Proton Structure Analyses in Hadronic Collisions

international collaboration of experimentalists and theorists

https://prosa.desy.de/

Katerina Lipka, DESY

of behalf of PROSA collaboration

Annual meeting of Helmholtz Alliance “Physics at the Terascale”, 2-4 December 2013

Proton Structure Analyses in Hadronic Collisions

Main Goal: advance the interpretation of the LHC results in many areas through improved precision of fundamental Standard Model (QCD and EWK) parameters

Discovery potential of the LHC
is currently constrained by

- missing full NNLO calculations
- uncertainties of couplings
- masses of c-, b- and t- quarks
- understanding of proton structure

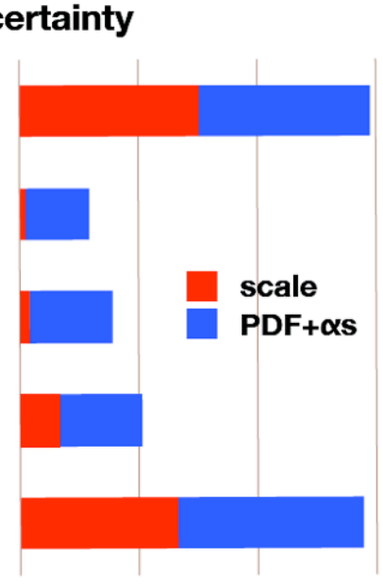
Particularly sensitive processes:
- Higgs production
- Top quark production
- W and Z production
- Jet and heavy quark production

Higgs production at 125 GeV

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CrossSections

- Model testing requires assessment of theoretical uncertainties
  - uncertainties from scale variation and PDF+strong coupling

		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%



Perturbative QCD: Status - John Campbell, Fermilab ICHEP2012 30

Precision physics in hadron collisions requires a **combined study of a diversity of SM processes** which goes beyond the scope of a single experiment or an individual theory group.
Most involved observables are interconnected by their sensitivity to the proton structure,
➜ integral part of proposed activities is coherent investigation of the proton structure

Cross Section for Different Processes in Hadronic Collisions

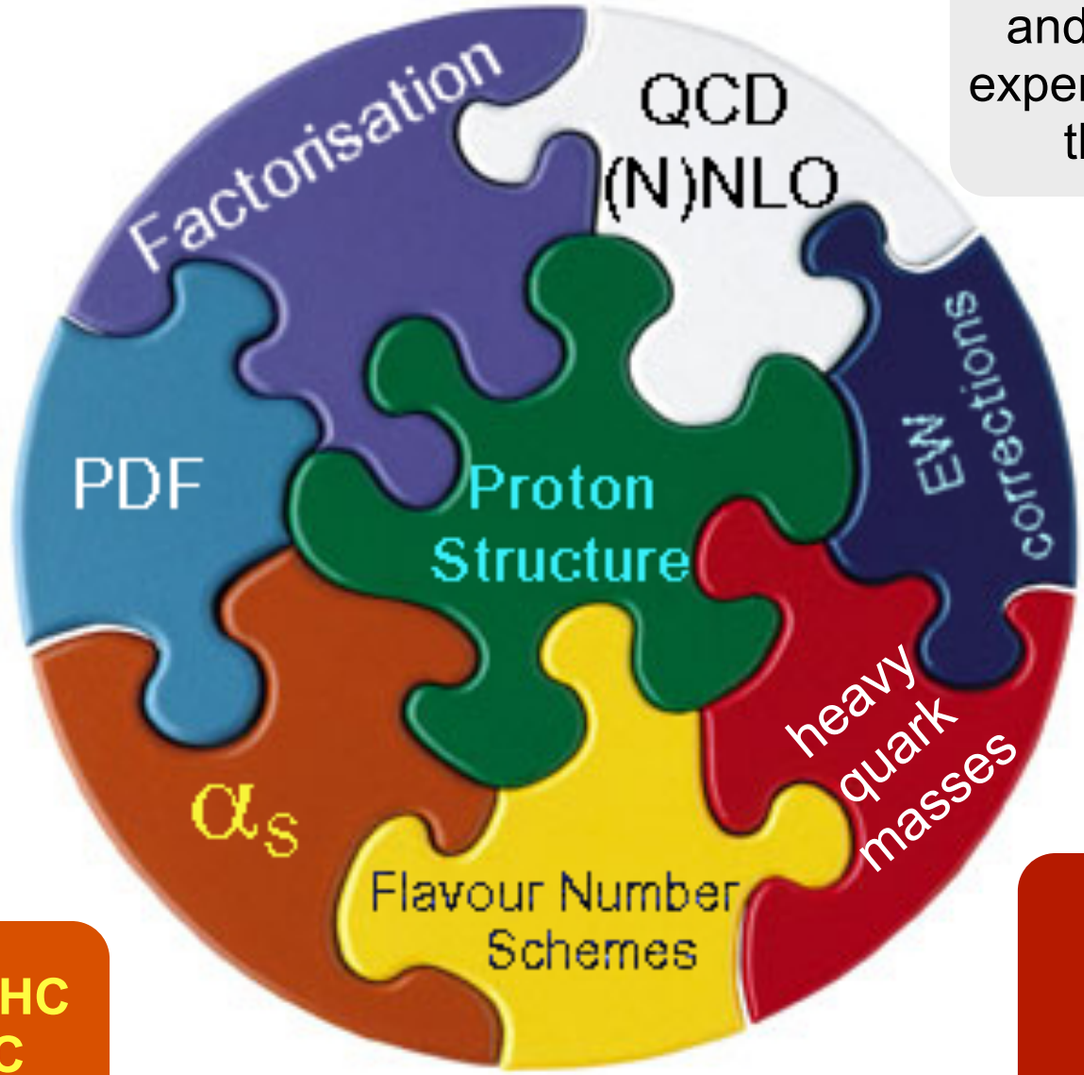
$$\sigma(s) = \sum_{i,j} \int_{\tau_0}^{1} \frac{d\tau}{\tau} \cdot \frac{dL_{ij}(\mu_F^2)}{d\tau} \cdot \hat{s} \cdot \hat{\sigma}_{ij} \; ; \tau \cdot \frac{dL_{ij}}{d\tau} \propto \int_0^1 dx_1 dx_2 (x_1 f_i(x_1, \mu_F^2) \cdot x_2 f_j(x_2, \mu_F^2)) + (1 \leftrightarrow 2) \delta(\tau - x_1 x_2)$$

low and medium x: *ep* DIS
valence,
gluon via scaling violations

high x: jets at TEVATRON,
jets at LHC
tt at LHC: gluon

medium x: DY@ LHC valence
and flavour separation

prompt photons@LHC: gluon



most QCD processes in ep
and pp calculated to NLO,
experimental precision higher
than theory accuracy

Jets and
top-pair production at
LHC receives significant
EW corrections.
ISR and FSR in DY

Jets at HERA, TEVATRON, LHC
top-pair production at LHC

Different approaches:
number of active flavours N_f
Fixed or variable N_f?
Transitions $N_f \rightarrow N_{f+1}$.

values of m_c, m_b, m_t
in particular scheme

running of masses

PROSA Structure

Exploit the expertise of the participants in an optimal way in 4 work packages:

Integrated physics analysis
determination of couplings, quark masses, etc. involving
data from (several) experiments and calculations from the theory groups.
realisation of the major goal

implementation of advanced analysis strategies

immediate application of theory calculations

Experimental analyses
production of jets, EW bosons, c-, b- and top quarks

involved experimentalists from:
ATLAS, CMS, CDF, D0, HERA

Tool development
FastNLO
ApplGrid
HERAFitter
OpenQCDrad

Theory calculations
Jets
EW corrections
heavy quarks in QCD
top-pair and single top
PDF determination

common platform
for exchange of knowledge
between experiment and theory

PROSA Activities in 2013

Experimental analyses: contributions to

- CMS differential top x-section measurements
- ATLAS W+c measurements
- ATLAS Drell-Yan measurements
- HERA measurements of charm production

Theory calculations: contributions to

- Phenomenology of threshold corrections for inclusive jet production at hadron colliders
- Approximate NNLO calculations for differential top-production

Tool developments: contributions to

- OPENQCDrad *see talk S. Alekhin, SMP session*
- FastNLO *see talk K. Rabbertz, SMP session*
- HERAFitter *see talk V. Radescu*
- Diftop *see talk M. Guzzi*
- WINHAC

Integrated physics analysis: contributions to

- Determination of heavy quark masses, strong coupling constant
- Determination of PDFs: *see talk S. Alekhin*
- Determination of strange content of the proton *see talk R. Placakyte*

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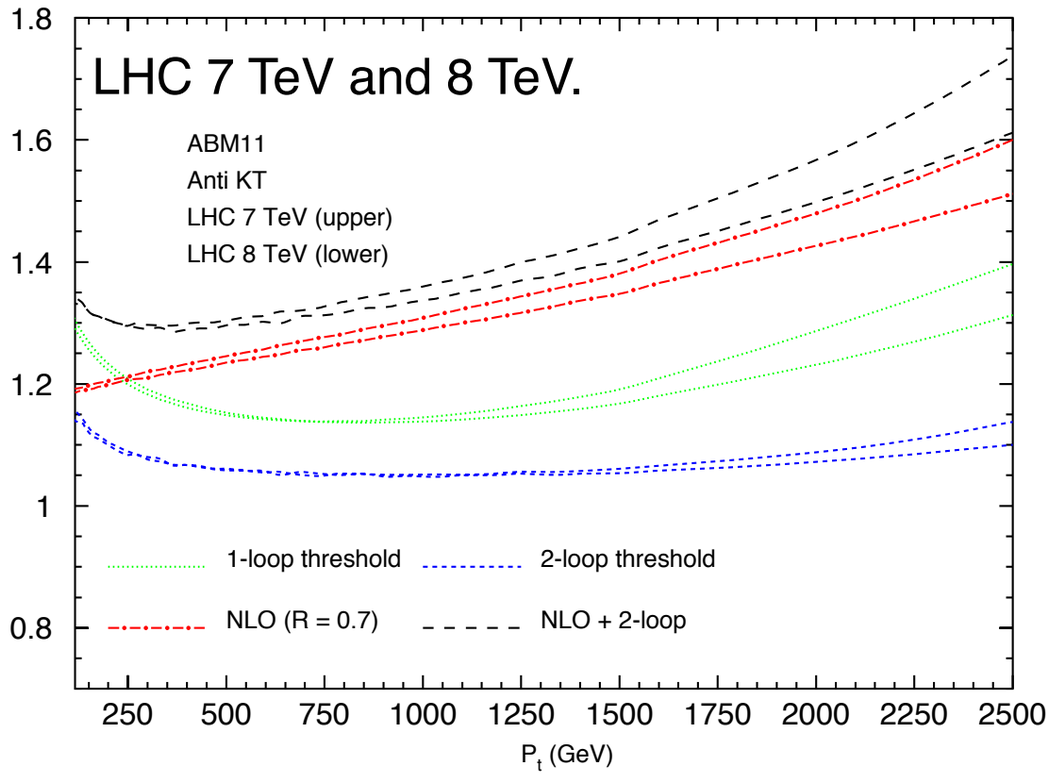
Threshold corrections for inclusive 1-jet production

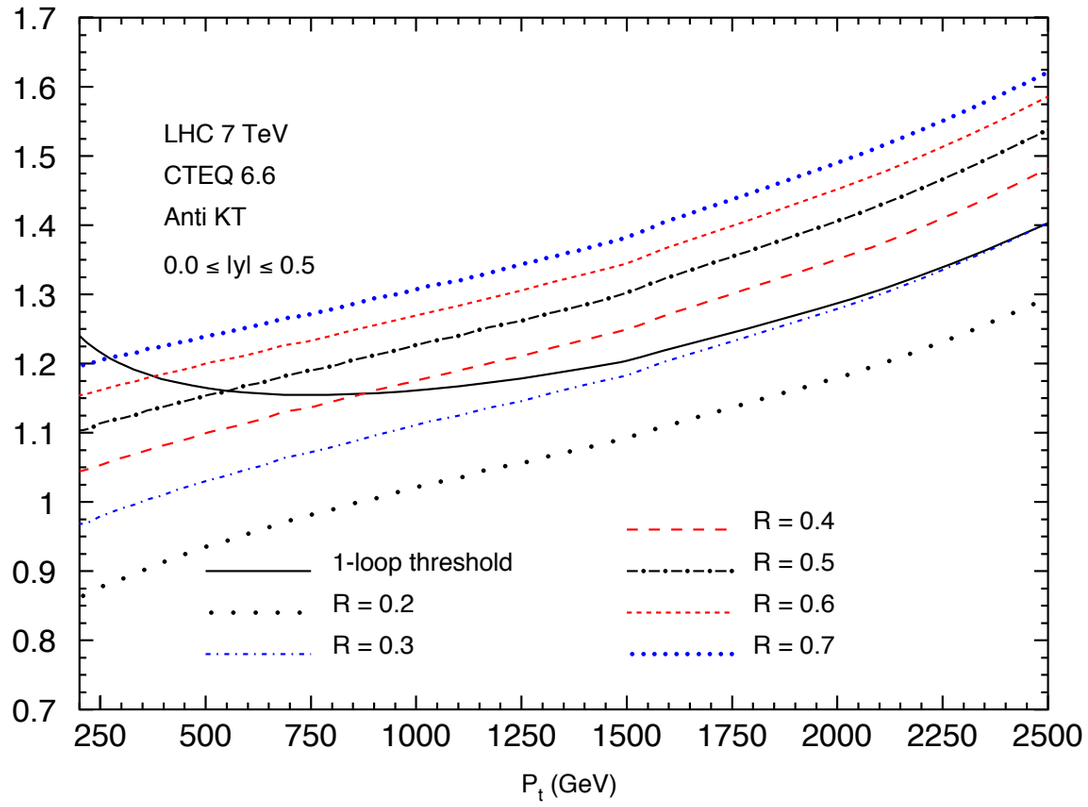
M. C. Kumar, S. Moch [arXiv:1309.5311]

Threshold corrections for inclusive jet producion re-calculated to NNLO at NLL accuarcy.
Soft-gluon resummation formalism is applied.

K-factors: 1-loop threshold, 2-loop threshold, exact NLO, NLO+2loop threshold ($NNLO_{approx}$)



Cone size (R) dependence of exact NLO corrections vs. 1-loop threshold corrections (given in terms of K-factor)



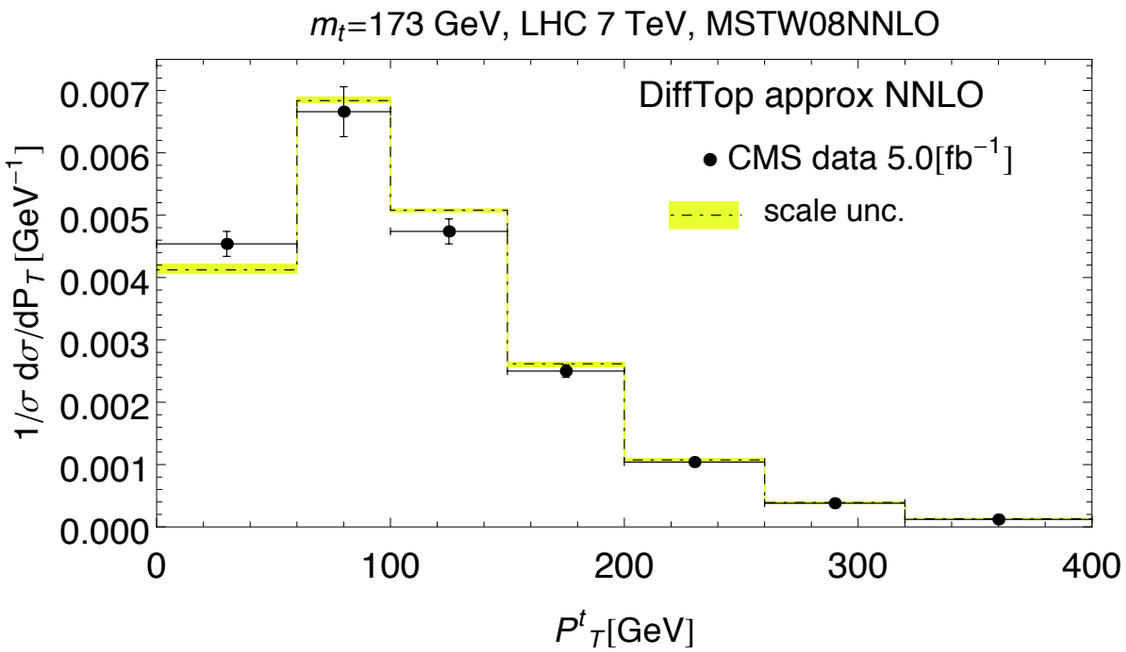
Approximate NNLO jet cross sections predicted using soft-gluon resummation formalism
Currently large theory uncertainty due to missing cone-size dependence
(included recently in de Florian et at [arXiv:1310.7192], need to be studied for all rapidity range)

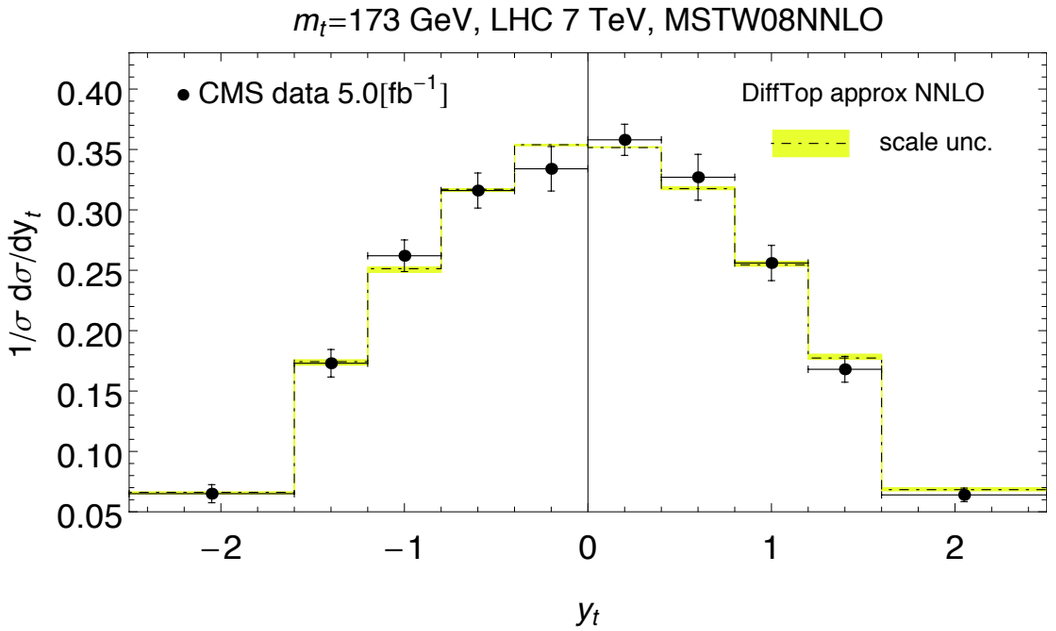
Outlook:
Implementation of the R-dependent, threshold corrections in fastNLO

Towards differential top-pair measurements in global QCD analysis

⇒ *see talk M. Guzzi*

Open-source approximate NNLO calculation for differential top-pair production based on threshold resummation expansion (soft gluon correction NLO, NNLO)





Calculation based on
N. Kidonakis, S.-O. Moch, E. Laenen, R. Vogt *[Phys Rev D 64 114001]*

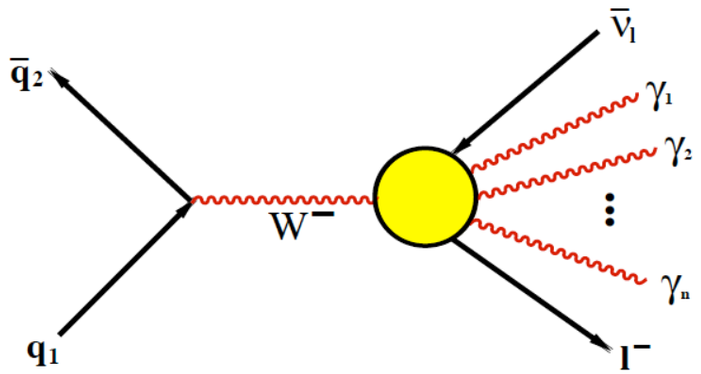
work in progress: predictions of M_{tt}, forward-backward asymmetry

WINHAC event generator for Drell-Yan processes in proton or ion collisions

W. Płaczek, S. Jadach, M. W. Krasny, arXiv:1310.5994 [hep-ph]

QED corrections in W-decays significantly affect W-boson transverse mass and lepton p_T distributions

Significant effects due to QED final-state radiation (FSR):
FSR O(α) corrections limit the precision of m_W measurement, $\Delta m_W > 100$ MeV
Corrections beyond QED FSR sizable for high $p^l{}_T$ and high $m^W{}_T$ values : important for BSM searches



WINHAC

charged current processes:

multi-photon FSR (+ interference) calculation based on Yennie-Frautschi-Suura exclusive exponentiation with O(α) EW corrections

neutral-current processes: multi-photon FSR via PHOTOS

Internal interface to PYTHIA 6.4 for QCD/QED parton showers and hadronisation/decays.

LHA - interface to QCD parton shower generators

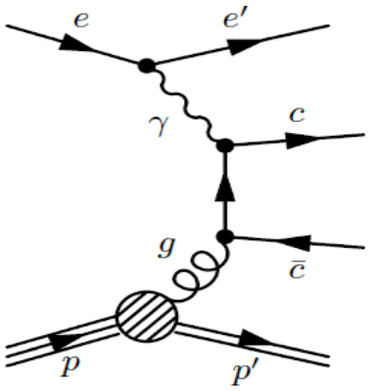
Options:

- Generation of weighted or unweighted events is possible
- Parallel computation of weights (various contributions, effects or corrections, PDF errors)

- Polarisation of W-bosons (L, T, left, right) in various frames;
- Various EW parameter options: fixed or running W/Z-boson width, different schemes

work in progress: including the NLO QCD corrections in the parton shower algorithm

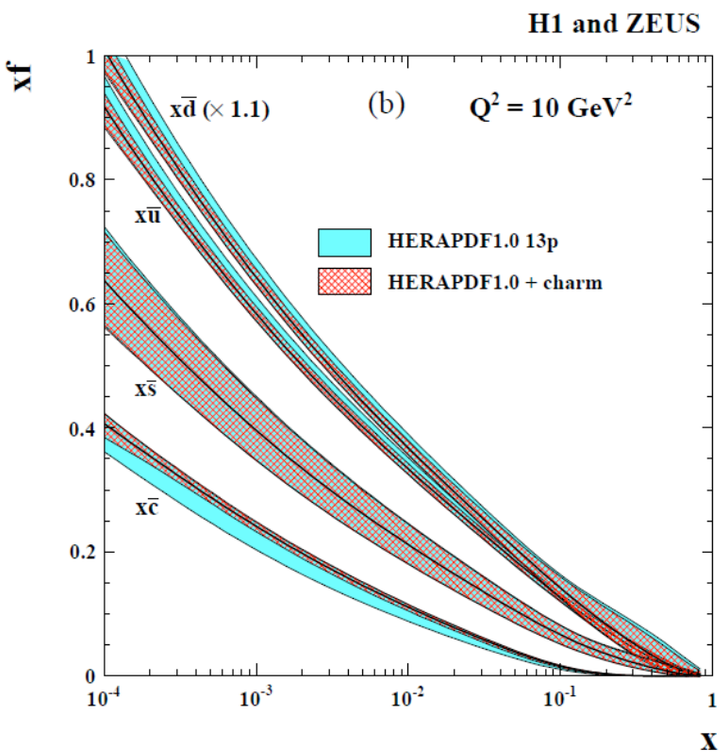
Determination of m_c, PDF and α_s using charm production in DIS

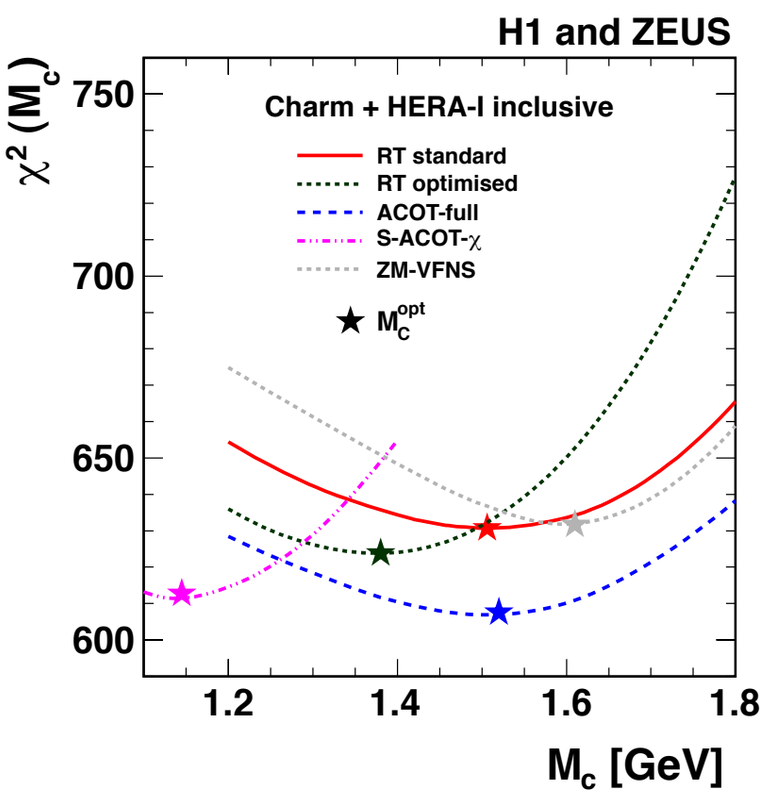


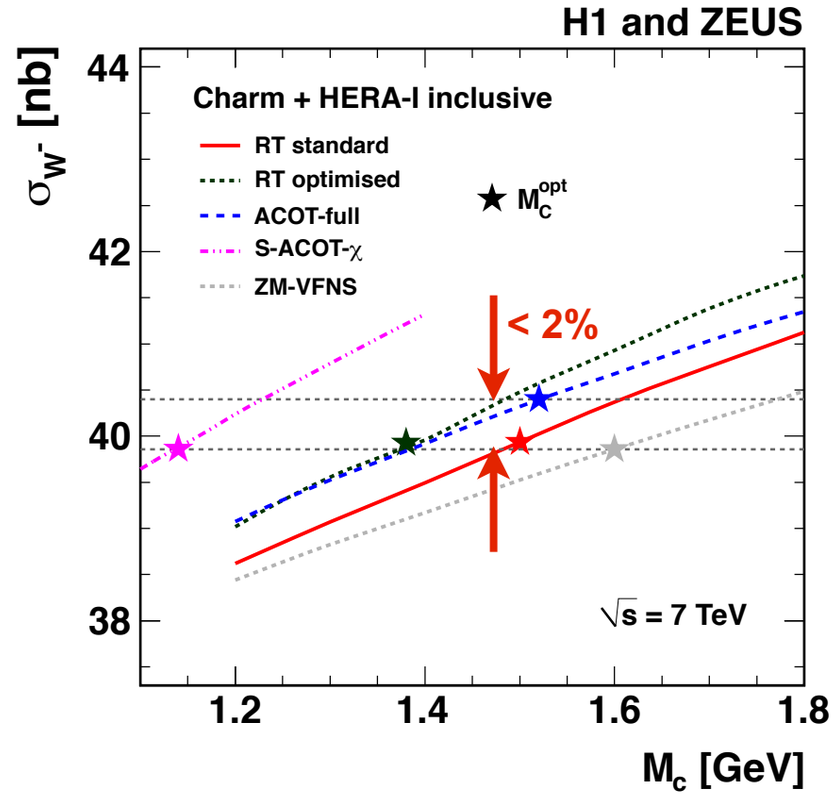
Charm-quark production at HERA used in the QCD analysis:

- determination of $m_c(m_c)$, entered PDG world average in 2013
- combination of H1 and ZEUS measurements
- tests of charm mass employed in different heavy flavour schemes

H1 and ZEUS Collaborations, Eur. Phys. J. C 73 (2013) 2311







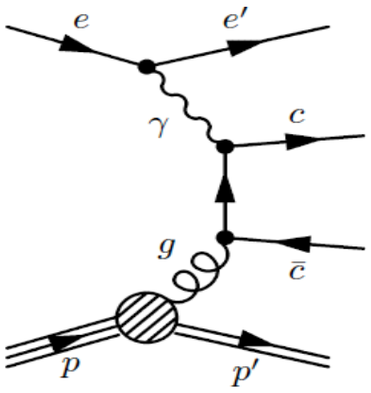
Inclusion of charm: reduced uncertainty on gluon, charm and light sea

...mostly due to better constrained charm-quark mass

optimal charm mass in PDF, M_c, using different VFNS determined

improved prediction of W and Z cross sections at the LHC

Determination of m_c, PDF and α_s using charm production in DIS



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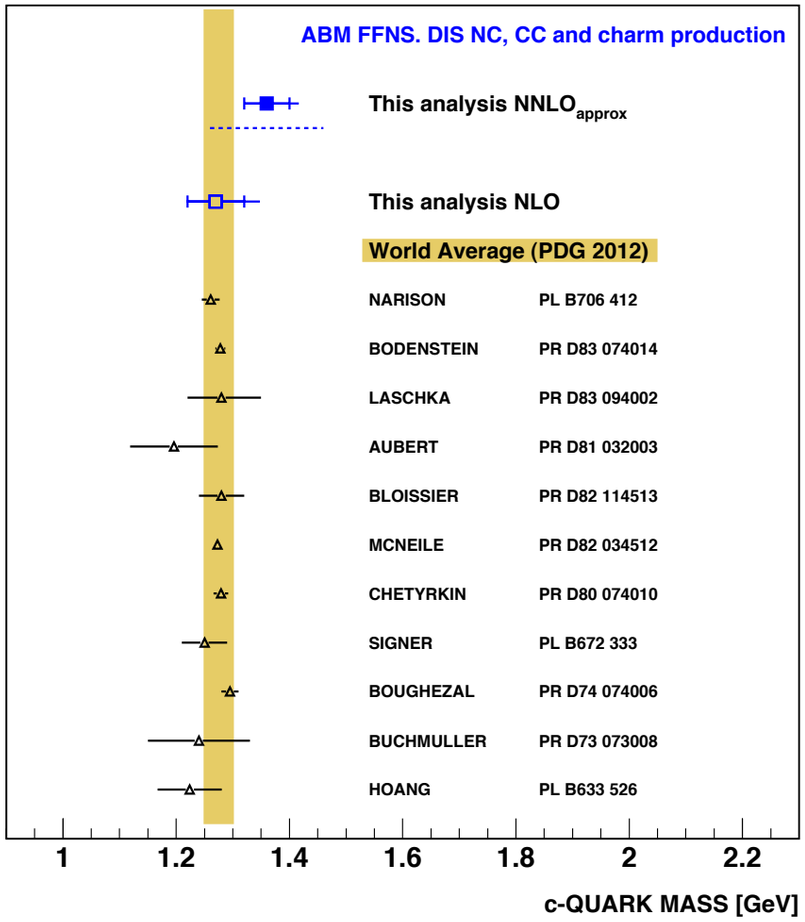
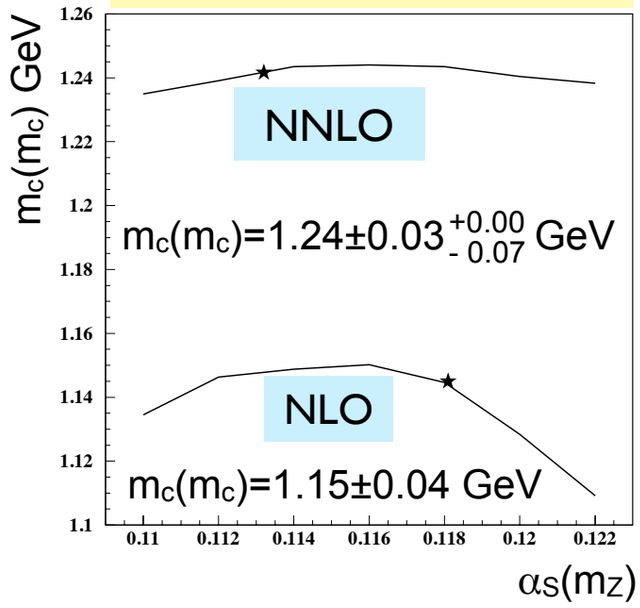
Phys. Lett. B 718 (2012) 550



$m_c(m_c)$ via D* production at H1
correlation of phase-space corrections
on $m_c(m_c)$, PDF, scales and α_S
consistently taken into account

global PDF fits: study of correlations of $m_c(m_c)$, PDF and α_S

Phys. Lett. B 720 (2013) 172



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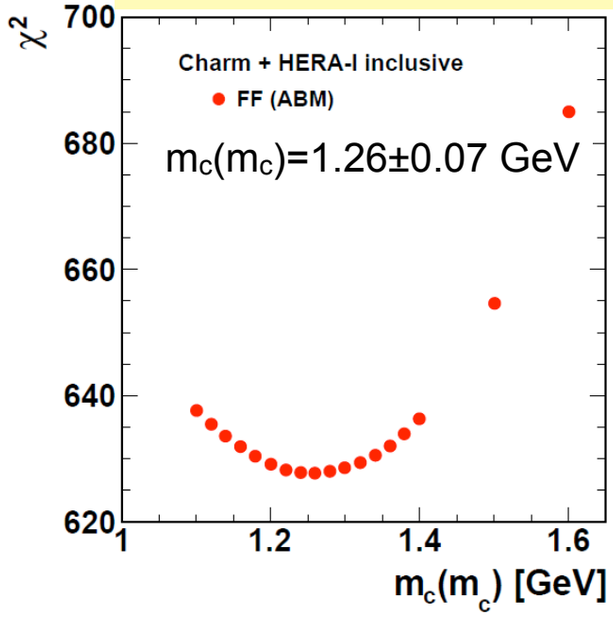

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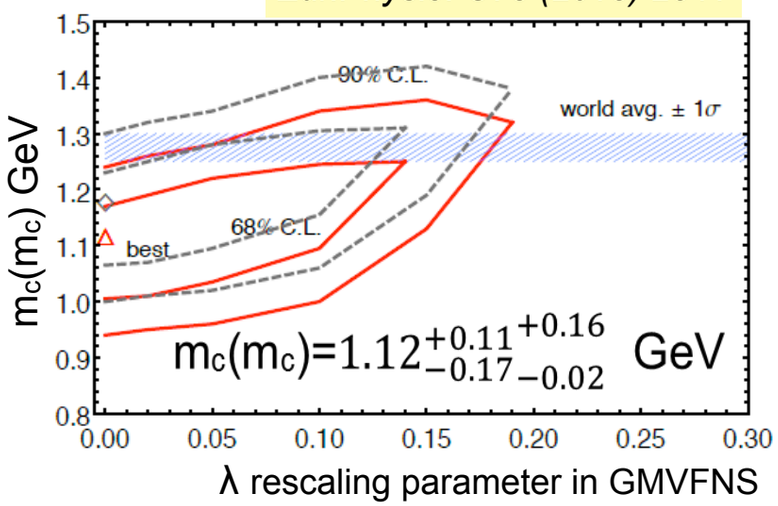
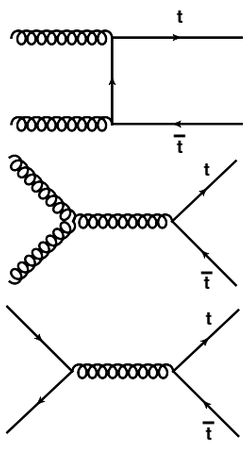
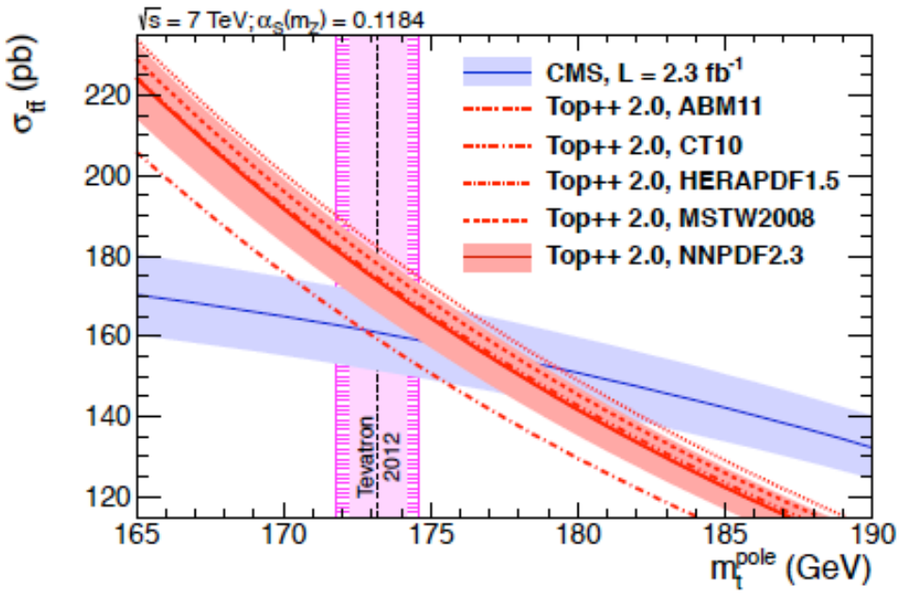


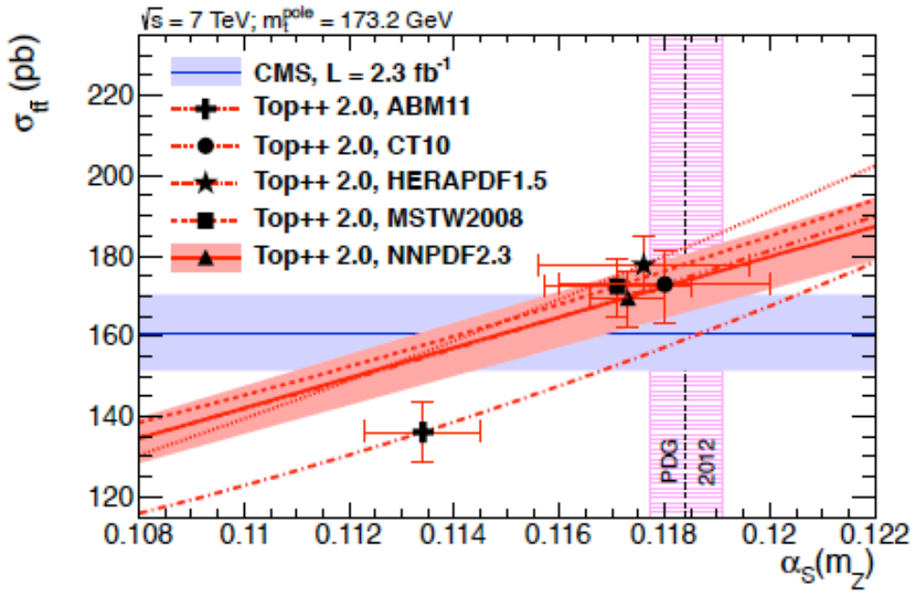
NLO results of $m_c(m_c)$
consistent
in different frameworks

QCD constraints using top-pair production at CMS *[CMS, arXiv1307.1907]*

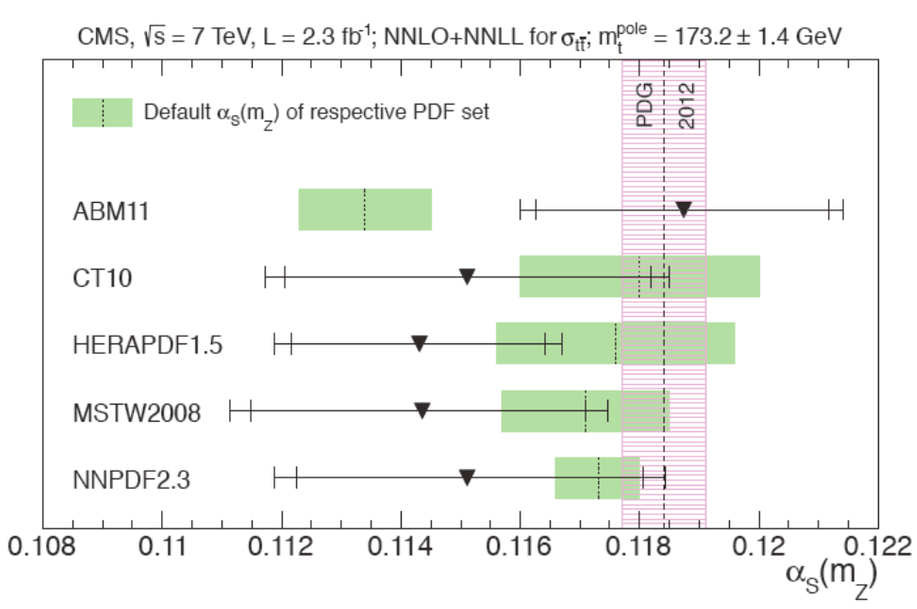
Top-quark pair production in pp collisions probes gluon distribution at high x, top mass and α_S

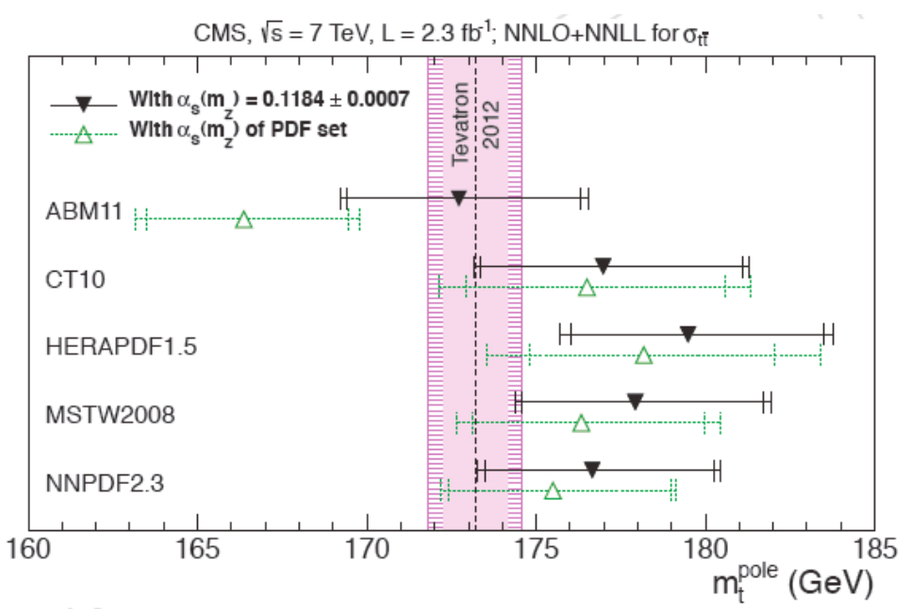






Determine m_t (α_S) fixing α_S (m_t) using total $t\bar{t}$ cross-section at CMS, use different PDFs





- determined m_t^{pole} consistent with direct measurements
- first determination of α_S at NNLO at hadron collider. Determined α_S (M_Z) consistent with PDG value

Next steps: simultaneous determination of g(x), α_S and m_t in a global QCD analysis

Improved determination of PDFs by including LHC data: ABM 12

arXiv:1310.3059 ⇒ *see talk S. Alekhin*

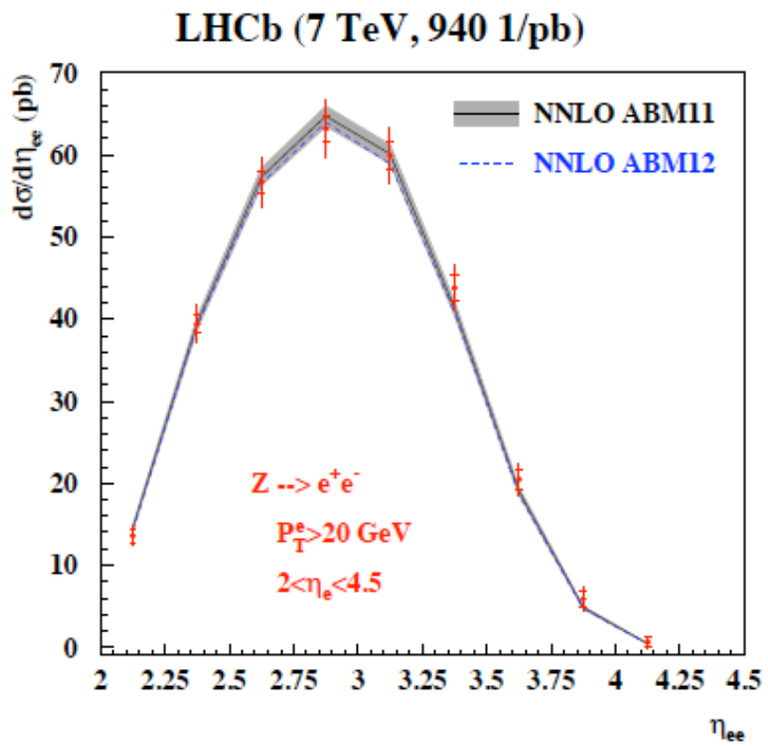
new data in the QCD analysis:

HERA I DIS Q^2 >1000 GeV^2, HERA combined charm cross-section

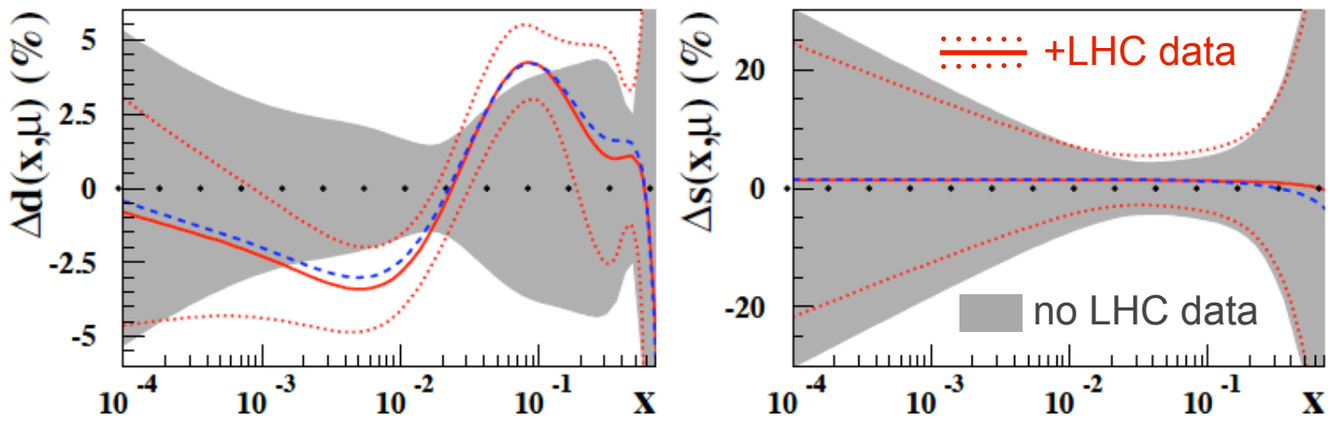
ATLAS W, Z/γ $\sqrt{s}$=7 TeV, 35 pb^{-1}, CMS electron charge asymmetry in W production, $\sqrt{s}$=7 TeV, 840 pb^{-1},

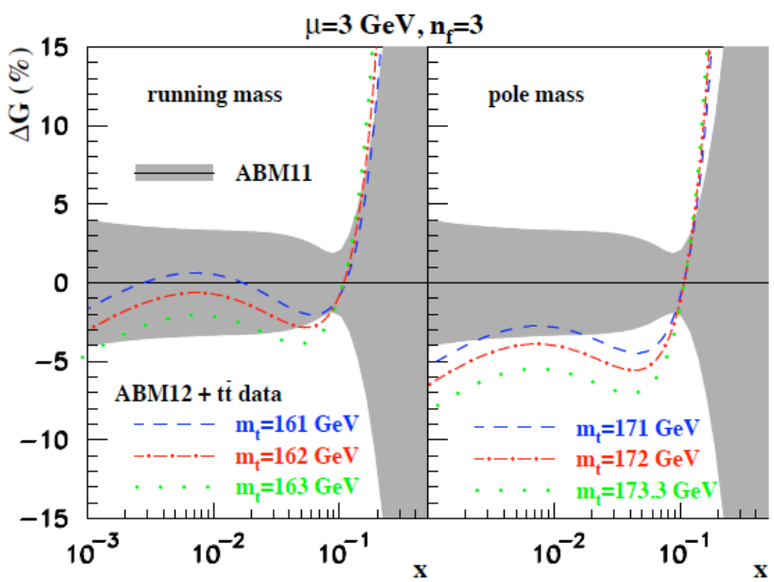
LHCb W, Z $\sqrt{s}$=7 TeV, 37 pb^{-1} ; $Z \to e^+e^-$, 0.94 fb^{-1}

Top-pair inclusive cross sections (ATLAS + CMS all channels) $\sqrt{s}$=7 TeV, semi-leptonic $\sqrt{s}$=8 TeV



observed change in the PDF shapes,
improvements of uncertainties in the whole x range





Simultaneous fit of top mass, PDF, α_S at NNLO using inclusive top-pair cross sections

$m_t(m_t) = 162.3 \pm 2.3$ GeV $m_t(\text{pole}) = 171.2 \pm 2.4$ GeV

$\alpha_S(M_Z) = 0.1132(11)$

Improved determination of PDFs through W± production at CMS

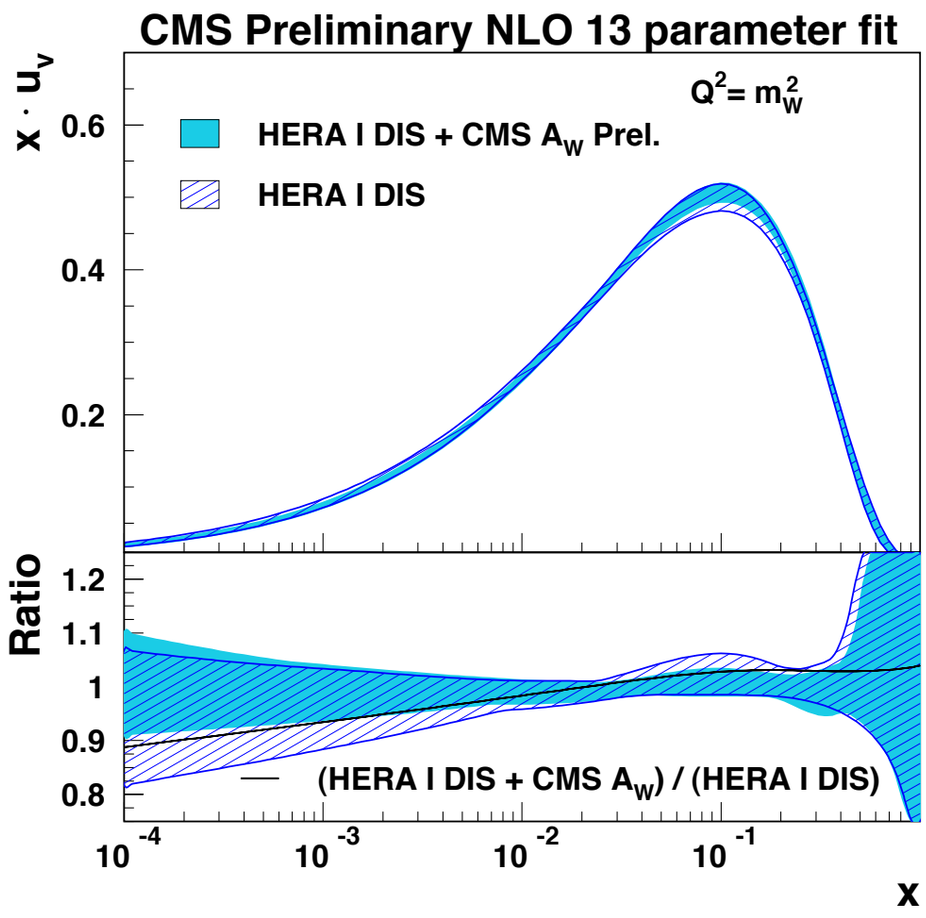
CMS-SMP-12-021 ⇒ *see talk R. Placakyte (SMP)*

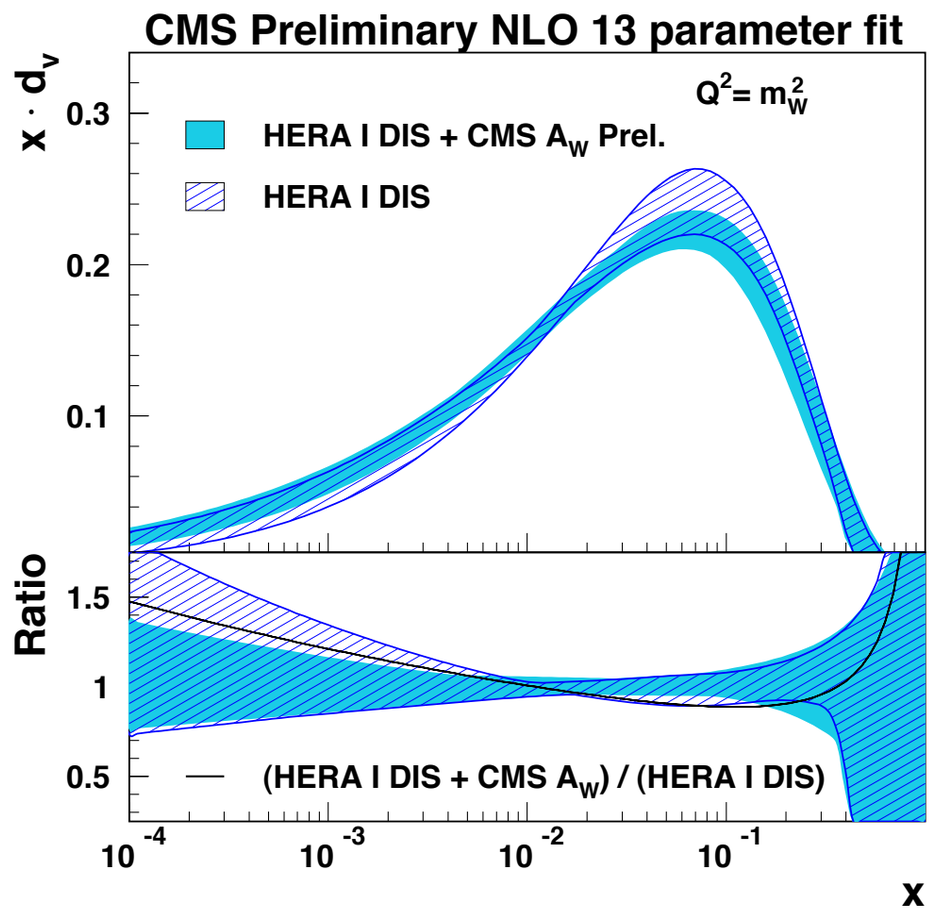
Lepton asymmetry in W production in pp collisions
sensitive to
differences between u and d quarks in the proton

$$A_W = \frac{W^+ - W^-}{W^+ + W^-} \approx \frac{u_v - d_v}{u_v + d_v + 2u_{sea}}$$

QCD analysis at NLO performed using HERAFitter, including

- HERA I combined DIS data *[JHEP 1001:109 (2010)]*
- Muon charge asymmetry in W production at 7 TeV *[CMS-SMP-12-021 (in the publication procedure)]*



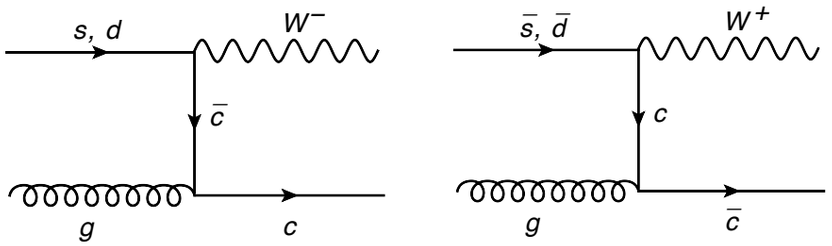


error bands represent total uncertainties (experimental, model and parametrisation uncertainties)

Improved constraints on the valence distributions

Determination of strange content in the proton using W+c production at CMS

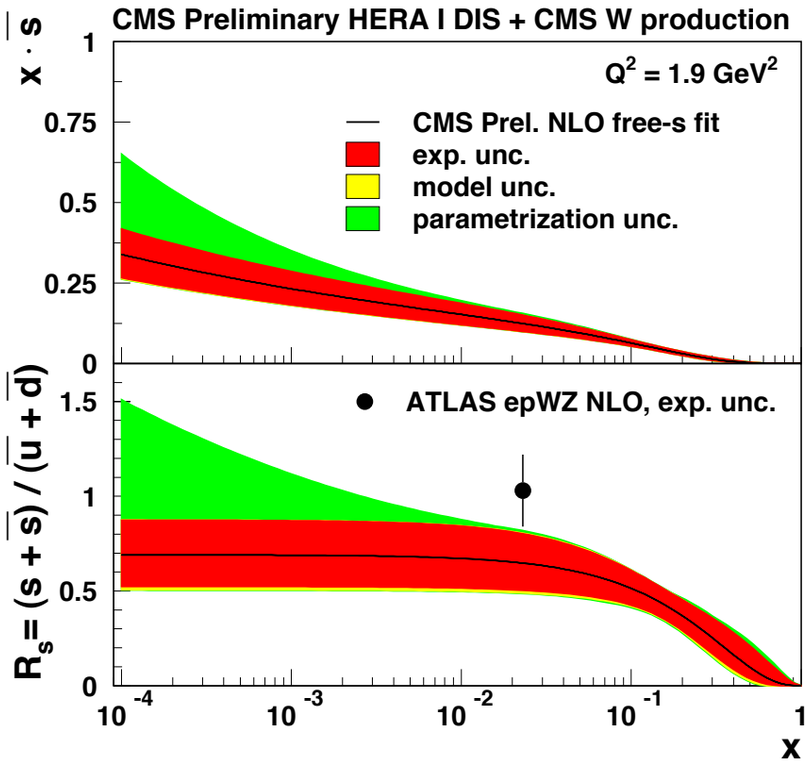
CMS-SMP-12-021 ⇒ *see talk R. Placakyte (SMP)*

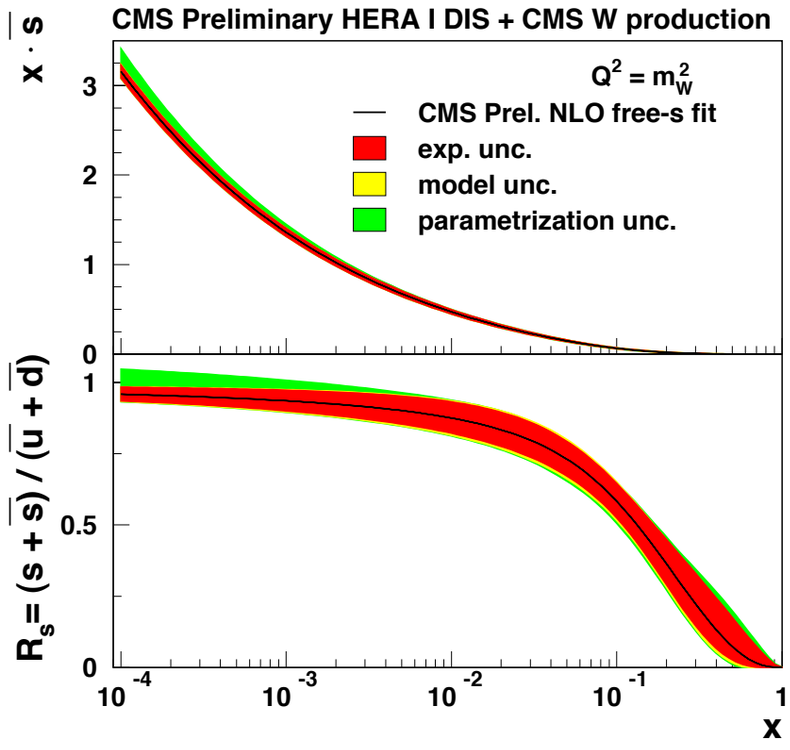


Associated W+c production in pp collisions probes strange quark in the proton directly at LO

QCD analysis at NLO performed using HERAFitter, including

- HERA I combined DIS data *[JHEP 1001:109 (2010)]*
- Muon charge asymmetry in W production at 7 TeV *[CMS-SMP-12-021 (in the publication procedure)]*
- Differential cross sections of associated W+c production at 7 TeV *[CMS, arXiv:1310.1138]*





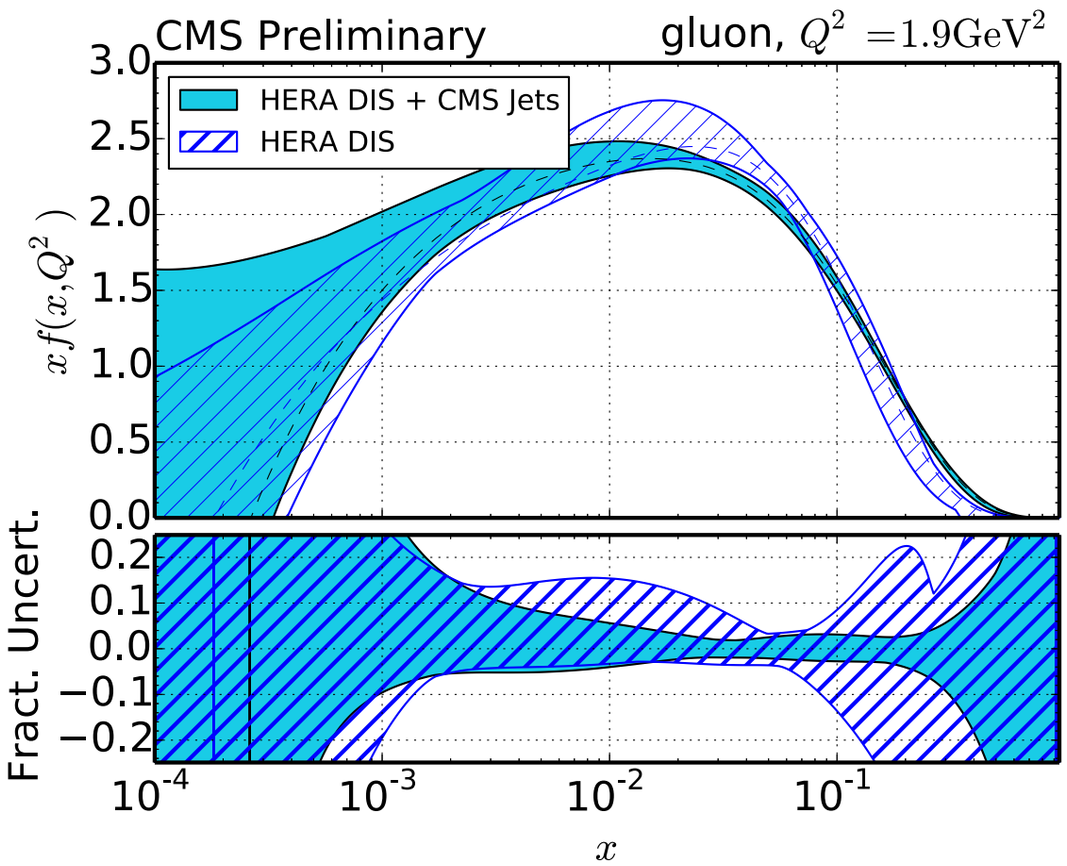
- Consistent with ATLAS epWZ *[PRL 109 (2012) 012001]*
- Strangeness suppression κ_S in good agreement with NOMAD measurement [*Nucl.Phys. B876 (2013) 339*]

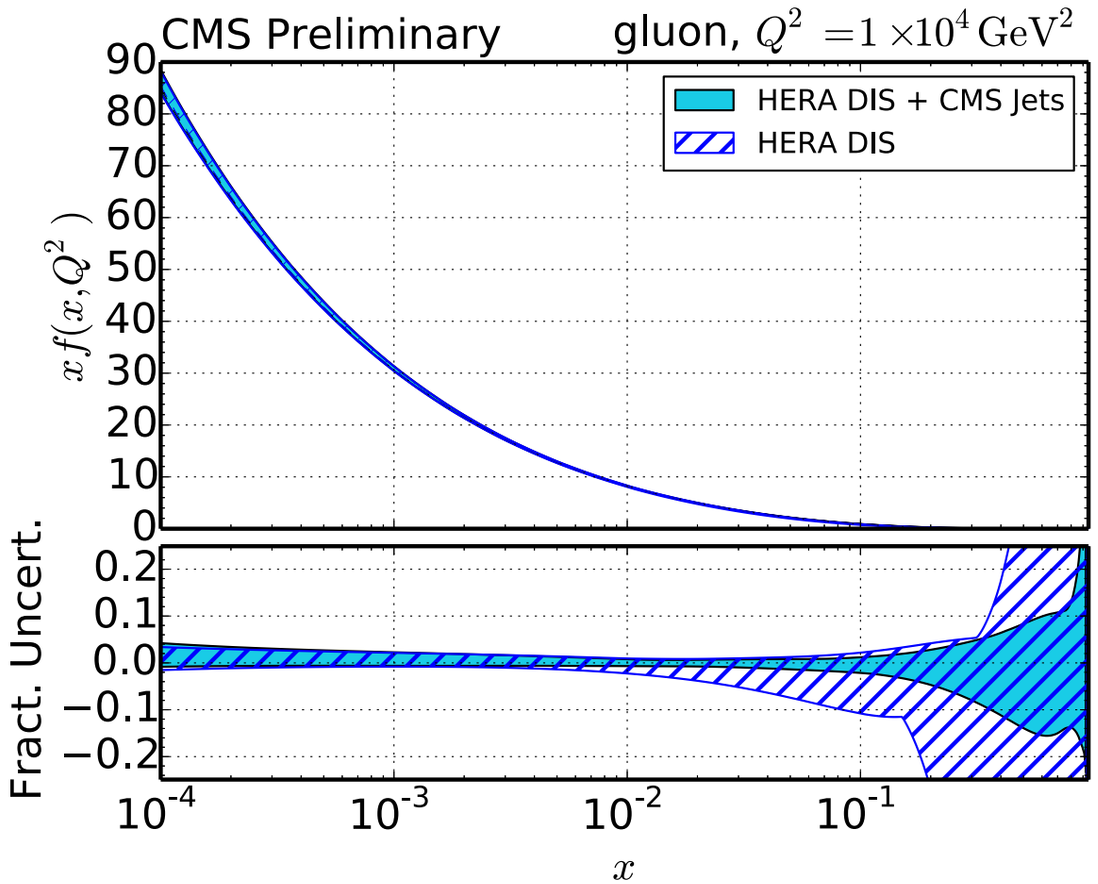
Direct constraints on the strange quark distribution using collider data only

Improved constraints on the gluon at high x and α_S using CMS jet data

CMS PAS SMP-12-028 ⇒ *see talk G. Sieber (SMP)*

QCD analysis at NLO [CMS PAS SMP-12-028] performed using HERAFitter, including
- HERA I combined DIS data *[JHEP 1001:109 (2010)]*
- Inclusive jet production at 7 TeV, 5 fb^{-1}, anti-kt R=0.7 *[CMS, Phys. Rev. D 87 (2012) 12002]*





Improved constraints on the PDFs, in particular gluon at high x

Simultaneous determination of PDF and $\alpha_s(M_Z) = 0.1192^{+0.0017}_{-0.0015}(\mathrm{exp})$
the uncertainty accounts for the experimental uncertainties of the data and the NP uncertainties

Summary

Proof of concept:

- Fast implementation of data and theoretical calculations into the global analysis tools
- Efficient exchange analyzers - tool developers - theorists
- Individual results published within experiments, theory groups, or by the tool developers
- Many ongoing activities, more PROSA-related publications expected 2014

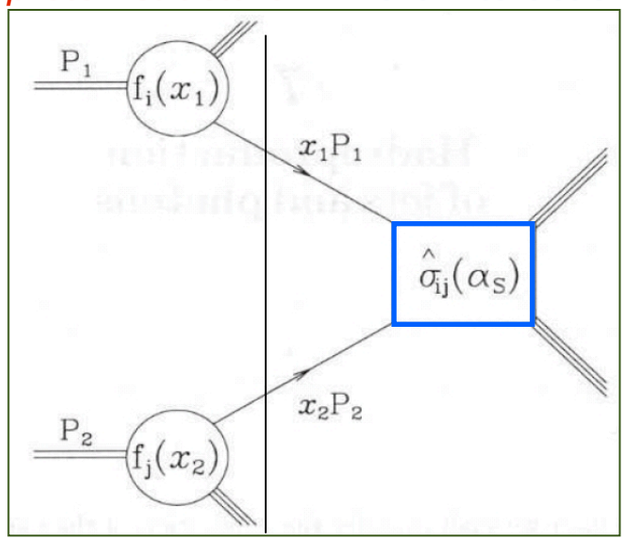
Many experimentalists and theory groups interested and contributing

Back Up Slides

Proton Structure Analyses in Hadronic Collisions

Cross sections of the processes in proton-(anti)proton collisions

proton structure *hard interaction*



Factorization: PDF⊗ hard sub-process ME

$$\sigma(s) = \sum_{i,j} \int_{\tau_0}^{1} \frac{d\tau}{\tau} \cdot \frac{dL_{ij}(\mu_F^2)}{d\tau} \cdot \hat{s} \cdot \hat{\sigma}_{ij}$$

calculable in pQCD

$$\tau \cdot \frac{dL_{ij}}{d\tau} \propto \int_0^1 dx_1 dx_2 (x_1 f_i(x_1, \mu_F^2) \cdot x_2 f_j(x_2, \mu_F^2)) + (1 \leftrightarrow 2)\delta(\tau - x_1 x_2)$$

PDF PDF

Participating members (countries in alphabetic order)

China: Shandong University Jinan,

France: CPP Marseille, LAPTH Annecy, LPSC Grenoble

Germany: Universities of Aachen (RWTH), Berlin (Humboldt), Bonn, Freiburg, Hamburg, Heidelberg, KIT, Mainz, MPI Munich, Munich TU, Wuppertal, Würzburg, DESY Hamburg/Zeuthen,

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