PARTON DISTRIBUTIONS
AT THE DAWN OF THE LHC

STEFANO FORTE
UNIVERSITÀ DI MILANO & INFN

UNIVERSITÀ DEGLI STUDI DI MILANO
DIPARTIMENTO DI FISICA

CTEQ-MCNET SUMMER SCHOOL

LAUTERBAD, JULY 30, 2010

SUMMARY

LECTURE II: ISSUES AND RECENT DEVELOPMENTS

- PDF UNCERTAINTIES
  - MONTE CARLO VS HESSIAN: GAUSSIAN UNCERTAINTIES
  - TOLERANCE
  - PARTON PARAMETRIZATION
- THEORETICAL ISSUES
  - HEAVY QUARKS
  - HIGHER ORDERS
- THE STATE OF THE ART
  - LHC STANDARD CANDLES
  - THEORETICAL UNCERTAINTIES?

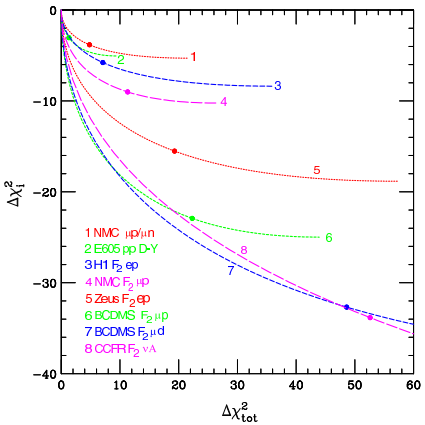
PDF UNCERTAINTIES

WHAT IS A ONE-σ UNCERTAINTY?

MSTW/CTEQ: THE SPREAD OF PDFS WITHIN AN ACCEPTABLE TOLERANCE

- 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?

MSTW/CTEQ: THE SPREAD OF PDFS WITHIN AN ACCEPTABLE TOLERANCE

CTEQ TOLERANCE CRITERION &

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

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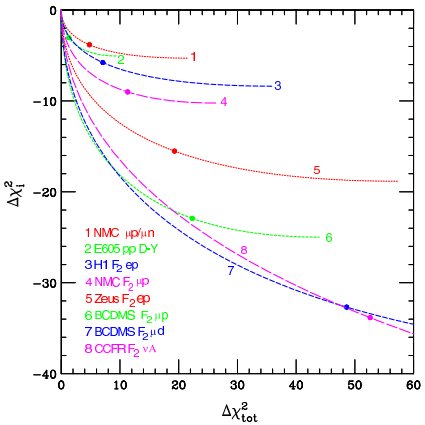

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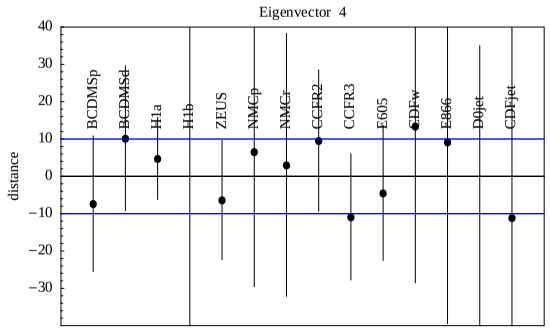
CTEQ TOLERANCE PLOT FOR 4TH EIGENVEC.



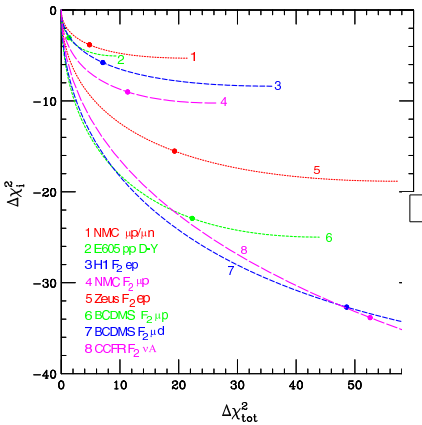
WHAT IS A ONE-σ UNCERTAINTY?

MSTW/CTEQ: THE SPREAD OF PDFS WITHIN AN ACCEPTABLE TOLERANCE

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



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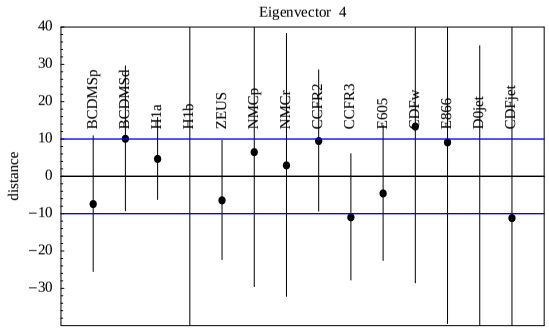
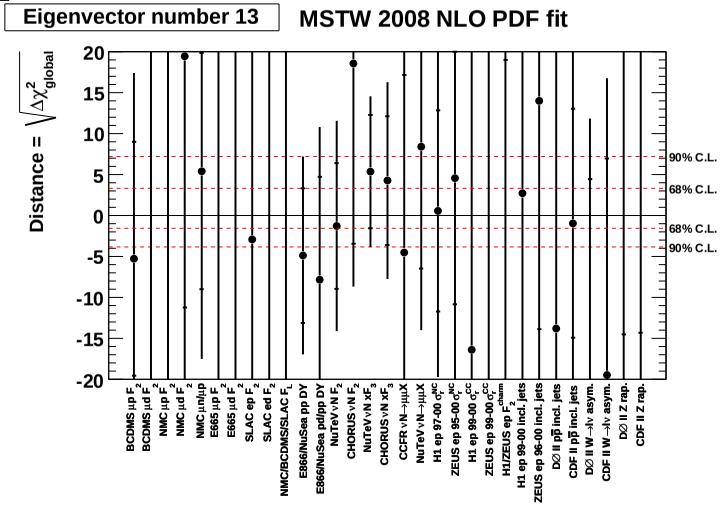
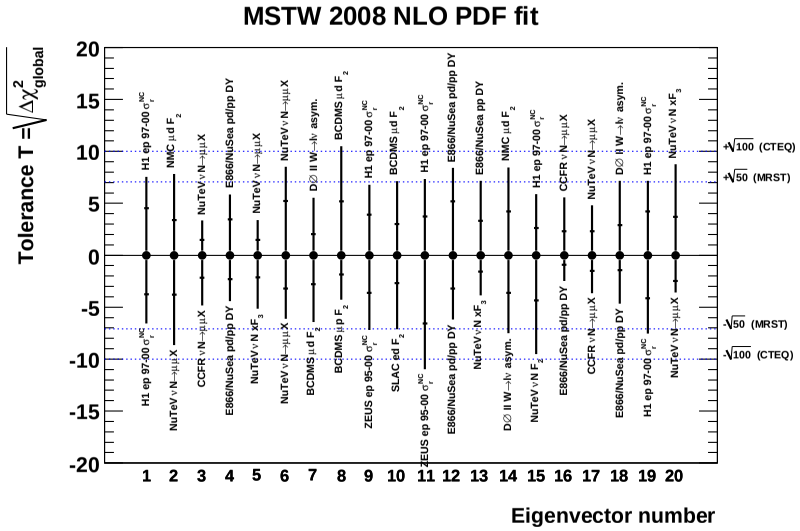


MSTW TOLERANCE PLOT FOR 13TH EIGENVEC.



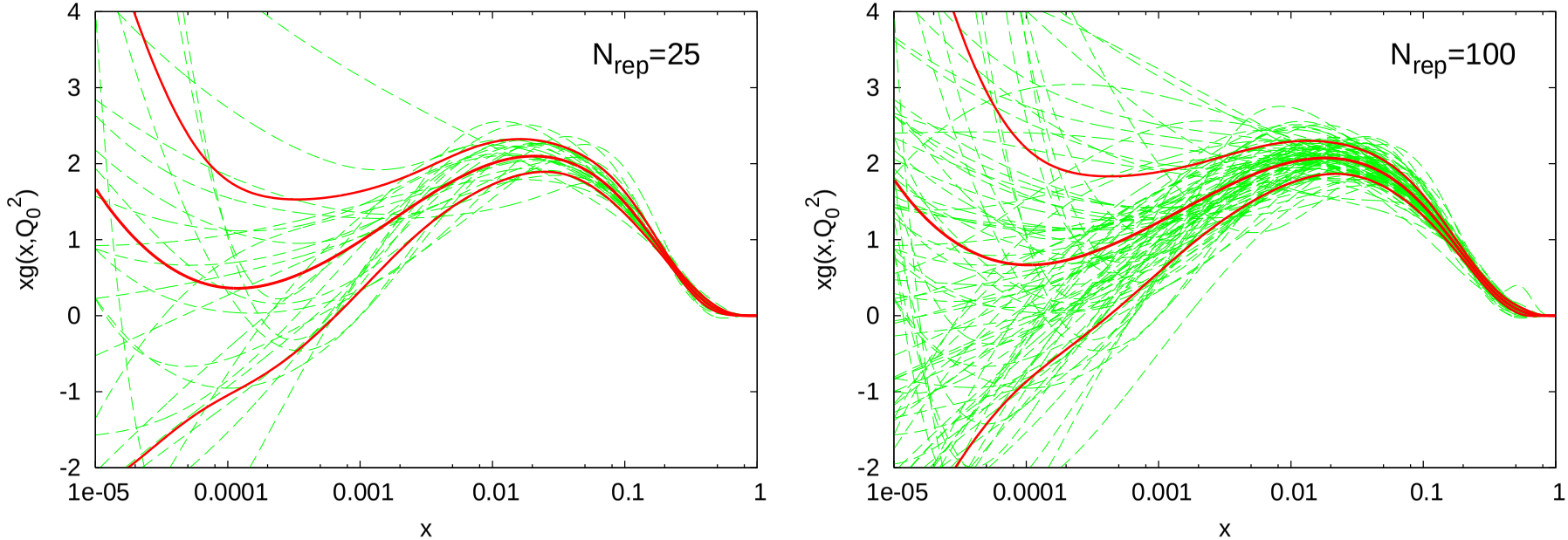
GLOBAL MSTW TOLERANCE



WHAT IS A ONE-σ UNCERTAINTY?

NNPDF: THE CENTRAL 68% OF THE MC DISTRIBUTION OF PDFS

Example: the gluon distribution in the NNPDF1.0 set



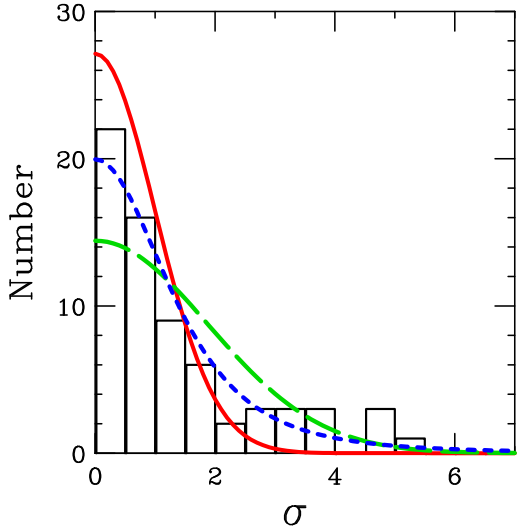
- ENSEMBLE OF REPLICAS $\leftrightarrow$ PROBABILITY DISTRIBUTION OF PDFS
- EXPECTED CENTRAL VALUE $\leftrightarrow$ MEAN; UNCERTAINTY $\leftrightarrow$ STANDARD DEVIATION
- ANY FEATURES OF DISTRIBUTION CAN BE DETERMINED
  (C.L. INTERVALS, CORRELATIONS...)

WHERE IS THE UNCERTAINTY COMING FROM?

WHY DOES ONE NEED LARGE TOLERANCES?

DATA INCOMPATIBILITY(Pumplin, 2009)

- CAN "REDIAGONALIZE": DIAGONALIZE SIMULTANEOUSLY χ^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 $2 \Rightarrow$ $\Delta\chi^2 \sim 10$ FOR 90%C.L.



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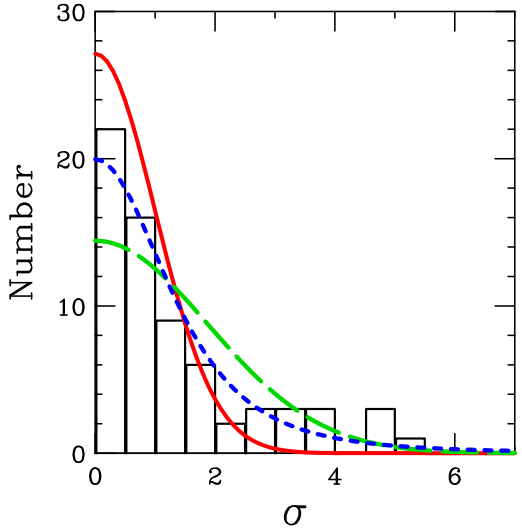
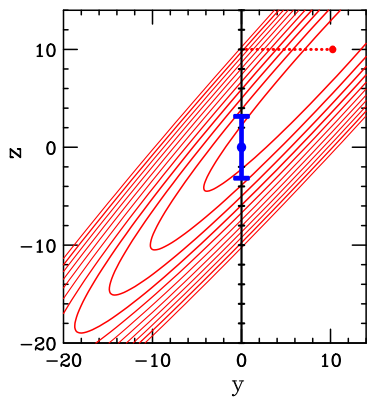
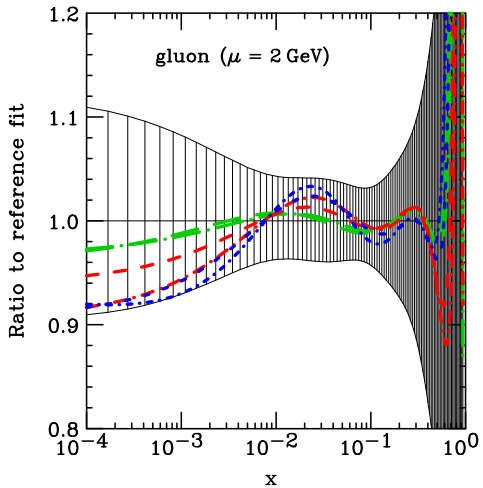


FUNCTIONAL BIAS (Pumplin, 2009)



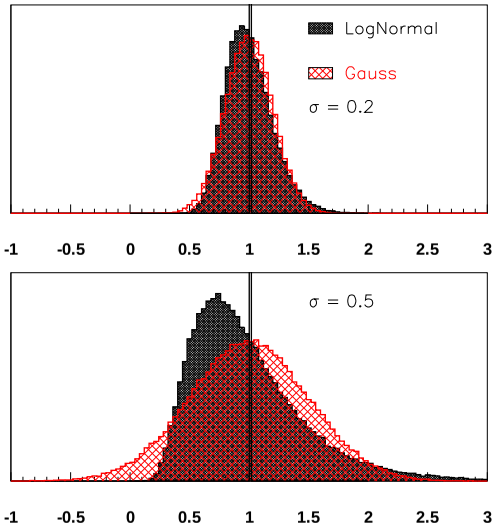
- IF PARM. NOT GENERAL ENOUGH, GLOBAL MIN. IS NOT TRUE MIN.
- ONE-σ VARIATION ABOUT FAKE MIN CORRESP. TO LARGE χ^2 VARIATION
- USE OF CHEBYSHEV POLYNOMIALS SUGGESTS "MOST GENERAL" PARM. WITHIN $\Delta\chi^2 = 10$ OF CTEQ6.6 PARM.



PARAMETRIZATION UNCERTAINTIES?

NONGAUSSIAN BEHAVIOUR?

LOGNORMAL VS. GAUSSIAN

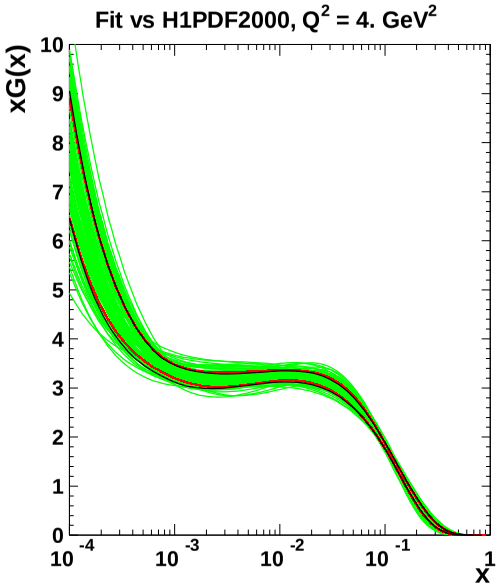


THE HERALHC BENCHMARK

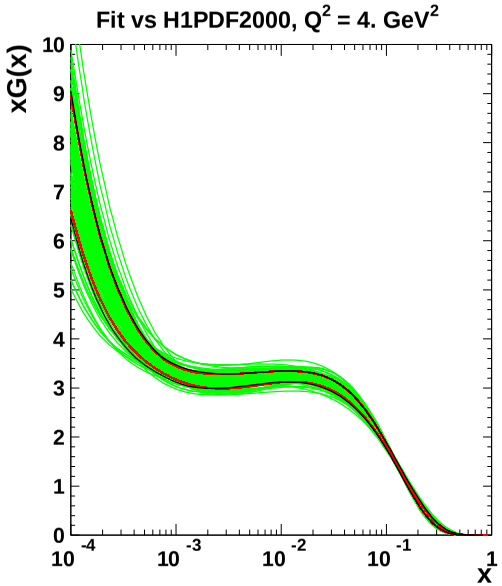
(Feltesse, Glazov, Radescu + NNPDF 2008)

- TRY EXPERIMENTAL SYSTEMATICS GIVEN BY EITHER GAUSSIAN OR LOGNORMAL DISTRIBUTION
- REPEAT (BENCHMARK) HERAPDF, WITH MONTECARLO LOGNORMAL OR GAUSSIAN, IN EITHER CASE DETERMINE UNCERTAINTY EITHER WITH HESSIAN OR MONTECARLO

LOGNORMAL: HESS. VS MC



GAUSSIAN: HESS. VS MC

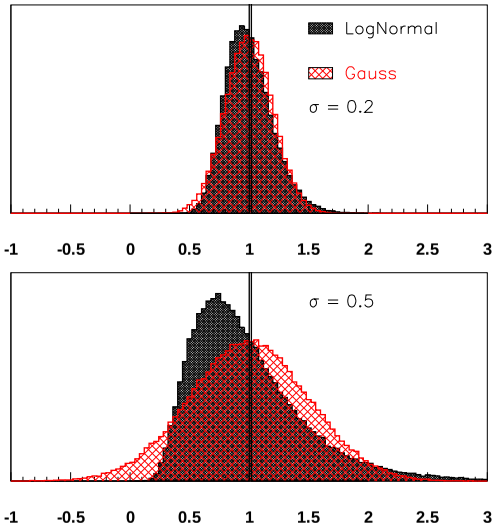


- NO DIFFERENCE BETWEEN LOGNORMAL, GAUSSIAN, MC, HESSIAN

PARAMETRIZATION UNCERTAINTIES?

NONGAUSSIAN BEHAVIOUR?

LOGNORMAL VS. GAUSSIAN



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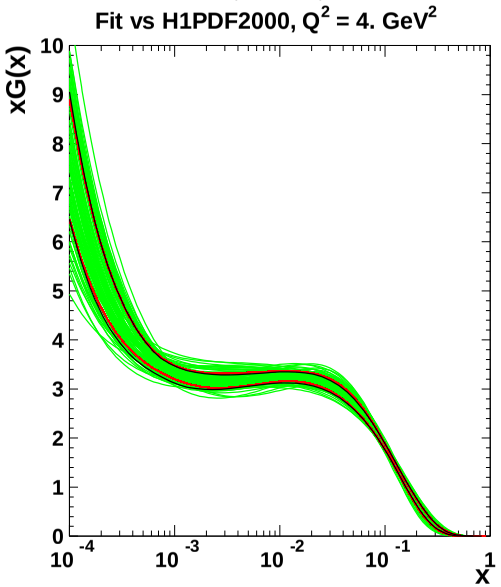
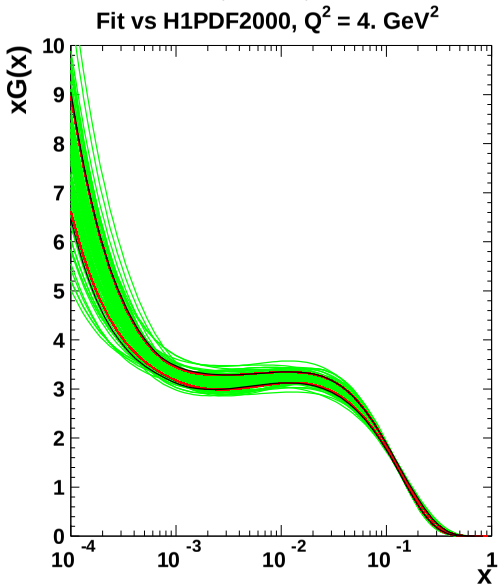
- COMPARE TO NNPDF FIT TO SAME DATA

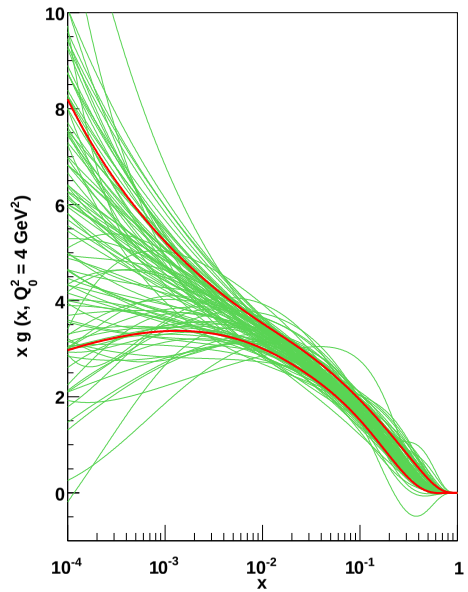
LOGNORMAL: HESS. VS MC



GAUSSIAN: HESS. VS MC



NNPDF

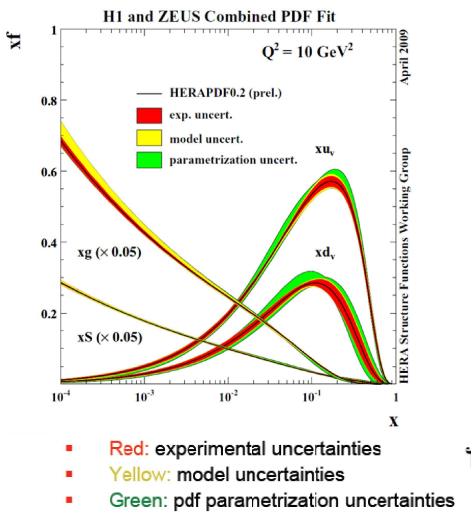


- NO DIFFERENCE BETWEEN LOGNORMAL, GAUSSIAN, MC, HESSIAN
- SIZABLE DIFFERENCE WR TO FLEXIBLE NNPDF PARAMETRIZATION

PARAMETRIZATION UNCERTAINTIES?

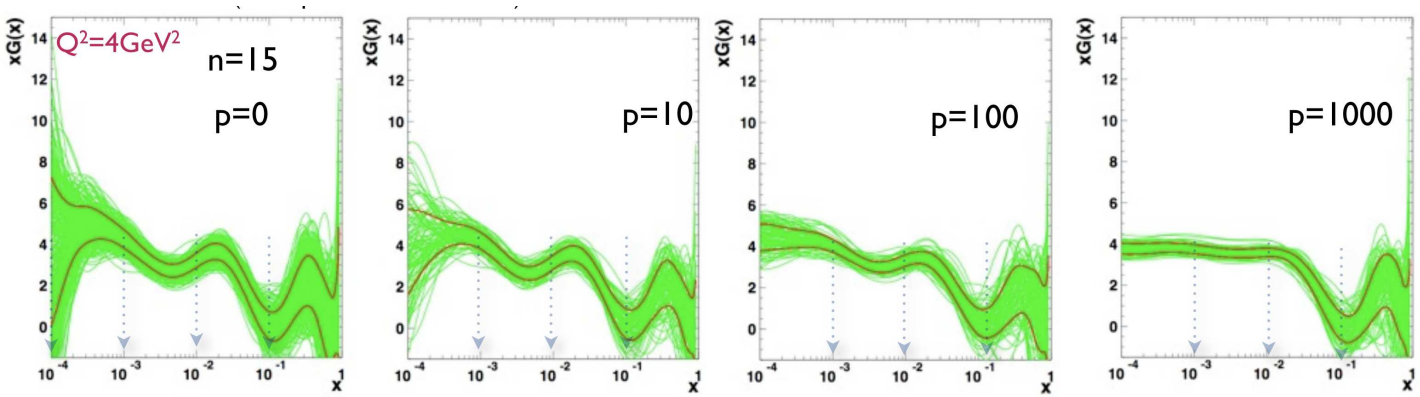
EXPLORING THE SPACE OF PARAMETERS: HESSIAN APPROACH

- IN HESSIAN APPROACH CAN VARY THE FUNCTIONAL FORM, ASSUMPTIONS, STARTING SCALE
- DONE IN THE HERAPDF1.0 FIT: VARIATION OF STRANGENESS FRACTION, LARGE x BEHAVIOUR, HIGHER ORDER POLYNOMIAL TERMS
- NO TOLERANCE ($\Delta\chi^2 = 1$), UNCERTAINTY DOUBLED



ORTHOGONAL POLYNOMIALS

- OLD IDEA (PARISI, SOURLAS, 1978; ZOMER 1996): EXPAND PDFS OVER BASIS OF ORTHOGONAL POLYNOMIALS
- GLAZOV, RADESCU, 2009: COUPLED TO MONTE CARLO METHOD
- LENGTH PENALTY TO STABILIZE THE FIT



(Glazov, Radescu, 2009)

PARAMETRIZATION UNCERTAINTIES?

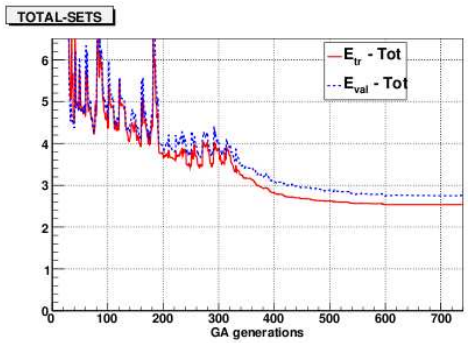
EXPLORING THE SPACE OF PARAMETERS: NNPDF APPROACH

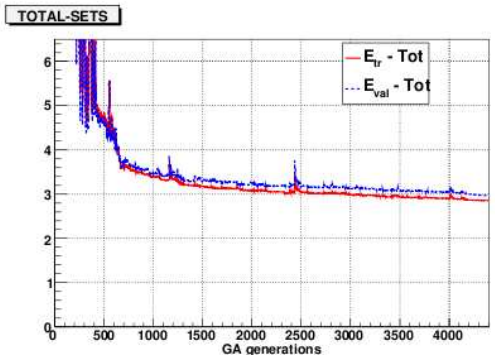
CENTRAL VALUES: VARYING PARTITION VS FIXED PARTITION

	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

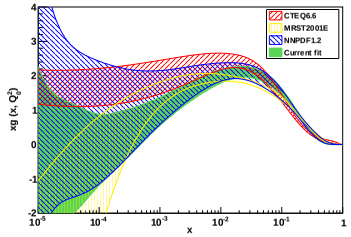
fixed partition results obtained averaging over 5 different choices of partition (100 replicas each); more partitions needed for accurate results

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

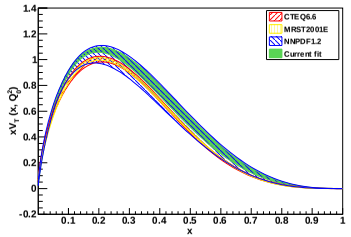




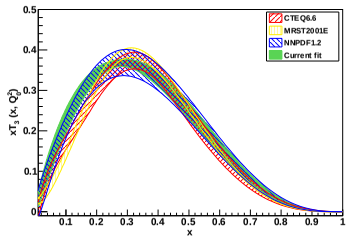
GLUE



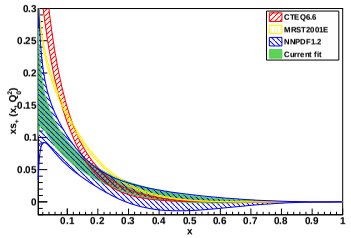
VALENCE



TRIPLET



STRANGE



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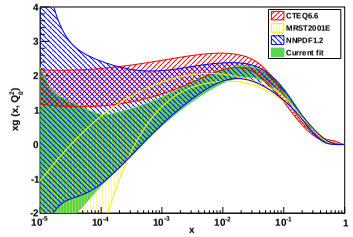

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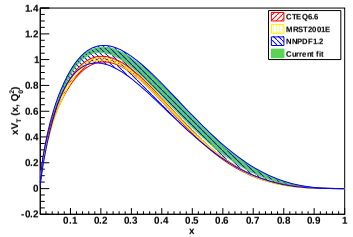

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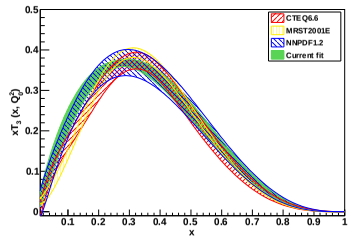

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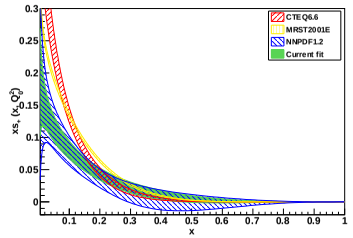

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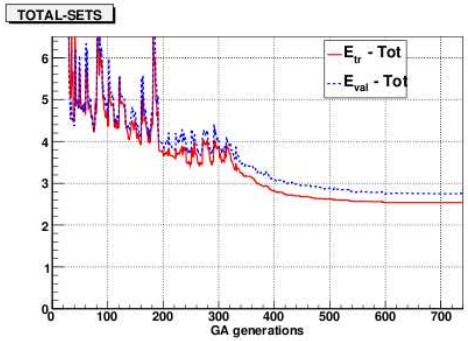
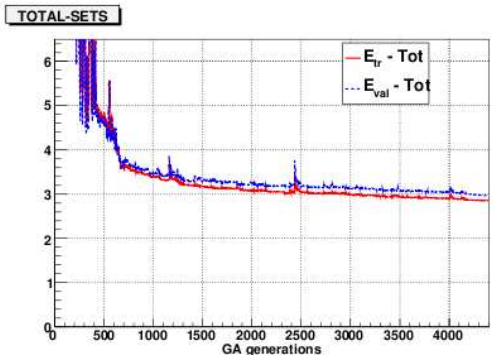




FUNCTIONAL UNCERTAINTY

- MORE THAN HALF OF UNCERTAINTY DUE TO "FUNCTIONAL FORM": $\langle\sigma^{\rm dat}\rangle =\sim 0.03$ 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.

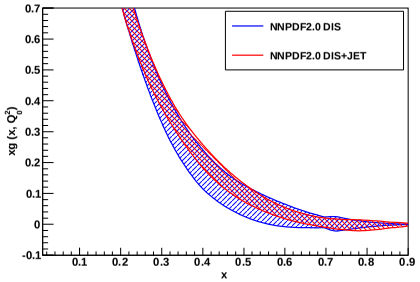
DATA INCOMPATIBILITY?

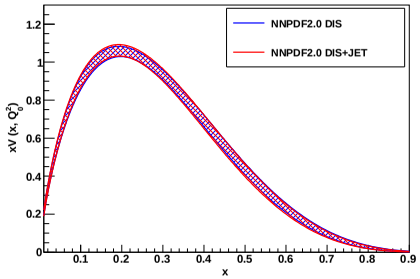
DIS VS. HADRONIC DATA

A SENSITIVE TEST: IS THE IMPACT OF A DATASET INDEP. OF THE DATA IT IS ADDED TO?

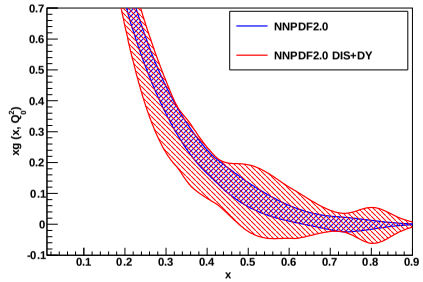
ADDING JET DATA...

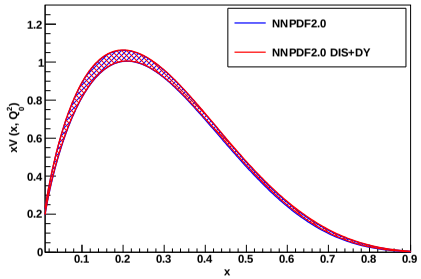
...TO DIS DATA





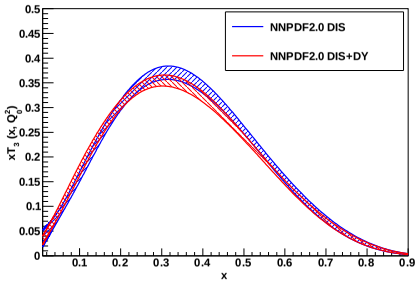
...TO DIS+DY DATA

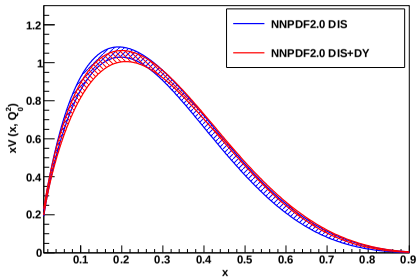


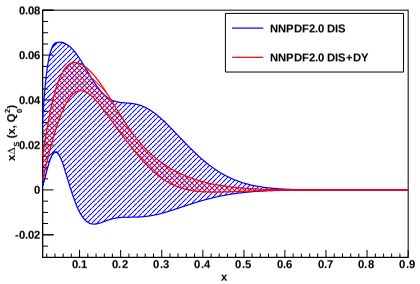


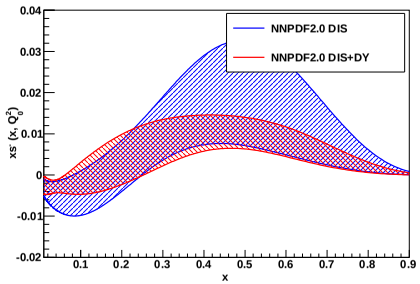
ADDING DRELL-YAN DATA...

...TO DIS DATA

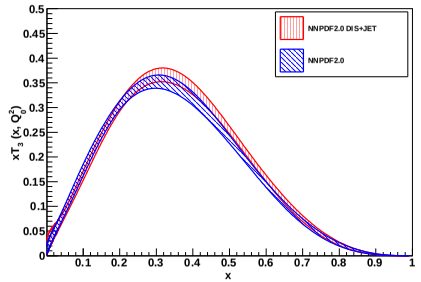


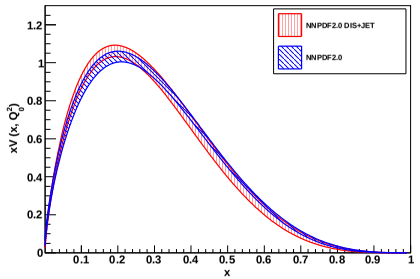


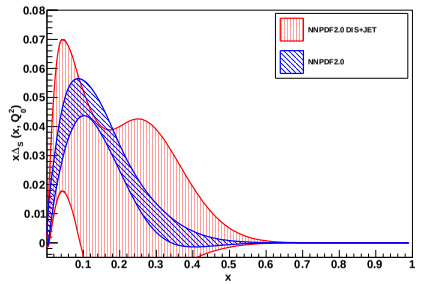


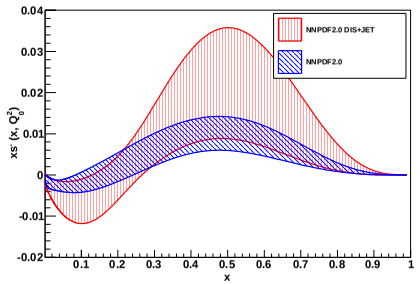


...TO DIS+JET DATA









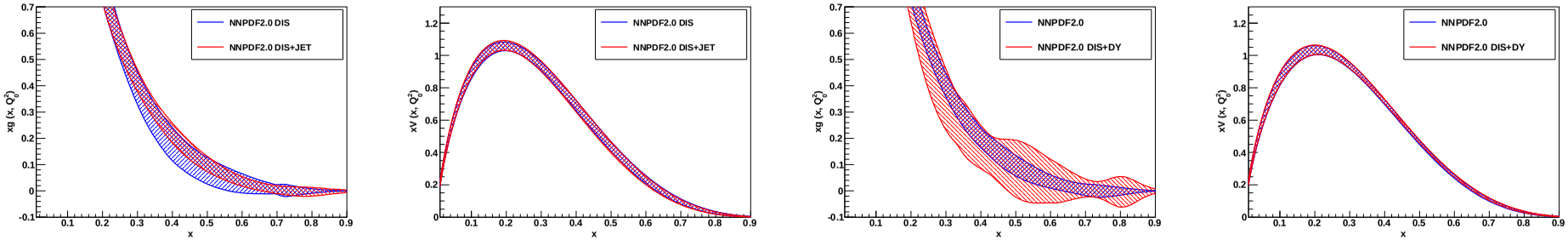
DATA INCOMPATIBILITY?

DIS VS. HADRONIC DATA

A SENSITIVE TEST: IS THE IMPACT OF A DATASET INDEP. OF THE DATA IT IS ADDED TO?

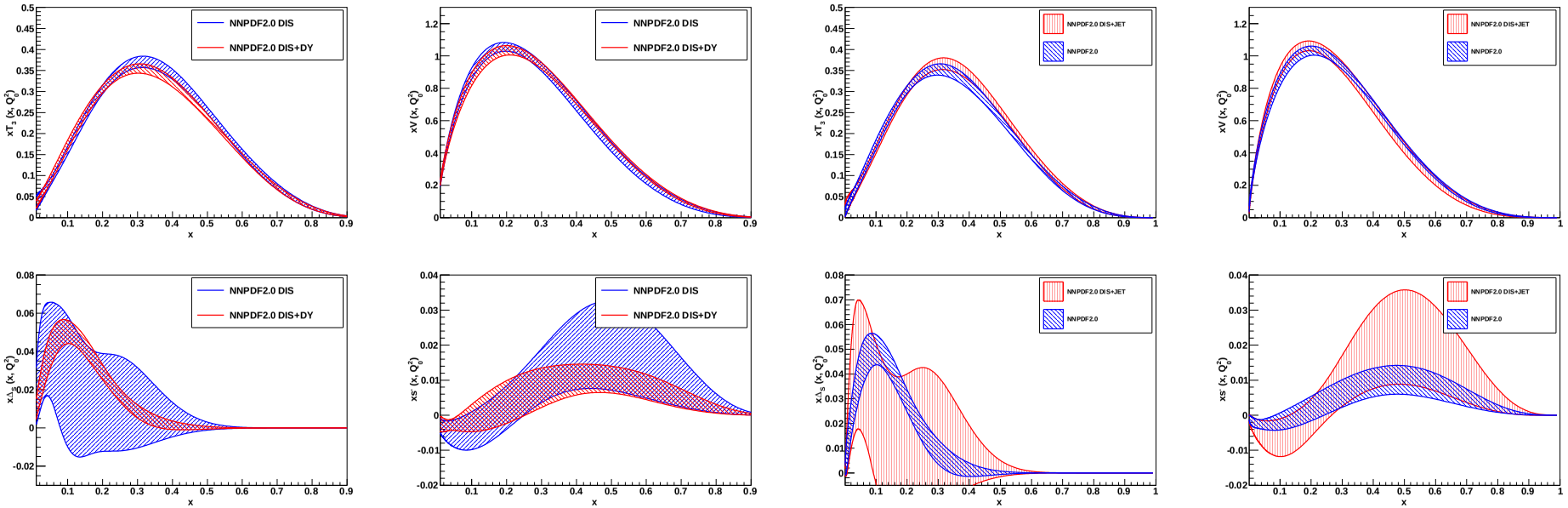
ADDING JET DATA...

...TO DIS DATA ...TO DIS+DY DATA



ADDING DRELL-YAN DATA...

...TO DIS DATA ...TO DIS+JET DATA

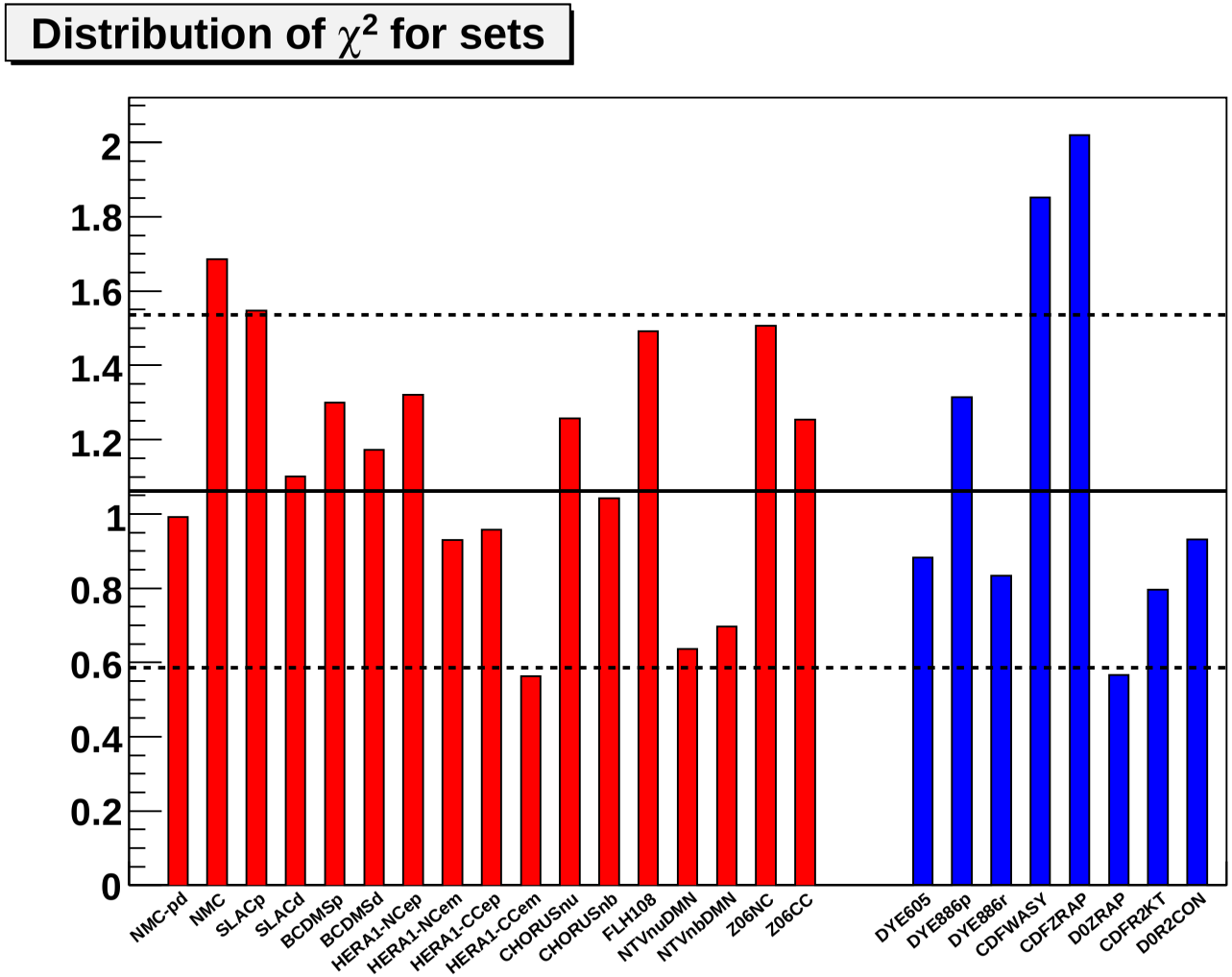


FITS COMMUTE $\Rightarrow$ GOOD COMPATIBILITY!

DATA INCOMPATIBILITY?

FIT QUALITY: DIS DATA AND HADRONIC DATA

NNPDF2.0



- NO OBVIOUS MUTUAL TENSION BETWEEN DIS AND HADRONIC DATA
- CLEAR SIGN OF INTERNAL DATA INCONSISTENCIES
  (NMC DIS DATA, CDF Z AND W RAPIDITY DISTRIBUTIONS)

THEORETICAL ISSUES

HEAVY QUARKS IN DIS

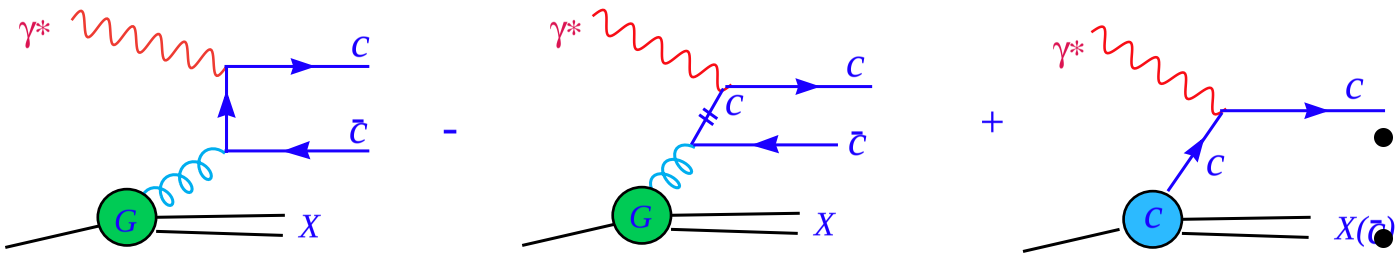
- IN $\overline{\text{MS}}$ SCHEME, $n_f = 6$ IN LOOPS, α_s RUNNING AND DGLAP EQNS AT ALL SCALES
  $\Rightarrow$ FOR $Q^2 >> m_q^2$, NEGLECT THE MASS
- WHEN $Q^2 << m_q^2$ A DECOUPLING SCHEME MORE CONVENIENT: LOOPS SUBTRACTED AT ZERO MOMENTUM, $n_f = n_l$ IN α_s RUNNING AND DGLAP EQNS
  $\Rightarrow$ FOR $Q^2 >> m_q^2$, NEGLECT THE HEAVY QUARK
- WHAT HAPPENS WHEN $Q^2 \approx m_q^2$?

MATCHED SCHEMES: ACOT (Aivazis, Collins, Olness, Tung, 1988, 1994)

$m_c \neq 0$, LO
charm radiation

$m_c = 0$, LO
charm radiation

$m_c = 0$
charm pdf



- USE $\overline{\text{MS}}$ FOR $Q^2 > m_q^2$ WITH FULL MASS DEP. RETAINED
- KEEP ALL FLAVOURS IN RUNNING, DGLAP
- SUBTRACT DOUBLE COUNTING

SIMPLIFIED SACOT:

EVEN IN MASSIVE CONTRIBUTION, NEGLECT m_q IN FINAL STATE

MATCHED SCHEMES: TR (Thorne, Roberts, 1998, 2008)

- SWITCH OFF HQ FOR $Q^2 < m_q^2$
- USE MASSLESS APPROX FOR $Q^2 > m_q^2$
- ADD MASSIVE TERMS AND ENFORCE CONTINUITY AT THRESHOLD VIA SUBL. TERMS

MATCHED SCHEMES: FONLL

(Cacciari, Greco, Nason, 1998; for DIS s.f., Laenen, Rojo, Nason, 2010)

- USE $\overline{\mathrm{MS}}$ (MASSLESS) PARTONS
- COMPUTE MASSIVE CONTRIBUTIONS IN THE DECOUPLING SCHEME, BUT EXPRESS EVERYTHING IN TERMS OF $\overline{\mathrm{MS}}$ PARTONS
- ADD MASSIVE EXPRESSION TO THE MASSLESS ONE, SUBTRACT DOUBLE COUNTING (TRIVIAL, AS EVERYTHING EXPRESSED IN SAME SCHEME)

$$F^{(n_l)}(x,Q^2) = x\int_x^1 \frac{dy}{y}\sum_{i=q,\bar{q},g} B_i\left(\frac{x}{y},\frac{Q^2}{m^2},\alpha_s^{(n_l+1)}(Q^2)\right) f_i^{(n_l+1)}(y,Q^2),$$

$$F^{(n_l,0)}(x,Q^2) \equiv x\int_x^1 \frac{dy}{y}\sum_{i=q,\bar{q},g} B_i^{(0)}\left(\frac{x}{y},\frac{Q^2}{m^2},\alpha_s^{(n_l+1)}(Q^2)\right) f_i^{(n_l+1)}(y,Q^2); \quad \lim_{m\to 0}\left[B_i(x,\frac{Q^2}{m^2}) - B_i^{(0)}\left(x,\frac{Q^2}{m^2}\right)\right] = 0$$

$$F^{\mathrm{FONLL}}(x,Q^2) \equiv F^{(d)}(x,Q^2) + F^{(n_l)}(x,Q^2); \qquad F^{(d)}(x,Q^2) \equiv \left[F^{(n_l+1)}(x,Q^2) - F^{(n_l,0)}(x,Q^2)\right]$$

THE PROBLEM OF DAMPING TERMS

- IN ANY SCHEME, DGLAP RESUMMATION PRODUCES TERMS $\sim \alpha_s(Q^2) \ln \frac{Q^2}{m_q^2}$ TO ALL ORDERS IN $\alpha_s(Q^2)$
- MASS CORRECTIONS TO SUCH TERMS ARE PROVIDED AT LOW ORDERS IN $\alpha_s(Q^2)$, BUT NOT TO HIGHER ORDERS
- THESE TERMS ARE COMPLETELY INACCURATE WHEN Q^2 IS JUST ABOVE m_q^2 AND CAN BE NON–NEGLIGIBLE IN PRACTICE
- SOLUTION: KILL THESE TERMS WITH A SUITABLE DAMPING PRESCRIPTION

THE IMPACT ON PHENOMENOLOGY

- MANY FITS (CTEQ<6, NNPDF, ALEKHIN<09) TREAT CHARM AS MASSLESS ABOVE THRESHOLD $\Rightarrow$ "ZMVFN" SCHEME
- TR/TR' PROCEDURE IMPLEMENTED SINCE '98 IN MRST

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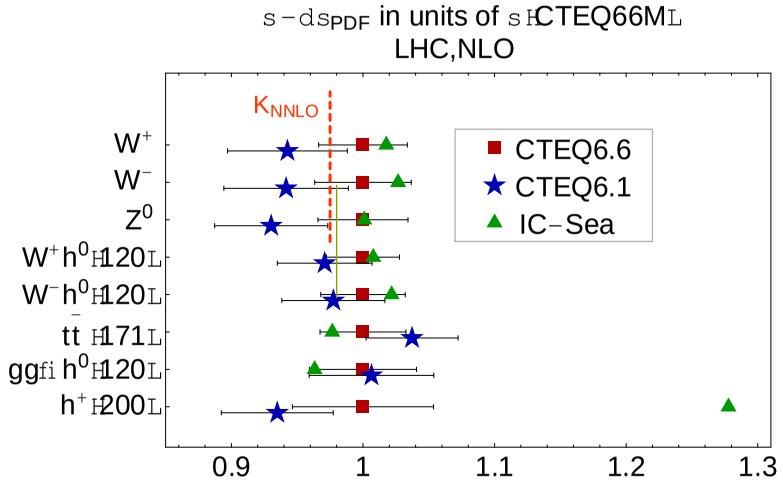
- WHEN CTEQ IMPLEMENTED ACOT IN 2008, SURPRISING CHANGE CTEQ61$\rightarrow$CTEQ6.5 IN σ_W, & AGREEMENT WITH MRST SPOILED (LATER RESTORED)



(Nadolsky et al., 2008)

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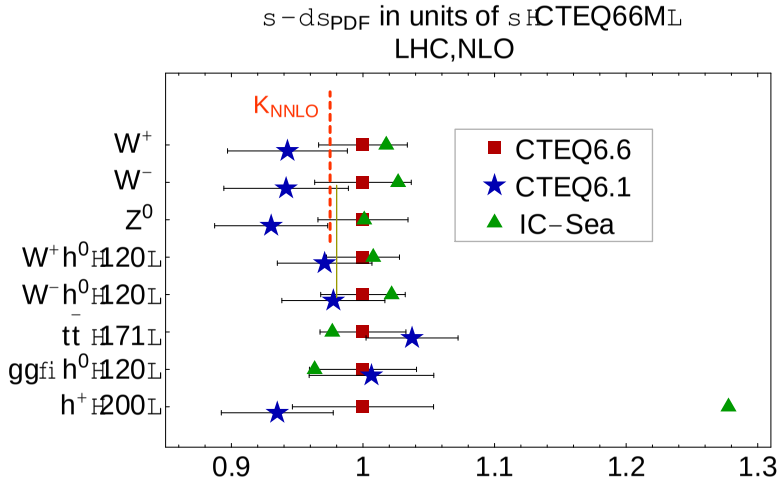
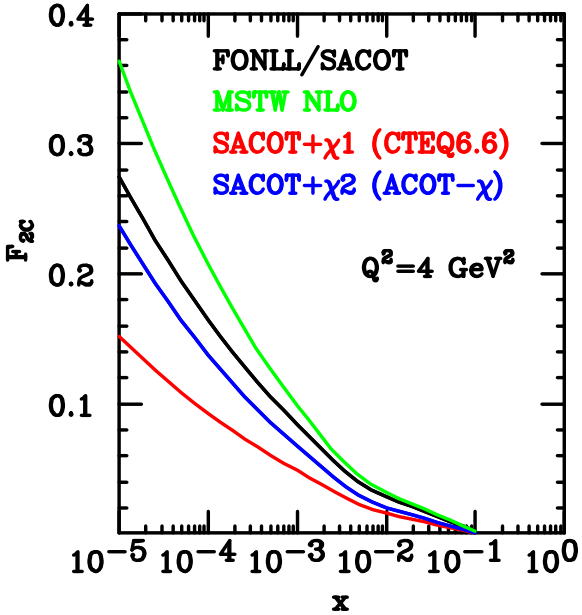


(Nadolsky et al., 2008)

RECENT PROGRESS: THE LES HOUCHES 2009 BENCHMARKS

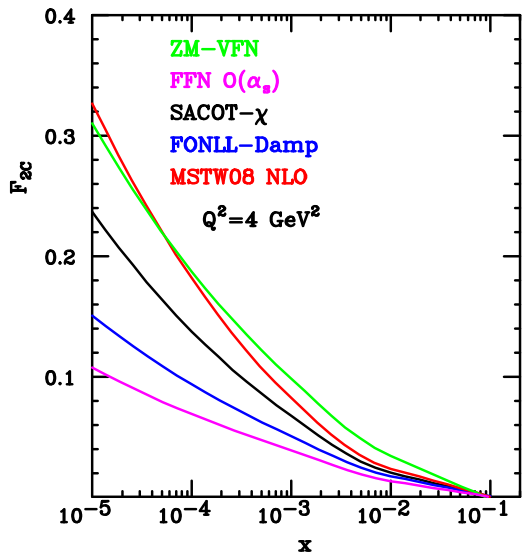


(Rojo et al., 2010)

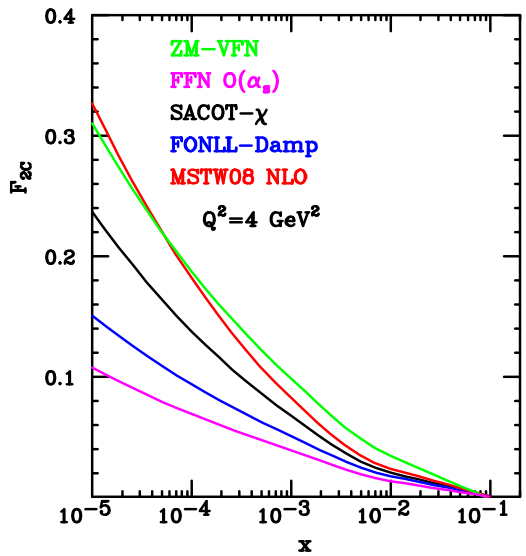
- TR, FONLL AND ACOT FOR DIS BENCHMARKED AT NLO AND NNLO
- $O(\alpha_s)$ FONLL, ACOT COINCIDE EXACTLY, TR' DIFFERS BY SUBLEADING $O(\alpha_s^2(m_c))$ Q^2–INDEP. TERM
- DIFFERENCES BETWEEN DAMPING PRESCRIPTIONS SIZABLE

THE PROBLEM OF DAMPING TERMS:
PHENOMENOLOGY

- IMPACT OF SUBLEADING TERMS SIZABLE CLOSE TO THRESHOLD
- DIFFERENCE BETWEEN DIFFERENT PRESCRIPTIONS (ACOT-χ–SCALING, FONLL-DAMPING, MSTW-MATCHING) AS LARGE AS DIFFERENCE BETWEEN FFN (NO DGLAP RESUMMATION FOR CHARM) AND ZMVFN (NO CHARM MASS)



THE PROBLEM OF DAMPING TERMS:
PHENOMENOLOGY



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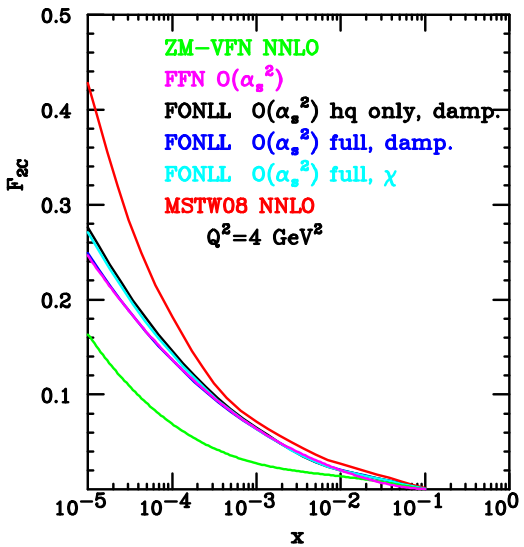
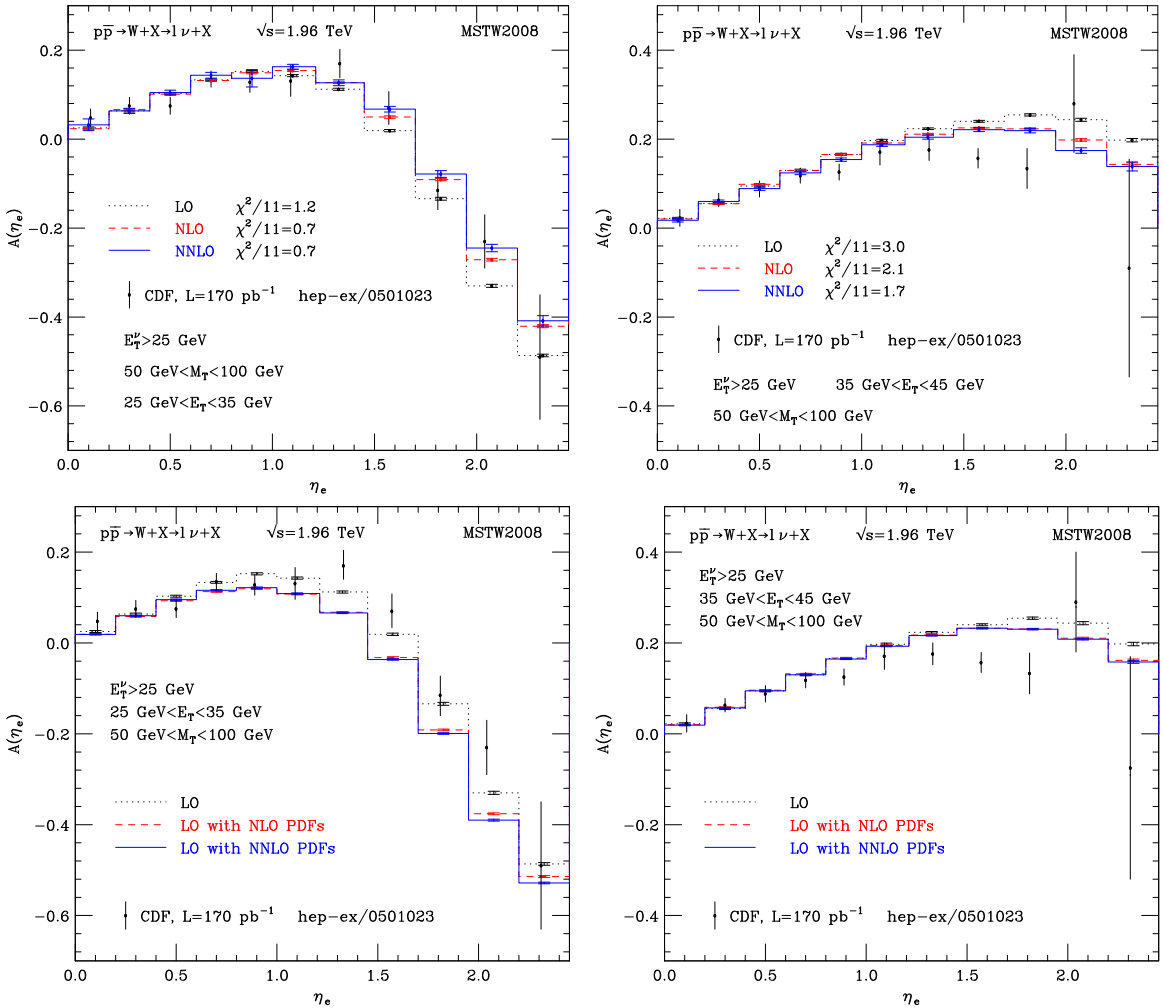


THE SOLUTION:
GO UP ONE ORDER

- IF EVERYTHING AT ONE EXTRA ORDER IN α_s, DIFFERENCES MINOR
- IN FONLL, CAN COMBINE $O(\alpha_s^2)$ TREATMENT OF HQ WITH STANDARD NLO $O(\alpha_s)$ TREATMENT OF LIGHT QUARKS $\Rightarrow$ EXCELLENT APPROX TO FULL RESULT (s.f., Laenen, Nason, Rojo 2010)
- RECENT PROGRESS: $O(\alpha^3)$ MASSLESS LIMIT OF HQ PRODUCTION COEFF. FCTNS. COMPUTED (Bierenbaum, Blümlein, Klein, 2009)

NNLO CORRECTIONS: THE W CHARGE ASYMMETRY

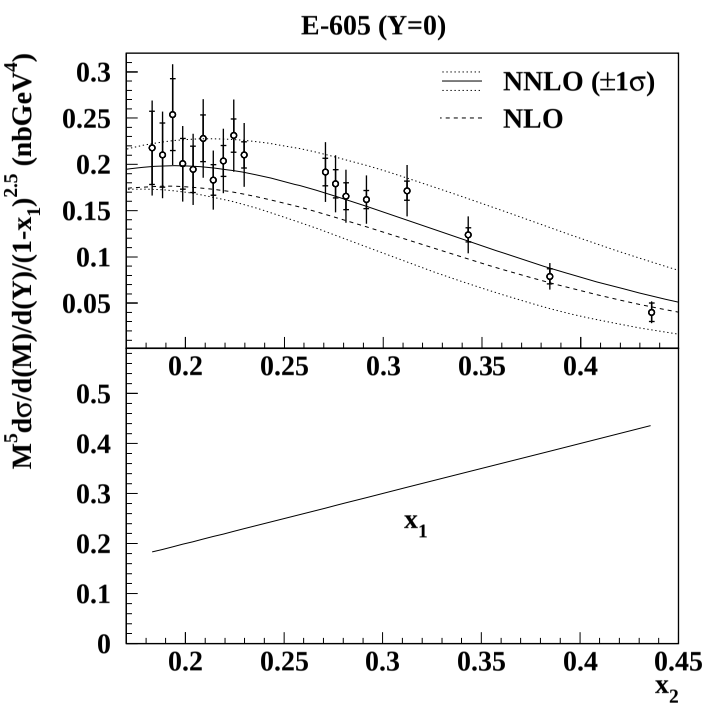


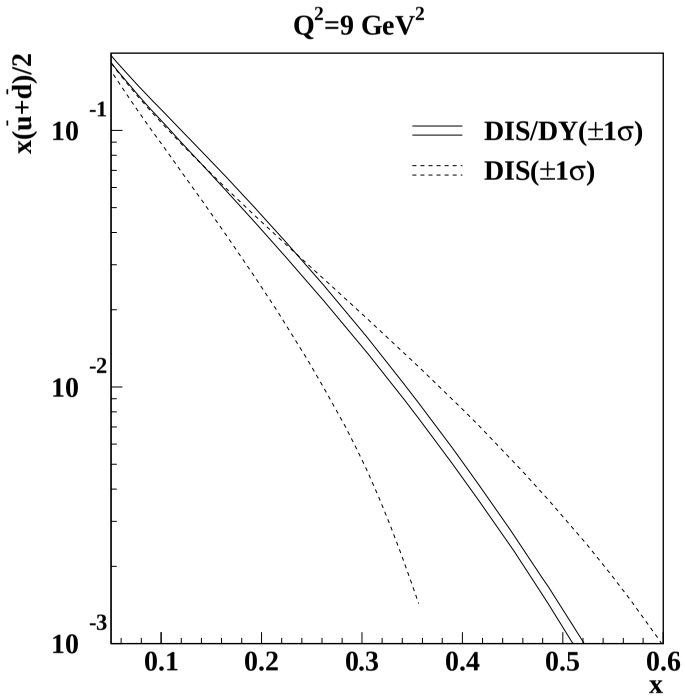
Catani, Ferrera, Grazzini, 2010

- NNLO CORRECTIONS VISIBLY IMPROVE AGREEMENT WITH DATA
- EFFECT ON MATRIX ELEMENT COMPARABLE TO EFFECT ON PDFs, BUT IN DIFFERENT REGIONS

NNLO NEEDED FOR STANDARD CANDLES!

NNLO PARTON DISTRIBUTIONS?





Alekhin, Melnikov, Petriello, 2006

- CURRENT GLOBAL PDF FITS ARE NLO
- MSTW08 NNLO TREATS DIS AT NNLO, JETS AT NLO, DRELL-YAN AT LO+K–FACTORS
- HERAPDF+ALEKHIN-SERIES FITS GENUINELY NNLO, BUT SMALLER DATASET
- BUT IMPACT NOT NEGLIGIBLE...

PROGRESS

Q: WHY IS NNLO NOT INCLUDED IN PARTON FITS?

PROGRESS

Q: WHY IS NNLO NOT INCLUDED IN PARTON FITS?

A: CONVOLUTIONS ARE HARD!

TOWARDS A SOLUTION: GRID–BASED METHODS

ORIGINAL IDEA

EXPANSION OF PDFS ON BASES OF POLYNOMIALS (PASCAUD, ZOMER, 2001

- PRECOMPUTE CONVOLUTION WITH BASIS FUNCTIONS
- EXPAND PDF OVER BASIS
- CONVOLUTIONS REDUCED TO LINEAR COMBINATIONS $\rightarrow$ MATRIX MULTIPLICATION

THE GRID IDEA

(CARLI, SALAM, SIEGERT 2005)

- REPRESENT PDFS ON INTERPOLATED GRID
- BASIS FCTNS $\leftrightarrow$ INTERPOLATING FCTNS
- DO CONVOLUTIONS OVER BASIS FUNCTIONS (IF MONTE CARLO USED, BASIS FCTNS $\rightarrow$ WEIGHTS FOR MC INTEGRAL)
- GRID CAN BE OPTIMIZED

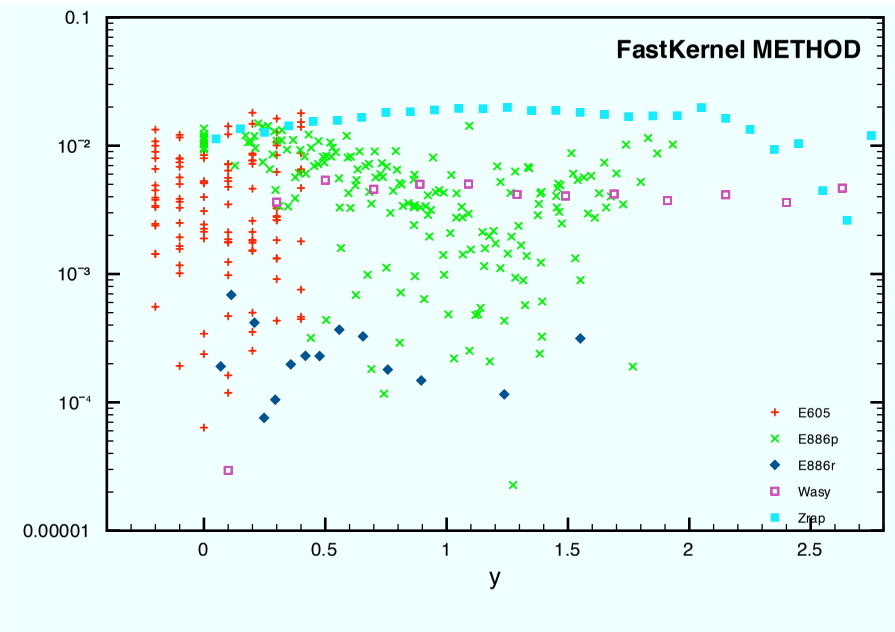
$$\int_{x_{0,1}}^{1} dx_1 \int_{x_{0,2}}^{1} dx_2\, f_a(x_1) f_b(x_2) C^{ab}(x_1, x_2) \rightarrow$$

$$\sum_{\alpha,\beta=1}^{N_x} f_a(x_{1,\alpha}) f_b(x_{2,\beta}) \int_{x_{0,1}}^{1} dx_1 \int_{x_{0,2}}^{1} dx_2\, \mathcal{I}^{(\alpha,\beta)}(x_1, x_2) C^{ab}(x_1, x_2)$$

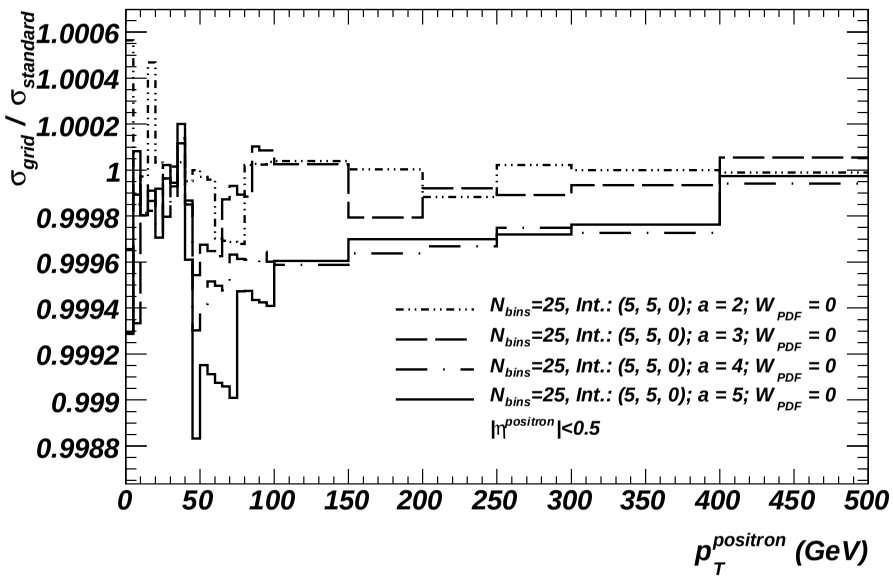
GRID–BASED METHODS
SOME RECENT NLO IMPLEMENTATIONS:

- FASTNLO: FAST INTERFACE FOR JET CROSS SECTIONS (Kluge, Rabbertz, Wobisch 2006)
- FASTKERNEL: GRID METHOD INTERFACED TO N-SPACE COMPUTATION OF GLAP GREEN FUNCTIONS, INTERFACED TO FASTNLO FOR JETS AND TO SUITABLE FAST-DY (NNPDF, 2010)
- APPLGRID: OPTIMIZED GRID, POTENTIALLY UNIVERSAL INTERFACE, IMPLEMENTED FOR JETS, W AND Z PRODUCTION (Carli et al., 2010)

FASTKERNEL PERC. ACCURACY



APPLGRID REL. ACCURACY

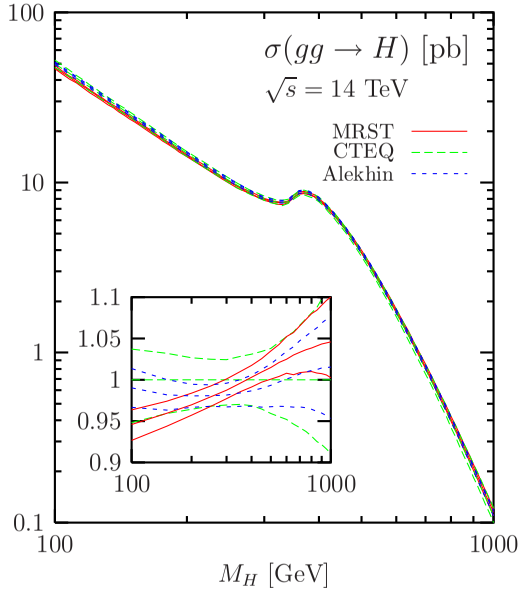


THE STATE OF THE ART

PDFS: TOWARDS LHC PHYSICS

THE HIGGS CROSS SECTION

FIRST PDFS WITH UNCERTAINTIES



(Djouadi, Ferrag, 2004)

PDFS WITH ERROR

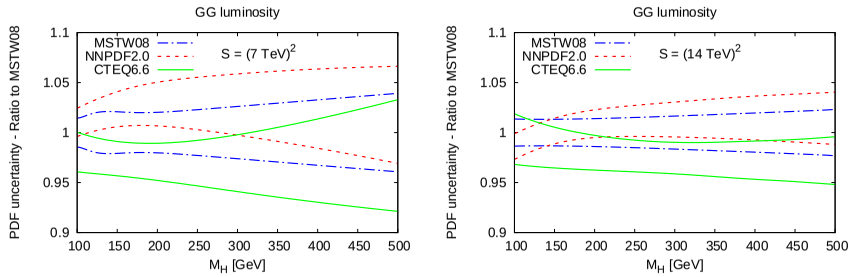
(2002-2003)

CTEQ, MRST (global); Alekhin (DIS)

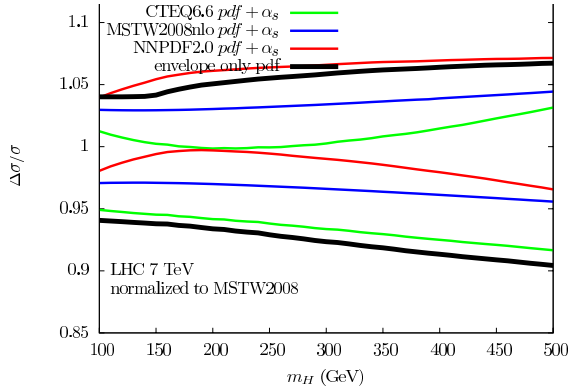
- WIDELY DIFFERENT UNCERTAINTY ESTIMATES
- UNSATISFACTORY AGREEMENT WITHIN UNCERTAINTIES
- $\Delta\chi^2 = 100$ (CTEQ); 50 (MRST); 1 (ALEKHIN)

CURRENT GLOBAL PDF SETS

gluon luminosities



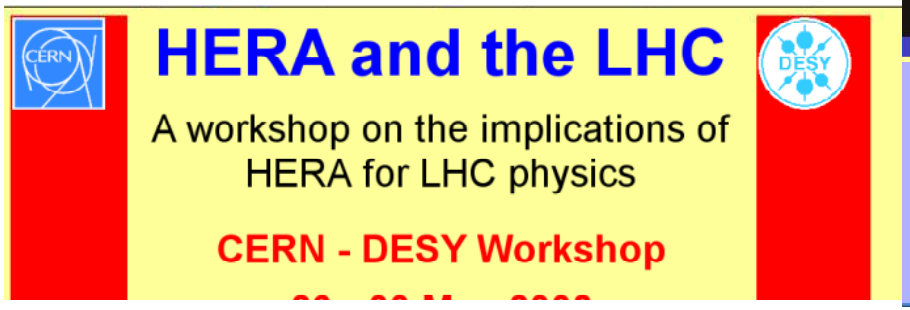
gg→H cross section



(Demartin et al., 2010)

- THREE GLOBAL (DIS+HADRONIC) PDF SETS AVAILABLE
- REASONABLE AGREEMENT OF CENTRAL VALUES & UNCERTAINTIES

AN ONGOING EFFORT



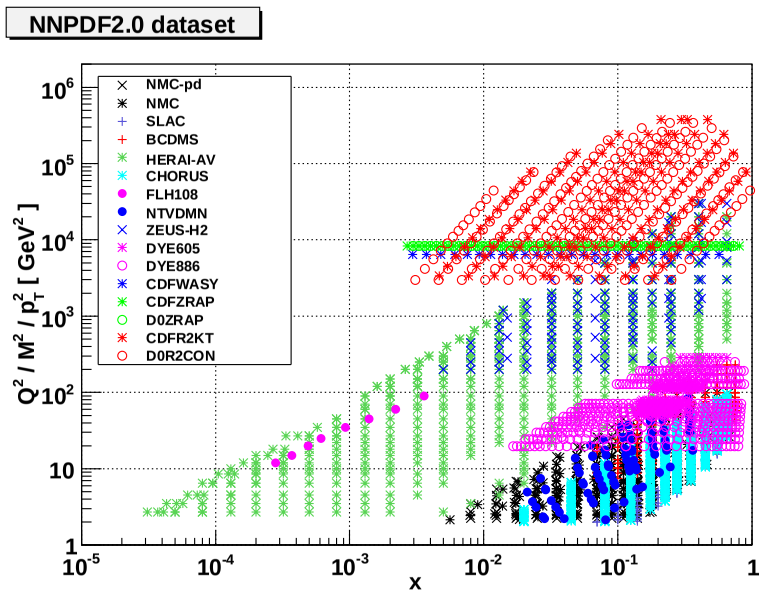
- HERALHC (2004-2008): A WORKSHOP TO TRANSFER KNOWN-HOW FROM HERA TO THE LHC COMMUNITY
  - two sessions (2004-2005; 2006-2007), four plenary meetings, five mid-term and working group meetings
  - two CERN/DESY reports (yellow books): **HEP-PH/0601012-HEP-PH/0601013**; **ARXIV:0903.3861**.
- PDF4LHC (2008 - ONGOING): A PERMANENT WORKING GROUP TO PROVIDE GUIDANCE ON PDF TO LHC EXPERIMENTS AND PHENOMENOLOGY
  - quarterly meetings, 10 since inception in February 2008
  - website `http://www.hep.ucl.ac.uk/pdf4lhc/` and wiki `https://wiki.terascale.de/index.php?title=PDF4LHC_WIKI` resources available
  - fruitful interactions with the LHC Higgs Cross Section WG

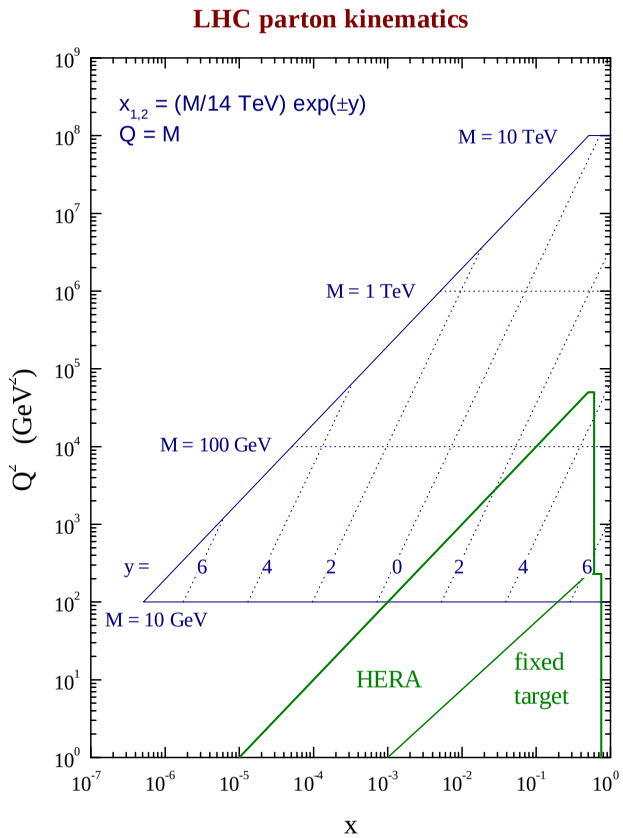
CURRENT PDF SETS

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

LHC kinematics

data for a global fit (NNPDF2.0)





- CTEQ6.6: GLOBAL, NLO, VFN WITH HQ MASS, SEVERAL α_s VALUES
- MSTW08: GLOBAL, NLO & NNLO, VFN WITH HQ MASS, SEVERAL α_s VALUES
- NNPDF2.0: GLOBAL, NLO, VFN WITHOUT HQ MASS, SEVERAL α_s VALUES
- ALEKHIN ABKM: DIS+SOME DY, NLO & NNLO, BMSN (FFN), SINGLE α_s VALUE
- HERAPDF1.0: ONLY HERA DATA, NLO, VFN WITH HQ MASS, SEVERAL α_s VALS.
- SETS BASED ON MODEL ASSUMPTIONS (GRV/GJR, STATISTICAL PDFS,...)

FEATURES, TRADEOFFS AND CHOICES

- DATASET:CTEQ, MSTW, NNPDF FIXED TARGET AND COLLIDER, eP AND $\bar{P}P$ DATA; ABKM, GJR GLOBAL DIS+ FIXET-TARGET DY; HERAPDF: HERA ONLY
- STATISTICAL TREATMENT: CTEQ HESSIAN WITH TOLERANCE; MSTW HESSIAN WITH DYNAMICAL TOLERANCE; HERAPDF, ABKM, GJR, STANDARD HESSIAN; NNPDF MONTE CARLO (ALSO STUDIED BY HERAPDF)
- PARTON PARAMETRIZATION:CTEQ, MSTW, HERAPDF $x^\alpha(1-x)^\beta\times$ POLYNOMIALS; GJR: DITTO + VALENCELIKE ASSUMPTION; NNPDF NEURAL NETS; CHEBYSHEV POLYNOMIALS STUDIED BY HERAPDF;
- HEAVY QUARKS:CTEQ: GM-VFN (SACOT-χ SCHEME); MSTW: GM-VFN (ACOT+TR' SCHEME); NNPDF: ZM-VFN, ORELIM: GM-VFN (FONLL-A SCHEME); ABKM: FFN ($N_f = 3, 4$ MATCHED WITH BMSN SCHEME); GJR: FFN ($N_f = 3$)
- PERTURBATIVE ORDER:CTEQ: NLO, BUT DY LO WITH K-FACTORS; MSTW: NNLO, BUT DY LO WITH K-FACTORS; NNPDF FULL NLO; ABKM, GJR: FULL NNLO
- α_s VALUE:CTEQ, NNPDF: EXTERNAL PARAMETER, SEVERAL VALUES AVAILABLE; MSTW: FITTED, BUT ALSO VARIABLE AS EXT.PARAMETER; ABKM, GJR: FITTED, NOT VARIABLE AS EXT. PARAMETER

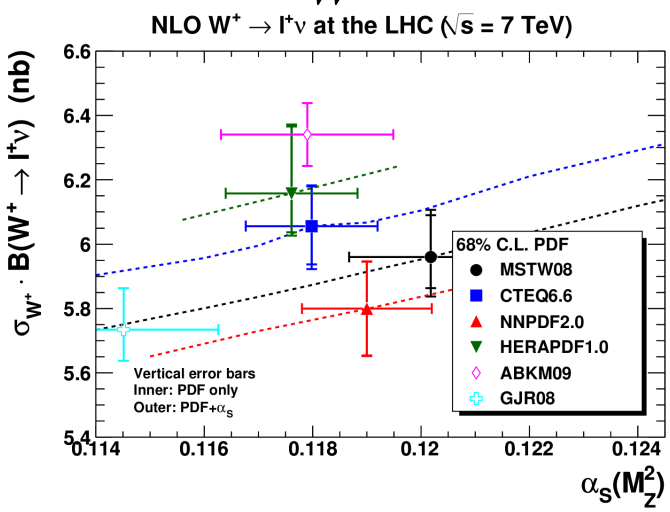
THE PDF4LHC RECOMMENDATION

- AT NLO, ENVELOPE OF CTEQ, MSTW, NNPDF
- AT NNLO, MSTW WITH UNCERTAINTY RESCALED MY MSTWNLO/NLO ENVELOPE

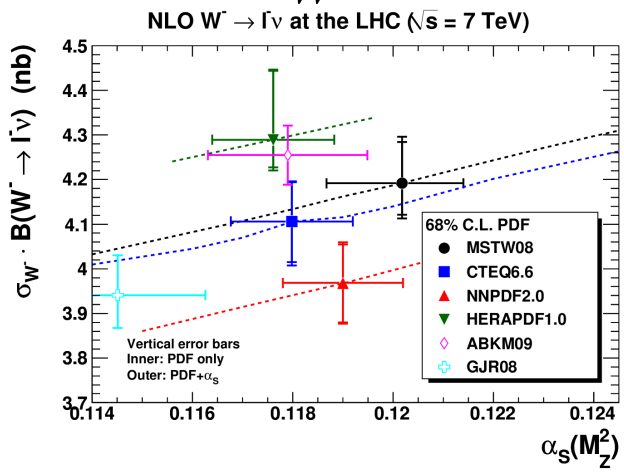
WHERE DO WE STAND?

LHC STANDARD CANDLES

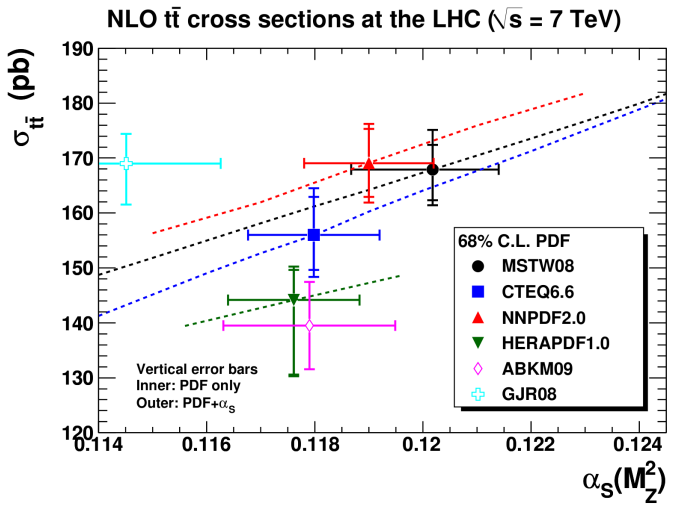
W^+



W^-



TOP



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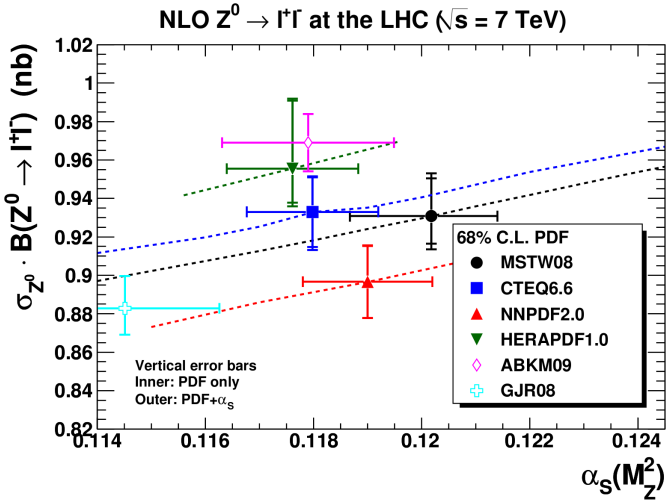


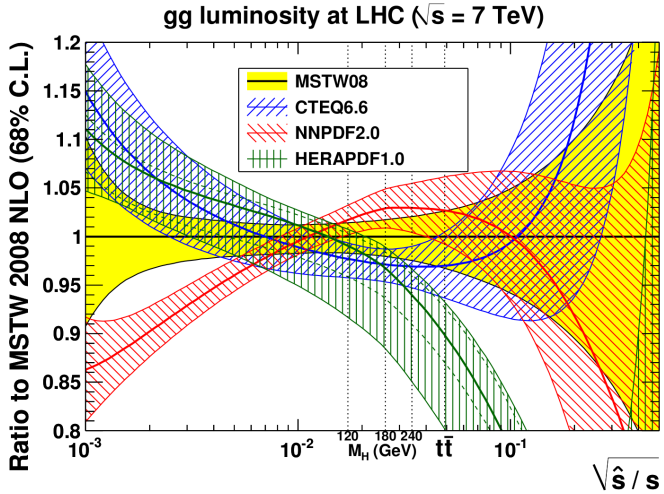
(G. Watt, 2010)

- GLOBAL FITS IN GOOD MUTUAL AGREEMENT
- CHOICE OF α_s VALUE IMPORTANT

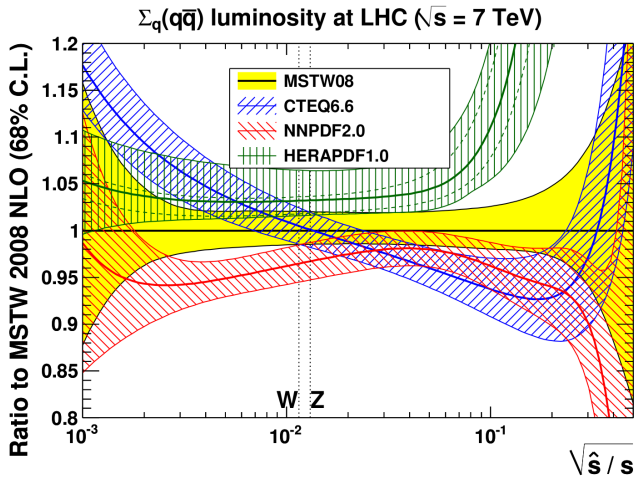
WHERE DO WE STAND?

PARTON LUMINOSITIES

GLUON-GLUON

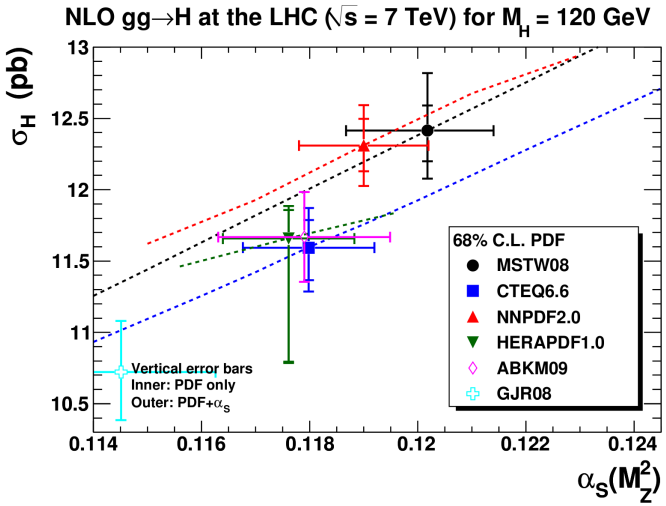


QUARK-QUARK

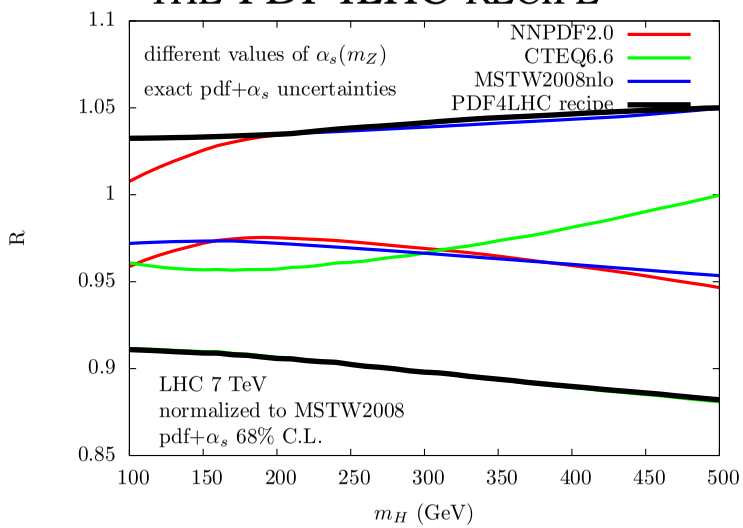


THE HIGGS CROSS SECTION

$m_H = 120$ GeV: DIFFERENT GROUPS



THE PDF4LHC RECIPE



(G. Watt, 2010)

ENVELOPE TAKES CARE OF POORLY UNDERSTOOD DISAGREEMENTS

WHERE ARE WE GOING?

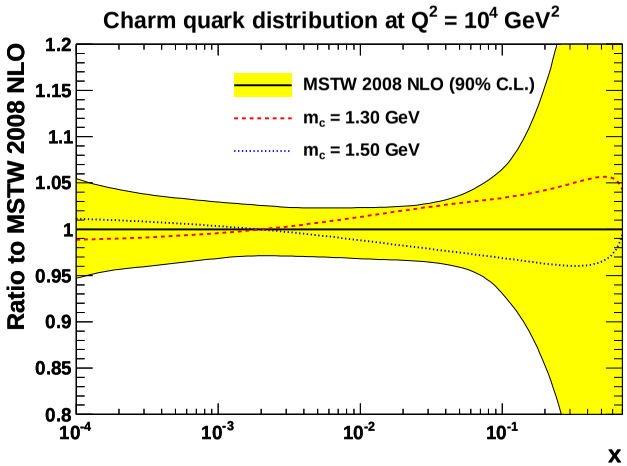
THEORETICAL UNCERTAINTIES

α_s UNCERTAINTIES: CAN BE COMBINED IN QUADRATURE WITH PDF UNCERTAINTIES (Lai et al, CTEQ, 2010); AVAILABLE FOR CTEQ, HERAPDF, MSTW, NNPDF

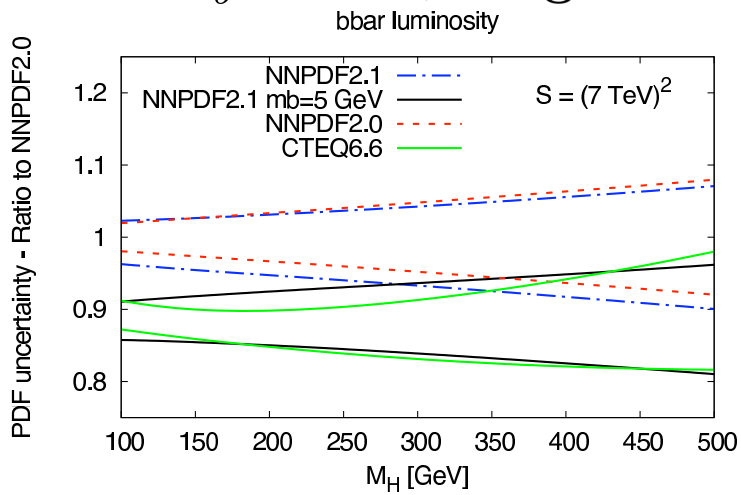
IN PROGRESS:

DEPENDENCE ON c & b MASS

m_c: MSTW08



m_b: NNPDF, CTEQ

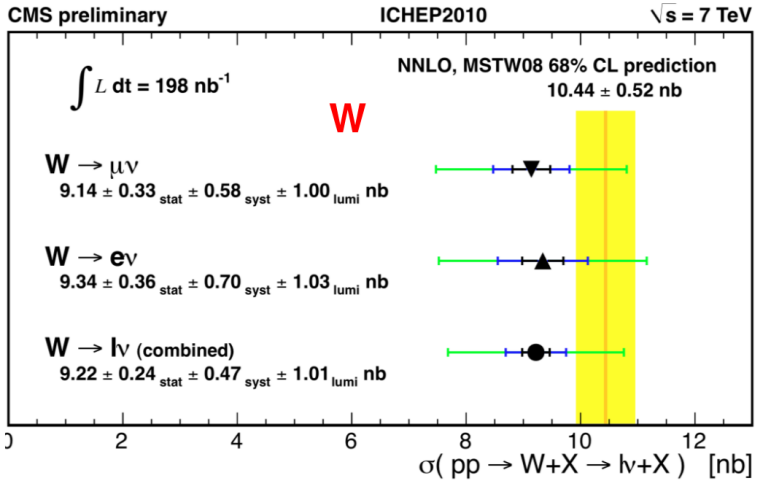


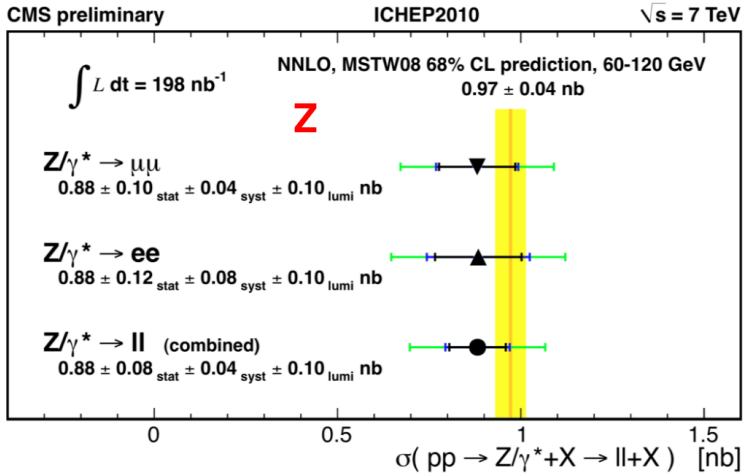
NEEDED:

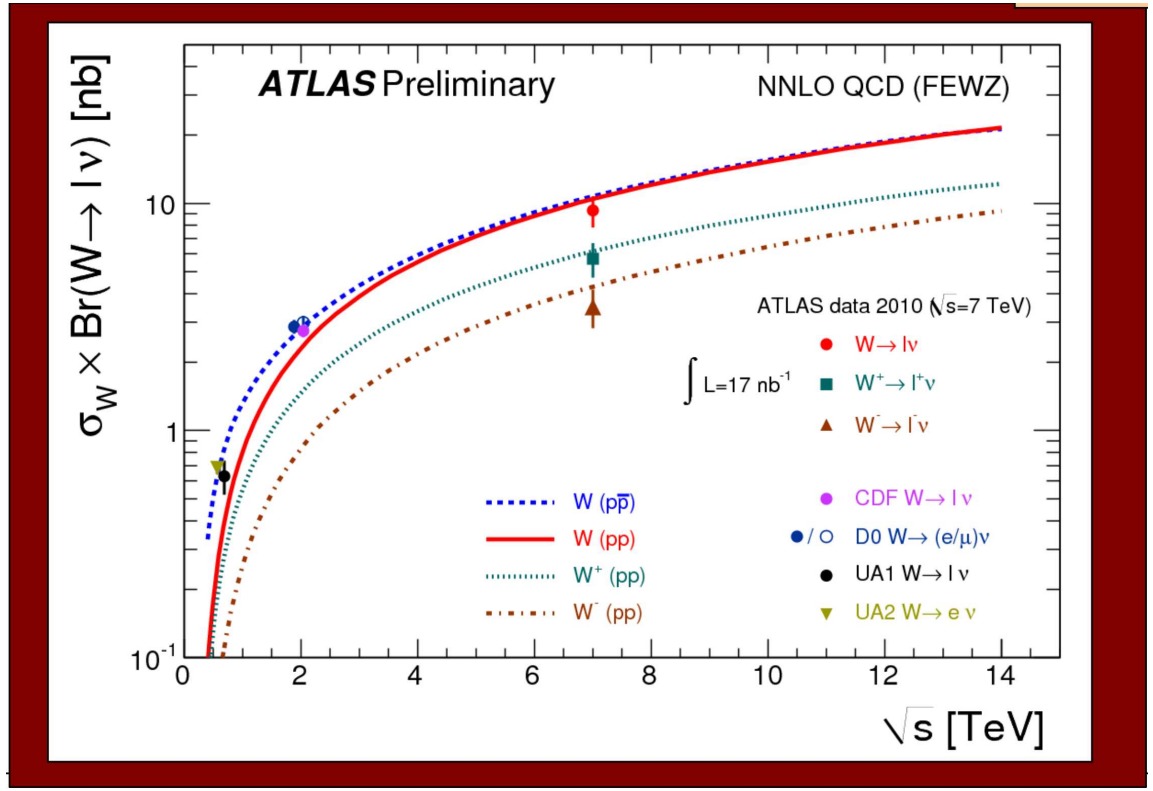
- ORDERS: RENORMALIZATION AND FACTORIZATION SCALE VARIATION
- HEAVY QUARKS: MATCHING SCHEME VARIATION
- RESUMMATION: SMALL x REGION AT HERA, LARGE τ REGION FOR FIXED-TARGET DY

CONCLUSION

THIS IS JUST THE BEGINNING!





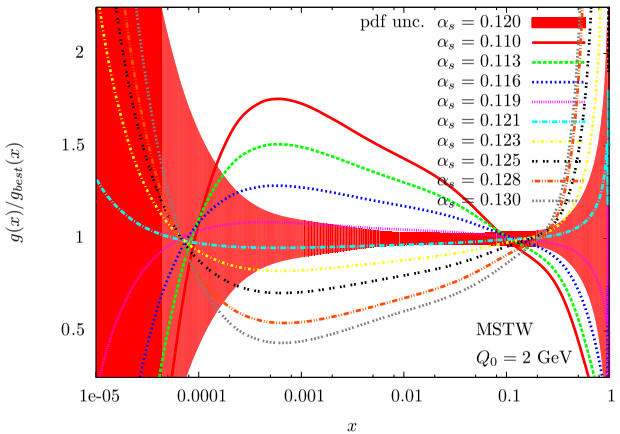


EXTRAS

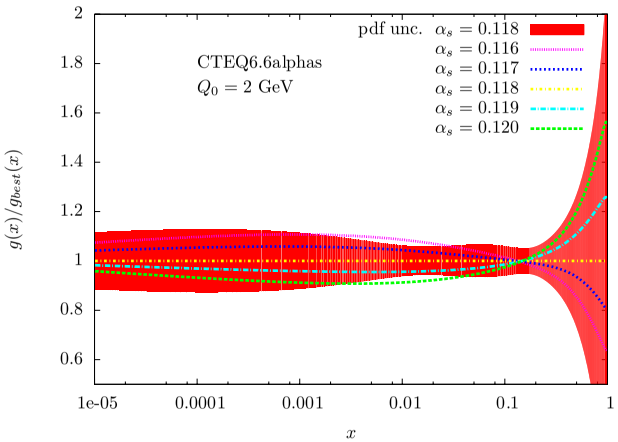
PDF DEPENDENCE ON α_s
THE GLUON DISTRIBUTION

$Q = 2$ GeV

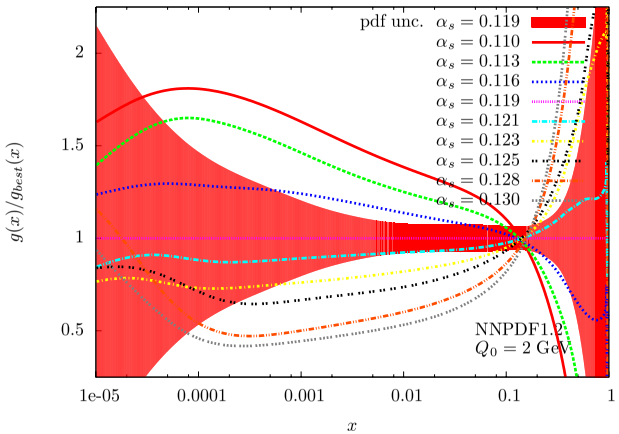
MSTW08



CTEQ6.6

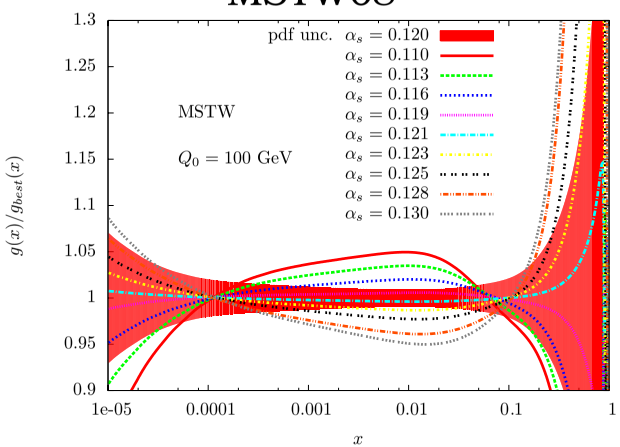


NNPDF1.2

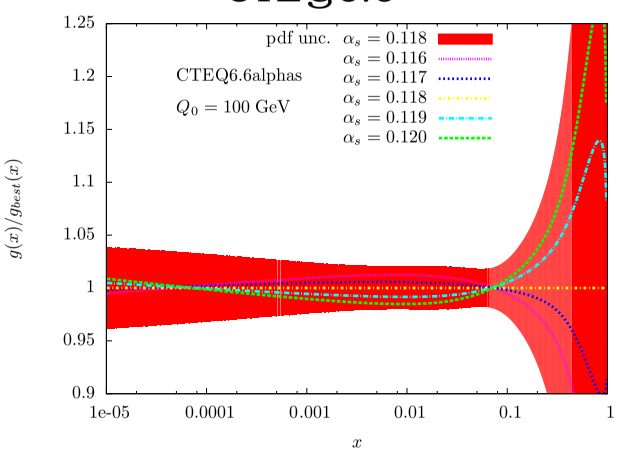


$Q = 100$ GeV

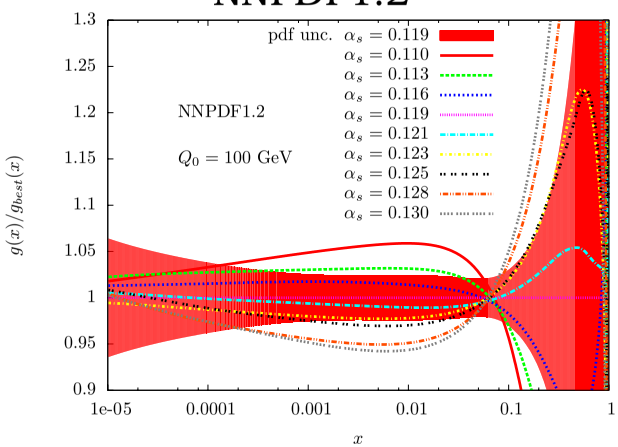
MSTW08



CTEQ6.6



NNPDF1.2



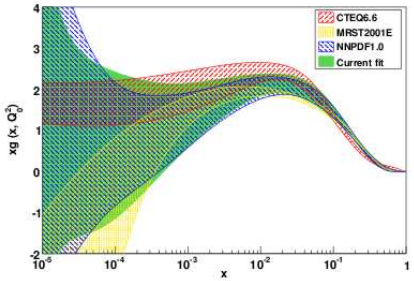
WHERE IS THE MONTE CARLO UNCERTAINTY COMING FROM?

FIT TO REPLICAS VS RANDOM SUBSET OF CENTRAL VAL.S

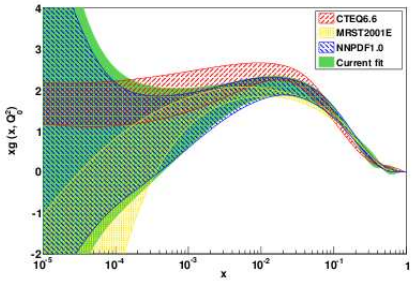
	REPLICAS	CENTRAL V.
χ^2	1.32	1.32
$\langle\chi^2\rangle_{\rm rep}$	2.79 ± 0.24	1.65 ± 0.20
$\langle\sigma^{\rm dat}\rangle$	0.039	0.035

GLUE

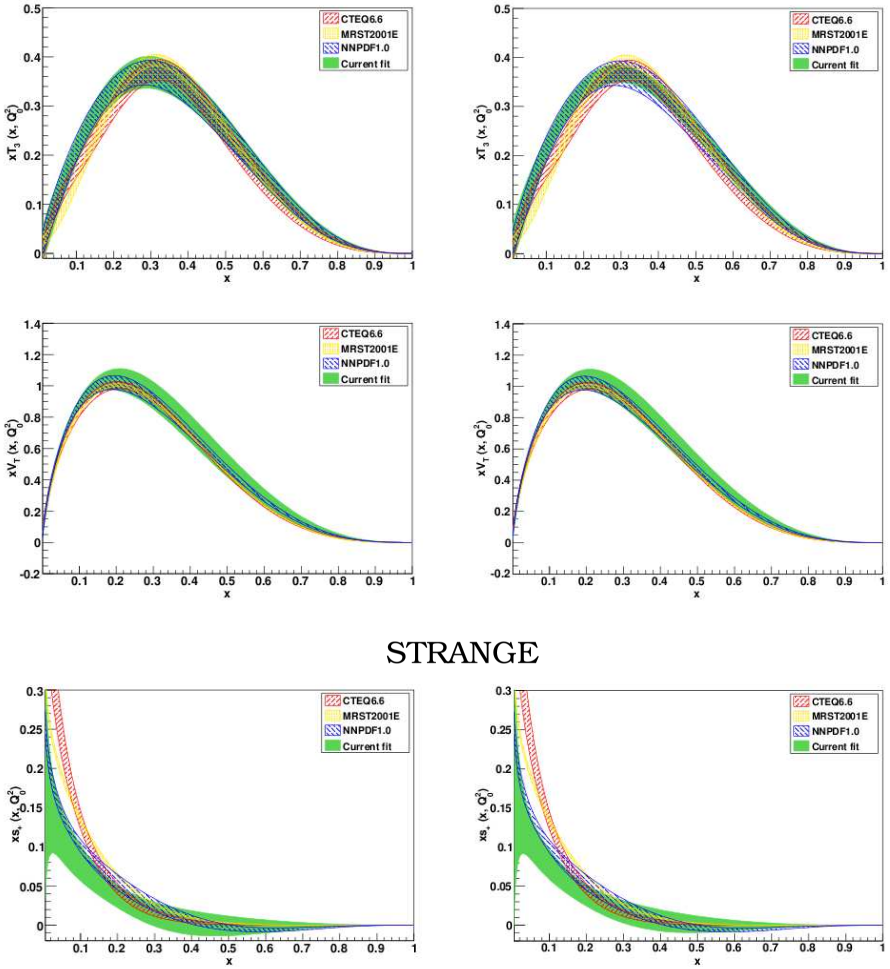
replicas



c. vals.



LIGHT QUARKS



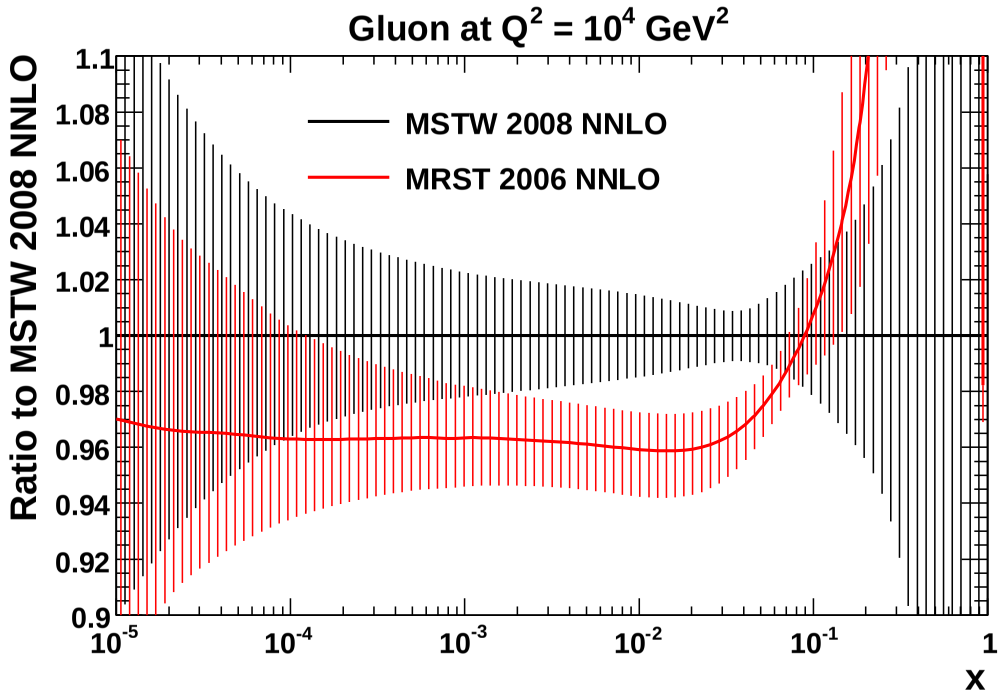
STRANGE

- 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

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.



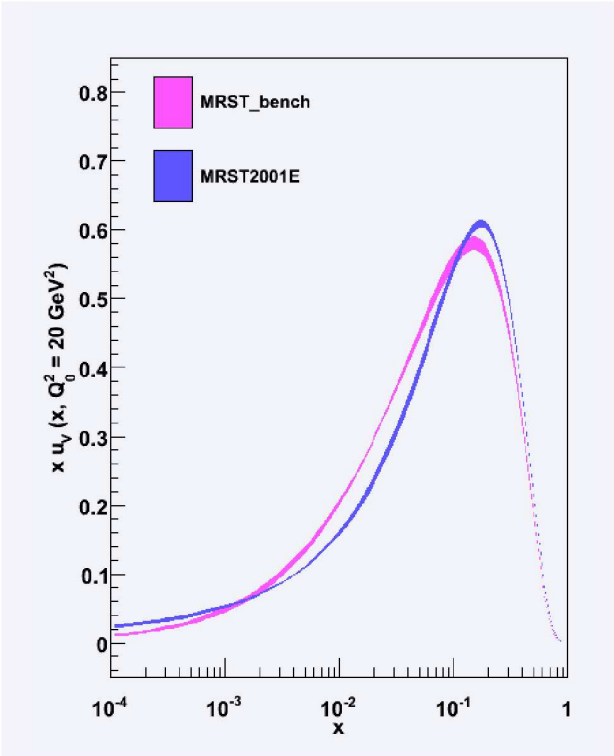
R. THORNE, HERALHC2008

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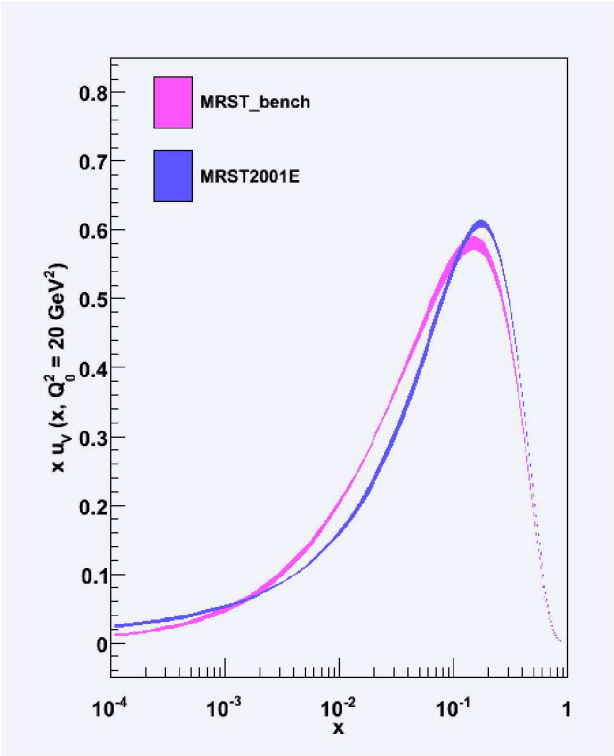
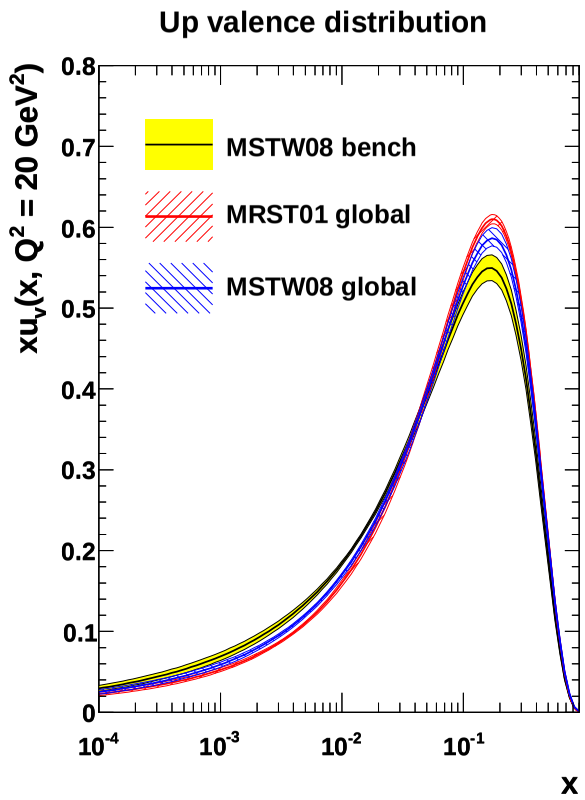
  $\Rightarrow$ RESULTS NOT CONSISTENT, UNCERTAINTY DOES NOT GROW AS DATASET DECREASES
- ...BUT MRST WAS DONE WITH TOLERANCE 50: REPEAT WITH DYNAMICAL TOLERANCE (MSTW08BENCH)
- IMPROVEMENT, BUT PROBLEM NOT SOLVED
  $\Rightarrow$ MUST TUNE PARAMETRIZATION AND STATISTICAL TREATMENT TO DATASET

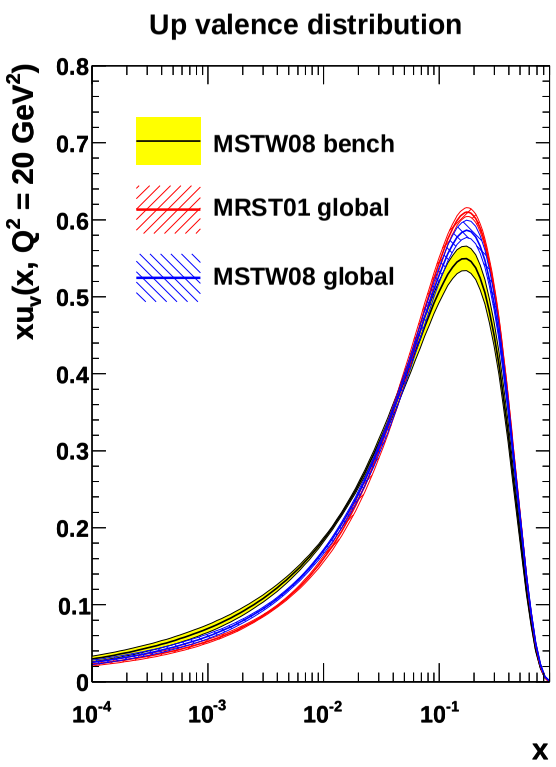




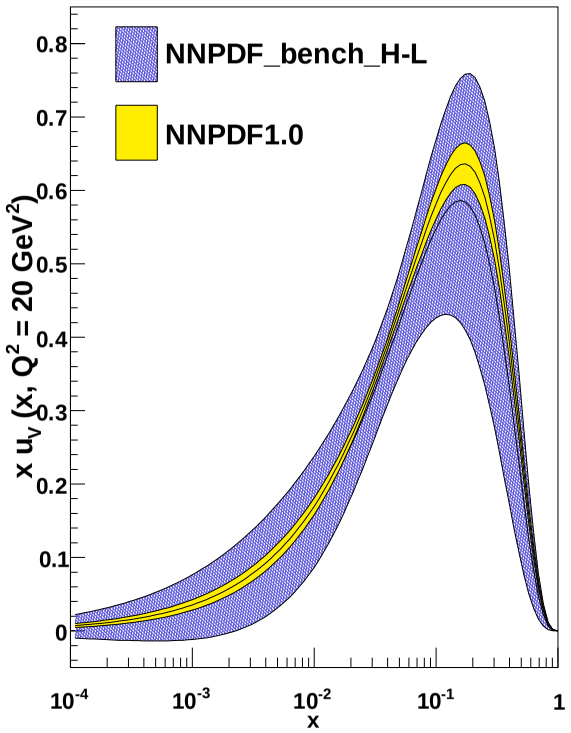
WHAT DETERMINES PDF UNCERTAINTIES?

THE NNPDF SOLUTION (HERALHC 2008)

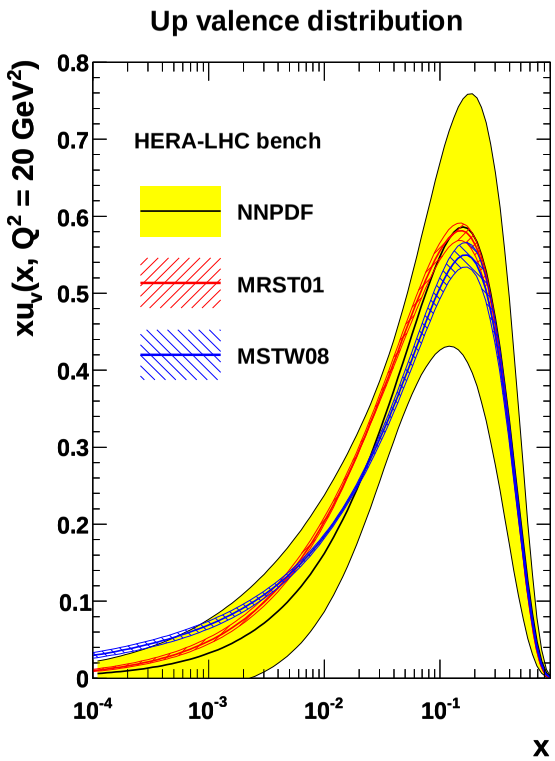
MRST/MSTW: BENCH VS REF



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