



THEORY UNCERTAINTIES ON PDFs

STEFANO FORTE
UNIVERSITÀ DI MILANO & INFN



UNIVERSITÀ DEGLI STUDI DI MILANO
DIPARTIMENTO DI FISICA



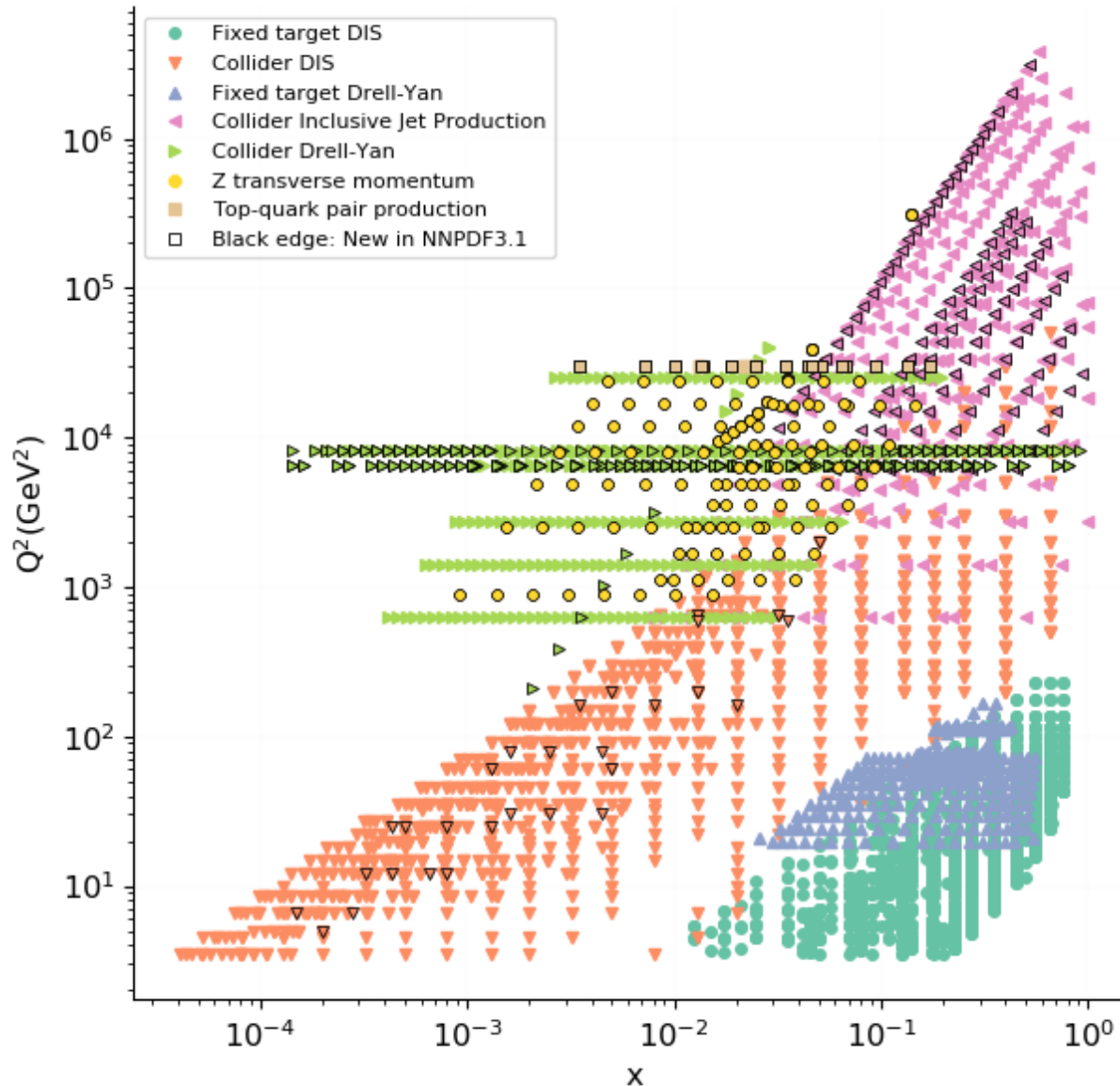
THEORY INSTITUTE

CERN, JULY 17 2018

PDF DATASET

LHC DATA!: NNPDF3.0 vs NNPDF3.1

Kinematic coverage



NEW DATA: (BLACK EDGE)

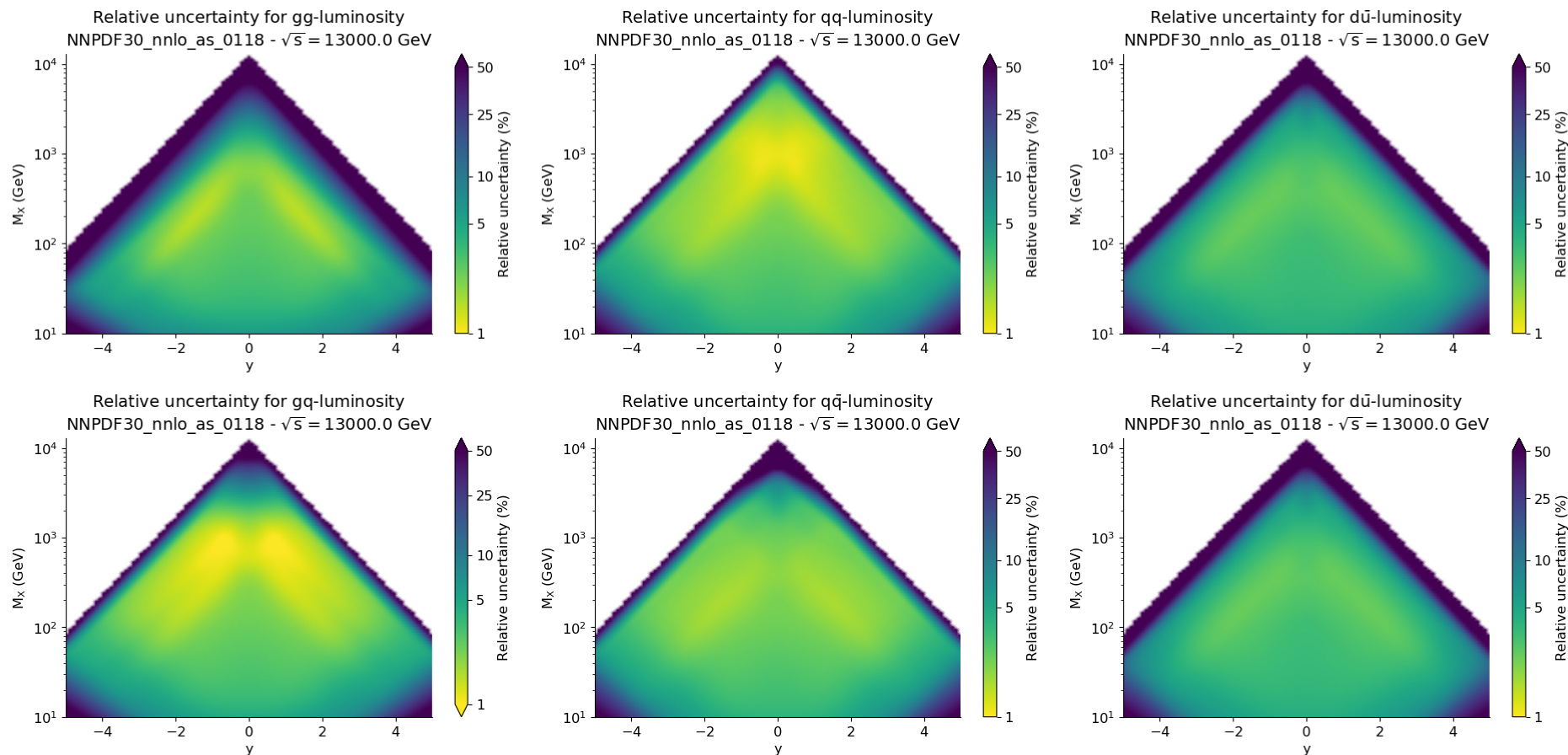
- HERA COMBINED F_2^b
- D0 W LEPTON ASYMMETRY
- ATLAS W, Z 2011, HIGH & LOW MASS DY 2011;
CMS $W^\pm$ RAPIDITY 8TeV
LHCb W, Z 7TeV & 8TeV
- ATLAS 7TeV JETS 2011, CMS 2.76TeV JETS
- ATLAS & CMS TOP DIFFERENTIAL RAPIDITY
- ATLAS $Z p_T$ DIFFERENTIAL RAPIDITY & INVARIANT MASS 8TeV,
CMS $Z p_T$ DIFFERENTIAL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

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

GLUON

SINGLET

FLAVORS



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

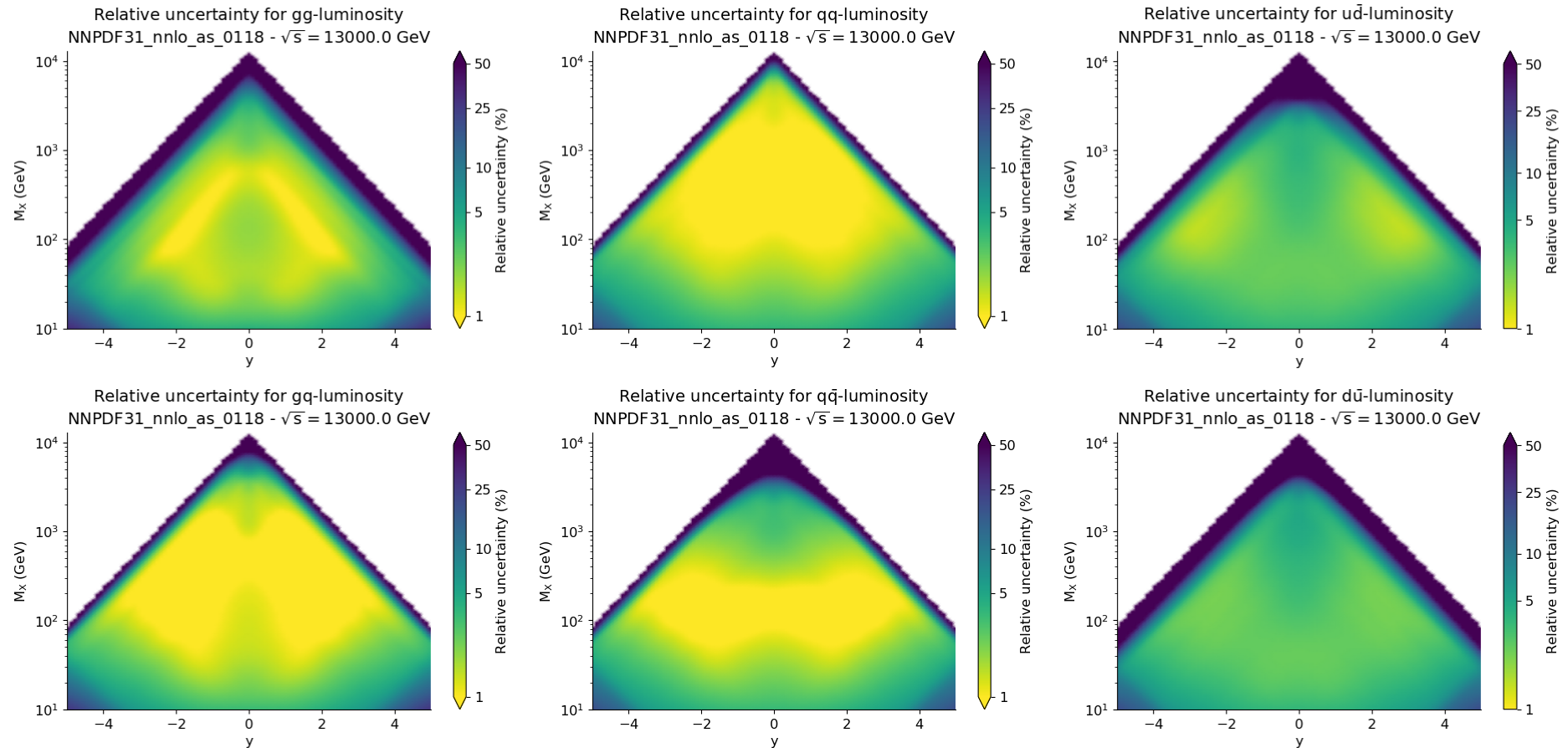
- .

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

GLUON

SINGLET

FLAVORS

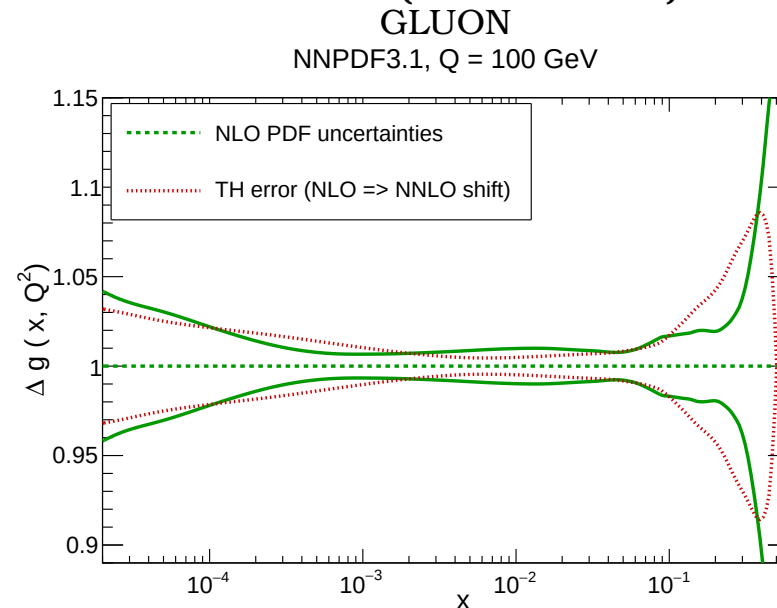
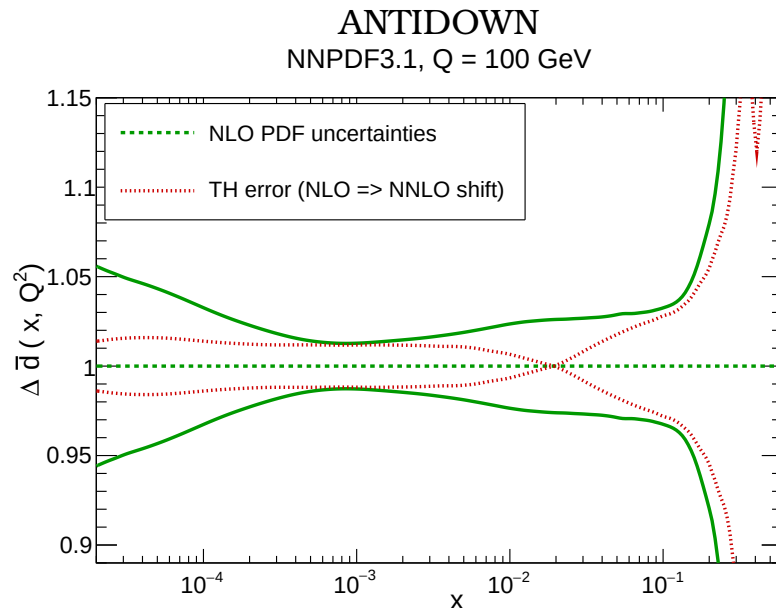


- TYPICAL UNCERTAINTIES IN DATA REGION $\sim 1 - 3\%$
- NEW LHC DATA $\Rightarrow$ SIZABLE REDUCTION IN UNCERTAINTIES

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)



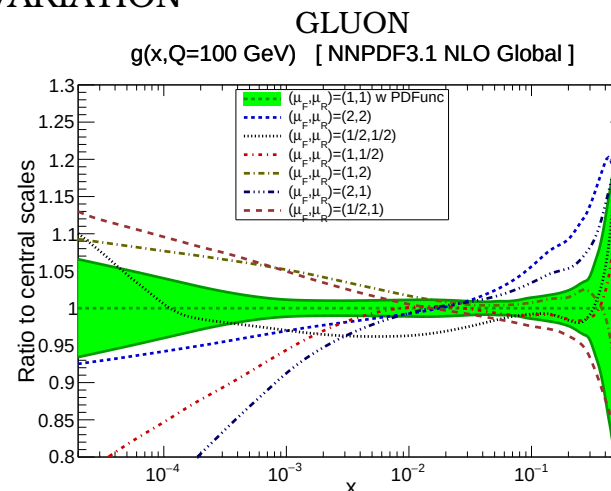
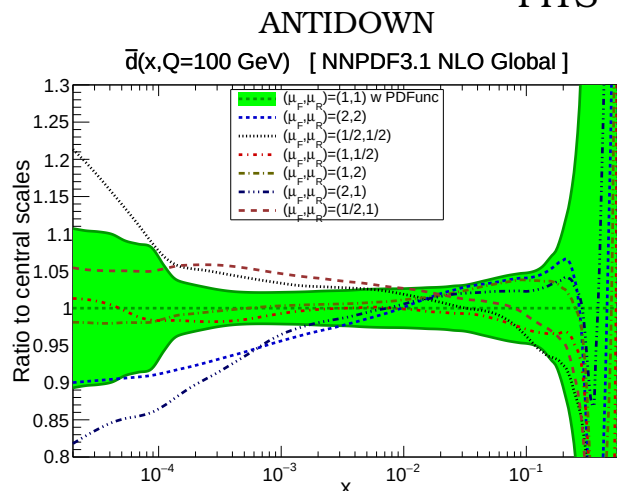
- TODAY: NLO PDF & MHOU UNCERTAINTIES COMPARABLE
- NEAR FUTURE: SHOULD WE WORRY ABOUT NNLO MHOU?

SCALE VARIATION IN PDF FITTING

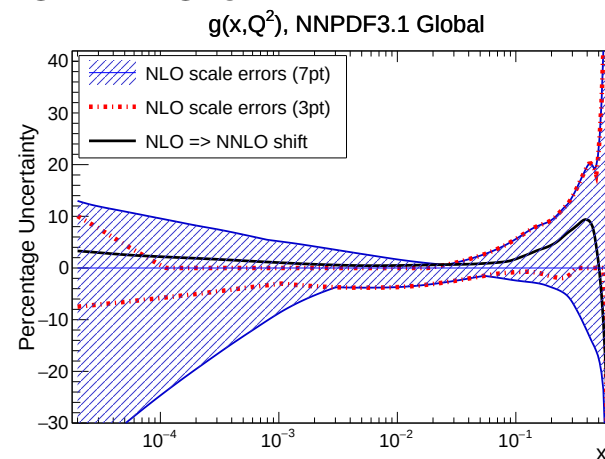
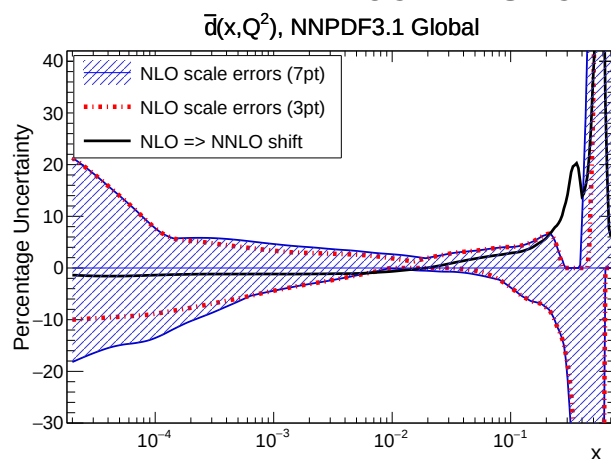
SIMPLEST IDEA FOR PDF MHOU ESTIMATE

- 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 CORRELATED ACROSS PROCESSES?

FITS WITH SCALE VARIATION



SCALE UNCERTAINTY VS NLO-NNLO SHIFT



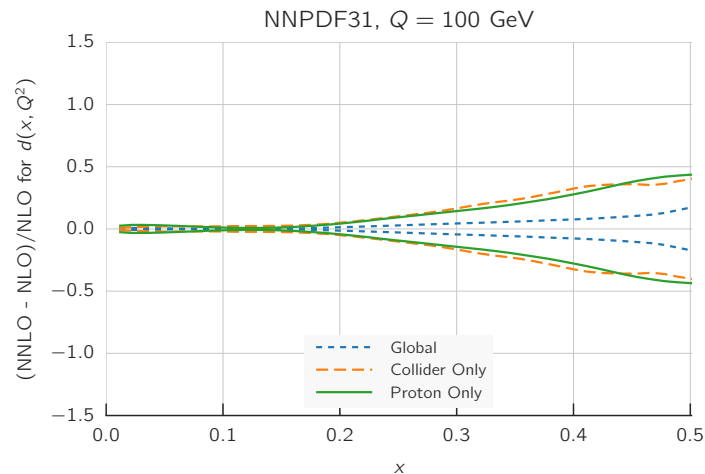
DEPENDENCE ON THE DATASET

PERTURBATIVE STABILITY

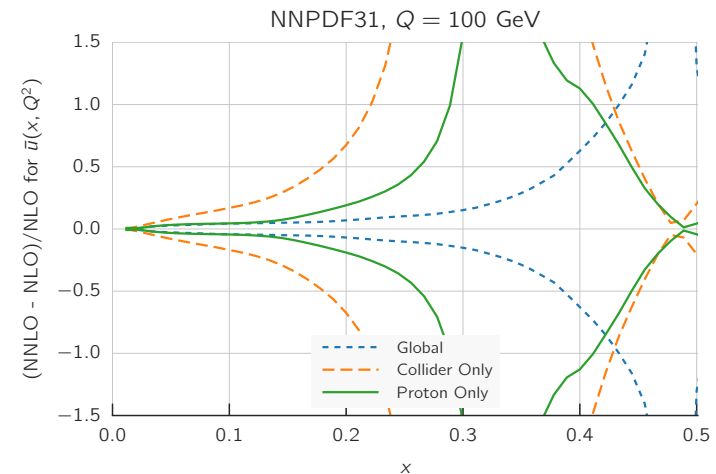
NNLO-NLO SHIFTS

GLOBAL VS. COLLIDER ONLY VS. PROTON ONLY PDFS

DOWN



ANTIUP

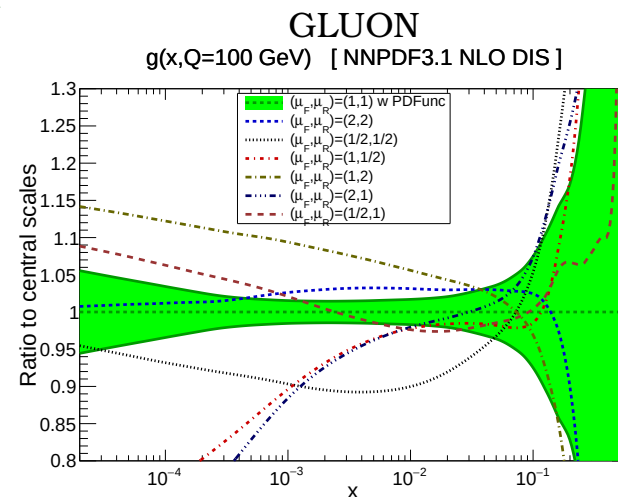
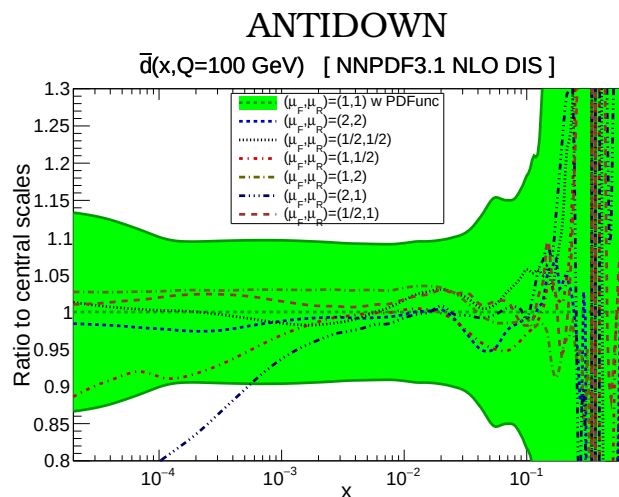


- MHOU **DEPENDS ON DATASET**
- NLO-NNLO **SHIFTS GENERALLY SMALLER** WITH LARGER DATASET
- $\Rightarrow$ **CORRELATION PATTERN** BETWEEN MHO TERMS

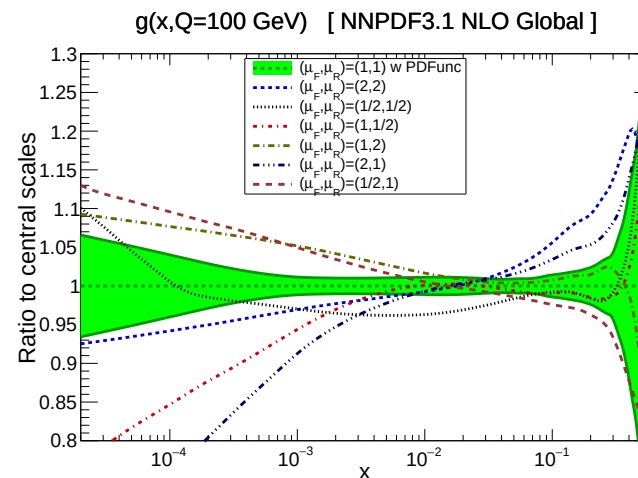
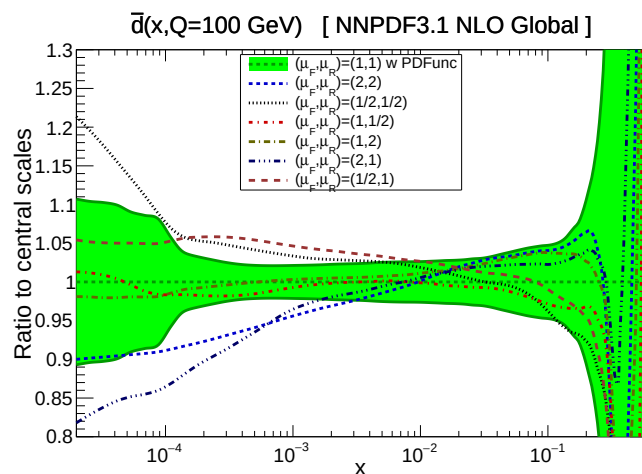
DEPENDENCE ON THE DATASET

SCALE VARIATION

DIS ONLY



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 MHOUE IN PDF ERRORS?

A BETTER IDEA FOR PDF MHOUE ESTIMATE

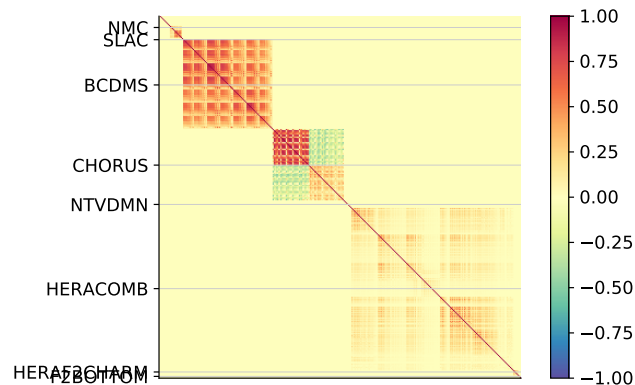
- PERFORM CALCULATION WITH VARIOUS SCALE CHOICES
- USE DISTRIBUTION OF RESULTS TO COMPUTE THEORY COVARIANCE MATRIX
- PERFORM FIT WITH EXTRA CONTRIBUTION TO COVARIANCE MATRIX
⇒ MHOUE INCLUDED IN PDF UNCERTAINTY

CORRELATION MATRICES

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

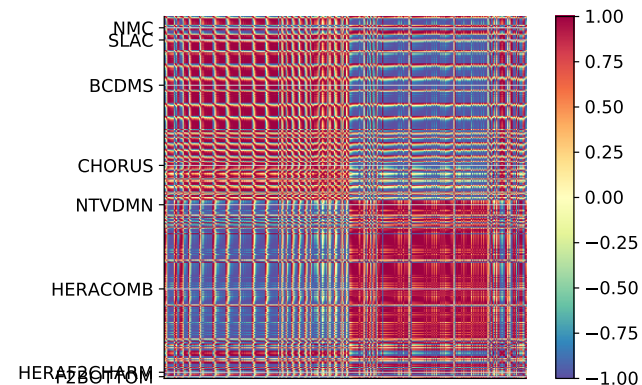
EXPERIMENT

Experiment correlation matrix



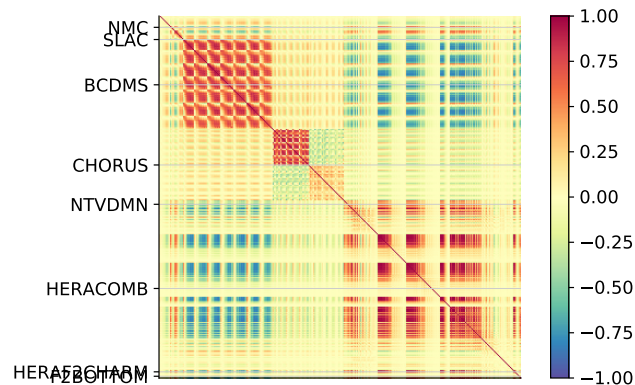
THEORY

Theory correlation matrix



CORRELATION

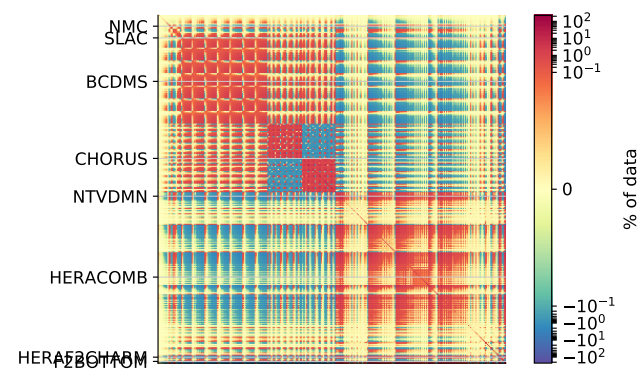
Experiment + theory correlation matrix



COMBINED EXP+TH

COVARIANCE

Experiment + theory covariance matrix



THEORY COVARIANCE MATRICES

SUBTLETIES I: DEFINITION

“STANDARD” DEFINITION OF SCALE VARIATION:
USE **RG INVARIANCE OF PHYSICAL OBSERVABLE**

- **HADRONIC** (HXS WG. . .): $\sigma(Q^2) = \sum_{ij} \hat{\sigma}_{ij} \left(\frac{Q^2}{\mu_F^2}, \frac{Q^2}{\mu_R^2}, \alpha_s(\mu_R^2) \right) f_i(\mu_F^2) f_j(\mu_F^2)$
 - 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: $\alpha(\mu_R'^2) \left(1 - \beta_0 \alpha \mu_R^2 \ln \frac{\mu_R'^2}{\mu_R^2} \right)$
 - 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 $\alpha(\mu_F^2) \rightarrow \alpha(\mu_R^2)$ 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 $\mu_F, \dots$
 - **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