LHC PHYSICS PROSPECTS:

STANDARD MODEL (EW+QCD)

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IX ATLAS ITALIA WORKSHOP

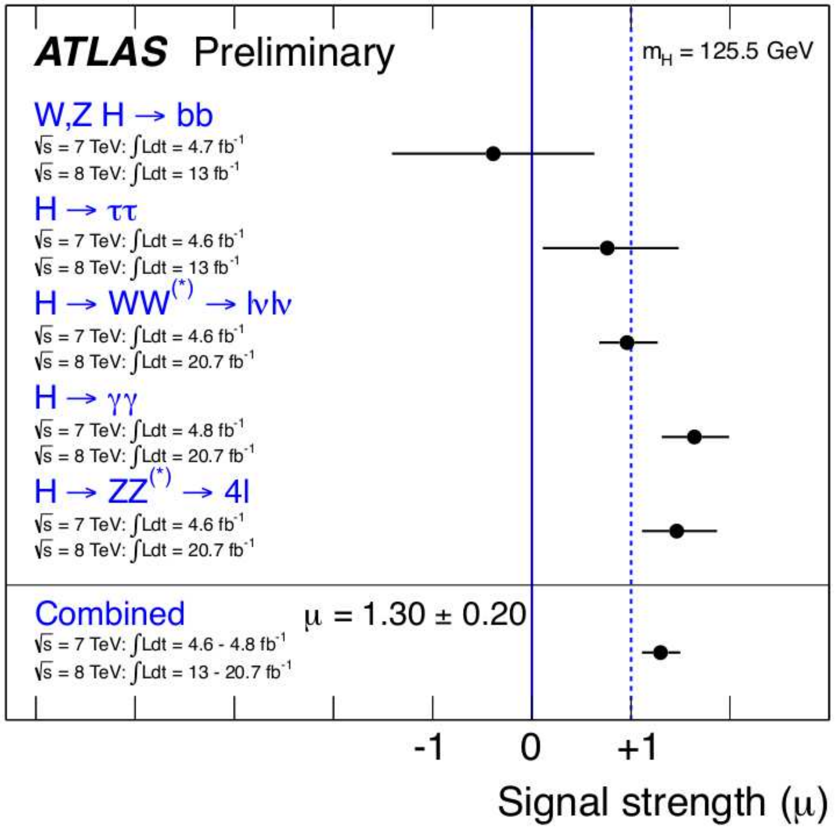
BOLOGNA, JAN. 15, 2014

MORE SM PHYSICS?

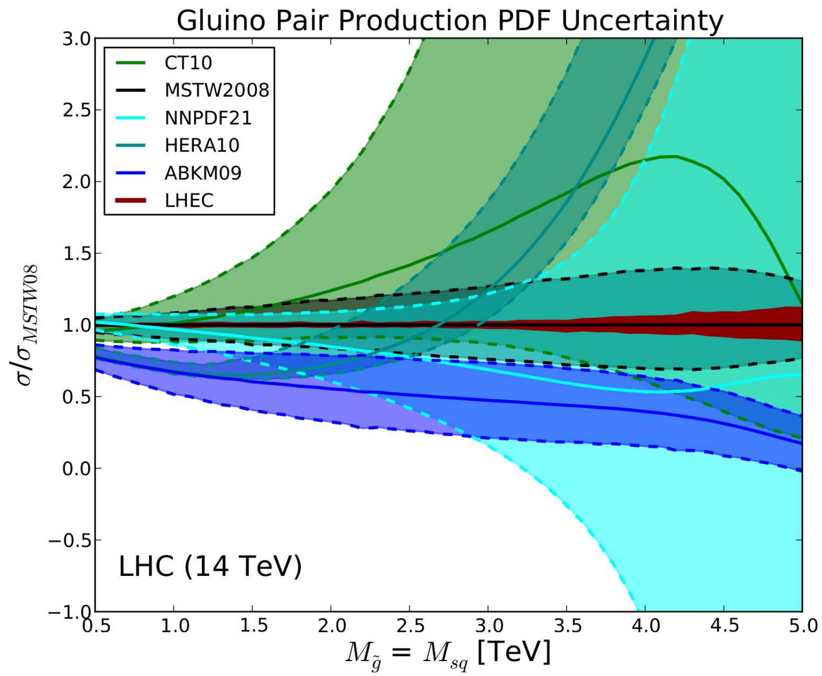
"future precision measurements of the top and Higgs sector would tell us the next energy scale"

(H. Murayama, 2013)

PRECISION: HIGGS



DISCOVERY: NEW PARTICLES



SUMMARY

- PDFs
  - THE STATE OF THE ART
  - ISSUES AND THE PDF4LHC PRESCRIPTION
  - THE IMPACT OF CURRENT AND FUTURE LHC DATA
- PRECISION SM PHYSICS
  - ELECTROWEAK CORRECTIONS
  - MEASURING ELECTROWEAK PARAMETERS
  - THE STRONG COUPLING
- GOING LESS INCLUSIVE
  - RESUMMATION
  - JETS
  - MATCHING TO MONTE CARLOS

DISCLAIMER:

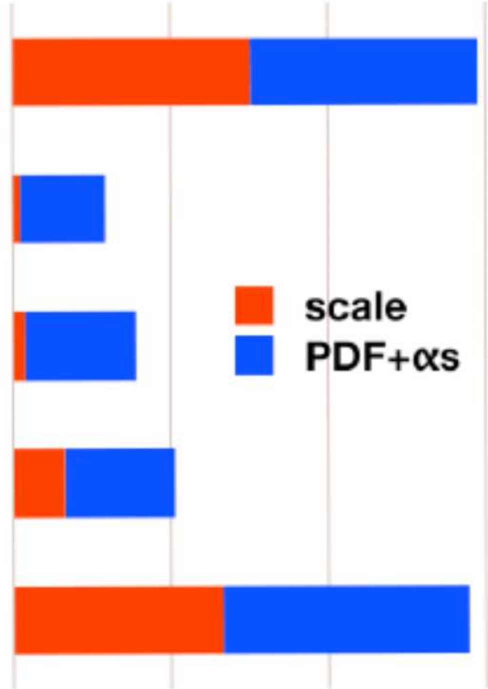
- FOCUS ON NEAR FUTURE
- NO ATTEMPT TO PROVIDE A COMPREHENSIVE REVIEW

PDFs & QCD corrections

THE IMPACT OF PDF UNCERTAINTIES

HIGGS PRODUCTION

		σ (8 TeV)	uncertainty
NNLL QCD +NLO EW	gg→H	19.5 pb	14.7%
	VBF	1.56 pb	2.9%
NNLO QCD +NLO EW	WH	0.70 pb	3.9%
	ZH	0.39 pb	5.1%
NLO QCD	ttH	0.13 pb	14.4%



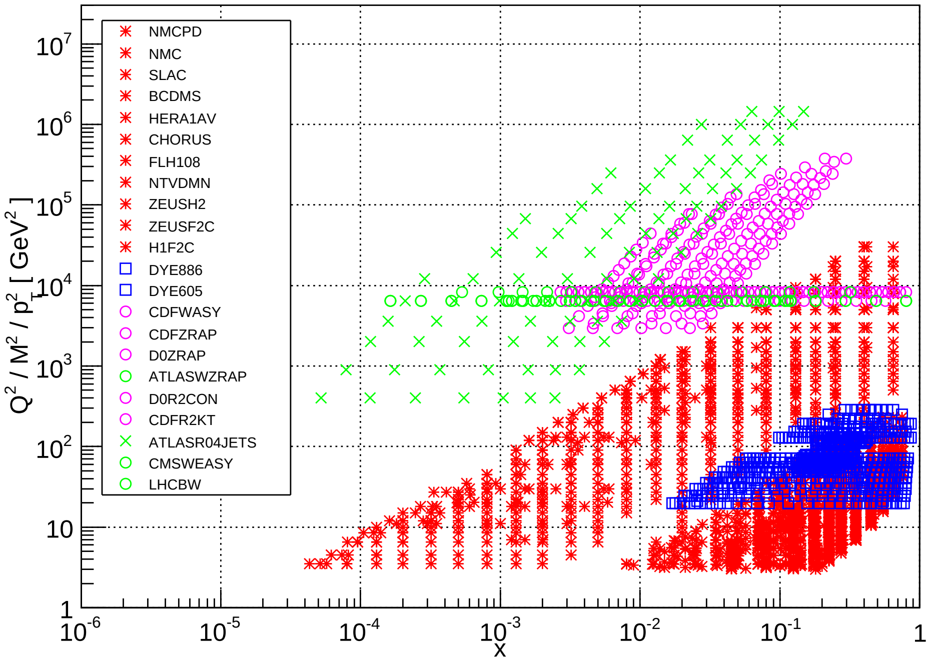
(J. Campbell, HCP2012)

- PDF UNCERTAINTY EITHER DOMINANT, OR VERY LARGE OR BOTH
- note uncertainty shown also includes α_s

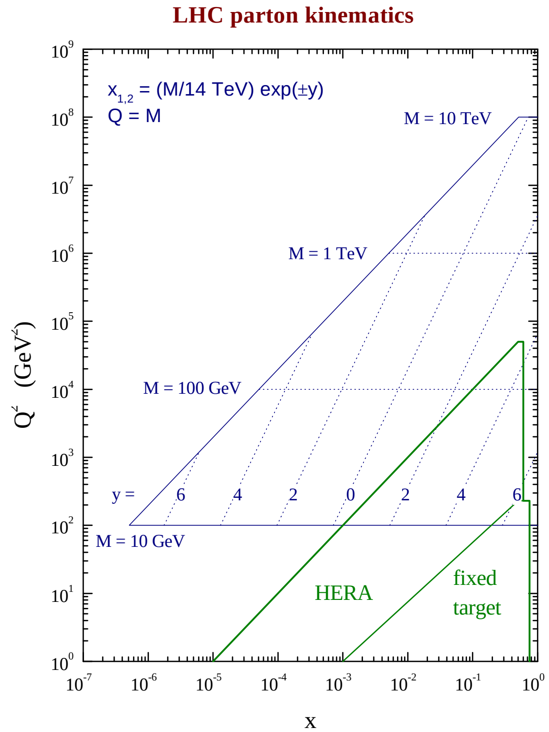
CURRENT PDF SETS: THE DATA

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

NNPDF2.3 Dataset



LHC KINEMATICS



	MSTW08	CT10	NNPDF2.3	HERAPDF1.5	ABM11	JR09
HERA DIS	✔	✔	✔	✔	✔	✔
FIXED-TARGET DIS	✔	✔	✔	✗	✔	✔
FIXED-TARGET DY	✔	✔	✔	✗	✔	✔
TEVATRON $W+Z$+JETS	✔	✔	✔	✗	✗	✗
LHC $W+Z$+JETS	✗	✗	✔	✗	✗	✗

CURRENT PDF SETS: THE APPROACH

METHODOLOGY

- 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, MSTW)
- PARTON PARAMETRIZATION: CTEQ, MSTW, HERAPDF $x^\alpha(1-x)^\beta\times$ POLYNOMIALS; GJR: DITTO + VALENCELIKE ASSUMPTION; NNPDF NEURAL NETS; CHEBYSHEV POLYNOMIALS STUDIED BY HERAPDF, MSTW;
- COVARIANCE MATRIX, NORMALIZATION UNCERTAINTIES, OUTLIERS, THEORETICAL UNCERTAINTIES ...

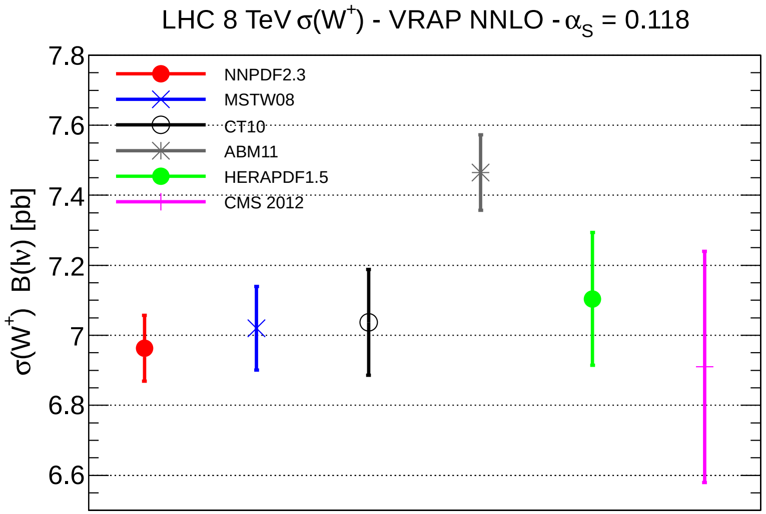
THEORY

- α_s VALUE: CTEQ: EXTERNAL PARAMETER, SEVERAL VALUES AVAILABLE; NNPDF: EXTERNAL PARAMETER, SEVERAL VALUES AVAILABLE, BEST-FIT DETERMINED; MSTW: FITTED, BUT ALSO VARIABLE AS EXT.PARAMETER; ABKM: FITTED, VARIABLE AS EXT.PARAMETER (ONLY CENTRAL VALUE); GJR: FITTED, NOT VARIABLE AS EXT. PARAMETER;
- 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 ($N_f=3$)
- NUCLEAR CORRECTIONS, HIGHER TWISTS, KINEMATIC CUTS, "INITIAL SCALE", ...

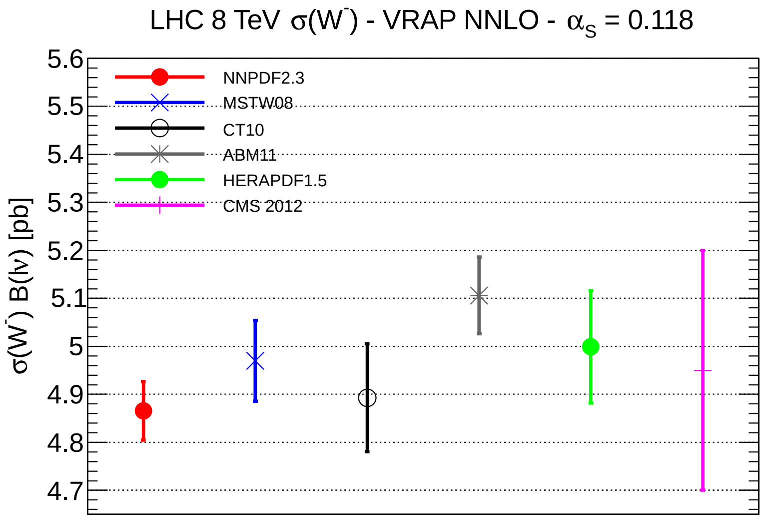
	MSTW08	CT10	NNPDF2.3	HERAPDF1.5	ABM11	JR09
NO. OF PDFS	7	6	7	5	6	5
STATISTICS	HESS.+DT	HESS.+DT	MC	HESS.+MODEL+PARM.	HESS.	HESS.+T
PDF PARMS.	20+8	25	259	14	24	12
HEAVY QUARKS	VFN TR	VFN ACOT	VFN FONLL	VFN TR	FFN	FFN

LHC EW STANDARD CANDLES

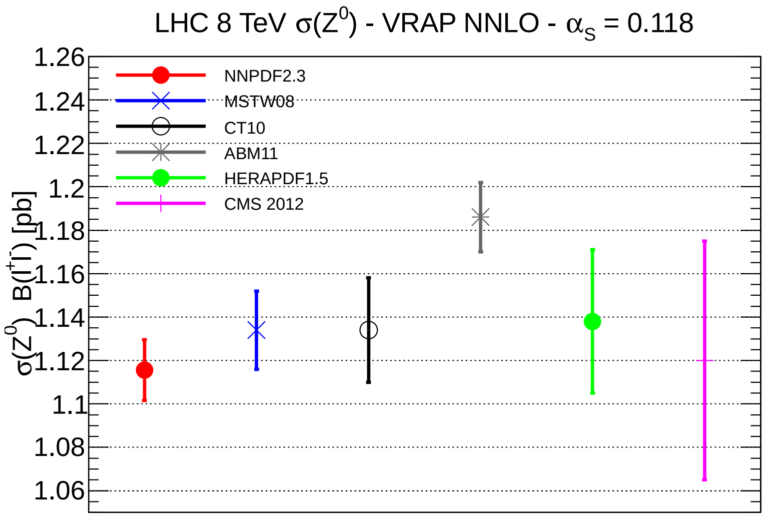
W^+



W^-



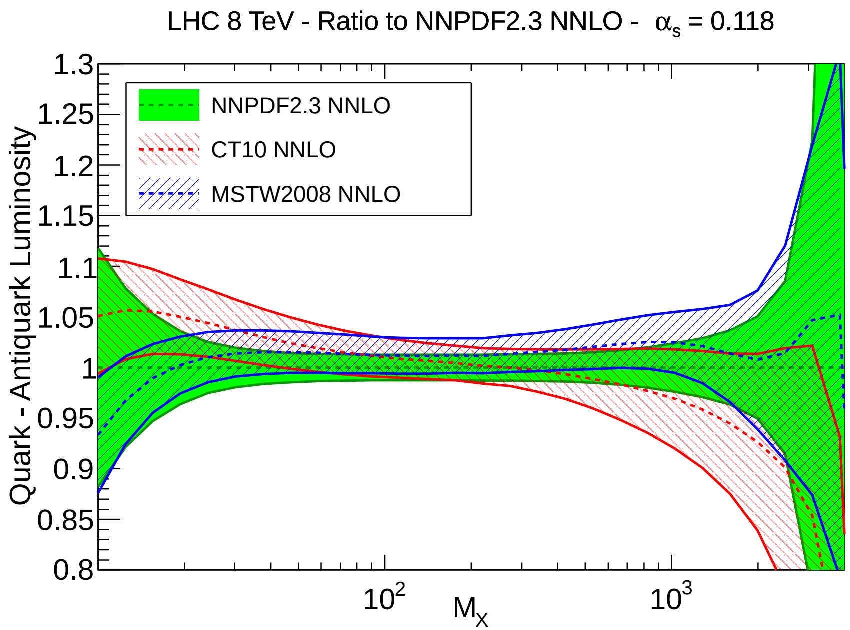
Z



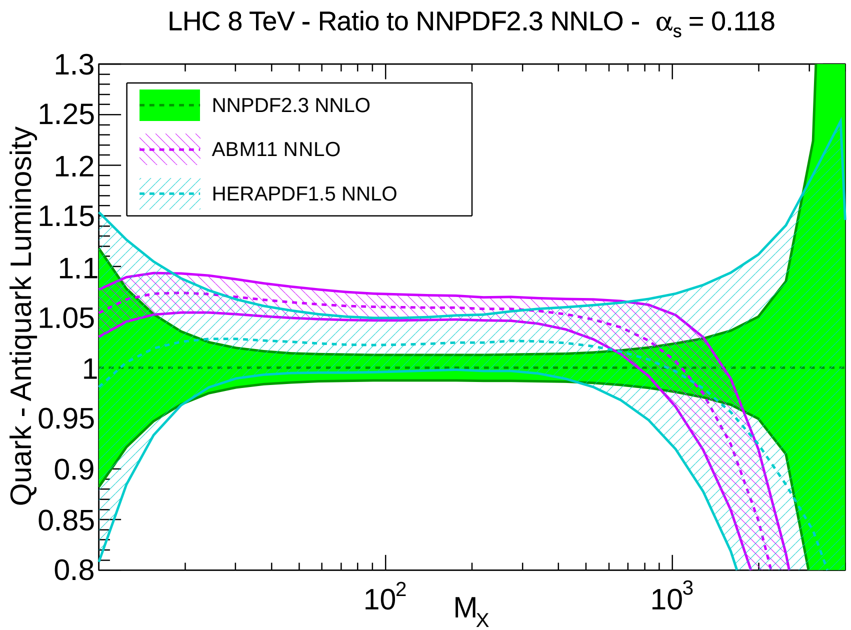
- AGREEMENT/DISAGREEMENT DRIVEN BY DATA
- DIS-ONLY FIT (HERAPDF) SAFE, BUT LARGE UNCERTAINTY
- FITS WITH SMALLER DATASETS PRONE TO TH. BIAS

PARTON LUMINOSITIES: QUARK SECTOR $(q\bar{q})$

GLOBAL PDF SETS
(ratio to NNPDF2.3)



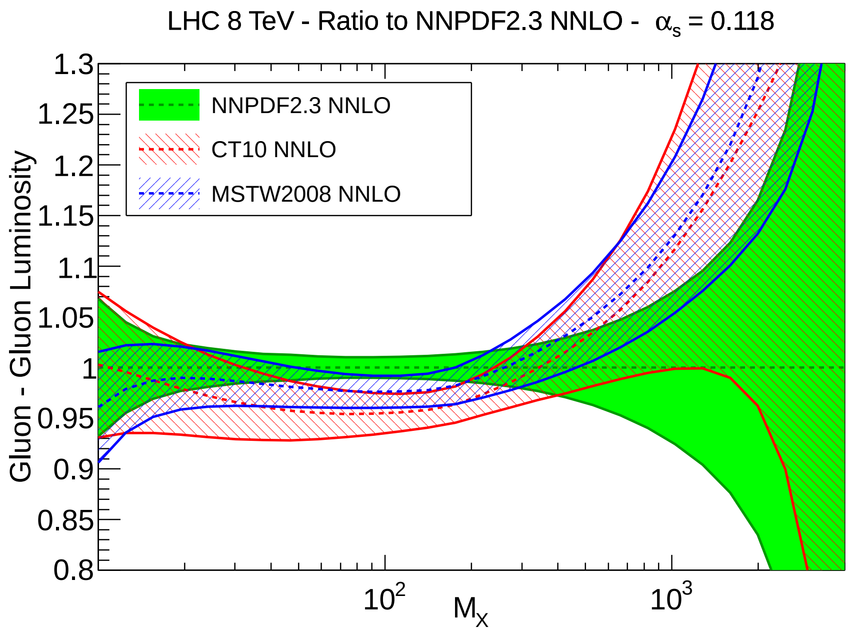
OTHER PDF SETS
(ratio to NNPDF2.3)



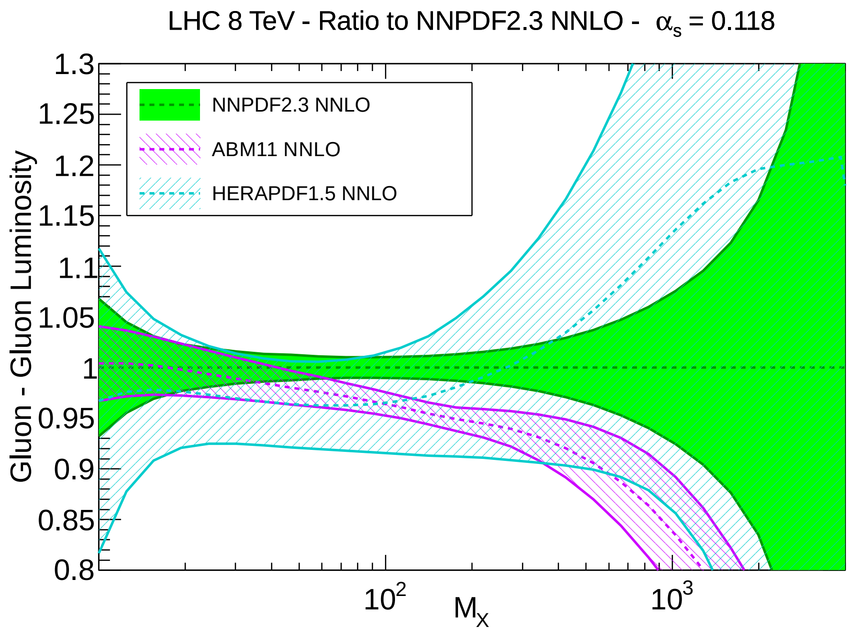
- CROSS-SECTIONS REFLECT UNDERLYING LUMINOSITIES
  FEWER DATA $\rightarrow$ LARGER UNCERTAINTIES (OR SYSTEMATIC BIAS)
- GLOBAL SETS: GOOD AGREEMENT IN THE REGION OF THE EW SCALE
- UNCERTAINTIES BLOW UP FOR LARGE-MASS FINAL STATES

PARTON LUMINOSITIES: GLUON SECTOR

GLOBAL PDF SETS
(ratio to NNPDF2.3)



OTHER PDF SETS
(ratio to NNPDF2.3)

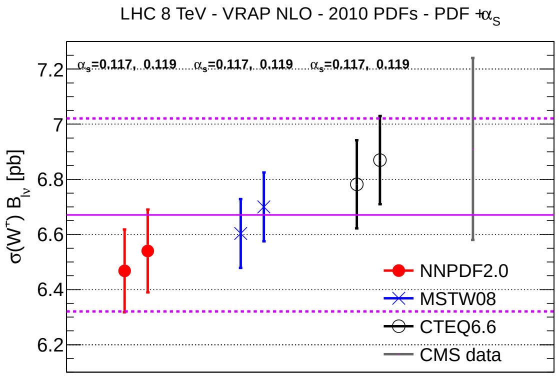


- FEWER DATA → LARGER UNCERTAINTIES (OR SYSTEMATIC BIAS)
- GLOBAL SETS: NOT SO GOOD AGREEMENT IN THE REGION OF THE EW SCALE
- UNCERTAINTIES BLOW UP FOR LARGE-MASS FINAL STATES

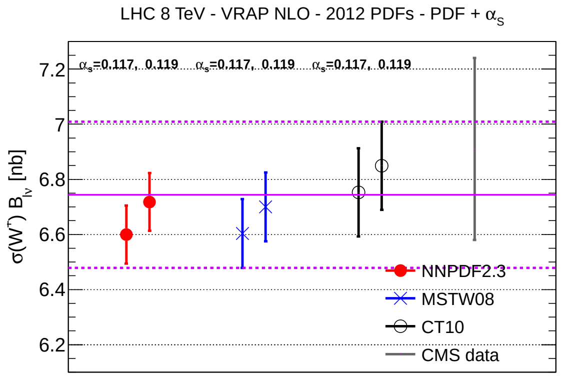
PROGRESS

GLOBAL PDF SETS: THE W^+ CROSS-SECTION

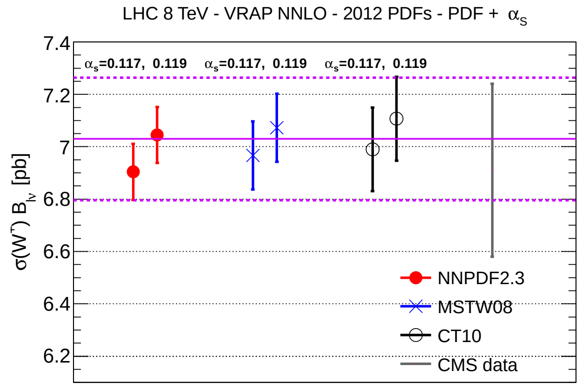
2010 NLO PDFs



2012 NLO PDFs



2012 NNLO PDFs



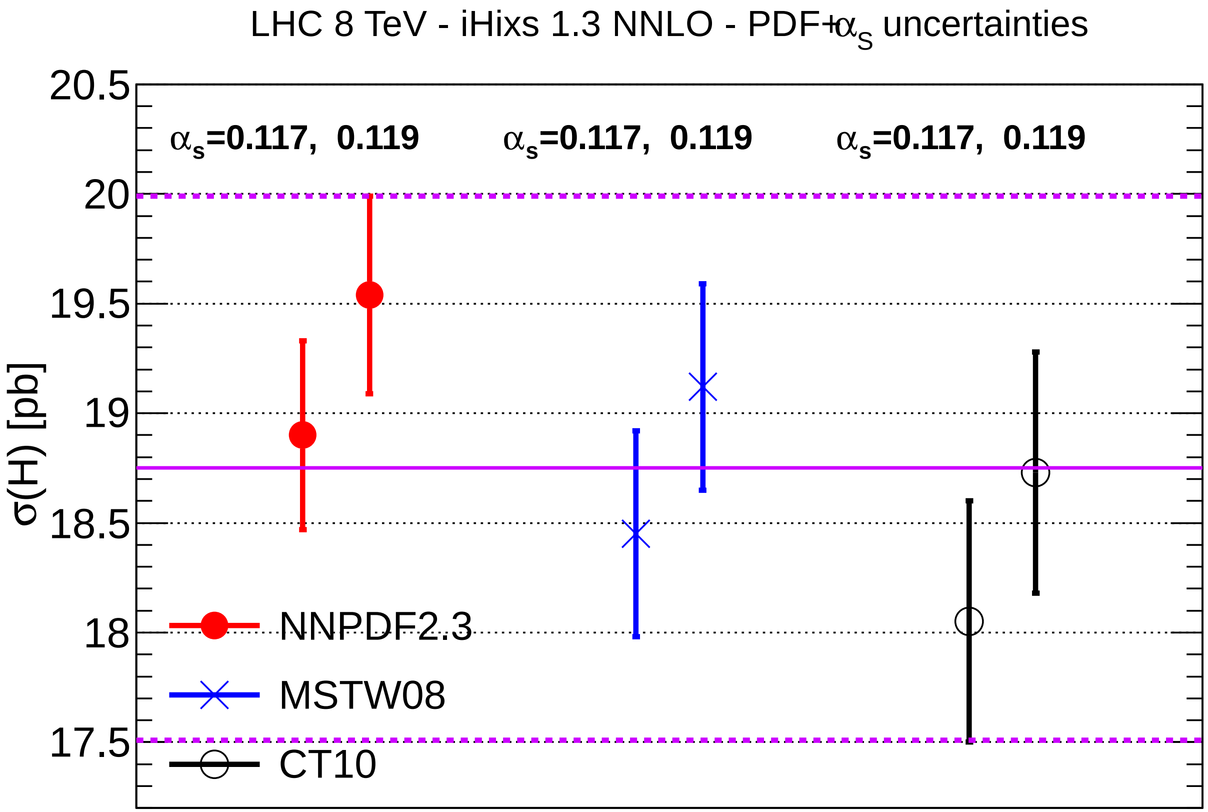
- Each datapoint includes PDF+α_s uncertainty; $\Delta\alpha_s = 0.001$
- $\alpha_s = 0.117$ and $\alpha_s = 0.119$ predictions given for each set (note all PDFs depend on α_s)
- horizontal (purple) line show envelope of predictions

IMPROVEMENTS: MOSTLY DATA-DRIVEN

- MORE GENERAL PARAMETRIZATION (CTEQ, MSTW)
- NNLO FITS AVAILABLE (NNPDF, CTEQ)
- FULL TREATMENT OF CHARM MASS (NNPDF)
- CONTINUOUS BENCHMARKING

DEALING WITH ISSUES: THE PDF4LHC PRESCRIPTION

HIGGS IN GLUON FUSION

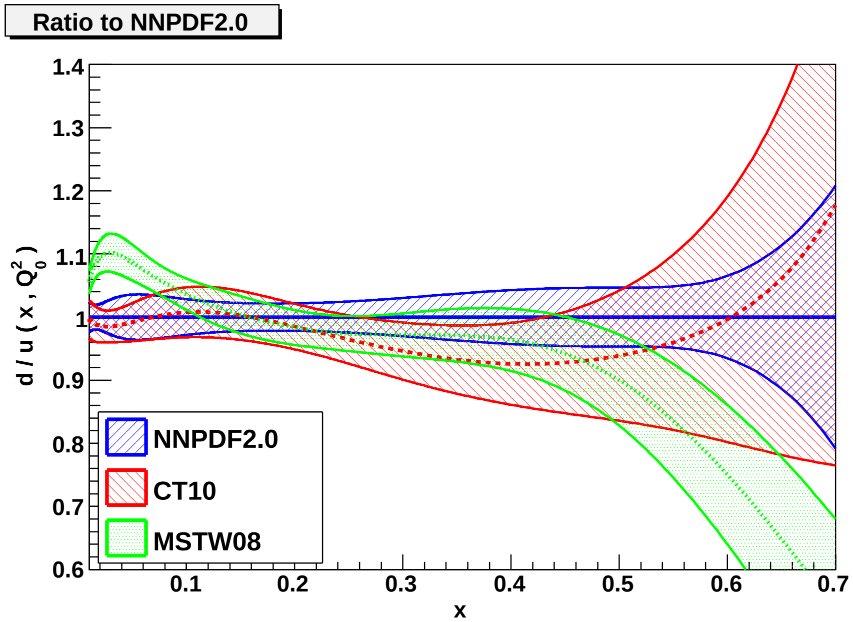


- HOW CAN ONE HANDLE DISCREPANCIES WHICH ARE NOT UNDERSTOOD?
- CONSERVATIVE ANSWER: TAKE THE ENVELOPE OF RESULTS

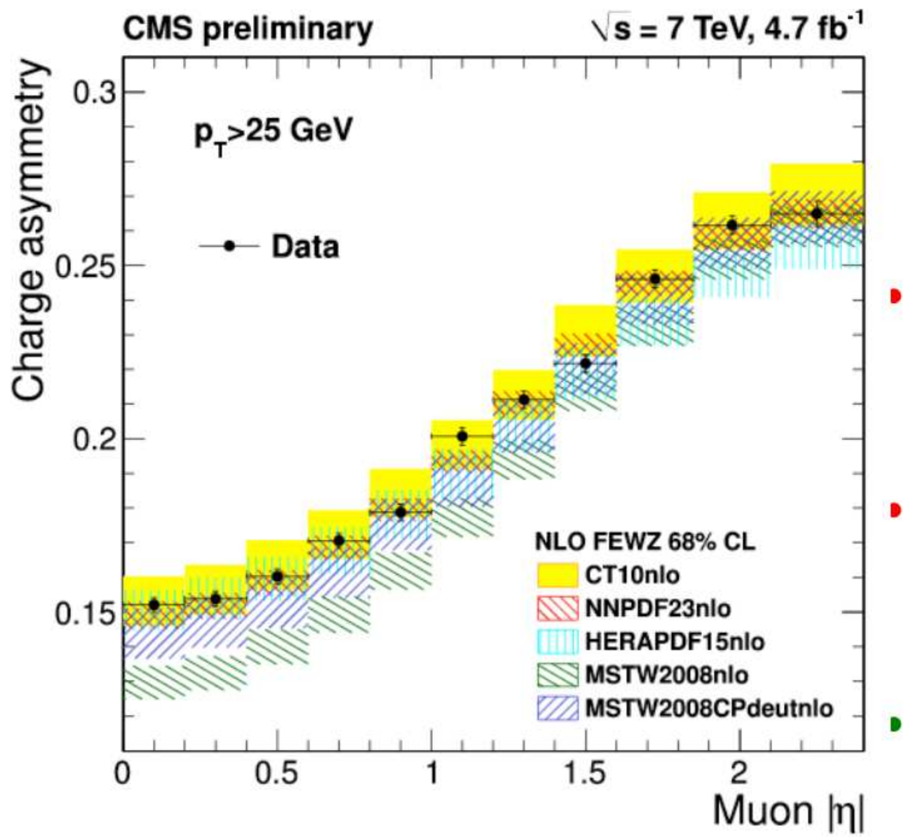
PROGRESS AND ISSUES: THE ROLE OF LHC DATA

AN EXAMPLE: THE d/u RATIO

THE d/u RATIO



THE CMS W ASYMMETRY



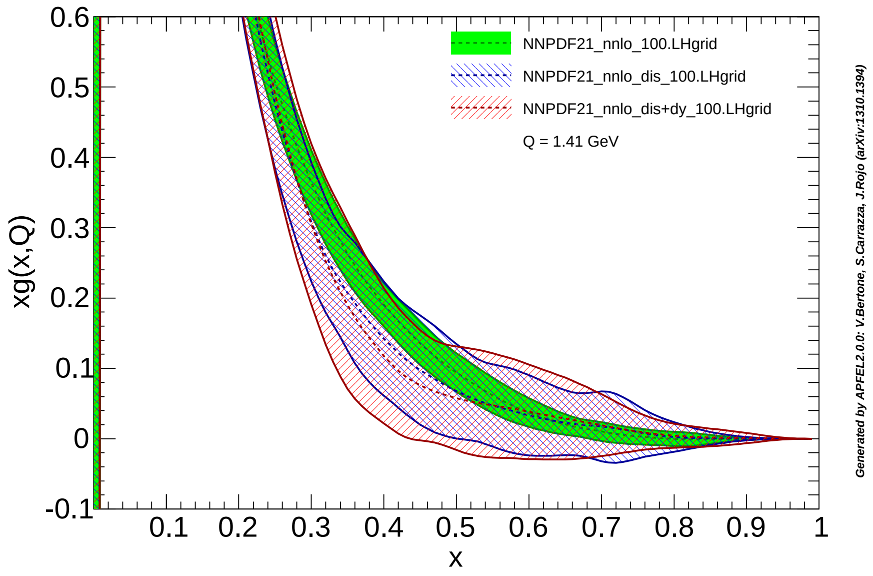
- LONG-STANDING DISCREPANCY IN THE d/u RATIO BETWEEN MSTW AND OTHER GLOBAL FITS
- RESOLVED BY W ASYMMETRY DATA
- EXPLAINED BY INSUFFICIENTLY FLEXIBLE PDF PARAMETRIZATION $\to$ NEW MSTW08DEUT SET
- PDF4LHC PRESCRIPTION VALIDATED, NO LONGER NECESSARY HERE

THE IMPACT OF HADRON COLLIDER DATA

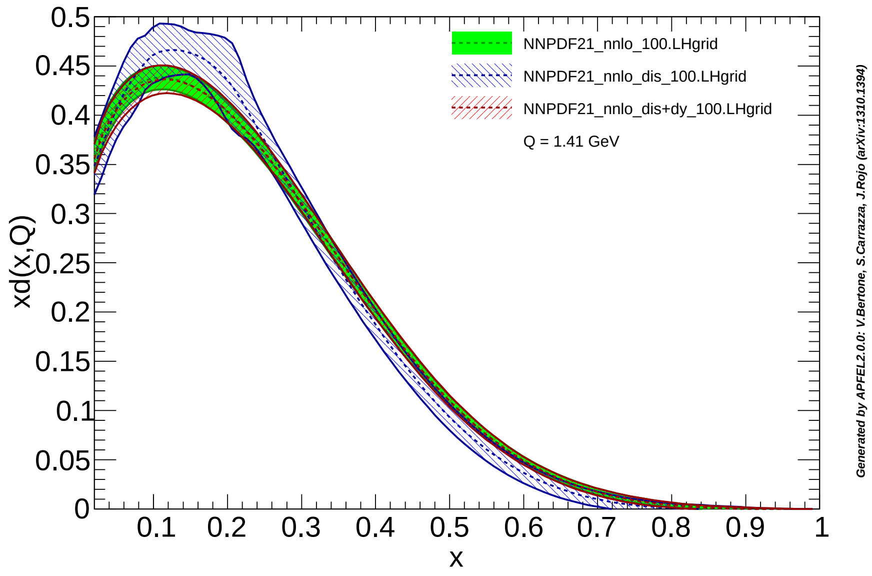
- CURRENT GLOBAL FITS INCLUDE SINGLE-INCLUSIVE JET AND DRELL-YAN RAPIDITY DISTRIBUTION DATA
- DRELL-YAN ⇒ SIZABLE IMPACT ON LIGHT FLAVOR SEPARATION & STRANGENESS
- JETS ⇒ SIZABLE IMPACT ON GLUON
- TEVATRON → LHC: DIVIDE x BY $\sqrt{s_{LHC}}/\sqrt{s_{TeV}}$

DIS VS DIS+DY VS DIS+DY+JET

GLUON



DOWN



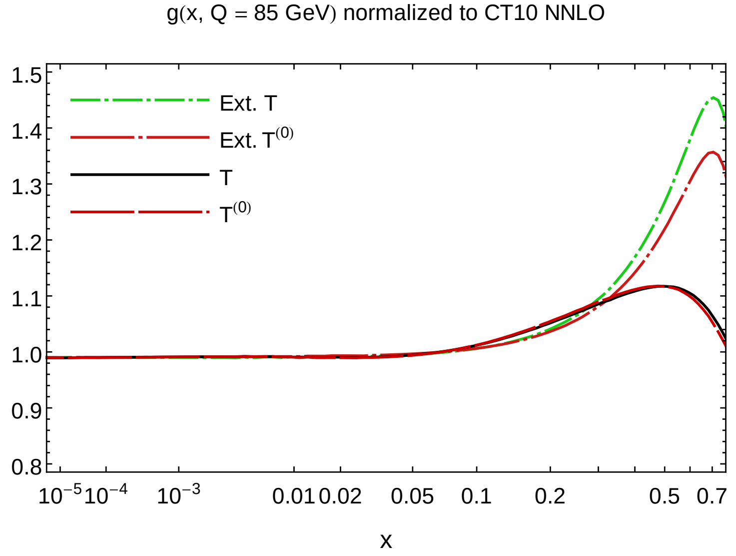
THE TREATMENT OF SYSTEMATIC UNCERTAINTIES

- HADRON COLLIDER DATA HAVE SIZABLE SYSTEMATICS
- IMPACT GREATLY REDUCED IF COVARIANCE MATRIX UNKNOWN

MULTIPLICATIVE VS. ADDITIVE SYSTEMATICS

- SYSTEMATICS CAN BE ADDITIVE (EXAMPLE: RADIATIVE CORRECTIONS) OR MULTIPLICATIVE (EXAMPLE: LUMINOSITY)
  multiplicative means shift depends on the value of the observable, thus stat uncertainty also scales with it
- MULTIPLICATIVE UNCERTAINTIES MUST BE TREATED WITH SUITABLE METHOD IN ORDER TO AVOID D'AGOSTINI BIAS
  $\Rightarrow$ T-METHOD (d'Agostini, 1994), T_0-METHOD, (NNPDF, 2010)
- ARE JET UNCERTAINTIES ALL MULTIPLICATIVE? (EXT-T) OR NOT? (T)

DEPENDENCE OF CT10 GLUON ON MULT VS. ADD SYSTEMATICS



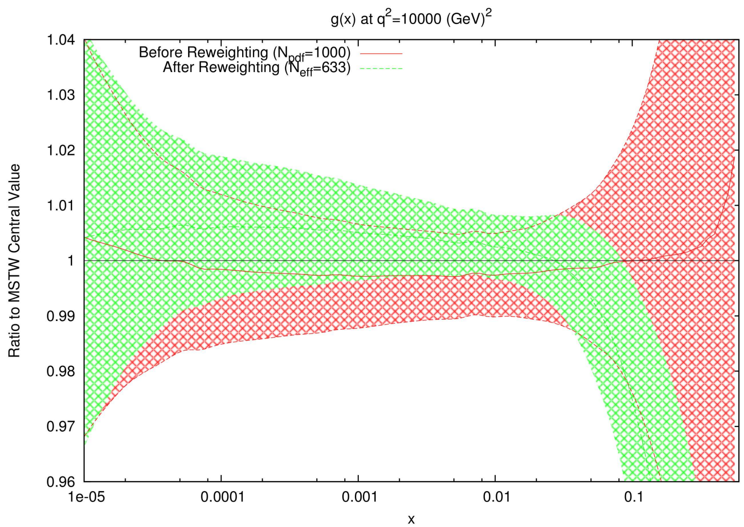
(CT10, Gao et al 2013)

THE IMPACT OF LHC DATA: PHENOMENOLOGY

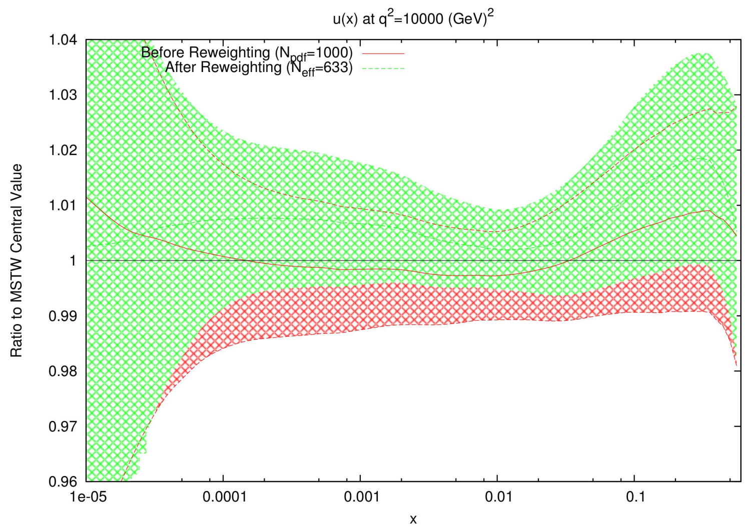
- LHC PROVIDES MORE JET AND DY DATA IN WIDER KINEMATIC REGION
- SO FAR, MODERATE IMPACT DUE TO SIZABLE UNCERTAINTIES
- SYSTEMATICS CAN BE GREATLY REDUCED BY LOOKING AT RATIOS BETWEEN DIFFERENT ENERGIES & DOUBLE RATIOS (E.G. RATIOS OF LUMINOSITY RATIOS OR ASYMMETRIES) (Mangano, Rojo, 2012)
- MEASUREMENTS OF DIFFERENT PROCESSES & DIFFERENT ENERGIES WITH FULLY CORRELATED SYSTEMATICS CRUCIAL
- RECENT MSTW STUDY OF ATLAS 2.76/7TeV JET RATIOS CONFIRMS SIGNIFICANT IMPACT
(PREVIOUS IMPACT OF ATLAS+CMS JET DATA ON NNPDF2.3 MODERATE)

ATLAS JET DATA INCLUDED IN MSTW08

GLUON



UP



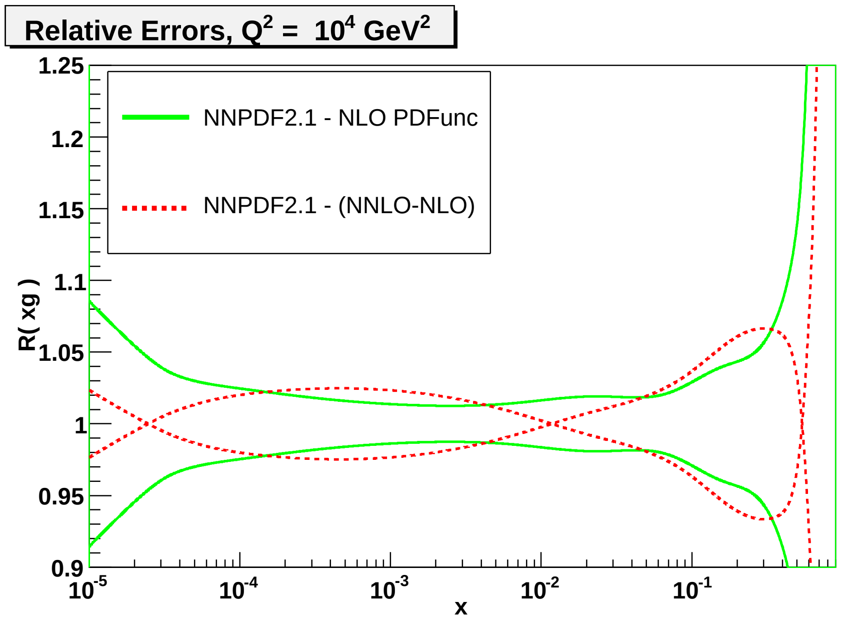
(B. Watt, Motylinski, Thorne, 2013)

THE IMPACT OF LHC DATA: THEORY

"2013 will be remembered as the year of $2 \to 2$ at NNLO" (L. Dixon)

- THEORETICAL UNCERTAINTIES ON NLO PDFs (NLO-NNLO SHIFT) COMPARABLE TO STAT. UNCERTAINTIES
  NOTE TH. UNCERTAINTIES NOT INCLUDED IN PDF UNCERTAINTIES $\Rightarrow$ NNLO CORRECTIONS CRUCIAL

NLO GLUON EXP VS TH UNCERTAINTY



THE IMPACT OF LHC DATA: THEORY

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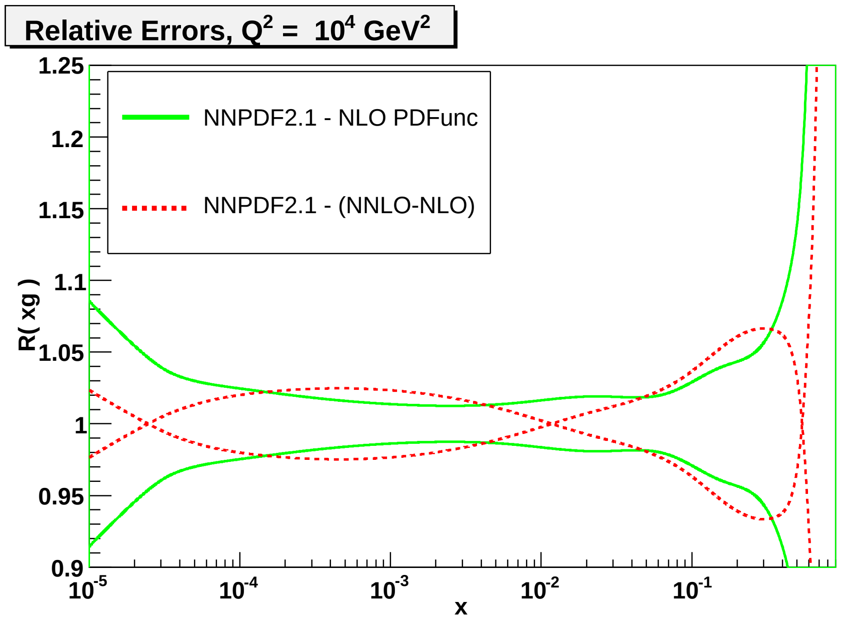
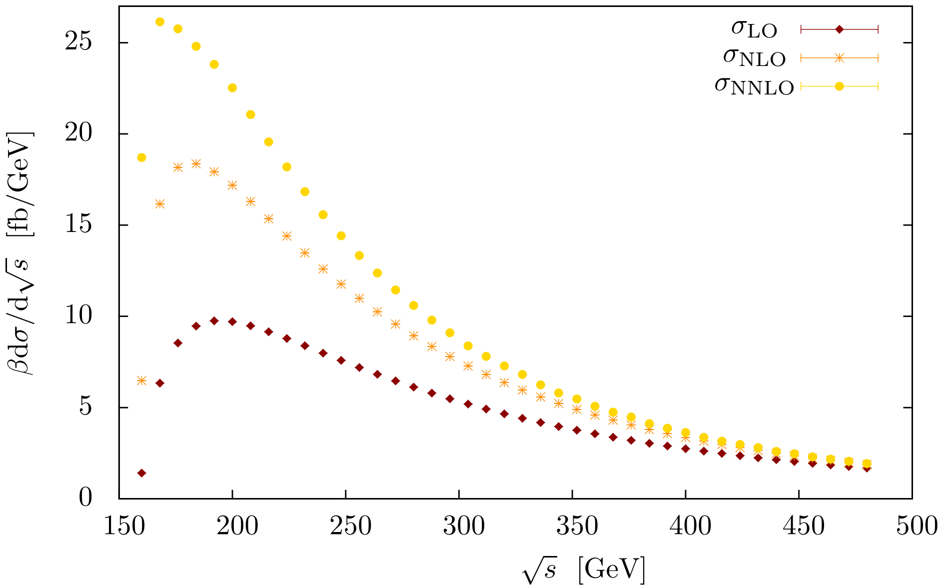
- THEORETICAL UNCERTAINTIES ON NLO PDFS (NLO-NNLO SHIFT) COMPARABLE TO STAT. UNCERTAINTIES
  NOTE TH. UNCERTAINTIES NOT INCLUDED IN PDF UNCERTAINTIES $\Rightarrow$ NNLO CORRECTIONS CRUCIAL
- MORE NNLO RESULTS RECENTLY AVAILABLE $\Rightarrow$ SIZABLE CORRECTIONS
  - HIGGS+ JET (Boughezal, Caola, Melnikov, Petriello, Schulze, 2013)
  - TOP PRODUCTION (Czakon, Mitov, 2013)
  - JET PRODUCTION (GLUONS) (Currie, de Ridder, Gehrmann, Glover, Pires, 2013)
- HIGGS+ JET $\Rightarrow Z\ p_t$ DISTRIBUTION: POSSIBLY CLEANEST PROBE OF GLUON PDF

NLO GLUON EXP VS TH UNCERTAINTY



HIGGS + JET XSECT
DIFF. WR TO PARTONIC CM ENERGY



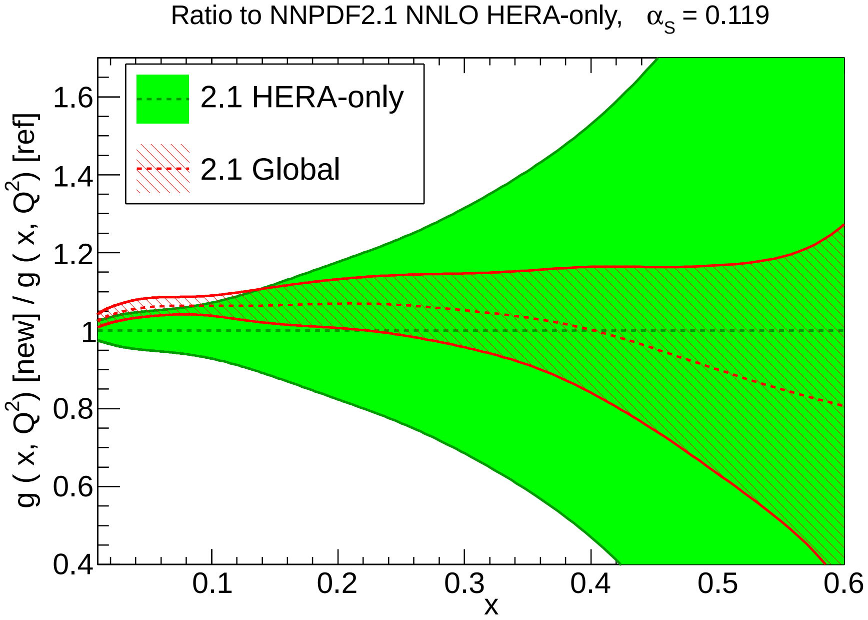
(Boughezal, Caola, Melnikov, Petriello, Schulze, 2013)

LHC DATA: TOP PRODUCTION & THE GLUON

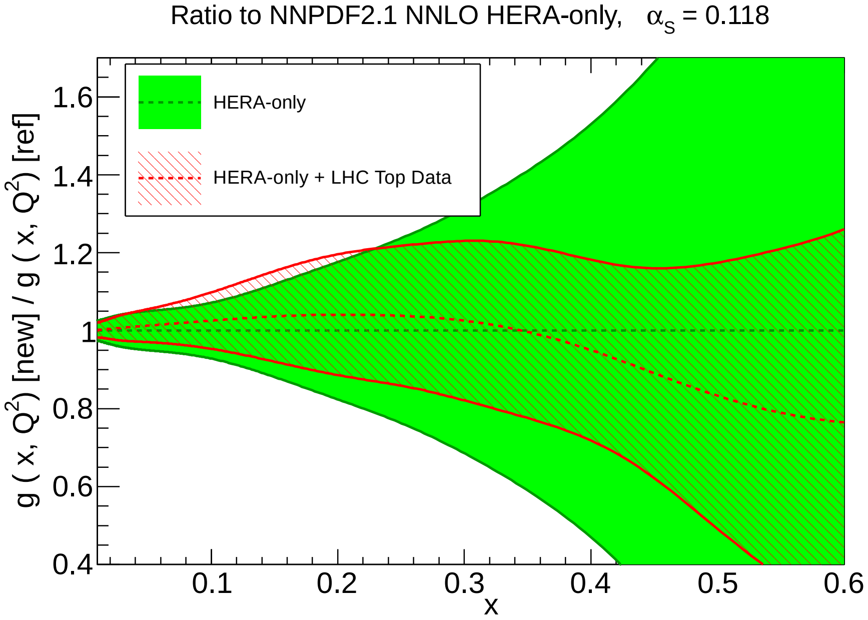
- GLUON IN GLOBAL FIT DETERMINED MOSTLY FROM SCALING VIOLATIONS (DIS) & JET DATA
- REMOVING ALL DATA BUT HERA ⇒ CLEAN DETERMINATION, BUT LARGE UNCERTAINTIES
- AVAILABLE LHC DATA ON TOP PRODUCTION ALONE CAN PROVIDE SAME INFORMATION AS ALL DATA BESIDES HERA IN GLOBAL FITS ⇒ POTENTIALLY VERY CLEAN DETERMINATION

DETERMINATION OF THE GLUON DISTRIBUTION

HERA ONLY VS GLOBAL FIT

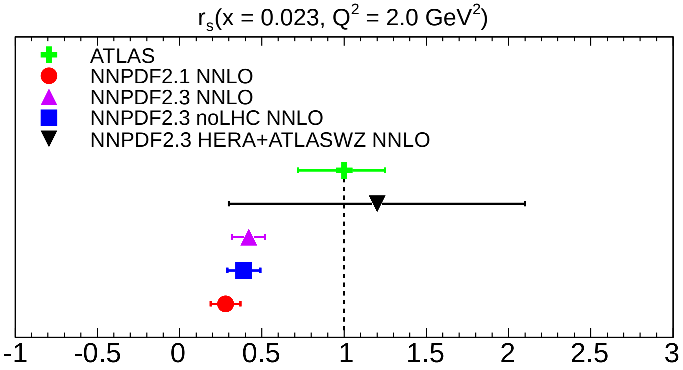


HERA ONLY VS HERA+TOP



(Czakon, Mangano, Mitov, Rojo, 2013)

LHC DATA: STRANGENESS & $W + c$ PRODUCTION



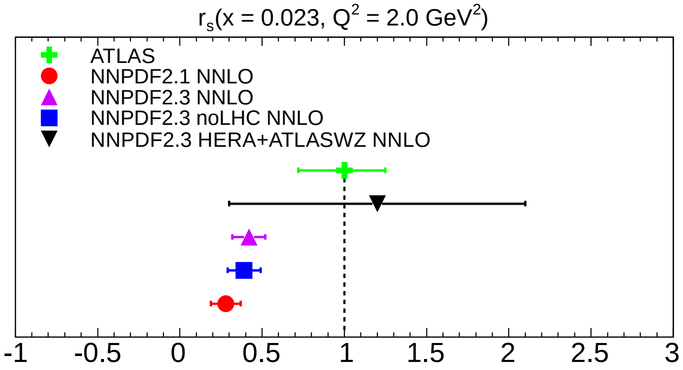
- ATLAS DRELL-YAN DATA (2012) SUGGEST LARGE (≈ 1) STRANGE FRACTION

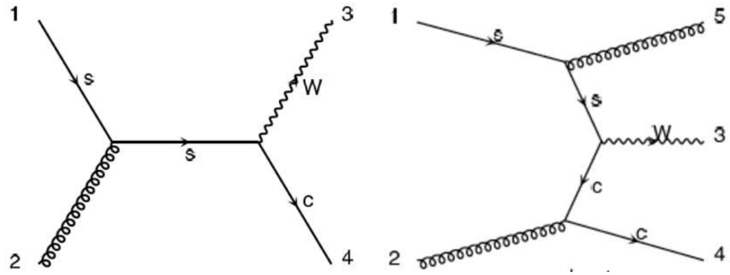
  $r_s(x, Q^2) = \frac{s(x,Q^2)+\bar{s}(x,Q^2)}{2\bar{d}(x,Q^2)}$

- HOWEVER LARGE UNCERTAINTIES (NNPDF2.3) $\Rightarrow$

  CONSISTENT WITH PREVIOUS DET. (FROM NEUTRINO DATA) WITHIN UNCERTAINTIES

LHC DATA: STRANGENESS & $W + c$ PRODUCTION





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- HOWEVER LARGE UNCERTAINTIES (NNPDF2.3) $\Rightarrow$

  CONSISTENT WITH PREVIOUS DET. (FROM NEUTRINO DATA) WITHIN UNCERTAINTIES

- STRANGENESS PROBED DIRECTLY IN $W + c$ PRODUCTION

$W + c$ PRODUCTION AT THE LHC

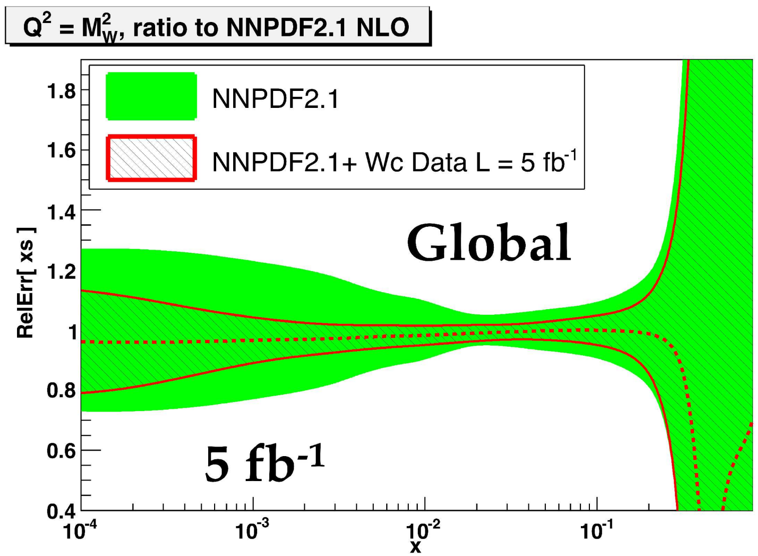
- SIMULATED MEASUREMENT OF c RAPIDITY DISTRIBUTION WITH AMC@NLO

(J. Rojo, S. Frixione, M. Mangano, 2012)

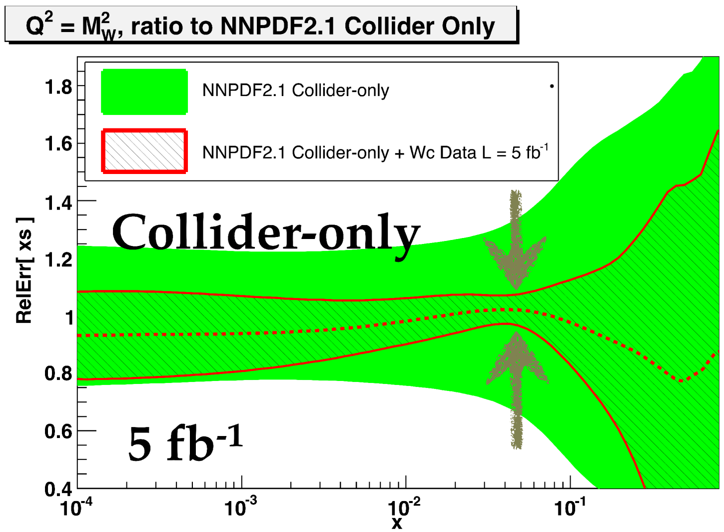
- CMS KINEMATICS $p_T^{\rm jet} > 20$ GeV, $p_T^{\mu} > 25$ GeV $\eta^{\rm jet}$, $\eta^{\mu} < 2.1$
- 15% CHARM TAGGING EFFICIENCY (CMS)
- CURRENTLY 36 PB^{-1}, BUT 5 FB^{-1} SUFFICIENT

THE IMPACT ON STRANGENESS

IN THE NNPDF2.1 FIT



IN THE COLLIDER-ONLY FIT

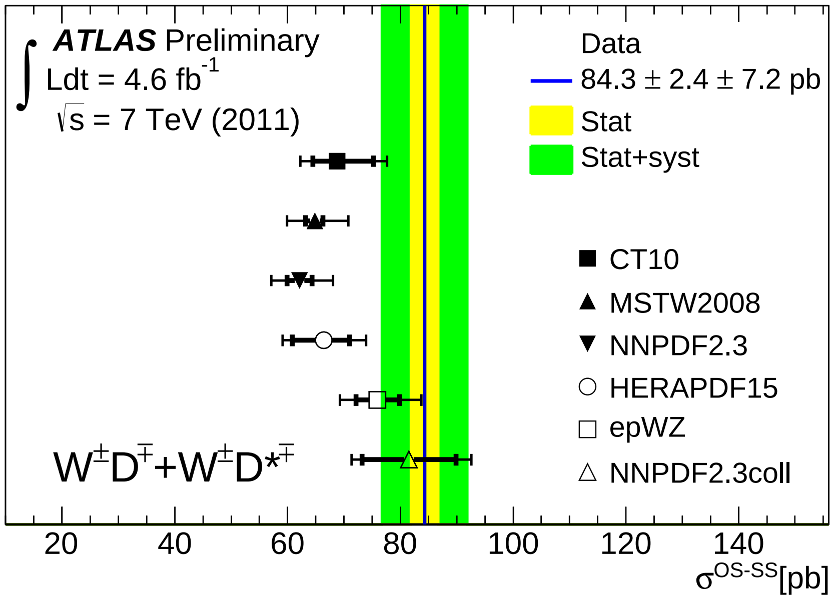


$W + c$ PRODUCTION AT THE LHC

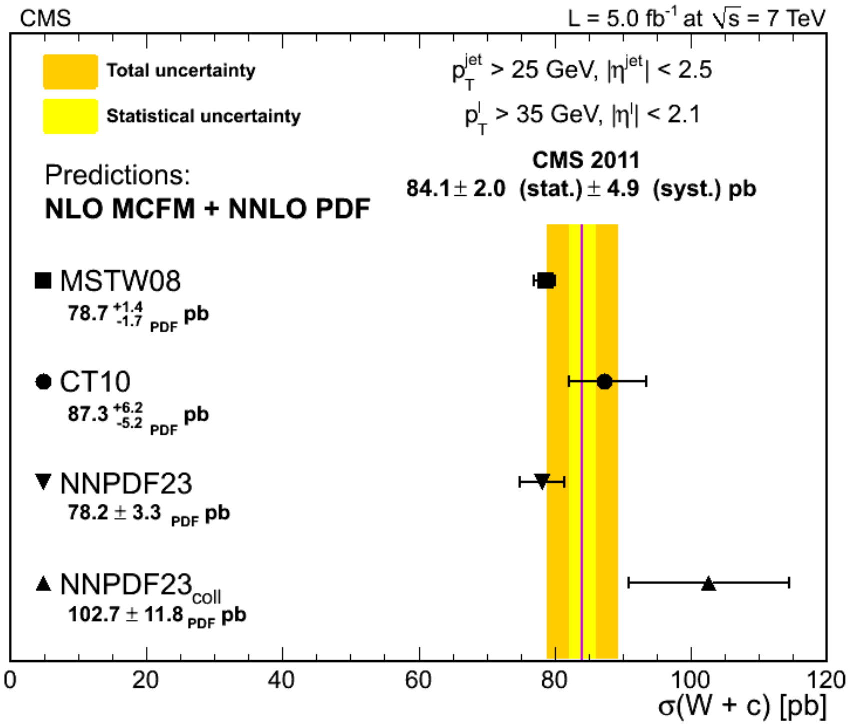
- MEASUREMENTS BY ATLAS AND CMS CONSISTENT WITHIN UNCERTAINTIES
- COMPARE TO AVAILABLE DEFAULT FITS & TO NNPDF "COLLIDER ONLY" FIT (NO NEUTRINO DATA) $\Rightarrow$ TENSION BETWEEN DY AND NEUTRINO DATA
- ATLAS CENTRAL VALUE FAVORS DY MEASUREMENT, CMS CENTRAL VALUE FAVORS NEUTRINO DATA

LHC MEASUREMENTS

ATLAS



CMS



LHC DATA
FOR PDF DETERMINATION
THE GOAL: A "COLLIDER ONLY" PDF DETERMINATION

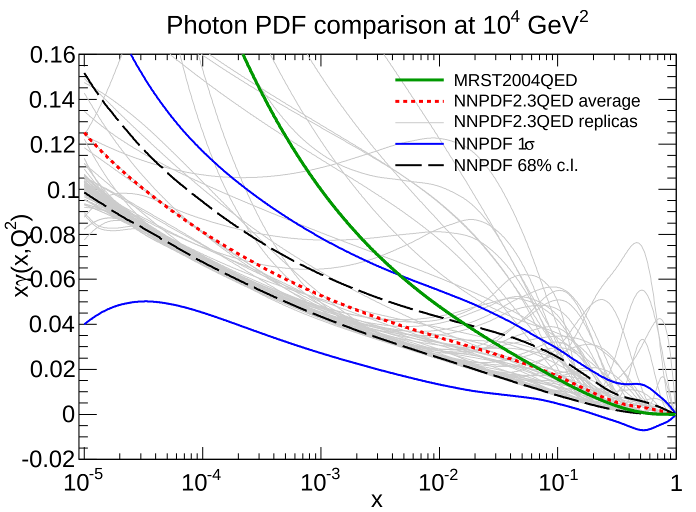
- MEDIUM & LARGE x GLUON
  - TOP RAPIDITY DISTRIBUTIONS (PARTIAL NNLO)
  - INCLUSIVE W, Z p_T DISTRIBUTIONS (NNLO SOON)
  - JETS (PARTIAL NNLO)
  - PROMPT PHOTONS (NLO)
  - DIJETS? (NLO)
  - W POLARIZATION? (NLO)
- LIGHT FLAVOR SEPARATION
  - LOW–MASS & HIGH–MASS DRELL-YAN (NNLO)
  - DOUBLE-DIFFERENTIAL DY RAPIDITY DISTRIBUTIONS (NNLO)
  - Z RAPIDITY DISTRIBUTIONS (NNLO)
  - W ASYMMETRIES (NNLO)
- STRANGENES & HEAVY FLAVORS
  - STRANGENESS $\Rightarrow$ $W + c$ (NLO)
  - CHARM $\Rightarrow$ $Z + c$, $\gamma + c$ (NLO)
  - BOTTOM $Z + b$ (NLO)
- NNLO THEORY IMPORTANT FOR TH. ACCURACY
- RATIOS AND DOUBLE RATIOS (8TEV/7TEV) IMPORTANT IN REDUCING UNCERTAINTIES
- COMPLETE INFORMATION ON CORRELATED SYSTEMATICS CRUCIAL!

EW CORRECTIONS
&
SM PARAMETERS

ELECTROWEAK CORRECTIONS
& PHOTON-INDUCED PROCESSES

- $\alpha \sim \alpha_s^2 \Rightarrow$ FOR ACCURACY AT THE PRECENT LEVEL QED & ELECTROWEAK CORRECTIONS IMPORTANT
- NLO EW CORRECTIONS DETERMINED FOR SEVERAL PROCESSED (DY, DY+JET, WW, JETS, HIGGS) DURING THE 2000'S; FOR DY MATCHING TO MC, TOWARDS $\alpha\alpha_s$ CORRNS.
- MUST DETERMINE A PHOTON PDF, INCLUDE QED EVOLUTION $\Rightarrow$ RECENT NNPDF2.3QED DETERMINATION USING LHC DY DATA
- ONLY ONE SET (MRST2004) AVAILABLE PREVIOUSLY, PHOTON PDF DETERMINED FROM MODEL & NO UNCERTAINTY DETERMINATION

THE PHOTON PDF



(NNPDF2.3QED, 2013)

(Boughezal, Li, Petriello, 2013)

ELECTROWEAK CORRECTIONS
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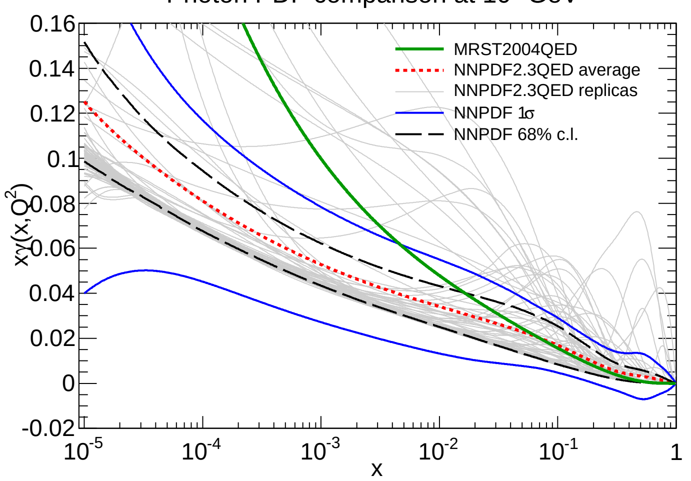
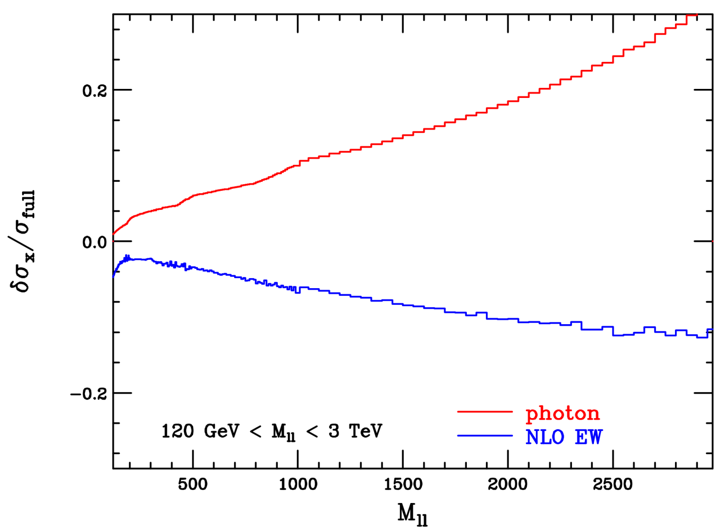
- PHOTON-INDUCED & EW CORRECTIONS TO DRELL-YAN BOTH SIZABLE AT HIGH MASS, OPPOSITE SIGN

THE PHOTON PDF



(NNPDF2.3QED, 2013)

DRELL-YAN:
NLO EW VS. PHOTON INDUCED

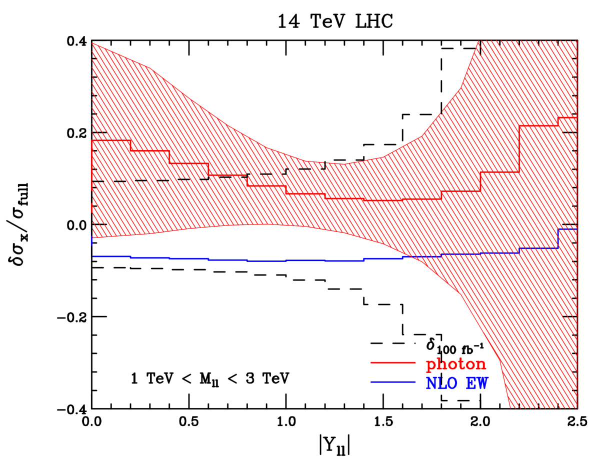


(Boughezal, Li, Petriello, 2013)

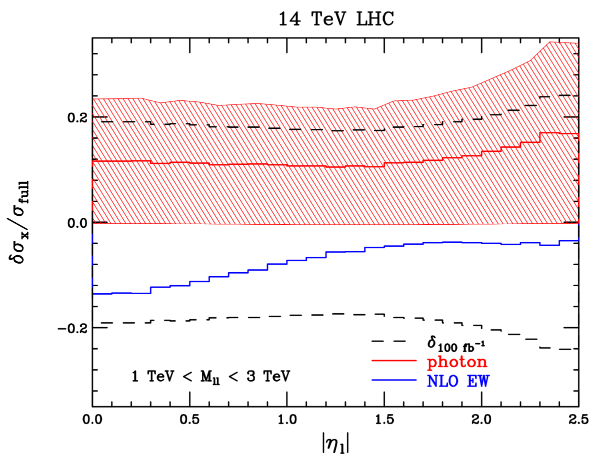
ELECTROWEAK CORRECTIONS: DRELL-YAN DISTRIBUTIONS

- EW CORRECTIONS LARGEST IN HIGH-MASS BINS WHERE PDFS POORLY KNOWN (LARGE x) RELEVANT FOR DISCOVERY PHYSICS ⇒ ELECTROWEAK SUDAKOV LOGS
- DIFFERENT INFORMATION CONTAINED IN DIFFERENTE KINEMATIC DISTRIBUTION:
  - DILEPTON RAPIDITY DISTN. AFFECTED BY PHOTON PDF AT CENTRAL RAPIDITY
  - LEPTON p_T DISTN PROBES SENSITIVE TO PHOTON PDF
  - LEPTON PSEUDORAPIDITY DISTRIBUTION PROBES THE ANGULAR STRUCTURE OF SUDAKOV LOGS
- FULLY DIFFERENTIAL MEASUREMENT DESIRABLE, NO EW CORRECTIONS SHOULD BE APPLIED AT EXPT. LEVEL

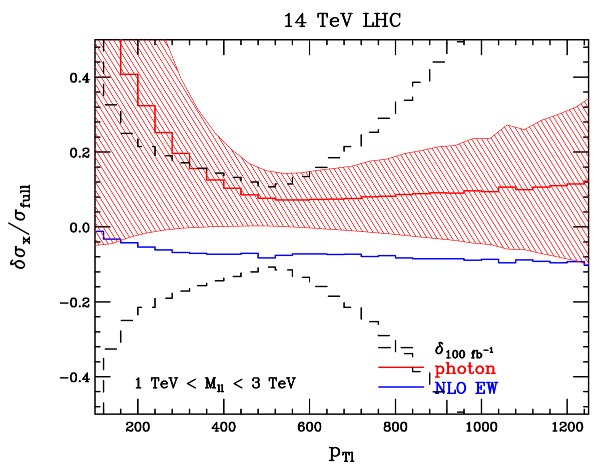
DILEPTON RAPIDITY



LEPTON PSEUDORAPIDITY



LEPTON p_T

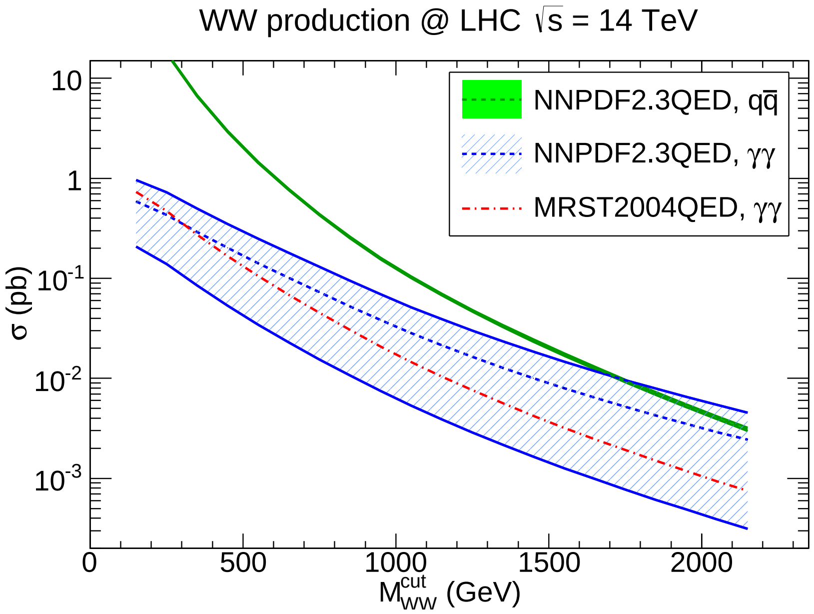


(Boughezal, Li, Petriello, 2013)

ELECTROWEAK CORRECTIONS: WW PRODUCTION

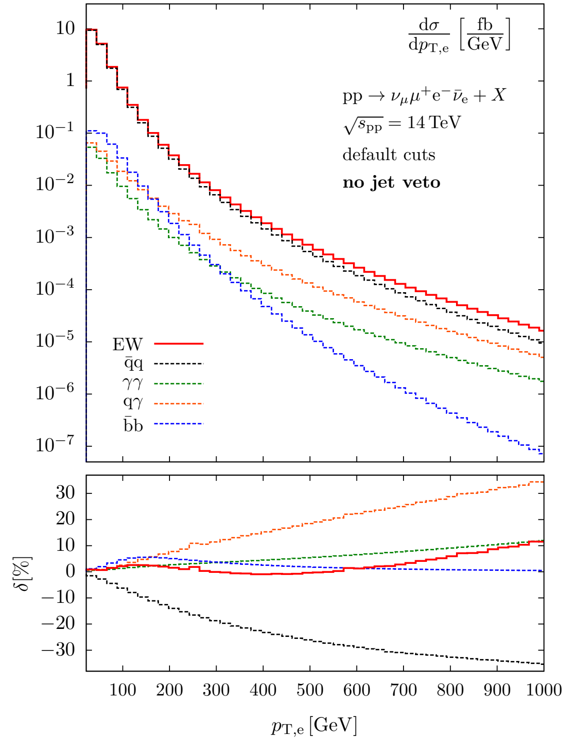
- DOUBLE GAUGE BOSON PRODUCTION VERY SENSITIVE TO PHOTON PDF FOR LARGE INVARIANT WW MASS
- NLO EW CORRECTIONS COMPUTED RECENTLY (Bierweiler, Kasprzik, Kühn, 2013), ALSO INCLUDING W DECAY EW CORRECTIONS LARGEST IN HIGH-MASS BINS WHERE PDFs (Billoni, Dittmaier, Jäger, Speckner, 2013)
- ALSO RELEVANT AS BACKGROUND TO NP SEARCHES

TOTAL XSECT FOR $M_{WW} > M_{WW}^{\rm cut}$



(NNPDF2.3QED, 2013)

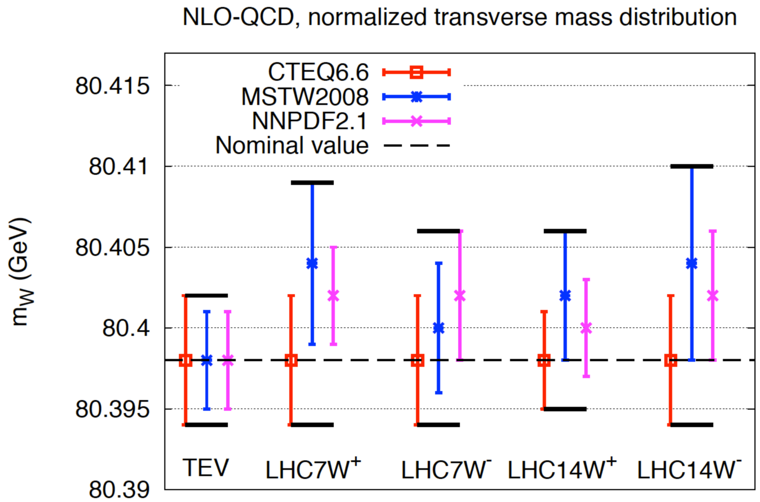
ELECTRON p_T IN $pp \to \mu^+\nu_\mu e^-\bar{\nu}_e$



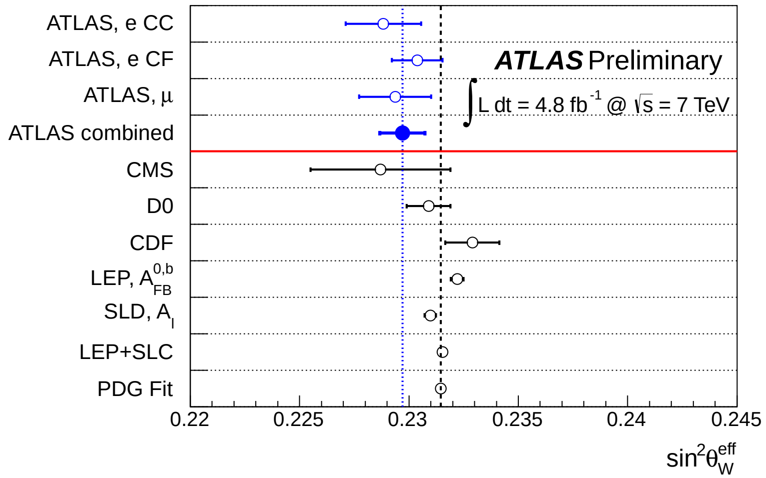
(Dittmaier et al. 2013)

THE W MASS…

- W MASS USING TEMPLATES FROM DY PRODUCTION AT LHC
- CURRENTLY PDF UNCERTAINTY OF ORDER 10 MeV (Bozzi, Rojo, Vicini, 2011), CAN BE REDUCED TO 5 MeV (NNPDF2.3) IF DISCREPANCIES BETWEEN PDF SETS RE-MOVED (Rojo, Vicini, 2013)



… AND THE EW MIXING ANGLE



- DETERMINED FROM FB ASYM; DILUTION AT pp COLLIDER $\Rightarrow$ UNCERTAINTY SMALLEST WITH ONE FORWARD & ONE CENTRAL LEPTON (FC) DESPITE LOWER RATE
- PDF UNCERTAINTY DOMINANT $\rightarrow$ MIGHT BE REDUCED BY FACTOR $2/3$? (Snowmass 2013)

THE VALUE OF α_s

α_s MIGHT BE AMONG THE DOMINANT SOURCES OF UNCERTAINTY!
EXAMPLE: HIGGS IN GLUON FUSION: $\Delta\sigma \sim 3\Delta\alpha$
(IN PERCENTAGE AT NNLO, BY POWER COUNTING)

WHAT IS THE VALUE OF α_s?

- PDG VALUE (S. BETHKE) $\alpha_s = 0.1184 \pm 0.0007$
- USUALLY FELT TO BE OVERLY OPTIMISTIC (PDF4LHC PRESCRIPTION ASSUMES MUST BE INFLATED $\sim 3\times$, Djouadi et al. ABOUT $\sim 5-6\times$):
  - IT IS AN AVERAGE OF AVERAGES
  - SOME DETERMINATIONS IN SHARP DISAGREEMENT: DIS (Blümlein et al); THRUST: (Stewart et al)
  - IN SOME PROCESSES (GLOBAL FITS) STRONG DEPENDENCE ON PERTURBATIVE ORDER

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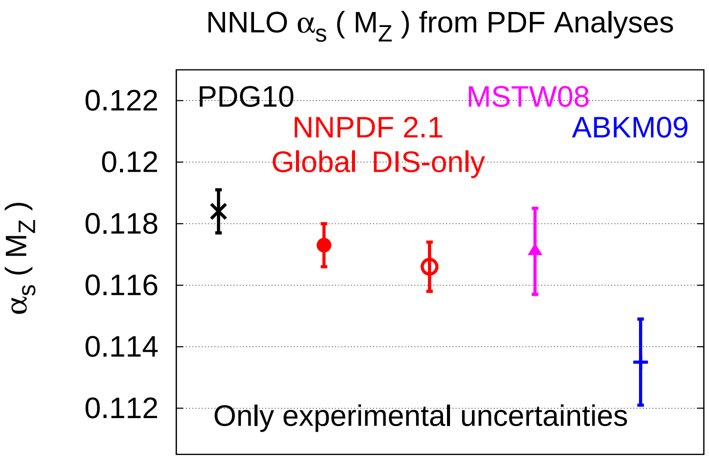


- AVERAGING THE TWO MOST RELIABLE VALUES (GLOBAL EW FIT & τ, BOTH N^3LO, NO DEP. ON HADRON STRUCTURE) GIVES $\alpha_s = 0.1197 \pm 0.0014$
- SOME SUB-AVERAGES (DIS) INCLUDE DATA/EXTRACTIONS WHICH HAVE BEEN SHOWN TO BE INCORRECT OR BIASED BY OBSOLETE DATA
- COLLIDER-ONLY FIT WITH LHC DATA $\Rightarrow$ OBSOLETE DATA REMOVED, OR EFFECT DILUTED

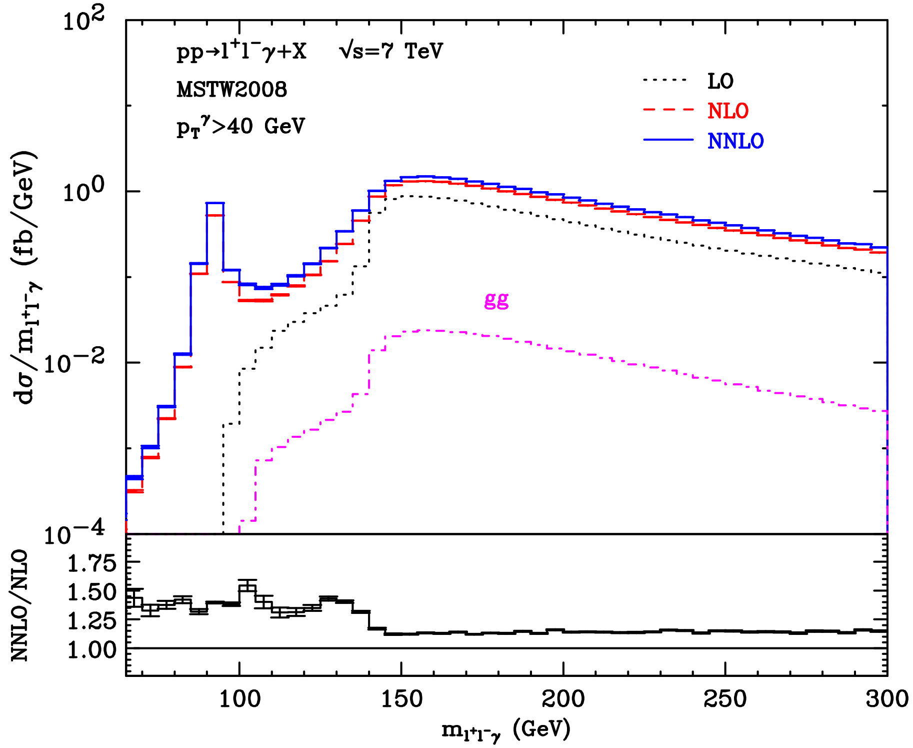
BEYOND INCLUSIVE OBSERVABLES

FULLY DIFFERENTIAL FINAL STATES

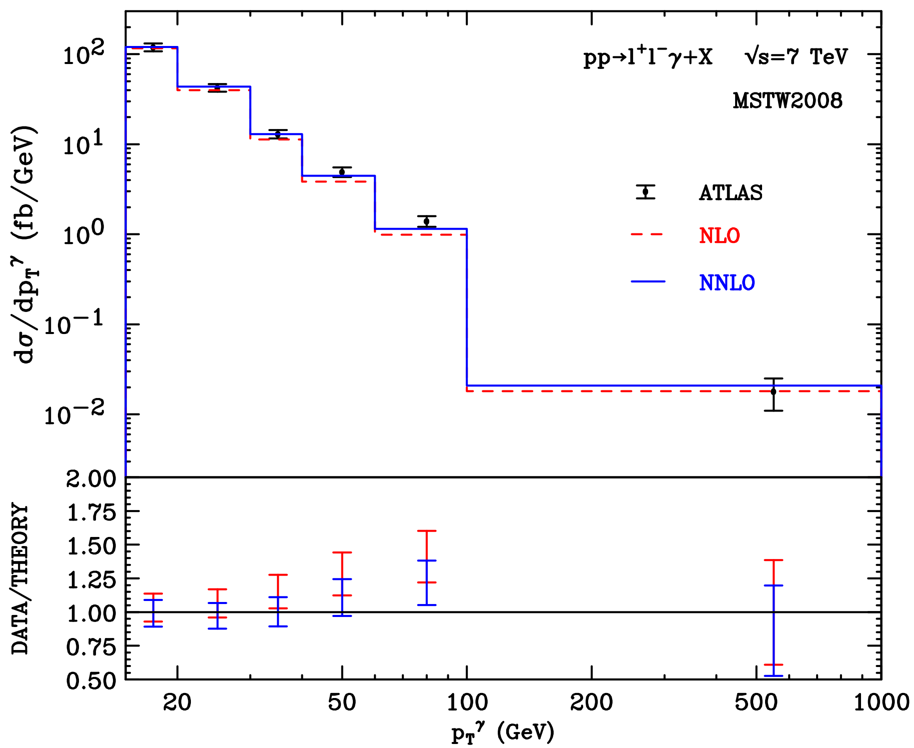
- DATA/TH COMPARISON SHOULD BE PERFORMED AT THE FIDUCIAL LEVEL
- NEED FULLY DIFFERENTIAL KINEMATICS
- MORE AND MORE FULLY DIFFERENTIAL PROCESSES/CODES AVAILABLE AT NNLO INCLUDING DECAYS (SINGLE AND DOUBLE GAUGE BOSON PRODUCTION, HIGGS+VB)
- SOMETIMES RESUMMATION NEEDED IN SPECIFIC KINEMATIC REGIONS

$Z\gamma$ PRODUCTION

INVARIANT MASS DISTN.



PHOTON p_T DISTN.



(Grazzini, Kallweit, Rathlev, Torre, 2013),

RESUMMATION

- ALL-ORDER RESUMMATION IS NEEDED FOR ACCURATE PREDICTIONS WHENEVER LARGE SCALE RATIOS MAY APPEAR:

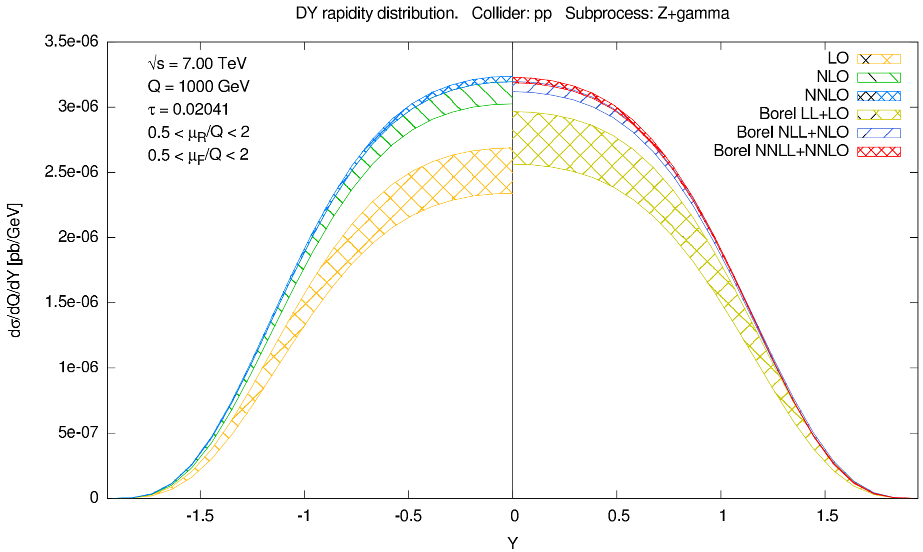
  e.g. $\frac{p_t}{M_X}$ (transverse momentum resummation), $\frac{s-M_X^2}{s}$ (threshold resummation)

- PERFORMED UP TO HIGH LOGARITHMIC ORDERS FOR SEVERAL PROCESSES (DRELL-YAN, HIGGS,...), MAY BE USEFUL TO IMPROVE FIXED-ORDER PREDICTION EVEN FAR FROM RESUMMATION REGION

DY PRODUCTION AT THE LHC 7TEV

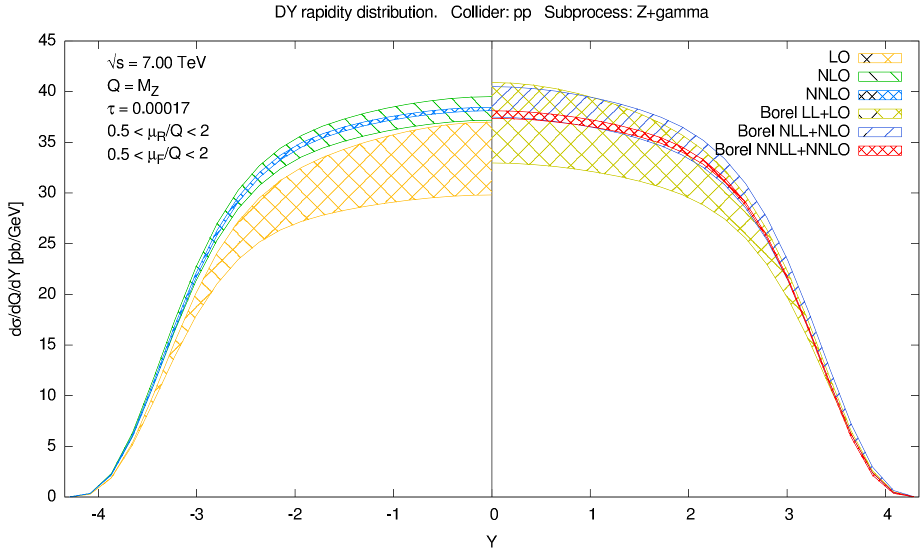
1 TEV Z'

UNRESUMMED VS RESUMMED



Z

UNRESUMMED VS RESUMMED



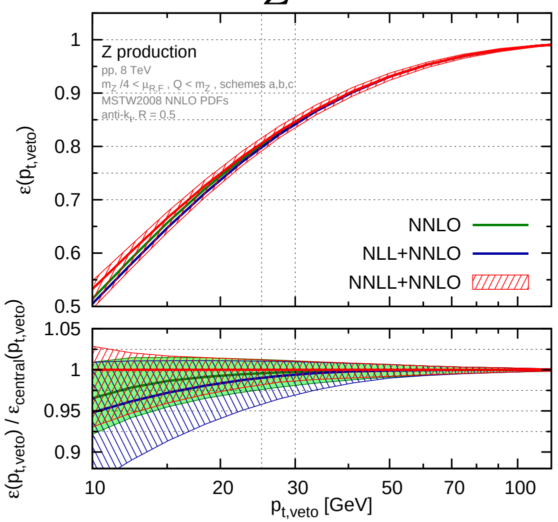
(Bonvini, SF, Ridolfi, 2012)

RESUMMATION AND JET VETOS

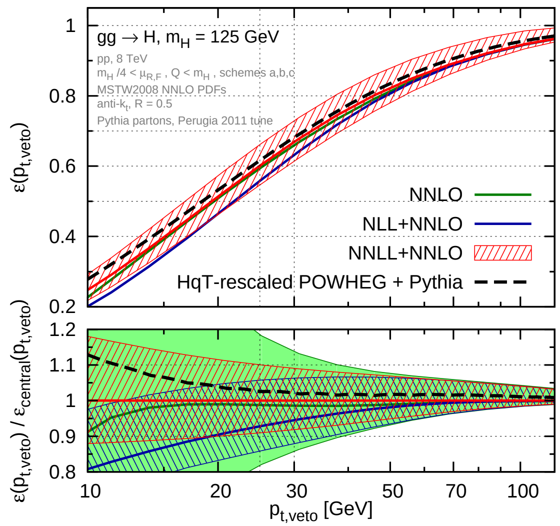
- RESUMMATION MANDATORY FOR JET VETOS
- CROSS SECTION FOR X (W, HIGGS) + AT LEAST ONE JET, CONTAINS LARGE LOGS OF MINIMAL p_T OF JET (CANCEL IN TOTAL CROSS SECTION): $L = \ln \frac{p_{T\,\mathrm{veto}}}{M_X}$
  $\sigma_{\geq 1} \sim (\alpha L^2)^n$; $\sigma_{tot} \sim \alpha^n \to \sigma_o \equiv \sigma_{tot} - \sigma_{\geq} 1 \sim (\alpha L^2)^n$;
- RESUMMATION PERFORMED UP TO NNLL+NNLO BOTH WITH PERTURBATIVE APPROACH (Banfi, Monni, Salam, Zanderighi, 2012) & SCET (Stewart, Tackmann, Walsh, Zuberi, 2012-2013; Becher, Neubert, Rothen, 2013)
- EXCLUSIVE ONE-JET CROSS-SECTION RESUMMED USING SCET (Liu, Petriello 2012)
- GOOD PERTURBATIVE STABILITY; SIGNIFICANTLY IMPROVED UNCERTAINTY ON EFFICIENCY (ESPECIALLY FOR HIGGS) $\epsilon_0(p_T^{\mathrm{cut}}) \equiv \frac{\sigma_0(p_T^{\mathrm{cut}})}{\sigma_{tot}}$

JET VETO EFFICIENCIES

Z



HIGGS



(Banfi, Monni, Salam, Zanderighi, 2012)

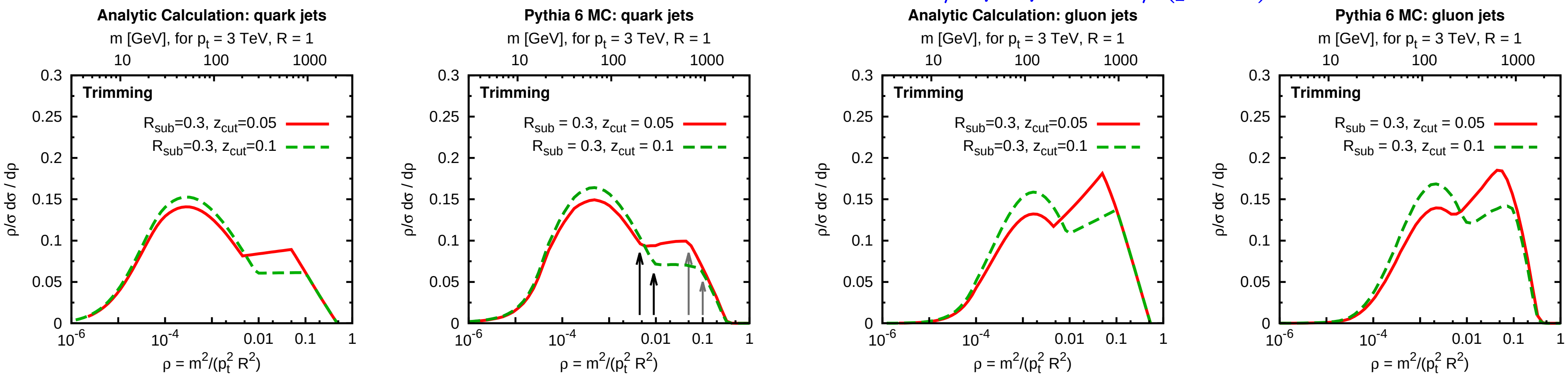
JET SHAPES AND SUBSTRUCTURE

JET STUDIES CRUCIAL FOR SEARCHES (BACKGROUNDS) & ALSO FOR REFINING SEARCH STRATEGIES

- SEVERAL JET PROPERTIES STUDIED ANALYTICALLY AND RESUMMED EXTENSION OF SEMINAL WORK ON NLO+NNLO (Banfi, Salam, Zanderighi 2003-2010)
  - BROADENING (MOMENTUM ORTHOGONAL TO THRUST AXIS, $b_t = \sum_i |p_i^T|$): NNLL RESUMMATION USING SCET (Becher, Bell, 2012)
  - INVARIANT MASS OF HARDEST JET RESUMMED AT NLL USING PERTURBATIVE (Dasgupta, Khelifa-Kerfa, Marzani, Spannowsky, 2012) OR SCET AT NLL (Chien, Kelley, Schwartz, Zhu, 2012) AND NNLL (Jouttenus, Stewart, Tackmann, Waalewijn, 2013)
  - GENERALLY "NON-GLOBAL" LOGS WHICH CHARACTERIZE A SINGLE JET RESUMMED TO NLL (Dasgupta, Salam, 2001; Banfi, Dasgupta, Khelifa-Kerfa, Marzani, 2012)
  - DIJET INVARIANT MASS SPECTRA RESUMMED USING MULTISCALE EXTENSION OF SCET HIERARCHY $m_l \lesssim M_{jj} \lesssim \hat{s}$ (Bauer, Tackmann, Walsh, Zuberi, 2012)

- ANALYTIC RESULTS AVAILABLE FOR JET SUBSTRUCTURE TOOLS (TRIMMING, PRUNING...) SUCCESFUL COMPARISON WITH MONTE CARLO (Dasgupta, Fregoso, Marzani, Salam, 2012)

TRIMMED JET MASS DISTRIBUTION $d\sigma/d\rho$; $\rho = m/(p_T R)$

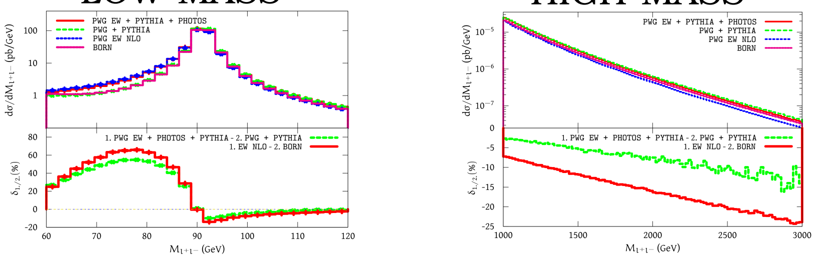


MATCHING TO MONTE CARLOS

- IDEALLY, THEORY SHOULD PROVIDE FULLY CONSISTENT PREDICTION AT THE LEVEL OF FINAL STATES ⇒ NEED PARTON SHOWERING AND HADRONIZATION (PERFORMED BY MONTECARLOS)
- COMBINED DESCRIPTION NEEDED FOR ACCURATE RESULTS IN ALL KINEMATIC REGIONS
- MUST MATCH NLO (NNLO?) MATRIX ELEMENT, RESUMMATION, MONTE CARLO
- SEVERAL MATCHED CALCULATIONS, GENERAL FRAMEWORKS GENEVA (Alioli, Bauer, Berggren, Hornig, Tackmann, Vermilion, Walsh, Zuberi) & NNLOPS (MINLO+POWHEG) (Hamilton, Nason, Re, Zanderighi)

NC DY INVARIANT MASS DISTN

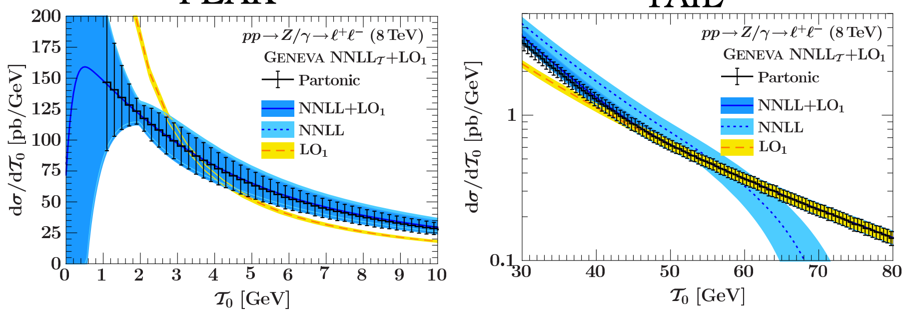
LOW MASS HIGH MASS



(Barzè, Montagna, Nason, Nicrosini, Piccinini, Vicini, 2013)

BEAM THRUST IN DRELL-YAN

PEAK TAIL



(GENEVA: Alioli et al, 2012)

OUTLOOK

- THERE IS A CLEAR ROADMAP OF SM MEASUREMENTS EXTENDING FOR THE FIRST SEVERAL YEARS OF LHC 14TEV RUN
- AFTER THAT, THE PHYSICS PROGRAM MUST BE DRIVEN BY NEW DISCOVERIES, OR SIGNIFICANTLY HIGHER PRECISION, POSSIBLY USING NEW MACHINES (LHEC?)

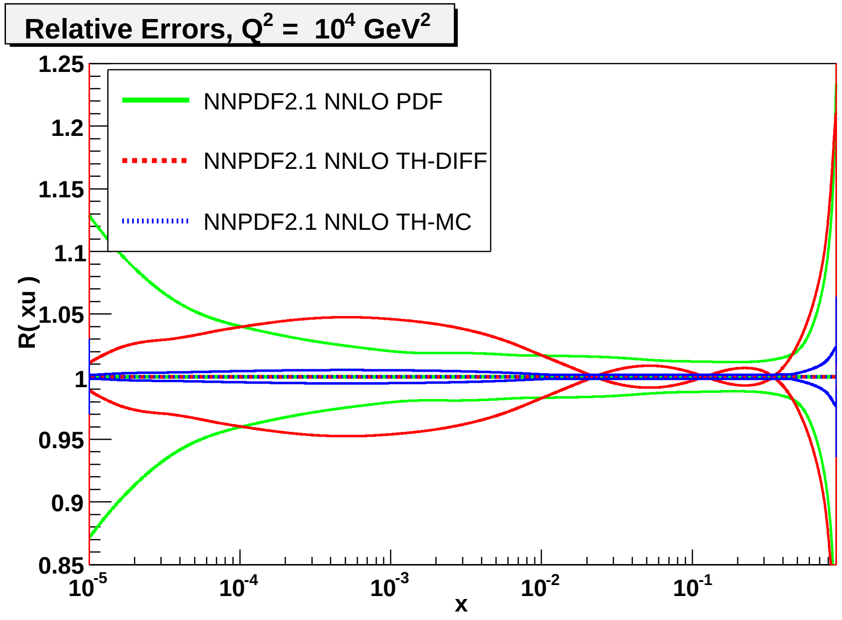
EXTRAS

THEORETICAL UNCERTAINTIES ON PDFs

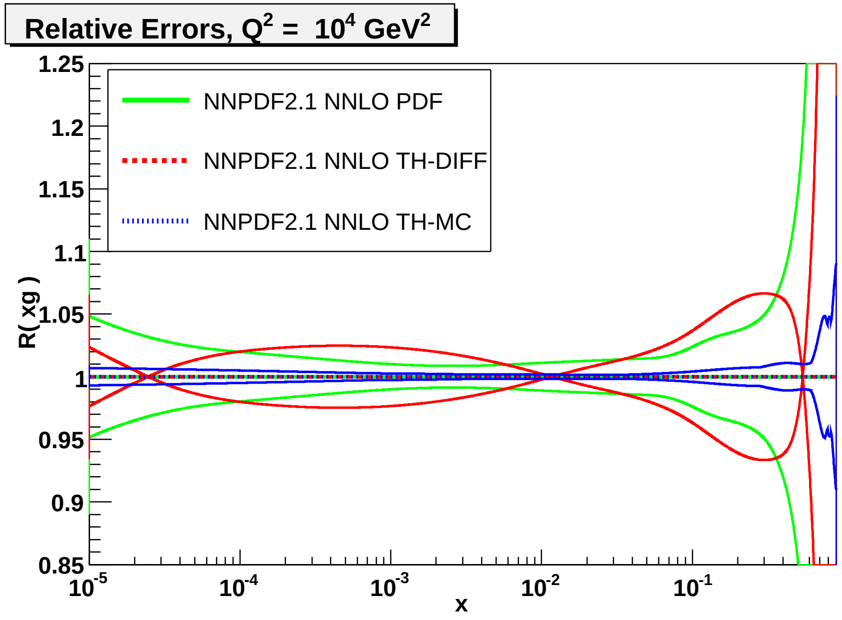
- PDFs CHANGE WITH PERTURBATIVE ORDER $\to$ HOW DO WE ESTIMATE UNCERTAINTY AT ANY GIVEN ORDER?
- AT NLO, WE KNOW: NLO-NNLO SHIFT $\sim$ TH. UNCERTAINTY ON THE NLO
- TURNS OUT TO BE COMPARABLE TO THE (STANDARD, STAT) PDF UNCERTAINTY
- CACCIARI-HOUDEAU (2011) METHOD $\Rightarrow$ ESTIMATE NEXT ORDER BASED ON PREVIOUS KNOWN ORDERS
- DOES PRETTY WELL AT NLO WHERE ANSWER KNOWN
- AT NNLO TH UNCERTAINTY $\ll$ PDF (STAT) UNCERTAINTY

NNLO-NLO SHIFT & (STAT) PDF UNCERTAINTY

UP



GLUON



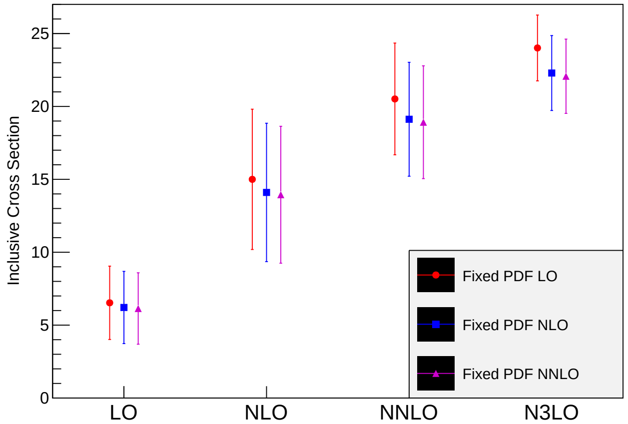
N^3LO PDFs
AND HIGGS PRODUCTION

- N^3LO QCD RESULTS: HIGGS IN GLUON FUSION (Anastasiou et al, in progress)
- DO WE NEED N^3LO PDFs? IN PRINCIPLE, YES
- STUDY THE HIGGS CROSS SECTION AS A FUNCTION OF THE PERTURBATIVE ORDER OF THE PDF AND THE CROSS SECTION
- PERTURBATIVE DEP. OF PDF NEGLIGIBLE IN COMPARISON TO MATRIX ELEMENT $\Rightarrow$ TH. UNCERTAINTY ALMOST ENTIREY DUE TO MATRIX ELEMENT
- IN PRACTICE, CAN USE NNLO PDFs WITH N^3LO MATRIX ELEMENT (AT LEAST FOR HIGGS)

HIGGS IN GLUON FUSION, LHC8 (in pb)

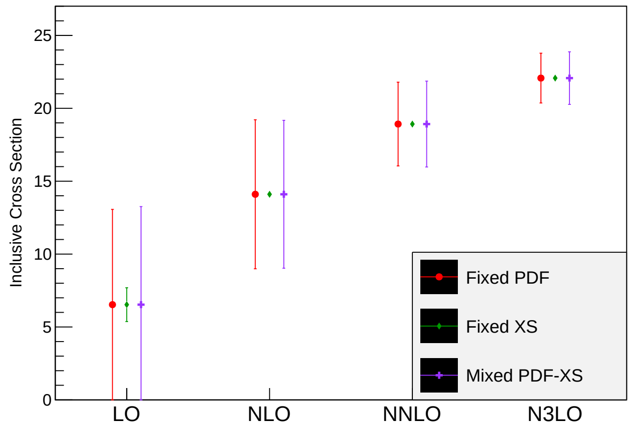
SCALE UNCERTAINTY:

DEP. ON PERTURBATIVE ORDER



TH UNCERTAINTY:

PDF; MATRIX ELEMENT; TOTAL

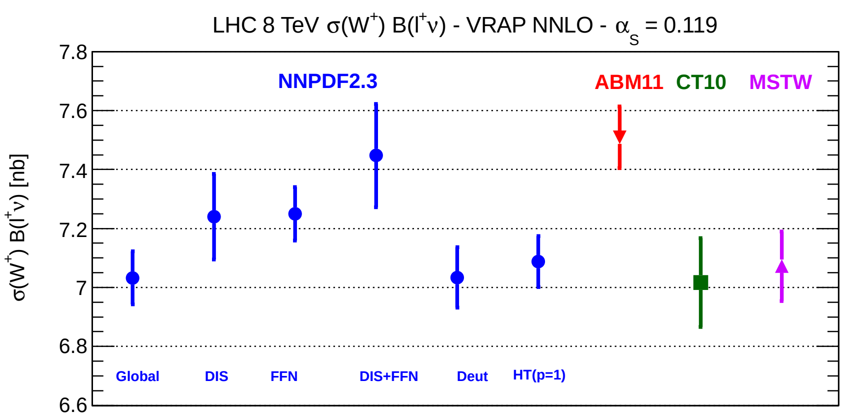


(s.f., Isgrò, Vita, prelim.)

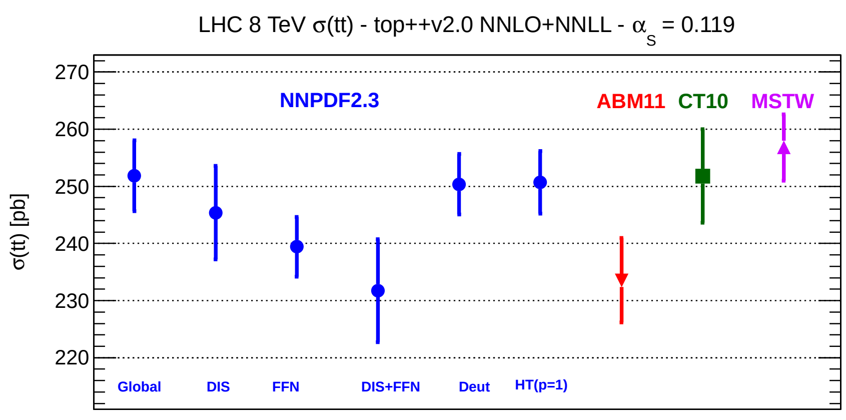
FFN PDFs

- some PDF sets adopt a FFN scheme (ABM, JR)
- ABM also includes higher twist & nuclear corrections
- also, ABM mostly based on DIS data
  (only hadronic data is fixed-target DY)
- what is the relative size of all these effects?
- NNPDF with FFN &DIS data set agrees with ABM;
  higher twist & nuclear corrrections have small & localized effect;
  similar results found by MSTW and CTEQ

W^+



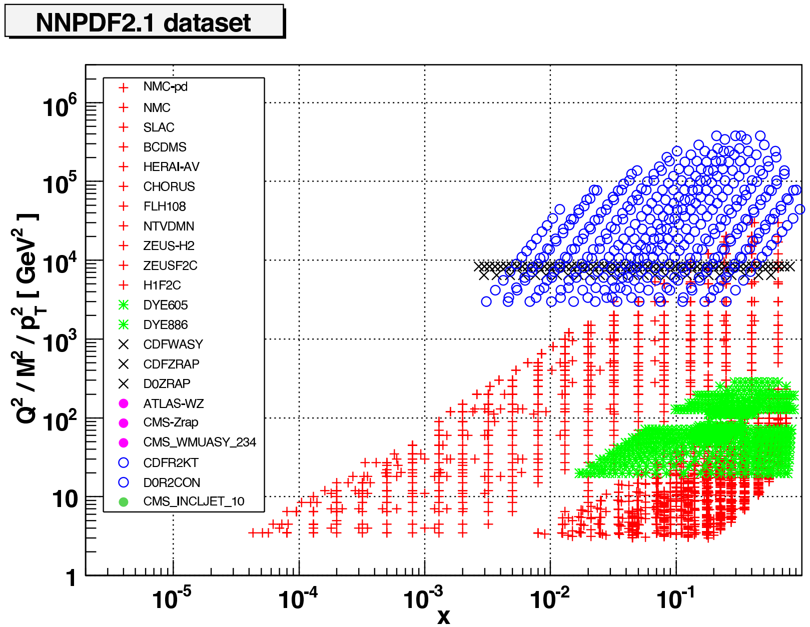
TOP



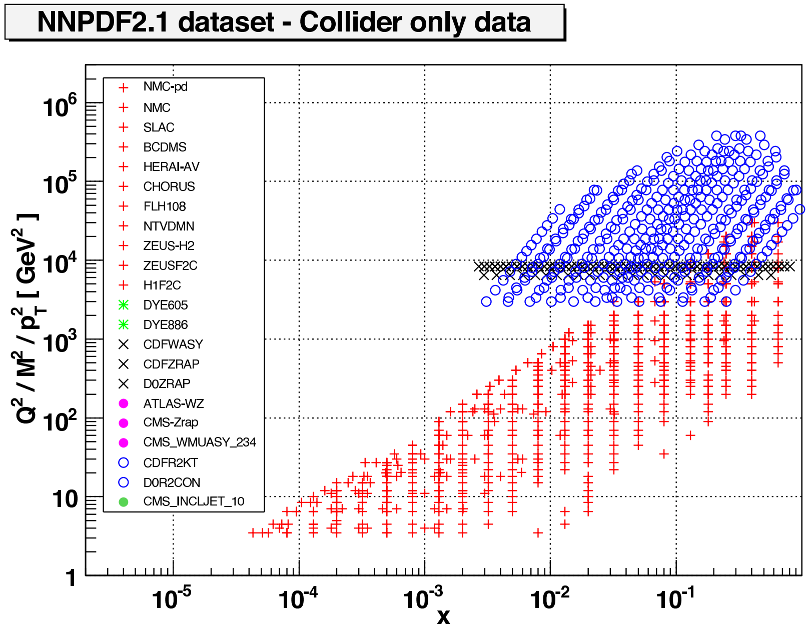
COLLIDER ONLY FITS?

NO FIXED TARGET DATA ⇔ NO LOW-ENERGY TROUBLE

THE NNPDF2.1 DATASET



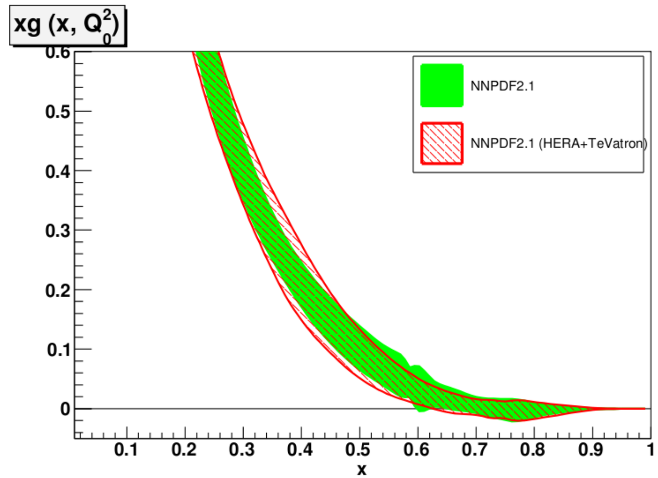
NNPDF2.1 - COLLIDER ONLY



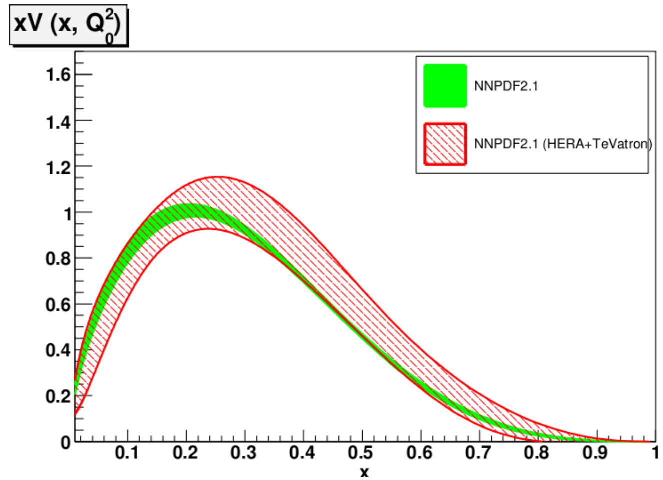
PDFs FROM HERA+TEVATRON DATA?

COLLIDER ONLY PDFs?

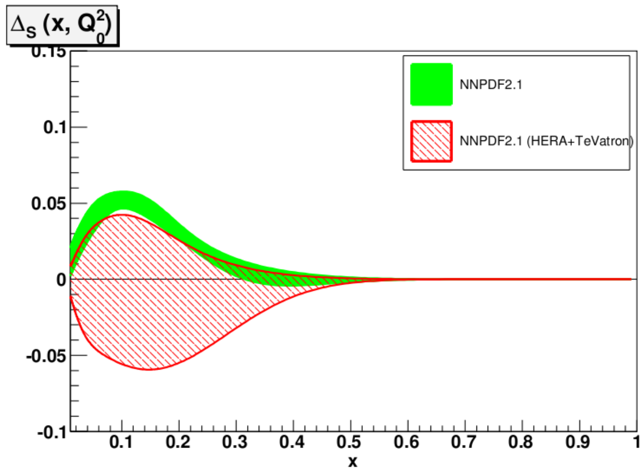
GLUON



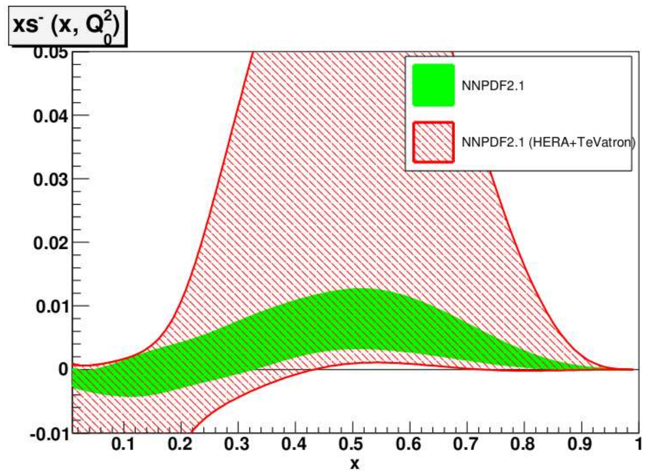
VALENCE



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



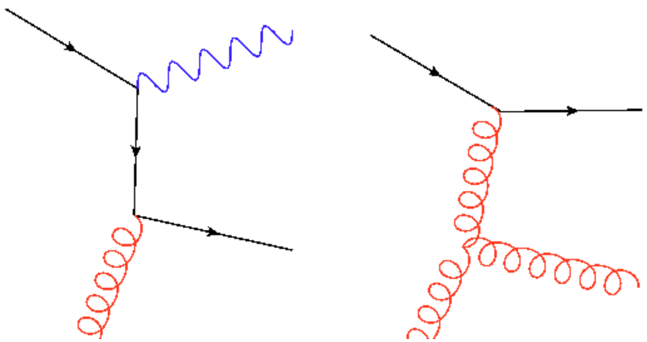
STRANGE: $s - \bar{s}$



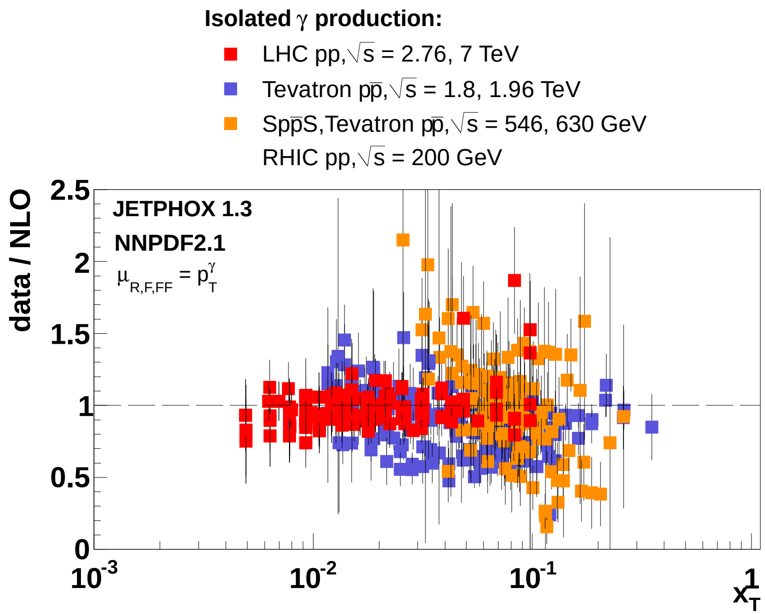
- GOOD ACCURACY FOR GLUON
- GREAT LOSS OF ACCURACY FOR FLAVOR SEPARATION

PROMPT PHOTON PRODUCTION

(D. d'Enterria, J. Rojo, 2012)



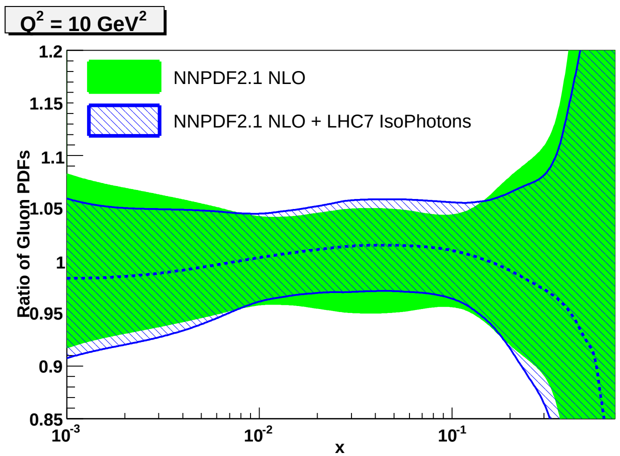
$x_t = x_1 x_2$ RANGE



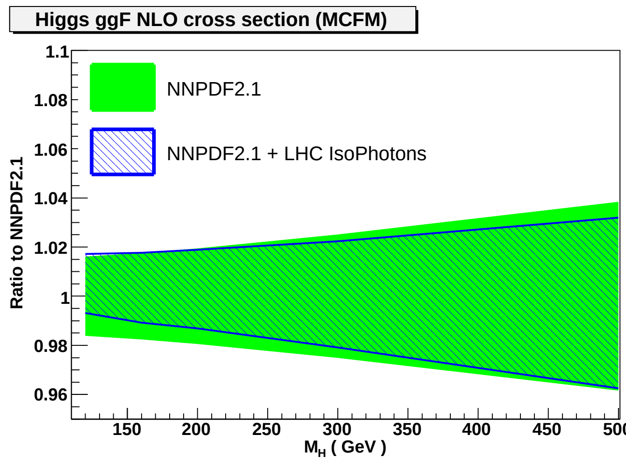
- DIRECT PROBE OF THE qg LUMINOSITY
- MEASURED BY CMS+ATLAS

THE IMPACT OF LHC PROMPT PHOTON DATA

GLUON

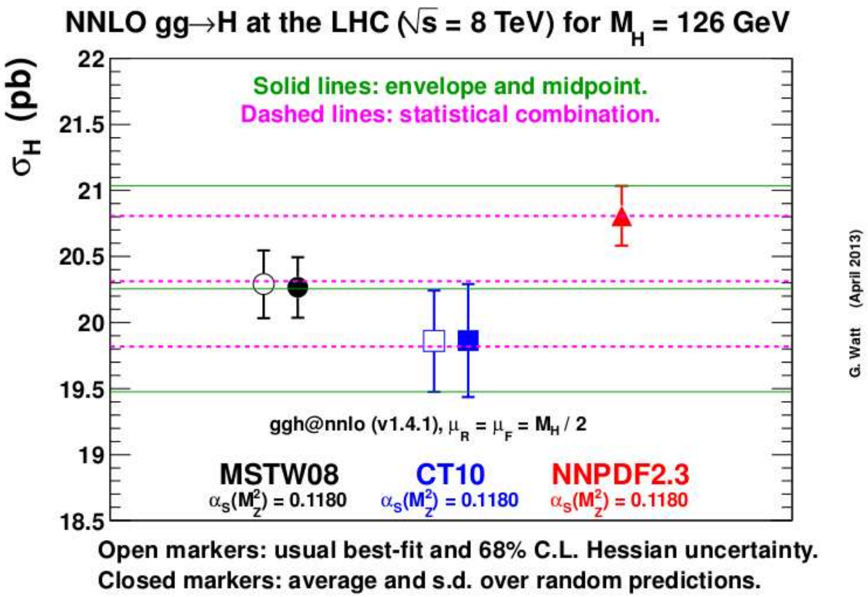


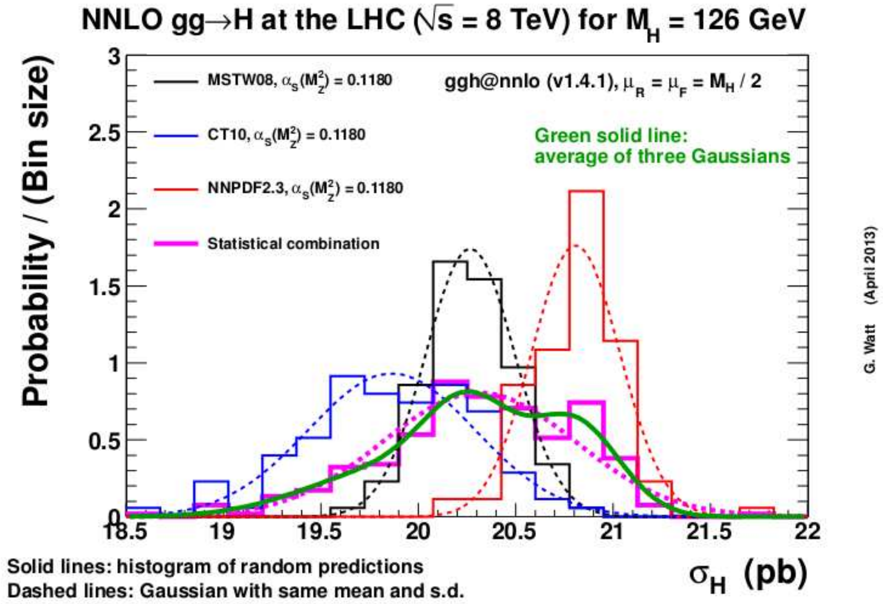
HIGGS FROM GLUON FUSION



- MODERATE IMPACT ON GLOBAL FIT (BUT COULD RESOLVE DISCREPANCIES)
- SUFFICIENT TO AFFECT HIGGS CROSS SECTION

THE PDF4LHC PRESCRIPTION
IMPROVEMENT





A LESS CONSERVATIVE PRESCRIPTION:

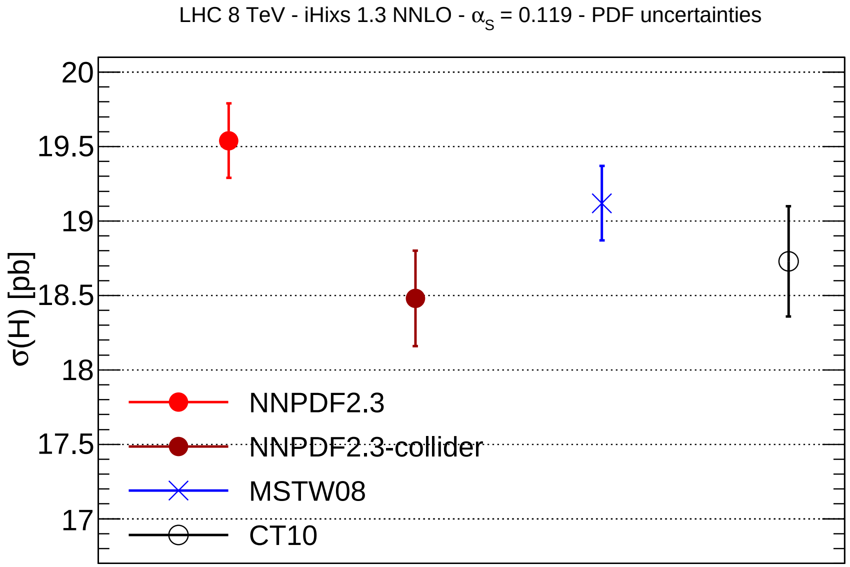
- COMBINE PDF UNCERTAINTIES WITH SINGLE CENTRAL α_s VALUE
- PERFORM STATISTICAL COMBINATION OF THREE SETS (COMBINE HISTOGRAMS)
- ADD α_s UNCERTAINTY IN THE END

(G.Watt, Higgs WG Theoretical Uncertainty Task Force, in progress)

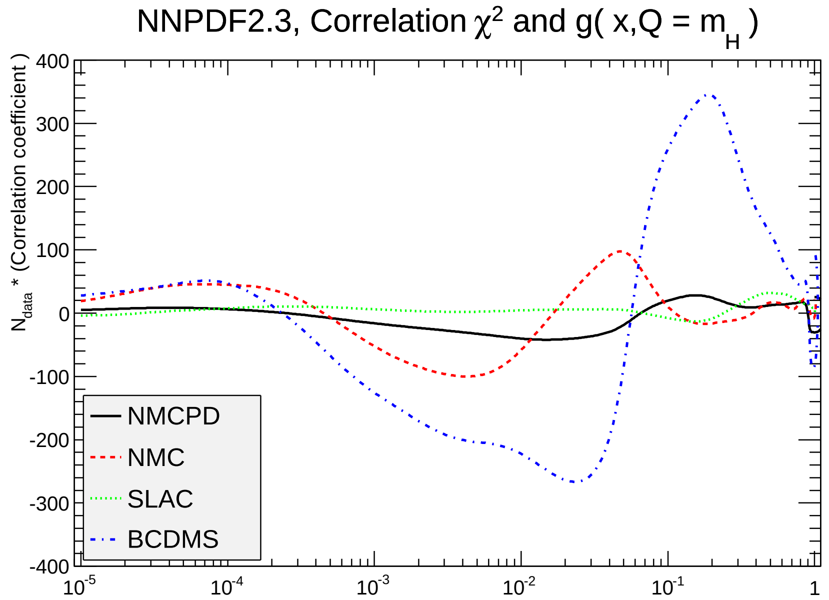
DISCREPANCIES VS. DATA

WHAT'S THE PROBLEM WITH THE GLUON?

HIGGS IN GLUON FUSION



CORRELATION BETWEEN GLUON AND EXPT χ^2



- REMOVE FIXED-TARGET DATA FROM GLOBAL FIT ⇒ NNPDF-COLLIDER AGREES WITH CTEQ
- VARIOUS FIXED-TARGET DATA MIGHT BE AFFECTED BY ISSUES (NEUTRINO DATA, NMC KNOWN TO HAVE INTERNAL INCONSISTENCIES...)
- CORRELATION BETWEEN THESE DATASETS & GLUON OBSERVED
- ONGOING BENCHMARKING WITHIN THE LES HOUCHES WORKSHOP & PDF4LHC