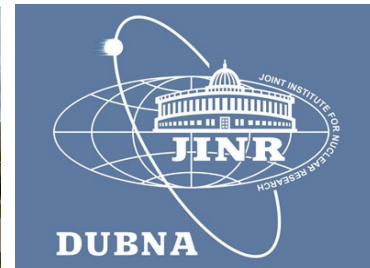
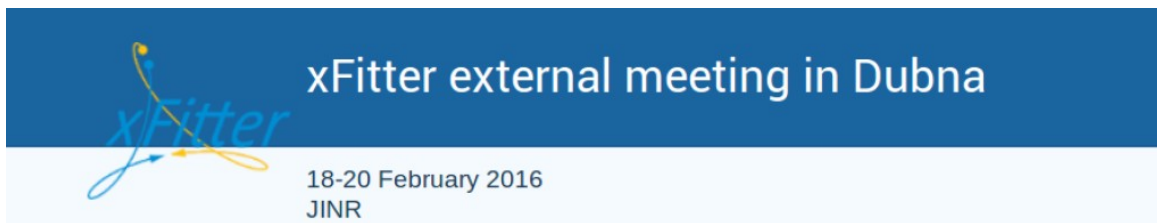


xFitter Performance in CMS: physics analyses and tools

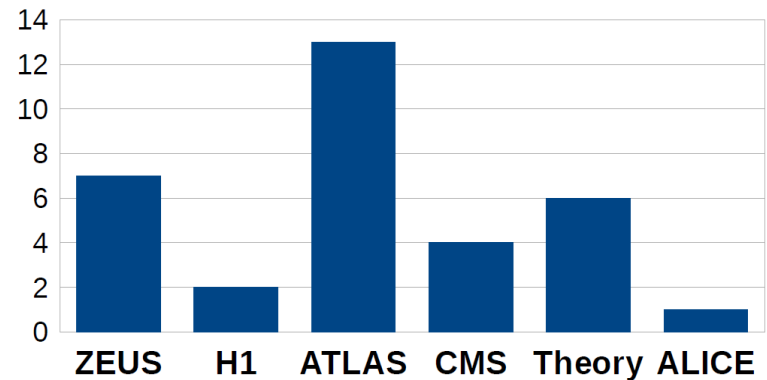




xFitter Related Activities and Person-Power in CMS

xFitter project connection to CMS collaboration

Person-power: [convener and 3 developers](#)



→ [connected to PDF@CMS forum](#)

convener and one of developers are conveners of the forum, other PDF@CMS conveners strongly support xFitter project

→ [physics analyses and data \(W analyses, inclusive jets and TMDs\)](#)

→ [tool development \(OpenQCDRAD, FastNLO, DiffTop, HATHOR \(HVQMNR\)\)](#)



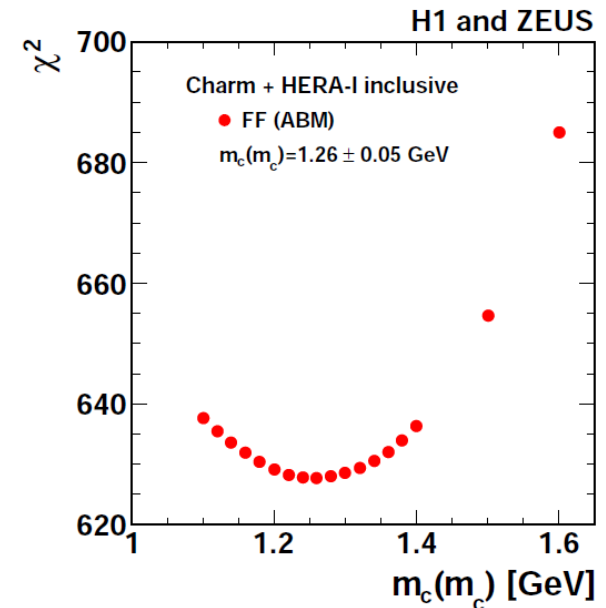
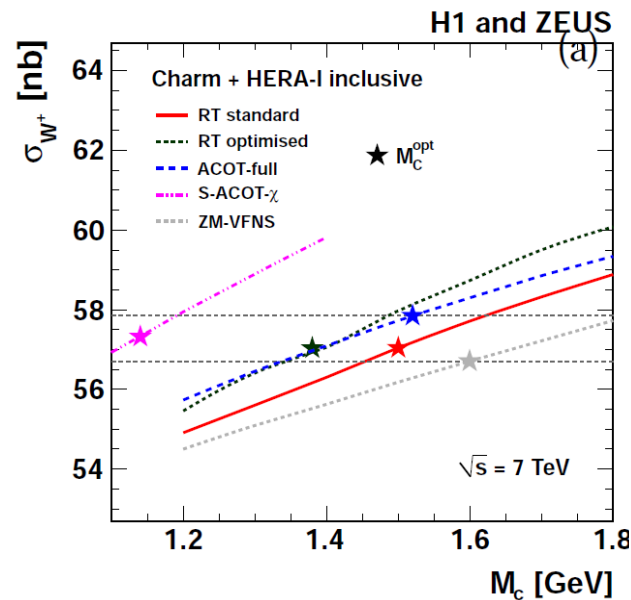
Physics Analyses in CMS using xFitter

process	sensitivity to PDFs	QCD analysis with xFitter
W asymmetry	→ quark flavour separation	✓
W+c production	→ strange quark	✓
W and Z production (differential)	→ valence quarks	
Drell-Yan (DY): high invariant mass	→ sea quarks, high-x	
Drell-Yan (DY): low invariant mass	→ low-x	
W,Z +jets	→ gluon medium-x	
Inclusive jet and di-jet production	→ gluon and $\alpha_s(M_Z)$	✓
Direct photon	→ gluon medium, high-x	
ttbar, single top	→ gluon and $\alpha_s(M_Z)$	✓

QCD analysis of charm production in DIS and impact W and Z boson production at LHC

Eur. Phys. J. C73 (2013) 2311

- various heavy flavour schemes and an impact on DY cross sections at LHC studied
- running mass of charm quark determined (via implementation to OpenQCDRAD in xFitter)



HERA charm measurements help to reduce uncertainties of predictions for the LHC

→ this study is possible to perform only with xFitter

W asymmetry probe valence quarks and PDF ratios
 W+charm provides direct sensitivity to strange quark

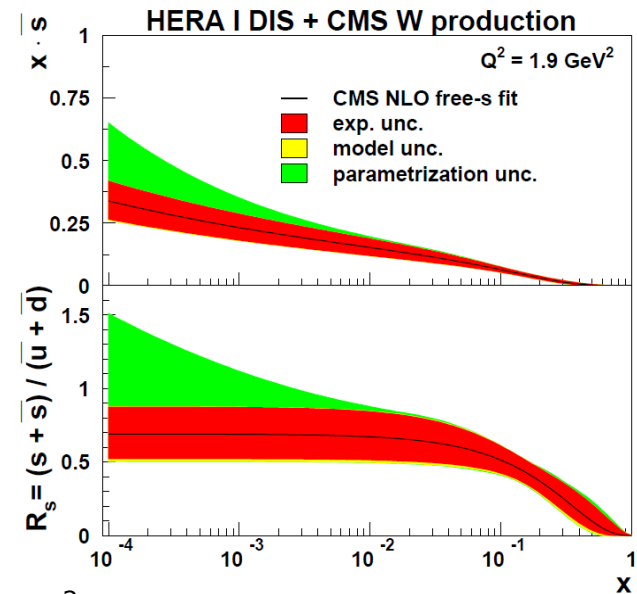
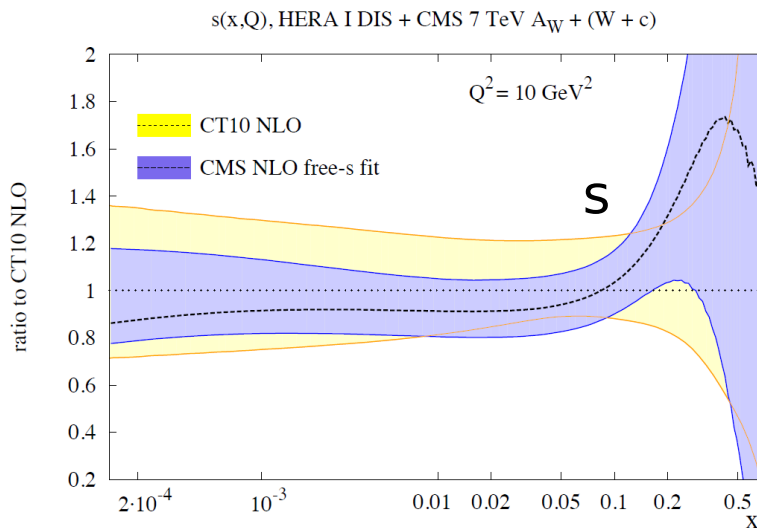
$$A_W = \frac{W^+ W^-}{W^{+c} W^{-c}} \approx \frac{u_v - d_v}{u_v + d_v + 2u_{sea}}$$

W lepton charge asymmetry and W+charm at 7 TeV

PRD 90 (2014) 034004

QCD analysis at NLO with HERA I combined DIS data

→ test of joint sensitivity of lepton charge asymmetry and W+c data to the strange content of the proton



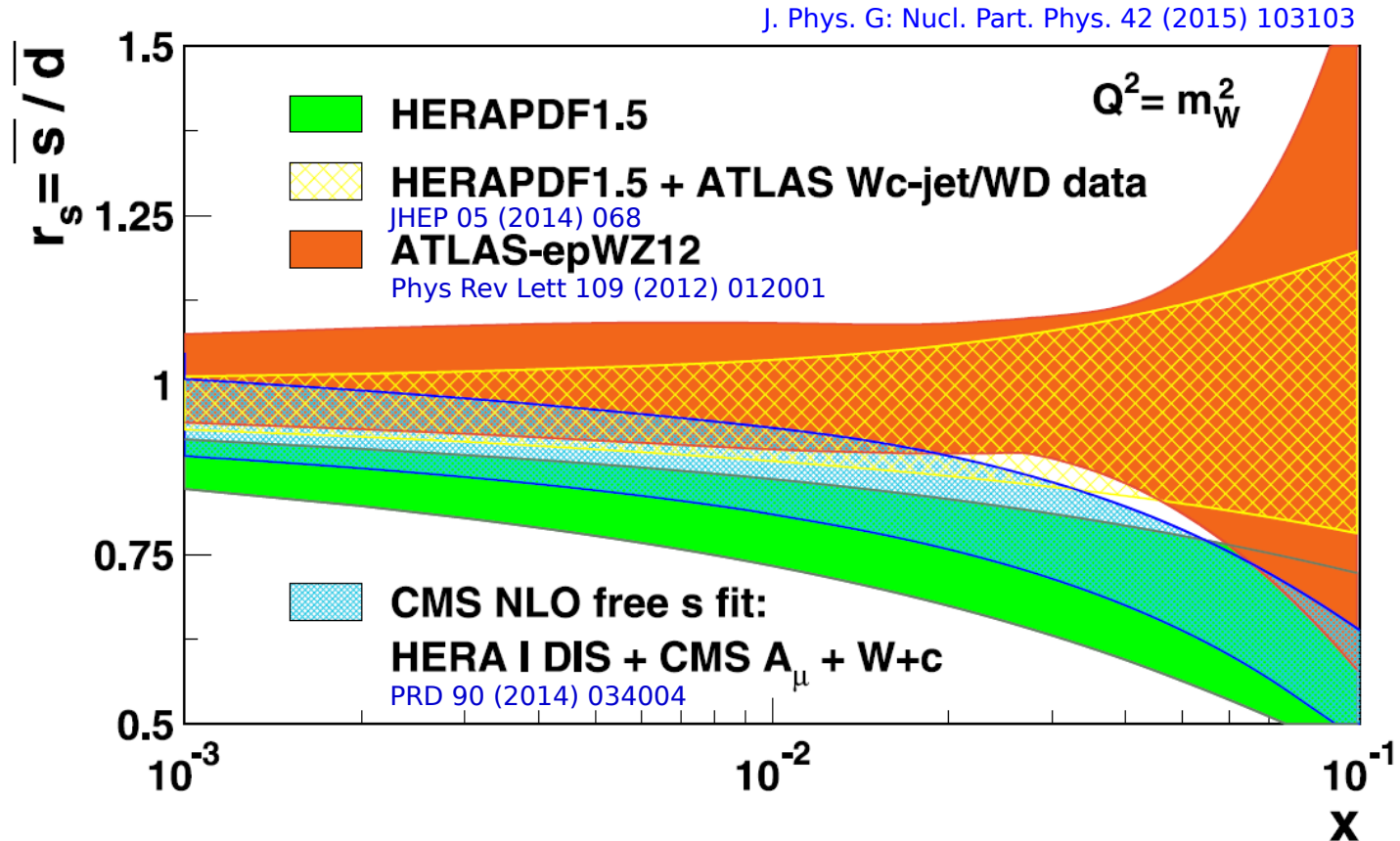
The determined strangeness suppression K_s (20 GeV^2):

$$K_s = 0.52^{+0.12}_{-0.10} (\text{exp.})^{+0.05}_{-0.06} (\text{model})^{+0.13}_{-0.10} (\text{parametrization})$$

NOMAD K_s (20 GeV^2) = 0.59 ± 0.019 Nucl.Phys. B876(2013) 339

xFitter s-quark from LHC

Comparison of the ratio of s over d ratio determined by ATLAS and CMS



Strange fraction determined in CMS is lower than in ATLAS but results are still consistent

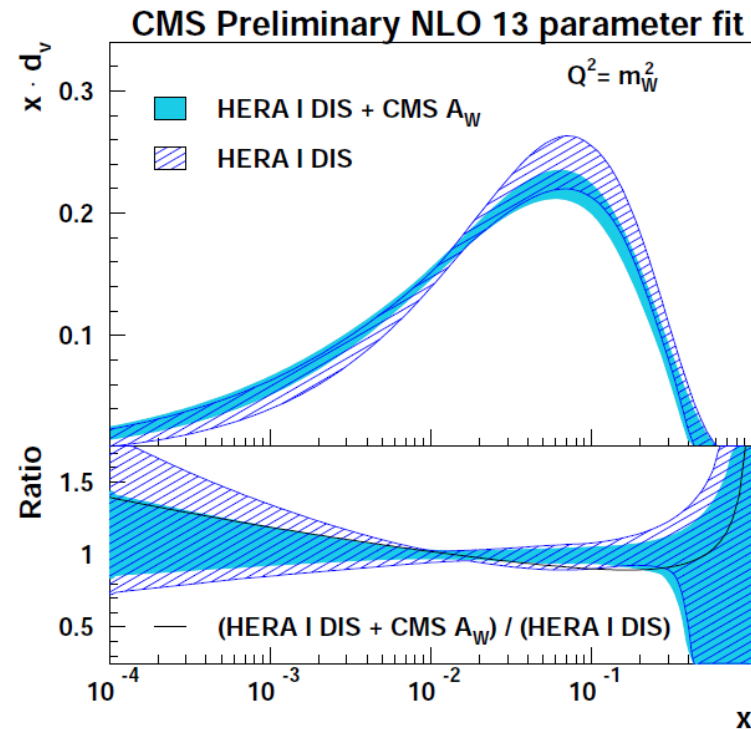
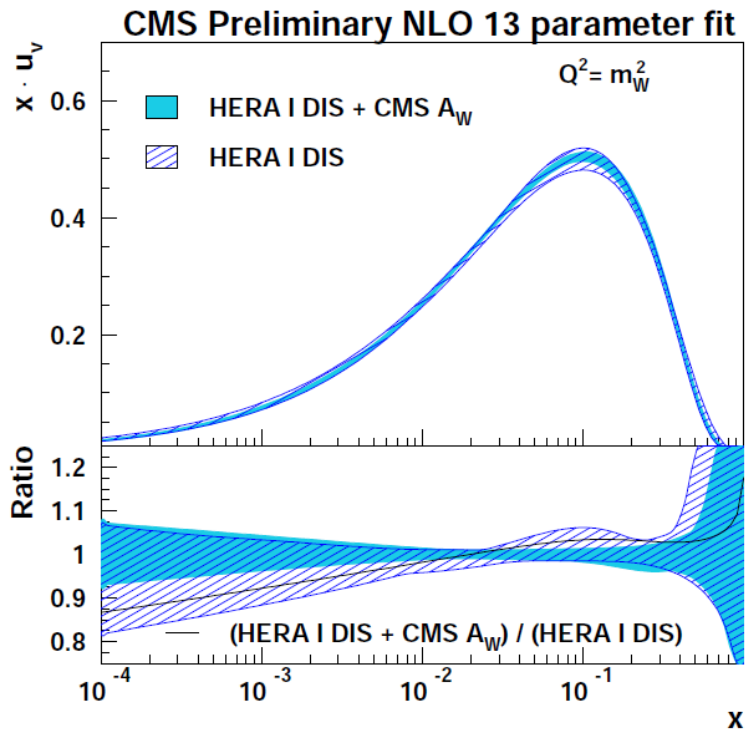
NOTE : all analyses performed with xFitter

CMS W Asymmetry at 8 TeV

CMS W muon charge asymmetry measurement

QCD analysis at NLO (preliminary) and NNLO

CMS-PAS SMP-14-022



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

Change of PDF shape, improved constraints on the valence distributions

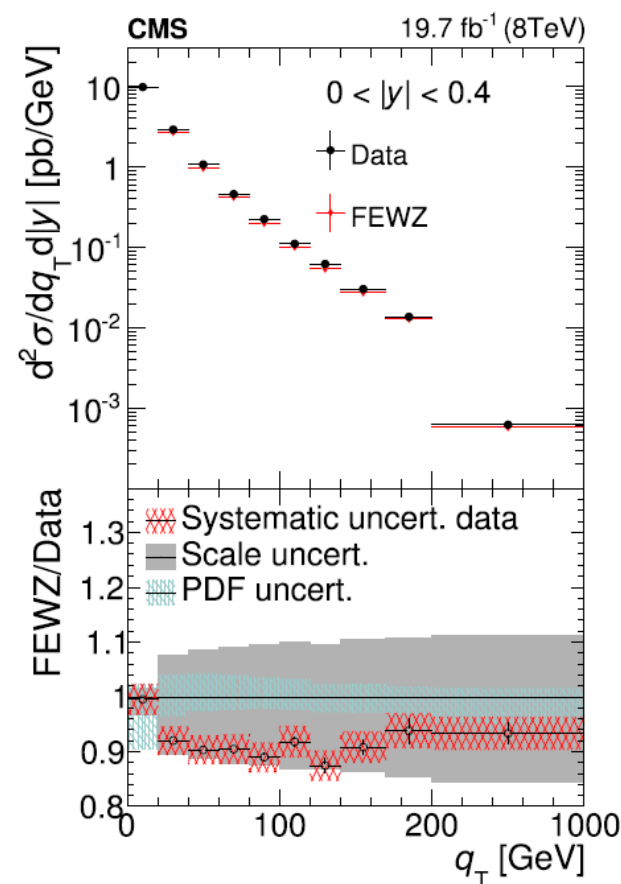
xFitter Z production (P_T)

CMS has studied the P_T spectrum in Z rapidity bins

PLB 749 (2015) 187

- low P_T region dominated by the emission of soft partons (resummation and shower models)
- high P_T region: quark-gluon scattering (PDFs)

Valuable data for various purposes (e.g. W mass, PDFs), currently limited by precision in theory



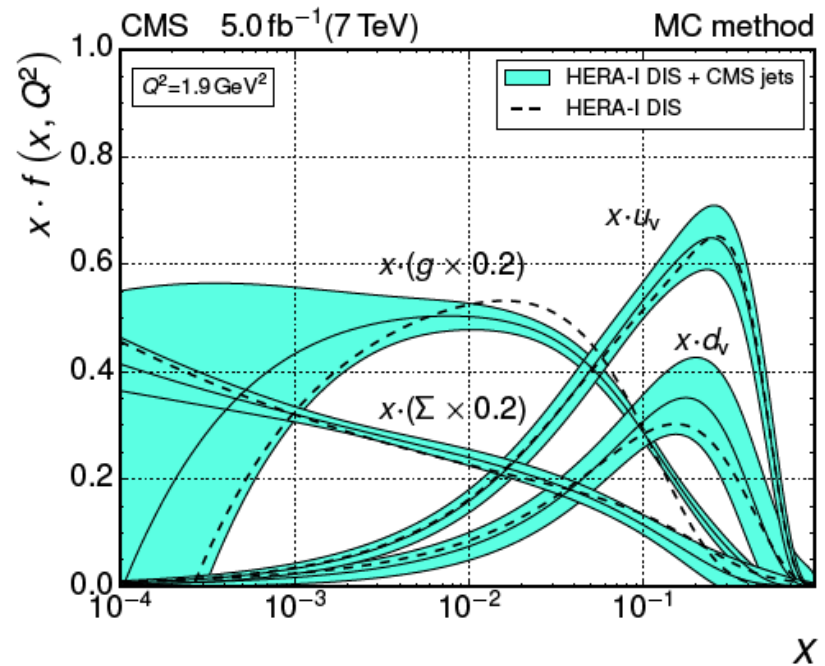
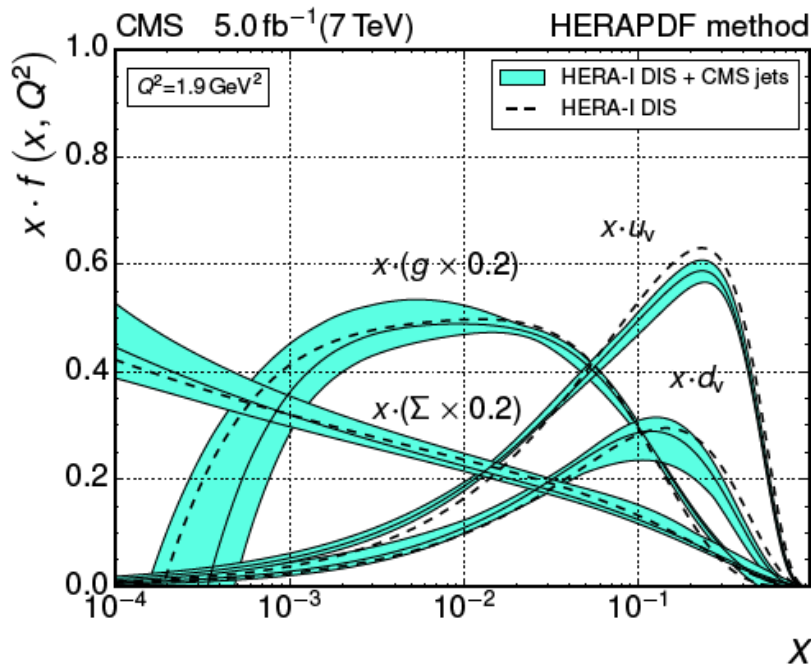
→ NLO QCD analysis performed with xFitter by CMS student Rajdeep Chatterjee (not public yet)

Inclusive Jet Production at 7 TeV

Inclusive jet measurements at LHC provide information about hard QCD, PDFs, strong coupling constant α_s

QCD analysis at NLO with (HERA I and) CMS inclusive jet data at 7 TeV

EPJC (2015) 75:288



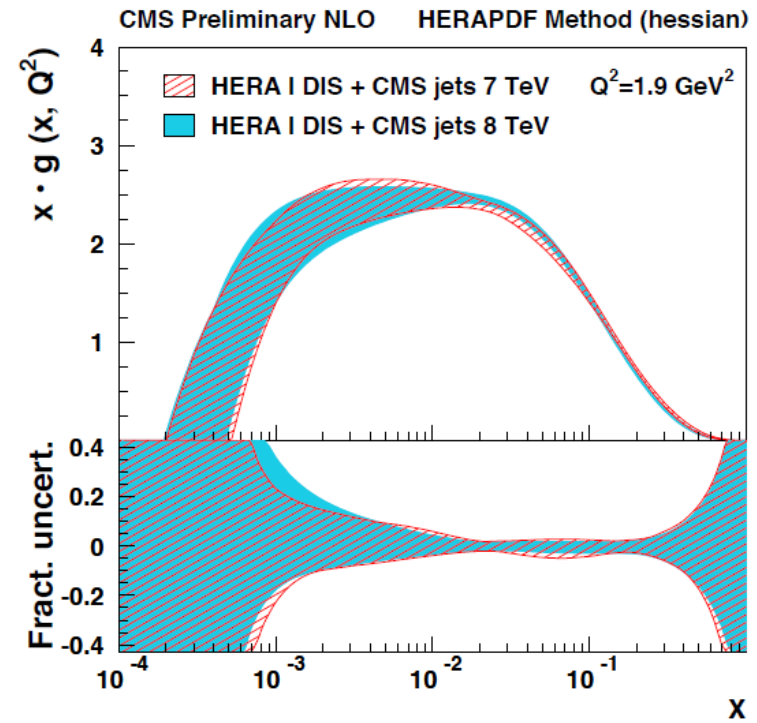
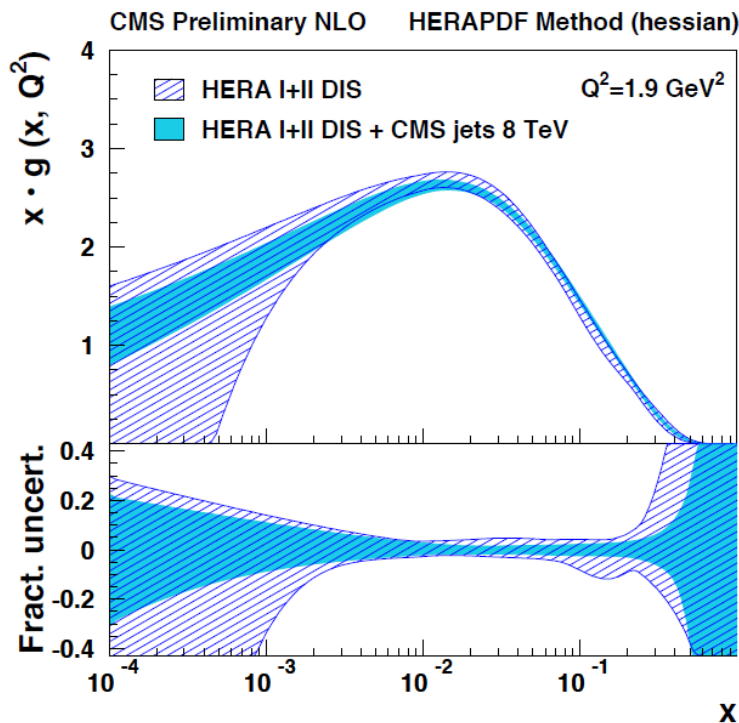
→ to study more flexible parametrisation, the MC method with data-driven regularisation was used for the first time (using xFitter)

Inclusive Jet Production at 8 TeV

Preliminary inclusive CMS jet measurement at 8 TeV

QCD analysis at NLO with (HERA I+II and) CMS inclusive jet data at 8 TeV

CMS PAS SMP-14-001



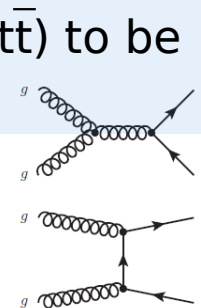
→ the QCD analysis performed with xFitter

There are new preliminary inclusive jet results from 2.76 TeV (CMS-SMP-14-017) and 13 TeV (CMS-SMP-15-007)

xFitter Top Quark at LHC

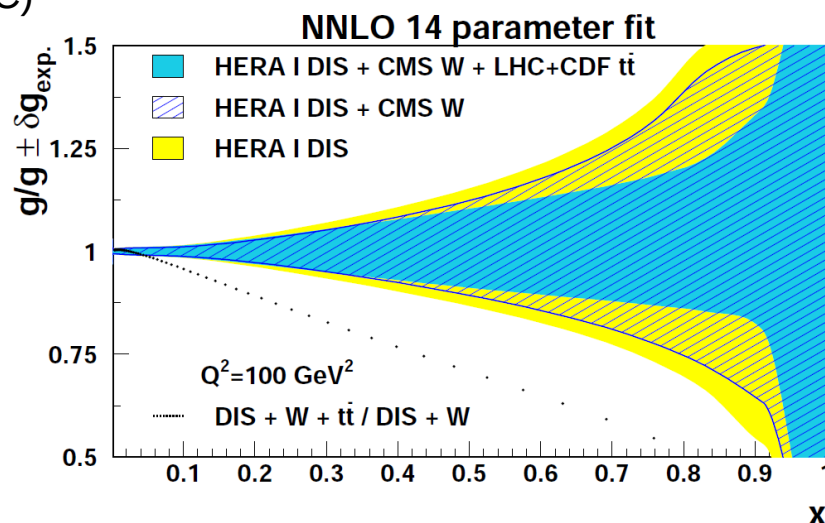
LHC provides possibility for high statistics of top quark pairs ($t\bar{t}$) to be measured (gluon-gluon fusion is a dominant sub-process)

→ probe of high- x gluon (high correlation between gluon, α_s and top quark mass)



Differential $t\bar{t}$ production cross section calculations at approximate NNLO

→ QCD analysis with ATLAS and CMS $t\bar{t}$ data (together with HERA, Tevatron and W production data at LHC)



JHEP 1501 (2015) 082

→ significant change of the shape of the gluon distribution observed

→ DiffTop has been implemented by Marco Guzzi (CTEQ/CMS) and Katerina (CMS)



xFitter Physics Cases: Transverse Momentum Dependent PDFs

DIS inclusive processes in ep and fixed target
Alternative to DGLAP formalism

→ at small- x and small- Q^2 DGLAP dynamics may be modified by non-perturbative QCD effects

Transverse Momentum Dependent PDFs (uPDFs)

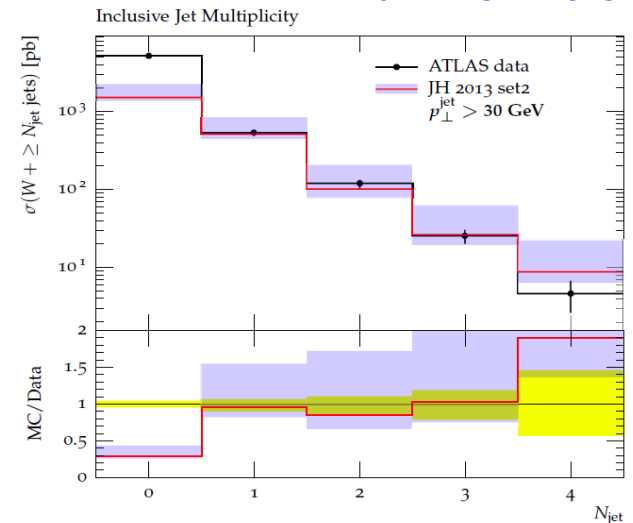
→ based on the kT-factorisation (CCFM) evolution

→ valid for inclusive DIS and for particular hadron-hadron scattering processes (heavy flavor, VB, Higgs production)

Transverse momentum dependent (TMD) parton distribution functions:
status and prospects

[Acta Phys Polon B 46 \(2015\) 2501](#)

[arXiv:1312.7875](#)



Within xFitter used to determine unintegrated TMD gluon density and ongoing work on the valence quark inclusion → [see Ola's/Hannes/Francesco talk tomorrow](#)

xFitter Tools in xFitter: FastNLO

Often perturbative higher-order calculations are extremely time consuming
→ not possible to include into PDF fits

solution: fast grid techniques

- based on assumption that PDF can be approximated by a set of the interpolation functions
- after first time (full) calculation, technique with interpolation functions can be used for the fast theory prediction calculations (for any PDF)

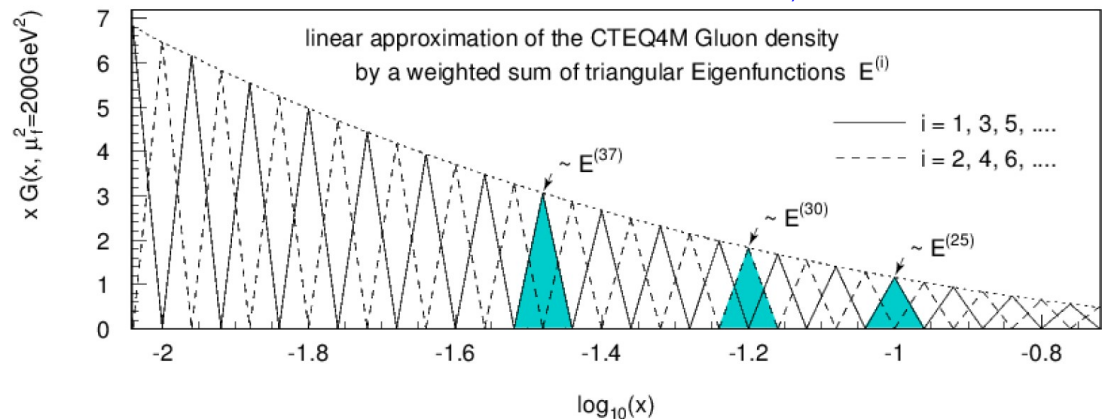
Currently available tools: **FastNLO** [Eur.Phys.J. C19 , 289 \(2001\), hep-ph/0609285](#)

and **APPLGRID** [hep-ph/0510324, arXiv:0911.2985](#)

M. Wobisch, DESY-THESIS-2000-049

PDFs ($f_{a/h}$) approximated by linear combination of the eigenfunctions $E^{(i)}$:

$$f_{a/h}(x) \simeq \sum_i f_{a/h}(x_i) E^{(i)}(x)$$



FastNLO is interfaced into xFitter thanks to Klaus (CMS) and Daniel (Atlas)
→ see Klaus talk tomorrow

The logo for xFitter, featuring a stylized 'x' with blue and yellow lines and a dot, followed by the text 'xFitter' in blue.

xFitter in CMS: summary

xFitter connected to CMS collaboration via

- man-power (currently one of conveners and 3 developers)
- QCD analyses (W and jet production)
 - data and theory files for published QCD analyses are available in xFitter package
- tool development: OpenQCDRAD, FastNLO, DiffTop, HATHOR (HVQMNR)

There are many new physics analyses results with Run I and II data coming out (differential DY, asymmetries, inclusive jets, di- and three-jets, ratios, ttbar, etc)

→ *lack of person power for QCD analyses in CMS and support of xFitter*

xFitter W and Z production at LHC

Z and W production at LHC

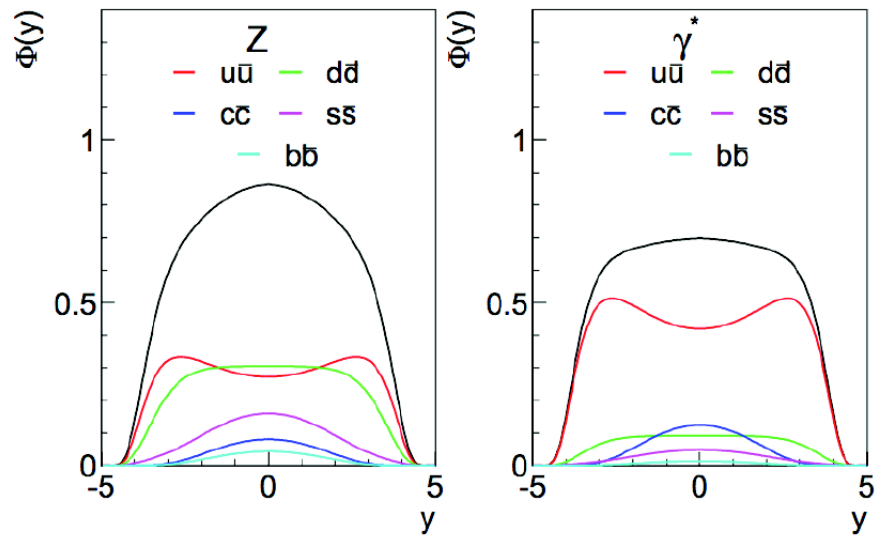
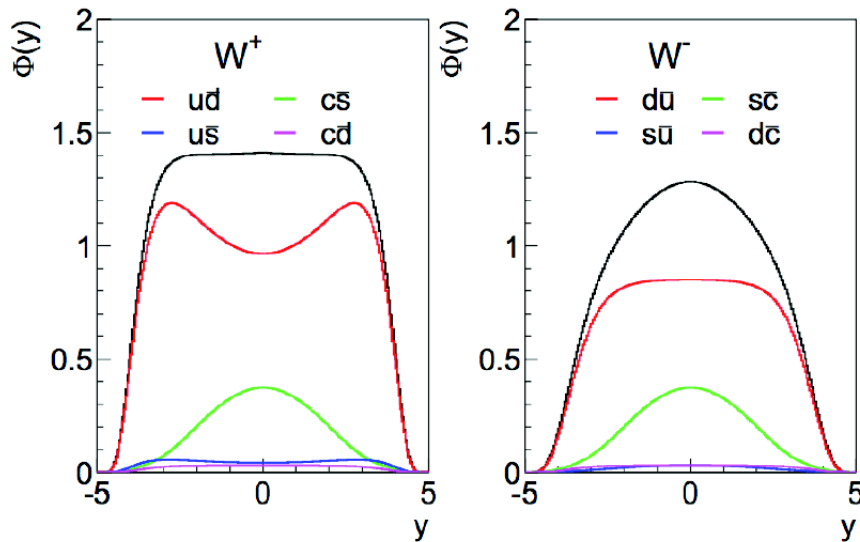
- probe different flavour combinations
- potential to improve quark PDFs

$$W^+ \approx 0.95(u\bar{d} + c\bar{s}) + 0.05(u\bar{s} + c\bar{d})$$

$$W^- \approx 0.95(d\bar{u} + s\bar{c}) + 0.05(d\bar{c} + s\bar{u})$$

$$Z \approx 0.29(u\bar{u} + c\bar{c}) + 0.37(d\bar{d} + s\bar{s} + b\bar{b})$$

$$\gamma^* \approx 0.44(u\bar{u} + c\bar{c}) + 0.11(d\bar{d} + s\bar{s} + b\bar{b})$$



(A.Glazov/V.Radescu)

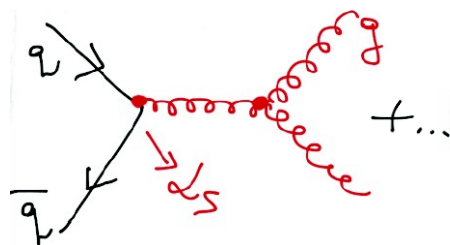
→ u and d quarks dominate for W, all flavours contribute to Z

xFitter Jet Production at LHC

Jet production at LHC

- provides information about hard QCD, PDFs, strong coupling constant α_s
 - PDFs and α_s depend on scale of the process → P_T of the jet

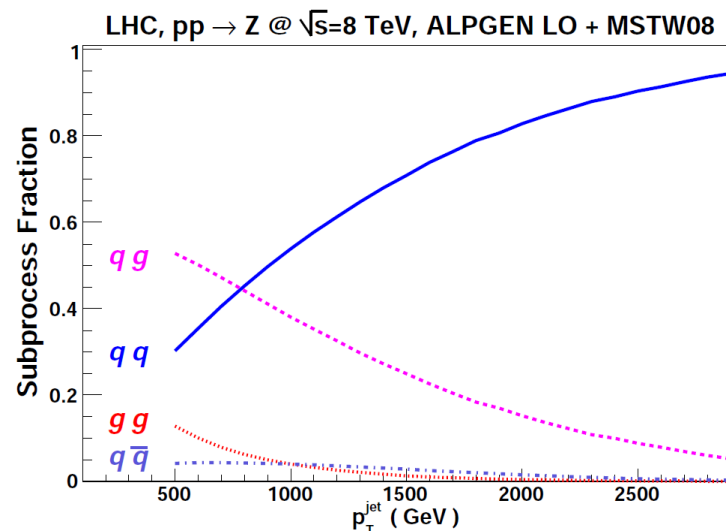
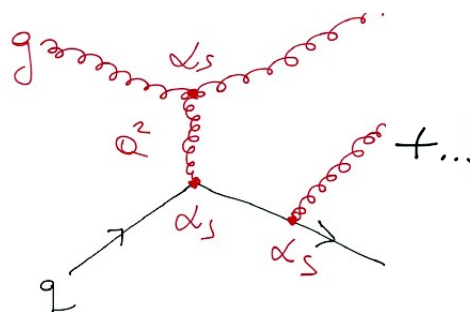
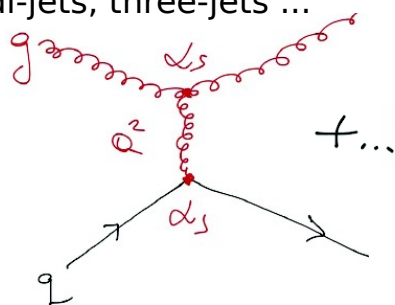
Inclusive jet production at LO



(G. Dissertori)

JHEP 08 (2012) 101

di-jets, three-jets ...



... and ratios (smart way of canceling large part of e.g. jet scale uncertainty)

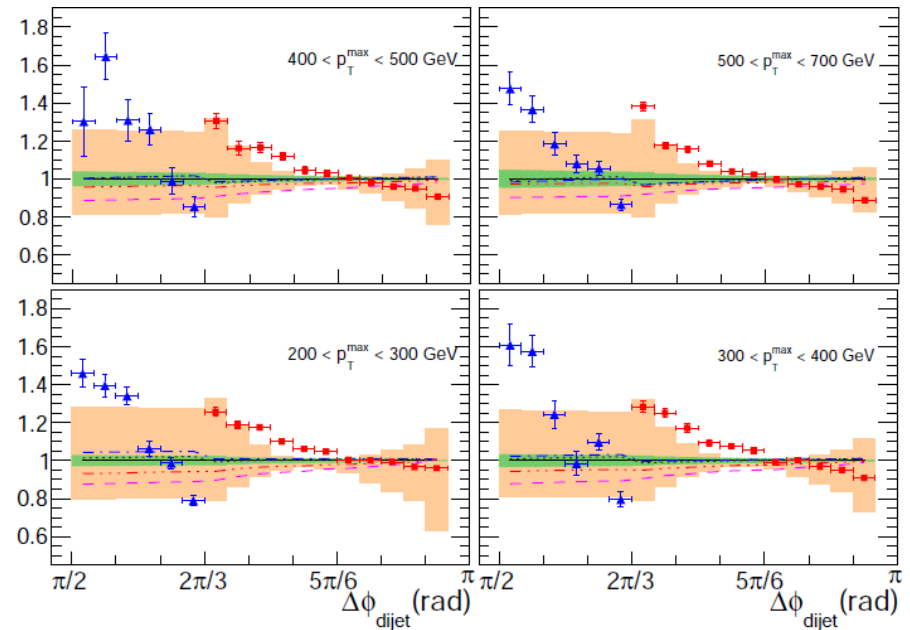
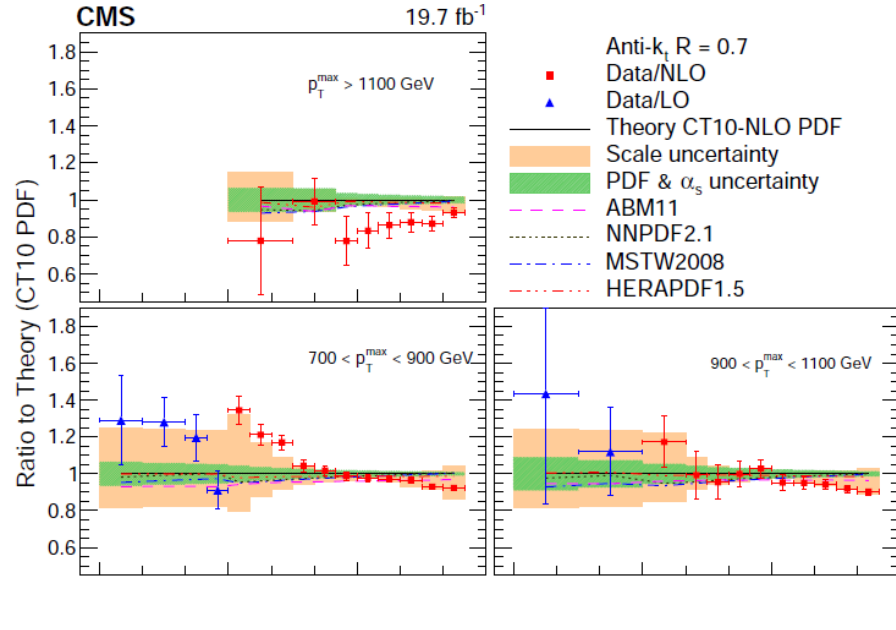
- LHC jet data provide constrains in high-x region
- at high scales may reveal new physics (depend how well gluon at high x is known)

xFitter Di-jet Azimuthal Decorrelation Measurement

Recent di-jet azimuthal decorrelation measurements from CMS at 8 TeV

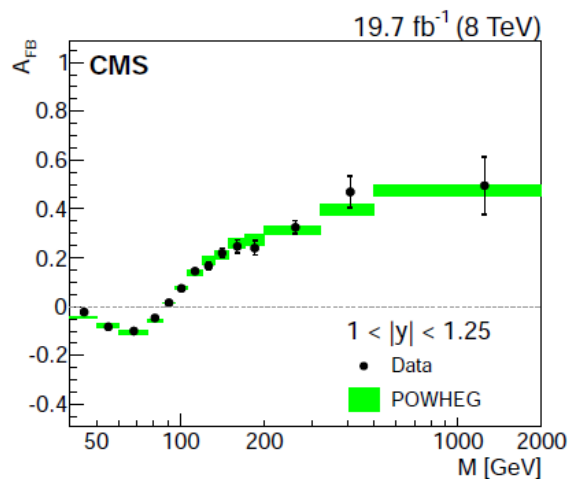
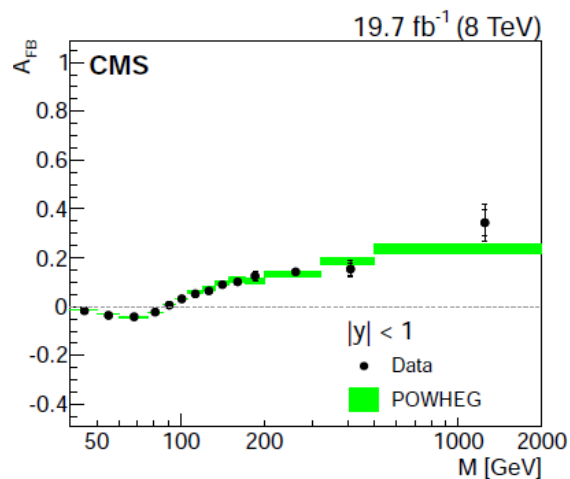
→ comparison with different PDFs (ratio to CT10 NLO)

arXiv:1602.04384



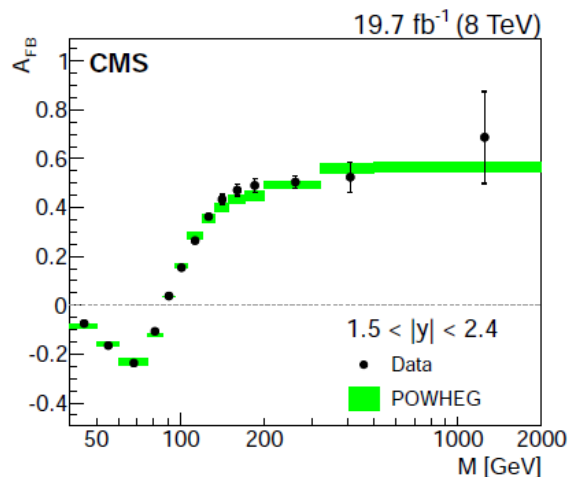
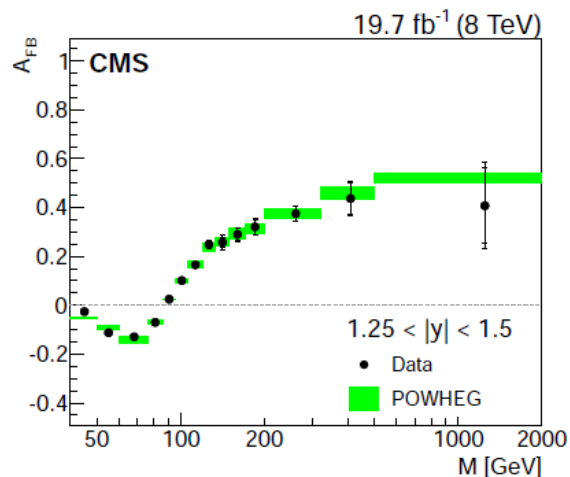
xFitter AFB measurements

AFB can also be used to extract the effective weak mixing angle $\sin 2\theta(m_Z)$ as well as the u and d quark weak couplings



[arXiv:1601.0476](https://arxiv.org/abs/1601.0476)

5 times more events than in 7 TeV data
→ measurement extended to high-mass region



xFitter Impact of LHCb Heavy Flavour Data to PDFs

LHCb heavy-flavour data impose additional constraints on the gluon and the sea-quark distributions at low x

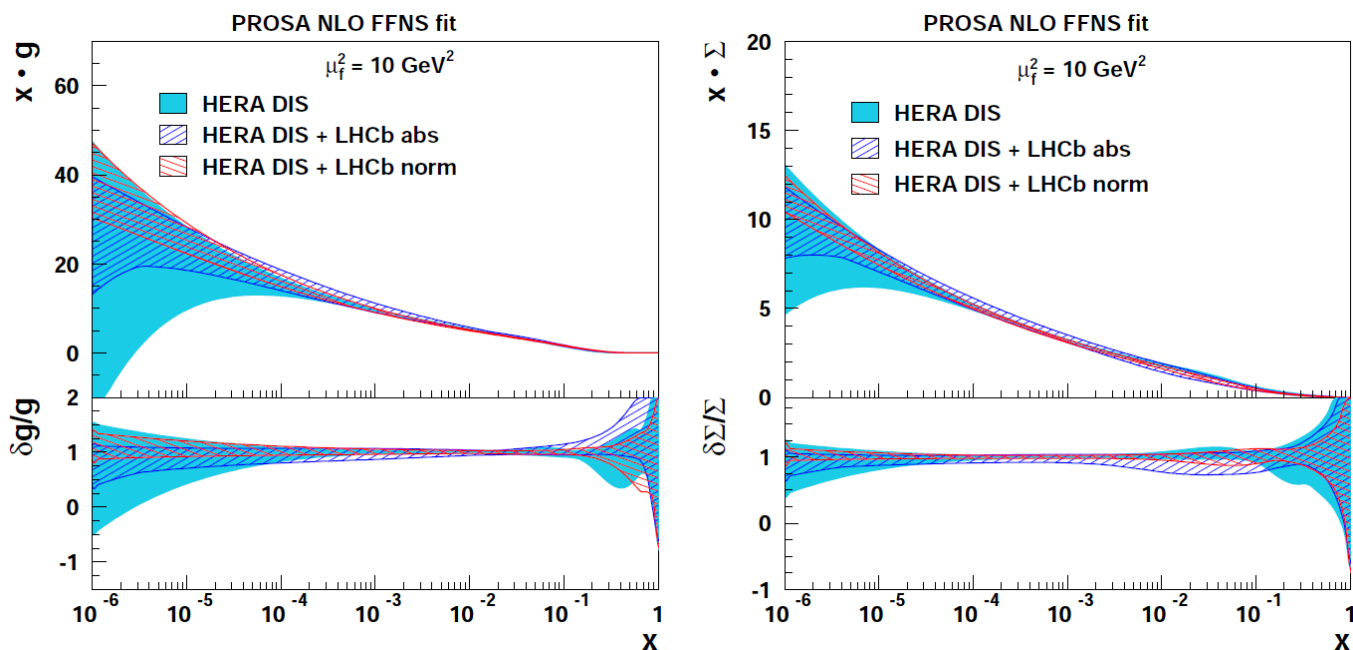
→ first time used to constrain PDFs

Nucl. Phys. B871 (2013) JHEP08 (2013) 117

→ NLO QCD analysis (together with HERA data) with the fixed-flavour number scheme

→ absolute and normalised cross sections

Eur.Phys.J. C75 (2015) 8, 396



→ significant reduction of the gluon uncertainty at very low x ($x \sim 5 \times 10^{-6}$)