PDF UNCERTAINTIES FOR LHC PHYSICS

STEFANO FORTE
UNIVERSITÀ DI MILANO

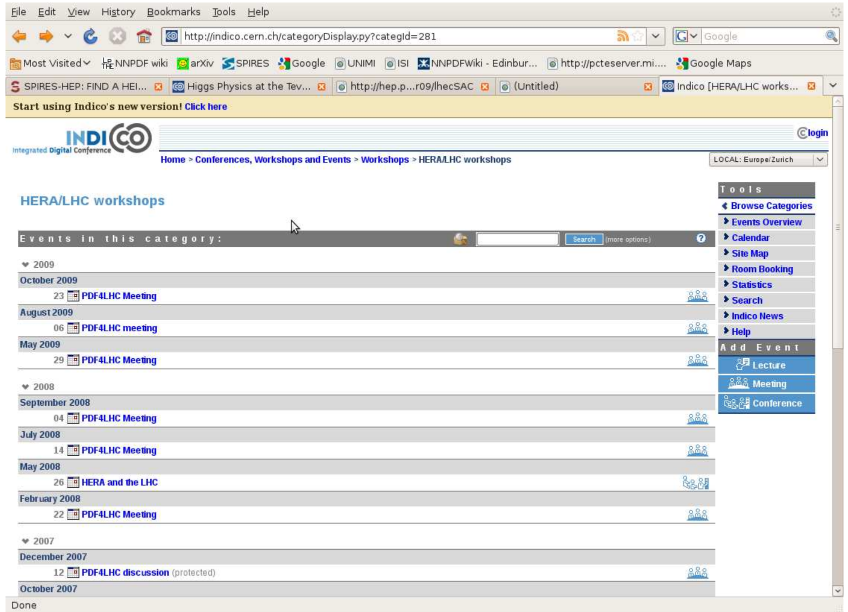
UNIVERSITÀ DEGLI STUDI DI MILANO
DIPARTIMENTO DI FISICA

Istituto Nazionale di Fisica Nucleare

HEPTOOLS HIGGS WORKSHOP

TORINO, NOVEMBER 23, 2009

PDFS FOR LHC:
AN ONGOING EFFORT



HERALHC: 2004–2008

PDF4LHC: 2008 — TO DATE; NEXT MEETING (CERN): JANUARY 29, 2010

INTERIM REPORT ON PDFS @ LHC: FORTHCOMING

SUMMARY

- DETERMINING PDFs
  - global fits
  - disentangling PDFs
- PDF UNCERTAINTIES:
  HOW ARE THEY DETERMINED?
  - the hessian method: tolerance
  - the monte carlo approach
- PDF UNCERTAINTIES:
  WHERE DO THEY COME FROM?
  - benchmarks
  - hessian compatibility & parametrization bias
  - NNPDF & parametrization independence
- SENSITIVITY TO α_s
  - CTEQ, MSTW & NNPDF
  - higher order corrections

DETERMINING PDFs

PARTON FITS...

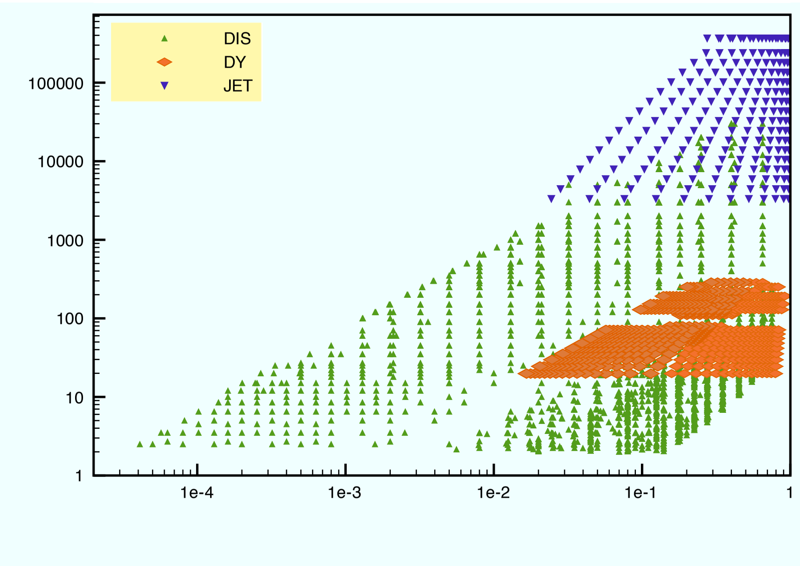
DATA $\rightarrow$ PARTON DISTRIBUTIONS

$$\sigma_X(s, M_X^2) = \sum_{a,b} \int_{x_{\min}}^1 dx_1\, dx_2\, f_{a/h_1}(x_1) f_{b/h_2}(x_2) \hat{\sigma}_{q_a q_b \to X}\left(x_1 x_2 s, M_X^2\right)$$

...ARE GLOBAL FITS!

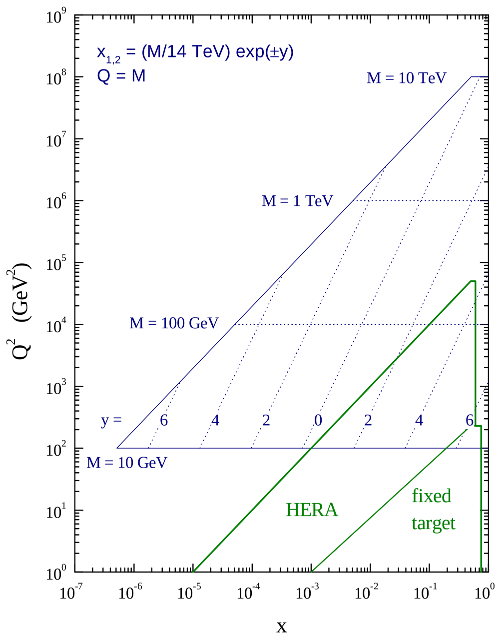
CURRENT

NNPDF2.0 data set

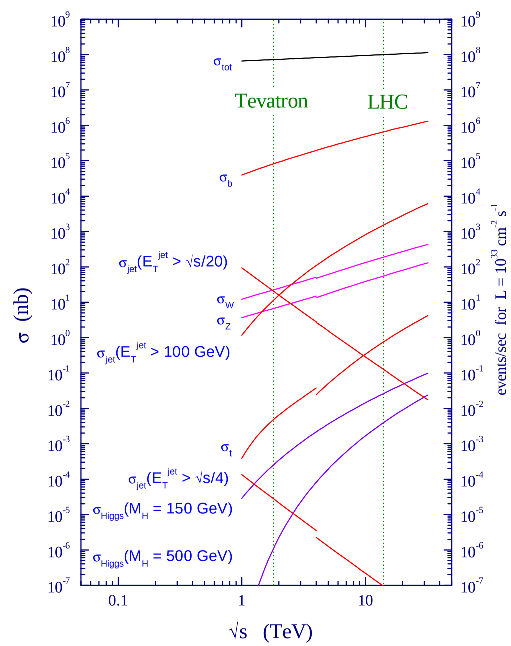


FUTURE

LHC kinematics



& processes

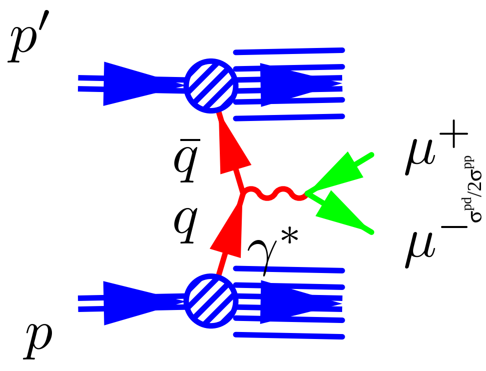


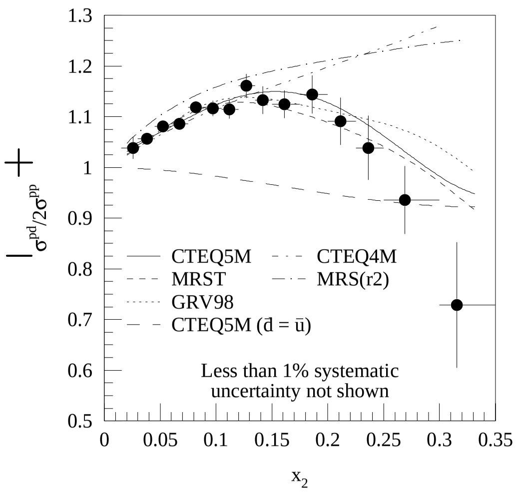
- DIFFERENT DATA CONTROLS DIFFERENT COMBINATIONS OF PDFs
- CROSS-TALK DUE TO SUM RULES, GLOBAL OBSERVABLES (TOTAL XSECTNS) &C

DISENTANGLING QUARKS FROM ANTIQUARKS

γ^* DIS ONLY MEASURES $q+\bar{q}$ COMBINATION!

DRELL-YAN p/d ASYMMETRY



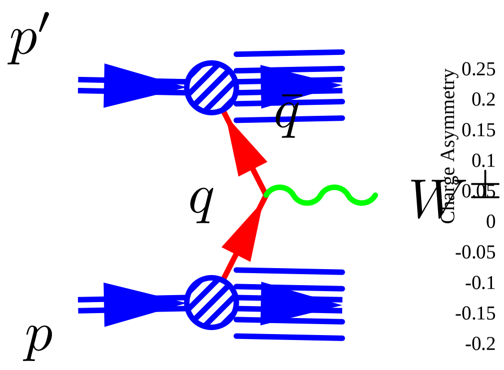


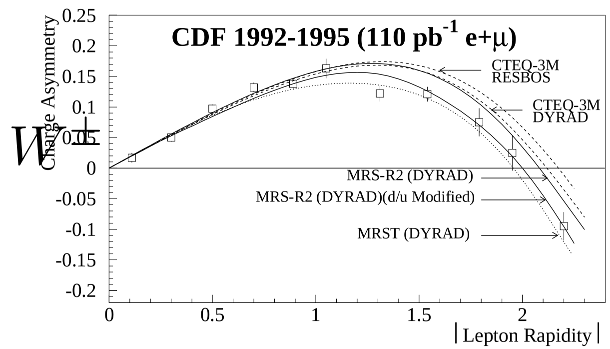
E866 (2001)

LIGHT ANTIQUARK ASYMMETRY

$$\frac{\sigma^{pn}}{\sigma^{pp}} \sim \left. \frac{\frac{4}{9}u^p\bar{d}^p + \frac{1}{9}d^p\bar{u}^p}{\frac{4}{9}u^p\bar{u}^p + \frac{1}{9}d^p\bar{d}^p} \right|_{\text{large } x} \approx \frac{\bar{d}}{\bar{u}}$$

$W^\pm$ ASYMMETRY





CDF (1998)

LIGHT QUARK ASYMMETRY

$$\frac{\sigma^{p\bar{p}}_{W+}}{\sigma^{p\bar{p}}_{W-}} \sim \frac{u^p d^p}{d^p u^p} \quad (q^p = \bar{q}^{\bar{p}})$$

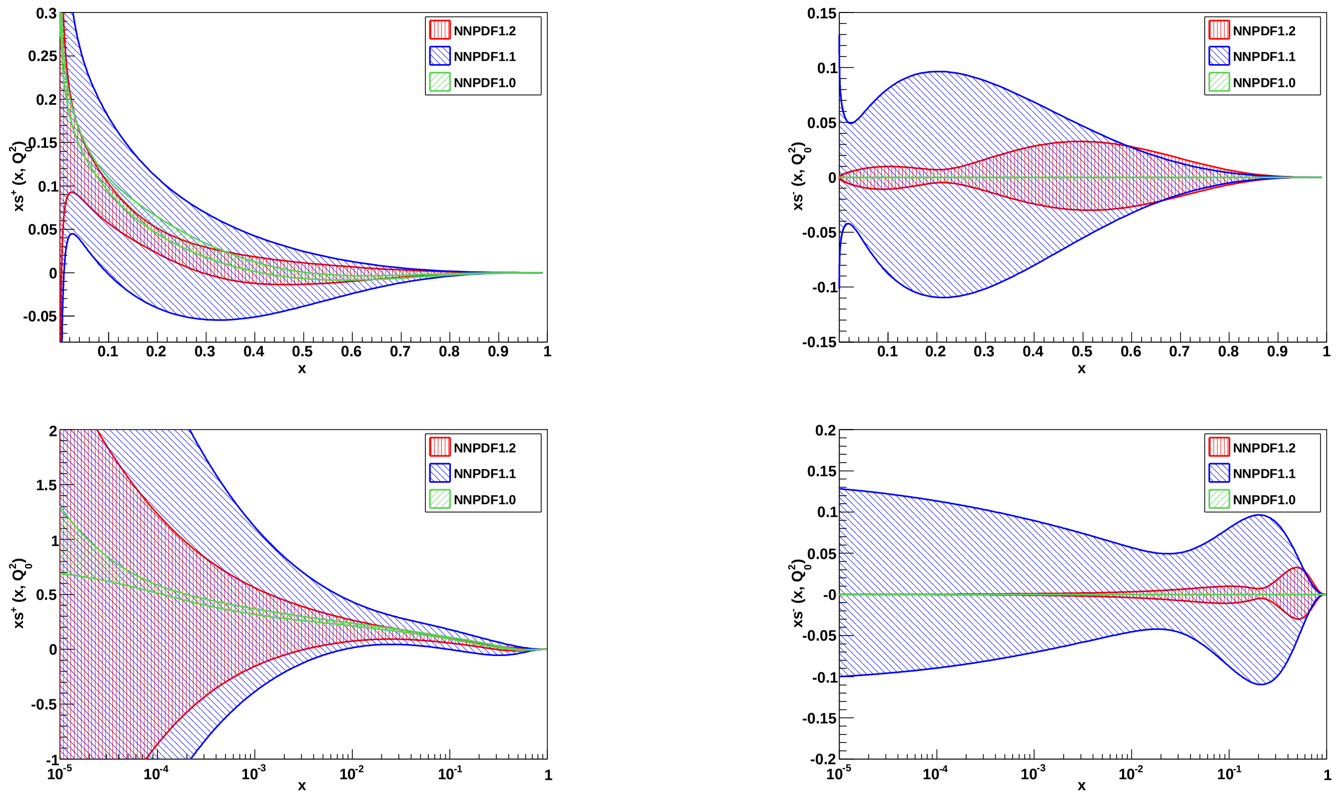
DISENTANGLING STRANGENESS

- STRANGENESS ALMOST UNCONSTRAINED BY INCLUSIVE DIS DATA
  NNPDF1.1: s, $\bar{s}$ (actually $s^{\pm}$) indep. parametrized, no dimuon data

- IN PARTON FITS UP TO 2009 $\rightarrow$ STRANGENESS FIXED BY ASSUMPTION
  NNPDF1.0: $s(x, Q_0^2) = \bar{s}(x, Q_0^2)$, $s + \bar{s} = \frac{1}{2}(\bar{u} + \bar{d})$

- IN CURRENT PARTON FITS $\rightarrow$ STRANGENESS FIXED BY DIS DIMUON PRODUCTION $\nu + s \rightarrow c$
  NNPDF1.2: s, $\bar{s}$ (actually $s^{\pm}$) indep. parametrized, dimuon data

STRANGE PDFS



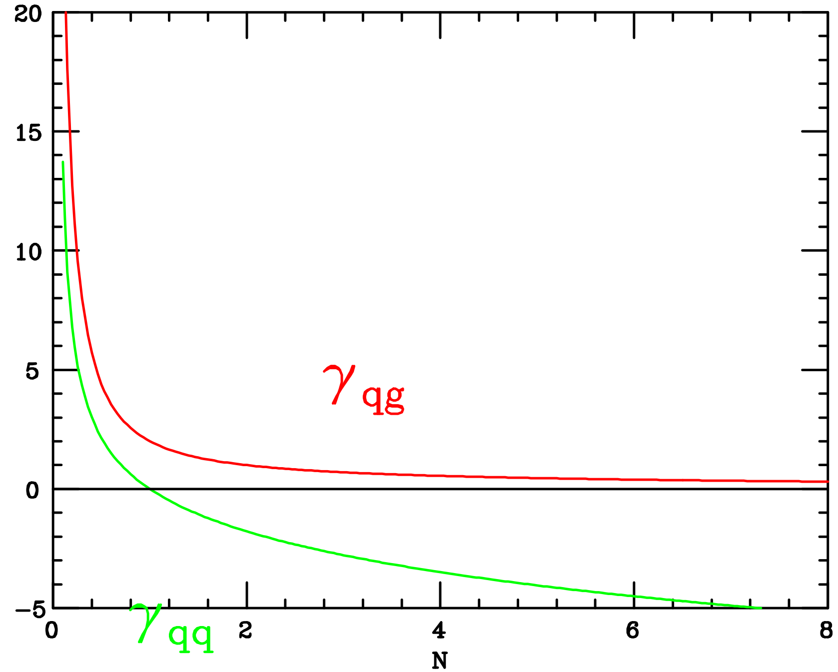
DETERMINING THE GLUON

SMALL x (SMALL N):

SINGLET SCALING VIOLATIONS (HERA)

$$\frac{d}{dt}F_2^s(N,Q^2) = \frac{\alpha_s(Q^2)}{2\pi}\left[\gamma_{qq}(N)F_2^s + 2\,n_f\,\gamma_{qg}(N)g(N,Q^2)\right] + O(\alpha_s^2)$$

ANOMALOUS DIMENSIONS

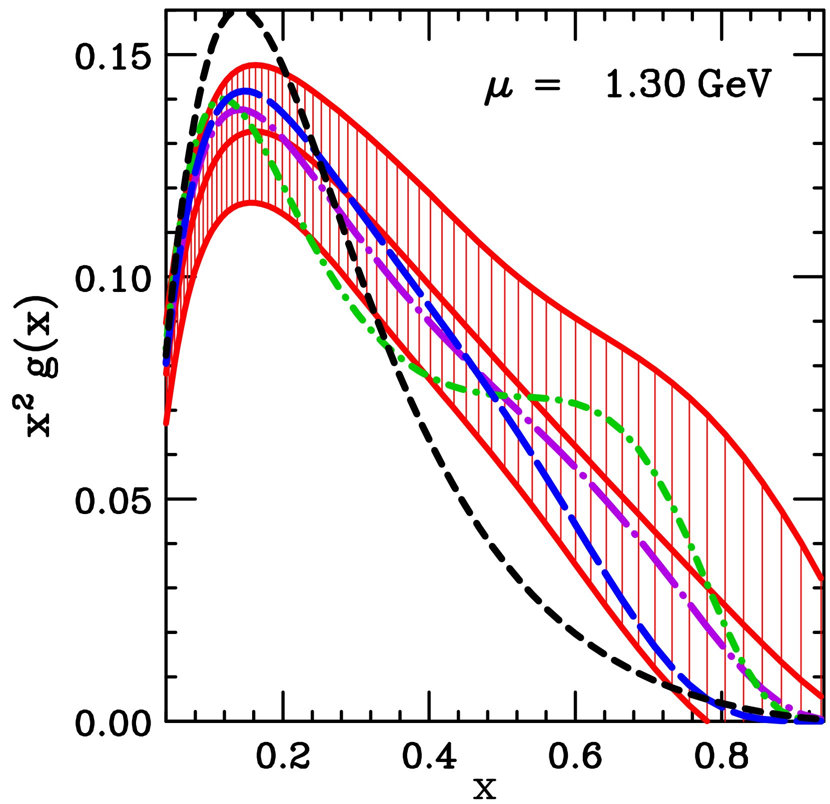


LARGE x:

HIGH p_T JETS (TEVATRON)

CTEQ6.6 GLUON

(DASHED: NO JET DATA)



PRESENT

- SMALL x GLUON & SINGLET $\Leftrightarrow$ PRECISE HERA DATA
- SMALL x FLAVOUR SEPARATION $\Leftrightarrow$ TEVATRON W ASYMMETRY DATA
- MEDIUM x FLAVOUR SEPARATION $\Leftrightarrow$ FIXED TARGET p/d DIS DATA, DRELL YAN, NEUTRINO INCLUSIVE
- STRANGENESS $\Leftrightarrow$ NEUTRINO DIMUON
- LARGE x GLUON $\Leftrightarrow$ TEVATRON JETS

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FUTURE

- W ASYMMETRY $\Leftrightarrow$ FULL FLAVOUR SEPARATION AT MEDIUM/SMALL x
- HIGH p_T JETS $\Leftrightarrow$ PRECISE GLUON AT INTERMEDIATE x
- HQ PRODUCTION $\Leftrightarrow$ INDIVIDUAL QUARK FLAVOURS & GLUON AT SMALL x
- HIGGS PRODUCTION $\Leftrightarrow$ MEDIUM x GLUON

PDF UNCERTAINTIES:
HOW ARE THEY DETERMINED?

THE "STANDARD" APPROACH (MSTW, CTEQ):

FUNCTIONAL PARTON FITTING

- CHOOSE A FIXED FUNCTIONAL FORM:
  - MSTW: 20 PARMS.

    $xq(x,Q_0^2) = A(1-x)^\eta(1+\epsilon x^{0.5}+\gamma x)x^\delta$, (5 indep. fns.); $x[\bar{u}-\bar{d}](x,Q_0^2) = A(1-x)^\eta(1+\gamma x+\delta x^2)x^\delta$;

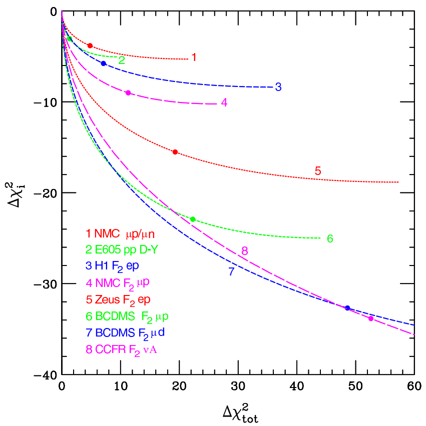
    $x[s-\bar{s}](x,Q_0^2) = A_-(1-x)^{\eta_s}x^{\delta_-}(1-x/x_0)$; $xg(x,Q_0^2) = A_g(1-x)^{\eta_g}(1+\epsilon_g x^{0.5}+\gamma_g x)x^{\delta_g}+A_{g'}(1-x)$
  - CTEQ6: 22 PARMS.

    $$x\,f(x,Q_0) = A_0\,x^{A_1}\,(1-x)^{A_2}\,e^{A_3 x}\,(1+e^{A_4}\,x)^{A_5}, \quad \text{(7 indep. functions)}$$
  - BASIS FUNCTIONS: $u_v \equiv u-\bar{u}$, $d_v \equiv d-\bar{d}$, $\bar{u}-\bar{d}$ (MSTW) OR $\bar{u}/\bar{d}$ (CTEQ), $s^\pm \equiv s \pm \bar{s}$, g.
- EVOLVE TO DESIRED SCALE & COMPUTE PHYSICAL OBSERVABLES
- DETERMINE BEST-FIT VALUES OF PARAMETERS
- DETERMINE ERROR BY PROPAGATION OF ERROR ON PARMS ('HESSIAN METHOD') OR BY PARM. SCANS ('LAGRANGE MULTIPLIER METHOD')

WHAT IS A ONE-σ UNCERTAINTY?

- STANDARD $\Delta\chi^2 = 1$ BANDS TOO NARROW $\Rightarrow$ LARGE DISCREPANCIES FOR INDIVIDUAL EXPERIMENTS

MINIMUM χ_i^2
VS GLOBAL χ^2

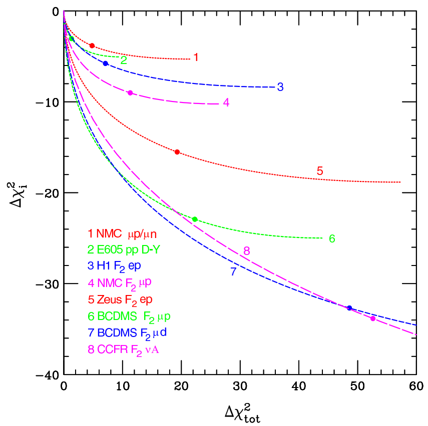


Collins, Pumplin
2001

WHAT IS A ONE-σ UNCERTAINTY?
CTEQ TOLERANCE CRITERION &

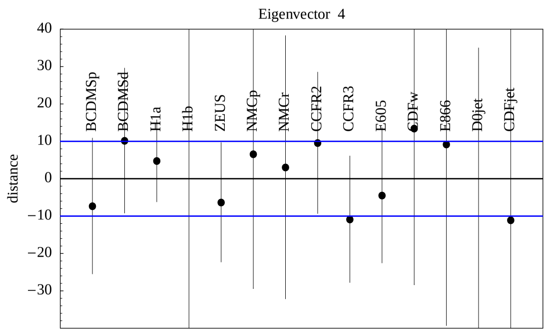
- STANDARD $\Delta\chi^2 = 1$ BANDS TOO NARROW $\Rightarrow$ LARGE DISCREPANCIES FOR INDIVIDUAL EXPERIMENTS
- TOLERANCE $\Rightarrow$ ENVELOPE OF UNCERTAINTIES OF EXPERIMENTS

MINIMUM χ_i^2 VS GLOBAL χ^2



Collins, Pumplin
2001

CTEQ TOLERANCE PLOT FOR 4TH EIGENVEC.

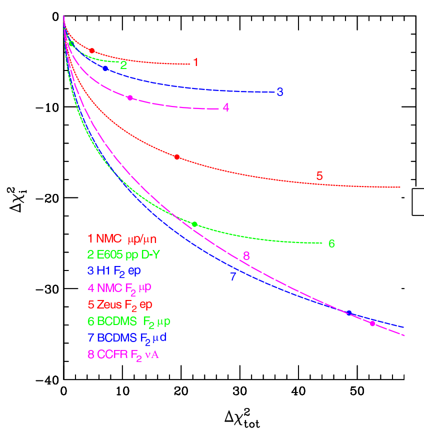


WHAT IS A ONE-σ UNCERTAINTY?

CTEQ TOLERANCE CRITERION & MSTW DYNAMICAL TOLERANCE

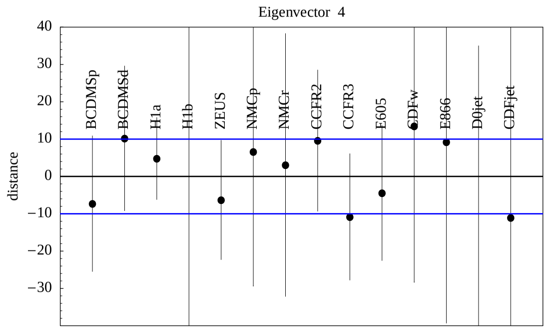
- STANDARD $\Delta\chi^2 = 1$ BANDS TOO NARROW $\Rightarrow$ LARGE DISCREPANCIES FOR INDIVIDUAL EXPERIMENTS
- TOLERANCE $\Rightarrow$ ENVELOPE OF UNCERTAINTIES OF EXPERIMENTS
- DYNAMICAL $\Rightarrow$ SEPARATELY DETERMINED FOR EACH HESSIAN EIGENVECTOR

MINIMUM χ_i^2 VS GLOBAL χ^2

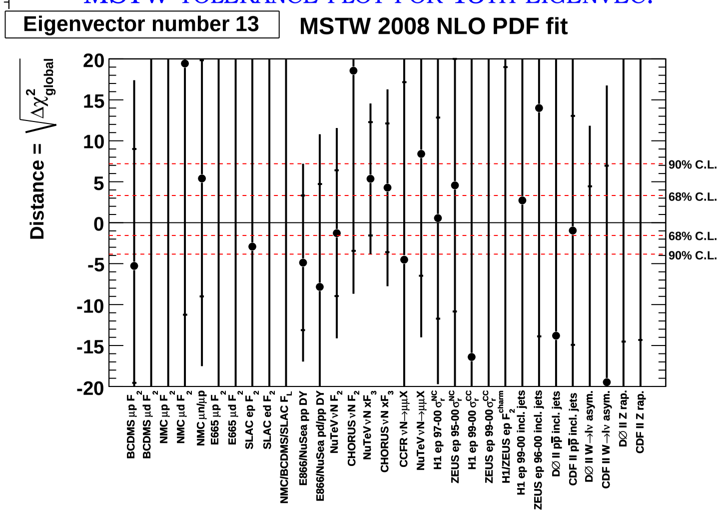


Collins, Pumplin 2001

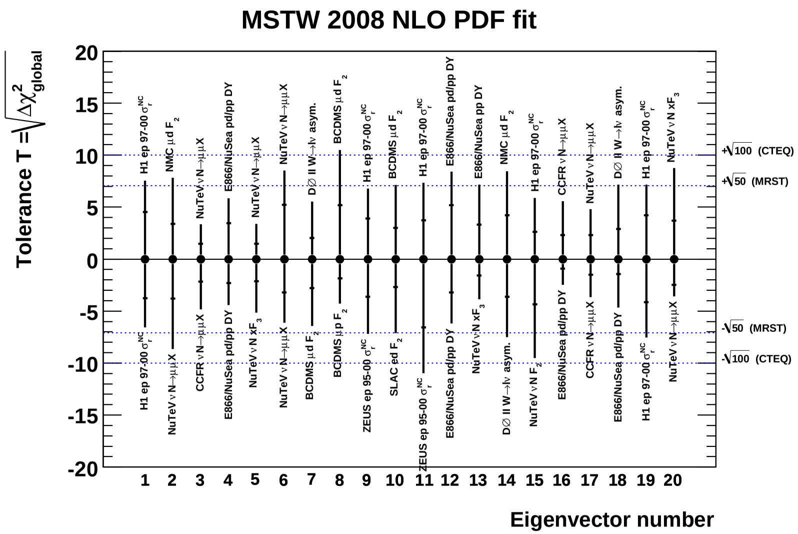
CTEQ TOLERANCE PLOT FOR 4TH EIGENVEC.



MSTW TOLERANCE PLOT FOR 13TH EIGENVEC.



GLOBAL MSTW TOLERANCE

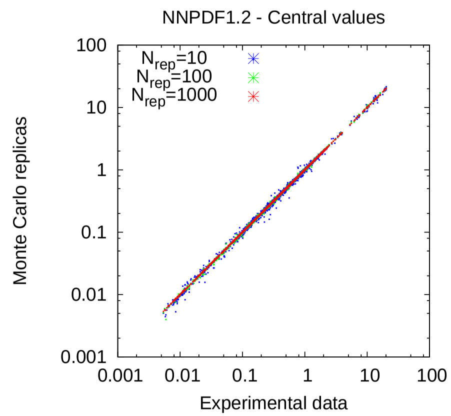


THE NNPDF APPROACH:
THE NEURAL MONTE CARLO

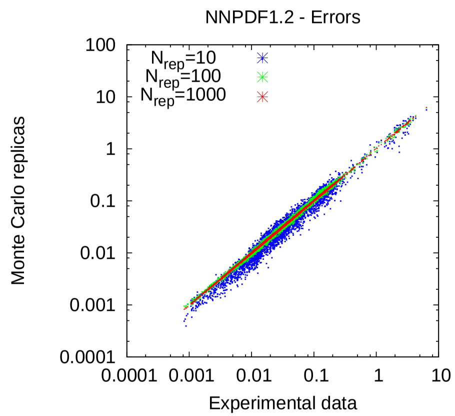
BASIC IDEA: MONTE CARLO SAMPLING OF THE PROBABILITY MEASURE IN THE (FUNCTION) SPACE OF PDFs

- START FROM MONTE CARLO SAMPLING OF DATA SPACE
- SPACE OF FUNCTIONS HUGE
  5 BINS FOR 10 PTS$\times$ 7 FCTNS $\rightarrow 5^{70} \sim 10^{49}$ BINS
- IMPORTANCE SAMPLING: DATA TELL US WHICH BINS ARE POPULATED

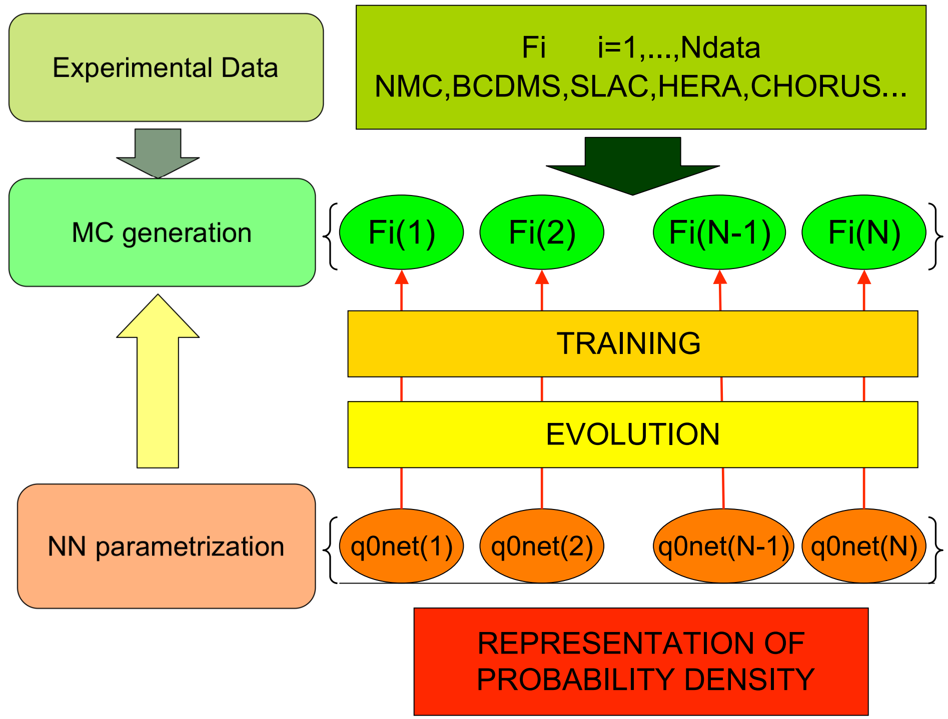
replica averages vs. central values



replica standard dev. vs. uncertainties

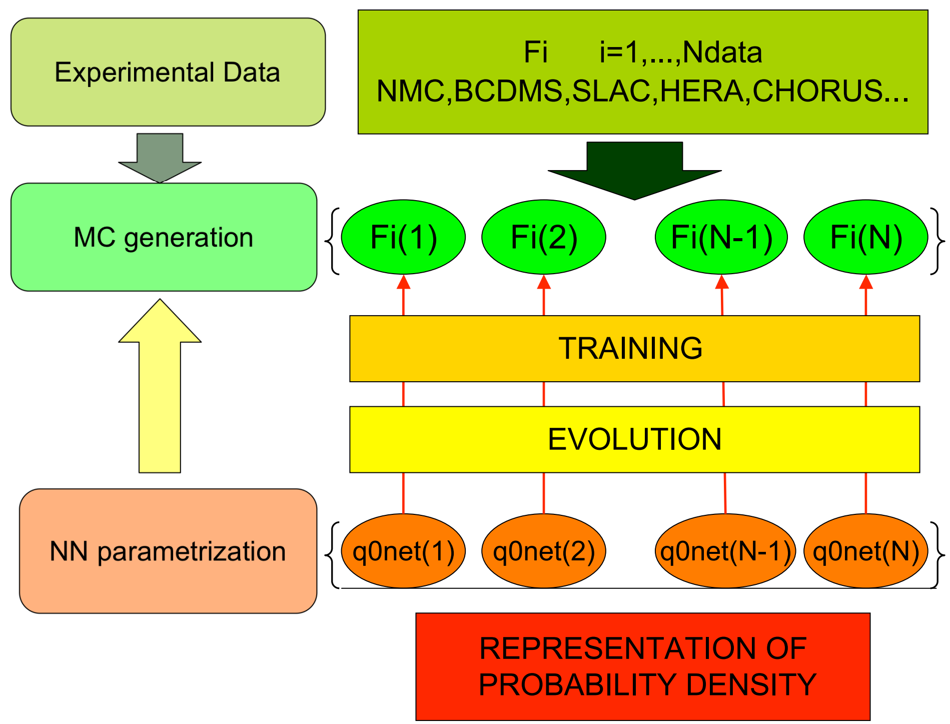


10 REPLICAS ENOUGH FOR CENTRAL VALS, 100 FOR UNCERTAINTIES, 1000 FOR CORRELNS



DATA MONTE CARLO $\Rightarrow$ PDF MONTE CARLO
NEURAL NETWORK PARM+ CROSS-VALIDATION METHOD

- EACH PDF$\leftrightarrow$ NEURAL NETWORK PARAMETRIZED BY 37 PARAMETERS
- NNPDF1.2: $37 \otimes 7 = 259$ PARMS (RECALL MSTW, CTEQ $\rightarrow$ 20 FREE PARAMETERS)
  "INFINITE" NUMBER OF PARAMETERS$\Rightarrow$ CAN REPRESENT ANY FUNCTION
- COMPLEX SHAPES (LARGE NO.OF PARAMETERS) REQUIRE LONGER FITTING
- FIT STOPS WHEN QUALITY OF FIT TO RANDOMLY SELECTED "VALIDATION" DATA (NOT FITTED) STOPS IMPROVING
- CAN OBTAIN A FIT WITH χ^2 LOWER THAN BEST FIT ("OVERLEARNING")

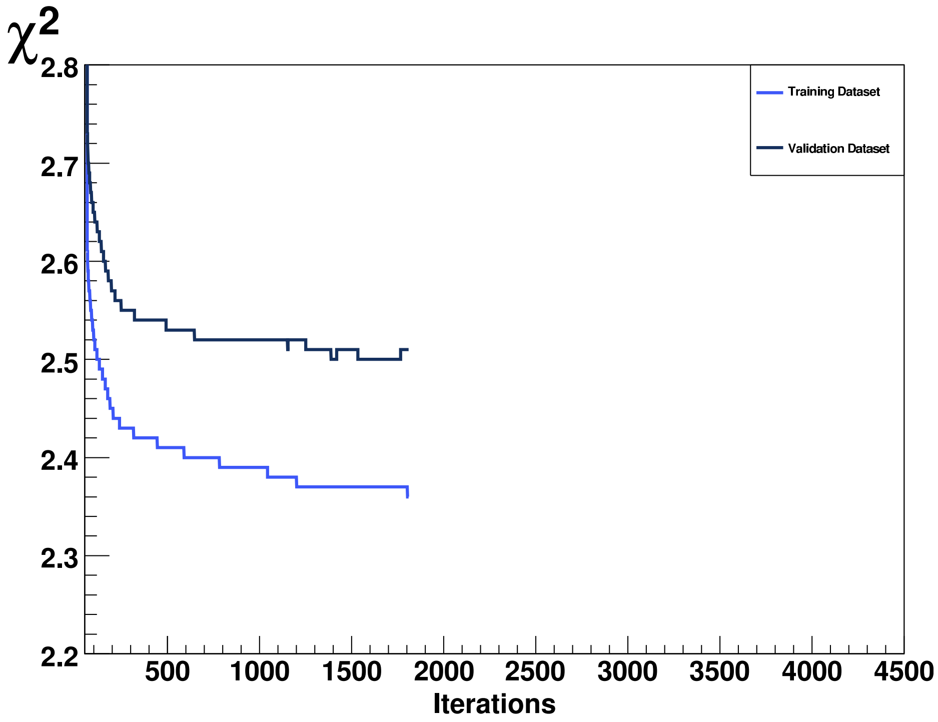


DATA MONTE CARLO $\Rightarrow$ PDF MONTE CARLO
CROSS-VALIDATION

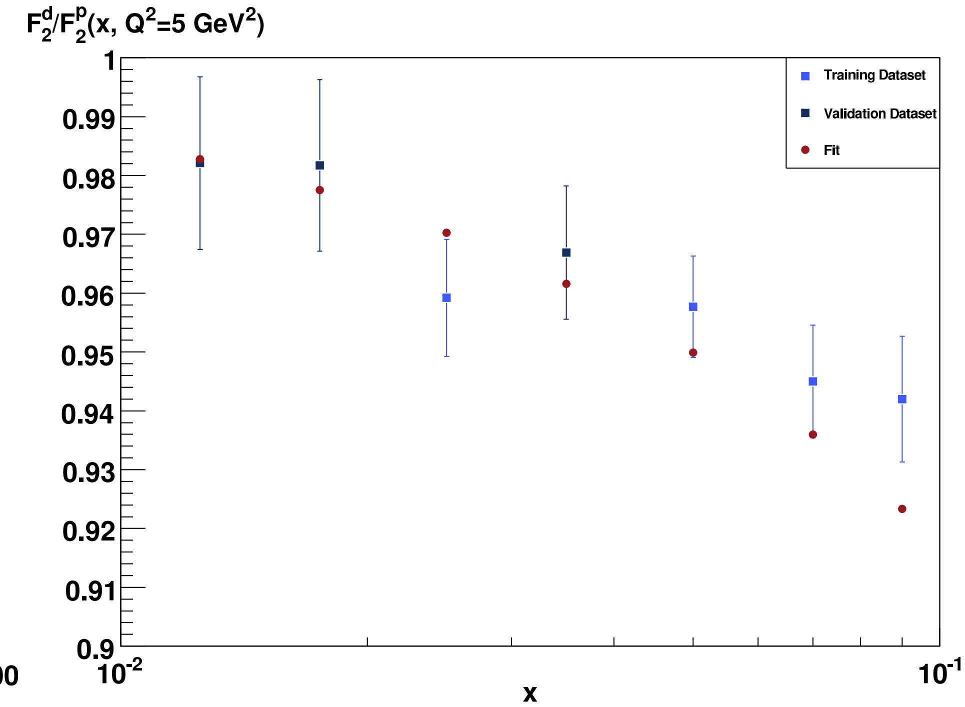
- REPLICAS ARE FITTED TO A DATA SUBSET
- A DIFFERENT SUBSET OF DATA USE FOR EACH REPLICA
- OPTIMAL FIT WHEN FIT TO VALIDATION (CONTROL) DATA STOPS IMPROVING
-

OPTIMAL FITTING

χ^2



FIT TO DATA

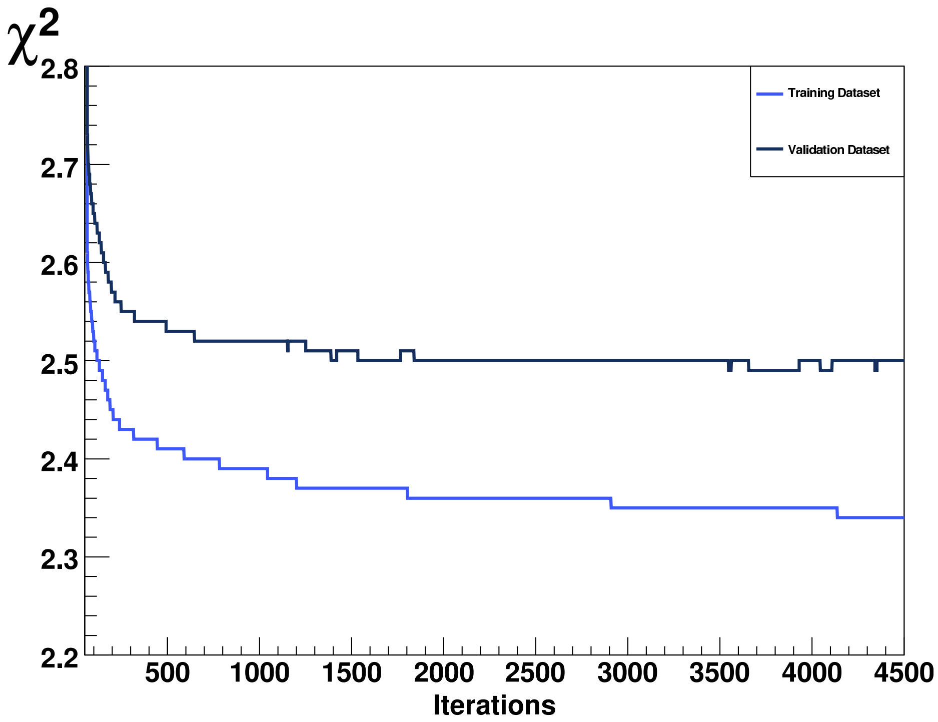


DATA MONTE CARLO $\Rightarrow$ PDF MONTE CARLO
CROSS-VALIDATION

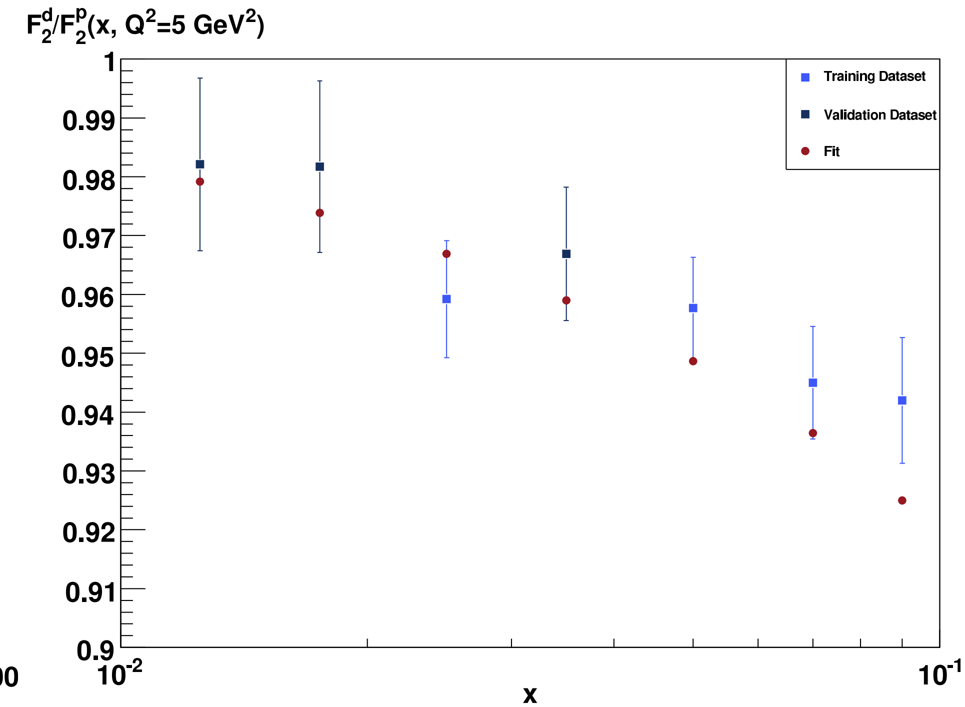
- REPLICAS ARE FITTED TO A DATA SUBSET
- A DIFFERENT SUBSET OF DATA USE FOR EACH REPLICA
- OPTIMAL FIT WHEN FIT TO VALIDATION (CONTROL) DATA STOPS IMPROVING
- THE BEST FIT IS NOT AT THE MINIMUM OF THE χ^2

OVERFITTING

χ^2



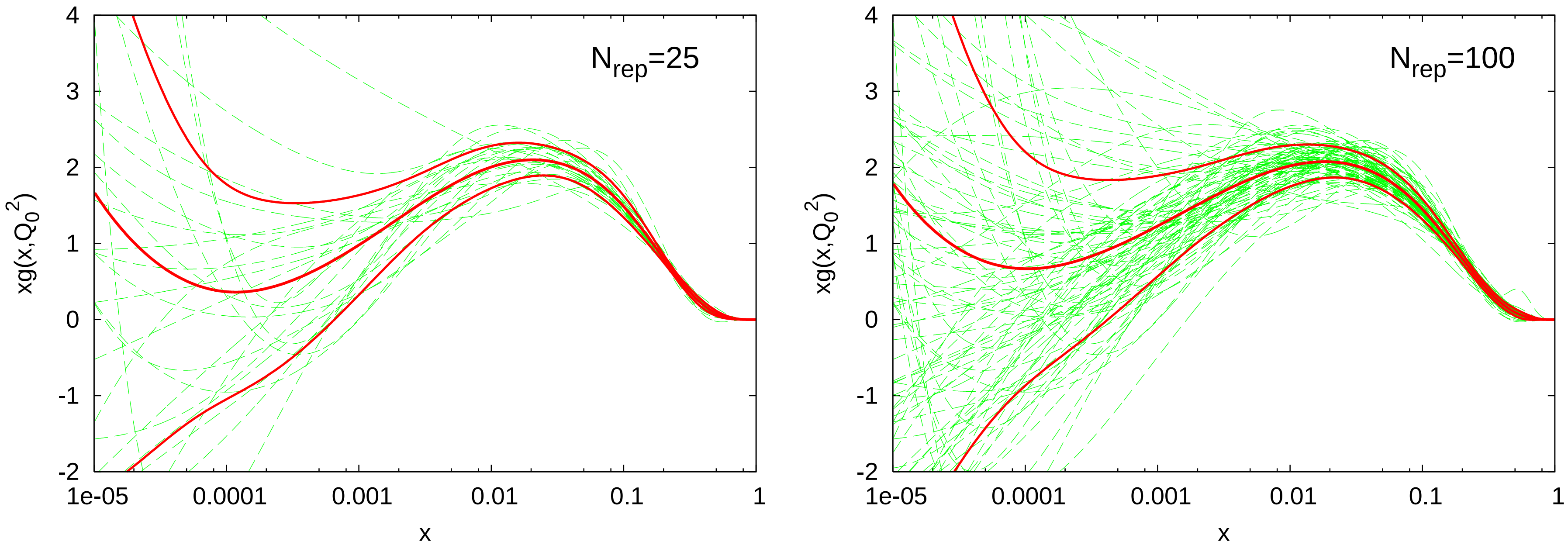
FIT TO DATA



WHAT IS A ONE-σ UNCERTAINTY?

A: THE CENTRAL 68% OF THE MC DISTRIBUTION OF PDFs

Example: the gluon distribution in the NNPDF1.0 set



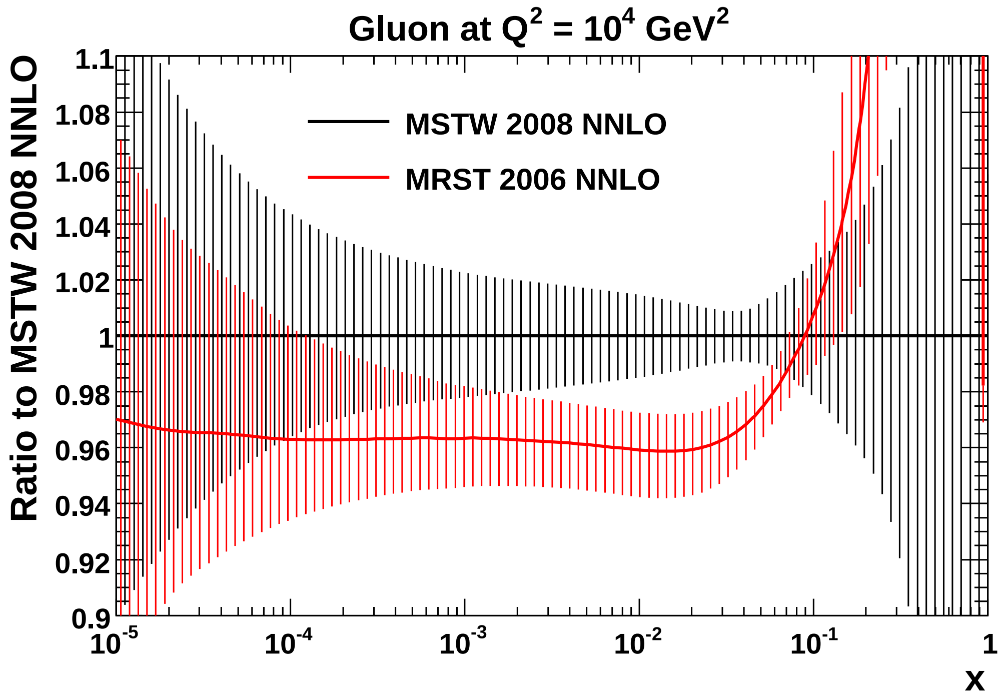
- ENSEMBLE OF REPLICAS $\leftrightarrow$ PROBABILITY DISTRIBUTION OF PDFs
- EXPECTED CENTRAL VALUE $\leftrightarrow$ MEAN; UNCERTAINTY $\leftrightarrow$ STANDARD DEVIATION
- ANY FEATURES OF DISTRIBUTION CAN BE DETERMINED (C.L. INTERVALS, CORRELATIONS...)

PDF UNCERTAINTIES:
WHERE DO THEY COME FROM?

WHAT DETERMINES PDF UNCERTAINTIES?

UNCERTAINTIES IN MSTW/CTEQ FITS OFTEN GO UP WHEN DATA ARE ADDED, BECAUSE OF THE NEED TO ADD PARAMETERS

Smaller high-x gluon (and slightly smaller α_S) results in larger small-x gluon – now shown at NNLO.



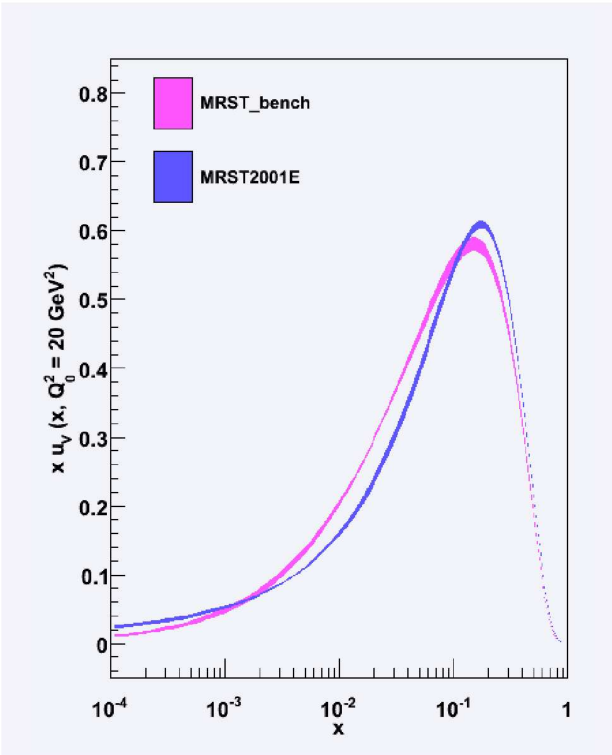
R. THORNE, HERALHC2008

Larger small-x uncertainty due to extrat free parameter.

WHAT DETERMINES PDF UNCERTAINTIES?

THE PROBLEM OF BENCHMARK FITS (HERALHC 2005-2008)

- PERFORM A MRST (MRSTBENCH) FIT TO A CONSISTENT SUBSET OF DATA, USE $\Delta\chi^2 = 1$
  $\Rightarrow$ RESULTS NOT CONSISTENT, UNCERTAINTY DOES NOT GROW AS DATASET DECREASES



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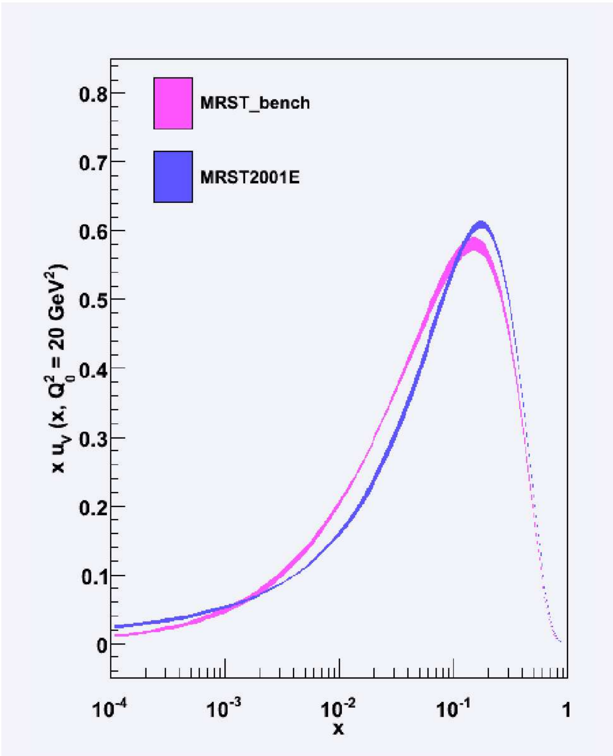
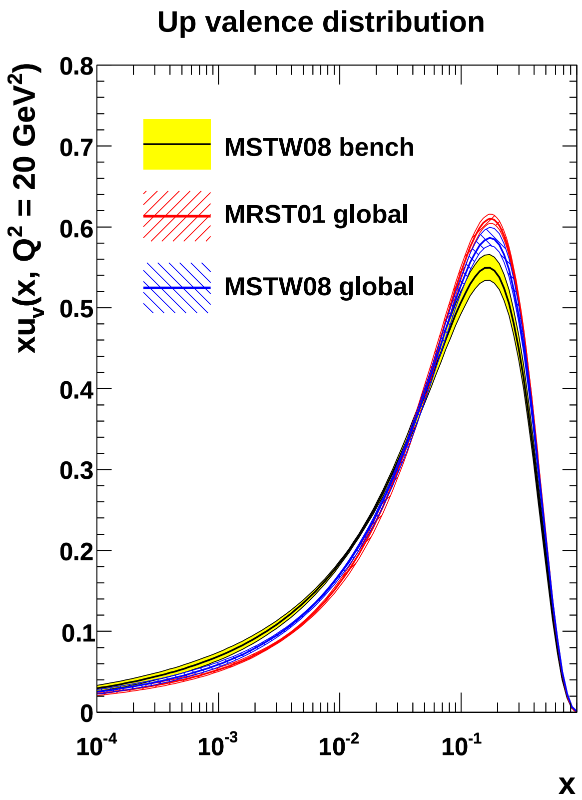
  $\Rightarrow$ RESULTS NOT CONSISTENT, UNCERTAINTY DOES NOT GROW AS DATASET DECREASES
- ...BUT MRST WAS DONE WITH TOLERANCE 50: REPEAT WITH DYNAMICAL TOLERANCE (MSTW08BENCH)
- IMPROVEMENT, BUT PROBLEM NOT SOLVED
  $\Rightarrow$ MUST TUNE PARAMETRIZATION AND STATISTICAL TREATMENT TO DATASET

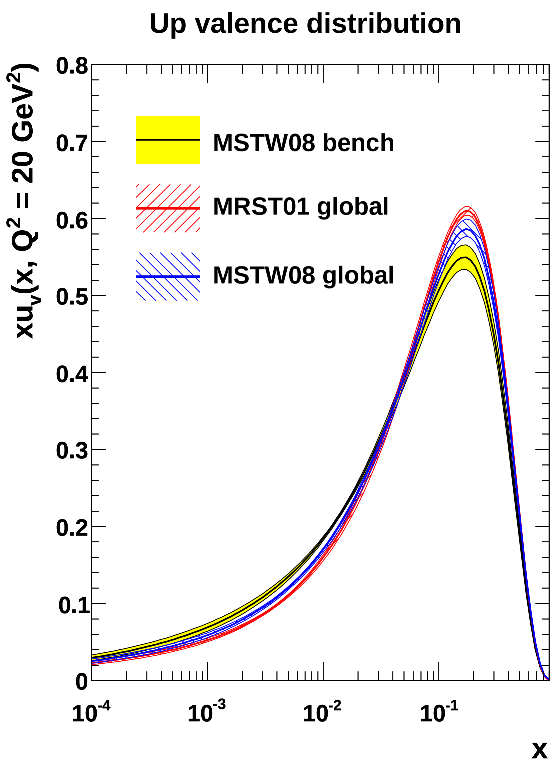




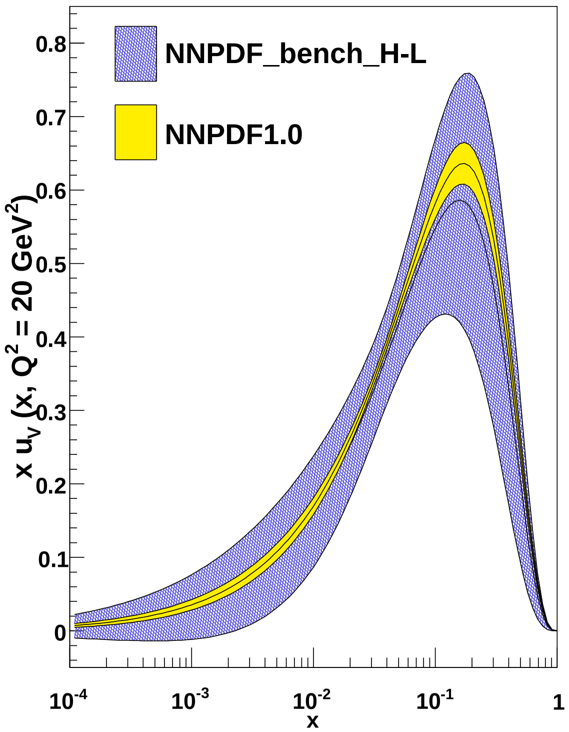
WHAT DETERMINES PDF UNCERTAINTIES?

THE NNPDF SOLUTION (HERALHC 2008)

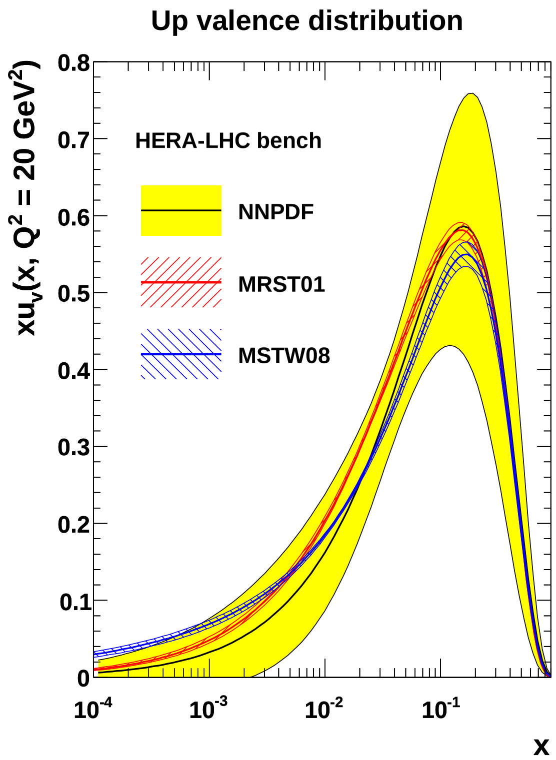
MRST/MSTW: BENCH VS REF



NNPDF: BENCH VS REF



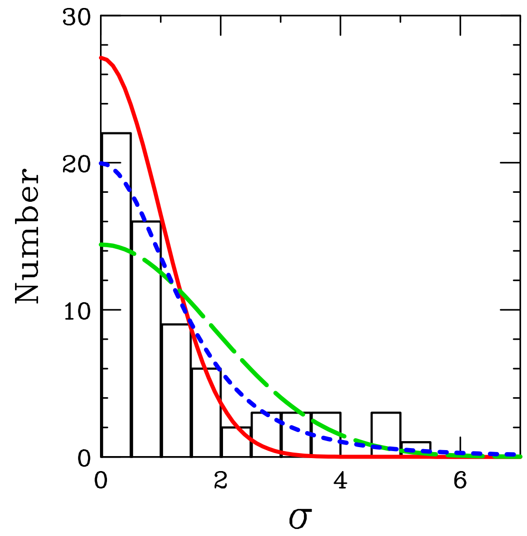
NNPDF BENCH VS MRST/MSTW BENCH



- SINGLE PARAMETRIZATION AND STAT. TREATMENT CAN ACCOMMODATE DIFFERENT DATASETS
- IMPACT OF DATA CAN BE STUDIED INDEPENDENT OF THEORETICAL FRAMEWORK

WHERE IS THE CTEQ/MSTW UNCERTAINTY COMING FROM?
WHY DOES ONE NEED LARGE TOLERANCES?

DATA INCOMPATIBILITY(Pumplin, 2009)



- CAN "REDIAGONALIZE": DIAGONALIZE SIMULTANEOUSLY chi^2 FOR TOTAL AND i–TH EXPT $\Rightarrow$ COMPATIBILITY OF EACH EXPT WITH GLOBAL FIT
- STUDY DISTRIBUTION OF DISCREPANCIES
- APPROX. GAUSSIAN WITH UNCERTAINTIES RESCALED BY 2 $\Rightarrow$ $\Delta\chi^2 = 4$ ($T \approx 10$ FOR 90%C.L.)

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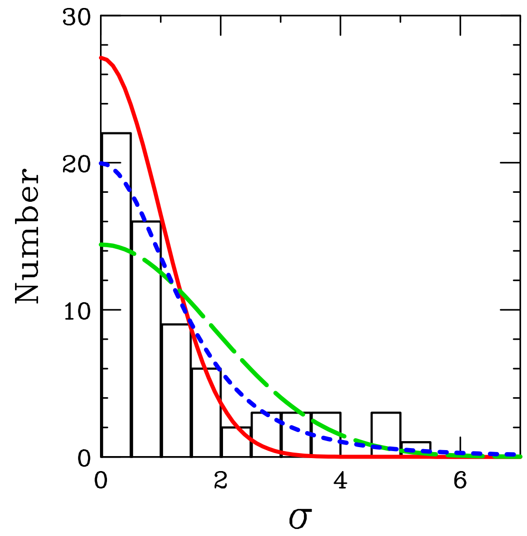
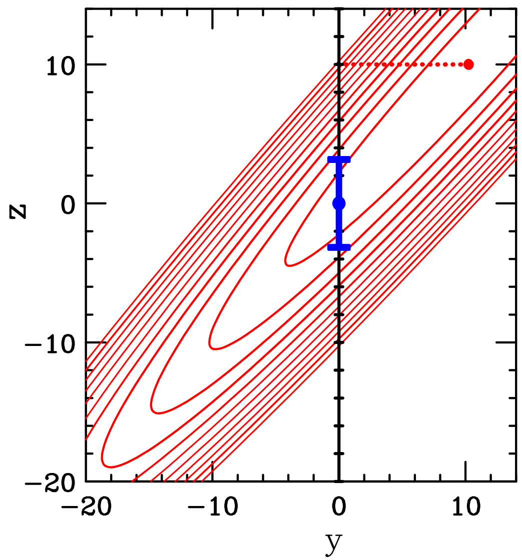


FUNCTIONAL BIAS (Pumplin, 2009)



- IF PARM. NOT GENERAL ENOUGH, GLOBAL MIN. IS NOT TRUE MIN.
- ONE-σ VARIATION ABOUT FAKE MIN CORRESP. TO LARGE χ^2 VARIATION, GREATER WITH ECCENTRICITY OF ERROR ELLIPSE
- $\Delta\chi^2 = 100$ OBTAINS IF FAKE MIN. BY 4 UNITS ABOVE TRUE MIN. AND ECCENTRICITIES UP TO 0.1 ALLOWED

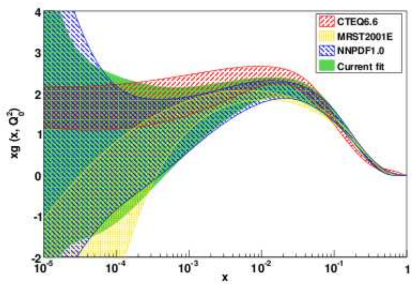
WHERE IS THE NNPDF UNCERTAINTY COMING FROM?

FIT TO REPLICAS VS RANDOM SUBSET OF CENTRAL VAL.S

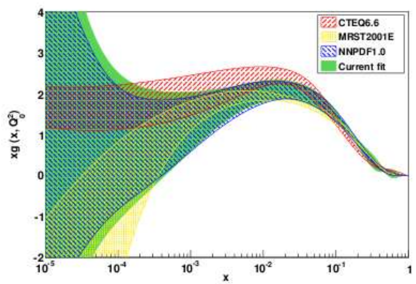
	REPLICAS	CENTRAL V.
χ^2	1.32	1.32
$\langle\chi^2\rangle_{\rm rep}$	2.79 ± 0.24	1.65 ± 0.20
$\langle\sigma^{\rm dat}\rangle$	0.039	0.035

GLUE

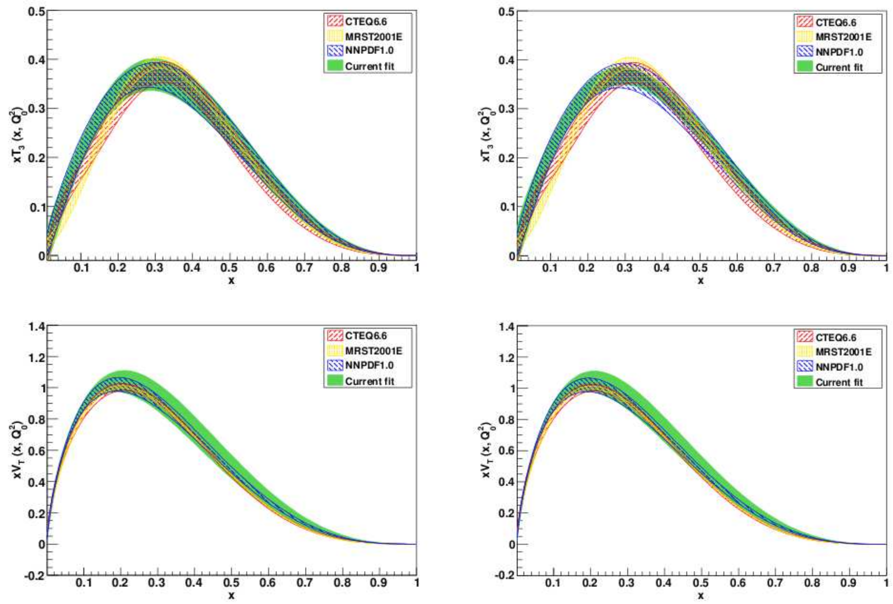
replicas



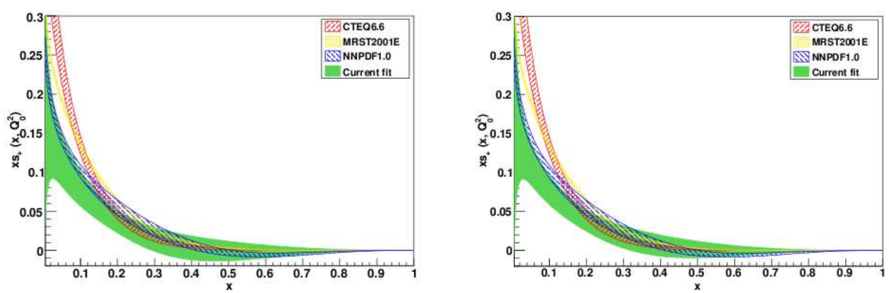
c. vals.



LIGHT QUARKS



STRANGE



- QUALITY OF FIT &PDFs UNCHANGED
- REDUCTION OF $\langle\chi^2\rangle_{\rm rep}$ BY FACTOR $\sim 2 \Rightarrow$ FLUCTUATIONS ABOUT TRUE VALUE HALVED
- UNCERTAINTY ON DATA ONLY REDUCED BY 1.1 $\Rightarrow$ EXPT. UNCERTAINTIES UNDERESTIMATED OR UNDERLYING INCOMPRESSIBLE UNCERTAINTY

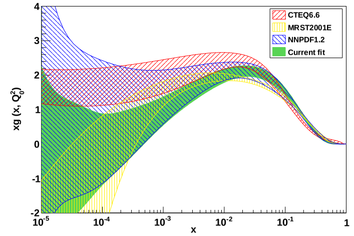
WHERE IS THE NNPDF UNCERTAINTY COMING FROM?

CENTRAL VALUES: VARYING PARTITION VS FIXED PARTITION

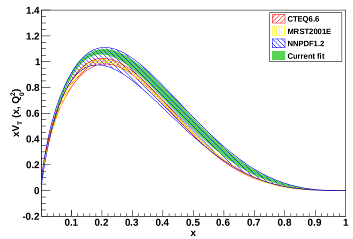
	REPLICAS	CENTRAL VALUE	FIXED PARTITION
χ^2	1.32	1.32	$\sim$1.3
$\langle\chi^2\rangle_{\rm rep}$	2.79 ± 0.24	1.65 ± 0.20	$\sim 1.6 \pm 0.2$
$\langle\sigma^{\rm dat}\rangle$	0.039	0.035	$\sim$0.03

fixed partition results obtained averaging over 5 different choices of partition (100 replicas each); more partitions needed for accurate results

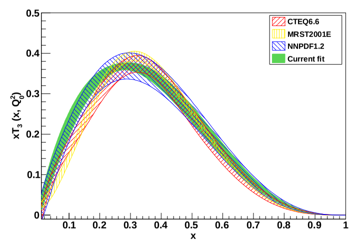
GLUE



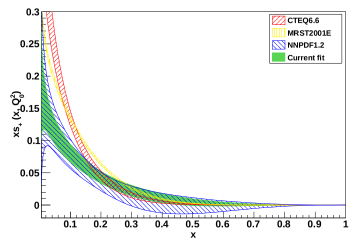
VALENCE



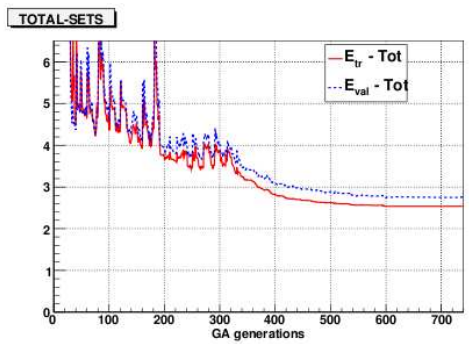
TRIPLET

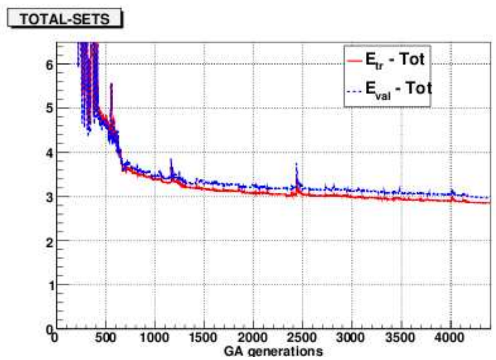


STRANGE



- QUALITY OF FIT UNCHANGED
- $\langle\chi^2\rangle_{\rm rep}$ UNCHANGED $\Rightarrow$ CENTRAL FIT UNCHANGED
- UNCERTAINTY ON PREDICTION (I.E. ON PDFS) REDUCED





FUNCTIONAL UNCERTAINTY

- MORE THAN HALF OF UNCERTAINTY DUE TO “FUNCTIONAL FORM”: $\langle\sigma^{\rm dat}\rangle =\sim 0.3$ SMALLER FOR HERA DATA
- REMAINING UNCERTAINTY ROUGHLY SCALES WITH DATA UNCERTAINTY: $\langle\sigma^{\rm dat}\rangle =\sim 0.005$ CENT.; $\langle\sigma^{\rm dat}\rangle =\sim 0.009$ REP.

SENSITIVITY TO α_s

DO PDFs DEPEND ON α_s?

DO PDFs DEPEND ON α_s?

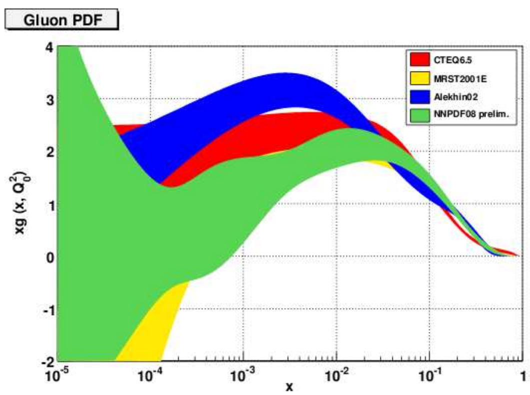
NNPDF: NO

- DETERMINE DISTANCE d IN UNITS OF STANDARD DEVIATION OF THE MEAN $s = \frac{\sigma}{\sqrt{N_{\rm rep}}}$ FOR EACH PDF$\Rightarrow$
  TWO DIFFERENT SUBSETS OF REPLICAS OF SAME FIT $\langle d \rangle = 1$
- DISTANCE BETWEEN PDFS WITH $\Delta\alpha_s = \pm 0.002$ COMPATIBLE WITH STATISTICAL FLUCTUATIONS
  for all PDFs, central values and uncertainties, data and extrapolation regions
- RECOMMENDED: TO ESTIMATE UNCERTAINTY, VARY α_s WITH PDFs FIXED AT STANDARD NNPDF SET

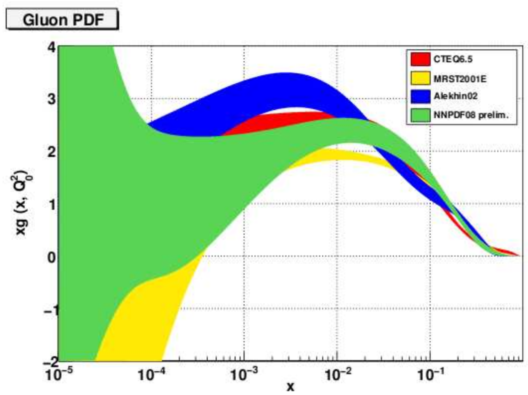
$\alpha_s(M_Z^2)$	0.117		0.121	
χ^2	1.35		1.33	
	Data	Extra	Data	Extra
$\Sigma(x, Q_0^2)$				
$\langle d[q] \rangle$	1.72	1.05	0.73	0.81
$\langle d[\sigma] \rangle$	1.05	1.03	1.22	0.95
$g(x, Q_0^2)$				
$\langle d[q] \rangle$	4.68	2.29	4.12	0.71
$\langle d[\sigma] \rangle$	1.00	0.91	0.88	0.83
$T_3(x, Q_0^2)$				
$\langle d[q] \rangle$	0.71	0.71	1.55	0.96
$\langle d[\sigma] \rangle$	0.93	0.75	1.11	0.78
$V(x, Q_0^2)$				
$\langle d[q] \rangle$	0.92	0.74	1.89	1.72
$\langle d[\sigma] \rangle$	0.94	0.71	0.67	0.65
$\Delta_S(x, Q_0^2)$				
$\langle d[q] \rangle$	0.74	0.58	0.86	1.36
$\langle d[\sigma] \rangle$	0.67	0.83	0.78	0.76

NNPDF GLUON

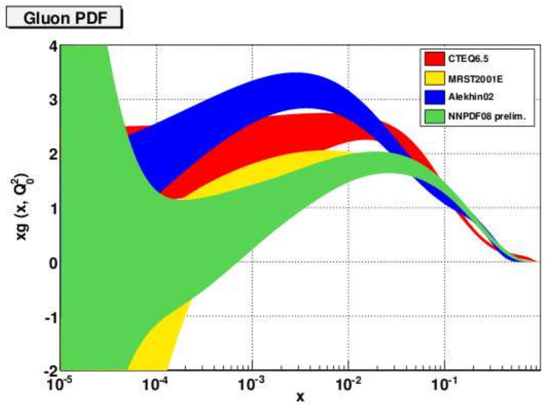
$\alpha_s = 0.119$



$\alpha_s = 0.117$



$\alpha_s = 0.121$



DO PDFs DEPEND ON α_s?

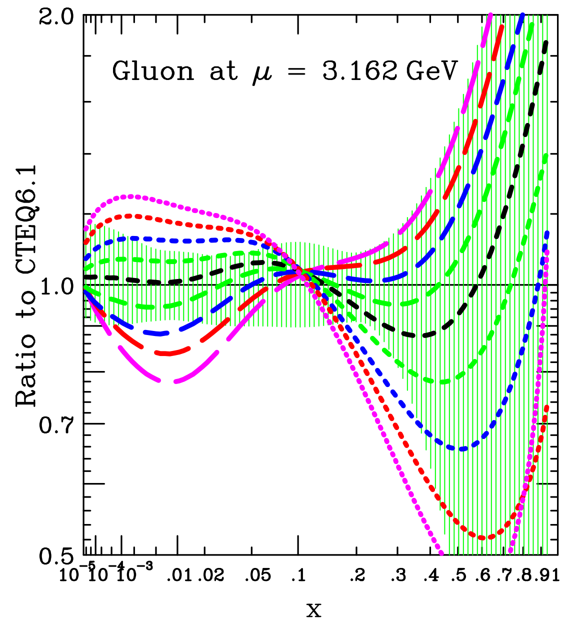
CTEQ: MILDLY

- CTEQ CENTRAL PARTON REDONE FIT WITH α_s FIXED
- MOST PDFs VARY LITTLE, GLUON MOST SENSITIVE
- SENSITIVITY OF GLOBAL FIT ON α_s WEAK,
  IF $\Delta\chi^2 = 100$ FOR 90%C.L., TO ONE σ $\Delta\alpha_s = 0.005$
- RECOMMENDED: TO ESTIMATE UNCERTAINTIES, VARY α_s WITH THE RESPECTIVE CENTRAL PDF SETS, THEN ADD UNCERTAINTY TO PDF UNCERTAINTY
  $\Rightarrow$ CORRELATION OF α_s TO PDF UNCERTAINTY NEGLIGIBLE, BUT CORRELN. TO CENTRAL VALUE THUS ACCOUNTED FOR

CTEQ6 GLUON

$\alpha_s = 0.110 \div 0.126$

top to bottom @ low x



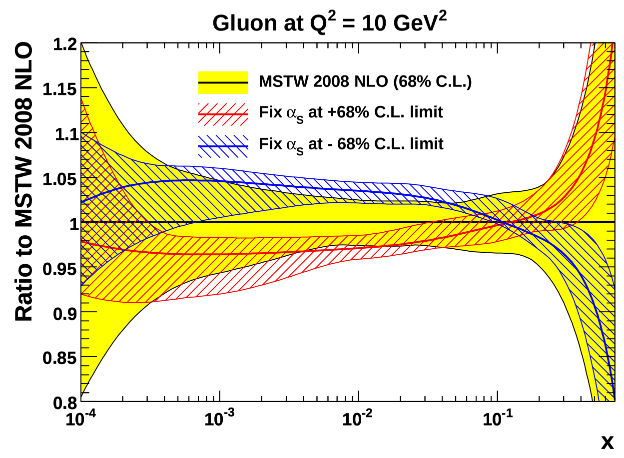
DO PDFS DEPEND ON α_s?

MSTW: STRONGLY

- α_s DETERMINED USING DYNAMICAL TOLERANCE CRITERION
- STRONG SENSITIVITY, UNCERTAINTY COMPETITIVE WITH CURRENT GLOBAL AVERAGE
- RECOMMENDED: TO ESTIMATE UNCERTAINTY, TAKE ENVELOPE OF PDF ERROR BANDS WITH FIVE α_s VALUES

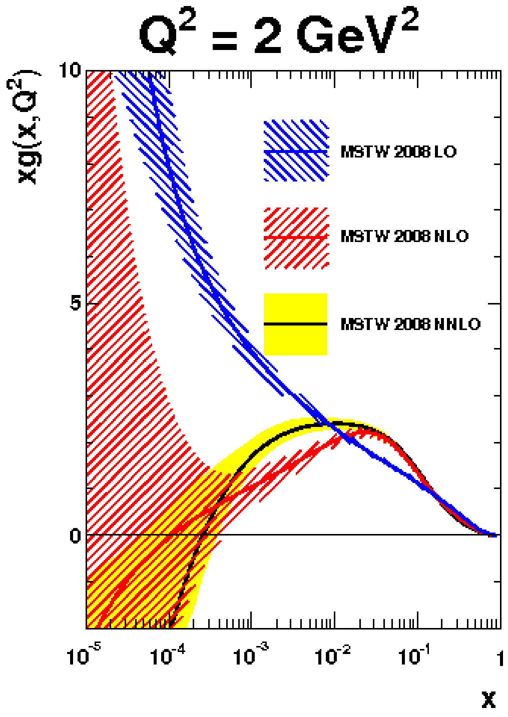
$\Rightarrow$ CORRELATIONS OF α_s TO BOTH PDF UNCERTAINTY & AND CENTRAL VALUE RELEVANT

MSTW GLUON



NNLO PDFS?

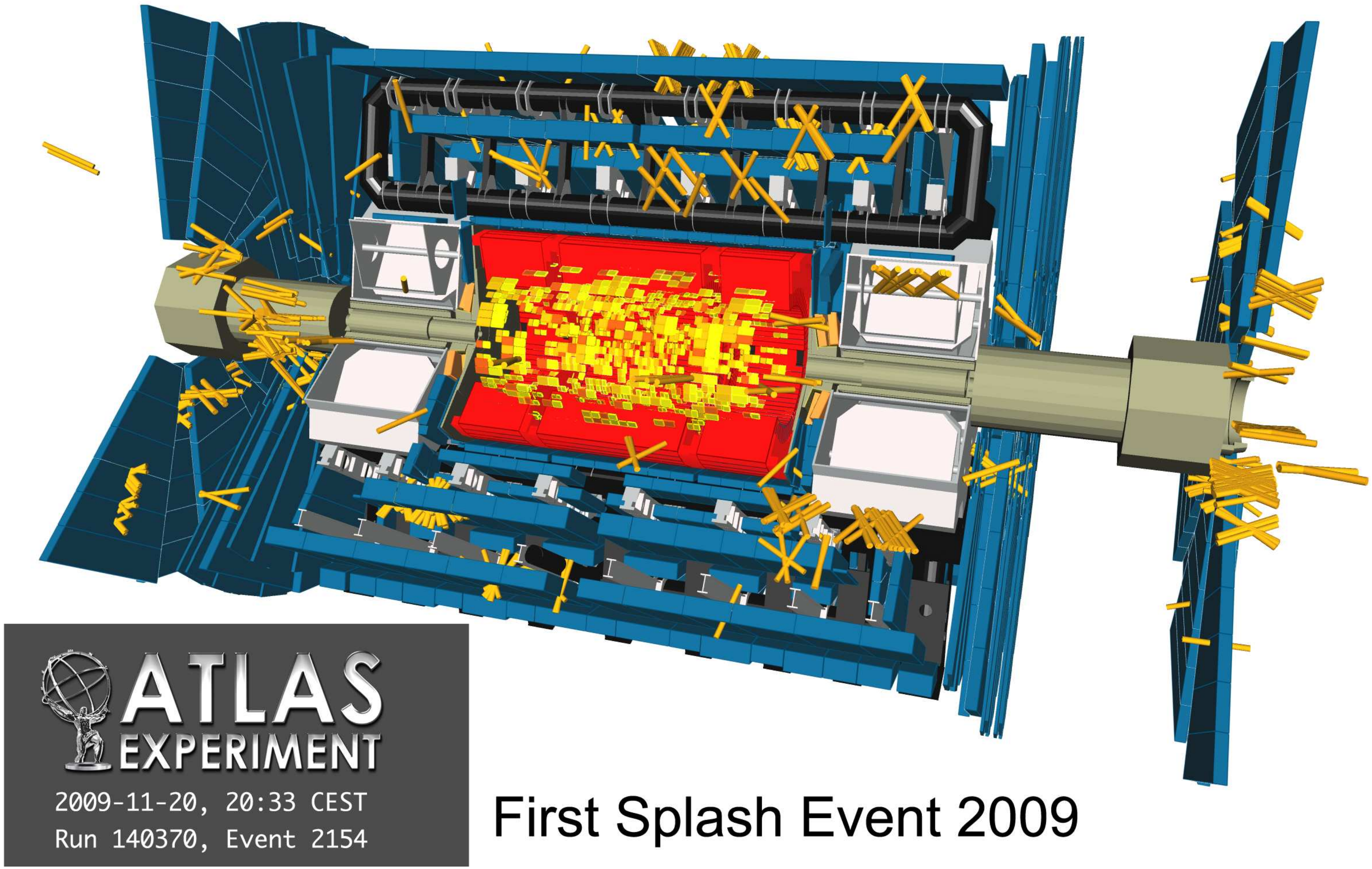
- MRST/MSTW NNLO PDFs AVALIABLE & SIGNIFICANTLY DIFFERENT FROM NLO
- ONLY DIS TREATED @ NNLO
- DRELL-YAN TREATED AT LO+ K–FACTORS (CTEQ ALSO DOES NLO DY WITH K FACTORS)
- NNLO FOR GLUON AT SMALL x UNSTABLE BECAUSE OF UNRESUMMED LOGS



CONCLUSIONS

- PDFs ARE THE RESULT OF THE INTERPLAY OF DIFFERENT PIECES OF DATA IN DIVERSE KINEMATIC REGIONS, LIKELY TO IMPROVE SIGNIFICANTLY AFTER FIRST LHC DATA
- PDF UNCERTAINTIES CANNOT BE OBTAINED AS ONE–σ PARAMETER VARIATIONS IN A LOW–DIMENSIONAL SPACE
- SIZABLE FRACTION OF THE PDF UNCERTAINTY DUE TO FUNCTIONAL FREEDOM (INFINTELY MANY CURVES GO THROUGH A FINITE SET OF DATA)
- RELATIVE IMPACT OF THEORETICAL UNCERTAINTIES SUCH AS HIGHER ORDER TERMS AND α_s VARIATION ACCORDINGLY LESS IMPORTANT

WE BETTER HURRY UP!



First Splash Event 2009

EXTRAS

Monte Carlo data generation

- BCDMS+ NMC proton & deuteron F_2 data (full correlated systematics available), taken at 4 beam energies

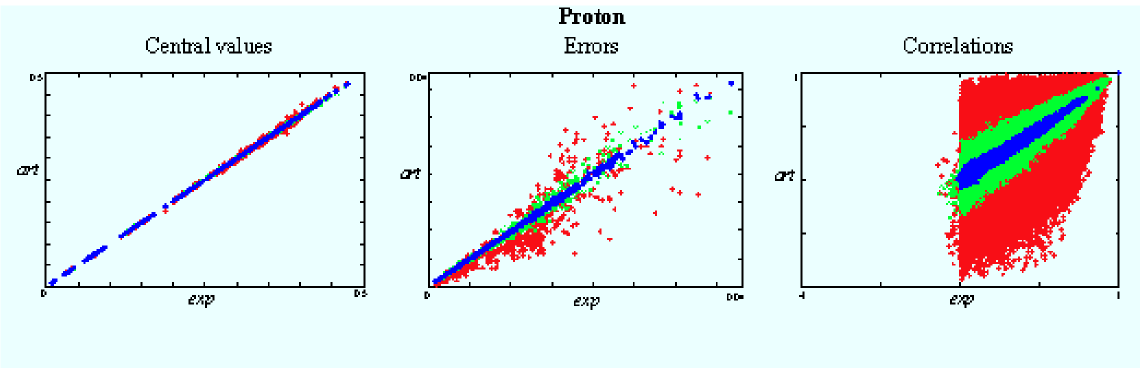
- on top of stat. errors, 4 systematics + 1 normalization (NMC) or 6 systematics + 1 absolute & 2 relative normalizations (BCDMS), with various forms of correlation (full, or for each target, or for each beam energy)

Generate data according to a multigaussian distribution

$$F_i^{(art)\,(k)} =$$

$$(1+r_5^{(k)}\,\sigma_N)\sqrt{1+r_{i,6}^{(k)}\,\sigma_{N_t}}\sqrt{1+r_{i,7}^{(k)}\,\sigma_{N_b}}\left[F_i^{(exp)} + \frac{r_{i,1}^{(k)}\,f_b + r_{i,2}^{(k)}\,f_{i,s} + r_{i,3}^{(k)}\,f_{i,r}}{100}F_i^{(exp)} + r_{i,s}^{(k)}\,\sigma_s^i\right]$$

r univariate gaussian random nos., one $r_{i,s}$ for each data, but single $r_{i,j}$ for all correlated data



scatter plot art. vs. exp. for 10 (red) 100 (green) and 1000 (blue) replicas

need 1000 replicas to reproduce correlations to percent accuracy

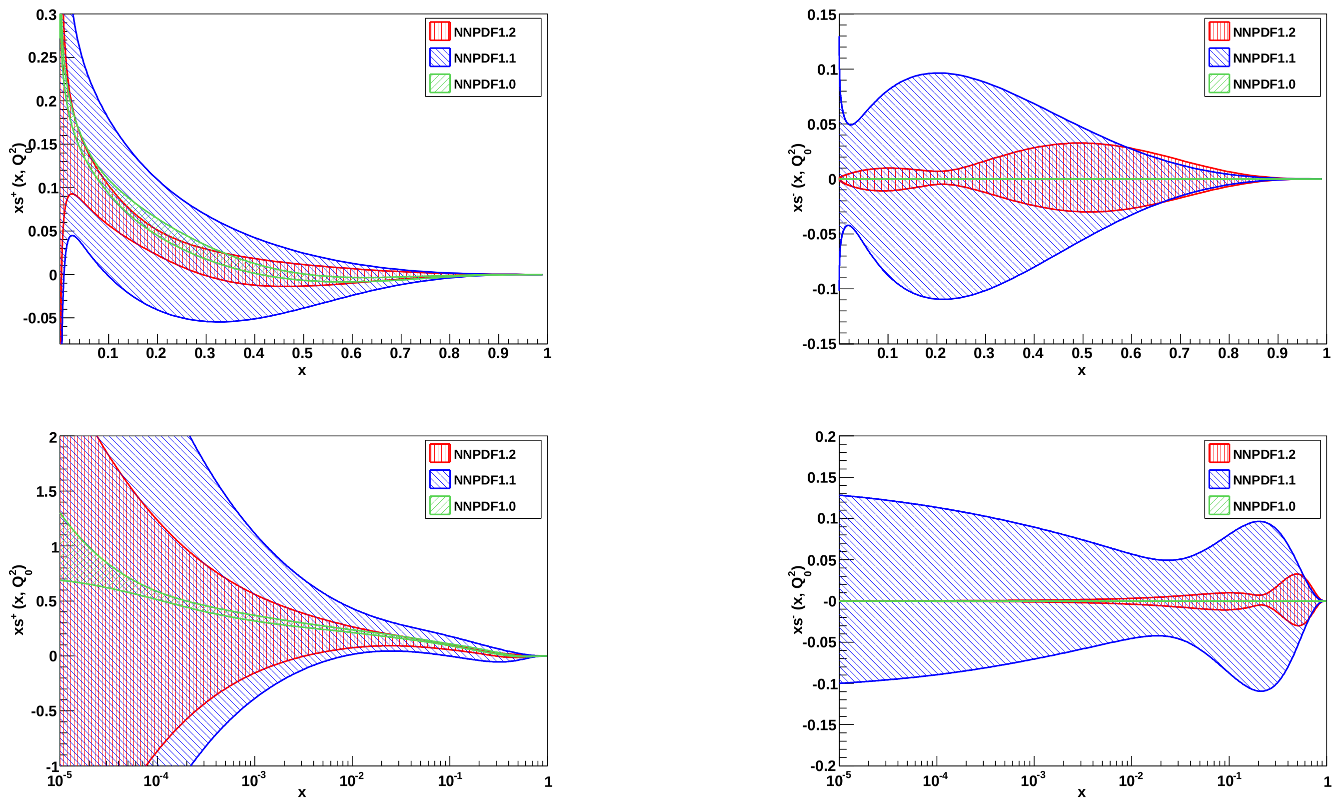
WHAT IS THIS GOOD FOR?

DETERMINATION OF WEAKLY CONSTRAINED QUANTITIES

THE STRANGE PDF

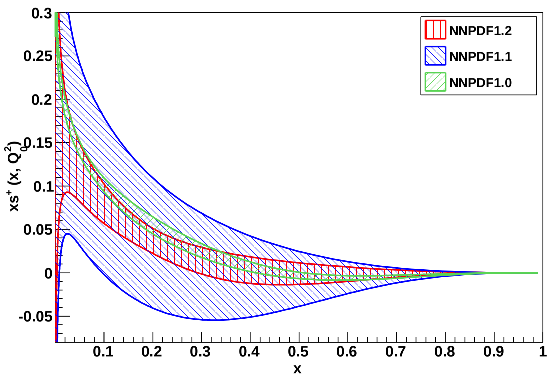
- NNPDF1.0: $s(x,Q_0^2)=\bar{s}(x,Q_0^2)$, $s+\bar{s}=\frac{1}{2}(\bar{u}+\bar{d})$, NO DIMUON DATA
- NNPDF1.1: s, $\bar{s}$ (ACTUALLY $s^{\pm}$) INDEP. PARAMETRIZED, NO DIMUON DATA
- NNPDF1.2: s, $\bar{s}$ (ACTUALLY $s^{\pm}$) INDEP. PARAMETRIZED, DIMUON DATA

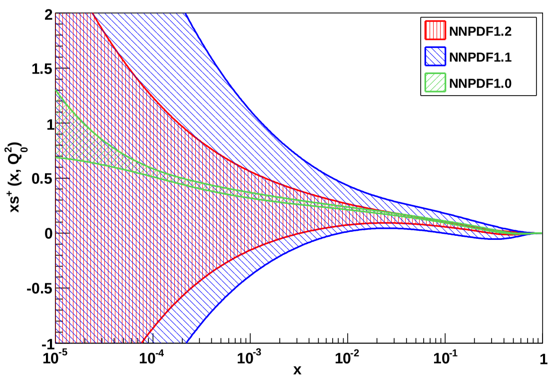
STRANGE PDFS



WHAT IS THIS GOOD FOR?
COMPATIBILITY CAN BE CHECKED QUANTITATIVELY

THE STRANGE PDF





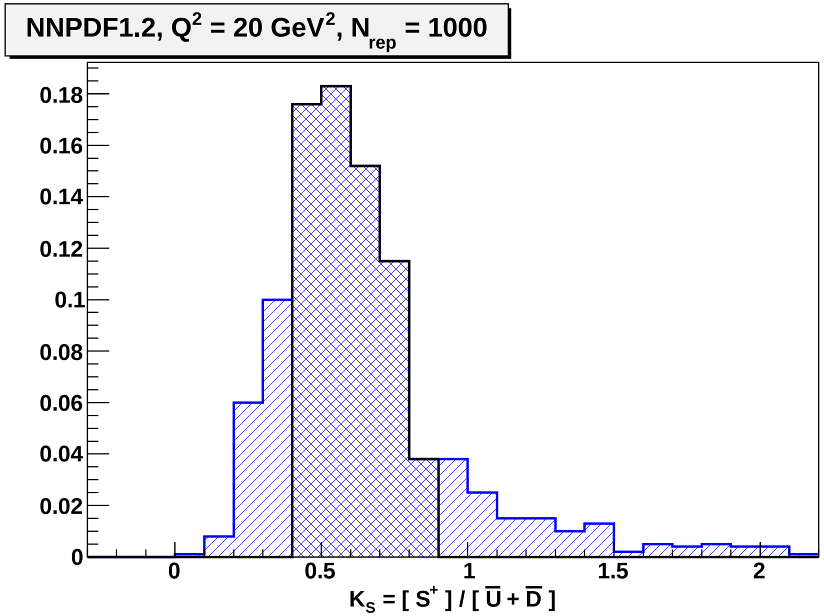
NNPDF1.2 vs. NNPDF1.1		
	Data	Extrapolation
$\Sigma(x, Q_0^2)$	$5\ 10^{-4} \le x \le 0.1$	$10^{-5} \le x \le 10^{-4}$
$\langle d[q] \rangle$	2.7	1.2
$\langle d[\sigma] \rangle$	3.1	1.8
$g(x, Q_0^2)$	$5\ 10^{-4} \le x \le 0.1$	$10^{-5} \le x \le 10^{-4}$
$\langle d[q] \rangle$	2.4	2.0
$\langle d[\sigma] \rangle$	1.3	1.4
$T_3(x, Q_0^2)$	$0.05 \le x \le 0.75$	$10^{-3} \le x \le 10^{-2}$
$\langle d[q] \rangle$	1.5	0.9
$\langle d[\sigma] \rangle$	1.1	1.2
$V(x, Q_0^2)$	$0.1 \le x \le 0.6$	$3\ 10^{-3} \le x \le 3\ 10^{-2}$
$\langle d[q] \rangle$	1.1	1.0
$\langle d[\sigma] \rangle$	1.3	1.4
$\Delta_S(x, Q_0^2)$	$0.1 \le x \le 0.6$	$3\ 10^{-3} \le x \le 3\ 10^{-2}$
$\langle d[q] \rangle$	0.8	0.8
$\langle d[\sigma] \rangle$	1.3	1.1
$s^+(x, Q_0^2)$	$5\ 10^{-4} \le x \le 0.1$	$10^{-5} \le x \le 10^{-4}$
$\langle d[q] \rangle$	2.0	1.6
$\langle d[\sigma] \rangle$	4.5	1.8
$s^-(x, Q_0^2)$	$0.1 \le x \le 0.6$	$3\ 10^{-3} \le x \le 3\ 10^{-2}$
$\langle d[q] \rangle$	1.1	1.3
$\langle d[\sigma] \rangle$	6.1	4.6

DISTANCE OF EXP. VALUES RESCALED BY $\sigma/\sqrt{N_{rep}}$

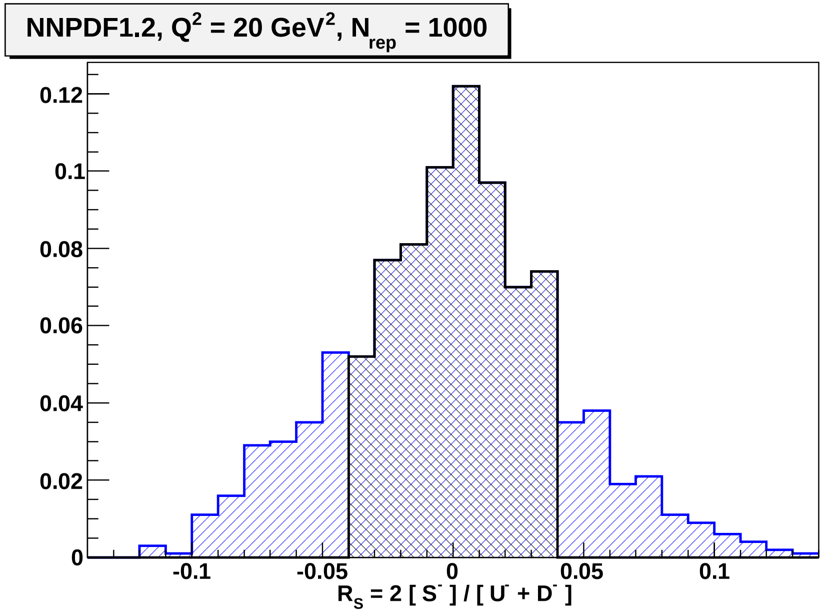
WHAT IS THIS GOOD FOR?
CAN DETERMINE RELIABLY LARGE & ASYMMETRIC UNCERTAINTIES

THE STRANGE MOMENTUM FRACTIONS

$s + \bar{s}$



$s - \bar{s}$



ANALYSIS	$K_S\left(Q^2 = 20\ \mathrm{GeV}^2\right)$
NNPDF1.2	$0.71^{+0.19}_{-0.31}$
MSTW08	0.56 ± 0.03
CTEQ66	0.72 ± 0.05
AKP08	0.59 ± 0.08

ANALYSIS	$[S^-](Q^2) \cdot 10^3$	Q^2 GeV^2	$[S^-](20\ GeV^2) \cdot 10^3$
NNPDF1.2	0.5 ± 8.6	20	0.5 ± 8.6
MSTW08	2.4 ± 2.0	1	1.4 ± 1.2
CTEQ6.5s	2.0 ± 1.8	1.69	1.2 ± 1.1
CTEQ6.1s	1.5 ± 1.5	1.69	1.2 ± 1.2
AKP08	1.0 ± 1.3	20	1.0 ± 1.3
NuTeV07	2.2 ± 1.3	16	1.3 ± 0.8
BPPZ03	1.8 ± 3.8	20	1.8 ± 3.8

AN IMPLICATION: THE "NUTEV ANOMALY" IS GONE

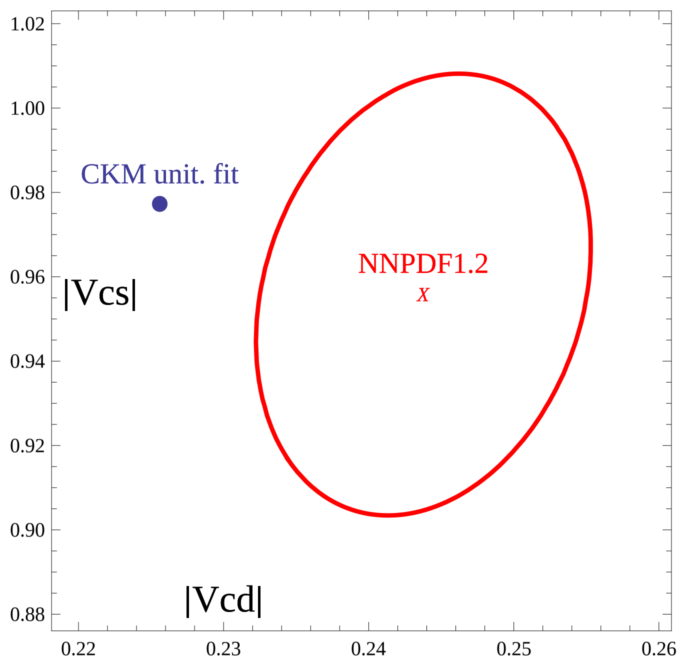
WHAT IS THIS GOOD FOR?

CAN DISENTANGLE PHYSICAL PARAMETERS FROM PDFs

DETERMINATION OF CKM PARMS FROM DIS

$$F_2^{\nu,c} = x\left[C_{2,q}\otimes\left(|V_{\rm cd}|^2(u+d)+2|V_{\rm cs}|^2 s\right)+C_{2,g}\otimes g\right]$$

$$F_2^{\bar\nu,c} = x\left[C_{2,q}\otimes\left(|V_{\rm cd}|^2(\bar u+\bar d)+2|V_{\rm cs}|^2 \bar s\right)+C_{2,g}\otimes g\right]$$



ANALYSIS	DETERMINATION	$\|V_{cs}\|$
NNPDF1.2	DIRECT FROM GLOBAL PDF ANALYSIS	$0.96 \pm 0.07^{\rm tot}$
CDHS	LO FROM $\nu N \to \mu^+\mu^- X$	≥ 0.59 (90% C.L.)
CCFR	NLO FROM $\nu N \to \mu^+\mu^- X$	≥ 0.74 (90% C.L.)
PDG08	AVERAGE FROM D DECAYS	1.04 ± 0.06
HOCKER	AVERAGE FROM $\nu N \to \mu^+\mu^- X$	1.04 ± 0.16
DELPHI	DIRECT FROM $W^+ \to c\bar s$ DECAYS	$0.94^{+0.32}_{-0.26} \pm 0.13$
PDG08	CKM UNITARITY FIT	0.97334 ± 0.00023

ANALYSIS	DETERMINATION	$\|V_{cd}\|$
NNPDF1.2	DIRECT FROM GLOBAL PDF ANALYSIS	$0.244 \pm 0.019^{\rm tot}$
CDHS	LO FROM $\nu N \to \mu^+\mu^- X$	0.24 ± 0.03
CCFR	NLO FROM $\nu N \to \mu^+\mu^- X$	$0.232^{+0.017}_{-0.019}$
PDG08	AVERAGE FROM $\nu N \to \mu^+\mu^- X$	0.230 ± 0.011
PDG08	AVERAGE FROM $D \to K/\pi l \nu$ DECAYS	0.218 ± 0.023
PDG08	CKM UNITARITY FIT	0.2256 ± 0.0010

$\Rightarrow$ MOST PRECISE AVAILABLE DIRECT DETERMINATION OF V_{cs}

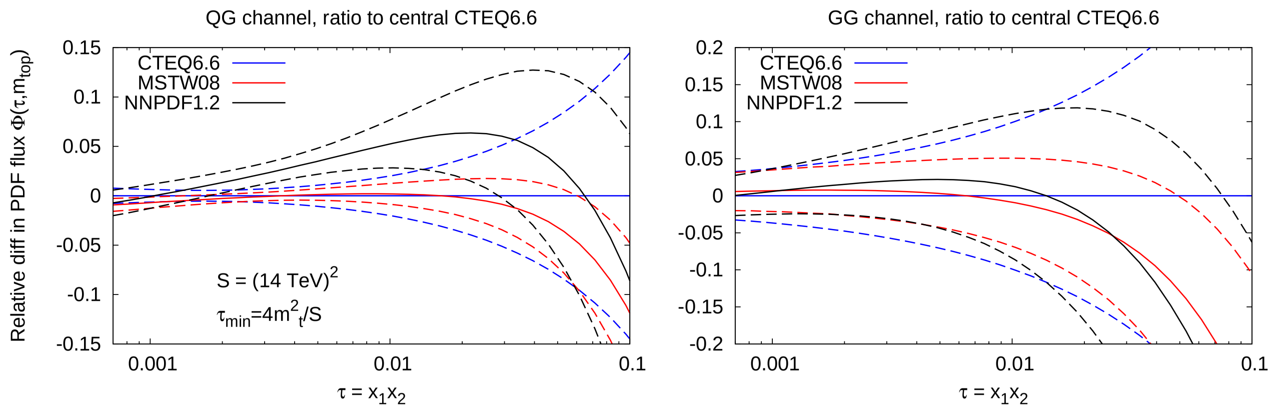
WHAT IS THIS GOOD FOR?

CAN TRUST RESULTS!

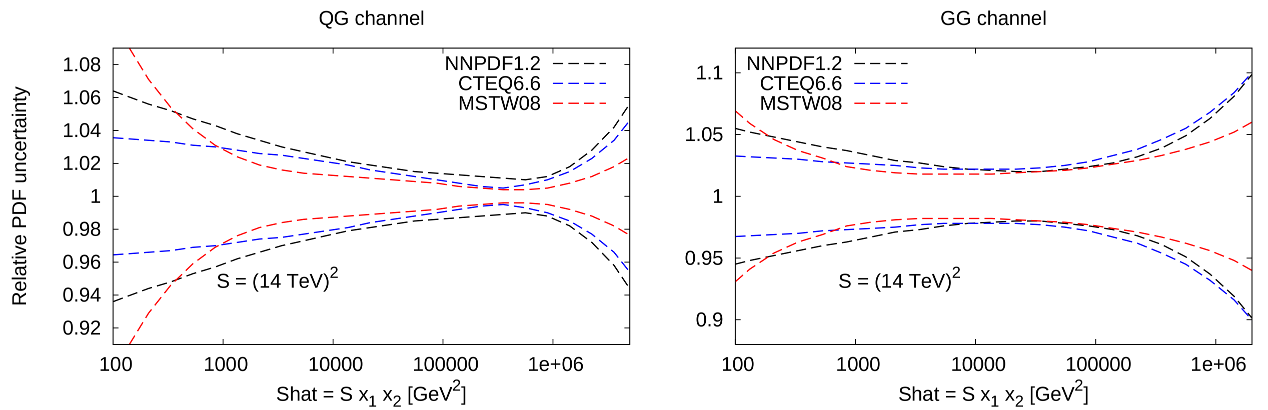
PARTON FLUXES AT THE LHC

$$\Phi_{ij}\left(\tau,\mu^2\right)=\int_0^1 dx_1\int_0^1 dx_2 q_i\left(x_1,\mu^2\right) q_j\left(x_2,\mu^2\right)\delta\left(x_1x_2-\tau\right)$$

FLUX



RELATIVE UNCERTAINTY ON FLUX

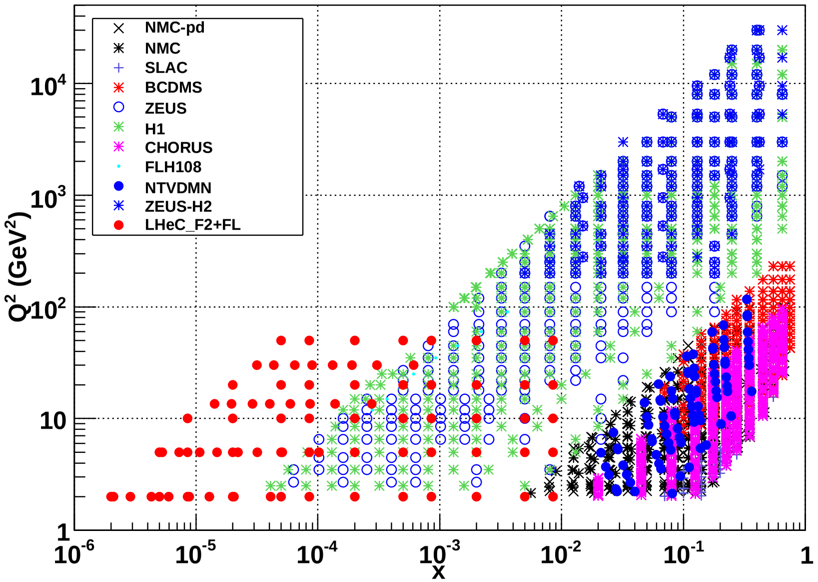


- UNCERTAINTIES IN FUTURE (GLOBAL) NNPDF FIT CAN ONLY DECREASE
- SENSITIVITY TO α_s OF NNPDF PARTONS NEGLIGIBLE

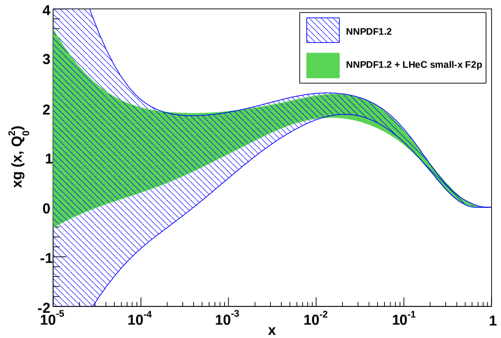
WHAT IS THIS GOOD FOR?

CAN STUDY UNCERTAINTIES AT FUTURE ACCELERATORS

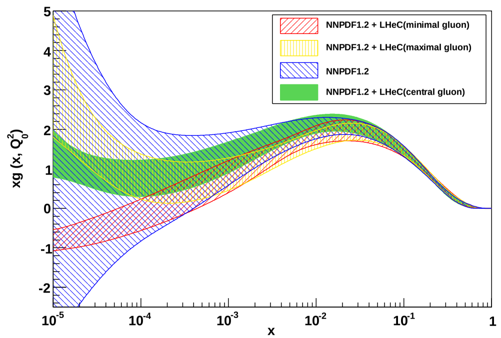
GLUON DETERMINATION AT THE LHEC



IMPACT OF LHEC F_2 DATA



LHEC $F_2 + F_L$ DATA

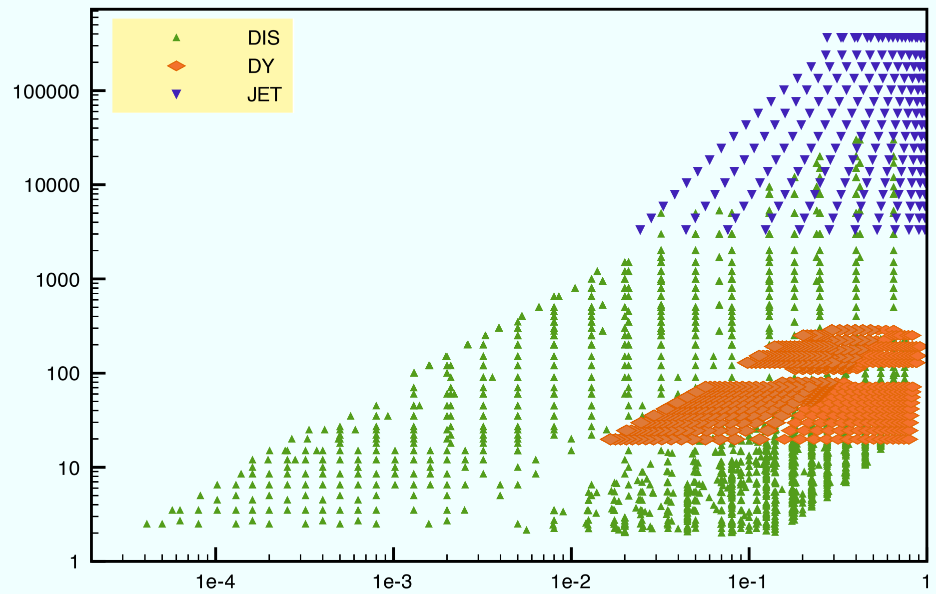


CAN DISENTANGLE DIFFERENT SCENARIOS FOR SMALL x GLUON BEHAVIOUR

- THE MONTE CARLO SAMPLE CAN BE USED DIRECTLY FOR SUCH STUDIES WITHOUT REFITTING:
  JUST REWEIGHT SAMPLE ACCORDING TO PROJECTED DATA
- LHC STUDIES ALONG THESE LINES POSSIBLE/IN PREPARATION
  (SEE McNULTY'S TALK)

WHAT NEXT?

NNPDF2.0



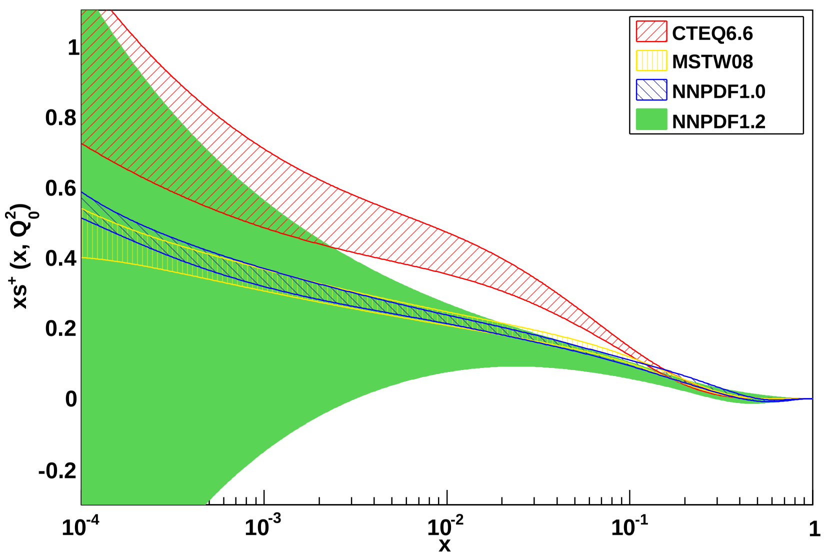
OBS	DATA SET
$d\sigma^{\mathrm{DY}}/dM^2dy$	E605
$d\sigma^{\mathrm{DY}}/dM^2dx_F$	E886
W ASYM.	D0/CDF
Z RAP. DISTR.	D0/CDF
INCL. σ^{jet}	CDF(k_T)
INCL. σ^{jet}	D0(CONE)

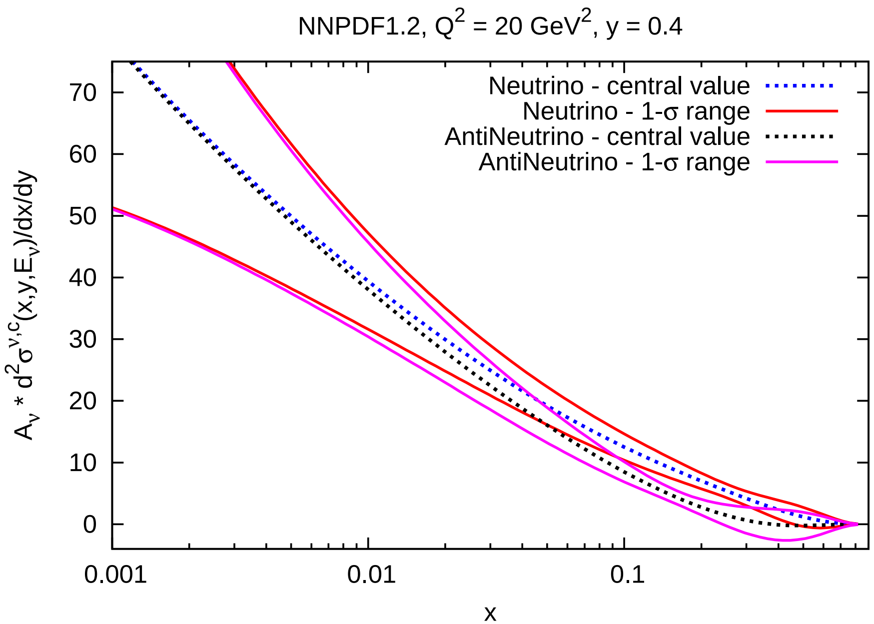
- $800_{\mathrm{DY}} + 200_{\mathrm{JET}}$ = $\mathcal{O}(1000)$ NEW DATA
- FASTDY ALGORITHM $\Rightarrow$ FIRST TRULY NLO FIT
- DEFECT: STILL ZM-VFN SCHEME FOR HEAVY QUARKS

POSITIVITY

- PDFs CAN GO NEGATIVE, PROVIDED PHYSICAL CROSS SECTIONS REMAIN POSITIVE DEFINITE
- (IN PRINCIPLE) THIS SHOULD BE TRUE FOR ANY OBSERVABLE
- IN PRACTICE, MOSTLY RELEVANT CLOSE TO THE DATA EDGE
- NNPDF1.X: POSITIVITY OF F_L ENFORCED

STRANGE PDF AND DIMUON XSECT

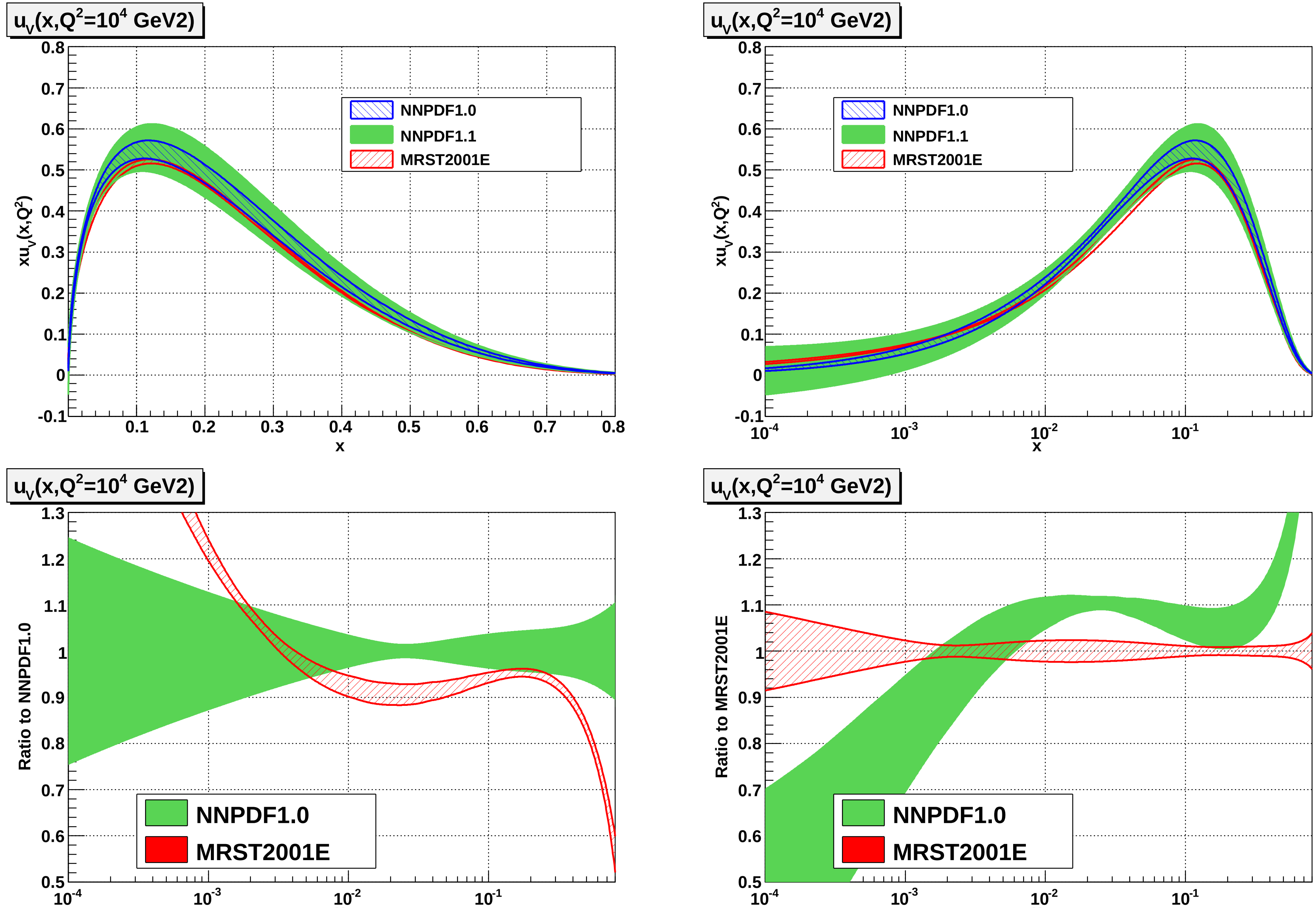




- STRANGENESS GOES NEGATIVE PRETTY SOON…
- BUT THE CROSS-SECTION REMAINS POSITIVE

COMPARISON PLOTS

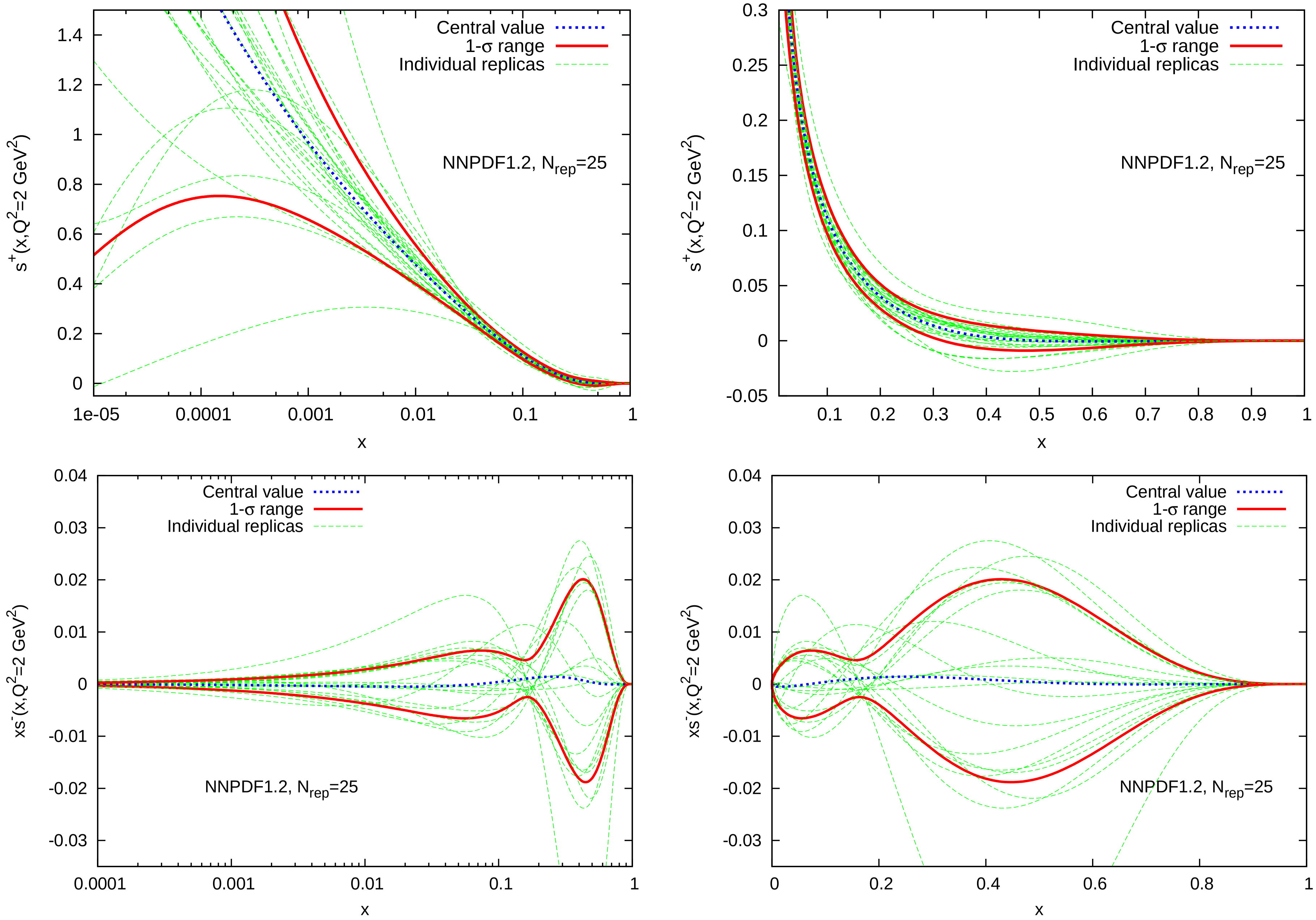
BEWARE OF RATIOS!



THE PDF IN THE NUMERATOR ALWAYS LOOKS SILLY!

REPLICAS: STRANGENESS

FLEXIBLE PARAMETRZATION WITH LITTLE INFORMATION



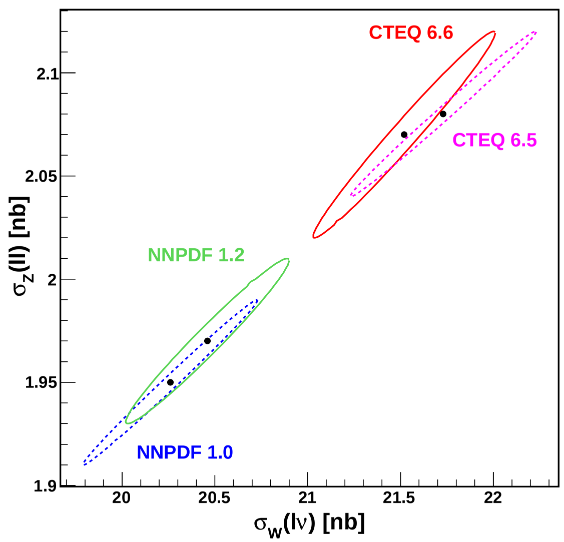
s^- MAY CHANGE SIGN SEVERAL TIMES!

IMPACT ON SOME LHC STANDARD CANDLES:

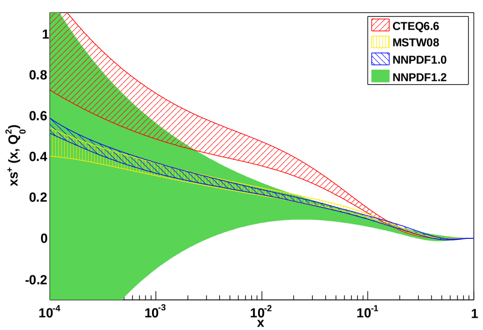
IT COULD BE WORSE

- TOTAL W/Z XSCT DOMINATED BY CENTRAL RAPIDITY REGION
  $\Rightarrow$ UNCERTAINTY ON STRANGENESS UNDER CONTROL
- AWAY FROM CENTRAL REGION UNCERTAINTY MUCH LARGER

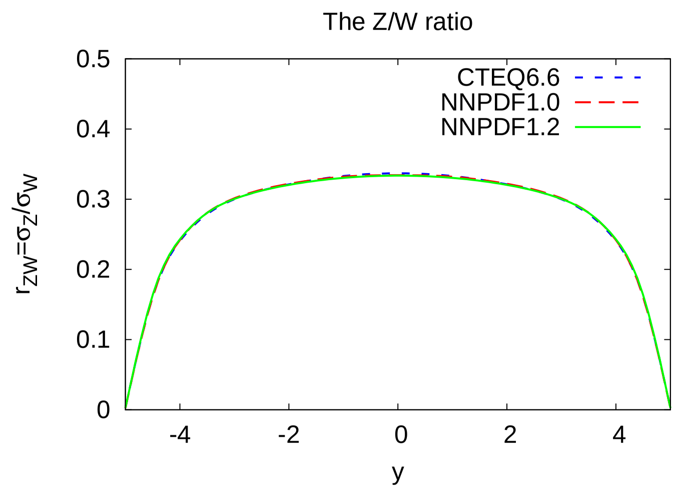
TOTAL XSECTNS



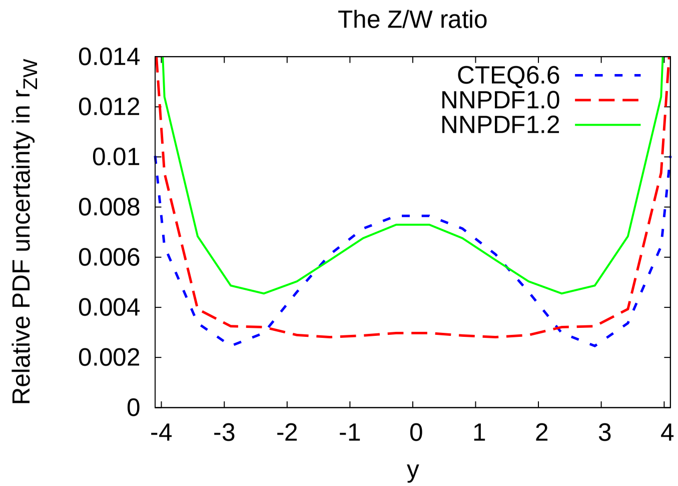
STRANGENESS (REMINDER)



RAPIDITY DISTRIBUTION

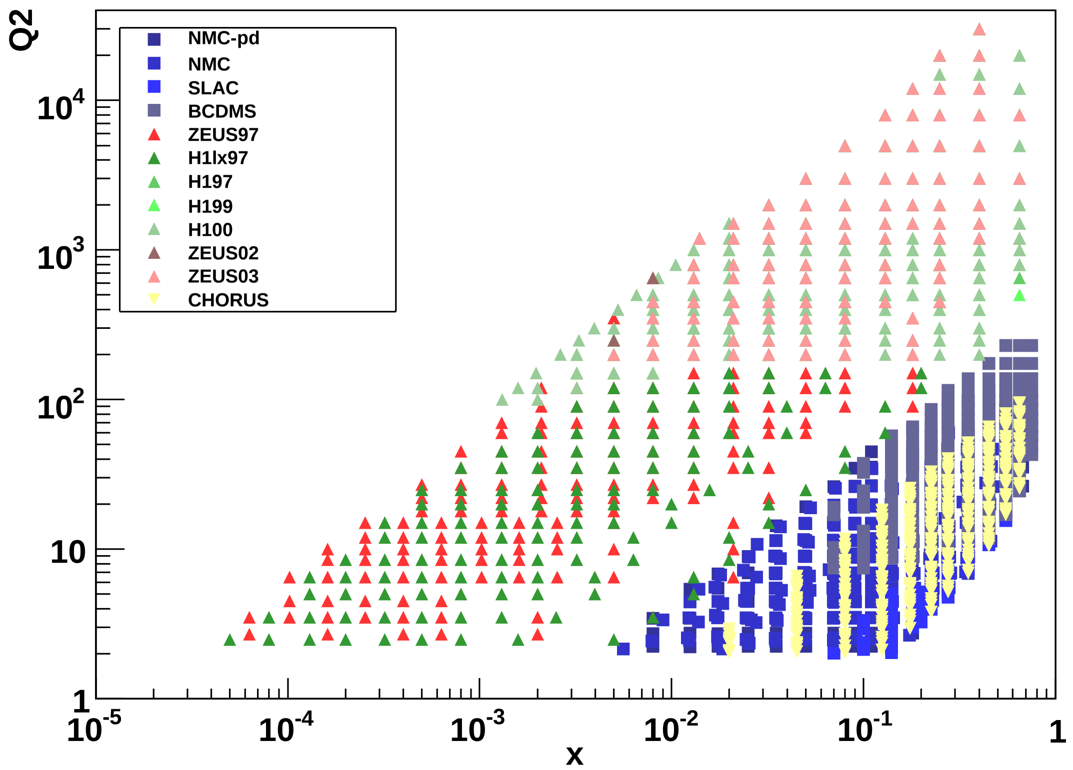


PERC. UNCERTAINTY



FEATURES OF THE FIT

THE DATASET



$Q^2 > 2\ \mathrm{GeV}^2$; $W^2 > 12.5\ \mathrm{GeV}^2$

NAME	DATA POINTS	TARGET
NMC_PD	153	F_2^d / F_2^p
NMC	245	F_2^p
SLAC	47 (47)	$F_2^{p(d)}$
BCDMS	333 (248)	$F_2^{p(d)}$
ZEUS97	240 (29)	$\tilde{\sigma}^{NC(CC),+}$
ZEUS02	92 (26)	$\tilde{\sigma}^{NC(CC),-}$
ZEUS03	90 (30)	$\tilde{\sigma}^{NC(CC),+}$
H1LX97	135	$\tilde{\sigma}^{NC,+}$
H197	130 (25)	$\tilde{\sigma}^{NC(CC),+}$
H199	139 (28)	$\tilde{\sigma}^{NC(CC),-}$
H100	147 (28)	$\tilde{\sigma}^{NC(CC),+}$
H108	8	F_L
CHORUS	471 (471)	$\tilde{\sigma}^{\nu(\bar{\nu})}$
TOTAL	3161	

FEATURES OF THE FIT

THEORY

- NLO EVOLUTION (N – SPACE, EXPANDED)
- ZM-VFN SCHEME FOR THRESHOLDS
- $\alpha_s(M_z) = 0.119$, PDFS GIVEN AT $Q_0^2 = 2$ GeV^2
- TARGET-MASS CORRECTIONS INCLUDED UP TO TWIST FOUR

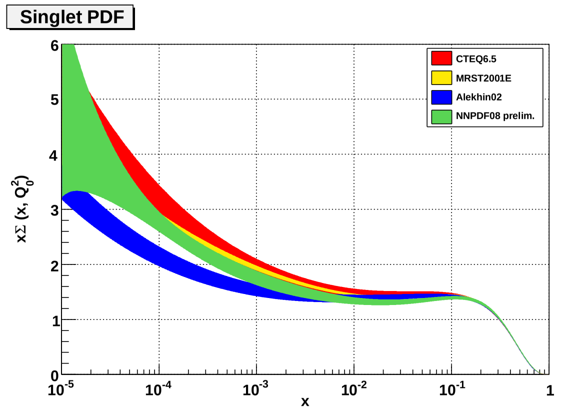
BASIS FUNCTIONS AND PARAMETRIZATION

- FIVE INDEPENDENT PDFs: SINGLET, GLUON, TOTAL VALENCE, TRIPLET, $\bar{d} - \bar{u}$.
- SYMMETRIC STRANGE SEA $s(x) = \bar{s}(x)$,
  PROPORTIONAL TO NON-STRANGE SEA, $\bar{s}(x) = \frac{C}{2}(\bar{u}(x) + \bar{d}(x))$, (C = 0.5)
- ALL PDFS PARAMETRIZED BY A 2-5-3-1 NEURAL NETWORK:
  $37 \times 5 = 185$ PARAMETERS
- MOMENTUM AND VALENCE SUM RULES ENFORCED STRICTLY
- POSITIVITY OF F_L ENFORCED for $x \geq 10^{-7}$, $Q^2 \geq 2$ GeV^2

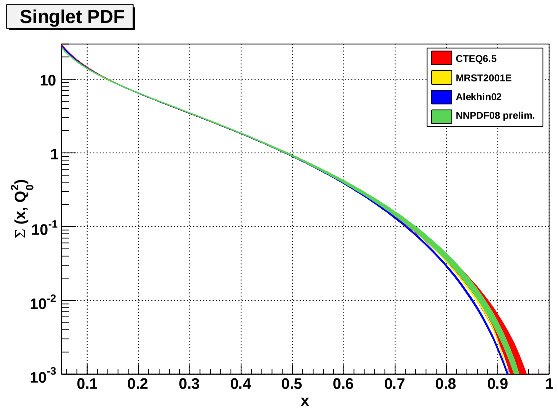
RESULTS

PARTON DISTRIBUTIONS

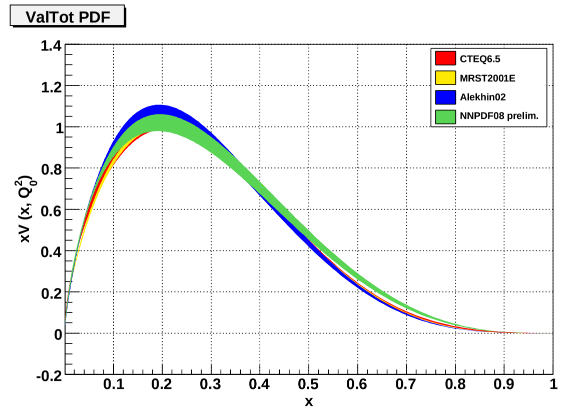
SINGLET



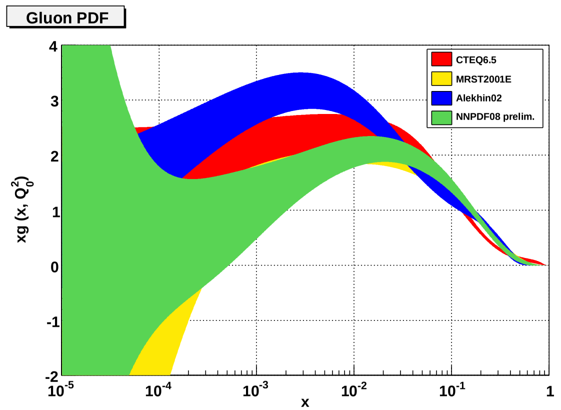
SINGLET



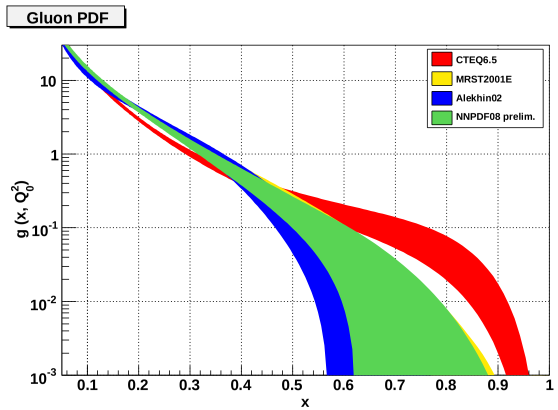
VALENCE



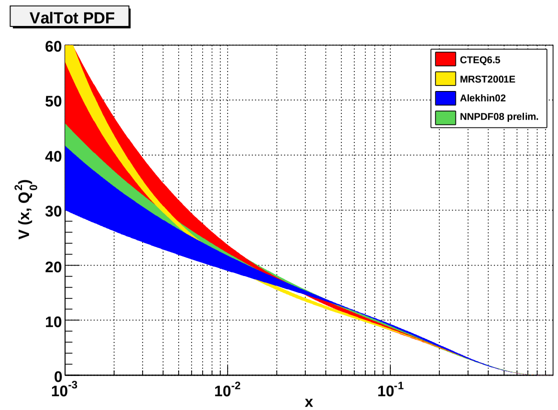
GLUON



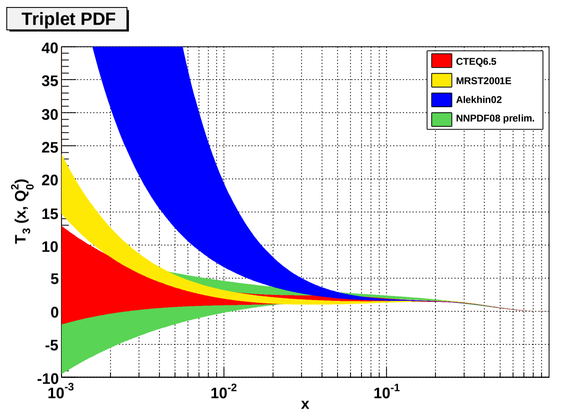
GLUON



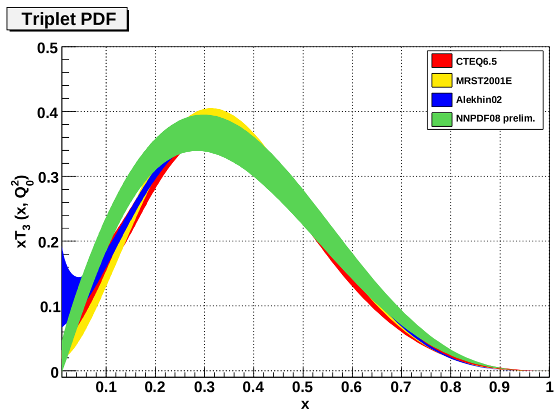
VALENCE



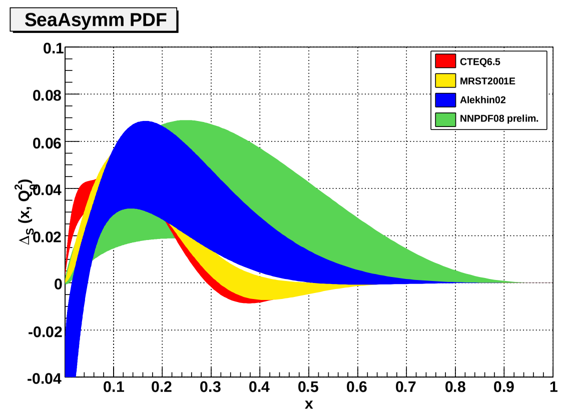
TRIPLET



TRIPLET



SEA ASYM.

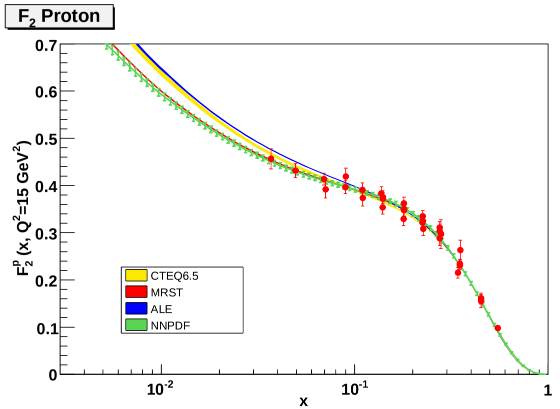


RESULTS

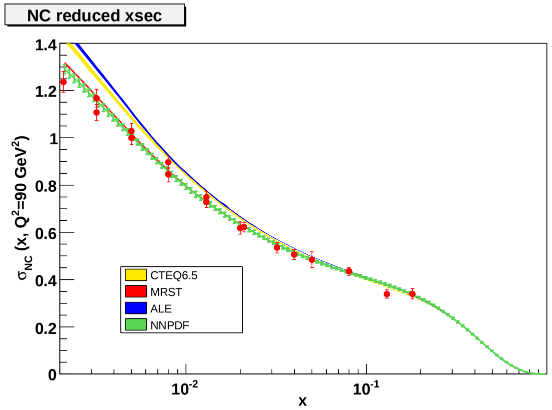
PHYSICAL OBSERVABLES

STRUCTURE FUNCTIONS

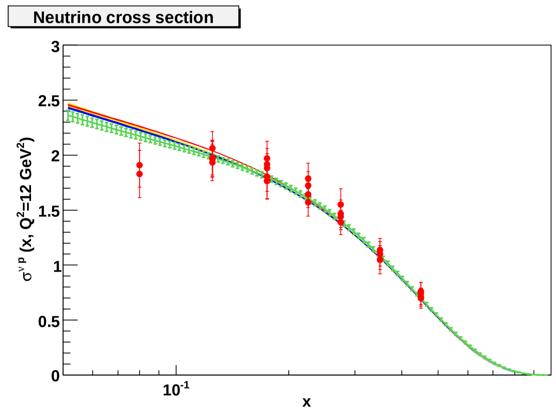
PROTON F_2



NC XSECT.

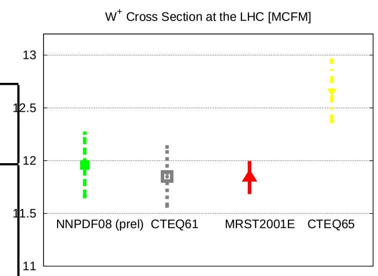


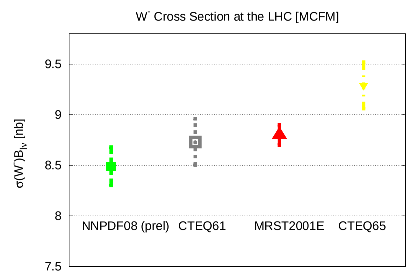
NEUTRINO XSECT.



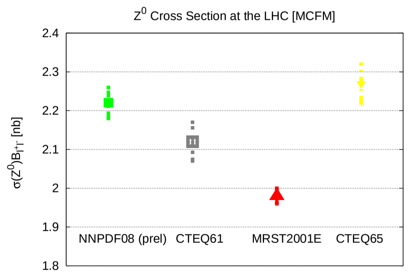
TOTAL CROSS-SECTIONS AT LHC, NLO FROM MCFM

-	$\sigma_{W^+}\mathcal{B}_{l^+\nu}$ [nb]	$\Delta\sigma/\sigma$ W^+	$\sigma_{W^-}\mathcal{B}_{l^-\nu}$ [nb]	$\Delta\sigma/\sigma$ W^-
NNPDF08	11.96 ± 0.30	2.5%	8.49 ± 0.19	2.3%
CTEQ6.5	12.66 ± 0.29	2.3%	9.29 ± 0.23	2.5%
CTEQ6.1	11.85 ± 0.28	2.4%	8.73 ± 0.23	2.6%
MRST01	11.84 ± 0.14	1.2%	8.80 ± 0.10	1.1%





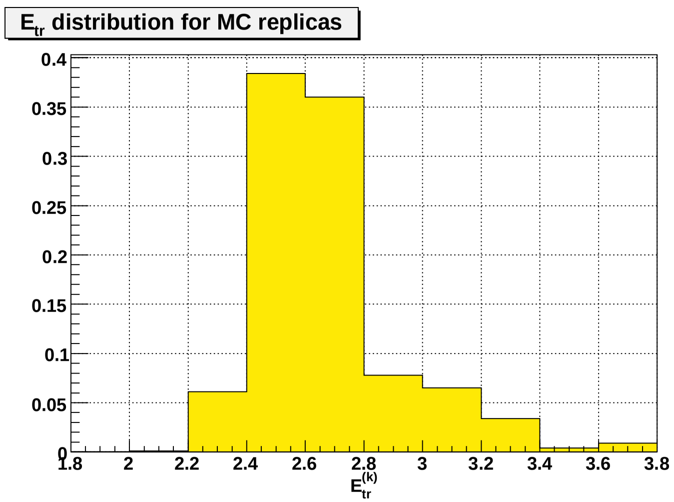
	$\sigma_Z\mathcal{B}_{l^+l^-}$ [nb]	$\Delta\sigma/\sigma$ Z	$\sigma_{t\bar{t}}$ [pb]	$\Delta\sigma/\sigma$ $t\bar{t}$	σ_H [pb]	$\Delta\sigma/\sigma$ H
NNPDF08	2.22 ± 0.04	2.0%	1014 ± 24	2.3%	35.79 ± 1.04	3.0%
CTEQ6.5	2.27 ± 0.05	2.2%	942 ± 19	2.0%	37.51 ± 0.80	2.2%
CTEQ6.1	2.12 ± 0.05	2.3%	970 ± 18	1.9%	38.50 ± 0.85	2.2%
MRST01	1.98 ± 0.02	1.0%	1013 ± 13	1.3%	37.52 ± 0.40	1.1%



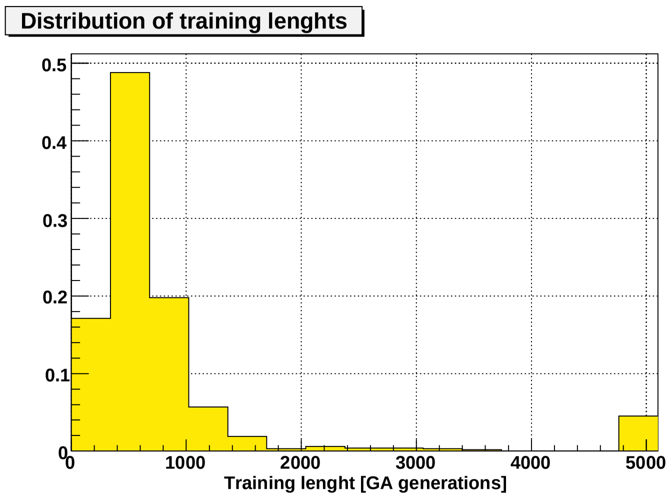
RESULTS

GENERAL STATISTICAL FEATURES

χ^2 AT STOPPING



TRAINING LENGTHS



$\chi^2_{\rm tot}$	1.34
$\langle E \rangle$	2.71
$\langle E_{\rm tr} \rangle$	2.68
$\langle E_{\rm val} \rangle$	2.72
$\langle {\rm TL} \rangle$	824.23
$N_{\rm rep}$	1000

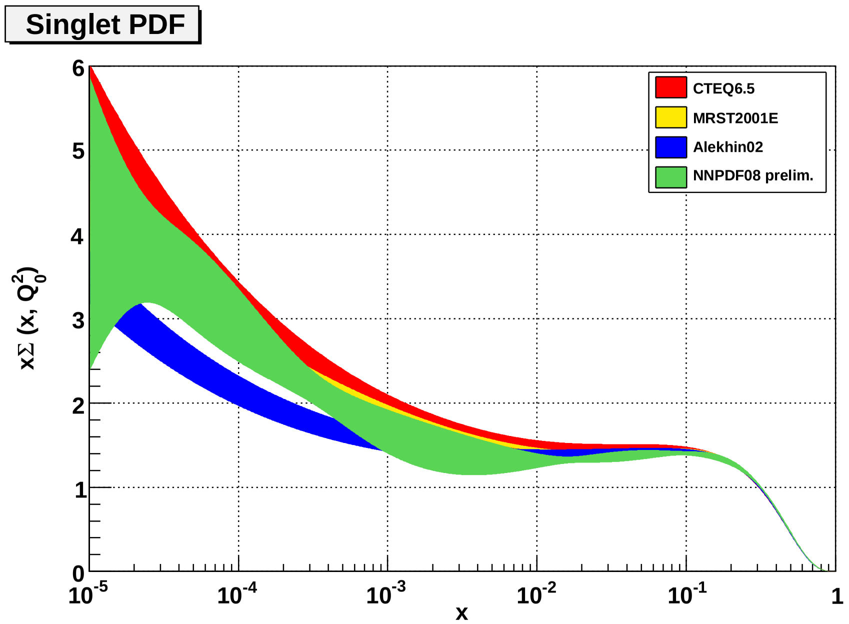
- POISSONIAN DISTRIBUTION OF TRAINING LENGTHS
- BEST FIT $\chi^2 = 1.34$: MINOR DATA INCOMPATIBILITIES (?)

PARAMETRIZATION INDEPENDENCE:
LACK OF BIAS

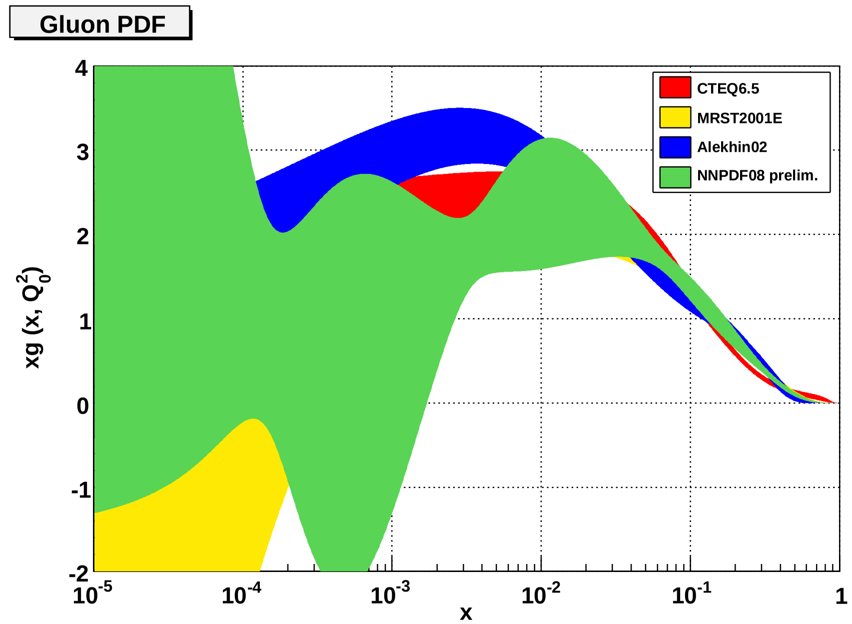
- IRREGULAR OR KNOTTY SHAPES ALLOWED IF DATA FLUCTUATE
- STATISTICS SHOW WHETHER THE EFFECT IS REAL

10 REPLICAS

SINGLET



GLUON

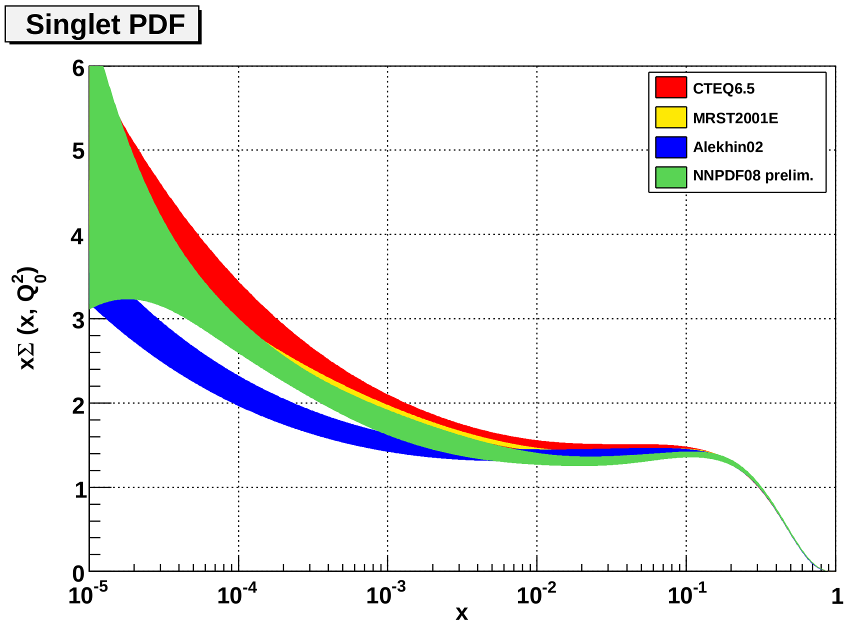


PARAMETRIZATION INDEPENDENCE:
LACK OF BIAS

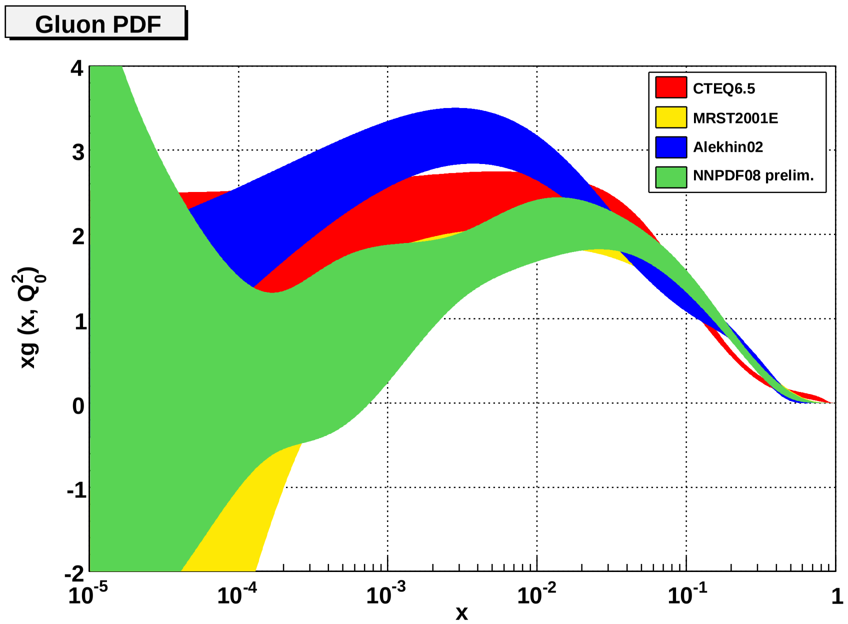
- IRREGULAR OR KNOTTY SHAPES ALLOWED IF DATA FLUCTUATE
- STATISTICS SHOW WHETHER THE EFFECT IS REAL

100 REPLICAS

SINGLET



GLUON

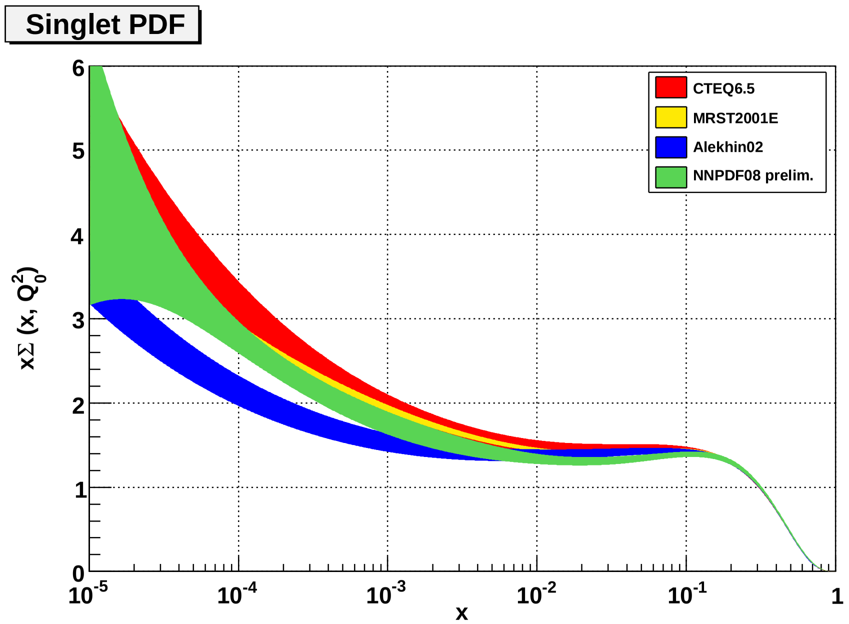


PARAMETRIZATION INDEPENDENCE:
LACK OF BIAS

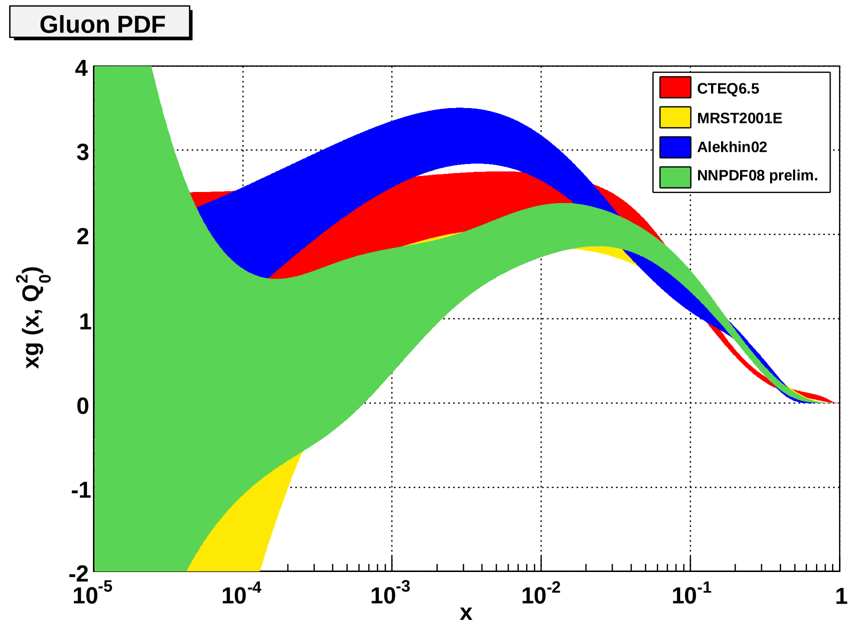
- IRREGULAR OR KNOTTY SHAPES ALLOWED IF DATA FLUCTUATE
- STATISTICS SHOW WHETHER THE EFFECT IS REAL

200 REPLICAS

SINGLET



GLUON

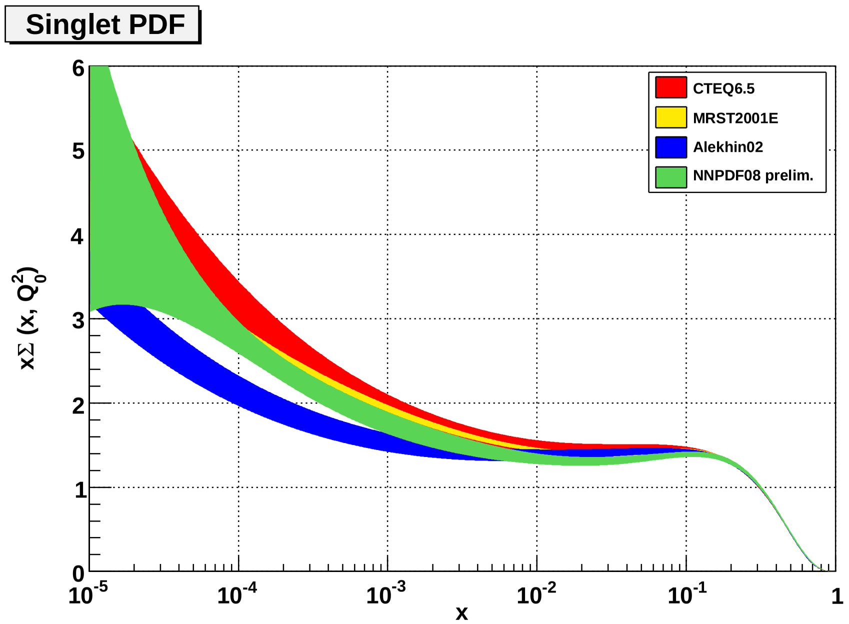


PARAMETRIZATION INDEPENDENCE:
LACK OF BIAS

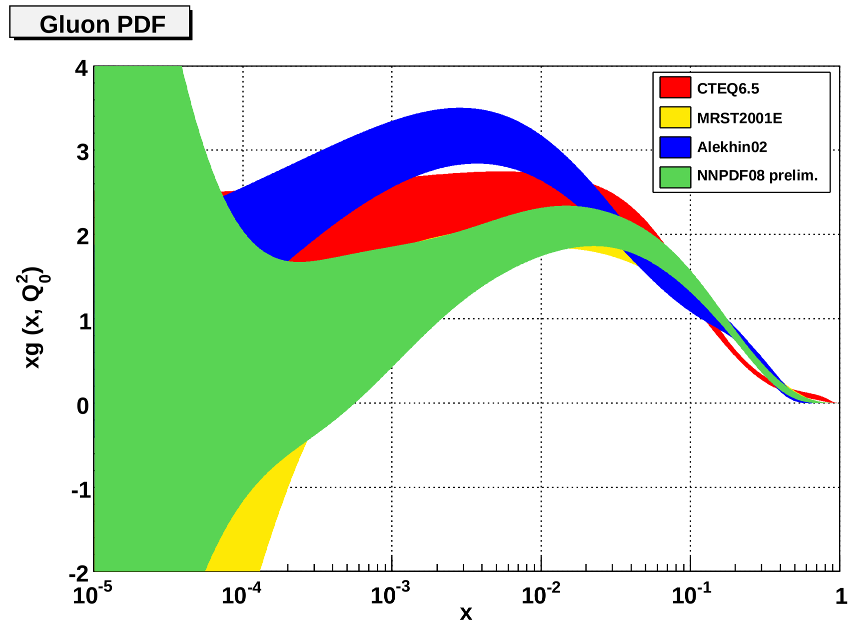
- IRREGULAR OR KNOTTY SHAPES ALLOWED IF DATA FLUCTUATE
- STATISTICS SHOW WHETHER THE EFFECT IS REAL

400 REPLICAS

SINGLET



GLUON

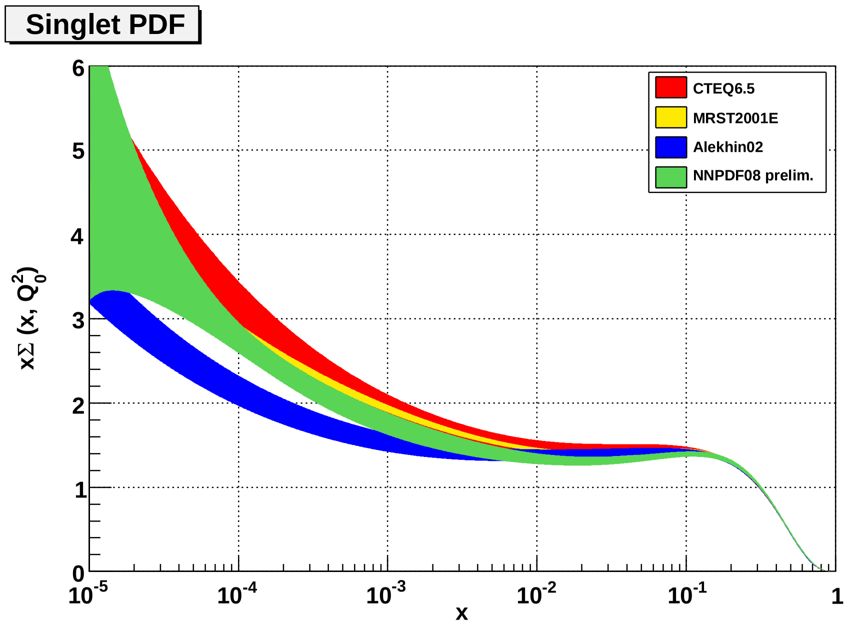


PARAMETRIZATION INDEPENDENCE:
LACK OF BIAS

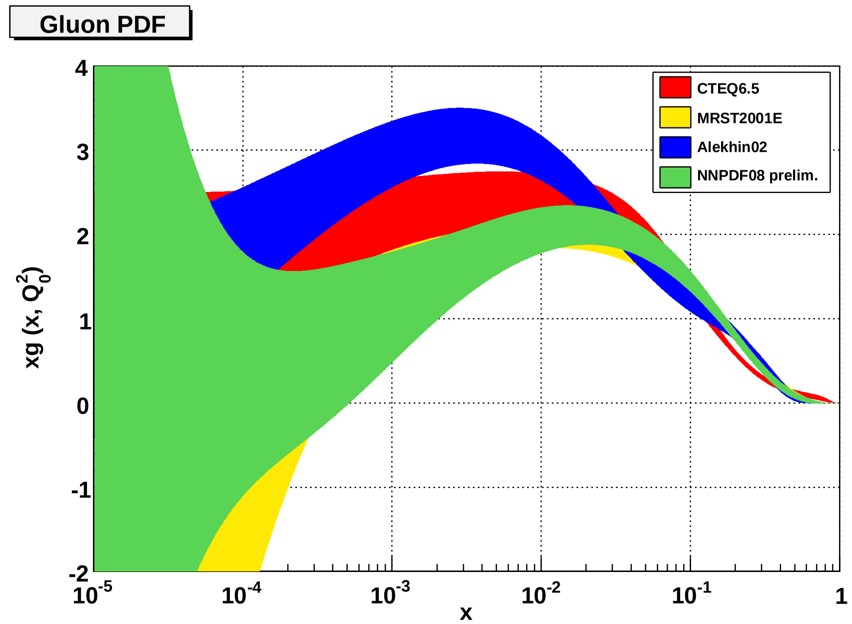
- IRREGULAR OR KNOTTY SHAPES ALLOWED IF DATA FLUCTUATE
- STATISTICS SHOW WHETHER THE EFFECT IS REAL

1000 REPLICAS

SINGLET



GLUON



PARAMETRIZATION INDEPENDENCE:
STATISTICAL STABILITY

COMPARE DISTANCE IN UNITS OF SIGMA OF RESULTS OBTAINED WITH DIFFERENT ASSUMPTIONS

- DISTANCE IN UNITS OF SIGMA

$$\langle d[q]\rangle = \sqrt{\left\langle \frac{\left(\langle q_i\rangle_{(1)} - \langle q_i\rangle_{(2)}\right)^2}{\sigma^2[q_i^{(1)}] + \sigma^2[q_i^{(2)}]} \right\rangle_{\mathrm{dat}}}$$

- NOTE σ $\Rightarrow$ ERROR ON AVERAGE
= (ERROR ON q_i)/$\sqrt{N}$
with 100 replicas, $d = 1$
$\rightarrow$ fits differ by 1/10 of nominal error

- TEST PREDICTIONS
FOR CENTRAL VALUES & ERRORS

DISTANCE BETWEEN STANDARD & FIT WITH SMALLER NEURAL NETS

2-4-3-1 VS 2-5-3-1 ARCHITECTURE
(31 vs. 37 parms per net)

	DATA	EXTRAPOLATION
SINGLET	$0.005 \le x \le 0.1$	$10^{-4} \le x \le 10^{-3}$
$\langle d[q]\rangle$	0.96	1.32
$\langle d[\sigma]\rangle$	1.23	1.32
GLUON	$0.005 \le x \le 0.1$	$10^{-4} \le x \le 10^{-3}$
$\langle d[q]\rangle$	1.40	1.13
$\langle d[\sigma]\rangle$	1.17	1.06
VALENCE	$0.1 \le x \le 0.6$	$0.03 \le x \le 0.3$
$\langle d[q]\rangle$	1.40	0.93
$\langle d[\sigma]\rangle$	1.09	0.96
TRIPLET	$0.05 \le x \le 0.75$	$0.01 \le x \le 0.1$
$\langle d[q]\rangle$	1.05	1.09
$\langle d[\sigma]\rangle$	1.68	2.5

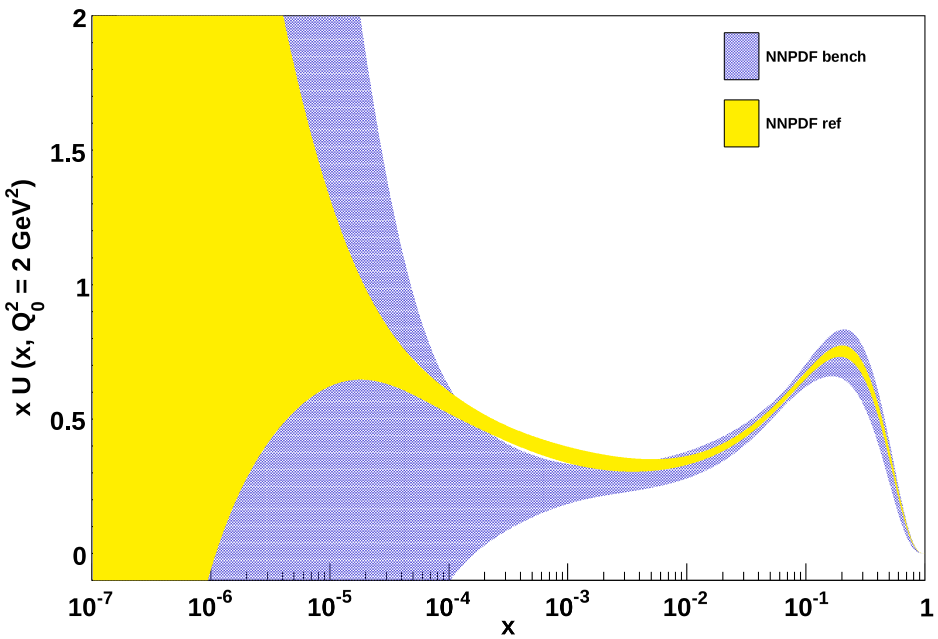
PARAMETRIZATION INDEPENDENCE:
THE "HERALHC BENCHMARK"

$Q^2 > 9$ GeV^2; $W^2 > 15$ GeV^2

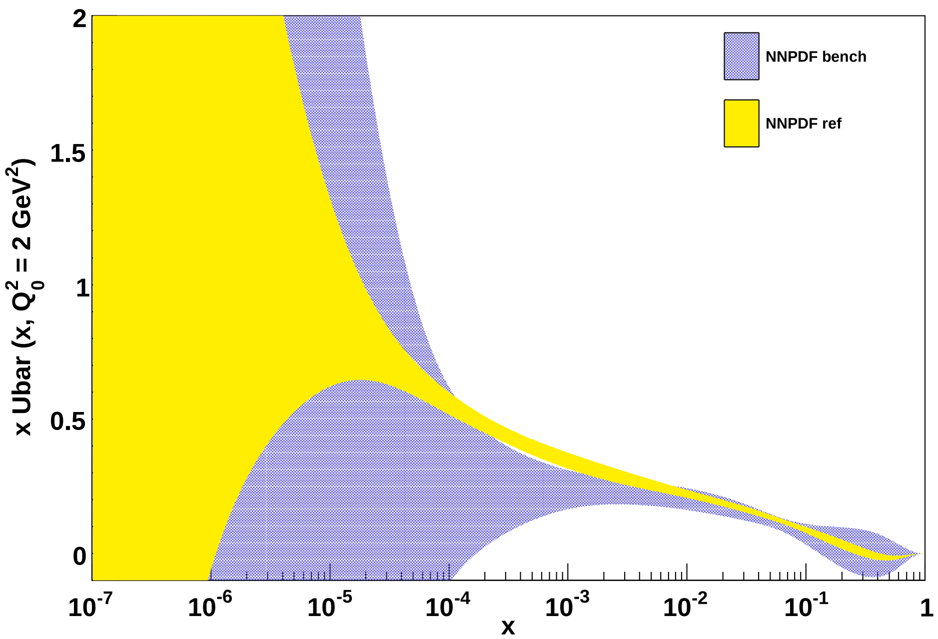
REDUCED DATASET ⇒ WIDER ERROR BAND
from 3161 to 773 datapoints
reduced info on small x sea (no low Q^2 data)
& large x valence (no neutrino data)

Name	Data points	Target
NMC_PD	73	F_2^d/F_2^p
NMC	95	F_2^p
BCDMS	322	F_2^p
ZEUS97	206	F_2^p
H1LX97	77	F_2^p
Total	773	

UP QUARK



UP ANTIQUARK



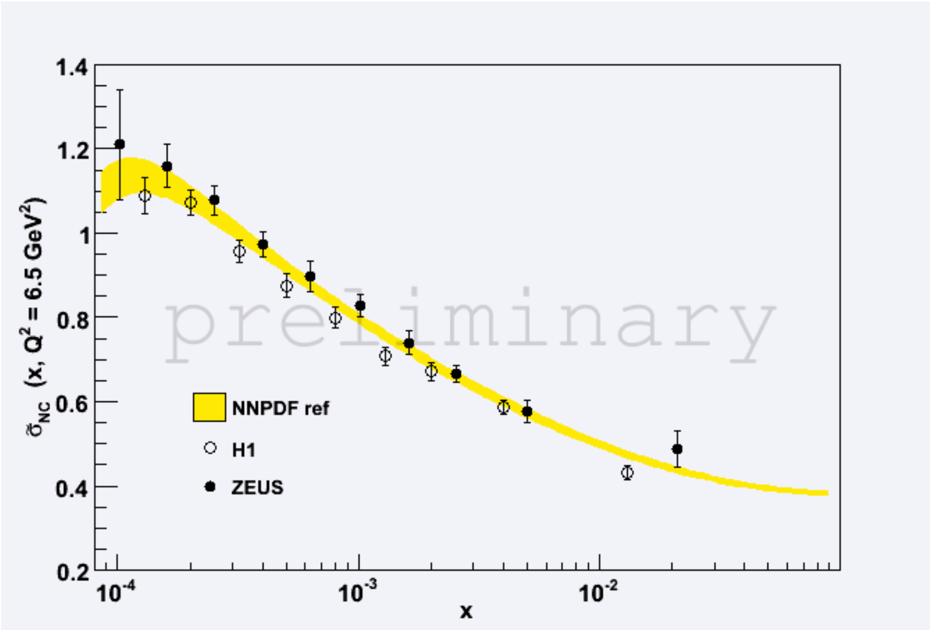
RESULTS COMPATIBLE TO WITHIN LESS THAN TWO SIGMA

PARAMETRIZATION INDEPENDENCE:
THE "HERALHC BENCHMARK":INCOMPATIBLE DATA

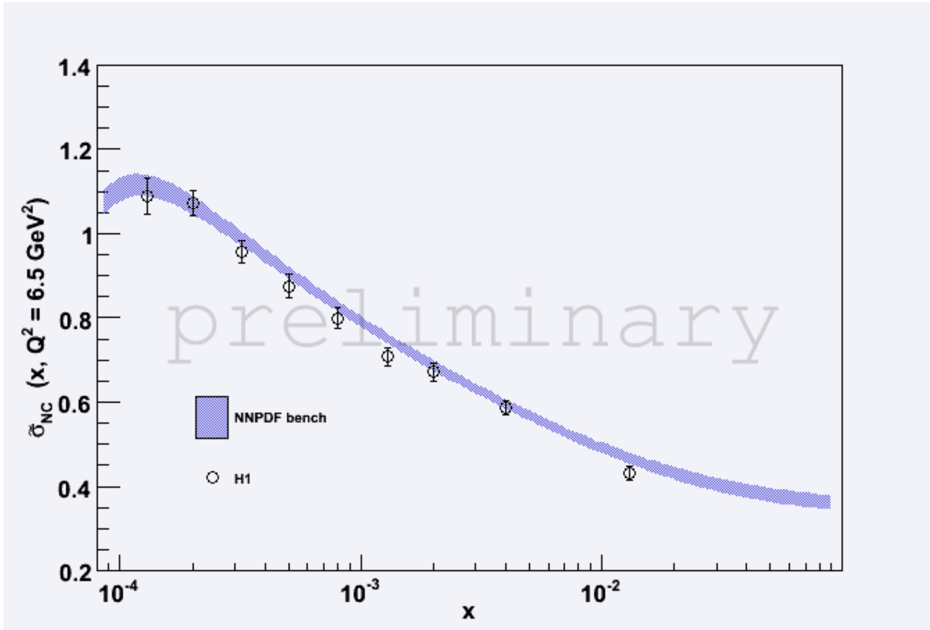
THE SMALL x CC REDUCED CROSS SECTION

results presented at the HERALHC workshop (NNPDF preliminary fit)

FULL DATASET



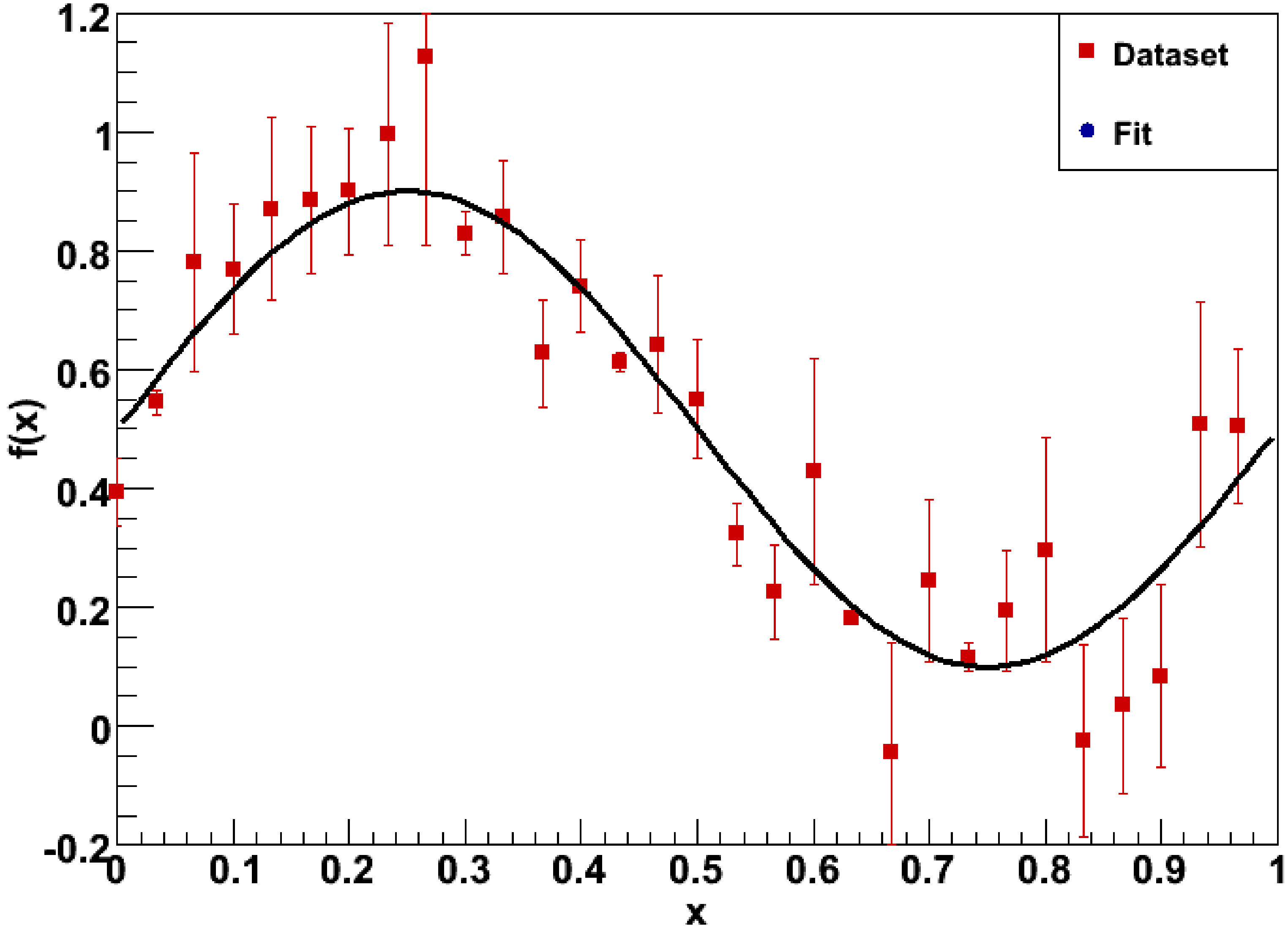
REDUCED "BENCHMARK" DATASET



NO ERROR REDUCTION WHEN DATA IN WIDER DATA SET ARE INCOMPATIBLE

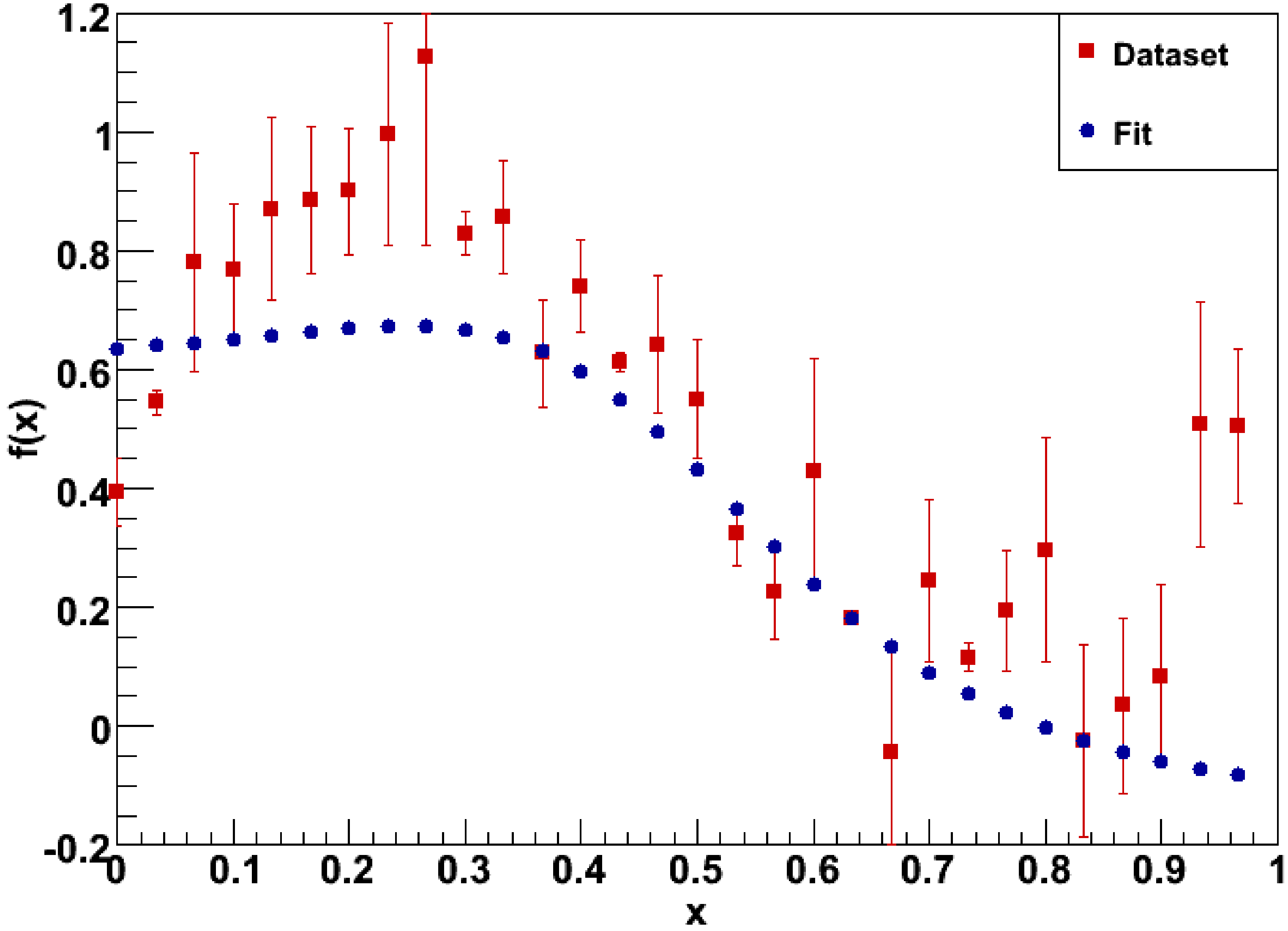
Optimal fitting vs. Overlearning: an example

the true function



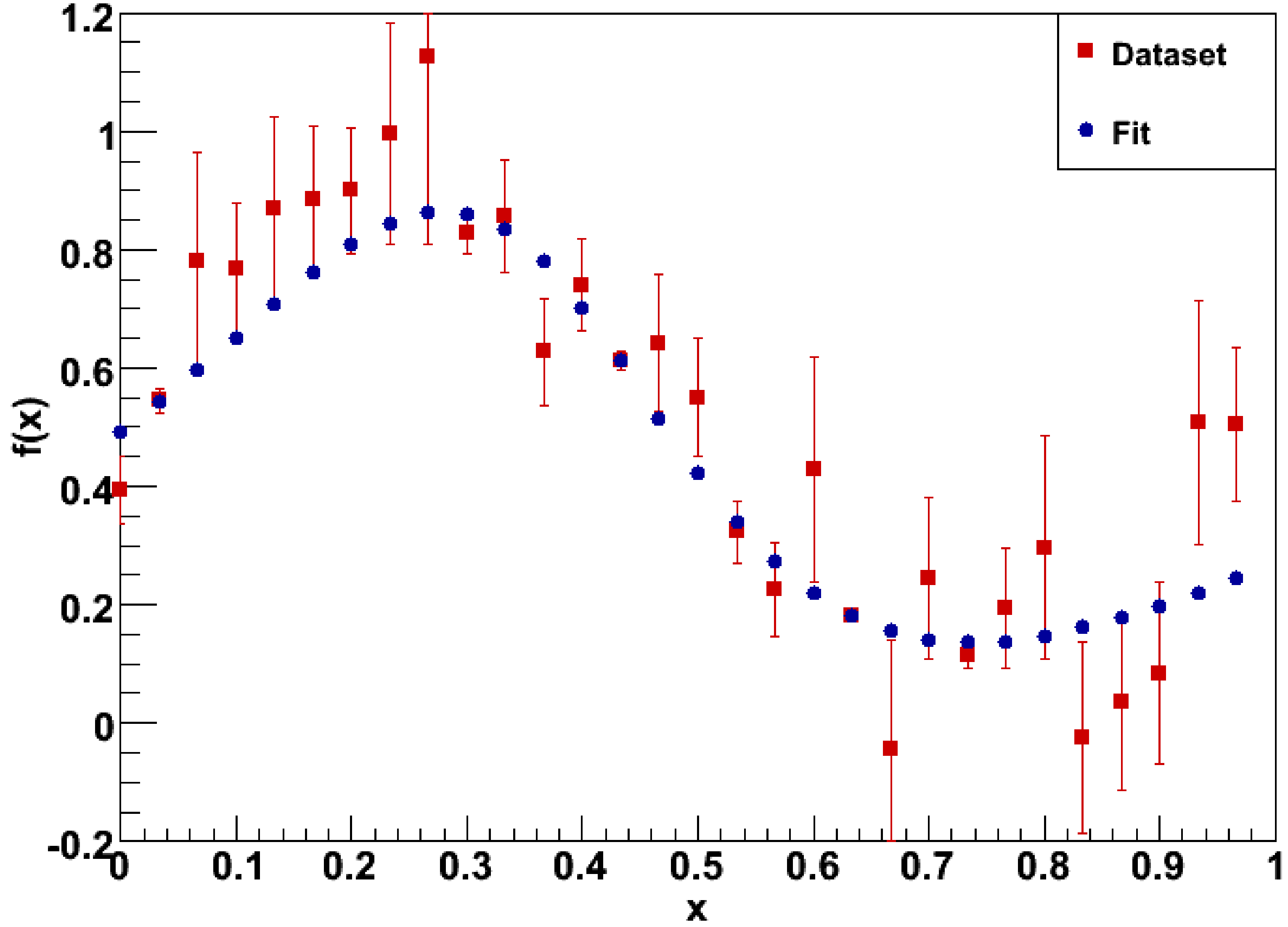
Optimal fitting vs. Overlearning: an example

underlearning



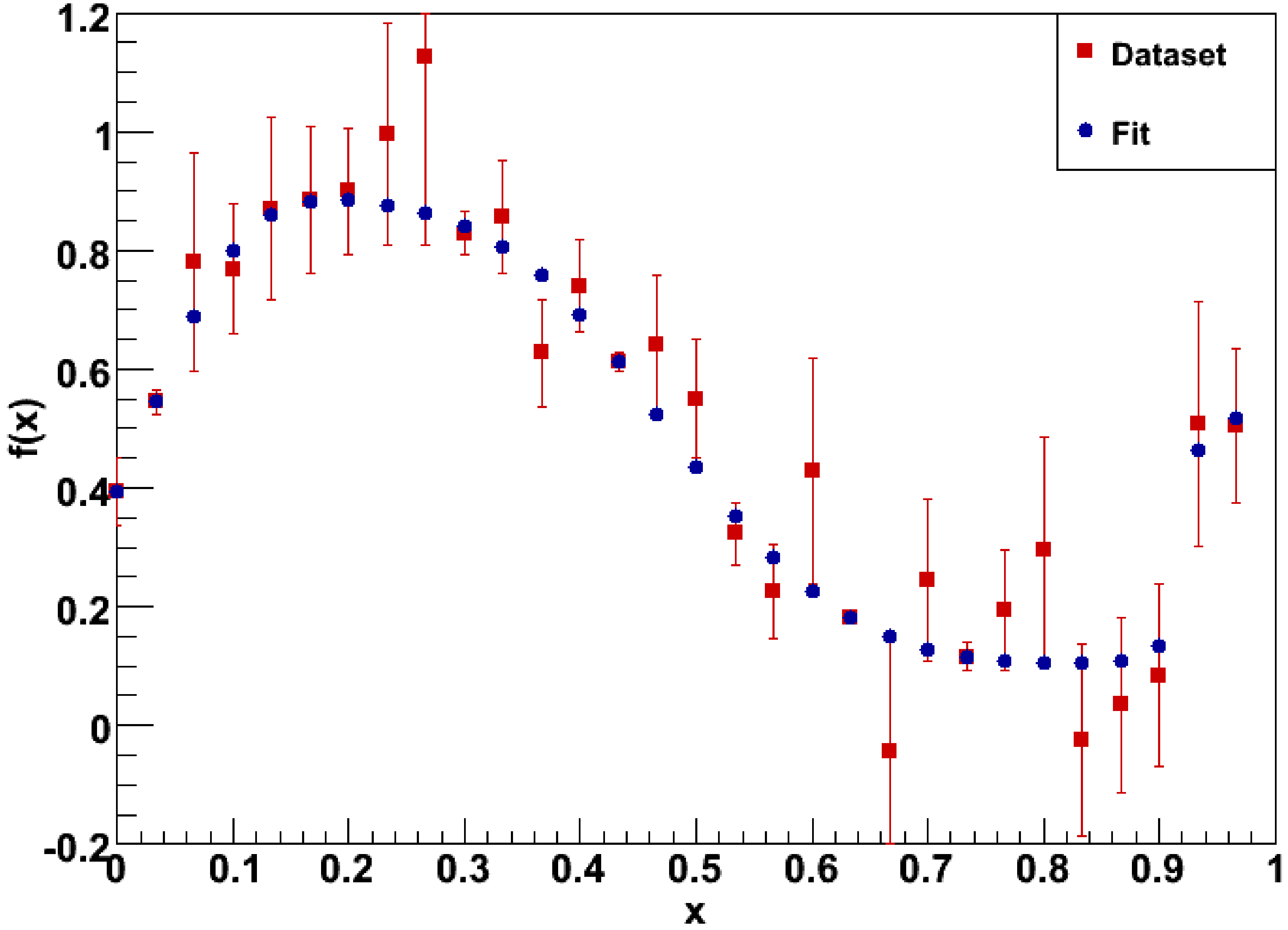
Optimal fitting vs. Overlearning: an example

optimal fit

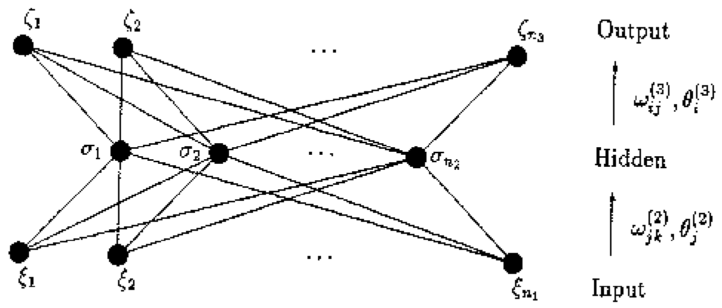


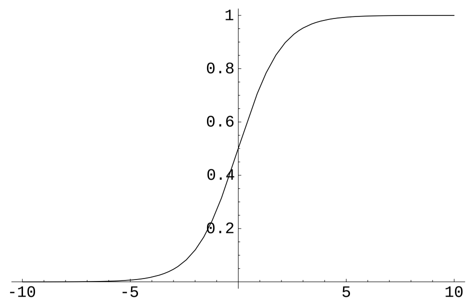
Optimal fitting vs. Overlearning: an example

overlearning



WHAT ARE NEURAL NETWORKS?





MULTILAYER FEED-FORWARD NETWORKS

- Each neuron receives input from neurons in preceding layer and feeds output to neurons in subsequent layer
- Activation determined by weights and thresholds

  $$\xi_i = g\left(\sum_j \omega_{ij}\xi_j - \theta_i\right)$$
- Sigmoid activation function $g(x) = \frac{1}{1+e^{-\beta x}}$

JUST ANOTHER SET OF BASIS FUNCTIONS!

A 1-2-1 NN: $$f(x) = \frac{1}{1+e^{\theta_1^{(3)} - \frac{\omega_{11}^{(2)}}{1+e^{\theta_1^{(2)} - x\omega_{11}^{(1)}}} - \frac{\omega_{12}^{(2)}}{1+e^{\theta_2^{(2)} - x\omega_{21}^{(1)}}}}}$$

ANY FUNCTION CAN BE REPRESENTED BY A SUFFICIENTLY BIG NEURAL NETWORK

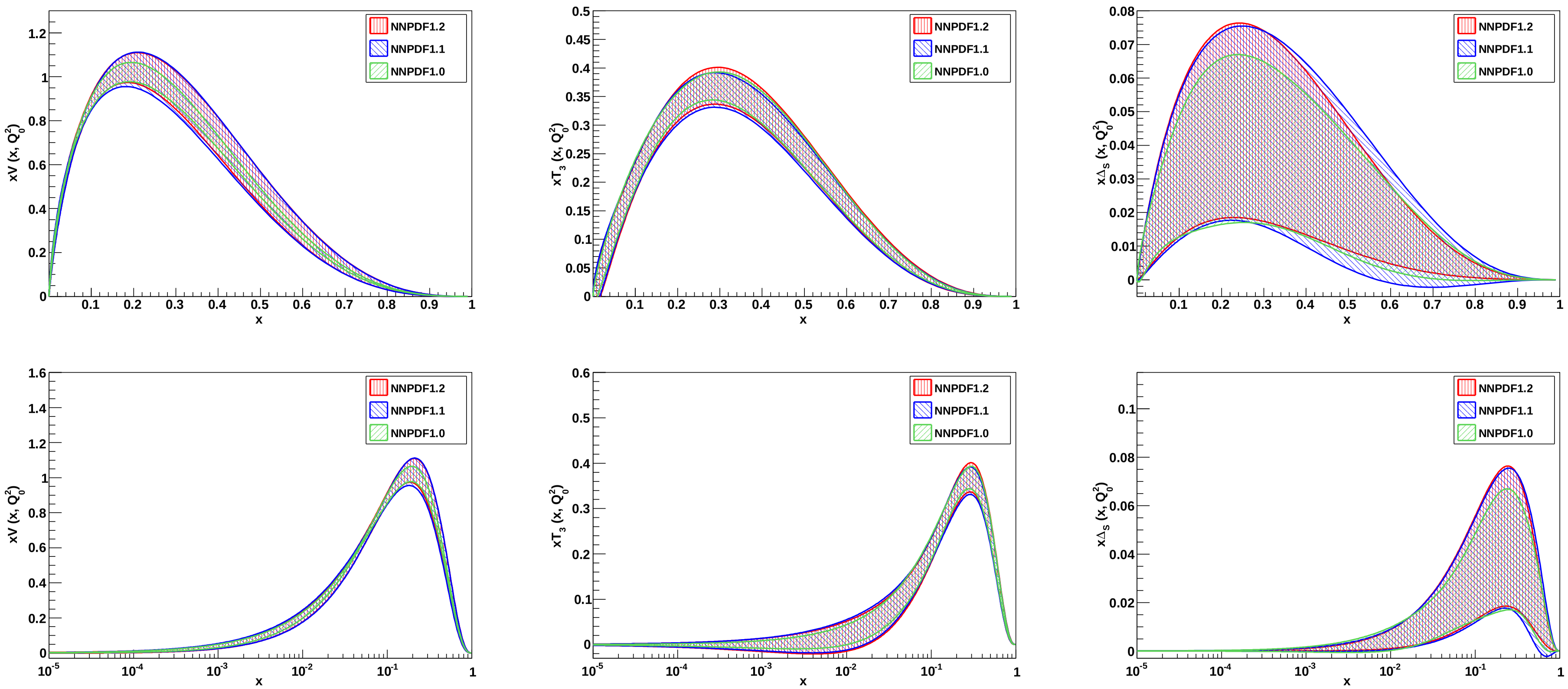
LESS PARAMETERS $\rightarrow$ SMOOTHER FUNCTIONS

STABILITY

COMPARISON TO PREVIOUS NNPDF SETS

- NNPDF1.0: $s(x,Q_0^2)=\bar{s}(x,Q_0^2)$, $s+\bar{s}=\frac{1}{2}(\bar{u}+\bar{d})$
- NNPDF1.1: s, $\bar{s}$ (ACTUALLY $s^{\pm}$) INDEP. PARAMETRIZED, NO DIMUON DATA
- NNPDF1.2: s, $\bar{s}$ INDEP. PARAMETRIZED, DIMUON DATA

NONSTRANGE PDFS



DETERMINING STRANGENESS

COMPARISON TO OTHER NNPDF SETS

- CTEQ6.6: $s = \bar{s}$, s^+ PARM W. TWO FREE PARAMETERS
- MSTW08: s^+ & s^- PARM W. TWO FREE PARAMETERS EACH
- EVERYBODY ENFORCES STRANGENESS SUM RULE

STRANGE PDFS