Parton Distributions at the LHC

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CMS Week

CERN, May 19, 2011

PDFs: yesterday and today

PDFs in 1984

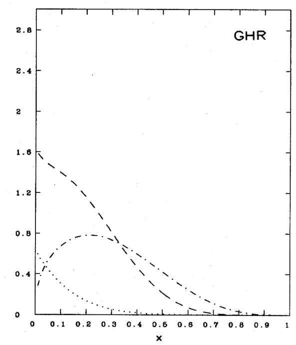


FIG. 25. Parton distributions of Glück, Hoffmann, and Reya (1982), at $Q^2=5$ GeV^2: valence quark distribution $x[u_v(x)+d_v(x)]$ (dotted-dashed line), $xG(x)$ (dashed line), and q_v (dotted line).

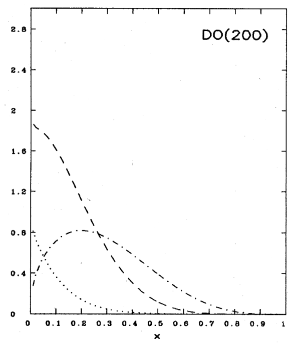


FIG. 27. "Soft-gluon" ($\Lambda=200$ MeV) parton distributions of Duke and Owens (1984) at $Q^2=5$ GeV^2: valence quark distribution $x[u_v(x)+d_v(x)]$ (dotted-dashed line), $xG(x)$ (dashed line), and $q_v(x)$ (dotted line).

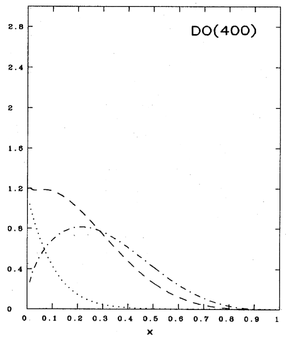


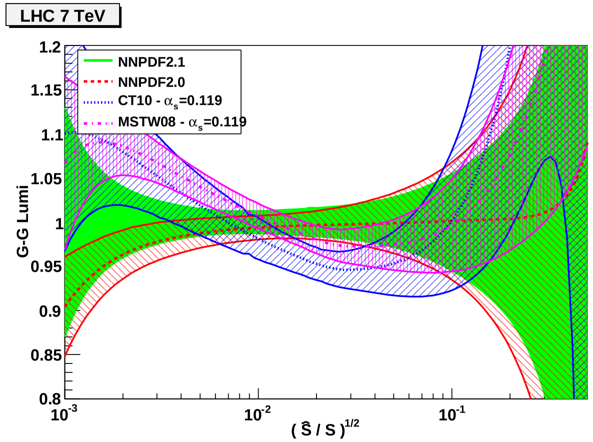
FIG. 26. "Hard-gluon" ($\Lambda=400$ MeV) parton distributions of Duke and Owens (1984) at $Q^2=5$ GeV^2: valence quark distribution $x[u_v(x)+d_v(x)]$ (dotted-dashed line), $xG(x)$ (dashed line), and $q_v(x)$ (dotted line).

Rev. Mod. Phys., Vol. 56, No. 4, October 1984

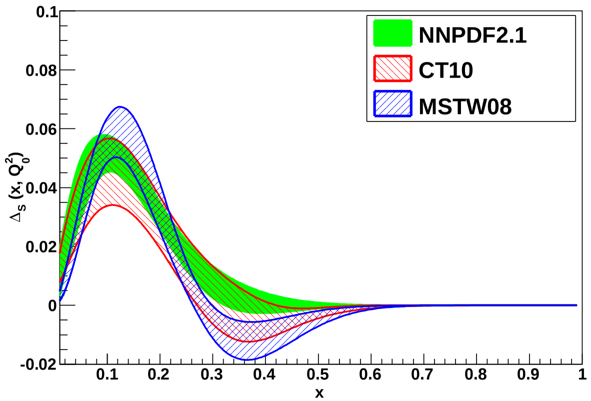
GHR vs Duke-Owens

PDFs in 2011

Gluon-gluon lumi



$\bar{u}-\bar{d}$



NNPDF vs MSTW vs CTEQ, 2011

- hadron colliders circa 1985 $\Rightarrow$ qualitative QCD: discovery physics
- DIS at NMC and HERA 1995-2005 $\Rightarrow$ quantitative QCD: precision physics
- hadron colliders circa 2010 $\Rightarrow$ precision QCD $\leftrightarrow$ new physics

SUMMARY

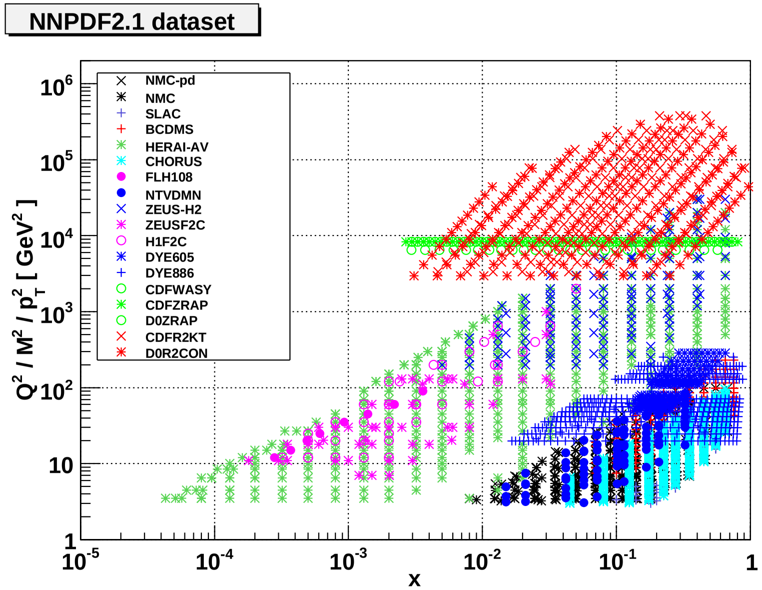
- PDFs TODAY
  - STANDARD CANDLES
  - RECENT PROGRESS
- ISSUES
  - METHODOLOGY
  - PDF UNCERTAINTIES
  - DATA CONSISTENCY
- FROM DATA TO PDFs
  - THE GLUON: JETS, PROMPT PHOTONS & TOP
  - FLAVOR SEPARATION: DRELL-YAN, W AND Z
- A ROAD MAP FOR THE FUTURE

THE STATE OF THE ART

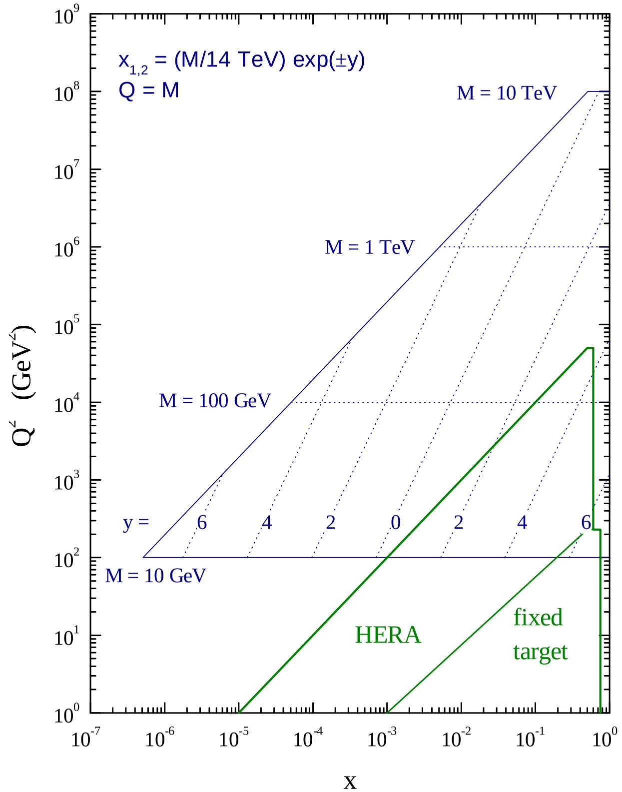
CURRENT PDF SETS

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

DATA IN GLOBAL FITS



LHC KINEMATICS



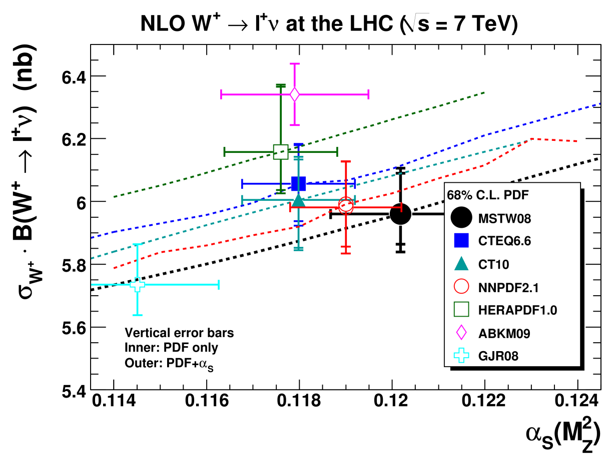
- CT10: GLOBAL, NLO, SEVERAL α_s VALUES, VFN
- MSTW08: GLOBAL, NLO & NNLO, SEVERAL α_s VALUES, VFN
- NNPDF2.1: GLOBAL, NLO, SEVERAL α_s VALUES, VFN
- ALEKHIN ABKM: DIS+SOME DY, NLO & NNLO, SINGLE α_s VALUE, FFN
- HERAPDF1.0: HERA DIS, NLO, SEVERAL α_s VALS, VFN
- SETS BASED ON MODEL ASSUMPTIONS (GRV/GJR, STATISTICAL PDFS,...)

FEATURES, TRADEOFFS AND CHOICES

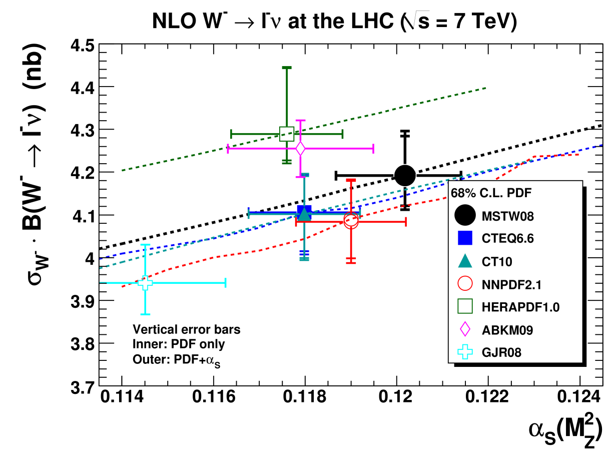
- DATASET: CTEQ, MSTW, NNPDF fixed target and collider, eP and $\bar{P}P$ data; ABKM, GJR global DIS+ fixet-target DY; HERAPDF: HERA DIS only
- STATISTICAL TREATMENT: CTEQ, MSTW Hessian with dynamical tolerance; HERAPDF, standard Hessian+parm. error analysis; GJR, Hessian with fixed tolerance; ABKM standard 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;
- 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
- PERTURBATIVE ORDER: CTEQ: NLO, but DY LO with K-factors; MSTW: NNLO, but DY LO with K-factors; NNPDF full NLO, NNLO DIS; ABKM, HERAPDF, GJR: NNLO
- HEAVY QUARKS: CTEQ: GM-VFN (SACOT-χ scheme); MSTW: GM-VFN (ACOT+TR' scheme); NNPDF: GM-VFN (FONLL scheme); ABKM: FFN ($N_f = 3, 4$ matched with BMSN scheme); GJR: FFN ($N_f = 3$)

WHERE DO WE STAND?
LHC STANDARD CANDLES

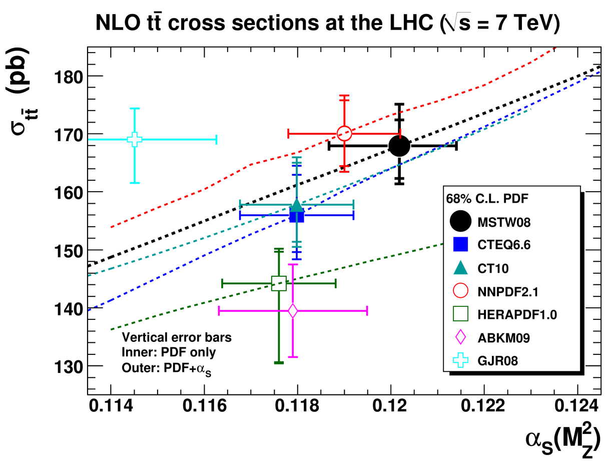
W^+



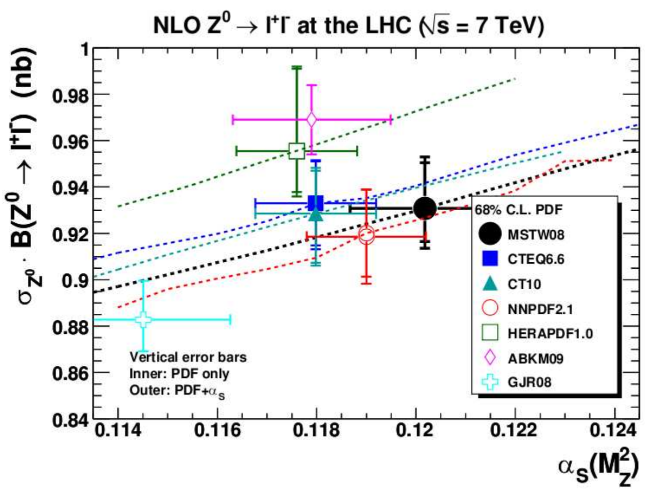
W^-



TOP



Z



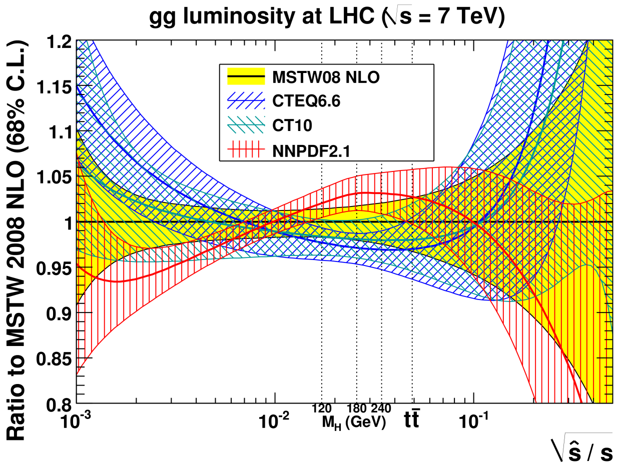
(G. Watt, 2011)

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

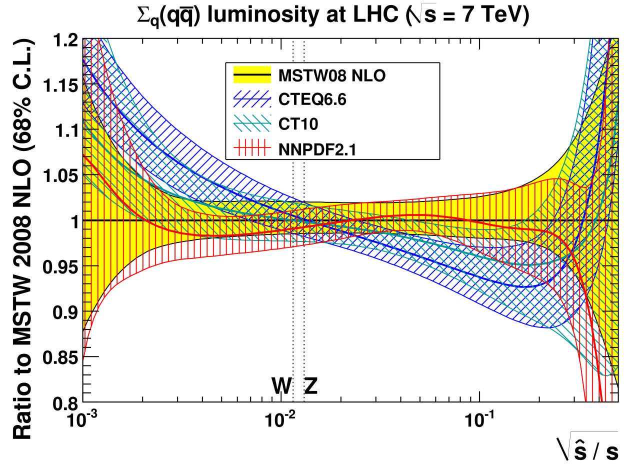
WHERE DO WE STAND?

PARTON LUMINOSITIES

GLUON-GLUON

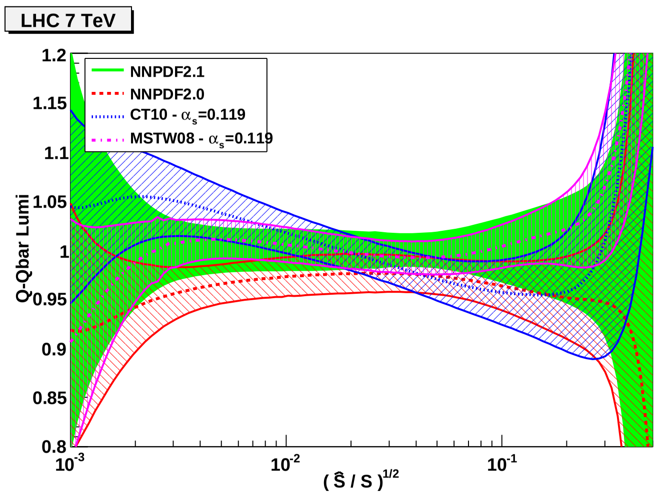


QUARK-QUARK

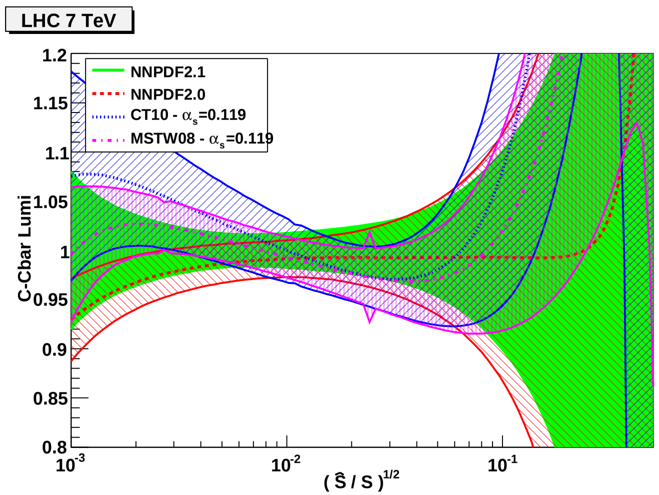


(G. Watt, 2011)

QUARK-GLUON



CHARM-CHARM



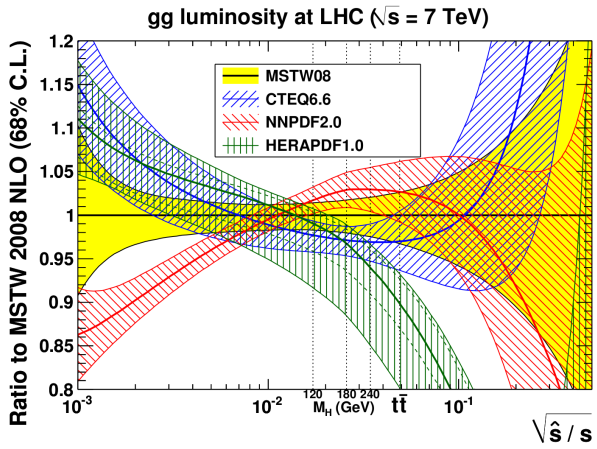
(NNPDF, 2011)

HOW DID WE GET THERE?

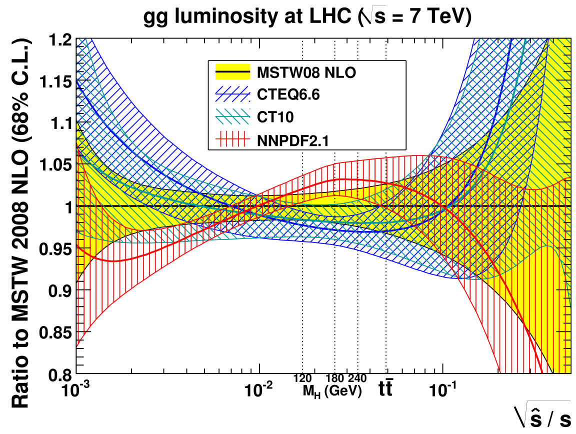
PARTON LUMINOSITIES

GLUON-GLUON

2010

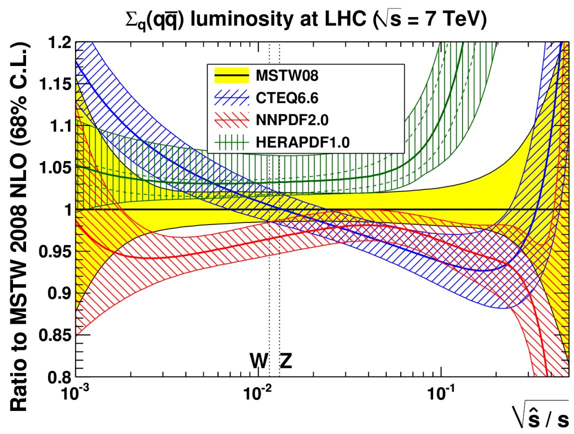


2011

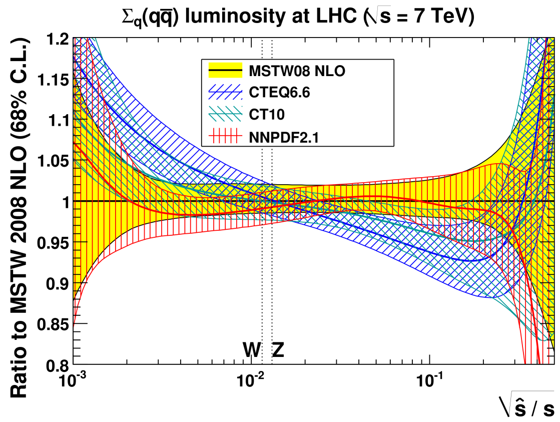


QUARK-QUARK

2010



2011



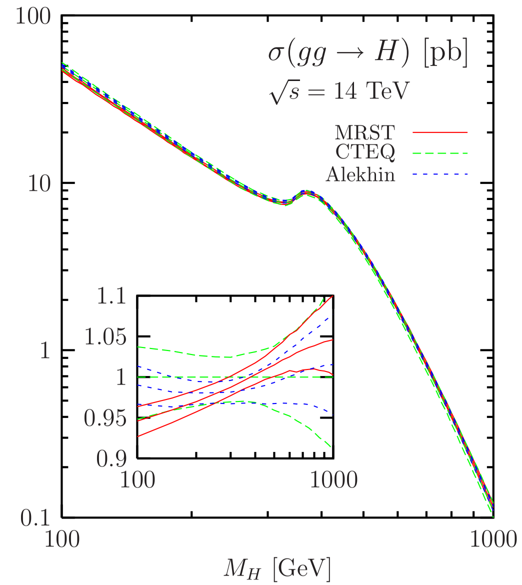
(G. Watt, 2011)

- NNPDF2.0 → NNPDF2.1: INCLUSION OF HW MASSES
- CTEQ6.6 → CT10: IMPROVED STATISTICS, PARAMETRIZATION, DATA
- CONSIDERABLY IMPROVED AGREEMENT!

THE HIGGS CROSS SECTION

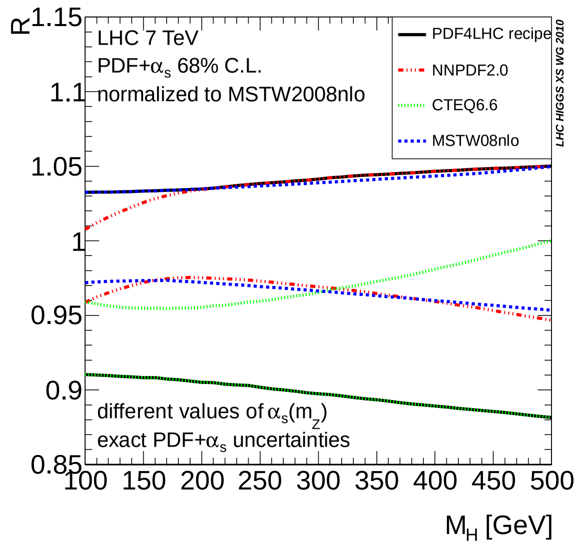
PAST

FIRST PDFs WITH ERRORS



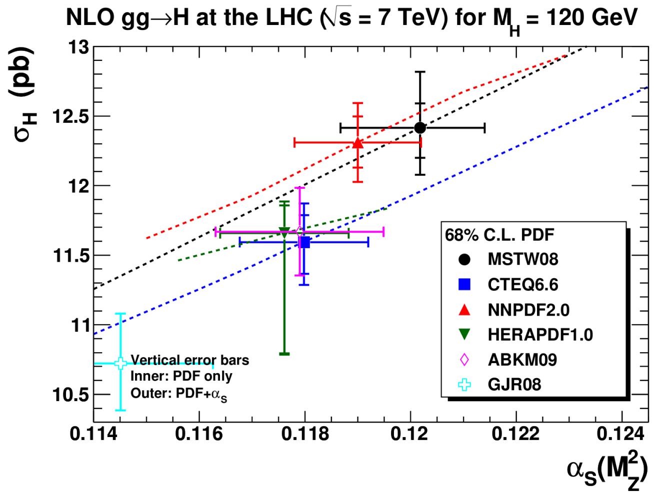
(Djouadi, Ferrag, 2004)

THE PDF4LHC RECIPE



(Higgs WG, 2011)

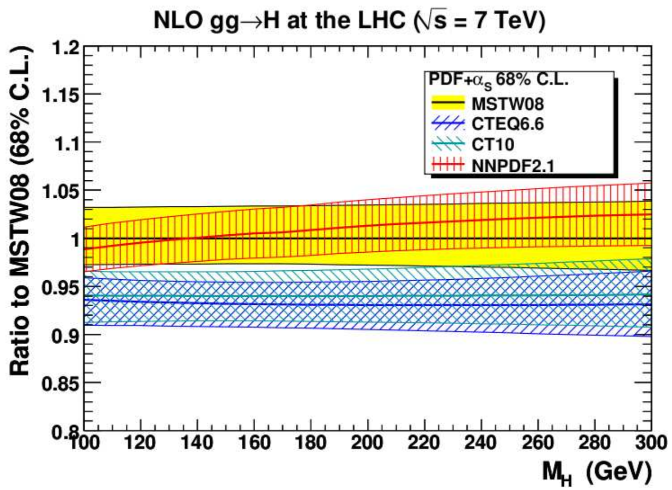
$m_H = 120$ GeV: 2010



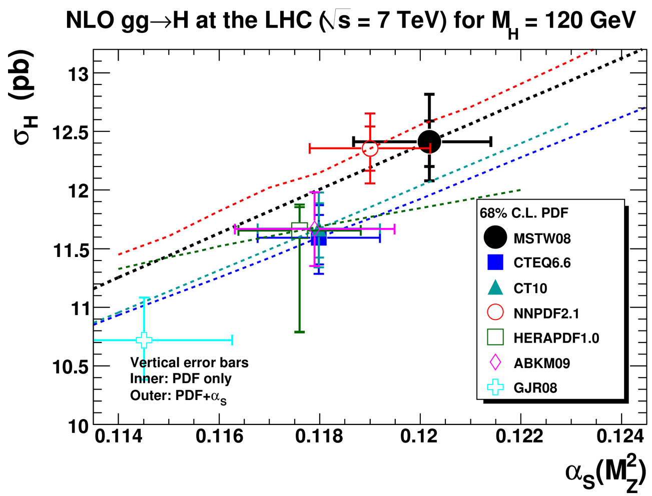
(G. Watt, 2010)

PRESENT

σ VS. m_H 2011



$m_H = 120$ GeV: 2011



(G. Watt, 2011)

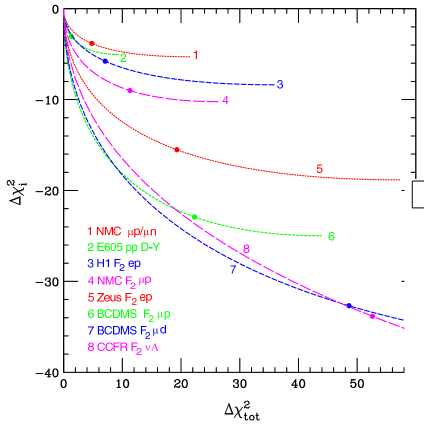
ISSUES

METHODOLOGY: "STANDARD" (HESSIAN) APPROACH

THE TOLERANCE PROBLEM

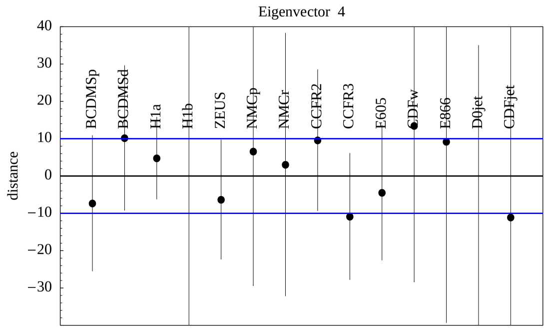
- CHOOSE A FIXED FUNCTIONAL FORM ($\sim 25 \div 30$ PARMS. GLOBALLY) AND FIT PARMS TO DATA
- UNCERTAINTIES DETERMINED FROM HESSIAN MATRIX AT MINIMUM
- STANDARD $\Delta\chi^2 = 1$ BANDS TOO NARROW $\Rightarrow$ LARGE DISCREPANCIES FOR INDIVIDUAL EXPERIMENTS
- TOLERANCE $\Rightarrow$ ENVELOPE OF UNCERTAINTIES OF EXPERIMENTS
- DYNAMICAL $\Rightarrow$ SEPARATELY DETERMINED FOR EACH HESSIAN EIGENVECTOR

MINIMUM χ_i^2 VS GLOBAL χ^2

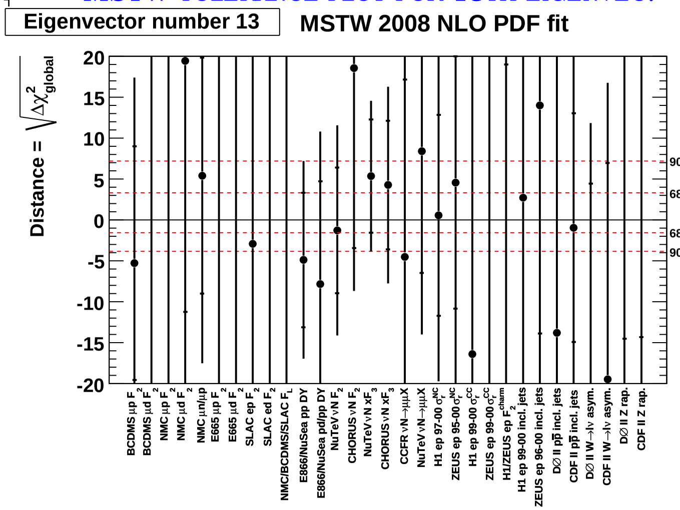


Collins, Pumplin 2001

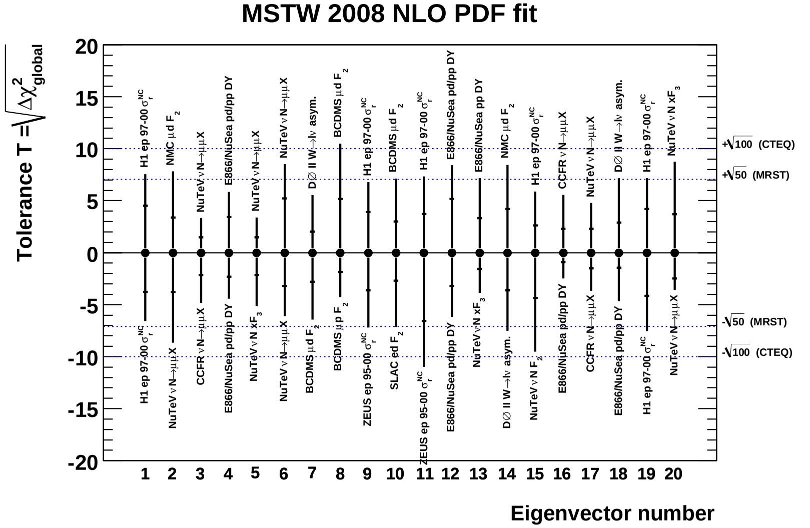
CTEQ TOLERANCE PLOT FOR 4TH EIGENVEC.



MSTW TOLERANCE PLOT FOR 13TH EIGENVEC.



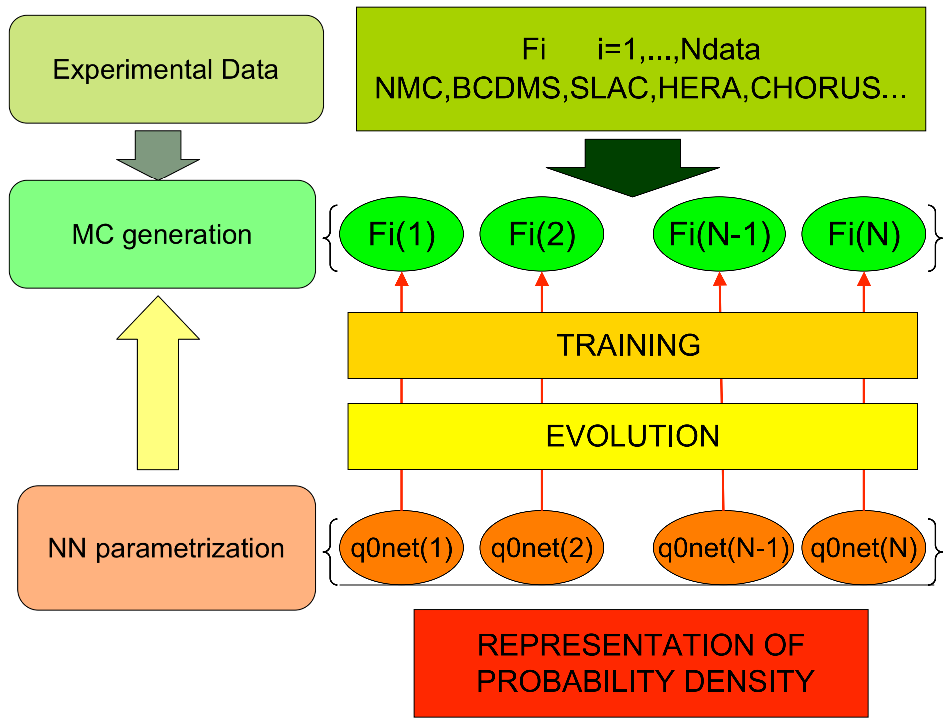
GLOBAL MSTW TOLERANCE



METHODOLOGY: NNPDF APPROACH

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

- START FROM MONTE CARLO SAMPLING OF DATA SPACE
- EACH PDF↔ NEURAL NETWORK PARAMETRIZED BY 37 PARAMETERS (NNPDF2.0: $37 \otimes 7 = 259$ PARMS)
  "INFINITE" NUMBER OF PARAMETERS⇒ CAN REPRESENT ANY FUNCTION
- FIT STOPS WHEN QUALITY OF FIT TO RANDOMLY SELECTED "VALIDATION" DATA (NOT FITTED) STOPS IMPROVING



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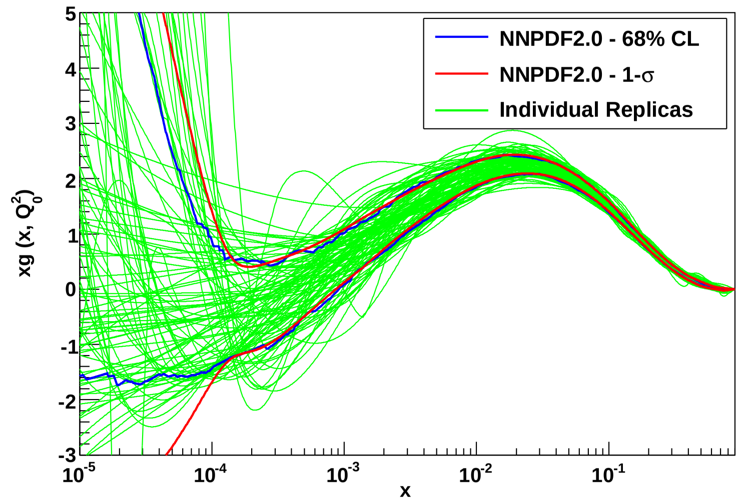
CAN DETERMINE BOTH 68C.L.& 1-σ



PDF UNCERTAINTIES:
DO THEY HAVE A STATISTICAL MEANING?

SOMETIMES STATED THAT "PDF UNCERTAINTIES ARE THEORETICAL UNCERTAINTIES" (THUS DEVOID OF STATISTICAL MEANING) IS IT TRUE?

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A WAY OF TESTING:

NEW DATA $\Rightarrow$ BAYES' THEOREM

$$\langle \mathcal{O} \rangle_{\rm new} = \int \mathcal{O}[f]\, \mathcal{P}_{\rm new}(f)\, Df, = \mathcal{N}_\chi \int \mathcal{O}[f]\, \mathcal{P}(\chi^2|f)\mathcal{P}_{\rm old}(f)\, Df,$$

IN A MONTE CARLO APPROACH...

$$\langle \mathcal{O} \rangle_{\rm new} = \frac{1}{N_{\rm rep}} \sum_{k=1}^{N_{\rm rep}} \mathcal{N}_\chi \mathcal{P}(\chi^2|f_k)\mathcal{O}[f_k] = \frac{1}{N_{\rm rep}} \sum_{k=1}^{N_{\rm rep}} w_k\, \mathcal{O}[f_k], \quad w_k = \mathcal{N}(\chi^2_k)^{n/2-1} e^{-\frac{1}{2}\chi^2_k}$$

$\Rightarrow$ EFFECT OF NEW DATA IS ACCOUNTED FOR BY REWEIGHTING MONTE CARLO AVERAGES

(CAN ALSO BE IMPLEMENTED IN HESSIAN FRAMEWORK (de Lorenzi, McNulty, 2010-2011))

- DETERMINE PDFS INCLUDING SOME DATA BY BAYES' THEOREM (REWEIGHTING)
- DETERMINE PDFS BY ENLARGING THE DATASET TO THE NEW DATA (REFITTING)
- COMPARE RESULTS $\Rightarrow$ IF THEY AGREE, PDFS DO HAVE A STATISTICAL INTERPRETATIONS ALRIGHT!

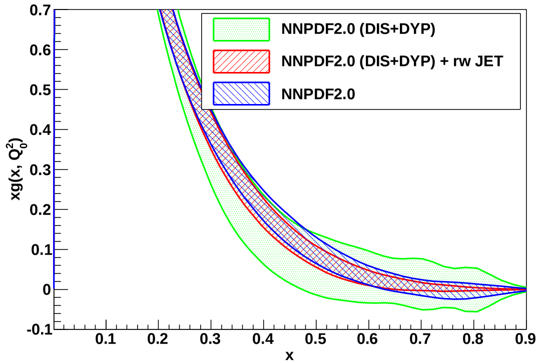
RUNNING THE TEST

INCLUSION OF JET DATA: REWEIGHTING VS. REFITTING

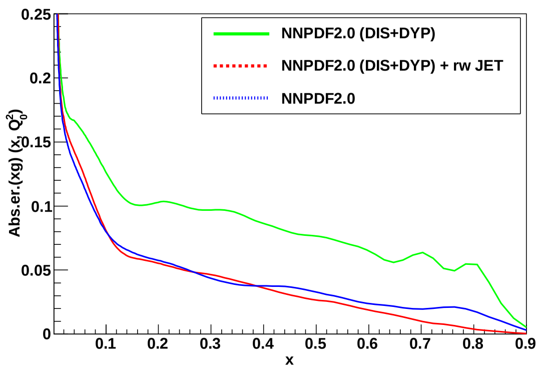
NNPDF2.0DIS+DY VS. NNPDF2.0FULL

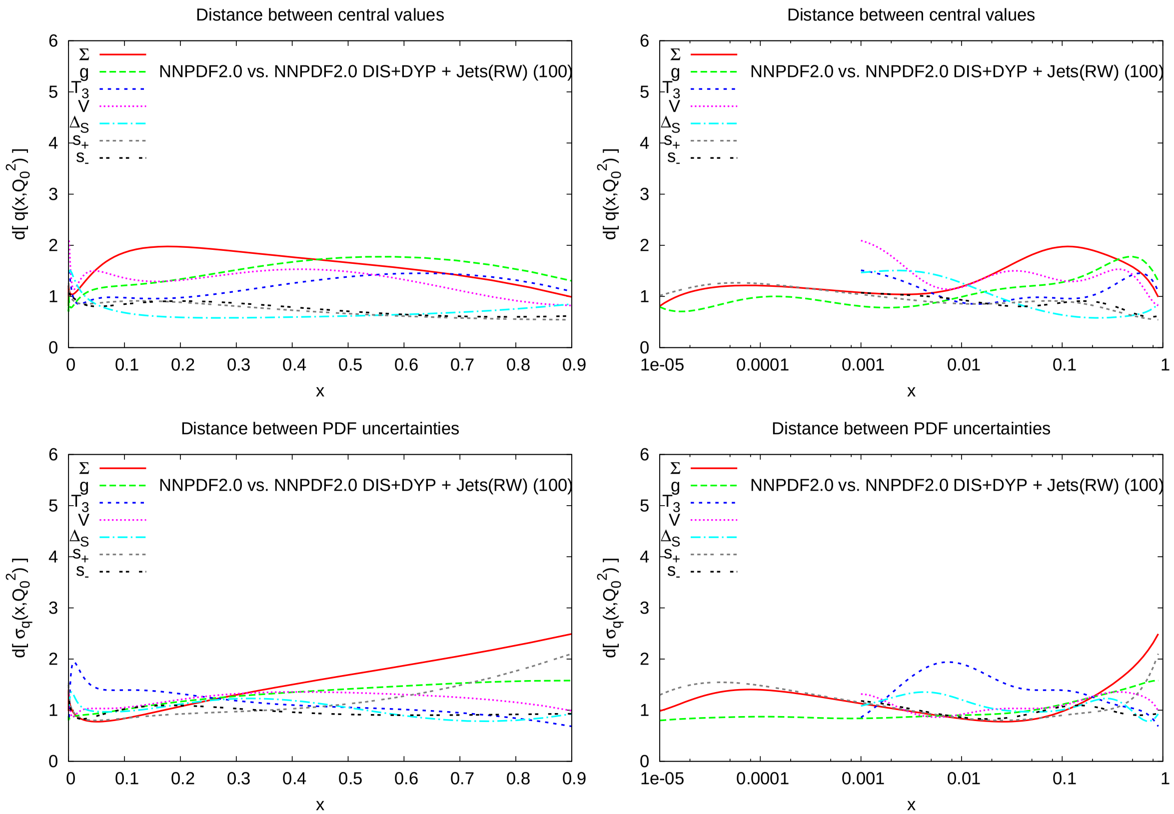
DISTANCES

GLUON



GLUON UNCERTAINTY





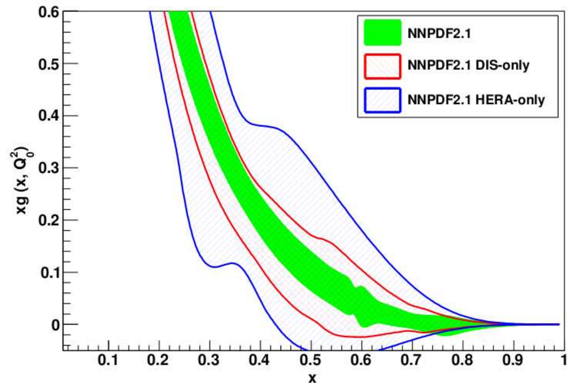
$d \sim 1 \Rightarrow$ STATISTICAL EQUIVALENCE
($d = n \Leftrightarrow n\ \sigma$ DISCREPANCY)

STATISTICAL INTERPRETATION VALIDATED

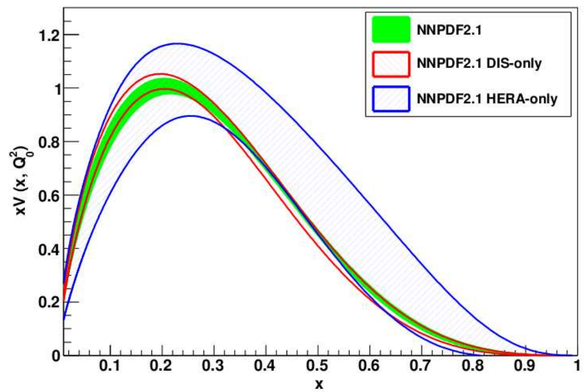
DATA CONSISTENCY: WHY WE NEED IT

- DIS ONLY FIT $\Rightarrow$ SIGNIFICANT LOSS IN ACCURACY
- LARGE x GLUON: NEED JETS
- LIGHT AND STRANGE FLAVOUR SEPARATION: NEEDS DRELL-YAN AND W PRODUCTION

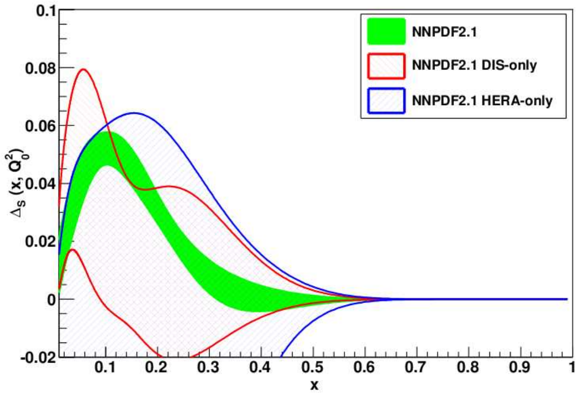
GLUON



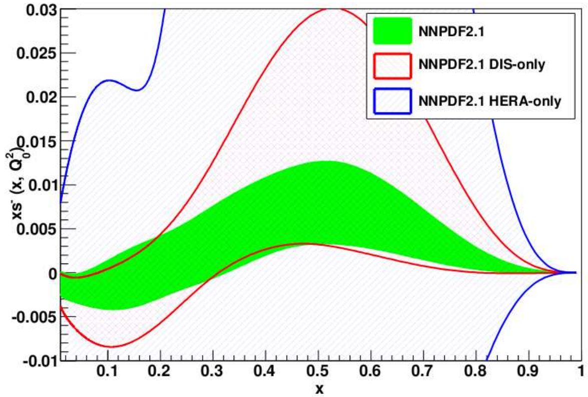
VALENCE



SEA ASYM: $\bar{u} - \bar{d}$



STRANGE: $s - \bar{s}$



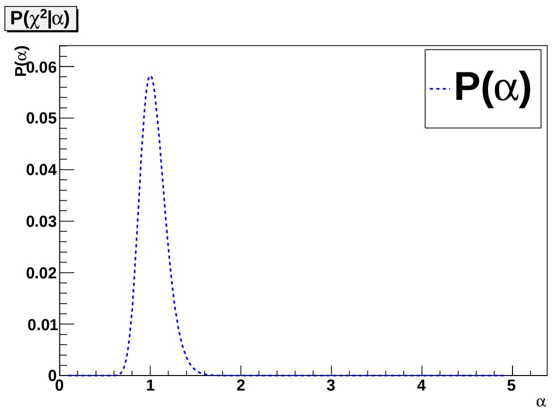
DATA CONSISTENCY: HOW TO TEST FOR IT

- INCONSISTENT DATA $\Leftrightarrow$ UNDERESTIMATED UNCERTAINTIES

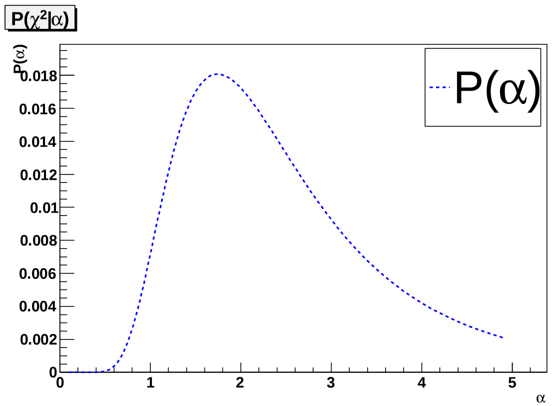
- RESCALE ALL UNCERTAINTIES IN A GIVEN EXPERIMENT BY SOME FACTOR α: $\chi^2_\alpha = \chi^2/\alpha$ (TOLERANCE)

- DETERMINE PROBABILITY DISTRIBUTION OF α VALUES BY BAYES' THEOREM $\Rightarrow$ REWEIGHTING: $\mathcal{P}(\alpha) = \frac{\mathcal{N}}{\alpha}\sum_{k=1}^{N} w_k w_k(\alpha)$.

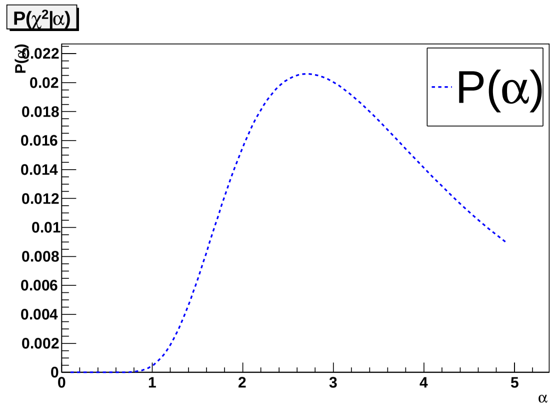
JETS



D0 e INCLUSIVE



D0 e HIGH E_T



- JETS: $\Rightarrow$ CONSISTENT DATA

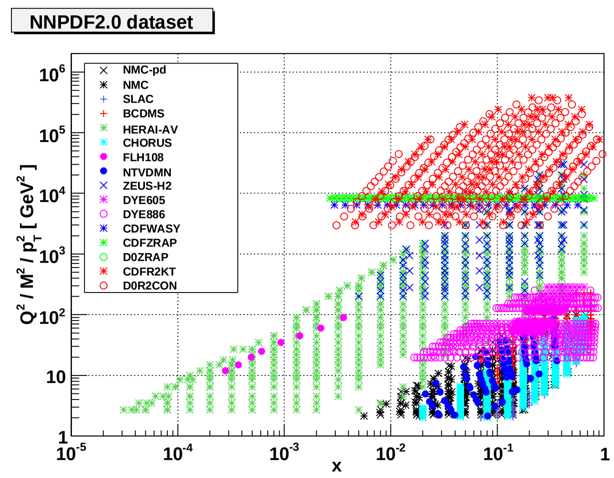
- $W^\pm$ CHARGE ASYMMETRIES, D0 INCLUSIVE e DATA $\Rightarrow$ UNCERTAINTIES UNDERESTIMATED BY $\sim 30\%$ (PROB. PEAKS AT $\alpha \sim 1.7$)

- $W^\pm$ CHARGE ASYMMETRIES, D0 e DATA WITH $E_T > 35$ GEV $\Rightarrow$ INCONSISTENT DATA

DATA $\Rightarrow$ PDFs

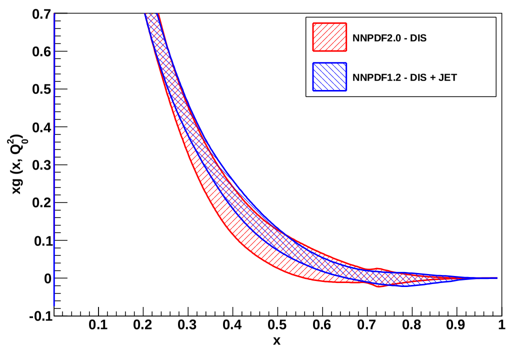
THE GLUON:
THE IMPACT OF JET DATA (NNPDF2.0)

	DIS	DIS+JET	NNPDF2.0
χ^2_{tot}	1.20	1.18	1.21
NMC-pd	0.85	0.86	0.99
NMC	1.69	1.66	1.69
SLAC	1.37	1.31	1.34
BCDMS	1.26	1.27	1.27
HERAI	1.13	1.13	1.14
CHORUS	1.13	1.11	1.18
FLH108	1.51	1.49	1.49
NTVDMN	0.71	0.75	0.67
ZEUS-H2	1.50	1.49	1.51
CDFR2KT	**0.91**	**0.79**	0.80
D0R2CON	**1.00**	**0.93**	0.93
DYE605	7.32	10.35	0.88
DYE866	2.24	2.59	1.28
CDFWASY	13.06	14.13	1.85
CDFZRAP	3.12	3.31	2.02
D0ZRAP	0.65	0.68	0.47

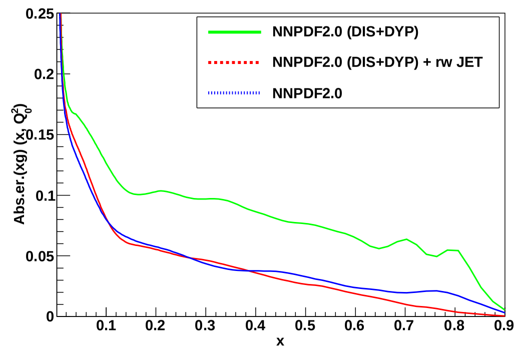


- HIGH E_T JET DATA WELL REPRODUCED EVEN WHEN NOT FITTED $\Rightarrow$
  LARGE x GLUON WELL DETERMINED BY SCALING VIOLATIONS!
- SIGNIFICANT IMPROVEMENT GLUON ACCURACY FOR $0.1 \lesssim x \lesssim 0.7$

GLUON



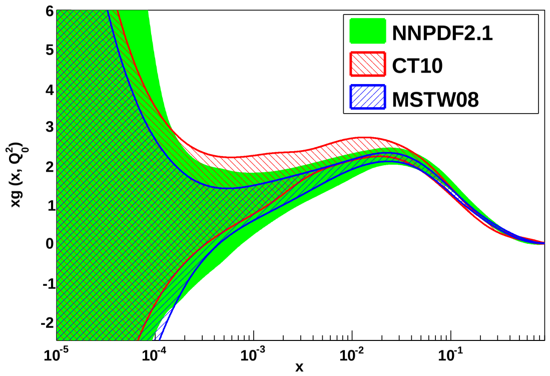
GLUON UNCERTAINTY



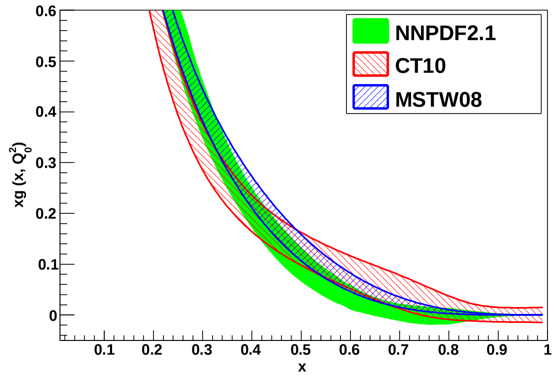
JETS AT THE LHC

- FOR SAME p_T & RAPIDITY, TEVATRON $\rightarrow$ LHC, $x \rightarrow x/7$
- LARGEST IMPACT EXPECTED IN MEDIUM–x REGION $0.05 \lesssim x \lesssim 0.2$
- CURRENTLY SOME DISAGREEMENT IN THIS REGION

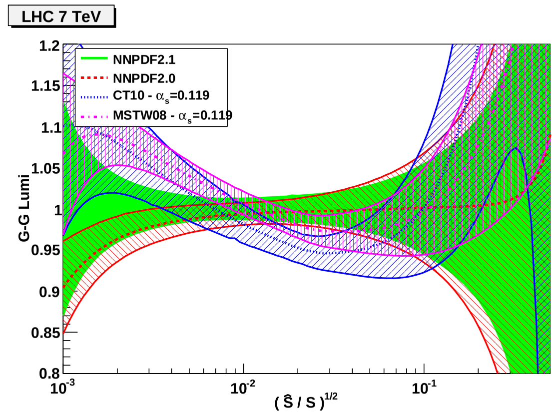
GLUON SMALL x



GLUON LARGE x



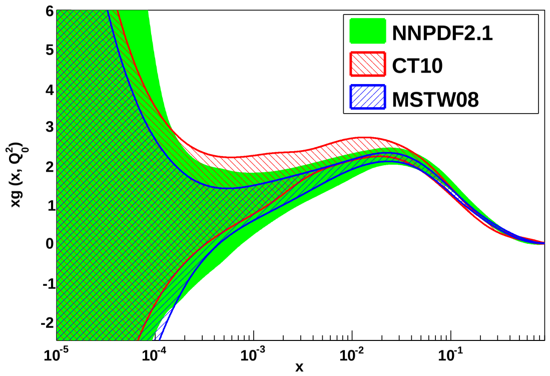
GLUON-GLUON LUMI



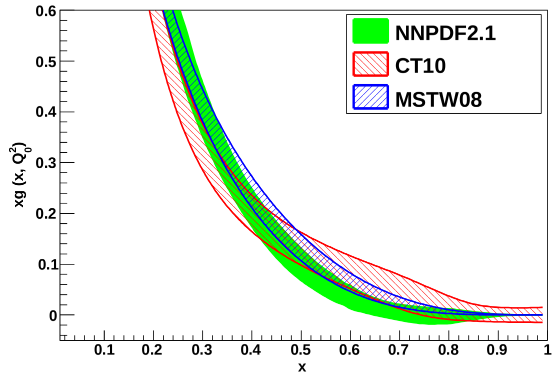
JETS AT THE LHC

- FOR SAME p_T & RAPIDITY, TEVATRON $\to$ LHC, $x \to x/7$
- LARGEST IMPACT EXPECTED IN MEDIUM–x REGION $0.05 \lesssim x \lesssim 0.2$
- CURRENTLY SOME DISAGREEMENT IN THIS REGION

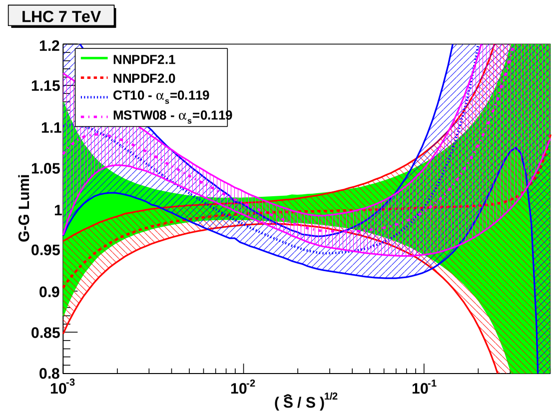
GLUON SMALL x



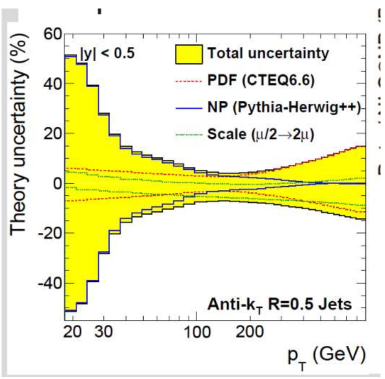
GLUON LARGE x

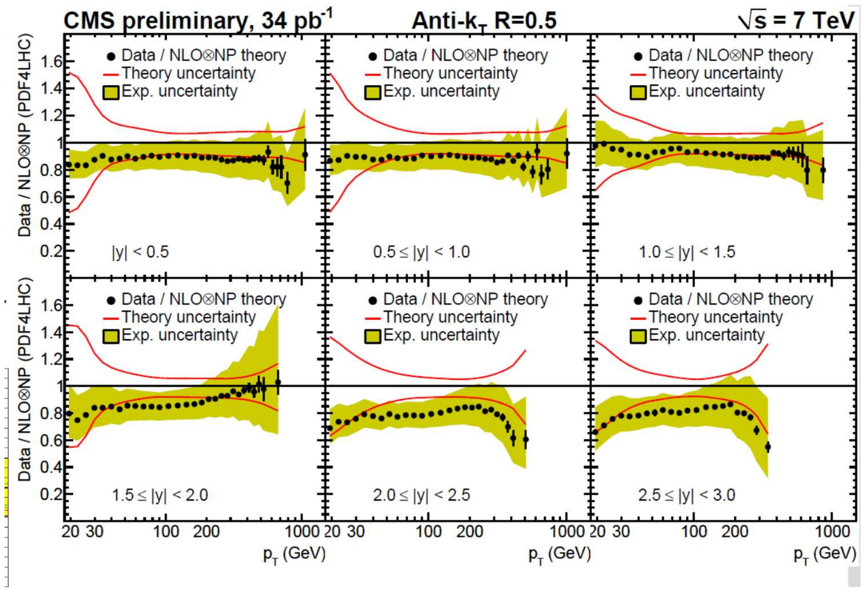


GLUON-GLUON LUMI



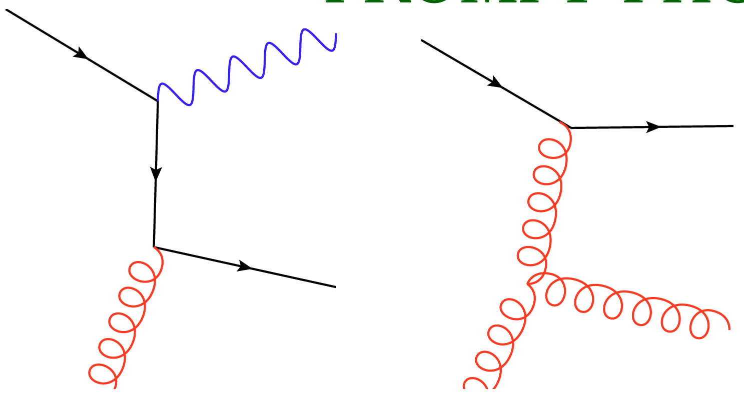
PRELIMINARY CMS DATA



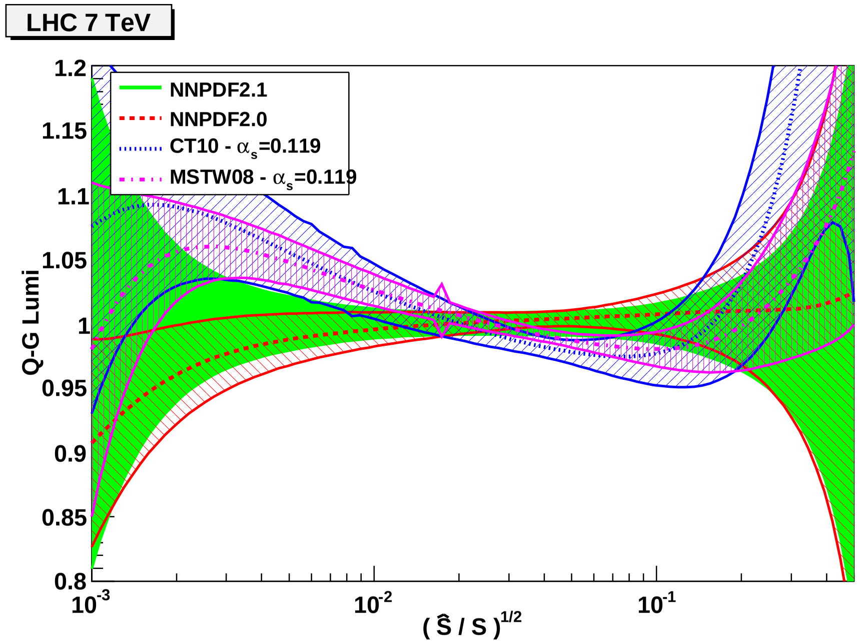


SYSTEMATICS LARGE, BUT GETTING THERE...

PROMPT PHOTON PRODUCTION

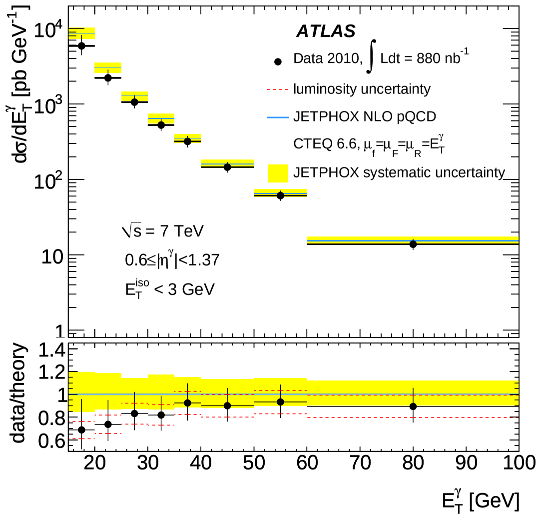


QUARK-GLUON LUMI

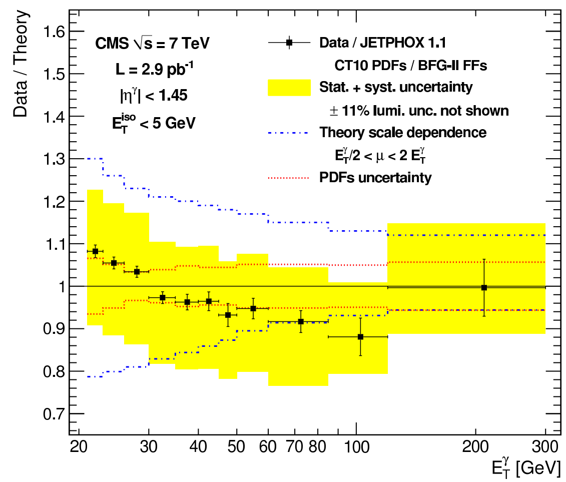


- DIRECT PROBE OF THE qg LUMINOSITY
- $x_1 x_2 = \frac{4p_T^2}{s}$: if $50 \lesssim p_T \lesssim 200$ GeV then $10^{-4} \lesssim x_1 x_2 \lesssim 10^{-3}$
- MEASURED BY CMS+ATLAS, POSSIBLE PROBLEMS RESTRICTED TO SMALL p_T REGION

ATLAS



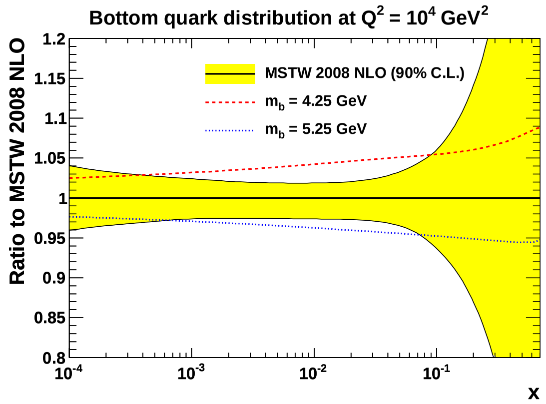
CMS



TOP PRODUCTION

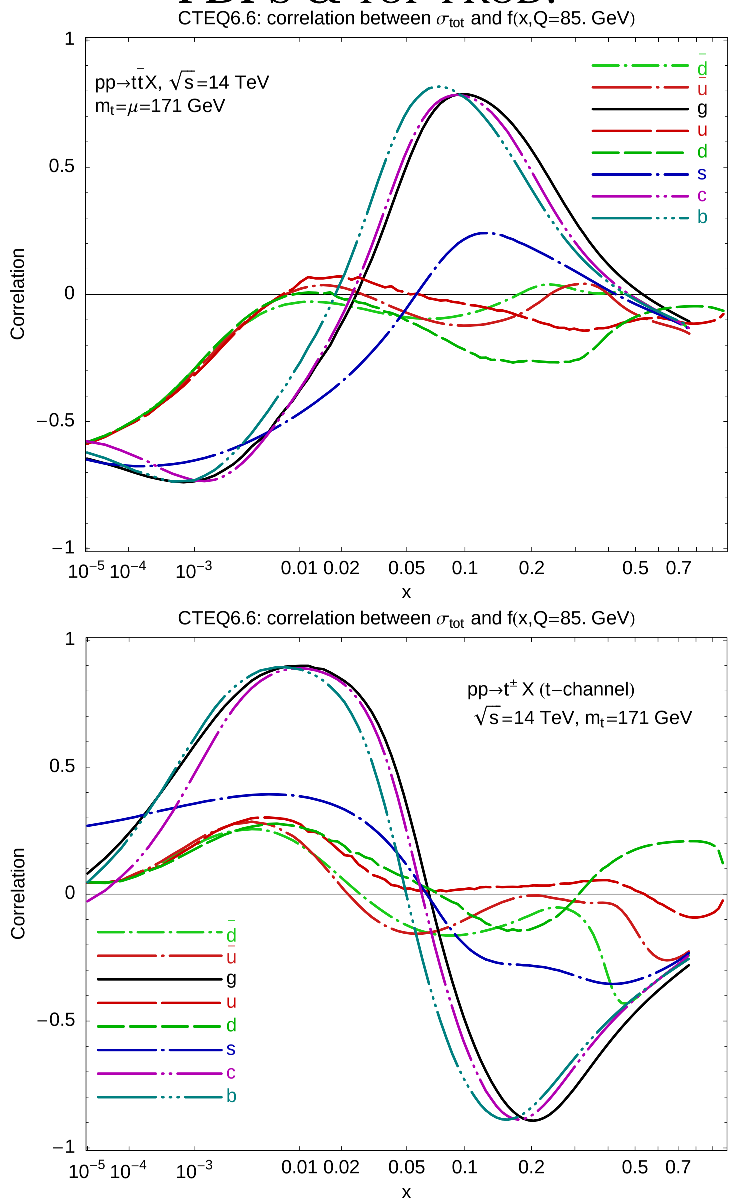
- $t\bar{t}$ STRONGLY CORRELATED TO ALL PDFs
- SINGLE TOP STRONGLY CORRELATED TO GLUON & HEAVY FLAVORS
- SENSITIVE PROBE OF GLUON
- HIGH SENSITIVITY TO b MASS & PDF

B VS M_b



(MSTW, 2010)

CORRELATION BETWEEN PDFs & TOP PROD.

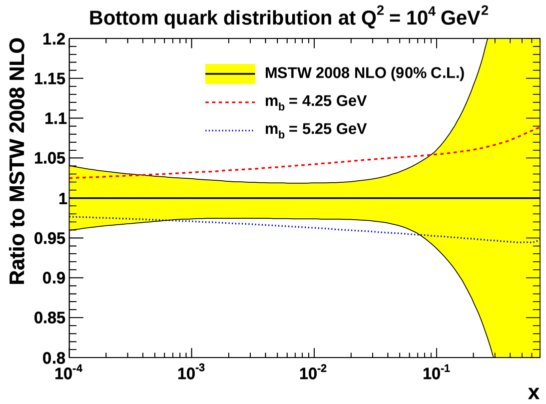


(CT10, 2010)

TOP PRODUCTION

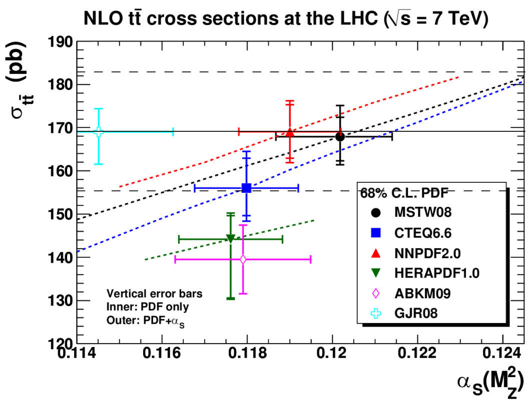
- $t\bar{t}$ STRONGLY CORRELATED TO ALL PDFs
- SINGLE TOP STRONGLY CORRELATED TO GLUON & HEAVY FLAVORS
- SENSITIVE PROBE OF GLUON
- HIGH SENSITIVITY TO b MASS & PDF
- ALREADY DISCRIMINATES BETWEEN PDFs

B VS M_b

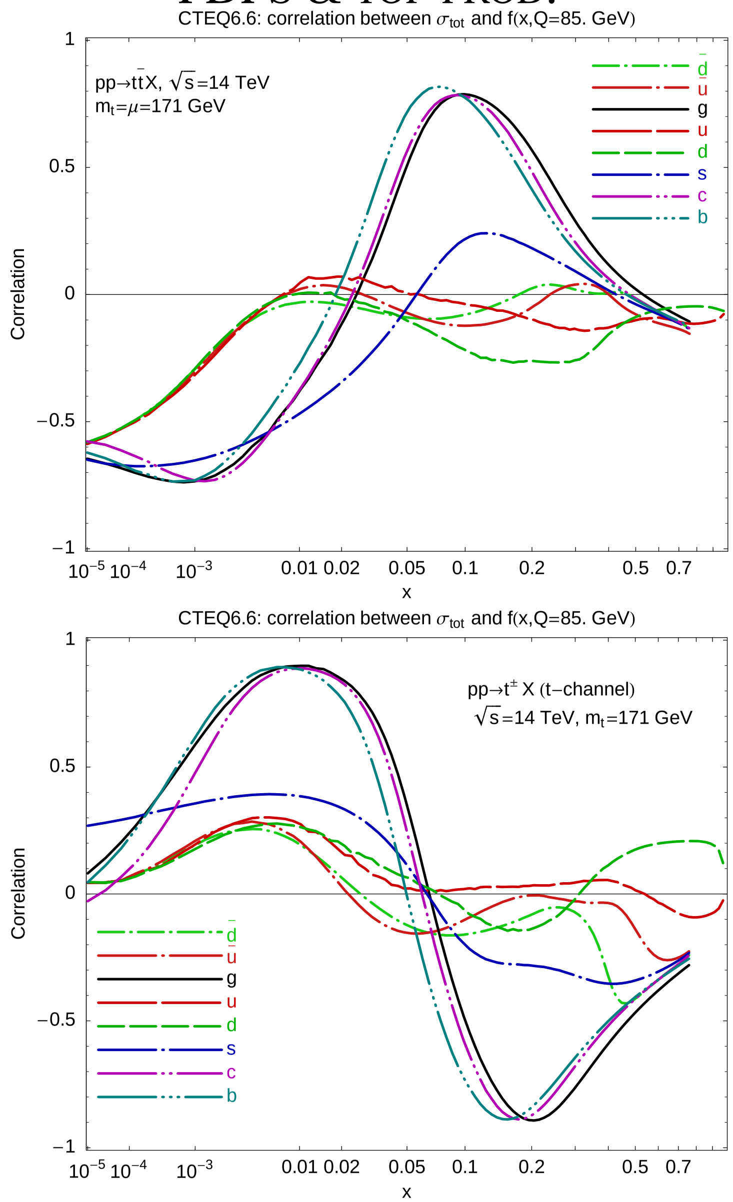


(MSTW, 2010)

$t\bar{t}$ ATLAS+CMS PRELIM. COMB. VS TH.



CORRELATION BETWEEN PDFs & TOP PROD.



(CT10, 2010)

FLAVOR SEPARATION: DIS VS. DRELL-YAN

DIS

NC	$F_1{}^{\gamma} = \sum_i e_i^2\,(q_i + \bar{q}_i)$
NC	$F_1{}^{Z,\,\mathrm{int.}} = \sum_i B_i(Q^2/M_Z^2)\,(q_i + \bar{q}_i)$
NC	$F_3{}^{Z,\,\mathrm{int.}} = \sum_i D_i(Q^2/M_Z^2)\,(q_i + \bar{q}_i)$
CC	$F_1^{W^+} = \bar{u} + d + s + \bar{c}$
CC	$-F_3^{W^+}/2 = \bar{u} - d - s + \bar{c},$

DRELL-YAN

γ	$\frac{d\sigma}{dM_X^2\,dy}(M_X^2, y) = \frac{4\pi\alpha^2}{9M_X^2\,s}\sum_i e_i^2 L^{ii}(x_1^0, x_2^0)$
W	$\frac{d\sigma}{dy} = \frac{\pi G_F M_V^2\sqrt{2}}{3s}\sum_{i,j}\lvert V_{ij}^{\mathrm{CKM}}\rvert L^{ij}(x_1^0, x_2^0)$
Z	$\frac{d\sigma}{dy} = \frac{\pi G_F M_V^2\sqrt{2}}{3s}\sum_i \left(V_i^2 + A_i^2\right) L^{ii}(x_1^0, x_2^0)$

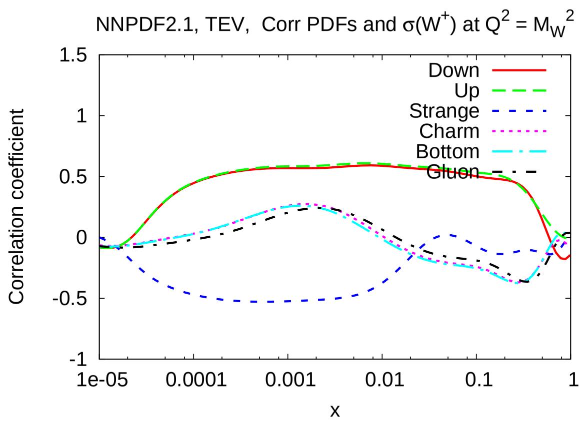
$$L^{ij}(x_1, x_2) \equiv q_i(x_1, M_X^2)\bar{q}_j(x_2, M_X^2) + q_i(x_2, M_X^2)\bar{q}_j(x_1, M_X^2)$$

- FIXED TARGET DIS $\Rightarrow$ SINGLET-TRIPLET SEPARATION $F_2^p - F_2^d = \frac{1}{3}[(u^p + \bar{u}^p) - (d^p + \bar{d}^p]$
- HERA THREE INDEPENDENT COMBINATIONS OF PDFS (NC+CC WITH $e^{\pm}$), ONE MORE FROM Q^2 OF Z CONTRIBUTION $\Rightarrow$ u, $\bar{u}$, $d + s$, $\bar{d} + \bar{s}$
  - F_2^c $\Rightarrow$ CHARM
- NEUTRINO DIS $\Rightarrow$ FOUR COMBINATIONS OF PDFS (NC+CC WITH ν, $\bar{\nu}$)
  - "DIMUON" $F_2^{\nu,\,c}$, $F_2^{\bar{\nu},\,c}$ $\Rightarrow$ STRANGE AND ANTISTRANGE
- FIXED TARGET DRELL-YAN (P AND NUCLEAR TARGETS) $\Rightarrow$ ANTIUP/ANTIDOWN SEPARATION
- W AND Z PRODUCTION $\Rightarrow$ UP/DOWN FLAVOR ASYMMETRIES; STRANGENESS

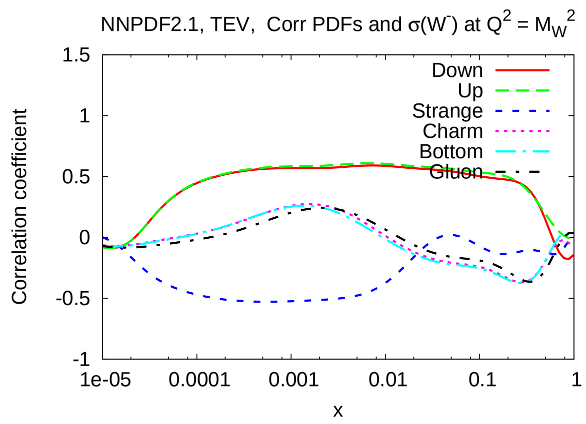
CORRELATIONS: INCLUSIVE DRELL-YAN VS. PDFS

TEVATRON

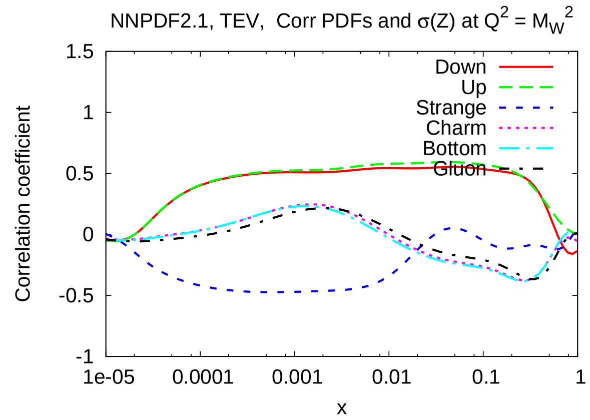
W^+



W^-

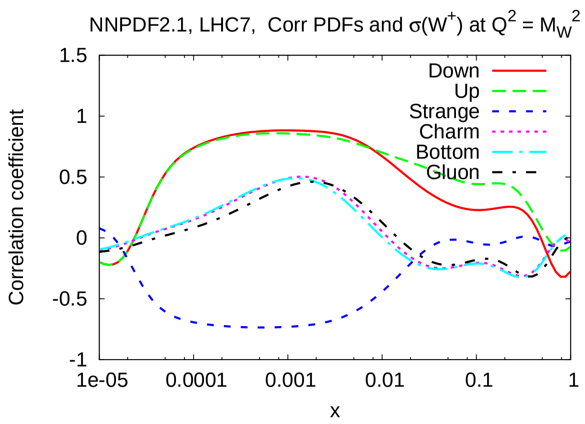


Z

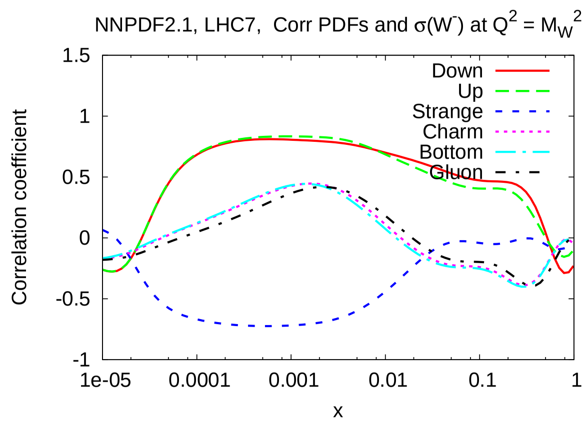


LHC

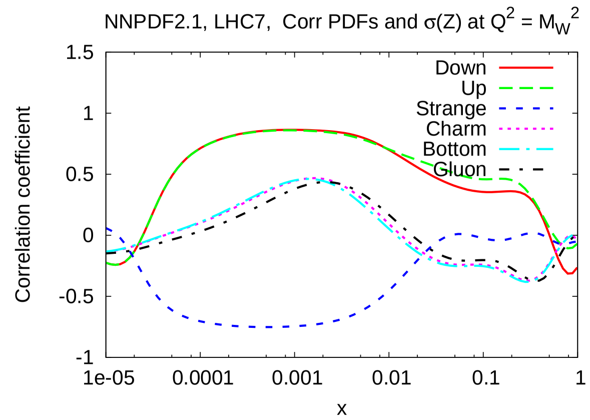
W^+



W^-



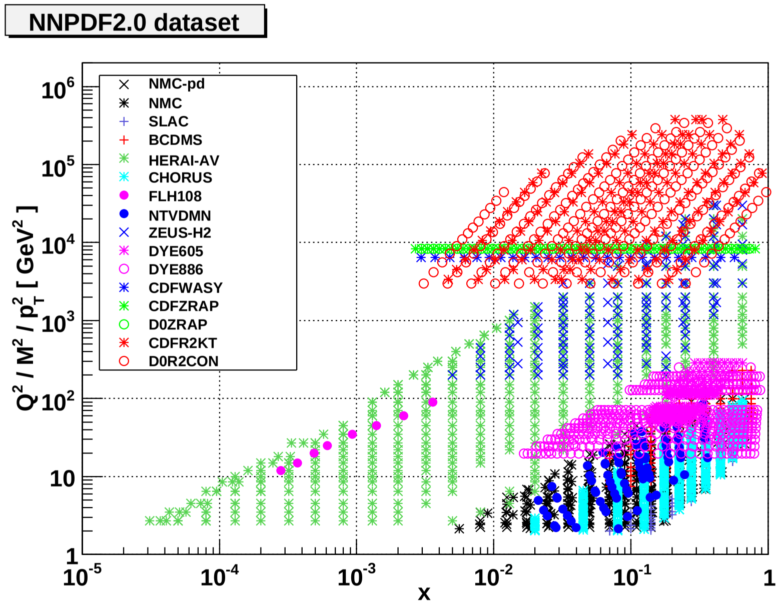
Z



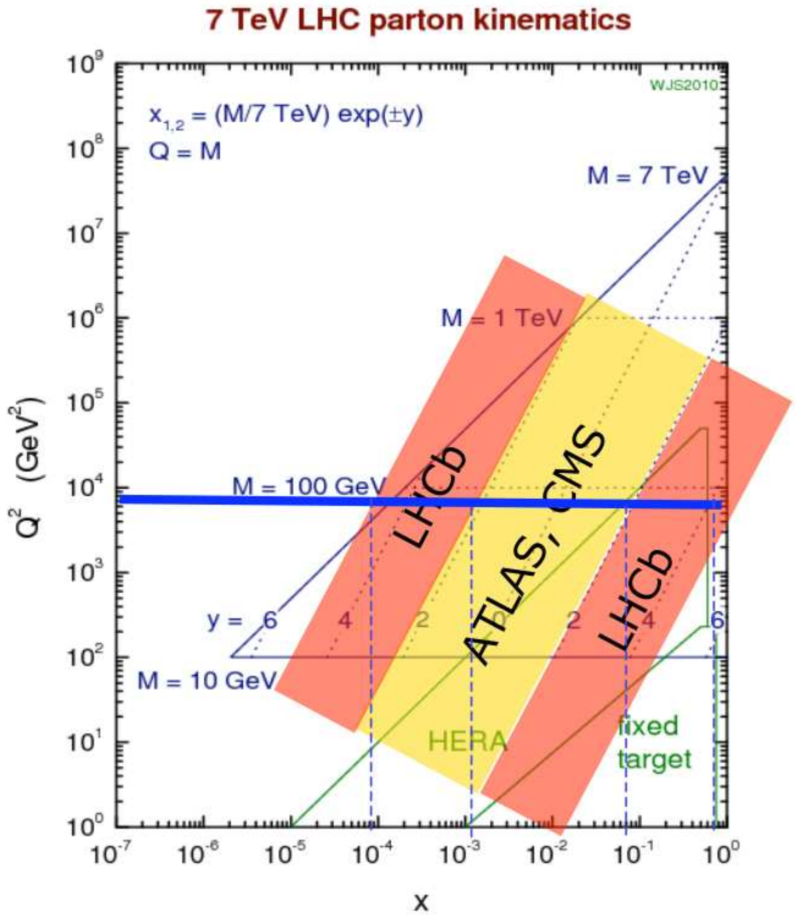
- LHC VS. TEVATRON $\Rightarrow$ CORRELNS. STRONGER IN WIDER KIN. REGION
- LIGHT FLAVORS $\Rightarrow$ LARGE CORRELATION IN WIDE RANGE $3 \cdot 10^{-5} \lesssim x \lesssim 0.3$
- GLUONS & HEAVY FLAVORS $\Rightarrow$ WEAKER CORRELN., MOSTLY AT MEDIUM-SMALL x

RAPIDITY DISTRIBUTIONS: KINEMATIC REGIONS

CURRENT FITS



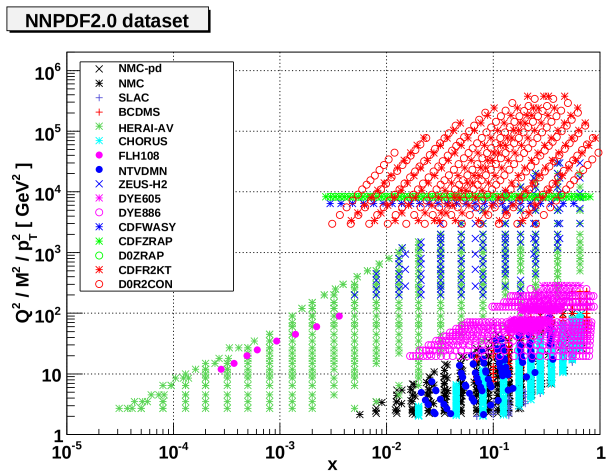
LHC



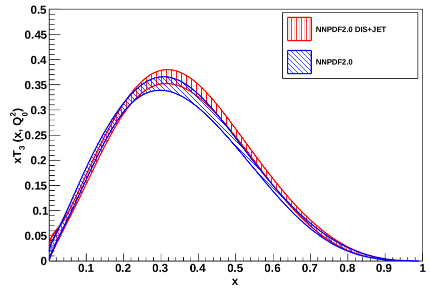
- ATLAS, CMS $\Rightarrow$ BROAD COVERAGE IN CENTRAL RAPIDITY REGION
- LHCb: OUTER RAPIDITY REGIONS $\Rightarrow$ SMALL AND LARGE x PDFs

TEVATRON DRELL-YAN+W-PROD. DATA(NNPDF2.0)

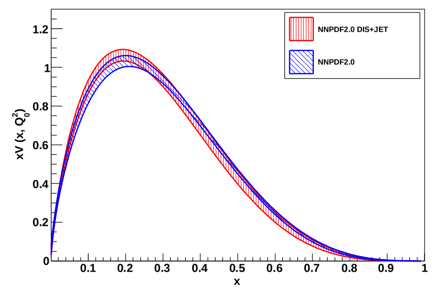
	DIS	DIS+JET	NNPDF2.0
$\chi^2_{\rm tot}$	1.20	1.18	1.21
NMC-pd	0.85	0.86	0.99
NMC	1.69	1.66	1.69
SLAC	1.37	1.31	1.34
BCDMS	1.26	1.27	1.27
HERAI	1.13	1.13	1.14
CHORUS	1.13	1.11	1.18
FLH108	1.51	1.49	1.49
NTVDMN	0.71	0.75	0.67
ZEUS-H2	1.50	1.49	1.51
CDFR2KT	0.91	0.79	0.80
D0R2CON	1.00	0.93	0.93
DYE605	7.32	**10.35**	**0.88**
DYE866	2.24	**2.59**	**1.28**
CDFWASY	13.06	**14.13**	**1.85**
CDFZRAP	3.12	**3.31**	**2.02**
D0ZRAP	0.65	**0.68**	**0.47**



ISOTRIPLET

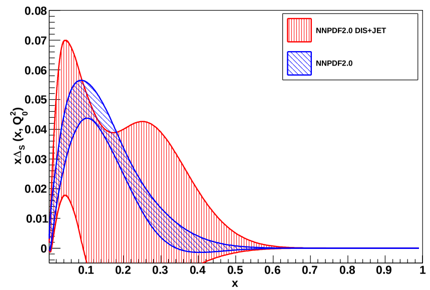


VALENCE

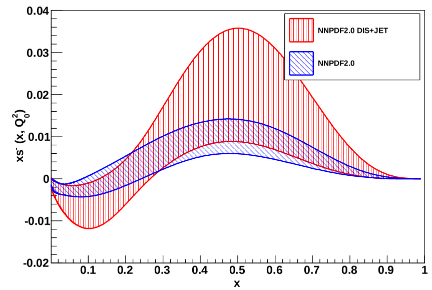


- VERY SUBSTANTIAL IMPROVEMENT IN FIT QUALITY WHEN DATA INCLUDED $\Rightarrow$ SOME PDF COMBINATIONS POORLY DETERMINED WITHOUT THESE DATA
- HUGE IMPROVEMENT IN SEA ASYM $\bar{u} - \bar{d}$ & STRANGENESS $s - \bar{s}$
- SIGNIFICANT IMPROVEMENT IN TOTAL VALENCE $(\sum_i (q_i - \bar{q}_i))$ & ISOTRIPLET $(u + \bar{u} - (d + \bar{d}))$

$\bar{d} - \bar{u}$



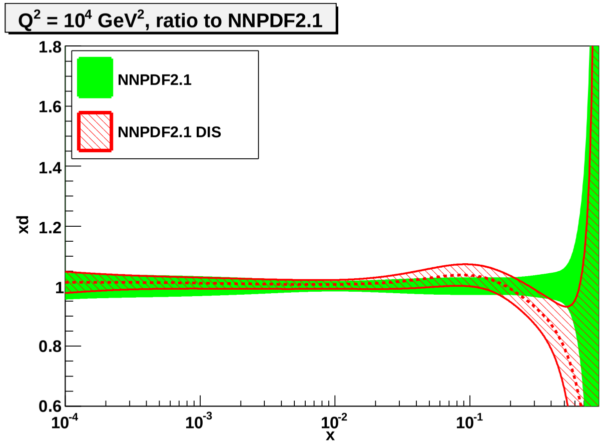
$s - \bar{s}$



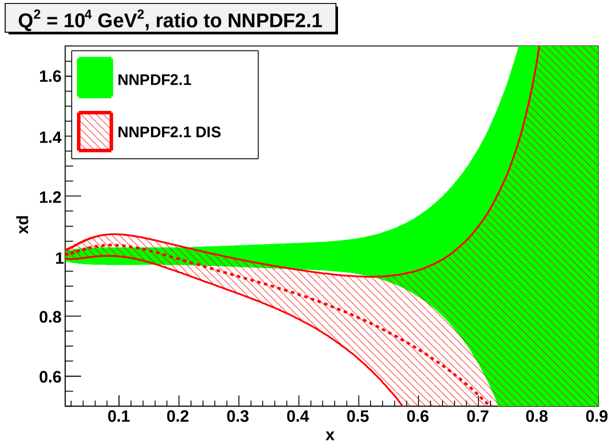
TEVATRON DRELL-YAN+W-PROD. DATA

DOWN

SMALL x



LARGE x

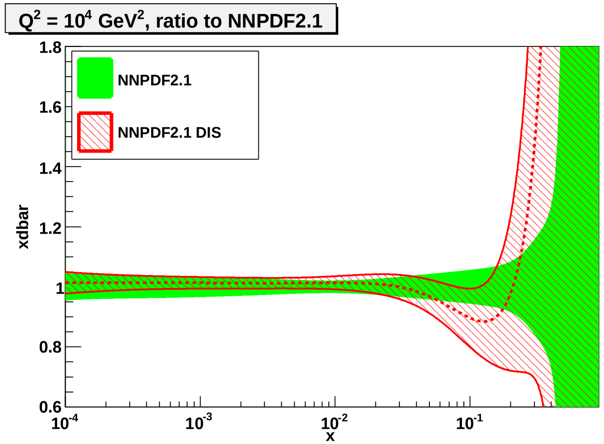


- WELL DETERMINED BY DIS AT SMALL X x
- SOME IMPROVEMENTS IN ACCURACY AT LARGE x
- TENSION BETWEEN DIS AND DY AT LARGE x

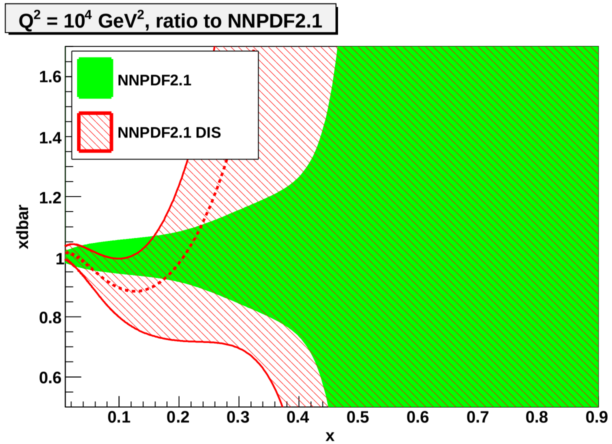
ANTIDOWN

- AT SMALL x ALL FLAVORS ARE ALIKE $\rightarrow$ WELL DETERMINED BY DIS DATA
- SOME TENSION BETWEEN DIS AND DY AT MEDIUM-SMALL x
- DRAMATIC IMPROVEMENT IN ACCURACY AT LARGE x

SMALL x



LARGE x



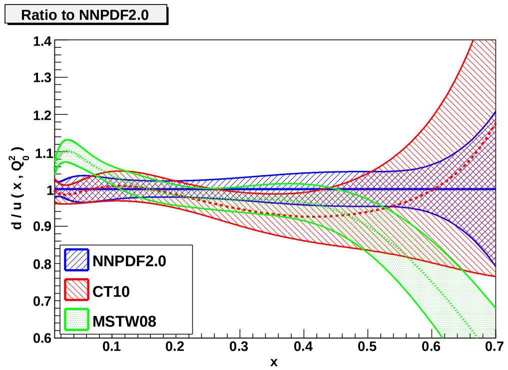
TENSION?

- SHAPES OF THE d QUARK FAVORED BY DIS AND DY DATA DO NOT AGREE
- IS THERE A PROBLEM WITH THE u/d RATIO?

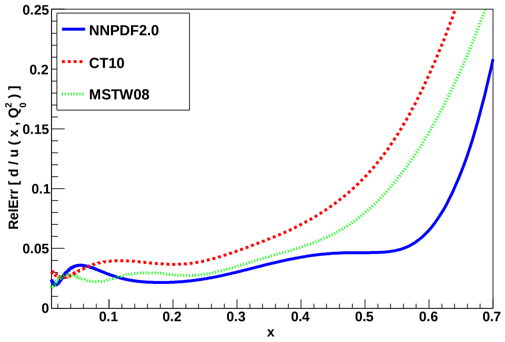
THE UP/DOWN RATIO

COMPARISON BETWEEN PDF SETS

u/d AT $Q^2 = 2$ GEV^2



RELATIVE UNCERTAINTY

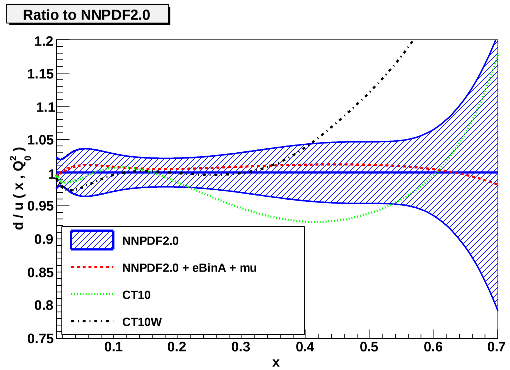


- u/d RATIO IN DIS DOMINATED BY BCDMS AND NMC DATA KNOWN TO HAVE CONSISTENCY PROBLEMS
- PERHAPS NUCLEAR CORRECTIONS & HIGHER TWISTS PLAY A ROLE IN NMC & BCDMS
- DIFFERENT PDF SETS BASED ON THE SAME DATA (BUT WITH DIFFERENT FIT QUALITY) IN PARTIAL DISAGREEMENT

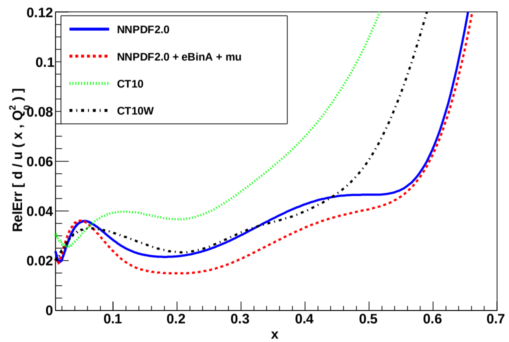
TEVATRON RUN II W ASYMMETRY DATA

- D0 RUN II LEPTON-LEVEL INCLUDED IN NNPDF2.1 VIA REWEIGHTING
- NNPDF: SIZABLE IMPROVEMENT IN FIT QUALITY
- CTEQ: NO GLOBALLY CONSISTENT FIT FOUND: CT10W WITH W DATA, CT10 WITHOUT

u/d AT $Q^2 = 2$ GEV^2



RELATIVE UNCERTAINTY



IMPACT OF THE TEVATRON DATA

- PRECISE W ASYMMETRY DATA DETERMINE THE u/d RATIO ACCURATELY
- EVENTUALLY, IT WOULD BE BETTER TO DO WITHOUT NMC/BCDMS DATA (NO LOW Q^2 DATA, NO NUCLEAR TARGETS)

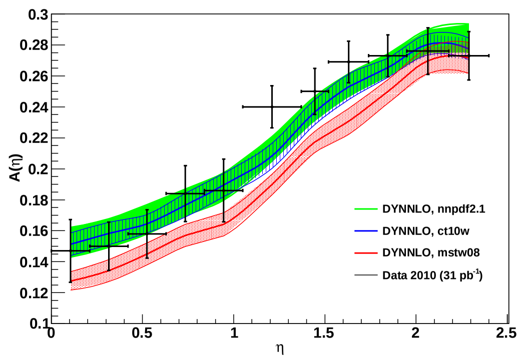
THE W LEPTON ASYMMETRY AT THE LHC

THE $p\bar{p} \to W^{\pm} \to l^{\pm}\nu$ ASYMMETRY: $A_\ell(y_\ell) = \frac{d\sigma(W^+)/dy_\ell - d\sigma(W^-)/dy_\ell}{d\sigma(W^+)/dy_\ell + d\sigma(W^-)/dy_\ell}$

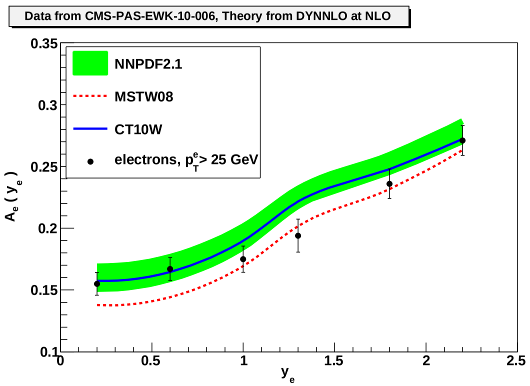
- ACCURATE ATLAS (arXiv:1103.2929) AND CMS (arXiv:1103.3470) DATA PUBLISHED
- LHCB PRELIMINARY DATA (UNCORRECTED FOR EW, NOT DISCUSSED HERE)

$\chi^2/N_{\rm dat}$ (EL)	ATLAS	CMS $p_T^l \geq 25$ GEV	CMS $p_T^l \geq 30$ GEV
NNPDF2.1	0.68	1.8	1.6
MSTW08	3.24	1.8	2.3
CT10W	0.81	1.2	1.3

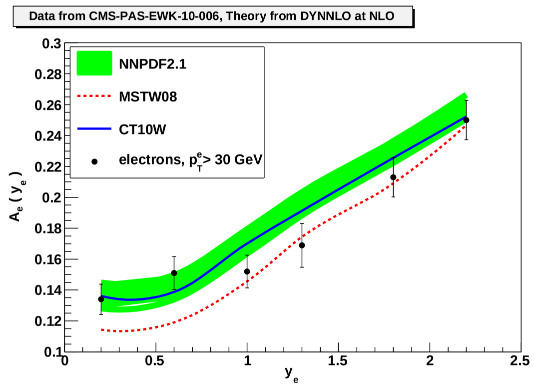
ATLAS



CMS $p_t > 25$ GEV

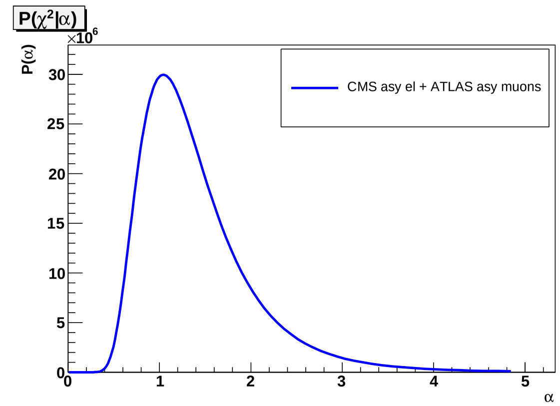


CMS $p_t > 30$ GEV



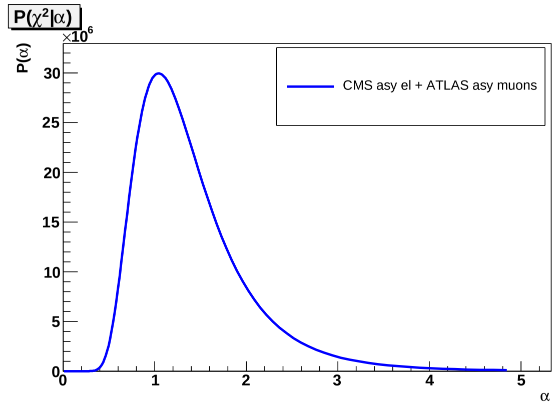
INCLUDING THE LHC W ASYMMETRY IN PDF FITS

- INCLUDED IN NNPDF2.1 USING REWEIGHTING
- CAN CHECK FOR CONSISTENCY

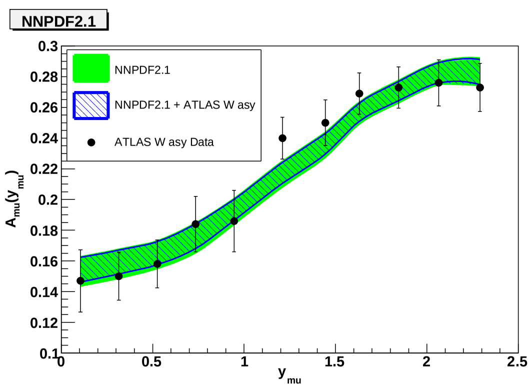


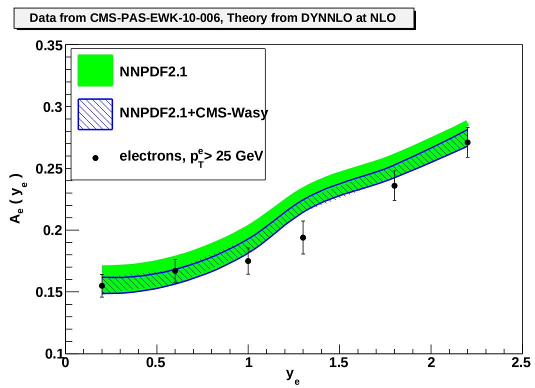
INCLUDING THE LHC W ASYMMETRY IN PDF FITS

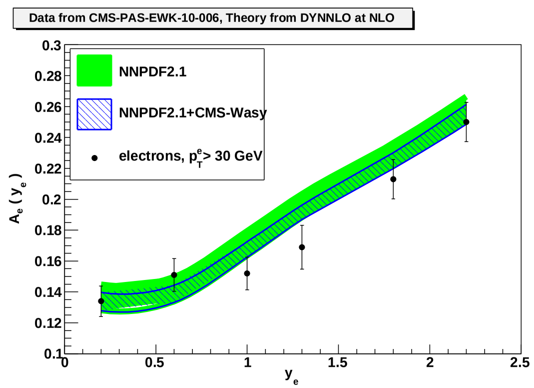
- INCLUDED IN NNPDF2.1 USING REWEIGHTING
- CAN CHECK FOR CONSISTENCY
- RECOMPUTE OBSERVABLES AFTER INCLUSION & VERIFIY FIT QUALITY



$\chi^2/N_{\rm dat}$ (EL)	ATLAS	CMS $p_T^l \geq 25$ GEV	CMS $p_T^l \geq 30$ GEV	ALL
NNPDF2.1	0.68	1.8	1.6	0.95
NNPDF2.1+EACH DATASET	0.63	1.03	1.16	-
NNPDF2.1+ALL DATA	-	-	-	0.92



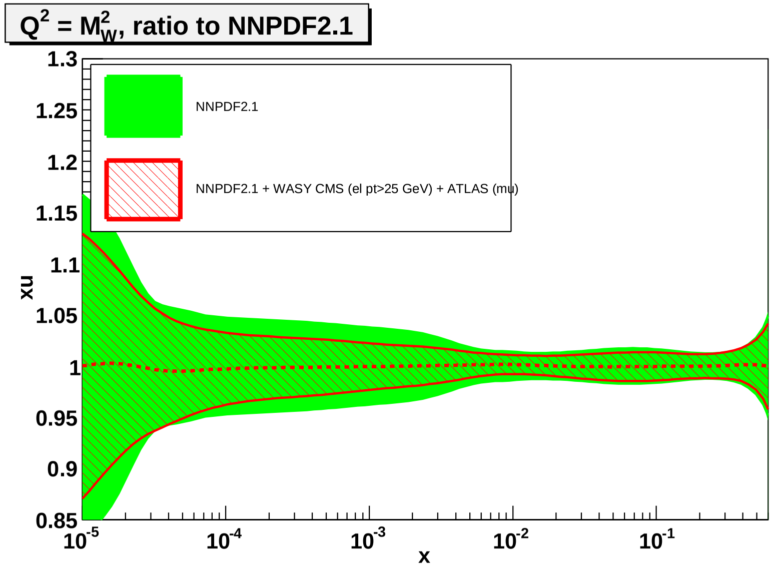




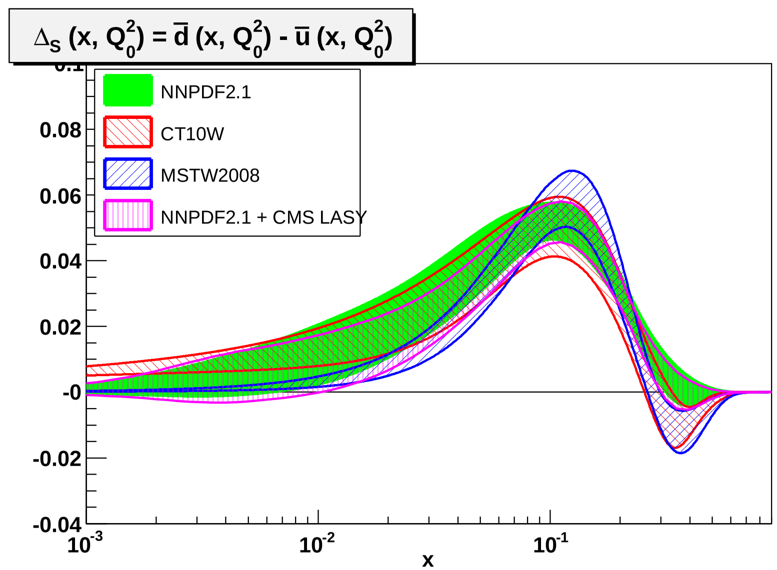
IMPACT OF THE LHC DATA
NNPDF2.1 PDFs

- ALL LIGHT QUARK UNCERTAINTIES REDUCED
- GOOD CONSISTENCY $\Rightarrow$
  - CENTRAL VALUES DON'T CHANGE MUCH
  - UNCERTAINTIES SHRINK
- OTHER PDF SETS: MAIN DIFFERENCE IS $\bar{u} - \bar{d}$ SHAP
  - NNPDF CENTRAL SHAPE UNCHANGED WITH SMALLER UNCERTAINTY
  - MSTW (CTEQ) SHAPE SOMEWHAT DIFFERENT $\Rightarrow$ DISFAVORED?

UP



$\bar{u} - \bar{d}$

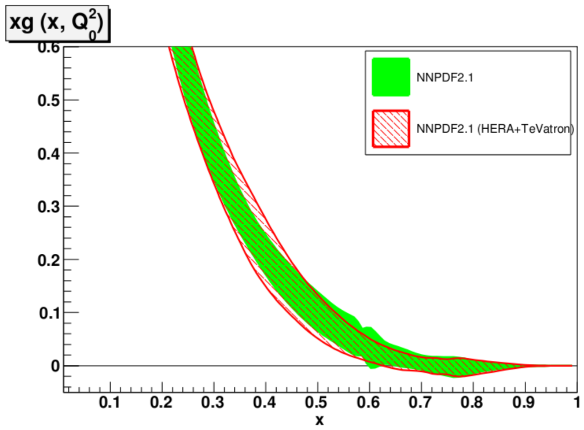


OUTLOOK

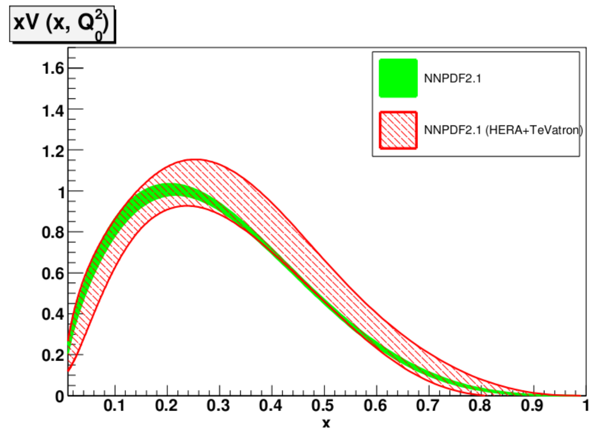
COLLIDER ONLY FITS

- NO FIXED TARGET DATA ⇔ NO LOW-ENERGY TROUBLE
- HERA+TEVATRON: GOOD ACCURACY FOR GLUON
- LOSS OF ACCURACY FOR FLAVOR SEPARATION
- HERA+LHC PDFs?

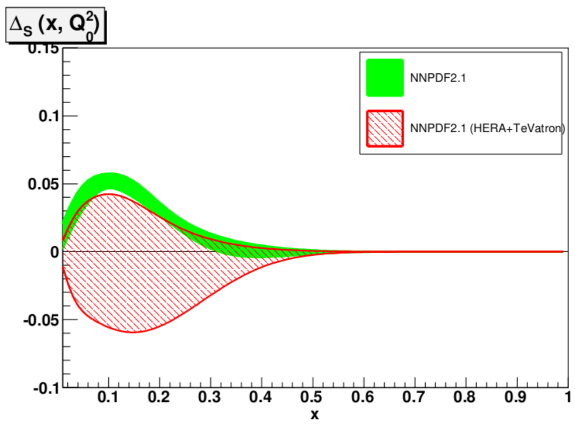
GLUON



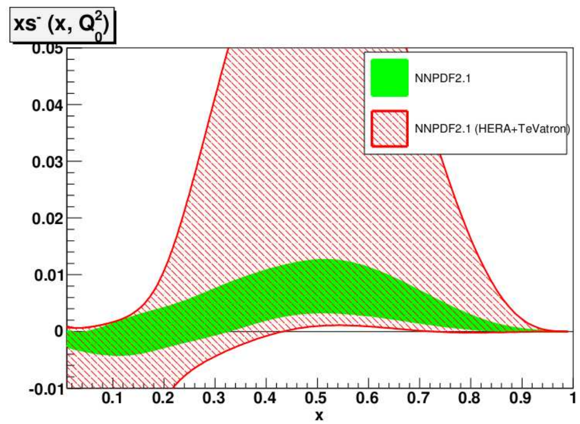
VALENCE



SEA ASYM: $\bar{u} - \bar{d}$



STRANGE: $s - \bar{s}$



WISHLIST ⇒ ROADMAP

- LHC CAN PROVIDE US PRECISION INFORMATION ON PDFS
- TOWARDS A “COLLIDER ONLY” HERA+LHC PDF FIT
  (TEVATRON DATA MIGHT BE SUPERFLUOUS)
  - MEDIUM & LARGE x GLUON
    - PROMPT PHOTONS AVAILABLE
    - (PRECISION) JETS IN PROGRESS
  - LIGHT FLAVORS AT MEDIUM @ SMALL x, FLAVOR SEPARATION @ SMALL x
    - LOW–MASS DRELL-YAN PRELIM.
    - Z RAPIDITY DISTRIBUTIONS PRELIM.
    - W ASYMMETRIES AVAILABLE
  - STRANGENES & HEAVY FLAVORS
    - STRANGENESS $\Rightarrow W + c$ FUTURE?
    - CHARM $\Rightarrow Z + c$, $\gamma + c$ FUTURE?
    - BOTTOM $Z + b$ IN PROGRESS

WISHLIST $\Rightarrow$ ROADMAP

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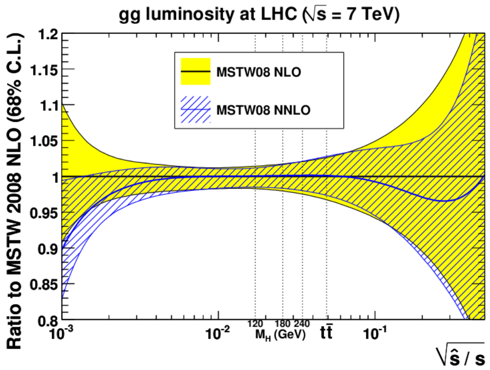
    * STRANGENESS $\Rightarrow W + c$ FUTURE?
    * CHARM $\Rightarrow Z + c$, $\gamma + c$ FUTURE?
    * BOTTOM $Z + b$ IN PROGRESS
- PRECISION "LEP" PHYSICS POSSIBLE @ LHC!
  - NEW PHYSICS FROM EW SECTOR
  - NEW QCD EFFECTS

EXTRAS

NNLO STATUS

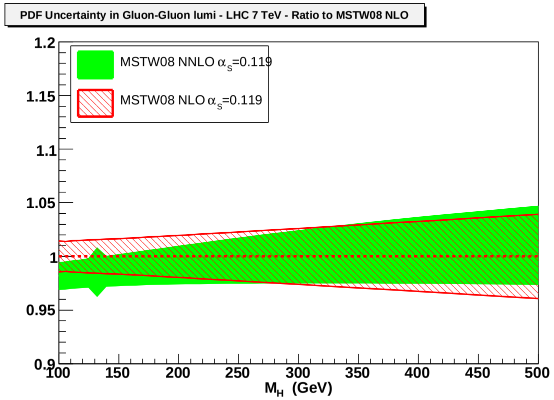
GLUON-GLUON PARTON LUMINOSITY

MSTW NNLO/NLO
best fit α_s



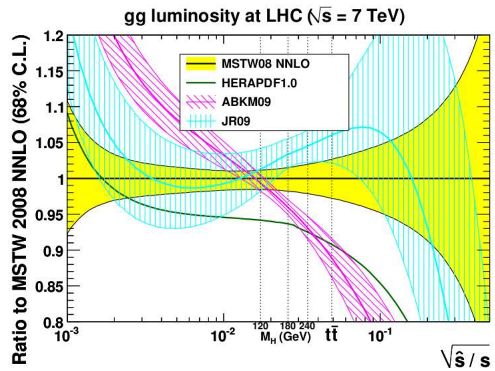
(G. Watt, 2011)

MSTW NNLO/NLO
fixed α_s



(J. Rojo, 2011)

LESS GLOBAL VS MSTW



(G. Watt, 2011)

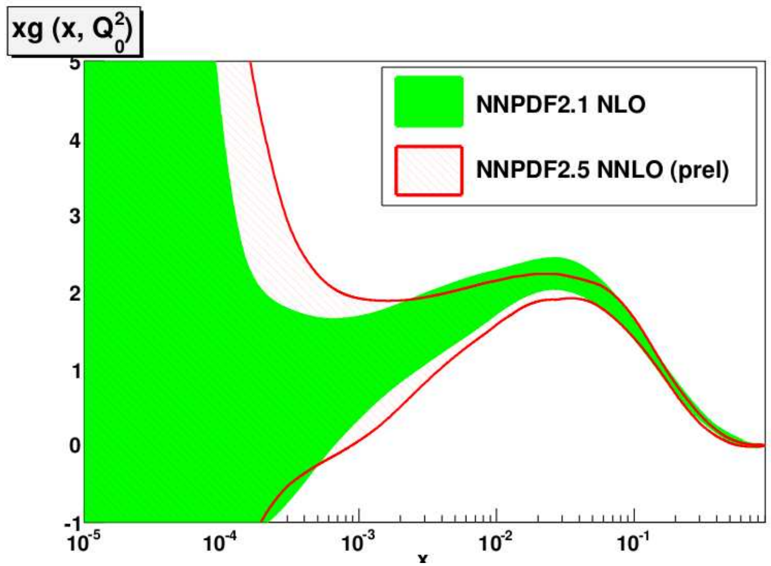
- NLO VS NNLO MSTW LUMINOSITIES QUITE CLOSE
  ... BUT PARTLY DUE TO LOWER NNLO α_s (0.117 VS 0.120)
- DIFFERENCES AS DATASED VARIED MUCH LARGER
  ... BUT IN SOME CASE ALSO α_s QUITE DIFFERENT (ABKM: 0.113)

NNLO PROGRESS

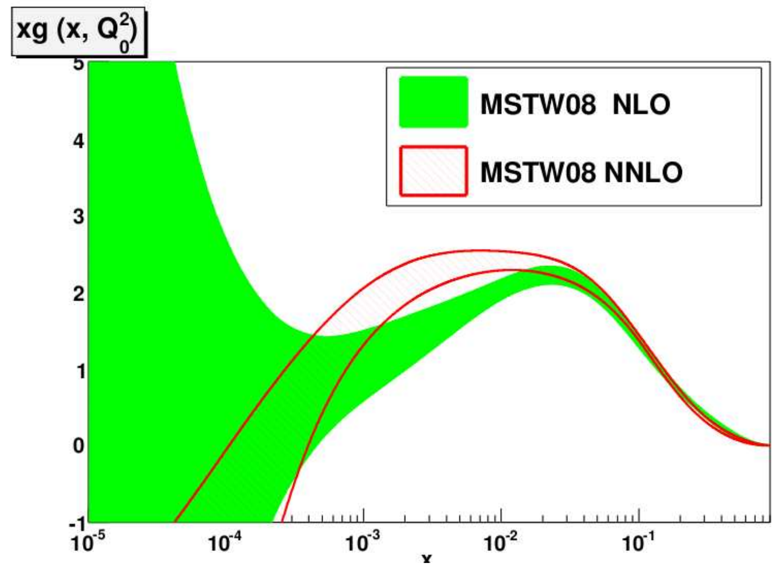
- CTEQ NNLO IN PREPARATION
- NNPDF NNLO PRESENTED IN PRELIM. FORM (DIS ONLY AT NNLO, FULL NNLO IN PREPARATION)
  - GLUON SIMILAR TO MSTW, BUT NO SMALL x INSTABILITY
  -

GLUON PDF: NLO VS NNLO

NNPDF



MSTW

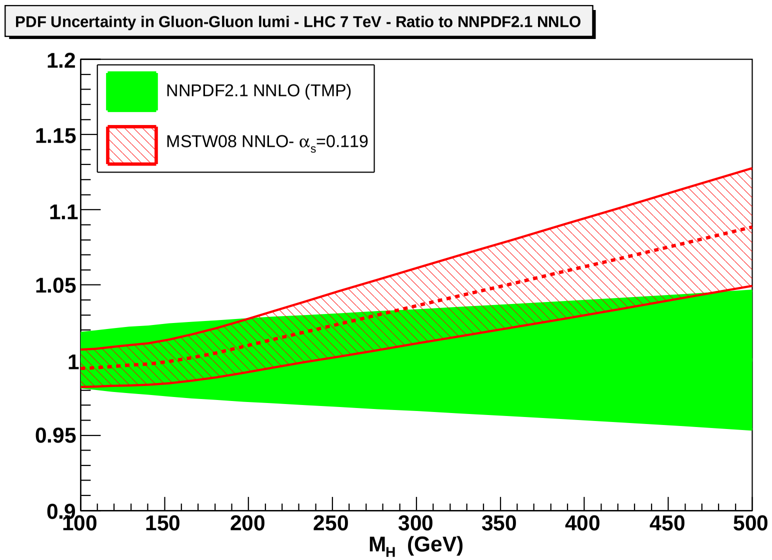


NNLO PROGRESS

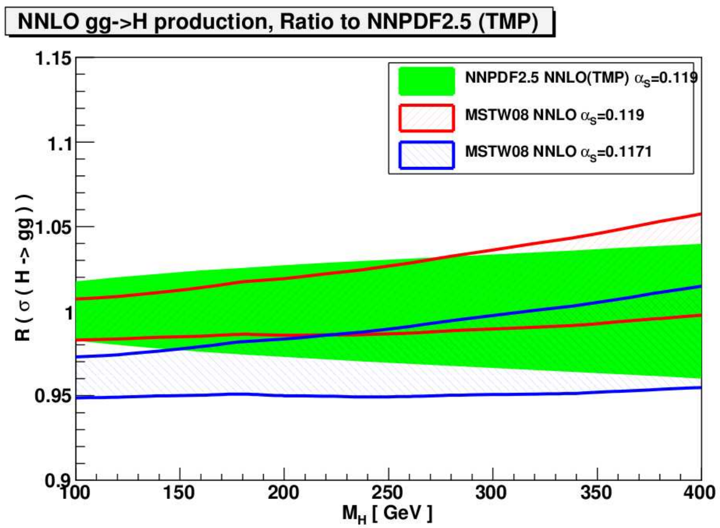
- CTEQ NNLO IN PREPARATION
- NNPDF NNLO PRESENTED IN PRELIM. FORM (DIS ONLY AT NNLO, FULL NNLO IN PREPARATION)
  - GLUON SIMILAR TO MSTW, BUT NO SMALL x INSTABILITY
  - LUMINOSITY & HIGGS XSECT QUITE CLOSE TO MSTW
    . . . PROVIDED SAME α_s USED

GLUON LUMI & HIGGS XSECT: NNPDF VS MSTW

GLUON LUMI



HIGGS XSECT.



NMC DATA: A PROBLEM?

- NMC PROTON AND DEUTERON DATA FOR DIS F_2 STRUCTURE FUNCTION
- F_2STRUCTURE FUNCTION DATA USED IN MSTW, CTEQ, NNPDF FITS,
  WOULD THE USE OF CROSS SECTION DATA MAKE A DIFFERENCE?
  (Alekhin, Blümlein, Moch, 2011)
  $\widetilde{\sigma}(x, y, Q^2) = F_2(x, Q^2)\left(2 - 2y + y^2/[1 + R(x, Q^2)]\right)$

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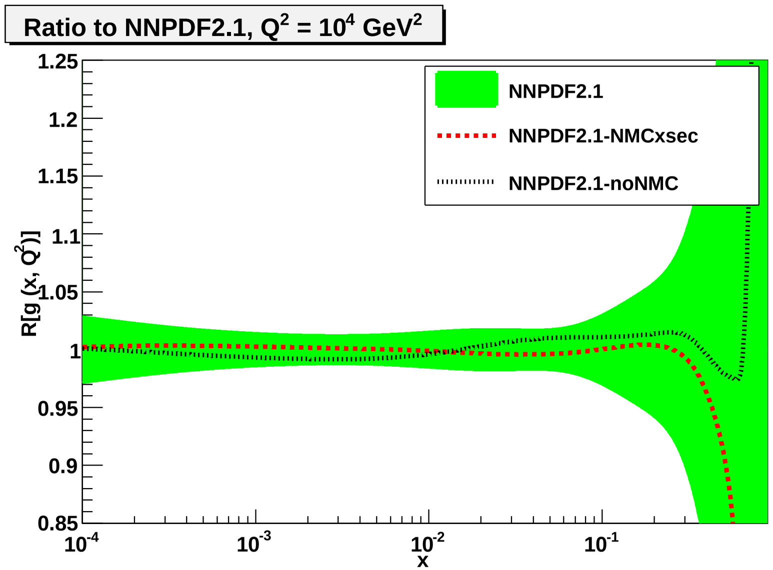
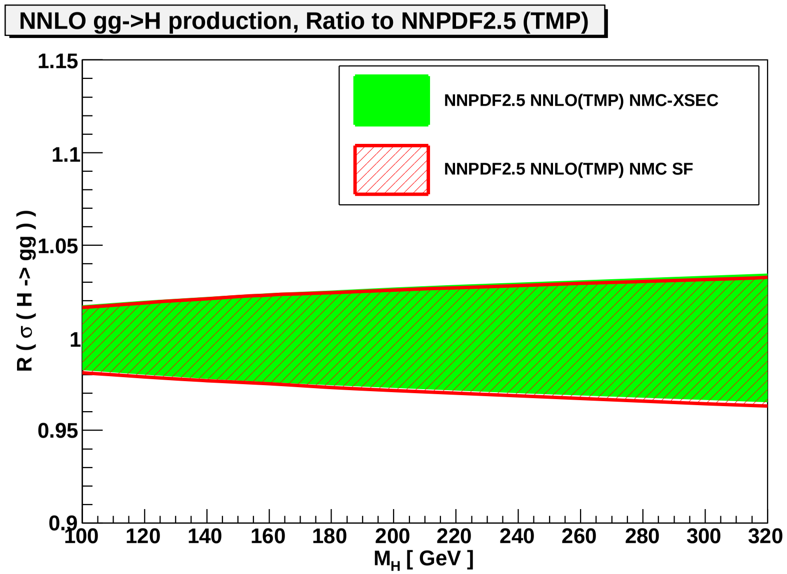
NNPDF FIT REPEATED WITH NMC XSECT OR NO NMC

(NLO: arXiv:1102.3182; NNLO: preliminary)

EFFECT ON GLUON



EFFECT ON HIGGS XSECT



NO SIGNIFICANT CHANGE OBSERVED

NMC DATA: A PROBLEM?

A CLOSER LOOK

- ALEKHIN ET AL. SEE LARGE SHIFT IN BEST-FIT α_s: FROM 0.1170 (NMC F_2) TO 0.1135 (NMC α_s)
- HOW MUCH OF THEIR CHANGE IN HIGGS XSECT ($\sim 8\%$) DUE TO CHANGE IN α_s?
- BASED ON POWER COUNTING, EXPECT $2.8\Delta\alpha_s = 8\%$ (!)
- EITHER REMOVE NMC DATA, OR CHANGE VALUE OF α_s IN MSTW FIT (Thorne, presented by Watt at PDF4LHC 2011):

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- EITHER REMOVE NMC DATA, OR CHANGE VALUE OF α_s IN MSTW FIT (Thorne, presented by Watt at PDF4LHC 2011):
  - IMPACT OF NMC DATA NEGLIGIBLE
  - IMPACT OF α_s VALUE COMPARABLE (SOMEWHAT SMALLER) TO WHOLE ABKM EFFECT
  - MSTW AND ABKM RESULTS STILL QUITE DIFFERENT EVEN FOR SAME $\alpha_s = 0.113$

NNLO PDF	$\alpha_S(M_Z^2)$	σ_H at Tevatron	σ_H at 7 TeV LHC
MSTW08	**0.1171**	**0.342 pb**	**7.91 pb**
Use R_{1990} for NMC	0.1167	-0.7%	-0.9%
Cut NMC ($x < 0.1$)	0.1162	-1.2%	-2.1%
Cut all NMC data	0.1158	-0.7%	-2.1%
Fix $\alpha_S(M_Z^2)$	0.1130	-11%	-7.6%
ABKM09	0.1135	-26%	-11%

THE VALUE OF α_s

- DEDICATED MUNICH MEETING (FEB 2011):
  S. BETHKE PROPOSES TWO UPDATED VALUES:
  - (1) $\alpha_s = 0.1174 \pm 0.0011$
  - (2) $\alpha_s = 0.1187 \pm 0.0006$
  - BOTH INCLUDE NEW VALUE FROM τ DECAYS $\alpha_s = 0.1213 \pm 0.0014$ (WAS $\alpha_s = 0.1197 \pm 0.0016$)
  - VALUE (1) ALSO INCLUDES NEW SCET VALUE FROM e^+e^- THRUST (Abbate et al., 2010) $\alpha_s = 0.1135 \pm 0.0010$, BUT ALL UNCERTAINTIES RESCALED BY FACTOR 2
  - VALUE (2) EXCLUDES IT

- AVERAGING THE TWO MOST RELIABLE VALUES (GLOBAL EW FIT & τ, BOTH N^3LO, NO DEP. ON HADRON STRUCTURE) GIVES
  $\alpha_s = 0.1209 \pm 0.0013$

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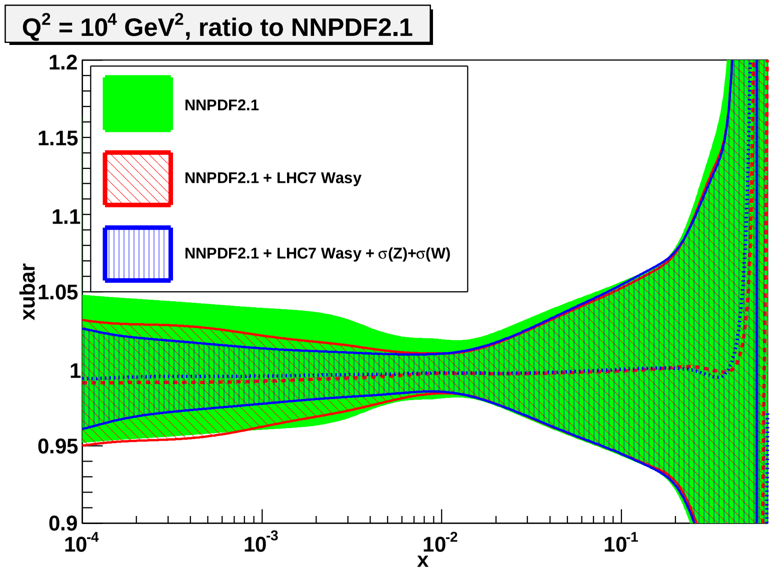
  $\alpha_s = 0.1209 \pm 0.0013$
- UNCERTAINTY LARGER THAN 0.002 QUITE UNLIKELY

FUTURE LHC DATA

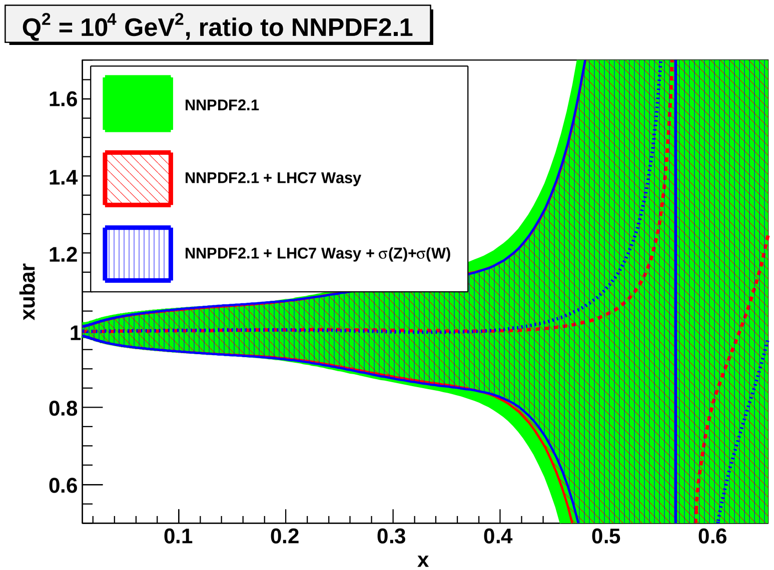
TEST THE IMPACT OF LHC 7TEV W AND Z DATA USING REWEIGHTING IN THE FOLLOWING "TOY" SCENARIOS:

- W ASYMMETRY MEASURED WITH $\sim 5\%$ ACCURACY AT ATLAS (KINEMATICS COURTESY OF A. GLAZOV) $\Rightarrow$ SIGNIFICANT IMPROVEMENT FOR ALL FLAVORS AT SMALL x
- W ASYMMETRY + TOTAL W AND Z CROSS-SECTIONS MEASURED TO 2% ACCURACY $\Rightarrow$
  - FURTHER IMPROVEMENT AT SMALL x
  - NOTE EFFECT SEEN ON ALL FLAVORS AND ANTIFLAVORS

ANTIUP SMALL x



ANTIUP LARGE x



PERCENTAGE ACCURACY ON W, Z CROSS SECTIONS?

- NNLO PROBABLY NECESSARY
- REQUIRES INDEPENDENT ACCURATE MEASUREMENT OF LUMINOSITY
- ACCURATE ACCEPTANCE CALCULATIONS
- EVEN FOR W^+/W^- RATIO NOT EASY
  $\Rightarrow$

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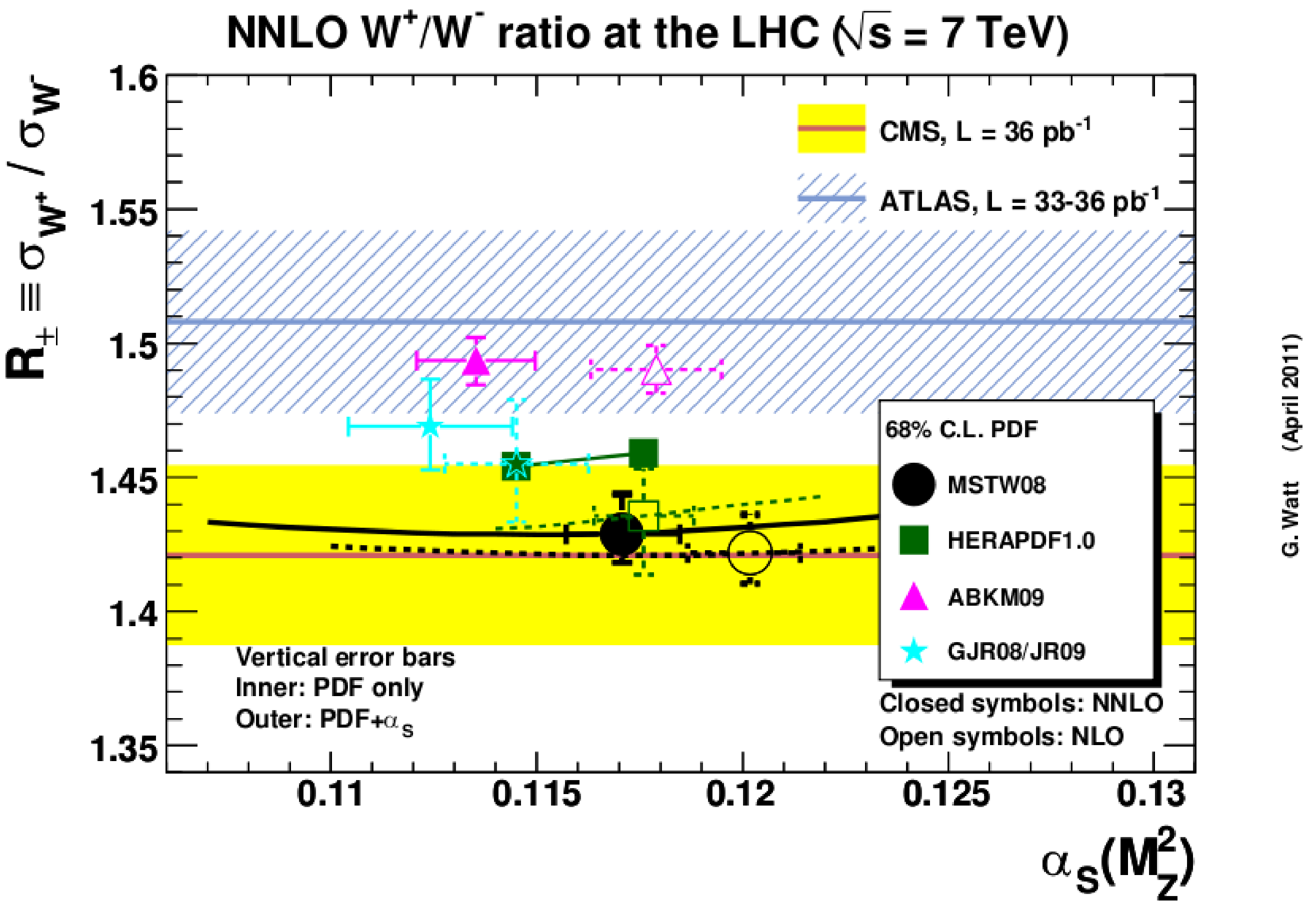
- EVEN FOR W^+/W^- RATIO NOT EASY
  $\Rightarrow$CURRENT CMS-ATLAS DISAGREEMENT (?)



ACCEPTANCE: PROBLEMS?

- CMS [arXiv:1012.2466, CMS PAS EWK-10-005] use POWHEG (with CTEQ6.6/CT10, MSTW08NLO, NNPDF2.0), check with FEWZ.

$$\Rightarrow \frac{\sigma^{\rm tot}_{W^+}}{\sigma^{\rm tot}_{W^-}} = \begin{cases} 1.418 \pm 0.008(\text{stat.}) \pm 0.022(\text{syst.}) \pm 0.029(\text{th.}) & (e) \\ 1.423 \pm 0.008(\text{stat.}) \pm 0.019(\text{syst.}) \pm 0.031(\text{th.}) & (\mu) \\ 1.421 \pm 0.006(\text{stat.}) \pm 0.014(\text{syst.}) \pm 0.030(\text{th.}) & (e+\mu) \end{cases}$$

- ATLAS [arXiv:1010.2130, ATLAS-CONF-2011-041] use PYTHIA (with MRSTLO*) $\Rightarrow \sigma^{\rm tot}_{W^+}/\sigma^{\rm tot}_{W^-} = 1.508 \pm 0.034$ $(e+\mu)$.

MC+PDF	A_{W^+}/A_{W^-}		$\sigma^{\rm tot}_{W^+}/\sigma^{\rm tot}_{W^-}$	
	e	μ	e	μ
PYTHIA+MRSTLO*	1.02	1.02	1.50	1.51
PYTHIA+CTEQ6.6	1.05	1.05	1.46	1.47
PYTHIA+HERAPDF1.0	1.03	1.04	1.48	1.49
MC@NLO+HERAPDF1.0	1.05	1.05	1.46	1.47
MC@NLO+CTEQ6.6	1.06	1.06	1.45	1.46

$$\frac{\sigma^{\rm tot}_{W^+}}{\sigma^{\rm tot}_{W^-}} = \frac{\sigma^{\rm fid}_{W^+}}{\sigma^{\rm fid}_{W^-}} \cdot \frac{A_{W^-}}{A_{W^+}}$$

Alternative acceptance calculations move ATLAS $\sigma^{\rm tot}_{W^+}/\sigma^{\rm tot}_{W^-}$ much closer to CMS.

- Precision requires better acceptance calculations and/or data to theory comparisons at level of fiducial cross section.

(G.Watt, 2011)

$\sin^2\theta_W$ FROM A_{FB} AT THE LHC?

- FORWARD/BACKWARD ASYMMETRY OF LEPTONS PRODUCED BY Z DECAY $\Rightarrow$ ELECTROWEAK MIXING ANGLE
- CURRENTLY $\sin^2\theta_W = 0.23153 \pm 0.00016$ FROM GLOBAL FIT BUT TWO MOST PRECISE MEASUREMENTS $\sin^2\theta_W = 0.23098 \pm 0.00026$ (SLD) & $\sin^2\theta_W = 0.23221 \pm 0.00029$ (B) DISAGREE BY THREE SIGMA
- $\rightarrow$ AIM AT 0.0001 LEVEL ACCURACY!
- IS IT POSSIBLE AT HADRON COLLIDER WHERE PDF UNCERTAINTIES PLAY A ROLE?

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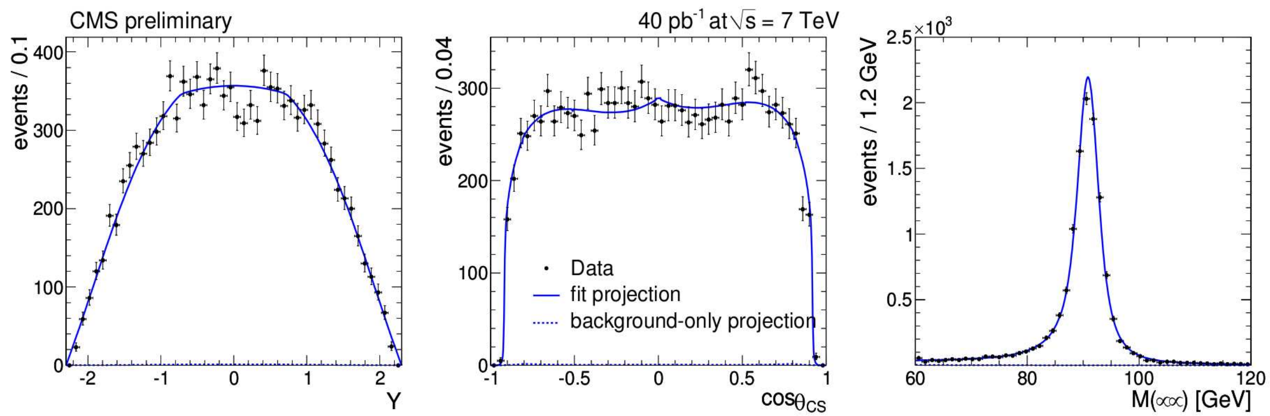
- MEASUREMENT PERFORMED BY CMS WITH 40 pb^{-1} $\Rightarrow$
  $\sin^2\theta_W = 0.2287 \pm 0.0077$ (STAT.) ± 0.0036 (SYSR.)



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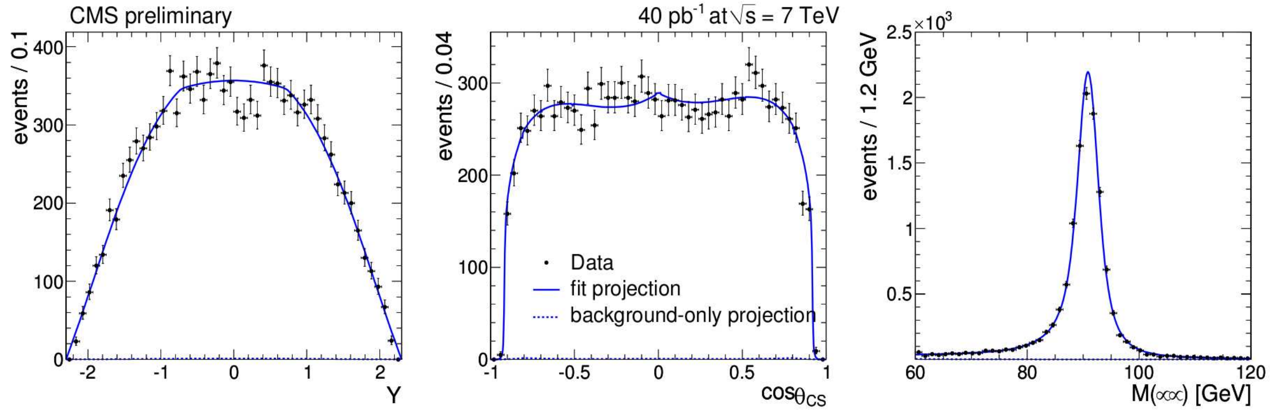
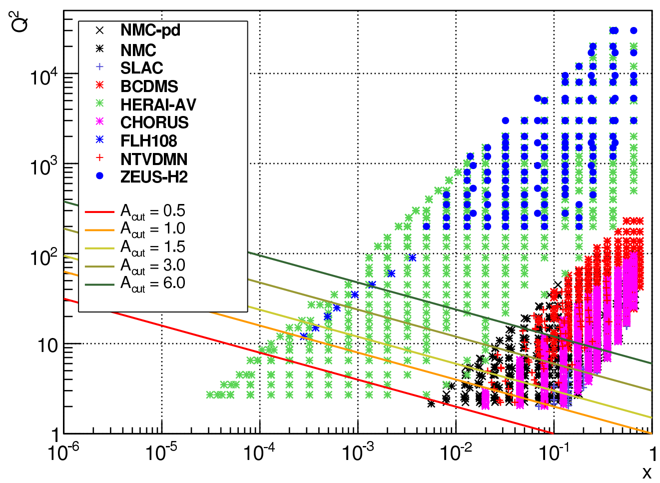
- MEASUREMENT PERFORMED BY CMS WITH 40 pb^{-1} $\Rightarrow$ $\sin^2\theta_W = 0.2287 \pm 0.0077$ (STAT.) ± 0.0036 (SYSR.)
- GREATER SENSITIVITY AT LARGE RAPIDITY $\Rightarrow$ LHCB PROPOSES MEASUREMENT FOR $2 \lesssim y \lesssim 4$ @ Z PEAK
- 0.0001 STAT. ACCURACY CAN BE ATTAINED WITH 50 fb^{-1}, BUT LARGE & SMALL x PDFS INVOLVED
- PDF+ THEORY (RESUMMATION) UNCERTAINTIES HARD!



BEYOND DGLAP?
DISCOVERING A NEW QCD EFFECT IN HERA DATA



IDEA: (Gélis, 2008, $\Rightarrow$ Caola, s.f. ,Rojo 2010)

- CUT OUT DATA IN THE "DANGEROUS" (SMALL x) REGION
- DETERMINE PDFs IN THE "SAFE" (LARGE x AND Q^2) REGION
- EVOLVE BACKWARDS AND COMPARE TO DATA

BEYOND DGLAP?
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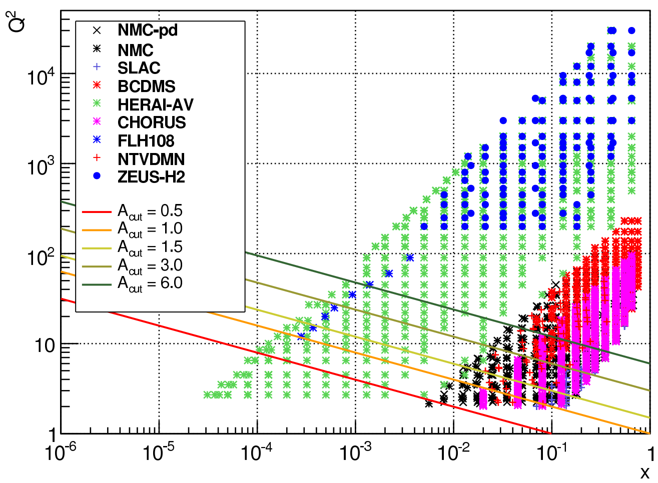

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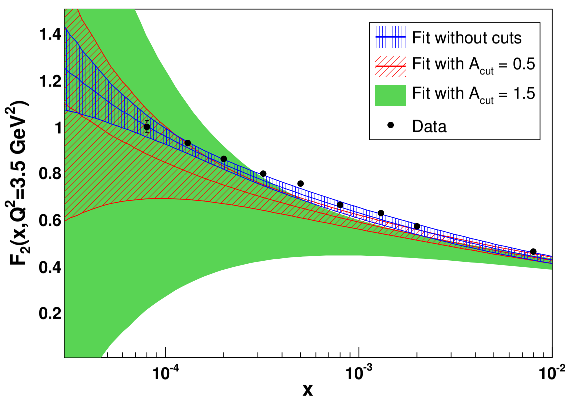
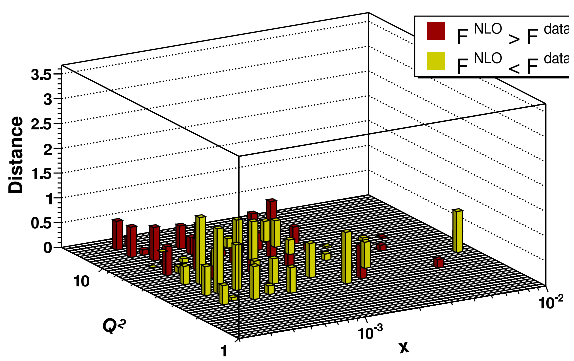
OLD HERA DATA

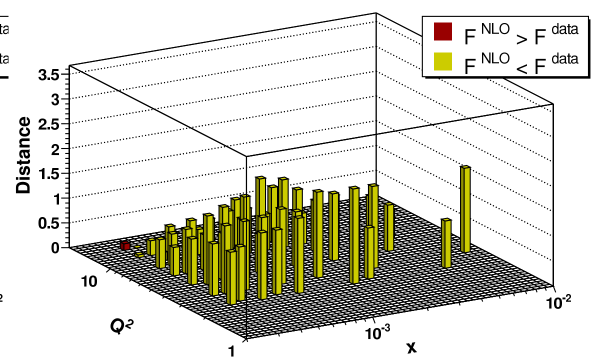
BACKWARD EV. VS DATA



DAT/TH DIST: NO CUT



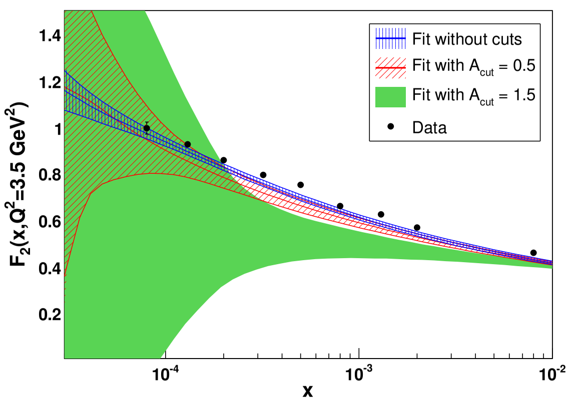
DAT/TH DIST: CUT



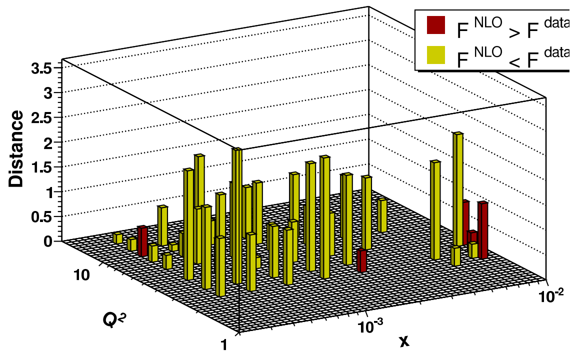
- BACKWARD EVOLVED FIT LIES SYSTEMATICALLY BELOW DATA
- DATA AT LOW x AND Q^2 SHOW LESS EVOLUTION THAN PREDICTED BY NLO DGLAP
- IF LOW x AND Q^2 DATA INCLUDED, THE FIT COMPENSATES READJUSTING PDFS

NEW COMBINED HERA DATA

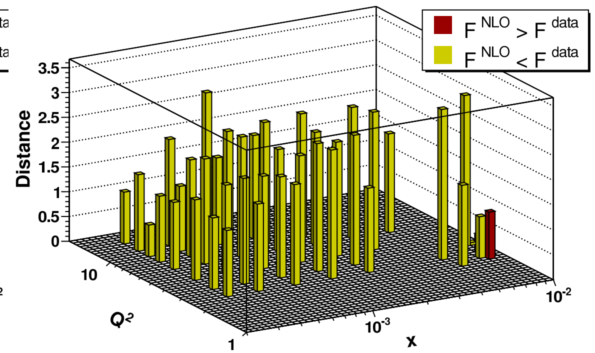
BACKWARD EV. VS DATA



DAT/TH DIST: NO CUT

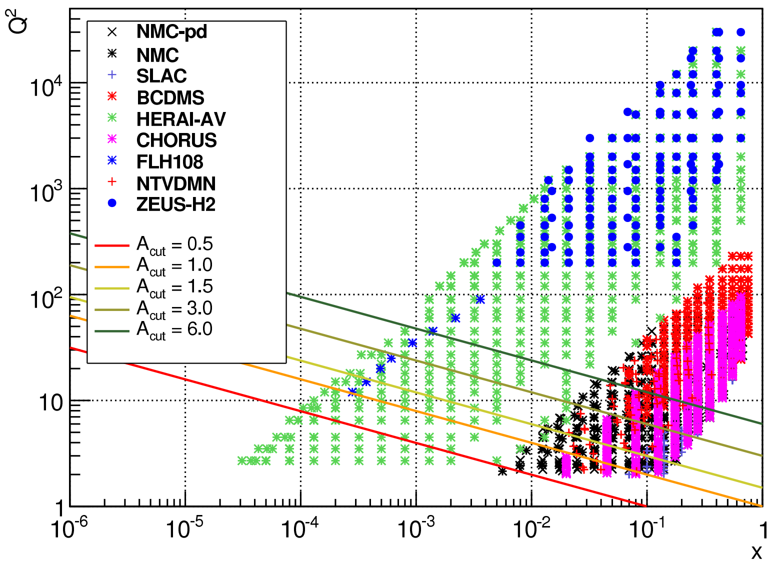


DAT/TH DIST: CUT

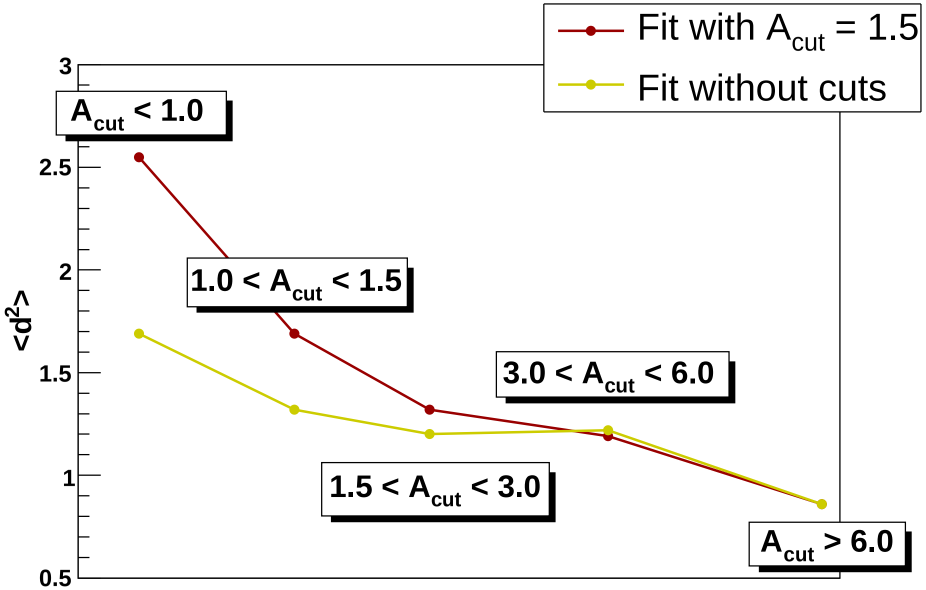


- DATA AT LOW x AND Q^2 SHOW LESS EVOLUTION THAN PREDICTED BY NLO DGLAP
- BACKWARD EVOLVED FIT LIES SYSTEMATICALLY BELOW DATA
- WITH MORE PRECISE DATA, THE FIT NO LONGER MANAGES TO COMPENSATE BY READJUSTING THE PDFs: EVEN FULL FIT LIES BELOW DATA

DETERIORATION IN FIT QUALITY:

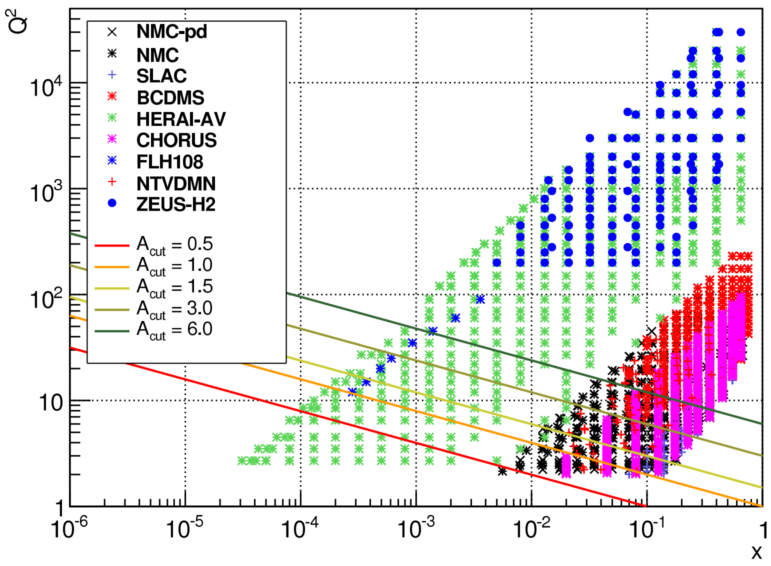


$\langle d^2 \rangle$ VS x SLICES

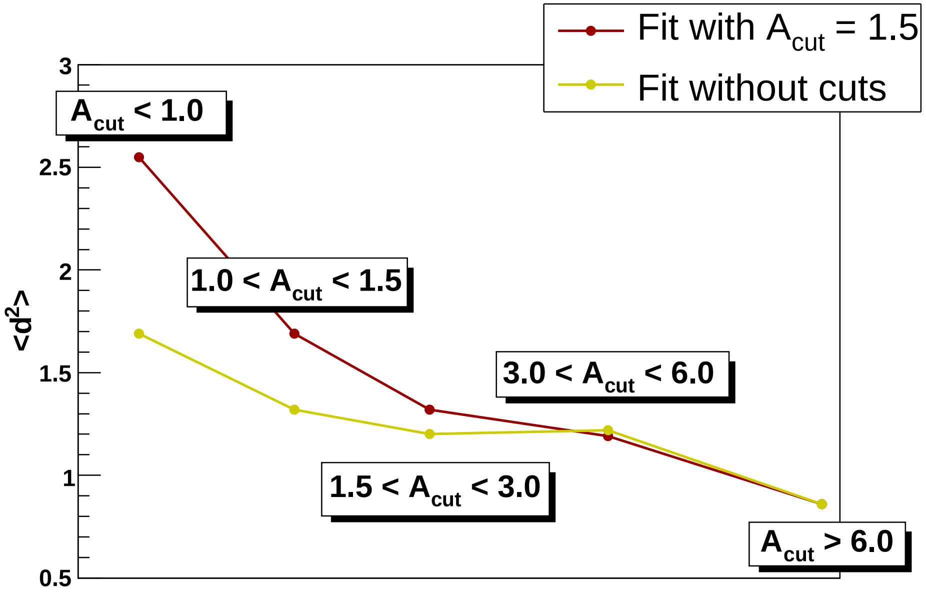


- QUALITY OF UNCUT FIT DETERIORATES IN LOW x REGIONS
- QUALITY OF CUT FIT INCREASINGLY POOR AS x DECREASES
- DISTANCE RISES DESPITE HUGE INCREASE IN UNCERTAINTY

DETERIORATION IN FIT QUALITY:

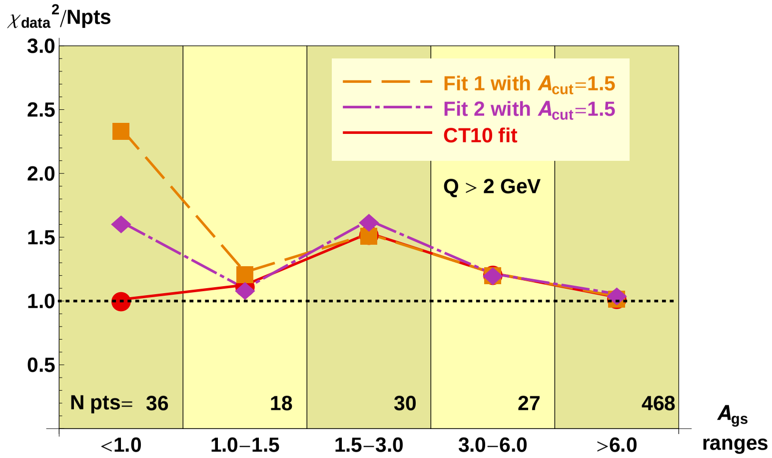


$\langle d^2 \rangle$ VS x SLICES



- QUALITY OF UNCUT FIT DETERIORATES IN LOW x REGIONS
- QUALITY OF CUT FIT INCREASINGLY POOR AS x DECREASES
- DISTANCE RISES DESPITE HUGE INCREASE IN UNCERTAINTY
- IN HESSIAN FIT (CTEQ) RESULTS DEPEND ON PARAMETRIZATION $\Rightarrow$ EVIDENCE INCONCLUSIVE

χ^2 VS x SLICES FOR CT10



THE STANDARD (HESSIAN) SOLUTION

(MSTW, CTEQ):

FUNCTIONAL PARTON FITTING

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

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

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

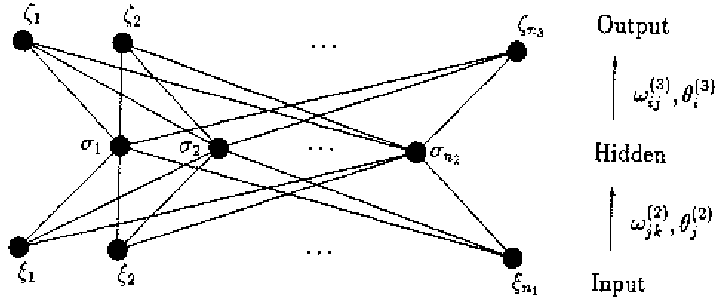
  - CTEQ/TEA: 22$\rightarrow$ 26 PARMS.

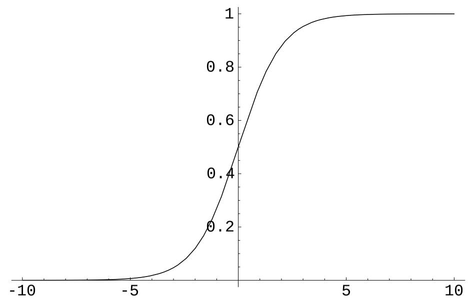
    $$x\,f(x,Q_0) = a_0\,x^{a_1}\,(1-x)^{a_2}\,\exp\left(a_3 x + a_4 x^2 + a_5\sqrt{x} + a_6 x^{-a_7}\right) \text{ (7 indep. functions)}$$

    a_6, a_7 ONLY USED FOR GLUON
  - BASIS FUNCTIONS: $u_v \equiv u-\bar{u}$, $d_v \equiv d-\bar{d}$, $\bar{u}\pm\bar{d}$ (MSTW) OR $\bar{u}$, $\bar{d}$ (CTEQ), $s^{\pm} \equiv s \pm \bar{s}$ (CTEQ $\bar{s}+s$ ONLY), g.
- EVOLVE TO DESIRED SCALE & COMPUTE PHYSICAL OBSERVABLES
- DETERMINE BEST-FIT VALUES OF PARAMETERS
- DETERMINE ERROR BY PROPAGATION OF ERROR ON PARMS. ('HESSIAN METHOD') PARM. SCANS ALSO POSSIBLE ('LAGR. MULTIPLIER METHOD')

NEURAL NETWORKS

A NONLINEAR FUNCTIONAL FORM





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
  $g(x) = \frac{1}{1+e^{-\beta x}}$

EXAMPLE: A 1-2-1 NN

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

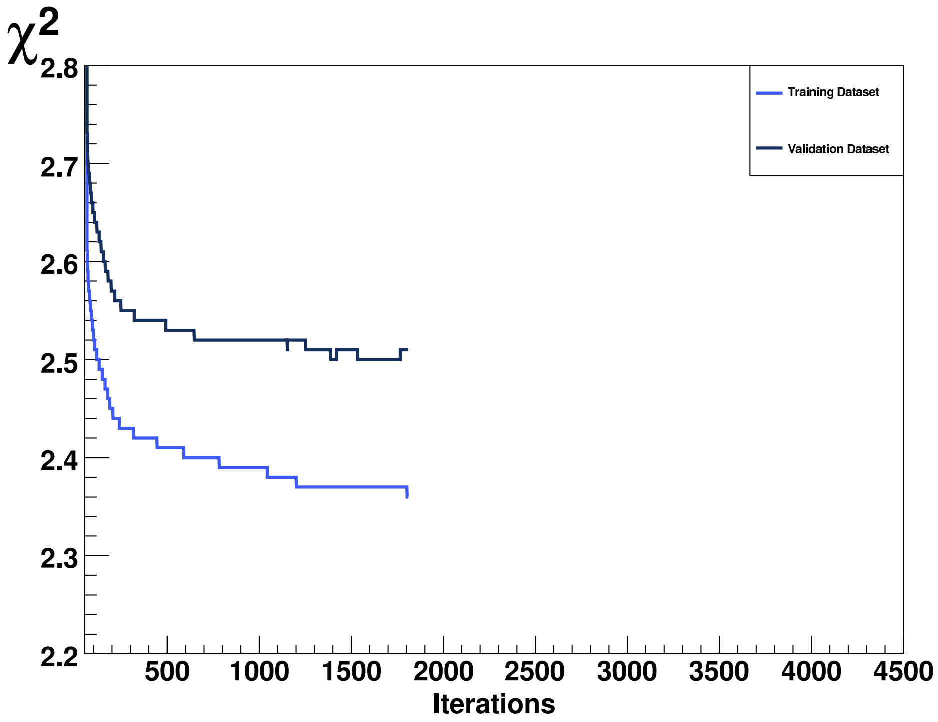
- ANY FUNCTION CAN BE REPRESENTED BY A SUFFICIENTLY BIG NEURAL NETWORK $\Rightarrow$ CAN CHECK INDEPENDECE OF SIZE
- MINIMZATION PERFORMED BY GENETIC ALGORITHM
- INFORMATION CONTAINED ("COARSENESS") IN NN INCREASES DURING MINIMIZATION

DATA MONTE CARLO ⇒ PDF MONTE CARLO
CROSS-VALIDATION

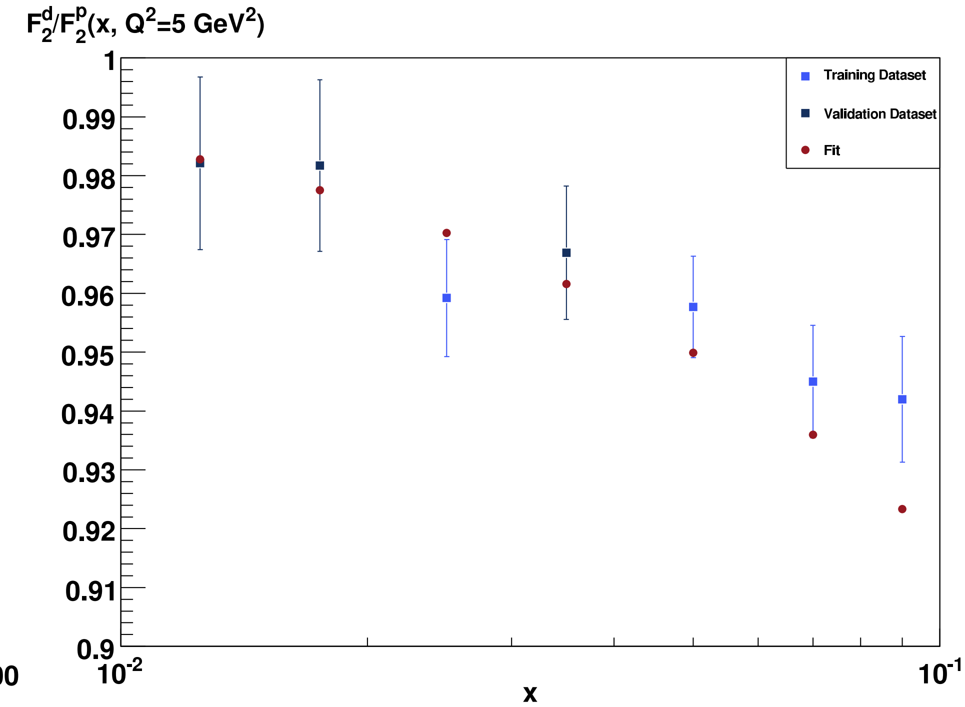
- REPLICAS ARE FITTED TO A DATA SUBSET
- A DIFFERENT SUBSET OF DATA USE FOR EACH REPLICA
- OPTIMAL FIT WHEN FIT TO VALIDATION (CONTROL) DATA STOPS IMPROVING
-

OPTIMAL FITTING

χ^2



FIT TO DATA

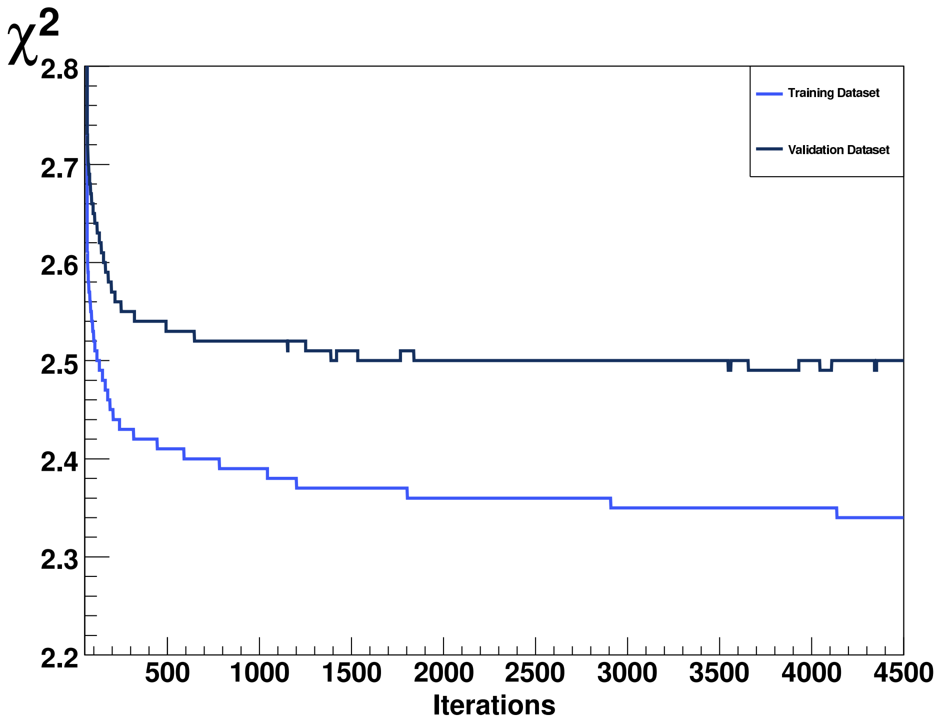


DATA MONTE CARLO ⇒ PDF MONTE CARLO
CROSS-VALIDATION

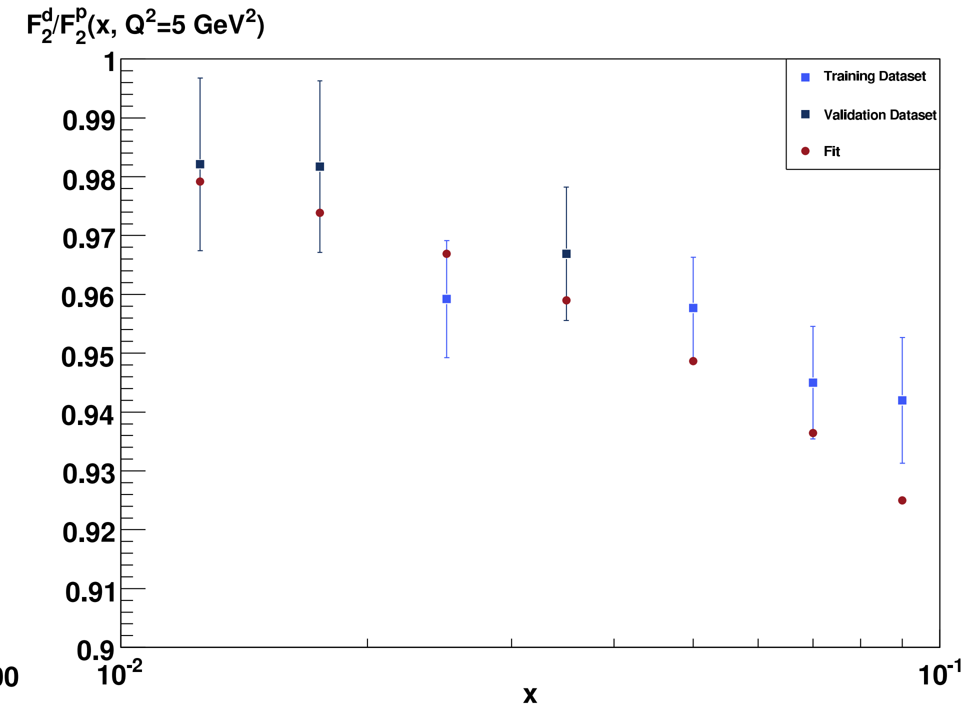
- REPLICAS ARE FITTED TO A DATA SUBSET
- A DIFFERENT SUBSET OF DATA USE FOR EACH REPLICA
- OPTIMAL FIT WHEN FIT TO VALIDATION (CONTROL) DATA STOPS IMPROVING
- THE BEST FIT IS NOT AT THE MINIMUM OF THE χ^2

OVERFITTING

χ^2



FIT TO DATA

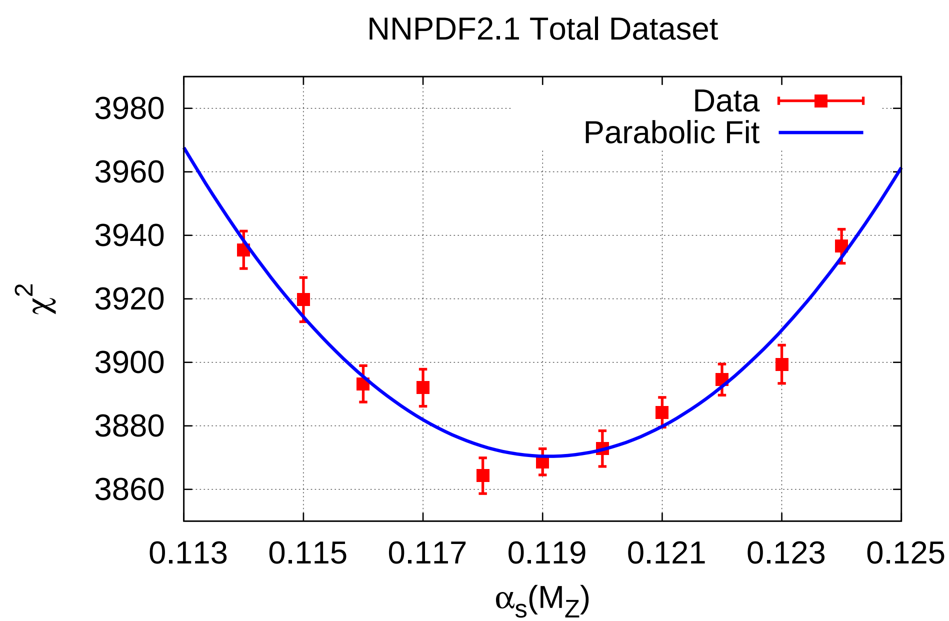


α_s FROM THE NNPDF2.1 GLOBAL FIT

NLO NNPDF2.1 GLOBAL DETERMINATION (ONLY STAT. ERROR KNOWN)

$N_{\rm rep} = 500$ PER VALUE OF α_s

$$\alpha_s(M_z) = 0.1191 \pm 0.0006(\text{stat.}) \pm 0.0001(\text{proc.})$$



$\chi^2/\text{d.o.f.} = 1.6$ for the parabolic fit

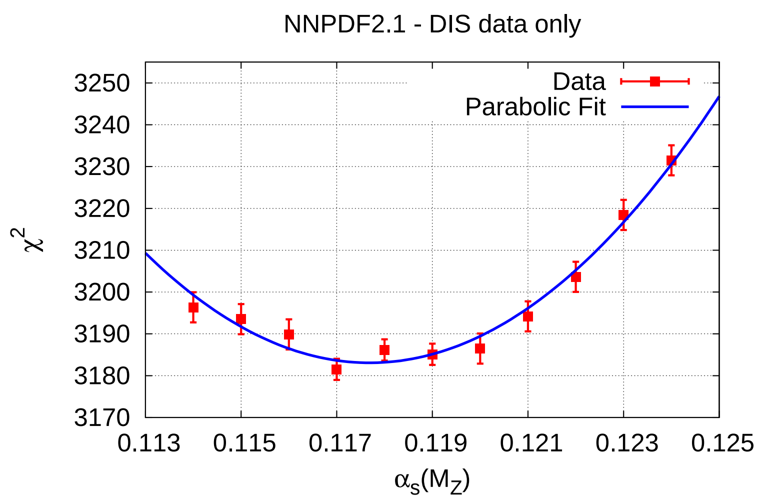
DIS ONLY

DO DIS DATA PREFER A SMALLER VALUE?

NLO NNPDF2.1 DEEP-INELASTIC DATA

$N_{\rm rep} = 500$ PER VALUE OF α_s

$$\alpha_s(M_z) = 0.1177 \pm 0.0009(\text{stat.}) \pm 0.0002(\text{proc.})$$

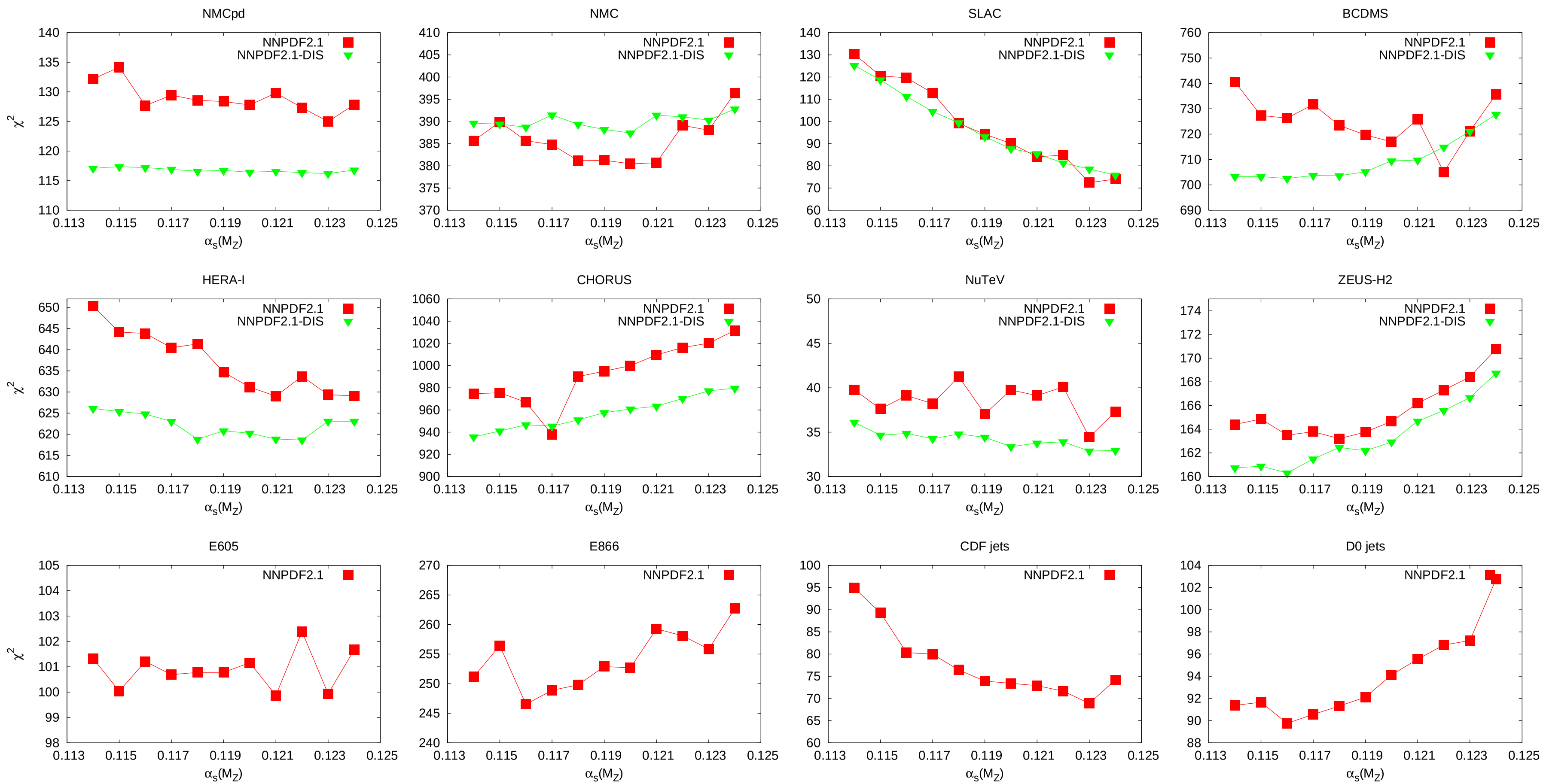


$$\chi^2/\text{d.o.f.} = 0.8 \text{ for the parabolic fit}$$

- YES
- BUT NOT MUCH SMALLER & WITH LARGER UNCERTAINTY
  (COMPATIBLE WITHIN UNCERTAINTIES, AS IT OUGHT TO)

INDIVIDUAL EXPERIMENTS: WHAT'S GOING ON?

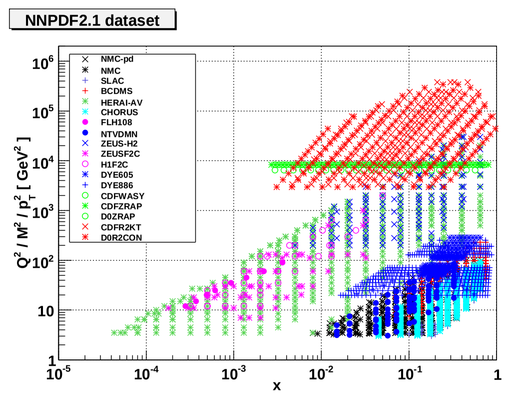
χ^2 PROFILE FOR INDIVIDUAL EXPERIMENTS IN GLOBAL & DIS FITS



- BCDMS SIMILAR TO HERA, NMC PRETTY FLAT
- DIS EXPERIMENTS (BCDMS+HERA) IN DIS FIT HAVE A "RUNAWAY DIRECTION" AT SMALL α_s, ABSENT IN GLOBAL FIT
- JET EXPERIMENTS EXCLUDE SMALL α_s

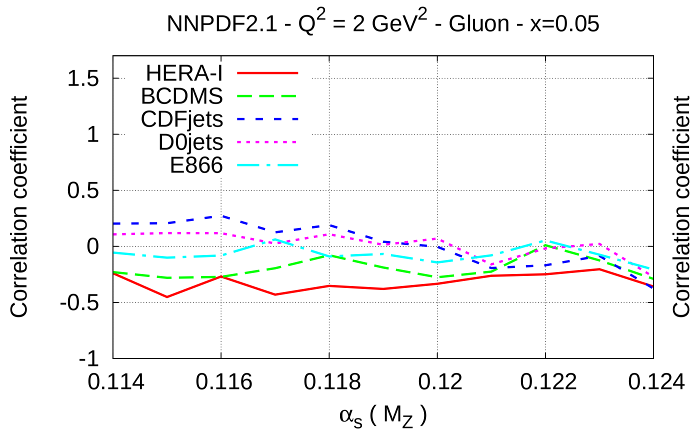
IS THERE A PROBLEM WITH DIS?

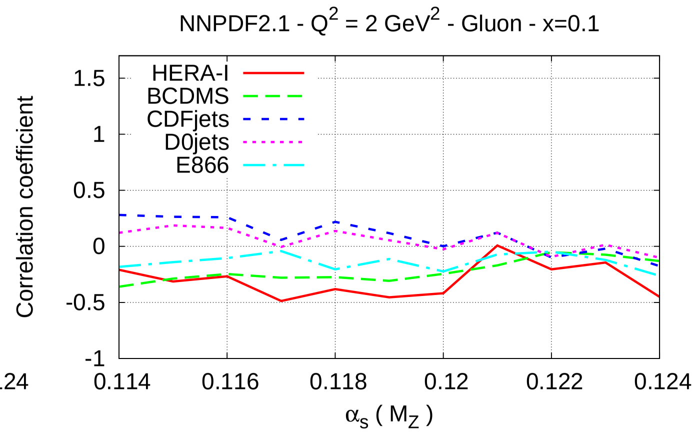
CONJECTURE



- IN DIS, GLUON DETERMINED BY SCALING VIOLATIONS $\Rightarrow$ CAN COMPENSATE SMALLER α_s WITH LARGER GLUON (OR CONVERSELY)
  $\Rightarrow$ RUNAWAY DIRECTIONS POSSIBLE IN DIS FIT
- JET DATA ARE AT MUCH LARGER SCALE, IF α_s TOO SMALL OR LARGE HIGH-SCALE GLUON WILL COME OUT WRONG
  $\Rightarrow$ RUNAWAY DIRECTION QUENCHED IN GLOBAL FIT

THE EVIDENCE



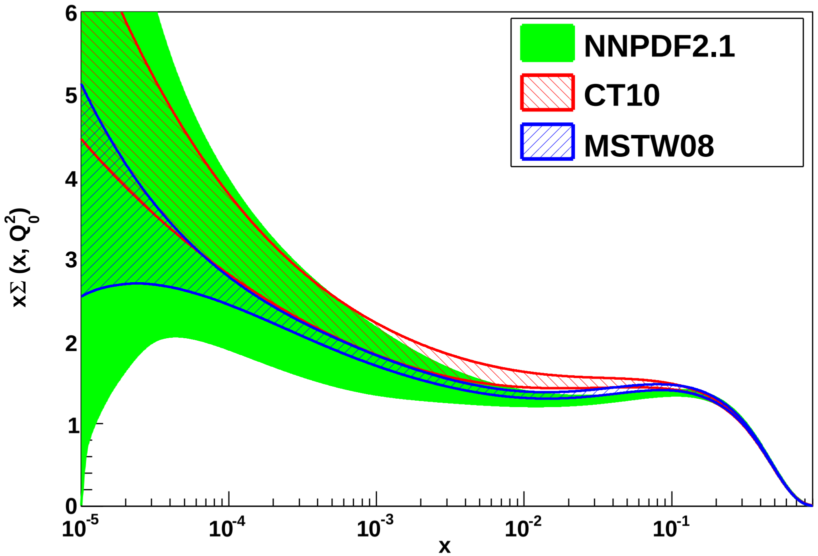


- COMPUTE THE CORRELATION BETWEEN χ^2 & PDFs AT THE GLOBAL BEST FIT
  LARGE (POSITIVE OR NEGATIVE) CORRN. $\Leftrightarrow$ RUNAWAY DIRECTION
- OPPOSITE SIGN CORRELATIONS $\Leftrightarrow$ DATA PULLING IN OPPOSITE DIRECTIONS
- AT LOW $\alpha_s = 0.114$ DIS FIT HAS A RUNAWAY DIRECTION STABILIZED BY JETS
- AT HIGH $\alpha_s = 0.122$ FIT IS GENERALLY STABLE,
  THOUGH STILL SOME PULL IN HERA LOW x

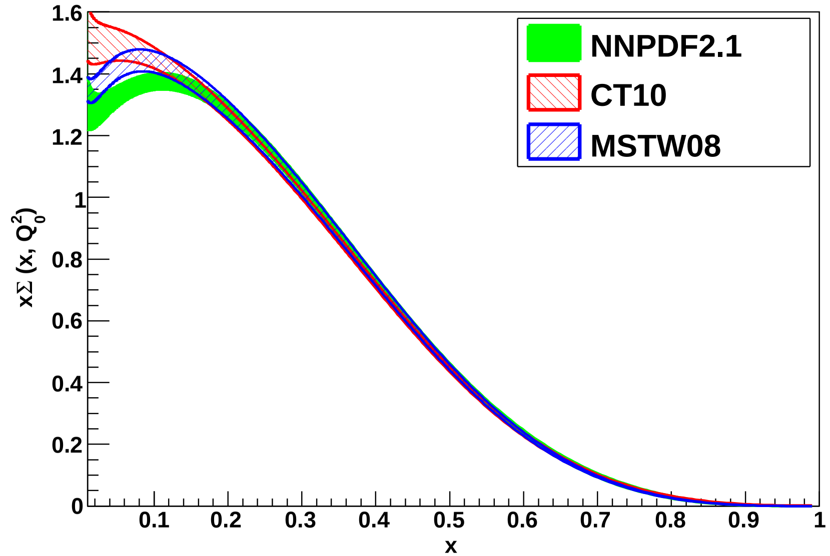
NNPDF2.1, MSTW08, CT10 COMPARISON

SINGLET SECTOR

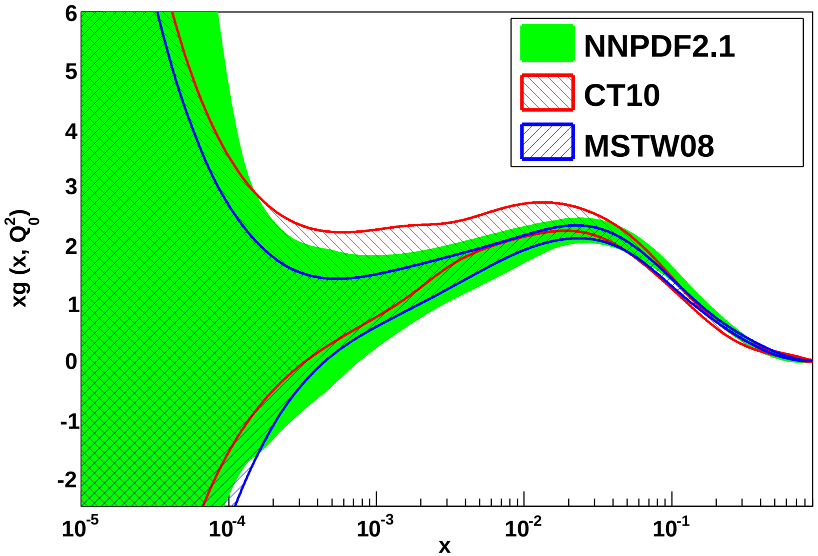
SINGLET



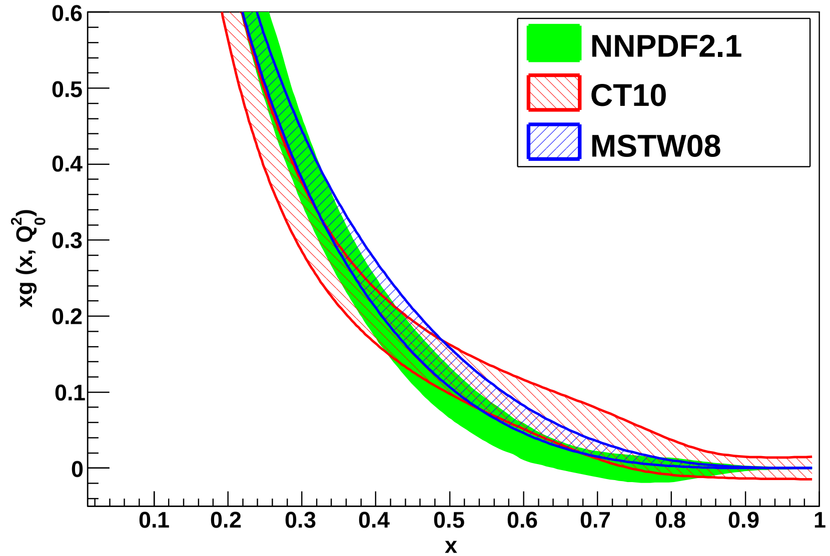
SINGLET



GLUON



GLUON

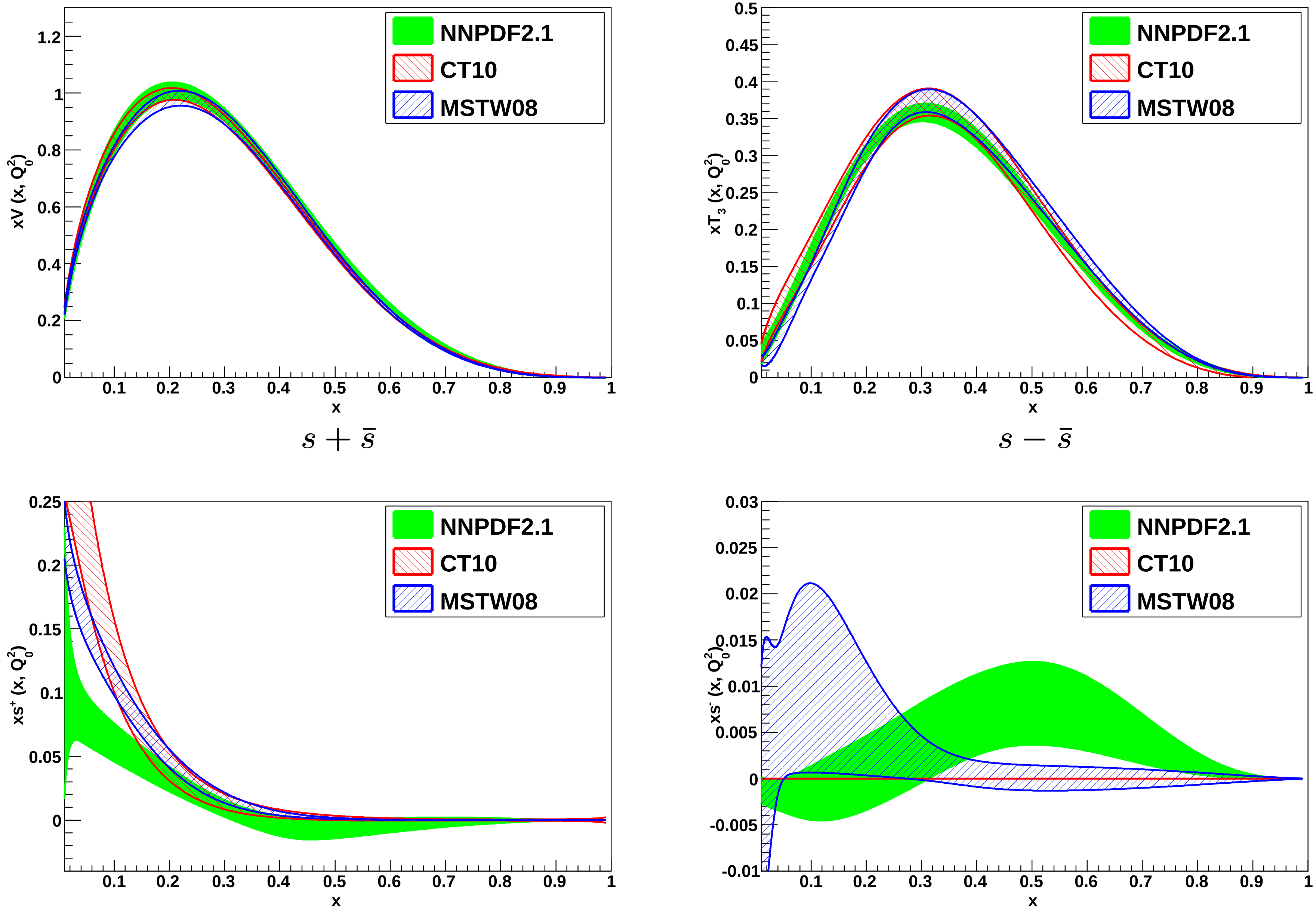


NNPDF2.1, MSTW08, CT10 COMPARISON

NONSINGLET SECTOR

TOTAL VALENCE

ISOSPIN TRIPLET



MONTE CARLO DATA GENERATION

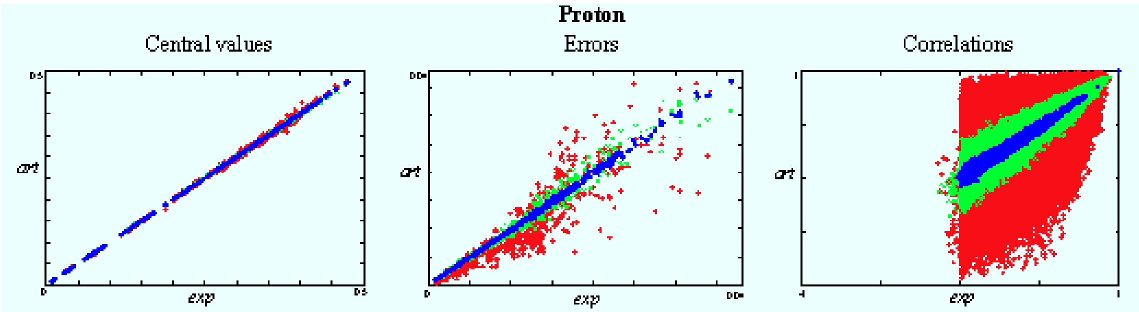
- BCDMS+ NMC PROTON & DEUTERON F_2 DATA (FULL CORRELATED SYSTEMATICS AVAILABLE), TAKEN AT 4 BEAM ENERGIES
- ON TOP OF STAT. ERRORS, 4 SYSTEMATICS + 1 NORMALIZATION (NMC) OR 6 SYSTEMATICS + 1 ABSOLUTE & 2 RELATIVE NORMALIZATIONS (BCDMS), WITH VARIOUS FORMS OF CORRELATION (FULL, OR FOR EACH TARGET, OR 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

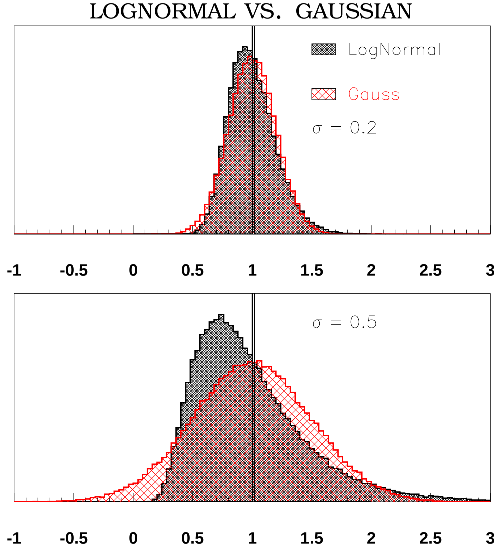


SCATTER PLOT ART. VS. EXP. FOR 10 (RED) 100 (GREEN) AND 1000 (BLUE) REPLICAS

NEED 1000 REPLICAS TO REPRODUCE CORRELATIONS TO PERCENT ACCURACY

PARAMETRIZATION UNCERTAINTIES?
NONGAUSSIAN BEHAVIOUR?

LOGNORMAL VS. GAUSSIAN

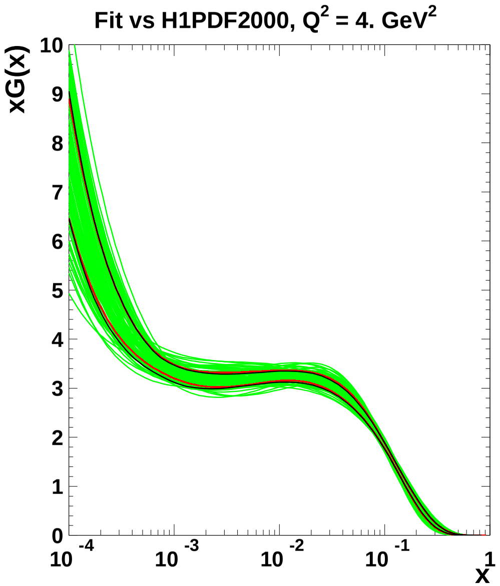


THE HERALHC BENCHMARK

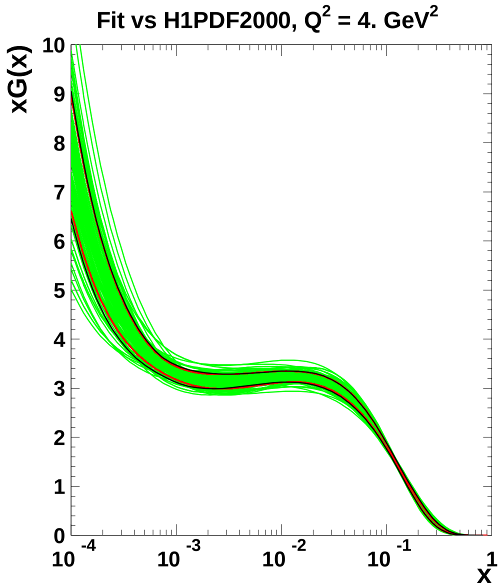
(Feltesse, Glazov, Radescu + NNPDF 2008)

- 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

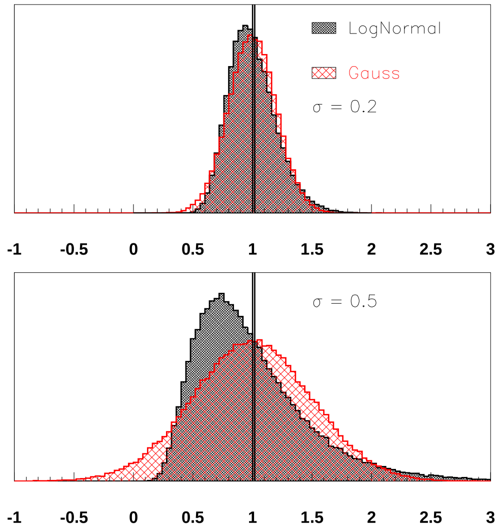


- NO DIFFERENCE BETWEEN LOGNORMAL, GAUSSIAN, MC, HESSIAN

PARAMETRIZATION UNCERTAINTIES?

NONGAUSSIAN BEHAVIOUR?

LOGNORMAL VS. GAUSSIAN

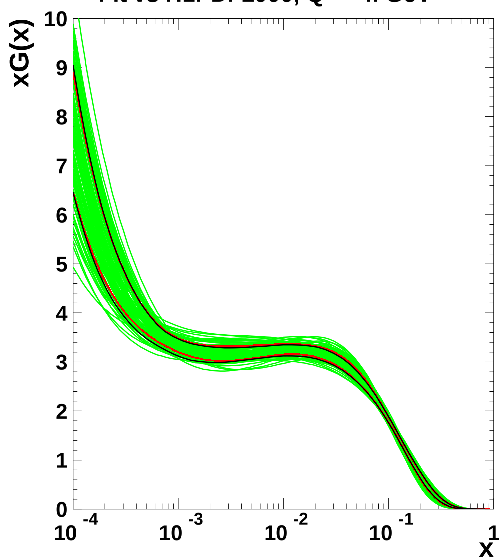


THE HERALHC BENCHMARK

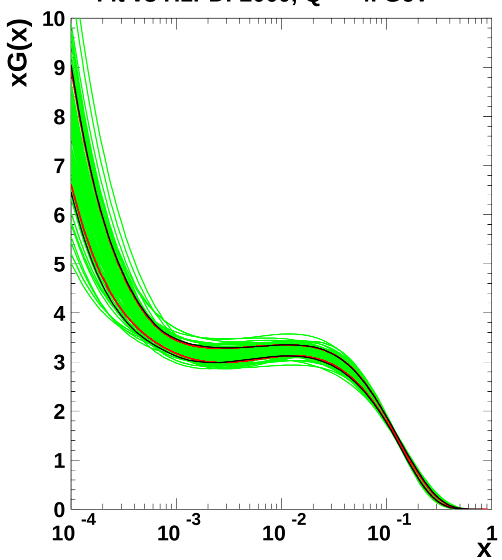
(Feltesse, Glazov, Radescu + NNPDF 2008)

- 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
- COMPARE TO NNPDF FIT TO SAME DATA

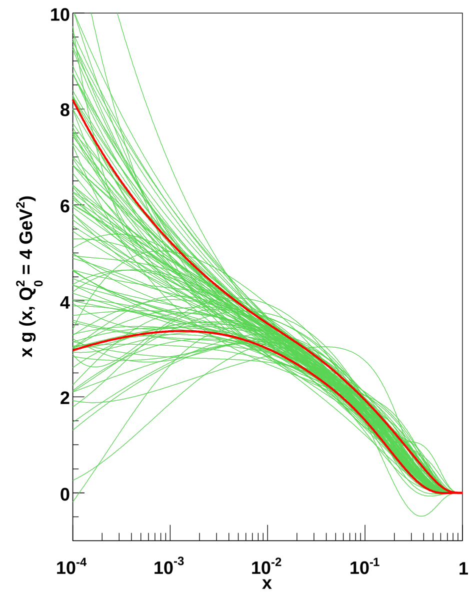
LOGNORMAL: HESS. VS MC



GAUSSIAN: HESS. VS MC



NNPDF

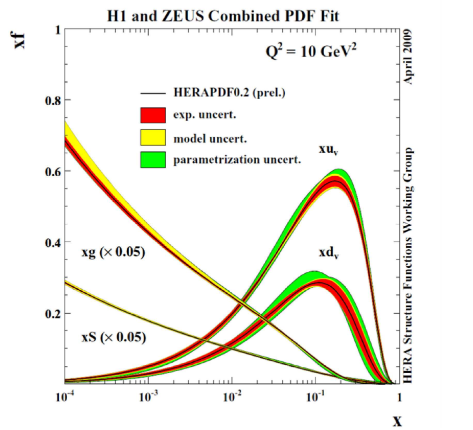


- NO DIFFERENCE BETWEEN LOGNORMAL, GAUSSIAN, MC, HESSIAN
- SIZABLE DIFFERENCE WR TO FLEXIBLE NNPDF PARAMETRIZATION

PARAMETRIZATION UNCERTAINTIES?

EXPLORING THE SPACE OF PARAMETERS: HESSIAN APPROACH

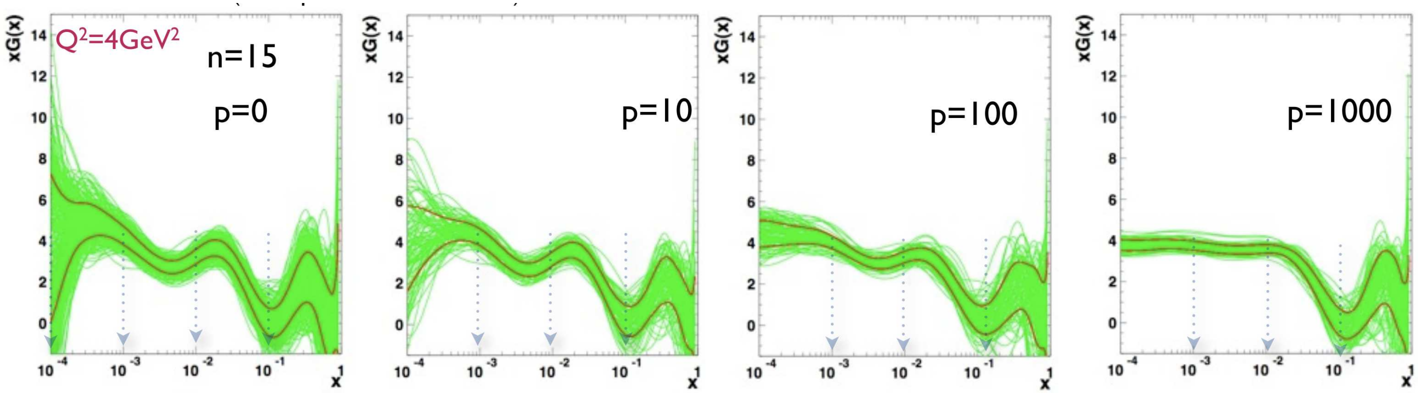
- IN HESSIAN APPROACH CAN VARY THE FUNCTIONAL FORM, ASSUMPTIONS, STARTING SCALE
- DONE IN THE HERAPDF1.0 FIT: VARIATION OF STRANGENESS FRACTION, LARGE x BEHAVIOUR, HIGHER ORDER POLYNOMIAL TERMS
- NO TOLERANCE ($\Delta\chi^2 = 1$), UNCERTAINTY DOUBLED



- Red: experimental uncertainties
- Yellow: model uncertainties
- Green: pdf parametrization uncertainties

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



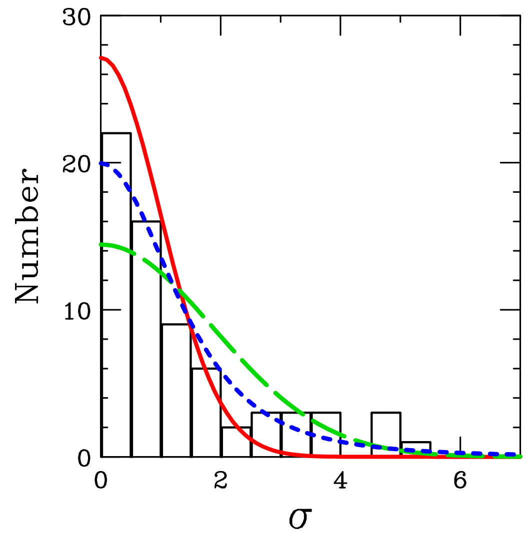
(Glazov, Radescu, 2009)

WHERE IS THE UNCERTAINTY COMING FROM?

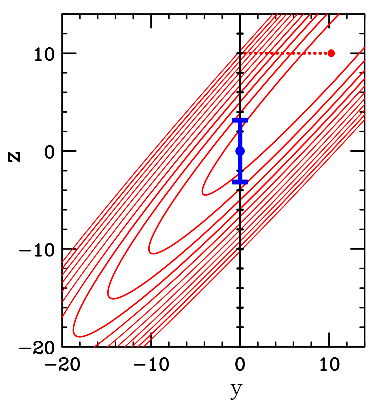
WHY DOES ONE NEED LARGE TOLERANCES?

DATA INCOMPATIBILITY (Pumplin, 2009)

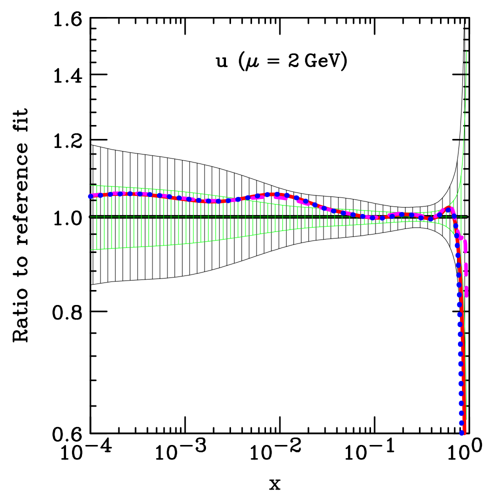
- CAN "REDIAGONALIZE": DIAGONALIZE SIMULTANEOUSLY χ^2 FOR TOTAL AND i–TH EXPT $\Rightarrow$ COMPATIBILITY OF EACH EXPT WITH GLOBAL FIT
- STUDY DISTRIBUTION OF DISCREPANCIES
- APPROX. GAUSSIAN WITH UNCERTAINTIES RESCALED BY 2 $\Rightarrow$ $\Delta\chi^2 \sim 10$ FOR 90%C.L.



FUNCTIONAL BIAS (Pumplin, 2010)



- 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. COMPATIBLE WITH $\Delta\chi^2 = 100$ RANGE OF CT10 PARM.



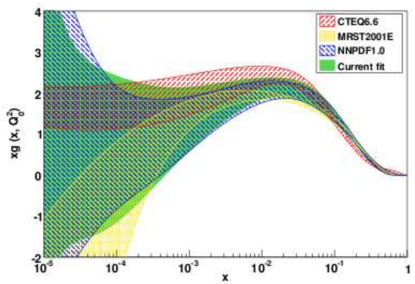
WHERE IS THE UNCERTAINTY COMING FROM?

FIT TO REPLICAS VS RANDOM SUBSET OF CENTRAL VAL.S

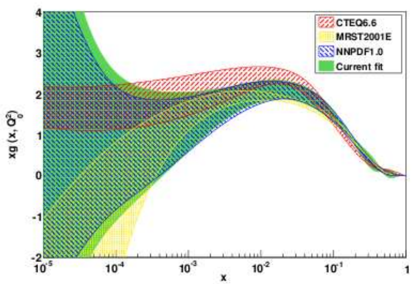
	REPLICAS	CENTRAL V.
χ^2	1.32	1.32
$\langle\chi^2\rangle_{\rm rep}$	2.79 ± 0.24	1.65 ± 0.20
$\langle\sigma^{\rm dat}\rangle$	0.039	0.035

GLUE

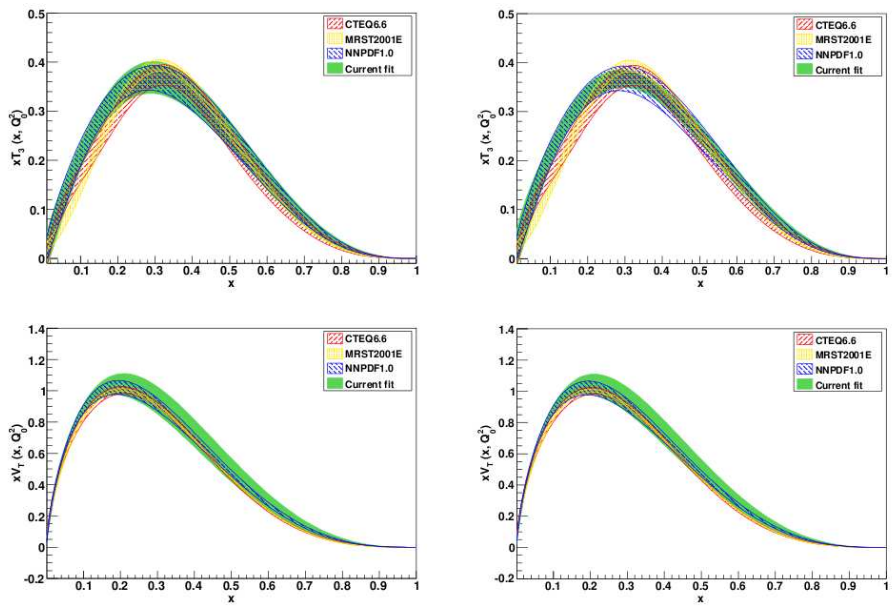
replicas



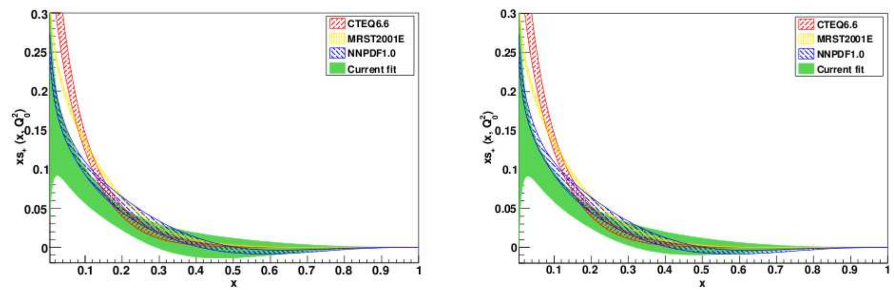
c. vals.



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

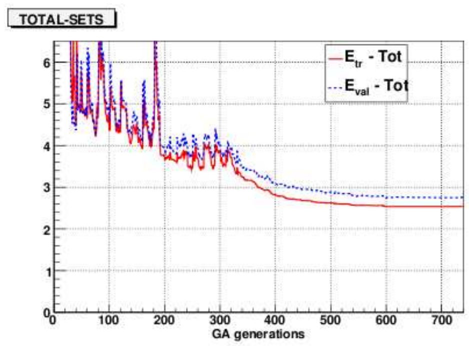
WHERE IS THE UNCERTAINTY COMING FROM?

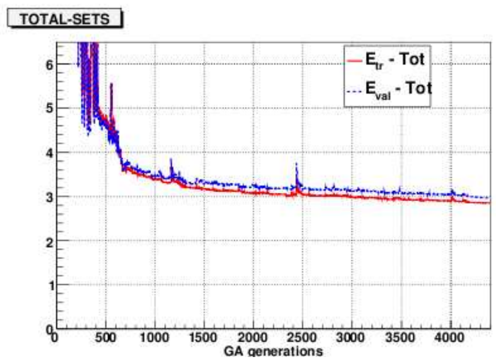
CENTRAL VALUES: VARYING PARTITION VS FIXED PARTITION

	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

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

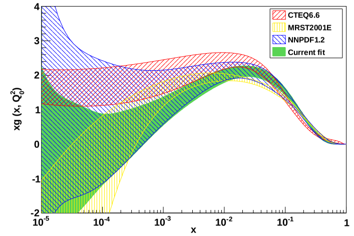




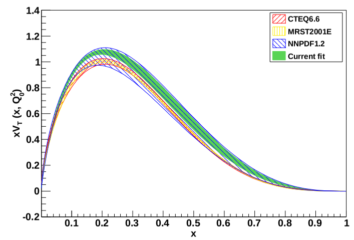
FUNCTIONAL UNCERTAINTY

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

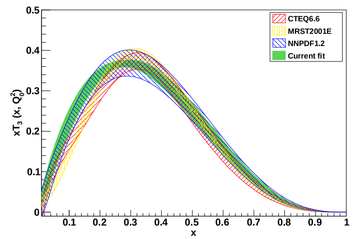
GLUE



VALENCE



TRIPLET



STRANGE