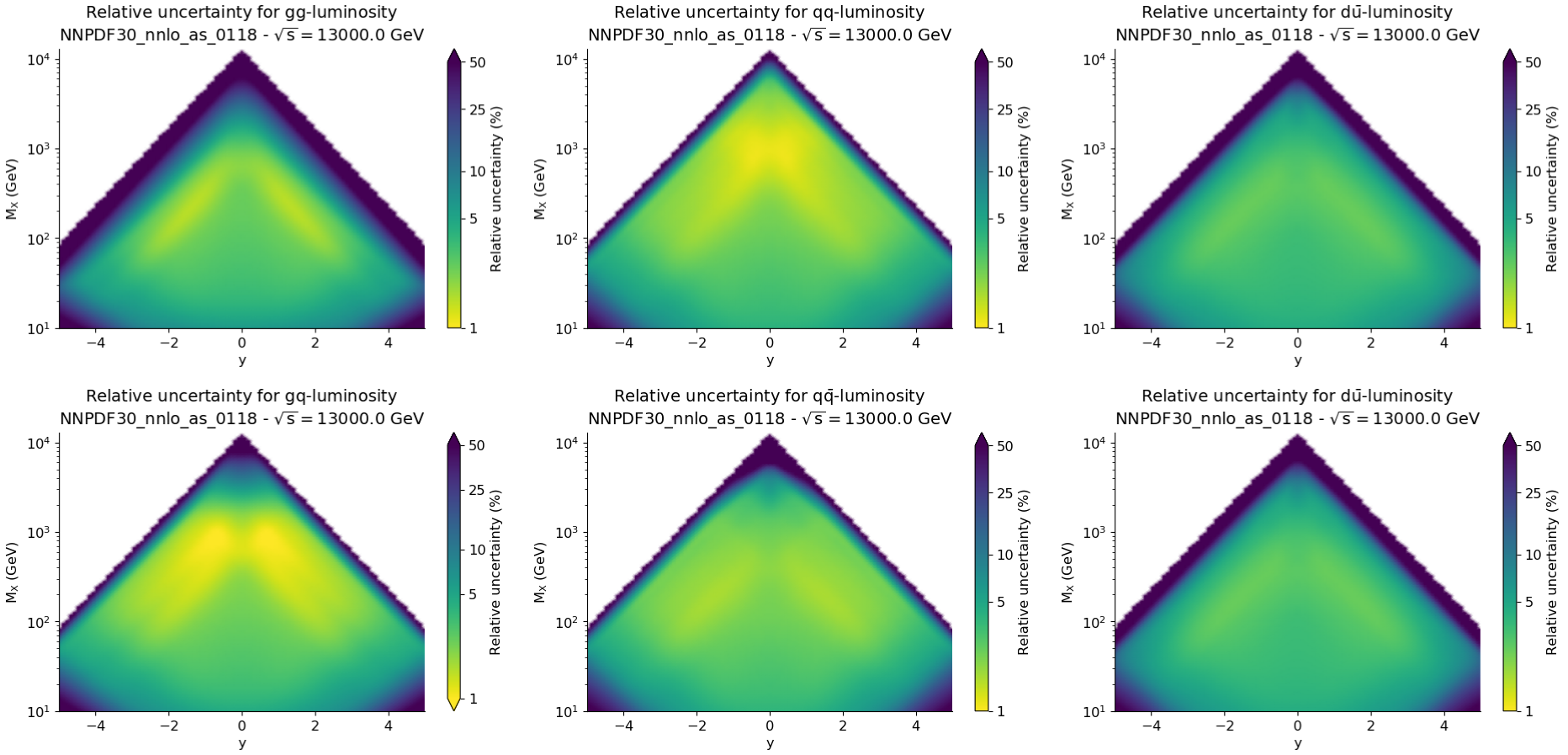


NEW DATA: (BLACK EDGE)

- HERA COMBINED F_2^b
- D0 W LEPTON ASYMMETRY
- ATLAS W, Z 2011, HIGH & LOW MASS DY 2011; CMS $W^{\pm}$ RAPIDITY 8TEV LHCB W, Z 7TEV & 8TEV
- ATLAS 7TEV JETS 2011, CMS 2.76TEV JETS
- ATLAS & CMS TOP DIFFERENTIAL RAPIDITY
- ATLAS Z p_T DIFFERENTIAL RAPIDITY & INVARIANT MASS 8TEV, CMS Z p_T DIFFERENTIAL RAPIDITY 8TEV

THE IMPACT OF LHC DATA
NNPDF3.0 (2014) PDF UNCERTAINTIES (NNLO)

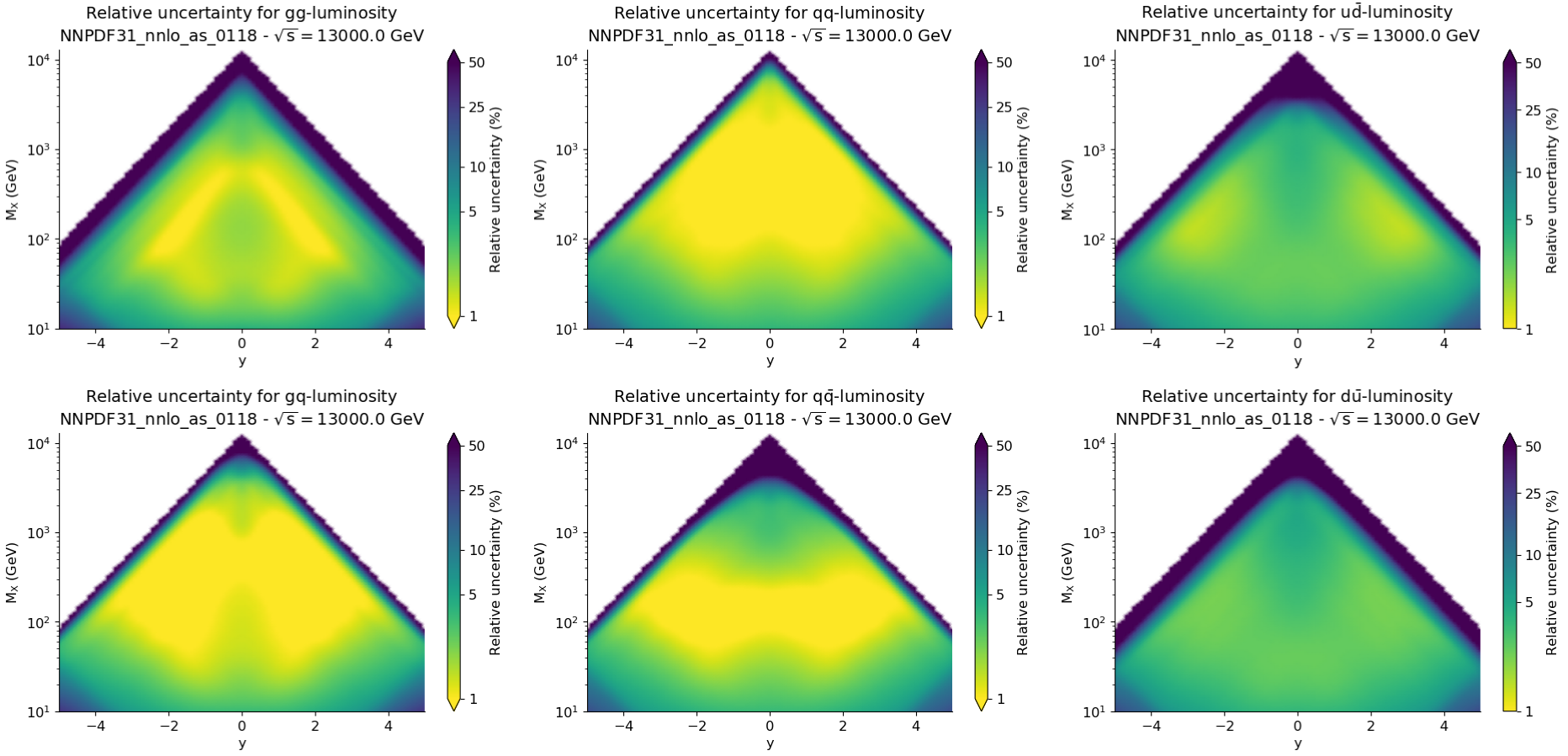
GLUON SINGLET FLAVORS



- TYPICAL UNCERTAINTIES IN DATA REGION $\sim 3 - 5\%$
- .

THE IMPACT OF LHC DATA
NNPDF3.1 (2017) PDF UNCERTAINTIES (NNLO)

GLUON SINGLET FLAVORS



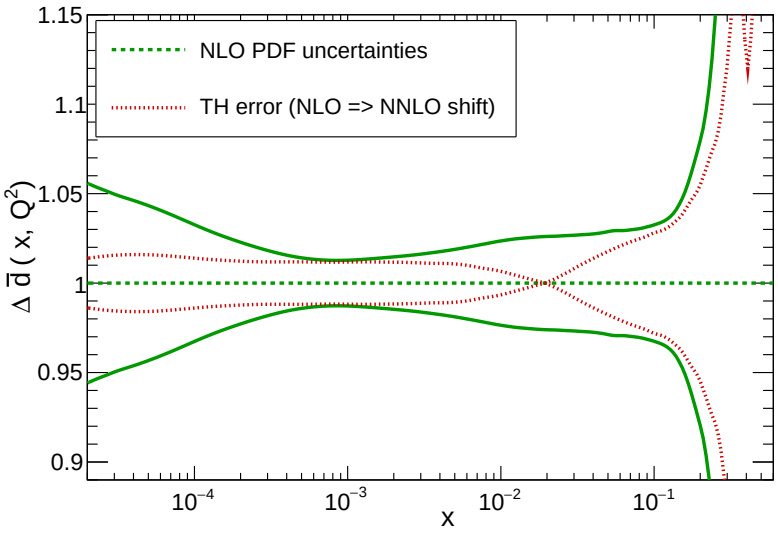
- TYPICAL UNCERTAINTIES IN DATA REGION $\sim 1 - 3\%$
- NEW LHC DATA $\Rightarrow$ SIZABLE REDUCTION IN UNCERTAINTIES

THE MISSING HIGHER ORDER UNCERTAINTY

- DOMINANT THEORY UNCERTAINTY ON QCD PREDICTIONS $\Rightarrow$ MHOU (SCALE)
- NOT INCLUDED IN PDF UNCERTAINTY
- HOW LARGE IS IT?
  $\Rightarrow$ AT NLO, CAN CHECK NLO-NNLO PDF SHIFT

NLO-NNLO SHIFT VS. NLO PDF UNCERTAINTY (NNPDF3.1)

ANTIDOWN



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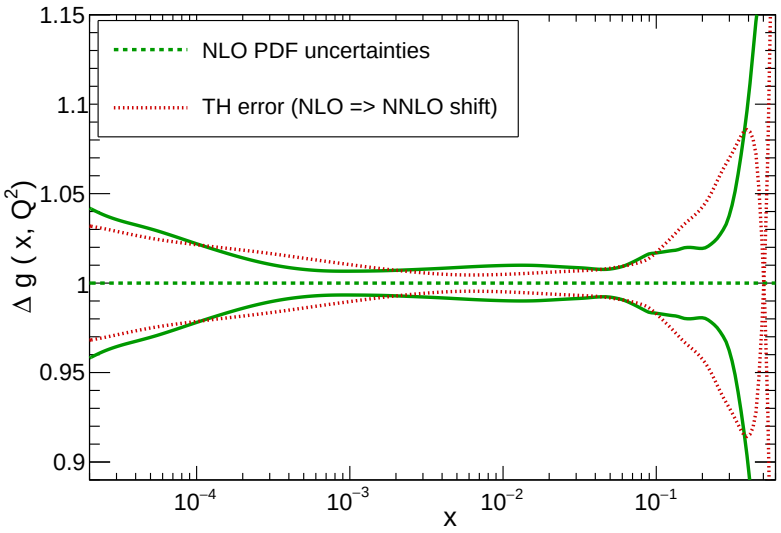


- TODAY: NLO PDF & MHOU UNCERTAINTIES COMPARABLE
- NEAR FUTURE: SHOULD WE WORRY ABOUT NNLO MHOU?

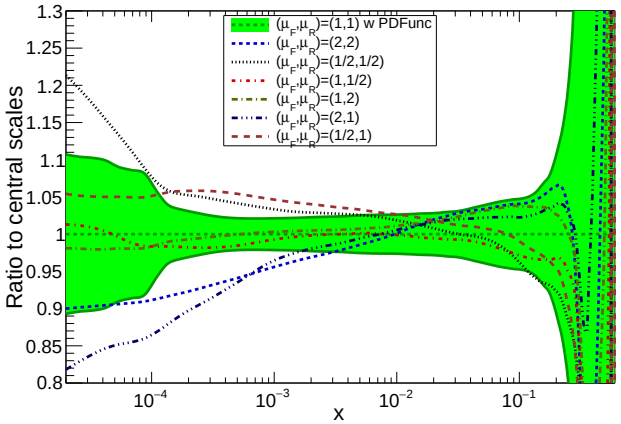
SCALE VARIATION IN PDF FITTING

SIMPLEST IDEA FOR PDF MHOU ESTIMATE

- PERFORM FIT WITH VARIOUS SCALE CHOICES
- TAKE ENVELOPE OF RESULTS (?)
- COMPARE TO NLO-NNLO SHIFT IN ORDER TO TUNE RANGE OF VARIATION & CORRELATION PATTERN: VARIATION FULLY CORRRELATED ACROSS PROCESSES?

FITS WITH SCALE VARIATION

ANTIDOWN



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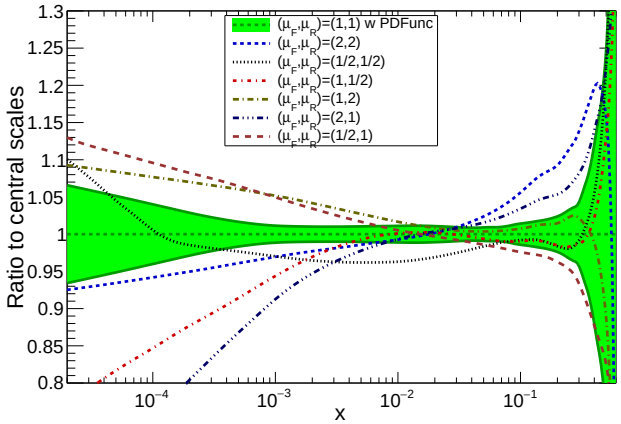
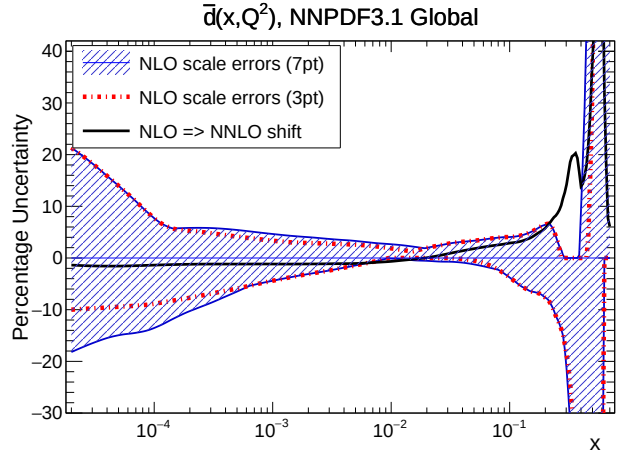
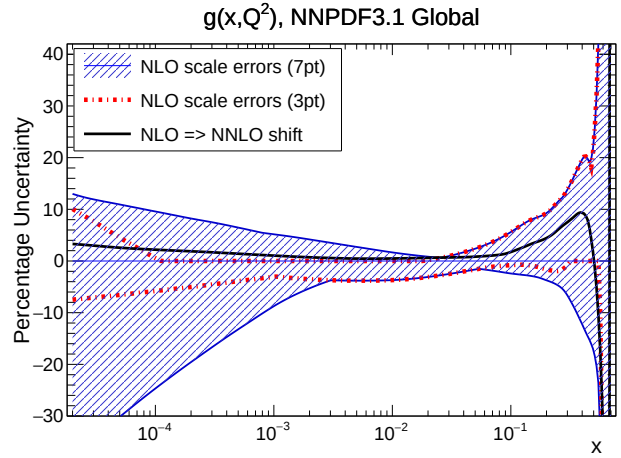


SCALE UNCERTAINTY VS NLO-NNLO SHIFT





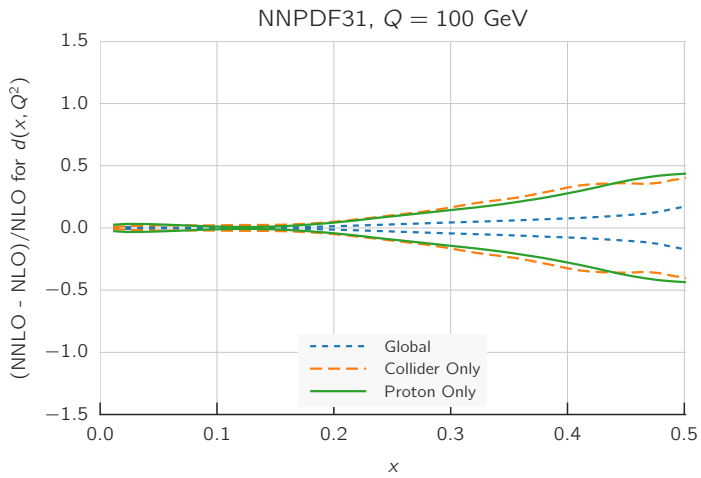
DEPENDENCE ON THE DATASET

PERTURBATIVE STABILITY

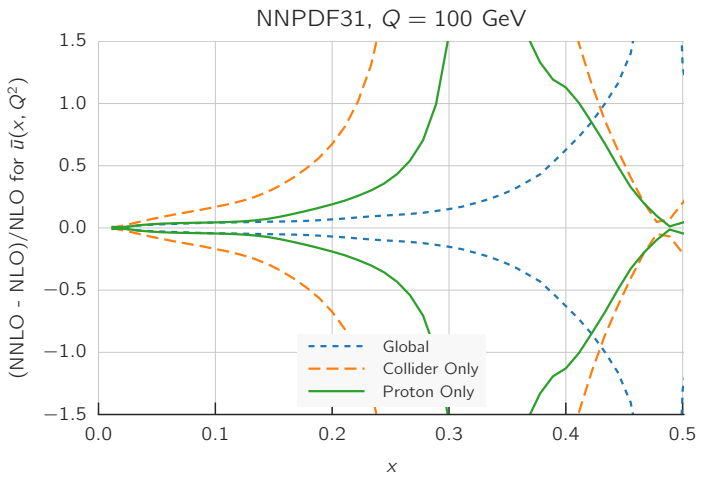
NNLO-NLO SHIFTS

GLOBAL VS. COLLIDER ONLY VS. PROTON ONLY PDFS

DOWN



ANTIUP



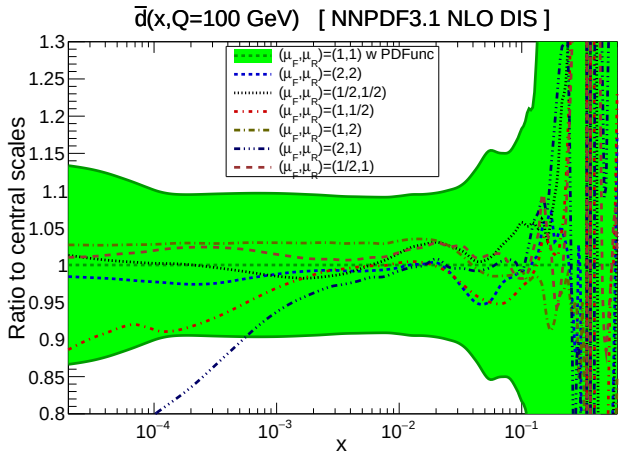
- MHOU DEPENDS ON DATASET
- NLO-NNLO SHIFTS GENERALLY SMALLER WITH LARGER DATASET
- $\Rightarrow$ CORRELATION PATTERN BETWEEN MHO TERMS

DEPENDENCE ON THE DATASET

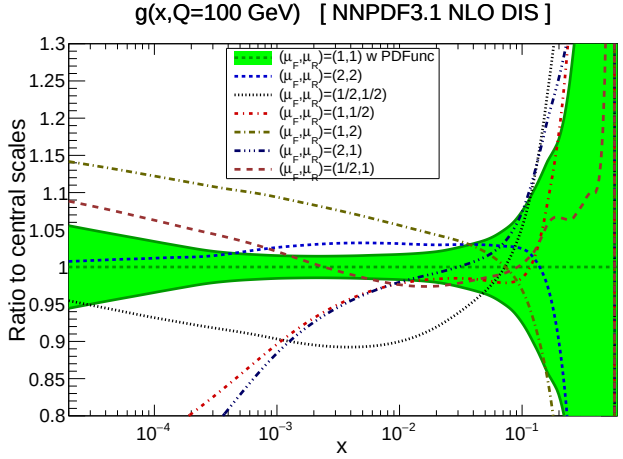
SCALE VARIATION

DIS ONLY

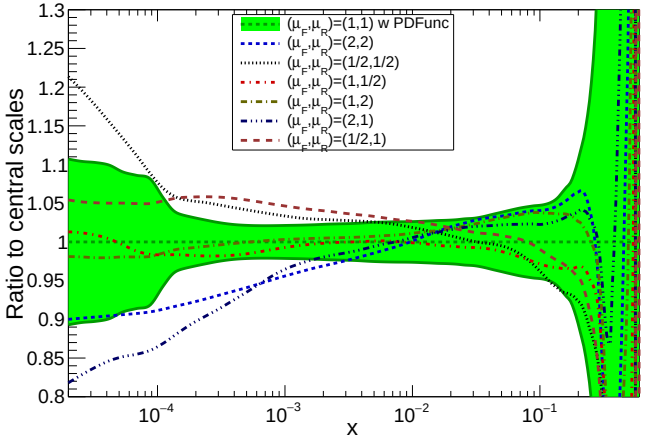
ANTIDOWN

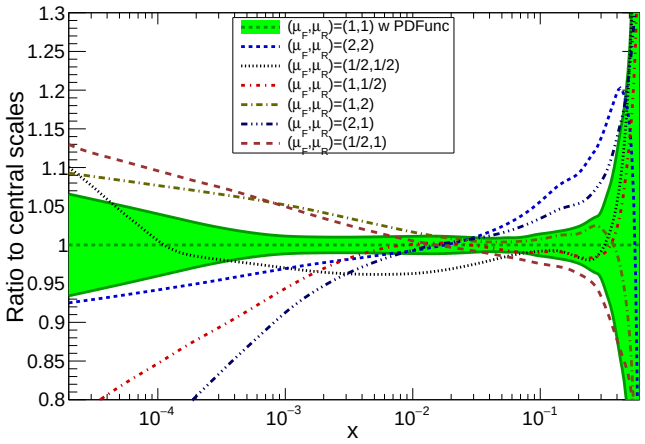


GLUON



GLOBAL





- SCALE DEPENDENCE IS (OF COURSE!) DATASET DEPENDENT
- BOTH SIZE AND PATTERN OF BEST-FIT RESULTS DEPEND ON PROCESS
- WHAT IS THE CORRELATION BETWEEN SCALE DEPENDENCES?
- ENVELOPE??

CAN WE CONSISTENTLY INCLUDE MHOU IN PDF ERRORS?

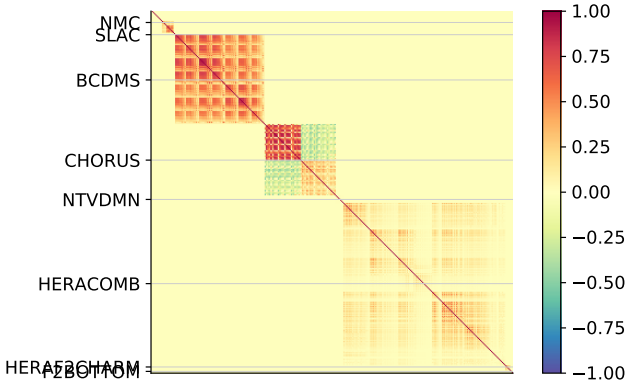
A BETTER IDEA FOR PDF MHOU ESTIMATE

- PERFORM CALCULATION WITH VARIOUS SCALE CHOICES
- USE DISTRIBUTION OF RESULTS TO COMPUTE THEORY COVARIANCE MATRIX
- PERFORM FIT WITH EXTRA CONTRIBUTION TO COVARIANCE MATRIX
  $\Rightarrow$ MHOU INCLUDED IN PDF UNCERTAINTY

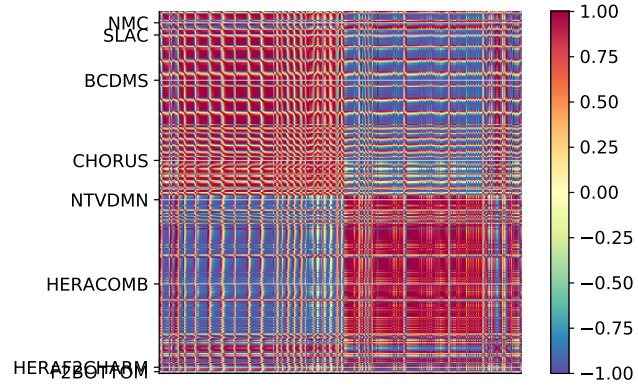
CORRELATION MATRICES

DIS $\mu_R = \mu_F$ VARIED BY 2 ABOUT Q

EXPERIMENT

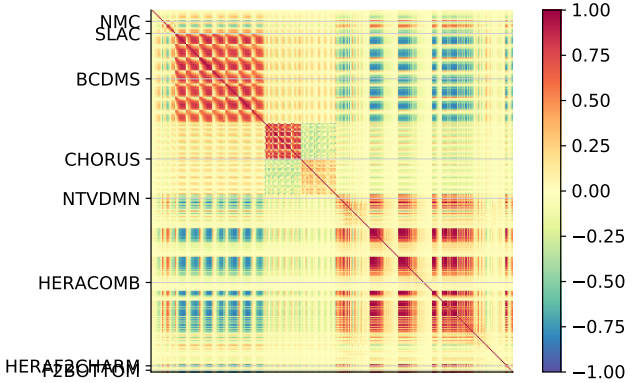


THEORY

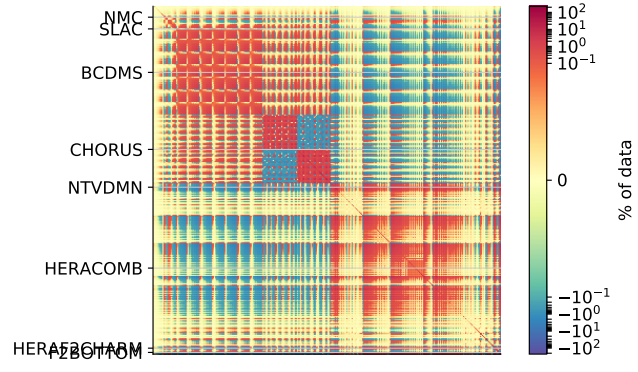


COMBINED EXP+TH

CORRELATION



COVARIANCE



THEORY COVARIANCE MATRICES
SUBTLETIES I: DEFINITION

"STANDARD" DEFINITION OF SCALE VARIATION:
USE RG INVARIANCE OF PHYSICAL OBSERVABLE

- HADRONIC (HXSWG...): $\sigma(Q^2) = \sum_{ij} \hat{\sigma}_{ij} \left(\frac{Q^2}{\mu_F^2}, \frac{Q^2}{\mu_R^2}, \alpha_s(\mu_R^2) \right) f_i(\mu_F^2) f_j(\mu_F^2)$
  - FACTORIZATION: $f_i({\mu'_F}^2) = \left(1 + P_0 \ln \frac{{\mu'_F}^2}{{\mu'_F}^2} \right) f_i(\mu_F^2)$
  - RENORMALIZATION: $\alpha(\mu'^2_r) \left(1 - \beta_0 \alpha \mu_R^2 \ln \frac{{\mu'_R}^2}{{\mu'_R}^2} \right)$
  - μ_F DEP IN PDF, μ_R DEP IN $\hat{\sigma}$
- DIS (Virchaux-Milsztajn, MRS, `PEGASUS`, `APFEL`,...):
  $F(Q^2) = \sum_i C_i \left(\frac{Q^2}{\mu_F^2}, \frac{Q^2}{\mu_R^2}, \alpha_s(Q^2) \right) f_i(\mu_F^2, \mu_R^2)$
  - FACTORIZATION: AS ABOVE
  - RENORMALIZATION: LET $\alpha(\mu_F^2) \to \alpha(\mu_R^2)$ IN EVOLUTION EQUATION
  - BOTH μ_R, μ_F VARIED IN PDF
- DIFFERENCE DIFFERENT NNLO TERMS GENERATED AT NLO
  "ADDITIVE" VS. "MULTIPLICATIVE"
  - DIS NLO $\ln \frac{\mu_R}{\mu_F}$, HADRONIC $\ln \frac{\mu_R}{Q} \ln \frac{\mu_F}{Q}$
  - DIS NLO $\beta_0 P_1$ TERMS, HADRONIC $\beta_0 + P_1$

$\Rightarrow$ ADOPT A COMMON PRESCRIPTION

THEORY COVARIANCE MATRICES

SUBTLETIES II: CORRELATIONS

THEORY COVARIANCE MATRIX: processes i, j, scale choice $\{\mu^{(k)}\}$, default $\{\mu_0\}$

$$\sigma_{i,j} = \frac{1}{N} \sum_k \left(\sigma_i[\{\mu^{(k)}\}] - \sigma_i[\{\mu_0\}]\right) \left(\sigma_j[\{\mu^{(k)}\}] - \sigma_j[\{\mu_0\}]\right)$$

- SINGLE PROCESS: k RUNS OVER COMMON SET OF SCALE CHOICES
- MANY PROCESSES: OPTIONS
  - UNCORRELATED n POINT: GIVEN SET OF n SCALE CHOICES, $k = (n_i, n'_j)$; EXAMPLES: TWO UPPER AND LOWER $\mu_R = \mu_F$, SEVEN (SIX) POINT μ_R AND μ_F, ...
  - CORRELATED FACTORIZATION: FOR EACH μ_F CHOICE, VARY μ_F ABOUT CENTRAL VALUE FOR TWO PROCESSES $k = (\mu_F, \mu_{R_i}, \mu'_{R_j})$
  - MORE?

EXAMPLE: $(i, j) = ggH,\ Z,\ t\bar{t}$

CORRELATION MATRIX

UNCORR. 3PT

$$\begin{pmatrix} 1. & -0.00089907 & -0.000558769 \\ -0.00089907 & 1. & 0.0000499357 \\ -0.000558769 & 0.0000499357 & 1. \end{pmatrix}$$

CORR. FACT.

$$\begin{pmatrix} 1. & 0.107548 & -0.0211511 \\ 0.107548 & 1. & -0.18569 \\ -0.0211511 & -0.18569 & 1. \end{pmatrix}$$

- CORRELATION PATTERNS DRIVEN BY CORRELATED/UNCORRELATED FACTORIZATION: UNCORRELATED FACTORIZATION $\Leftrightarrow$ EFFECTIVELY BLOCK-DIAGONAL COV. MAT.
- CANNOT DO SEVEN POINT WITH CORRELATED FACTORIZATION

A TENTATIVE ROADMAP

- COMPUTE NLO-NNLO SHIFT
- PERFORM SCALE-VARIATION FITS
- COMPUTE THEORY COVARIANCE MATRIX WITH VARIOUS PRESCRIPTIONS
- VALIDATE THEORY COVARIANCE MATRIX BY COMPARING TO FITS
- VALIDATE DIAGONAL UNCERTAINTY BY COMPARING SHIFT TO FIT WITH THEORY COVARIANCE MATRIX
- VALIDATE CORRELATION BY STUDYING DATASET DEPENDENCE