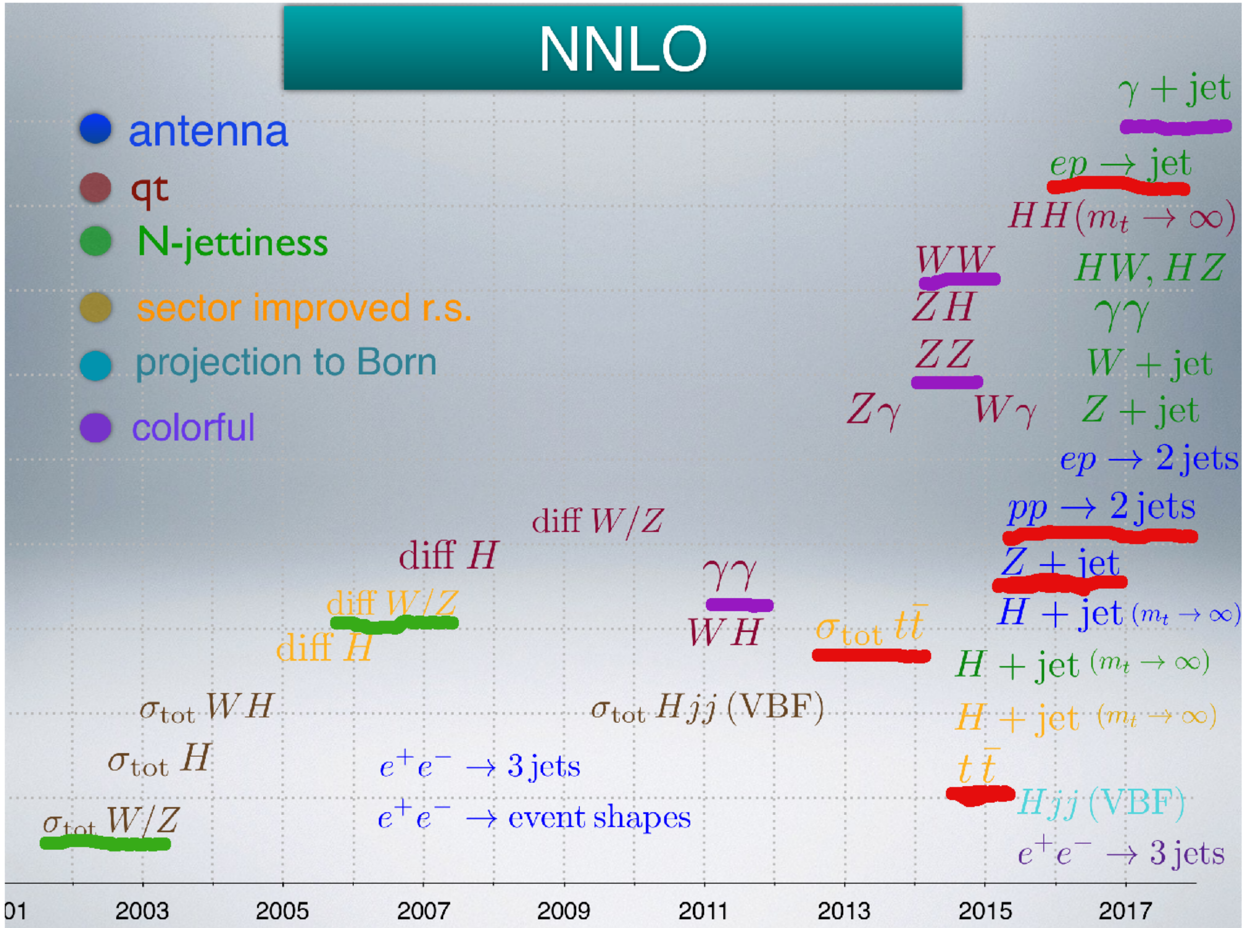
THE FRONTIER OF THEORY

THE NNLO FRONTIER

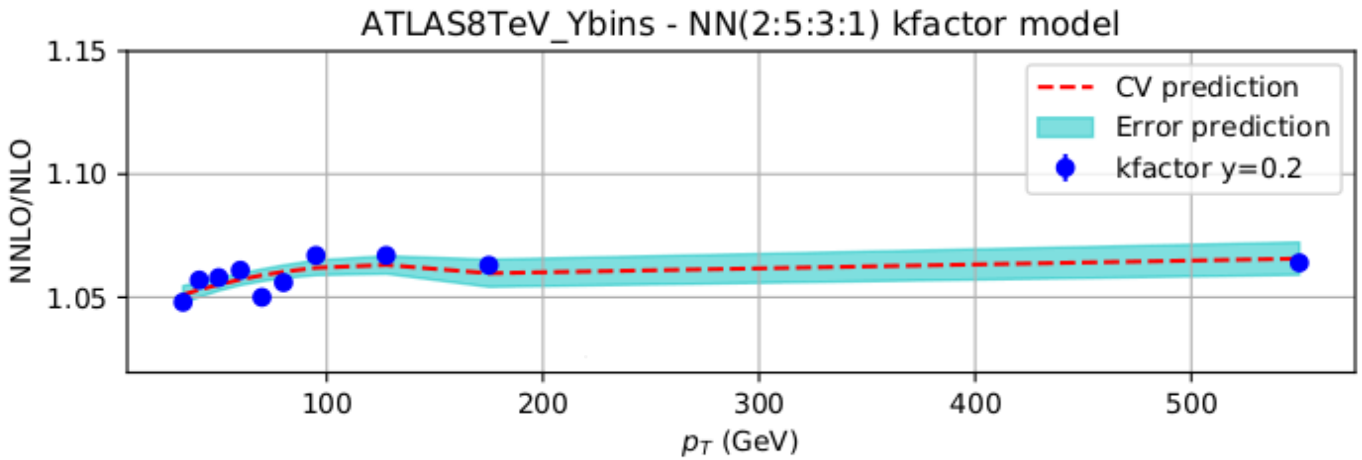


(G. Heinrich, LHCP, May 2017)

- NNLO CORRECTIONS NOW KNOWN AT INCREASINGLY EXCLUSIVE LEVEL (INCLUDING DECAYS)
- TYPICALLY LARGER THAN NAIVE SCALE VARIATION $\Rightarrow$ NEEDED FOR PRECISION PHENO
- NNLO PDF STANDARD SINCE $\sim$ 2010 INCLUDE DIS, DRELL-YAN
- NEW GENERATION PDFS ALSO TOP, JETS, $Z\ p_t$
- FUTURE GENERATIONS: PROMPT PHOTON, DIBOSON...

THEORY CHALLENGES
THE UNCERTAINTY IN THEORY CALCULATIONS

AN EXAMPLE: ATLAS 7 TEV p_T DISTRIBUTION
THE NNLO/NLO K-FACTOR



(Boughezal, Liu, Petriello, 2016-2017)

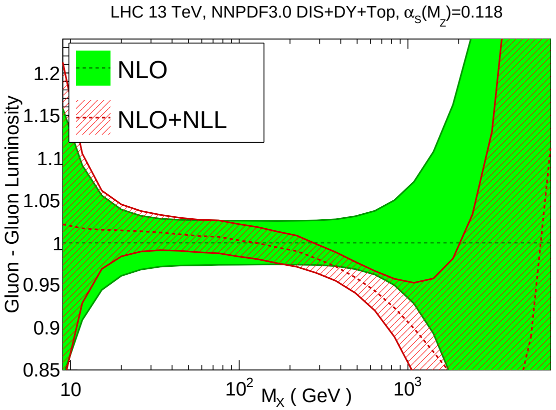
- UNCORRELATED STATISTICAL UNCERTAINTIES AT PERMILLE LEVEL
- LARGE NNLO CORRECTIONS $\sim 10\%$
- NOMINAL K-FACTOR UNCERTAINTIES VERY SMALL: UNDERESTIMATED?
- FIT ONLY POSSIBLE WITH RELIABLE ESTIMATE OF UNCERTAINTY ON THEORY PREDICTION
- NNPDF3.1: EXTRA 1% THEORY UNCERTAINTY ESTIMATED BASED ON FLUCTUATIONS W.R. TO INTERPOLATION (SHADED IN PLOT)

RESUMMED PDFs

- RESUMMATION NOT INCLUDED IN DEFAULT PDF SETS
- RESUMMED CALCULATIONS MUST USE RESUMMED PDFs! (M. Spira)
- KEPT UNDER CONTROL IN FITS BY CHOICE OF CUTS

PDFs WITH THRESHOLD (LARGE x) RESUMMATION

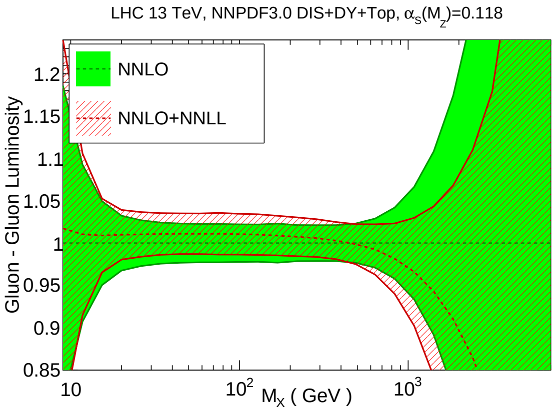
GLUON: NLO VS NLL



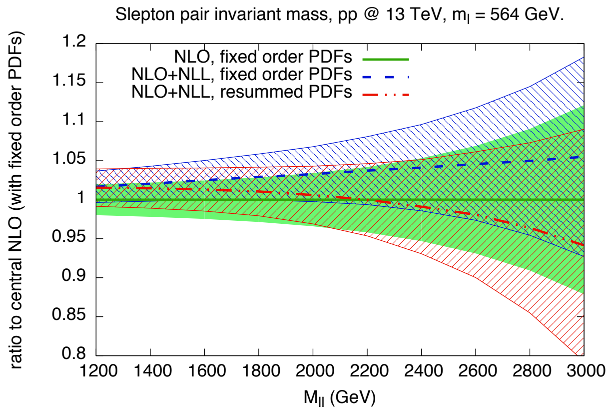
- FIRST SET: `NNPDF3.0resum`
- RESUMMATION INCLUDED IN FIT (DIS, DY, TOP DATA), EFFECTS NOT NEGLIGIGLE AT NLLO, LARGE x, MORE MODERATE AT NNLO
- EFFECT ON PDFs COMPARABLE TO EFFECT ON MATRIX ELEMENT, ANTICORRELATED TO IT
- RELEVANT FOR NEW PHYSICS SEARCHES

(Bonvini et al., 2015)

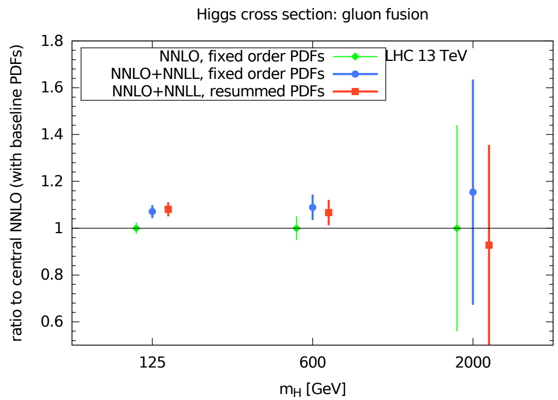
GLUON: NNLO VS NNLL



SLEPTON PAIR PRODUCTION

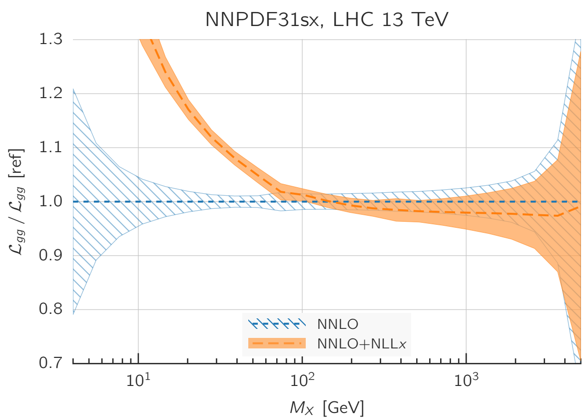


HIGGS IN GLUON FUSION VS m_H



PDFs WITH HIGH ENERGY (SMALL x) RESUMMATION

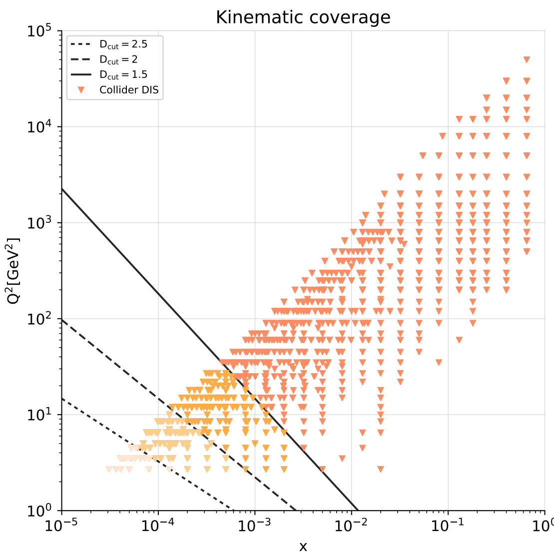
GLUON LUMINOSITY



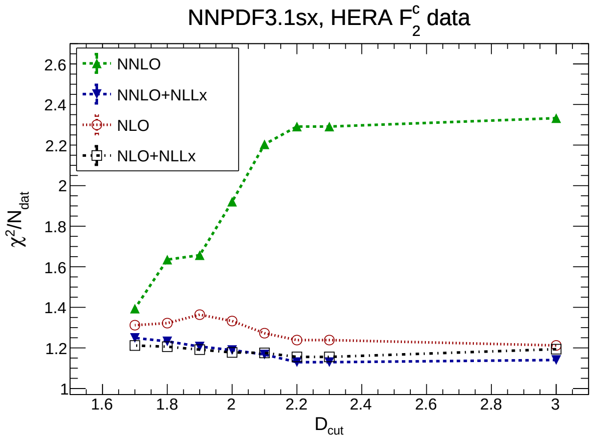
- FIRST SET: `NNPDF3.0sx`
- HIGH ENERGY RESUMMATION INCLUDED IN GLAP EVOLUTION& FOR DIS, EFFECTS
- STABILIZES PERTURBATIVE EXPANSION
- LARGE EFFECTS FOR FUTURE COLLIDERS, OR LIGHT FINAL STATES (b PRODUCTION AT LHC)

(Ball et al., 2017)

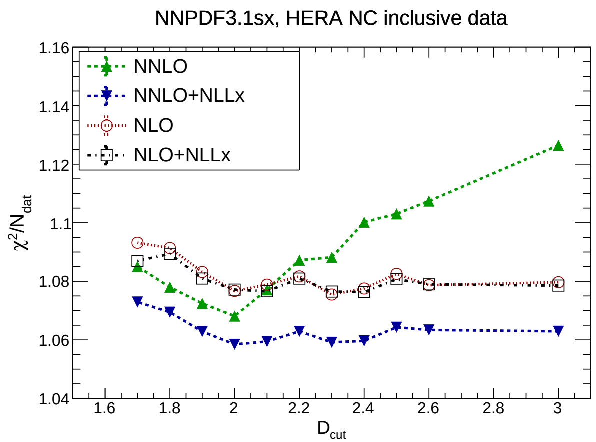
KINEMATIC CUTS



INCLUSIVE F_2 FIT QUALITY

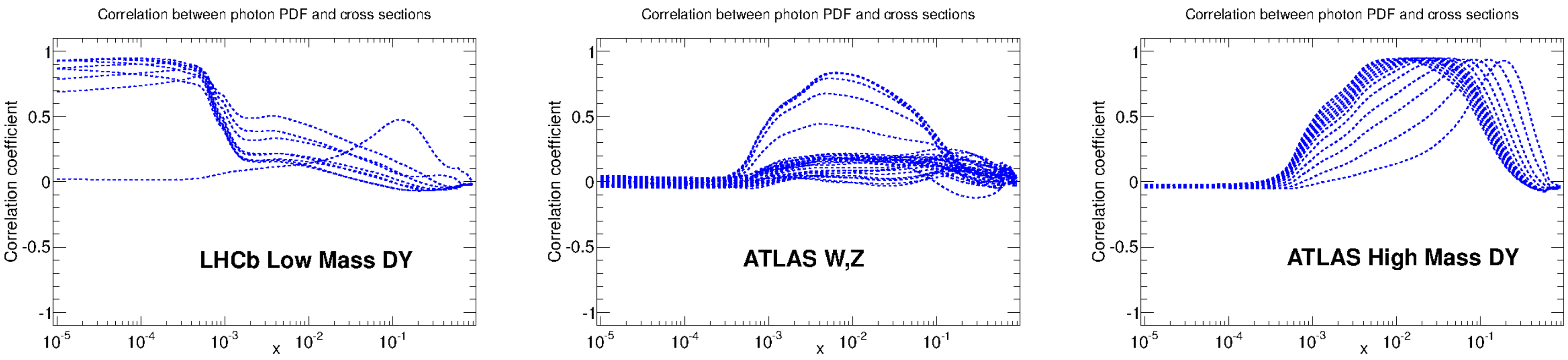


CHARM F_2^c FIT QUALITY



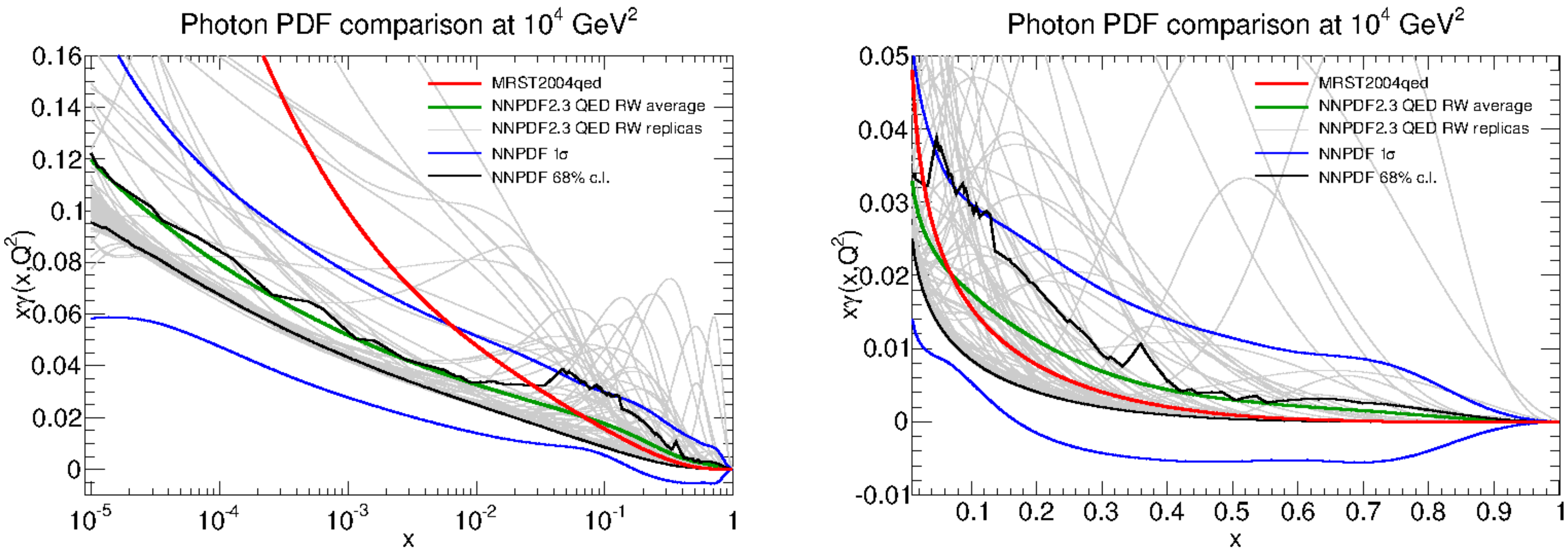
THE PHOTON PDF

CORRELATION BETWEEN DATA AND γ PDF



- PHOTON-INDUCED CONTRIBUTIONS CAN BE SIZABLE
- PHOTON PDF MODELED (MRST2004) OR DETERMINED FROM DRELL-YAN WITH SIZABLE UNCERTAINTY (NNPDF2.3-NNPDF3.0QED)
- SIGNIFICANT UNCERTAINTY EG ON SEARCHES

NNPDF2.3QED PHOTON



THE PHOTON PDF BREAKTHROUGH

(Manohar, Nason, Salam, Zanderighi, 2016)

- QED IS PERTURBATIVE DOWN TO LOW SCALES $\Rightarrow$ THE PHOTON PDF MUST BE COMPUTABLE IF THE INPUT QUARK SUBSTRUCTURE IS KNOWN
- WRITE THE CROSS-SECTION FOR A CHOSEN PROCESS: SUSY PRODUCTION IN EP COLLISION (Drees, Zeppenfeld, 1989)
- COMPUTE IT DIRECTLY, OR USING THE PHOTON PDF
- $\Rightarrow$ PDF EXPRESSED IN TERMS OF THE STRUCTURE FUNCTION INTEGRATED OVER ALL SCALES
- F_s AT HIGH Q^2 FROM PDFS, IN RESONANCE REGION FROM DATA, IN ELASTIC LIMIT FROM FORM FACTORS

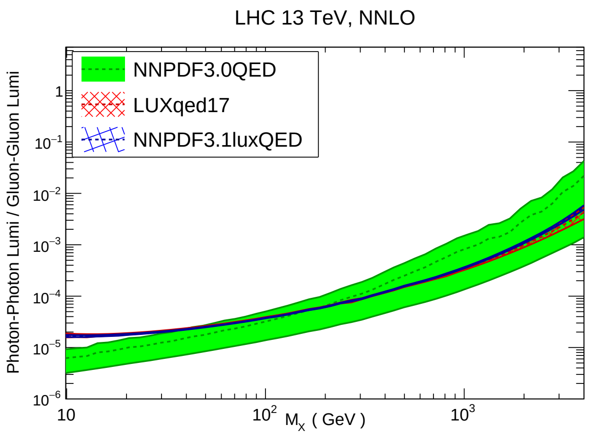
$$xf_{\gamma/p}(x,\mu^2) = \frac{1}{2\pi\alpha(\mu^2)}\int_x^1 \frac{dz}{z}\left\{\int_{\frac{x^2m_p^2}{1-z}}^{\frac{\mu^2}{1-z}} \frac{dQ^2}{Q^2}\alpha^2(Q^2)\left[\left(zp_{\gamma q}(z)+\frac{2x^2m_p^2}{Q^2}\right)F_2(x/z,Q^2)-\right.\right.$$
$$\left.\left. z^2F_L\left(\frac{x}{z},Q^2\right)\right] - \alpha^2(\mu^2)z^2F_2\left(\frac{x}{z},\mu^2\right)\right\},$$

THE LUXQED PHOTON PDF

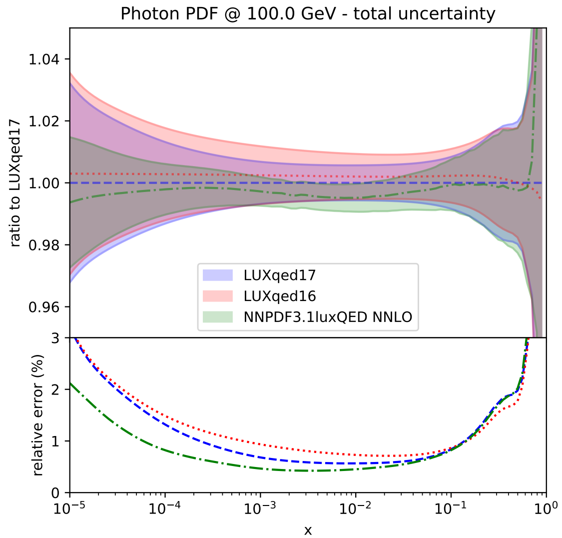
(Carrazza et al., 2017)

- LUX16/LUX17 SETS CONSTRUCTED FROM PDF4LHC15 $\Rightarrow$ AGREE WELL WITH NNPDF3.0 QED, MUCH SMALLER UNCERTAINTY
- FIRST PDF SET BASED ON CONSISTENT FIT WITH LUX CONSTRAINT: NNPDF3.0LUXQED
- NNPDF3.1LUXQED VS LUX17: GOOD AGREEMENT BUT SMALLER UNCERTAINTIES
- SIZABLE IMPACT ON PRECISION PHYSICS: EG ASSOCIATE HIGGS PROD. WITH W

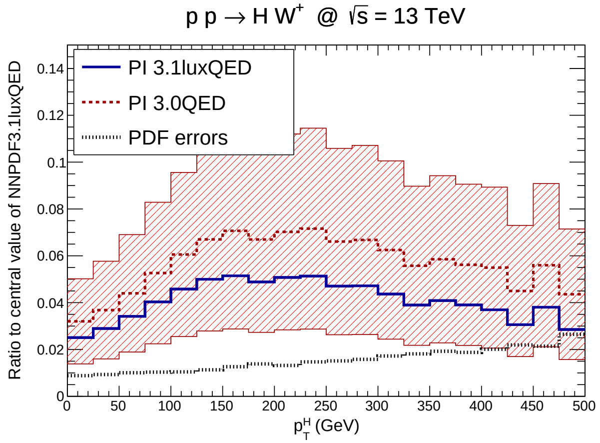
$\gamma\gamma$ LUMI: NNPDF3.0QED, LUX17, NNPDF3.1LUXQED



γ PDF: LUX17 VS. NNPDF3.1LUXQED



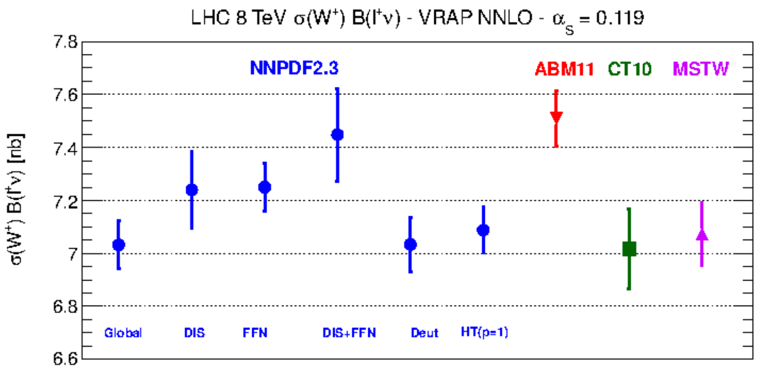
γ-INDUCED VS QCD: HW



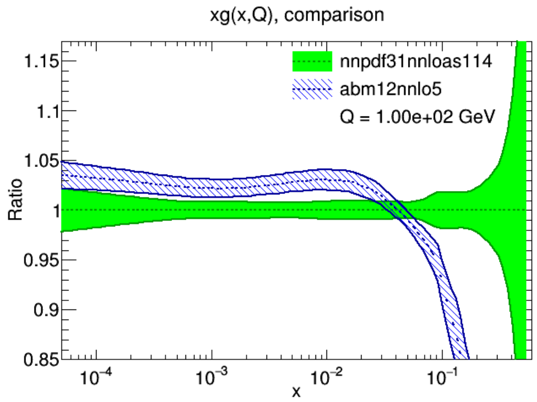
HEAVY QUARKS
DECOUPLING SCHEMES

- ALL GLOBAL PDF SETS USE MATCHED VARIABLE-FLAVOR HQ SCHEMES
  ACOT, FONLL, THORNE-ROBERTS EXTENSIVELY BENCHMARKED 2010-2014
- ABM USE MASSIVE FFN SCHEME
  $\Rightarrow$ SERIOUS DISCREPANCY, BEST FIT $\alpha_s = 0.113$
- ABMP16 $n_3 f = 3$ FOR DIS, $n_f = 5$ FOR LHC $\Rightarrow$ EFFECTIVELY, ZM-VFN
  $\Rightarrow$ DISCREPANCY REDUCED, BEST FIT $\alpha_s = 0.115$

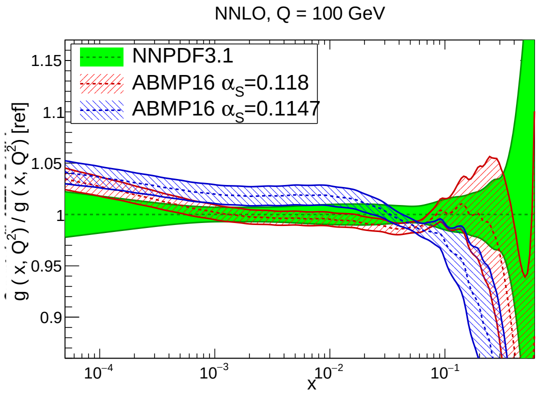
W^+ TOTAL XSECT



GLUON: ABM12 VS NNPDF3.0 ($\alpha_s = 0.114$)



GLUON: ABMP16 VS. NNPDF3.1

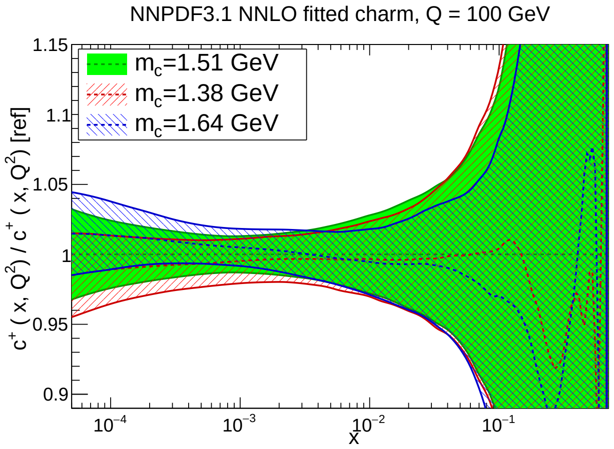


DETERMINING CHARM FROM THE DATA

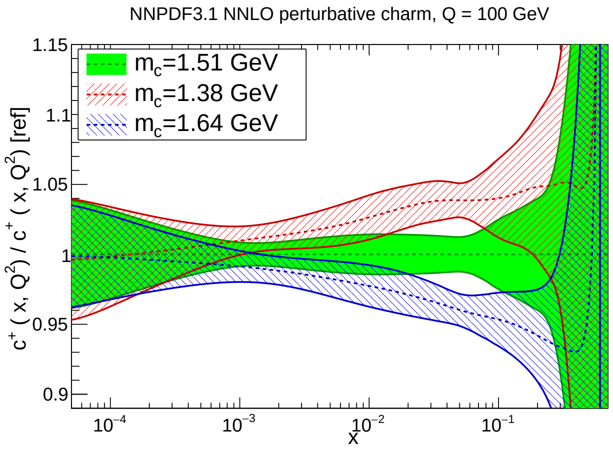
WHY SHOULD THE CHARM PDF BE DETERMINED FROM THE DATA?

- BECAUSE ITS SIZE SHOULD NOT DEPEND STRONGLY ON THE CHARM MASS
- BECAUSE IT MIGHT HAVE A NONPERTURBATIVE COMPONENT

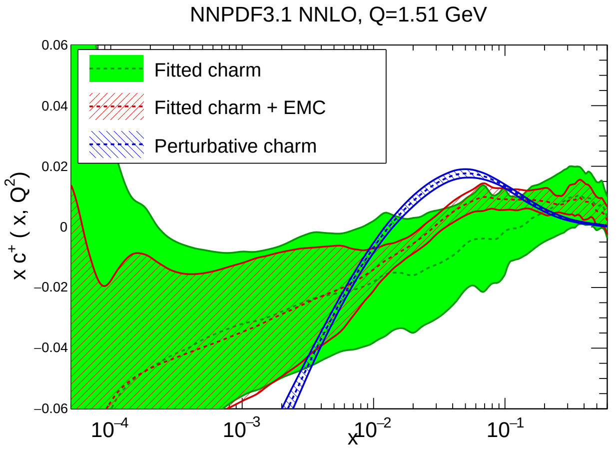
FITTED CHARM VS m_c



PERTURBATIVE CHARM VS m_c



FITTED VS. PERTURBATIVE CHARM

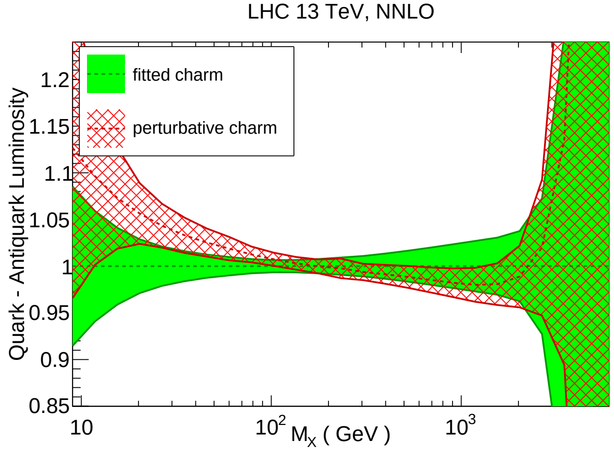


- BECAUSE ITS SHAPE SHOULD NOT BE DETERMINED BY FIRST-ORDER MATCHING (NO HIGHER NONTRIVIAL ORDERS KNOWN)
- $\Rightarrow$ SUPPRESSED AT MEDIUM-SMALL x, ENGANCED AT VERY SMALL, VERY LARGE x

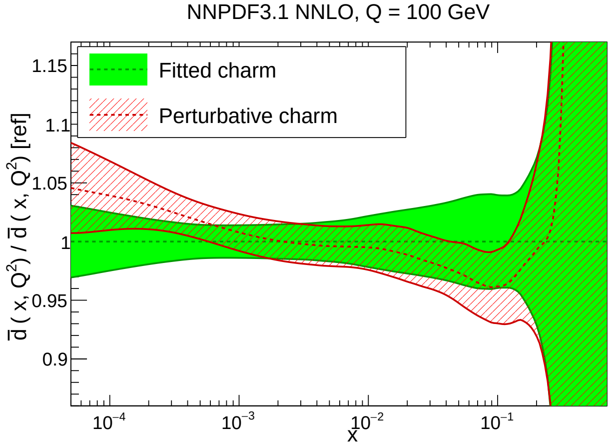
HEAVY QUARKS
IMPACT ON LIGHT QUARK PDFS

FITTED VS. PERTURBATIVE CHARM

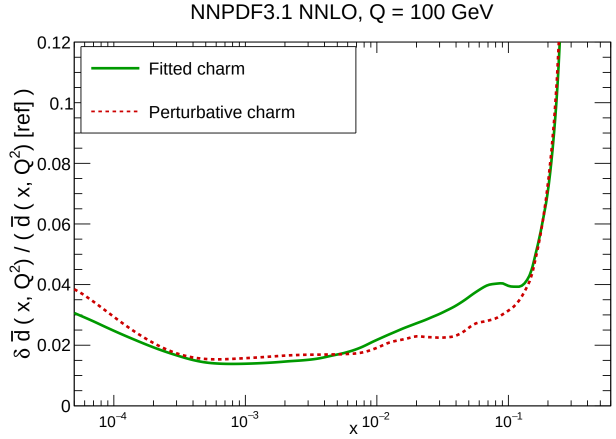
QQBAR LUMI



ANTIDOWN PDF



ANTIDOWN PDF UNCERTAINTY



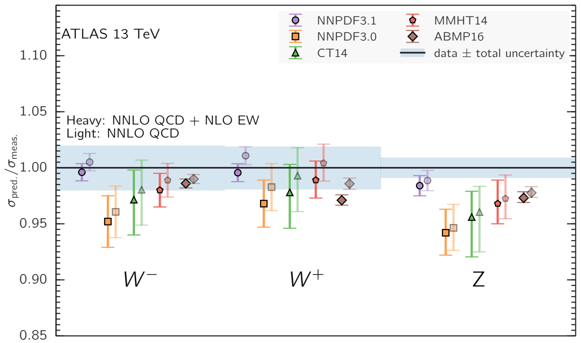
THE CHARM PDF FROM DATA...

- QUARK (ESPECIALLY QUARK-ANTIQUARK) LUMI AFFECTED BECAUSE OF CHARM SUPPRESSION AT MEDIUM-x
- FLAVOR DECOMPOSITION ALTERED
- UNCERTAINTIES ON LIGHT QUARKS NOT SIGNIFICANTLY INCREASED

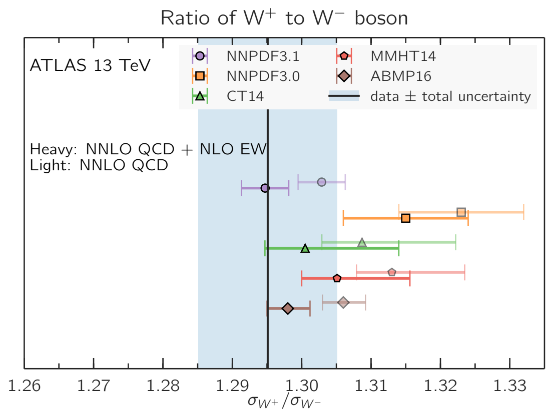
HEAVY QUARKS

THE CHARM PDF & PRECISION LHC PHYSICS

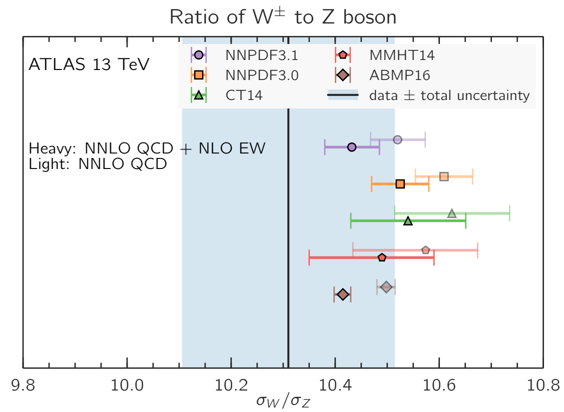
DRELL-YAN XSECTS



W^+/W^- XSECT RATIO



W/Z XSECT RATIO



- W, Z CROSS-SECTIONS AT 13 TEV IN PERFECT AGREEMENT WITH DATA
  DIFFICULT TO FIT WITH PERTURBATIVE CHARM
- ELECTROWEAK CORRECTIONS IMPORTANT
- NOTE ALSO SMALL-x RESUMMATION OF F_2^c REQUIRES FITTED CHARM

THEORY: SUMMARY

- WITH SUB-PERCENT DATA UNCERTAINTIES,

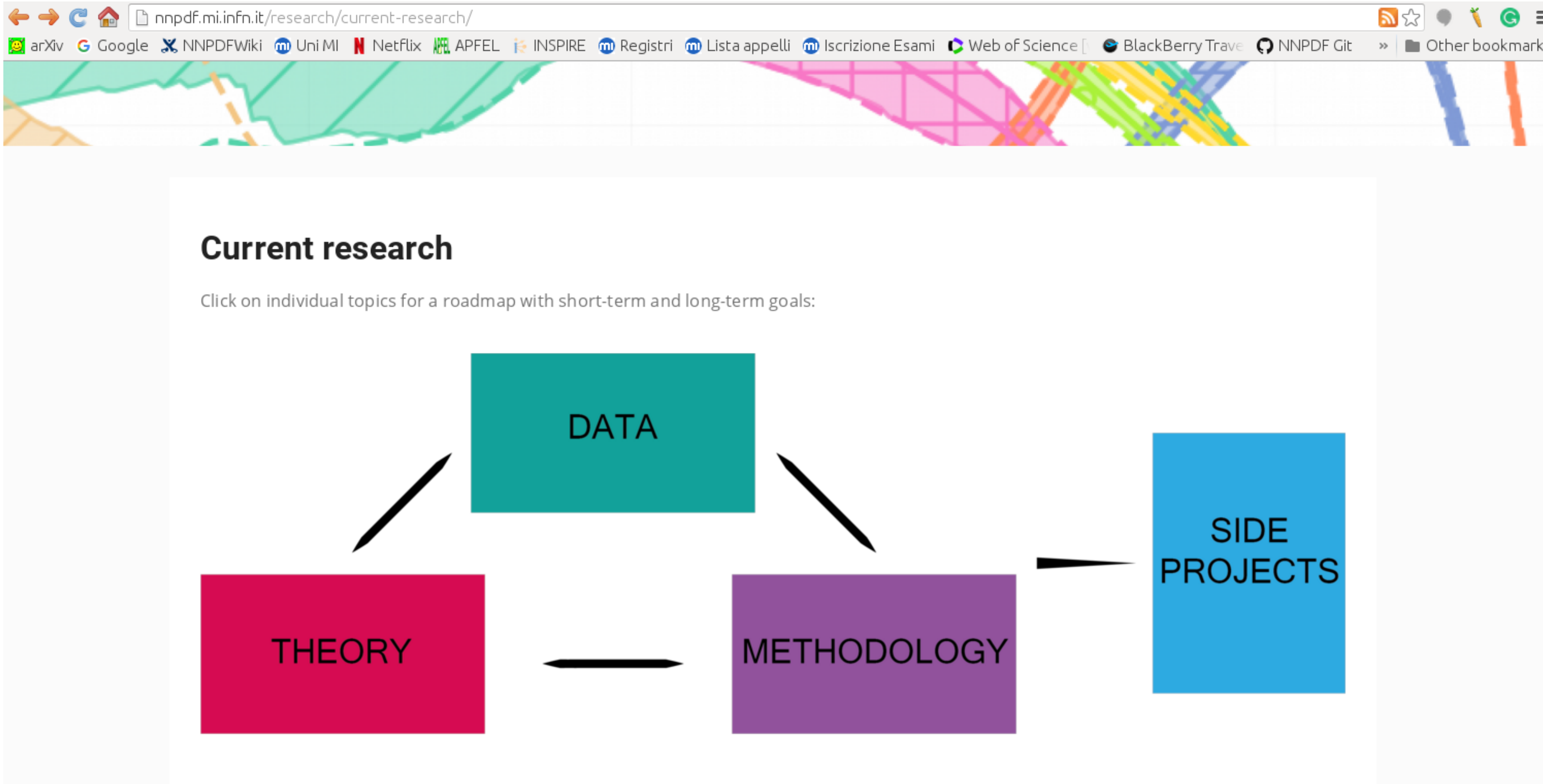
  THEORY UNCERTAINTIES DOMINANT

- RESUMMATION ADVANTAGEOUS

- ELECTROWEAK CORRECTIONS MANDATORY

BEYOND THE FRONTIER

OPEN ISSUES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Click on individual topics for a roadmap with short-term and long-term goals:
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THEORY
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SIDE PROJECTS

DATA

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Data

All to be implemented including NNLO QCD, photon-induced, and NLO electroweak

Short-term goals

OLD DATASETS

- NNPDF3.1 wrap-up: full implementation, restoring data cut because of large PI or EW
  - ATLAS W, Z 7TeV
  - ATLAS high-mass Drell-Yan 8 TeV
  - Low-mass DY
- New datasets for processes already in NNPDF3.1:
  - LHCb 8, 13 TeV W, Z production
  - ttbar 5, 8, 13 TeV
  - jets 8Tev, 13 Tev

NEW DATASETS

- Prompt photons
- Single top
- Dijets

Medium-term goals

In rough order of priority:

NEW DATASETS

- Diboson production
- Z phi* distribution
- Z+c
- Hera jets
- V+jets
- LHC D* production
- W+c

METHODOLOGY

nnpdf.mi.infn.it/research/current-research/methodology/

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Methodology

Short-term goals

- PDF parametrization
  - Fit preprocessing
  - Neural network architecture:
    - Single-layer for each PDF
    - One single (multilayer or perhaps deep) NN for all PDFs
- Minimization algorithms
  - CMA algorithm: validation
    - Closure test
    - Check against reweighting
    - Check of positivity
  - CMA algorithm: optimization
    - Grid search

Mid- to long-term goals

- Minimization algorithms
  - CMA algorithm: optimization
    - Gradient-based methods
  - Weight minimization + other new methods

THEORY

Theory

Short to Medium-term goals

- Missing Higher Order Corrections Uncertainties (MHOU)
  - Implementation of scale variation at NLO
  - Determination of the contribution to the covariance matrix due to MHOU estimated with scale variation
  - Fit with the MHOU uncertainty included in the covariance matrix
  - Fit with scale variation in the theory
  - Comparison of:
    - NNLO-NLO shift
    - shift due to scale variation in the fit
    - increase of PDF uncertainties due to MHOU included in covariance matrix
- Nuclear & deuterium corrections:
  - Fit with one ore more models
  - Implementation in the covariance matrix as for MHOU
  - Fit with extra nuclear uncertainty
- Full computation for all processes in fit of NLO EW and PI
- Inclusion in the covariance matrix of further uncertainties in the NNLO QCD computation:
  - N3LO terms due to the use of K-factors
  - Uncertainties on NNLO corrections due to numerical instabilities, estimated by refitting

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Medium to Long-term goals

- Implementation of scale variation at NNLO
- Alternative ways of estimating MHOU, including constrained partial dataset fitting
- Approximate N3LO PDFs

SIDE PROJECTS

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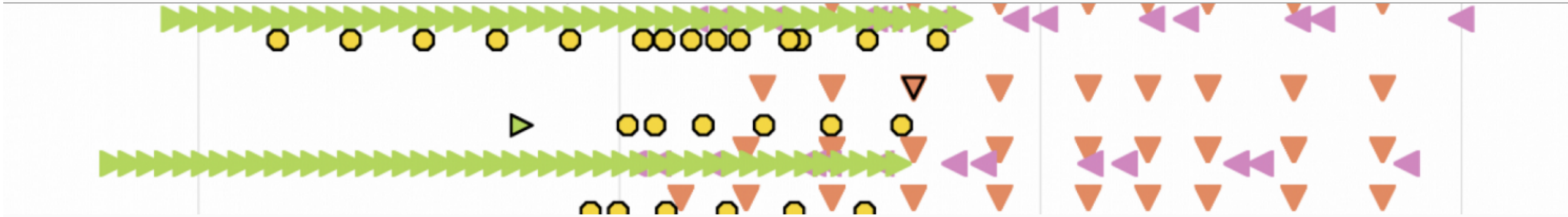
NNPDF Home The collaboration Research For users Documents News For the public



Side projects

Short-term goals

- Jets: choice of scale and comparison of theory predictions to data before inclusion in the fit
- Polarized PDFs
- Fragmentation functions

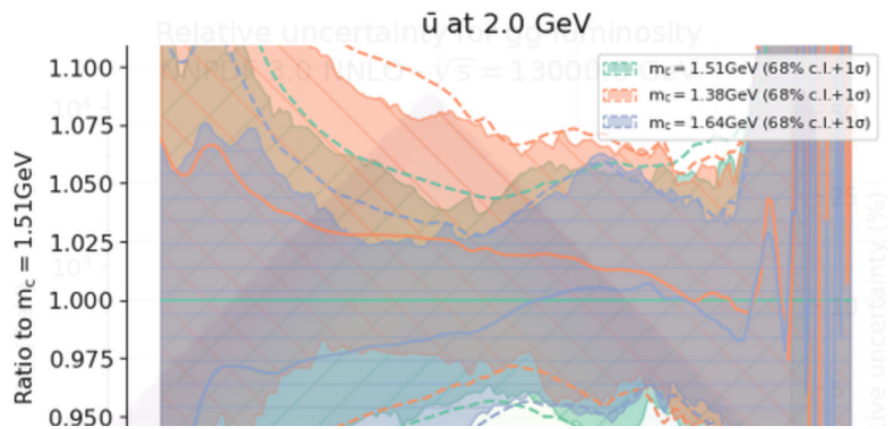
Medium-term goals

- Polarized PDFs
- Fragmentation functions
- Resummed PDF sets for LHC phenomenology
- PDFs at the LH-HE collider

N^3PDF

N3PDF
Machine Learning • PDFs • QCD

The **N3PDF** project, led by PI **Stefano Forte**, aims at revolutionizing the theory of strong interactions and its application to the determination of the structure of the proton, by introducing extensively techniques of artificial intelligence (AI). The core of the project is the development of an AI agent for the determinations of the parton distributions which encode the quark and gluon structure of the proton, using machine learning techniques. The project also includes an integrated set of studies on higher-order computations and resummation in perturbative QCD, and the development of parton distributions interfaced to resummation and Monte Carlo generators. The project will work in synergy with the NNPDF collaboration, to which it will provide methods and tools, and from which it will gain physics input and insight.



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NEWS

Tweets by @NNPDF_Team

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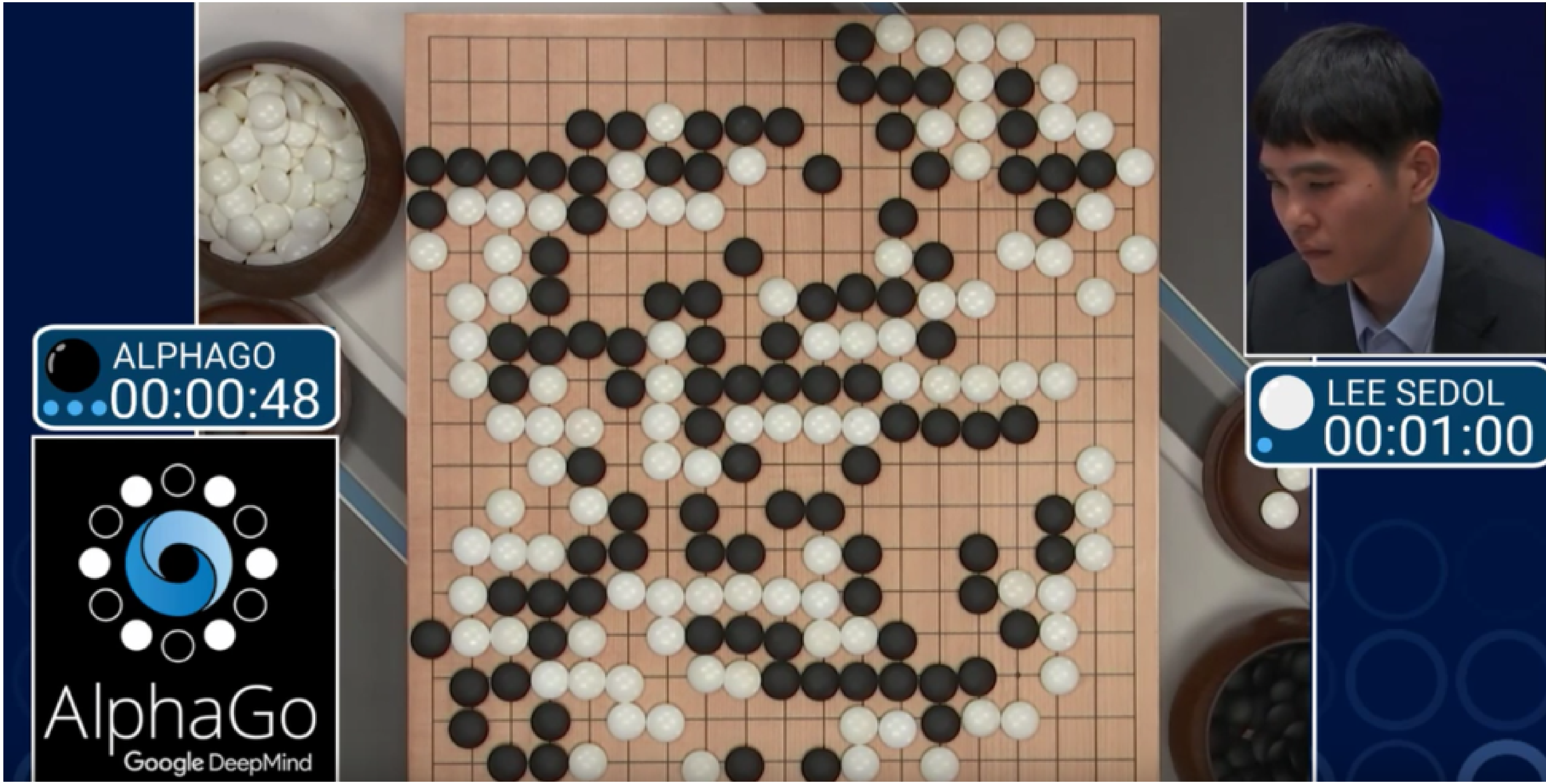
@jonmbutterworth
After 40 years of studying the strong nuclear force, a revelation theguardian.com/science/life-a...
Me at Life & #Physics on BFKL and all that.

Embed View on Twitter

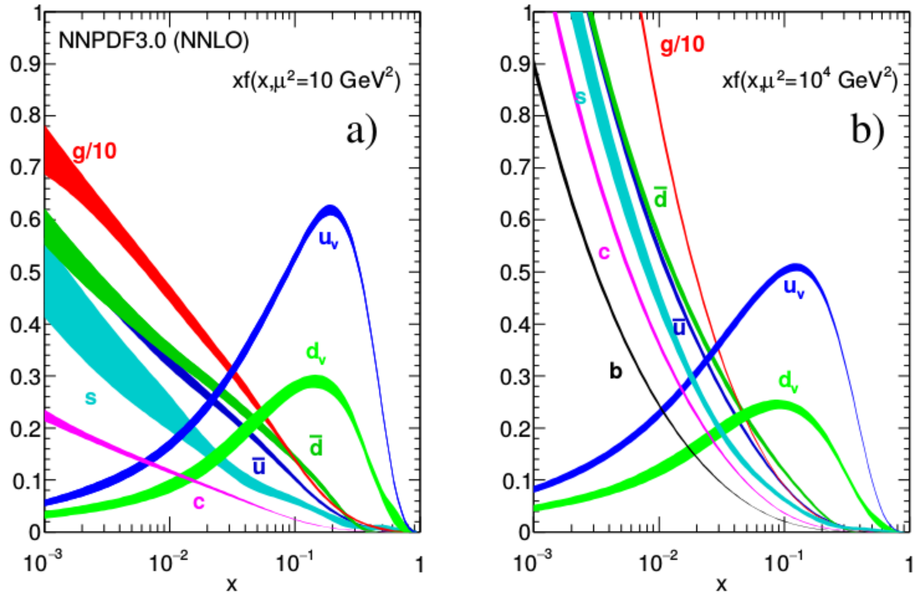
JOBS

There are currently no positions available but we will be looking for two PhD students very soon!

AI & GO



AI & PDFs



N3PDF

Machine Learning • PDFs • QCD