



HERAFitter

An Open Source QCD Fit Framework

Voica Radescu
(DESY)



PDF4LHC meeting

chaired by Albert De Roeck (CERN)

Wednesday, 17 April 2013 from **09:00** to **19:00** (Europe/Zurich)
at **CERN (4-3-006 - TH Conference Room)**



Current status on PDFs

◆ A list of active PDF groups:

	MSTW08	CTEQ6.6/CT10	NNPDF2.1/2.3	HERAPDF1.0/1.5	ABKM09/ABM11	GJR08/JR09
PDF order	LO, NLO, NNLO	LO, NLO, NNLO	LO, NLO, NNLO	NLO, NNLO	NLO, NNLO	NLO, NNLO
HERA DIS	✓ (old)	✓ (old/new)	✓ (new)	✓ (new/newest)	✓ (new)	✓ (new)
Fixed target DIS	✓	✓	✓	-	✓	✓
Fixed target DY	✓	✓	✓	-	✓	✓
Tevatron W, Z	✓	✓	some	-	some	some
Tevatron jets	✓	✓	✓	-	✓	✓
LHC	-	-	-/W,Z+jets	-	-	-
HF Scheme	RTGMVF	SACOT GMVFN	FONLL GMVFN	RT GMVFN	BMSN FFNS	FFNS
Alphas (NLO)	0.120	0.118(f)	0.119	0.1176(f)	0.1179	0.1145
Alphas (NNLO)	0.1171	0.118(f)	0.1174	0.1176(f)	0.1135	0.1124

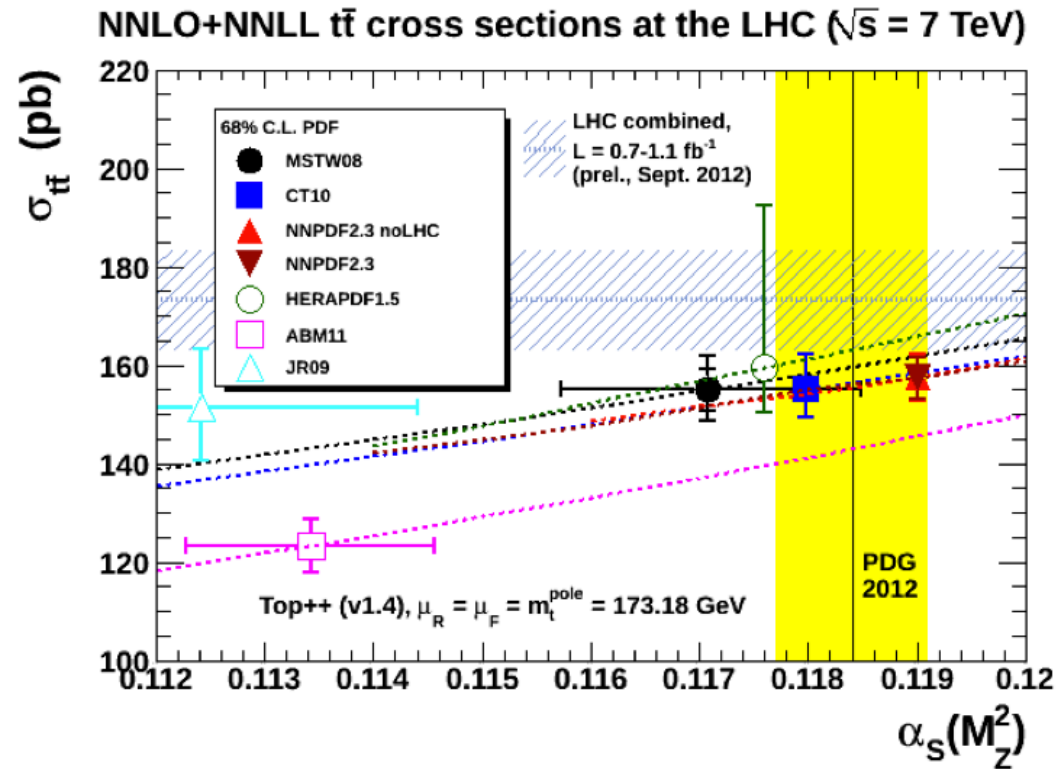
The analyses differ in many areas:

- different treatment of heavy quarks
- inclusion of various data sets and account for possible tensions
- different alphas assumption



Motivation for a QCD platform for benchmarking

- ◆ Current benchmarking of PDFs:



[G. Watt, Nov 2012]

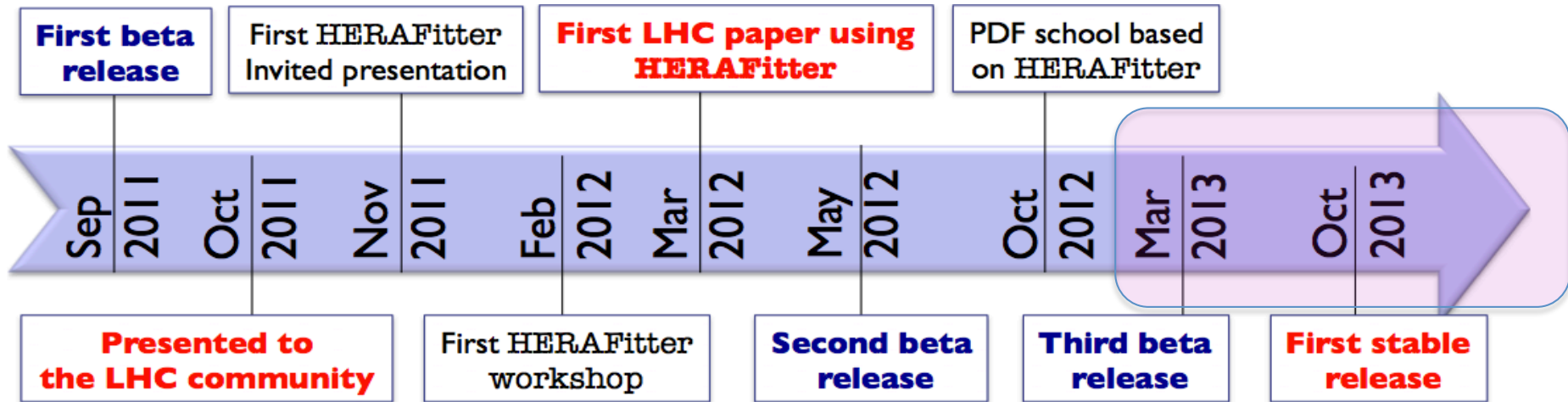
- ◆ In addition, current high- x searches are dominated by PDF uncertainties (20%)
[ATLAS-CONF-2012-129]
- ◆ Would help to reduce the PDF uncertainty arising from difference among PDFsets



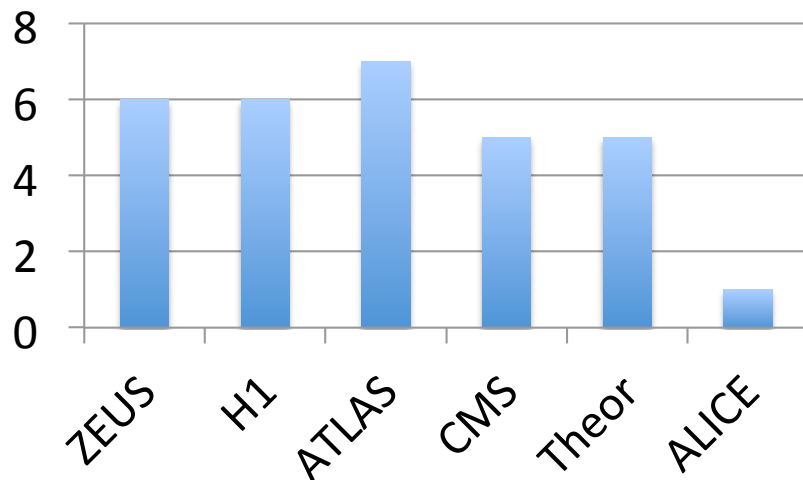
HERAFitter QCD platform



- ◆ HERAFitter Package is an open source QCD platform ready to analyse new data



- ◆ Statistics of developers team



The releases are publicly accessed via:

<https://www.herafitter.org>



VoicaRadescu Settings Logo

HERAFitter

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- HERAFitter**

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- Attachments

More Actions:

HERAFitter

Welcome to HERAFitter

The proton parton distribution functions (PDFs) are essential for precision physics at the LHC and other hadron colliders. The determination of the PDFs is a complex endeavor involving several physics process. The main process is the lepton proton deep-inelastic scattering (DIS), with data collected by the HERA ep collider covering a large kinematic phase space needed to extract PDFs. Further processes (fixed target DIS, ppbar collisions etc.) provide additional constraining powers for flavour separation. In particular, the precise measurements obtained or to come from LHC will continue to improve the knowledge of the PDF. HERAFitter project is an open source QCD fit framework ready to extract PDFs and assess the impact of new data which we would like to present here. The framework includes modules allowing for a various theoretical and methodological options, capable to fit a large number of relevant data sets from HERA, Tevatron and LHC. This framework is already used in many analyses at the LHC.

Downloads of HERAFitter software package

☀ New HERAFitter release is publicly available. The HERAFitter releases can be accessed [HERE](#) .

HERAFitter Meetings

- **User's Meetings:** monthly meetings to enhance communication between users and developers (open access)
- **Developer's Meeting:** technical weekly meetings to ensure communication among developers (restricted access)
- **Steering Group's Meeting** (restricted access)

Developers Info (restricted to developers)

[Internal Developments](#)

Organisation

- **Conveners:** Voica Radescu, Ringaile Placakyte, Amanda Cooper-Sarkar
- **Release coordinator:** Sasha Glazov
- **Contact Persons:** Klaus Rabbertz (CMS), Bogdan Malaescu (ATLAS), Olaf Behnke (ZEUS), Cristi Diaconu (H1), Ronan McNulty (LHCb), Gavin Salam (theory)
- **Steering Group:** Voica Radescu, Ringaile Placakyte, Sasha Glazov, Amanda Cooper-Sarkar, Gavin Salam (theory), Klaus Rabbertz (CMS), Bogdan Malaescu (ATLAS), Ronan McNulty (LHCb), Olaf Behnke (ZEUS), Cristi Diaconu (H1, chair)
- **Librarians:** authors/developers of individual modules
- **Getting help:** Send email to herafitter-help@desy.de



Releases of the HERAFitter QCD analysis package

- Versioning convention: **i.j.k** with
 - **i** - stable release
 - **j** - beta release
 - **k** - bug fixes.
- The release notes can be found in this attachment: @HERAFitter_release_notes.pdf.

Date	Version	Files	Remarks
03/2013	0.3.0	@herafitter-0.3.0.tgz	latest release includes @manual-0.3.0.pdf and decoupled @theoryfiles.tgz
07/2012	0.2.1	@herafitter-0.2.1.tgz	fix release for 0.2.0
05/2012	0.2.0	@herafitter-0.2.0.tgz	added functionality for LHC users
09/2011	0.1.0	@herafitter-0.1.0.tgz	first release

Documentation

- From 0.3.0 on a manual is provided together with an example directory.
- The **README** file (accessible via the package) gives an explanation for a quick start.

Web access to SVN

- For users with a valid DESY account, the SVN repository is accessible on the web at [https://svn.desy.de](#)
- For users without DESY account, the SVN repository is accessible on the web at <https://herafitter-user@desy.de> account and PDFfits password.

Doxygen Documentation

- The doxygen documentation is located [here](#)

Links to external packages

External packages that could be run with HERAFitter via configuration flags can be accessed for convenience [HERE](#).

HERAverager data combination package

Information can be accessed here <https://wiki-zeuthen.desy.de/HERAverager>.

Subscription

We encourage users to subscribe to mailing list for news and updates related to the HERAFitter webpage. (average rate of e-mails is once a month), please contact herafitter-help@desy.de (or by creating a user account to this wiki we get a notification)

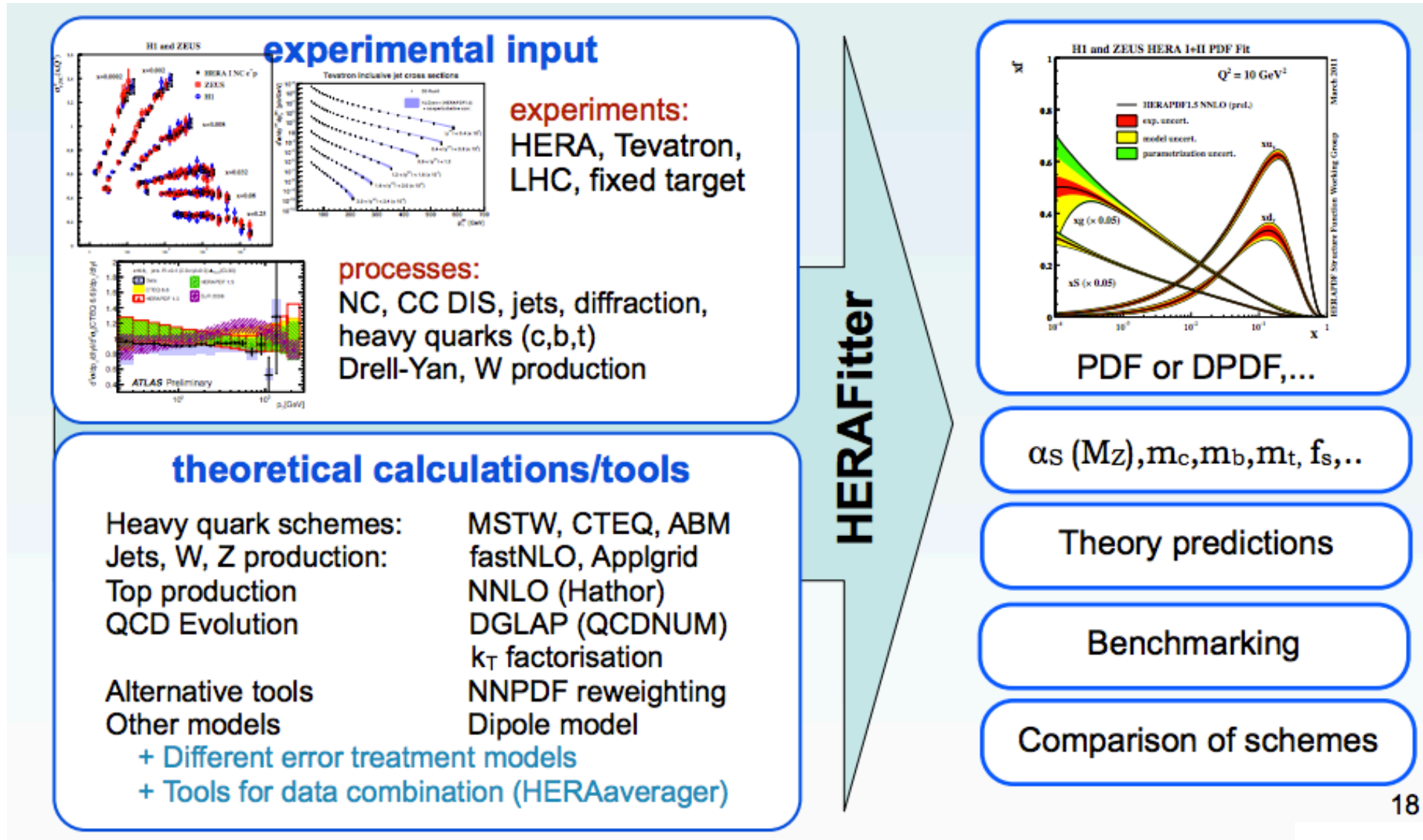
HERAFitter / DownloadPage / ExternalLinks

Links to external packages that are set to run with HERAFitter:

Package	Description	Remarks
QCDNUM	evolution code	./configure
APPLGRID	Interfaced to MCFM, access to jets and DY calculations	./configure --enable-applgrid
LHAPDF	access to global PDFs	./configure --enable-lhapdf
HATHOR	ttbar cross section calculations	./configure --enable-hathor



What package can do in a quick look:

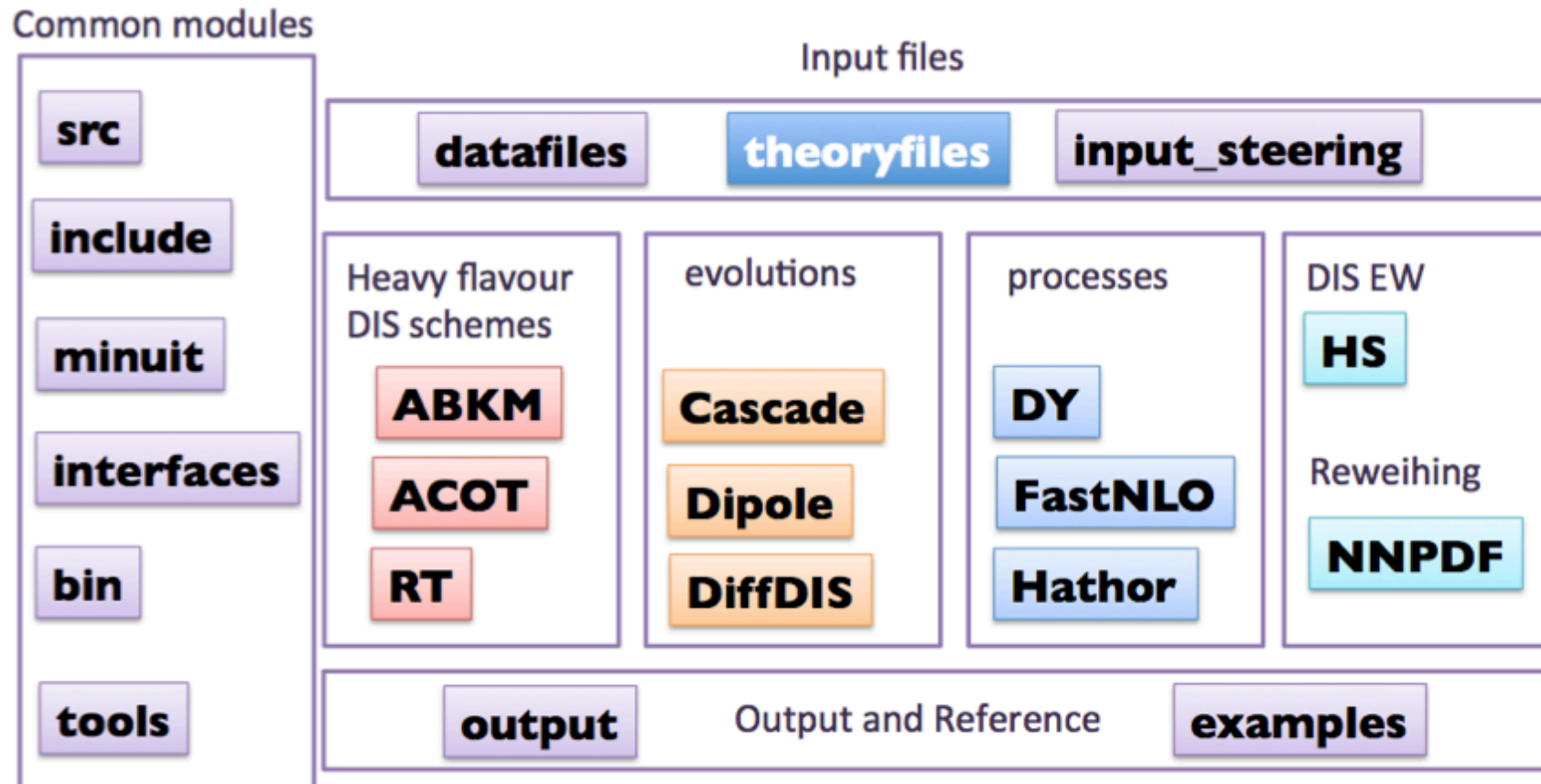




HERAFitter Modular Structure



- ◆ HERAFitter package has a convenient modular structure for independent developments, the current structure contains the following modules:



External dependencies:
QCDNUM – evolution [default - compulsory]
APPLGRID for jets, DY, WZ [optional]
LHAPDF for external PDFs [optional]



HERAFitter-0.3.0 release

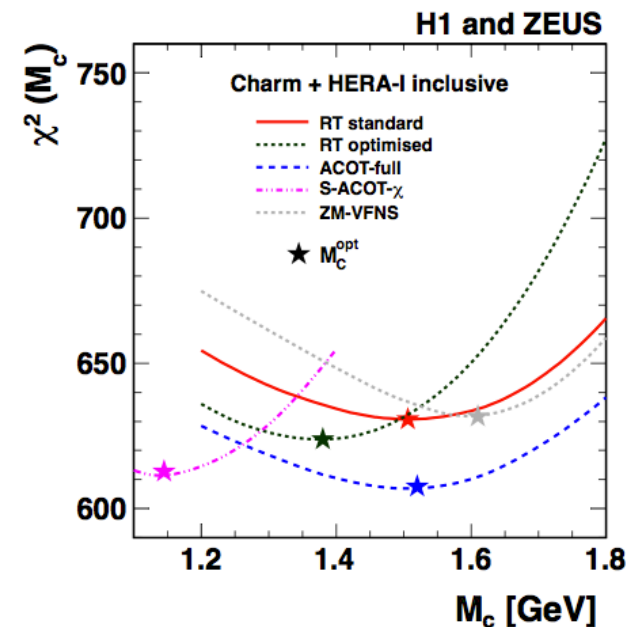


Functionalities:

- ◆ For the DIS process, several schemes are available for heavy quark treatments:
 - ▶ VFNS (Variable Flavour Number Schemes):
 - ✧ RT-VFNS schemes (RT Standard, RT Optimal) – implemented by G.Watt, Robert Thorne (ast variants based on k-factors RT FAST, RT OPT FAST - runs 15min)
 - ✧ Zero Mass VFNS [qcdnum, ACOT variant]
 - ✧ ACOT Full, ACOT Chi, ACOT ZM, they are all based on k-factors – implemented by F. Olness
 - ▶ FFNS (Fixed Flavour Number Scheme) *
 - ✧ via QCDNUM
 - ✧ via ABM (openqcdrad-1.6) [from Sergey Alekhin]

[used in F2 charm HERA combined paper]

[Eur. Phys. J. C73 (2013) 2311]





HERAFitter-0.3.0 release



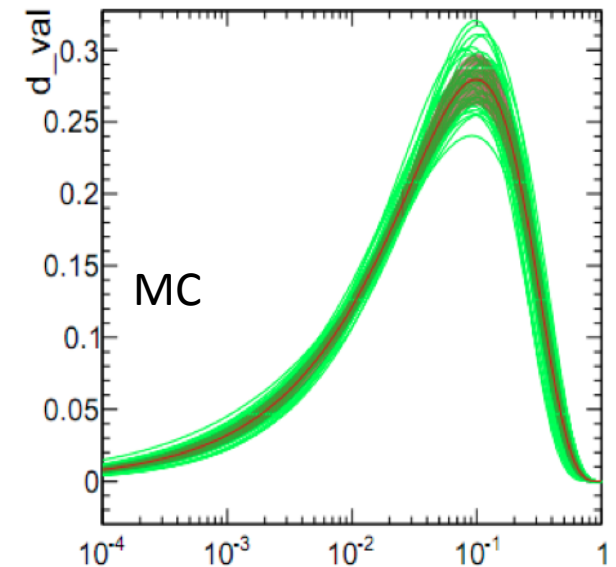
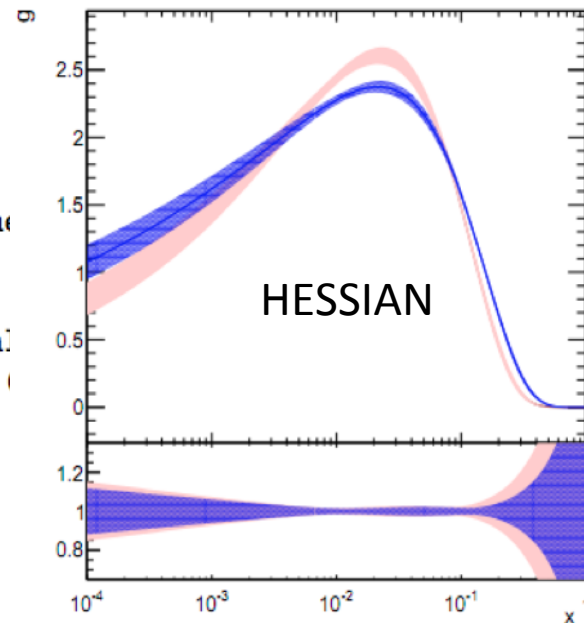
Functionalities:

- ◆ The HERAFitter package allows for various types of data uncertainty treatment:
 - ◆ Hessian and toy Monte Carlo error propagation

&MCErrors

```
lRAND = False
lRANDDATA = True
lSeedMC = 123456
! --- Choose what distribution for the
! STATYPE (SYS_TYPE) = 1 gauss
! STATYPE (SYS_TYPE) = 2 uniform
! STATYPE (SYS_TYPE) = 3 lognormal
! STATYPE (SYS_TYPE) = 4 poisson
STATYPE = 1
SYSTYPE = 1
```

&End

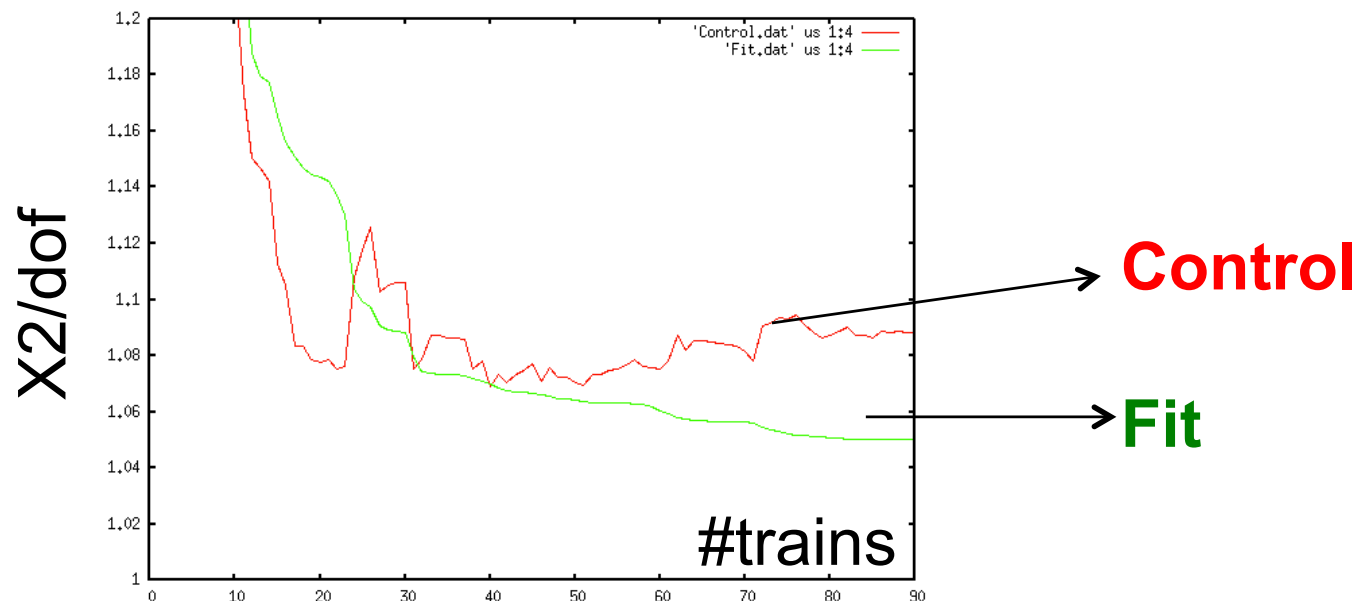


- ✧ Regularisation methods: to constrain PDFs in a flexible parametrisation style:
 - Data Driven Regularisation (as used by NNPDF): fit and control samples
 - External Regularisation based on a penalty term in χ^2
[was shown at QCD@LHC 2012]



HERAFitter-0.3.0 release

- ◆ Data driven regularisation works by splitting data randomly into “fit” and “control” samples to HERA I here
 - ✧ “Fit” sample is used for determining PDF parameters, it semi-monotonically decreases in chisquare
 - ✧ “Control” sample used to protect against over-fitting: it starts by decrease in chisquare but later on gets to increase due to fluctuation of the sample.
 - ✧ Technically:
 - Request MIGRAD minimisation with 100 calls and repeat this procedure 100 times (trains)
 - Save the output of minuit minimisation for each train





HERAFitter-0.3.0 release

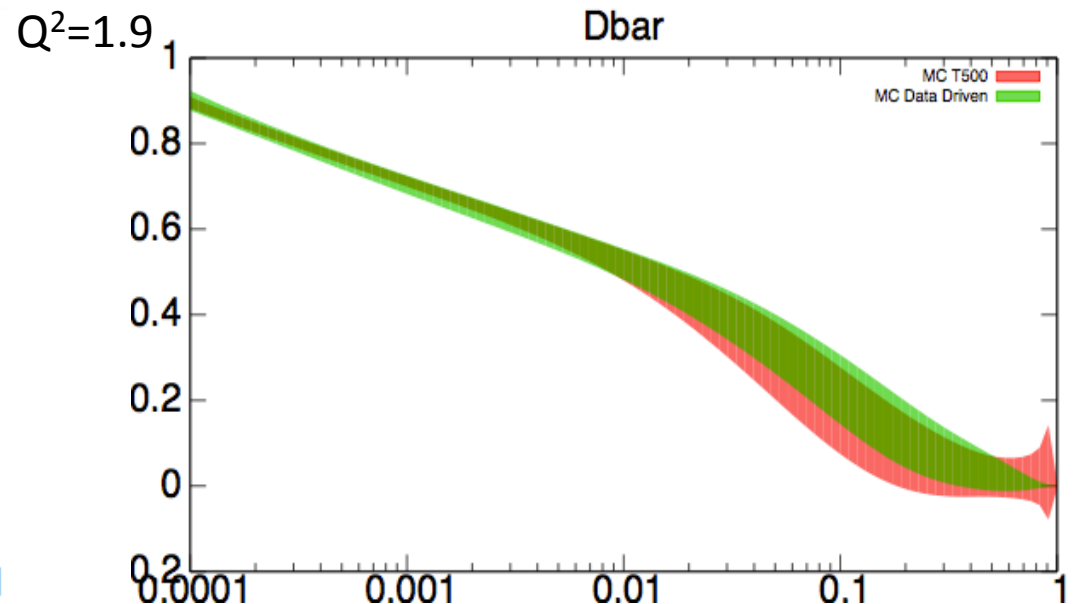
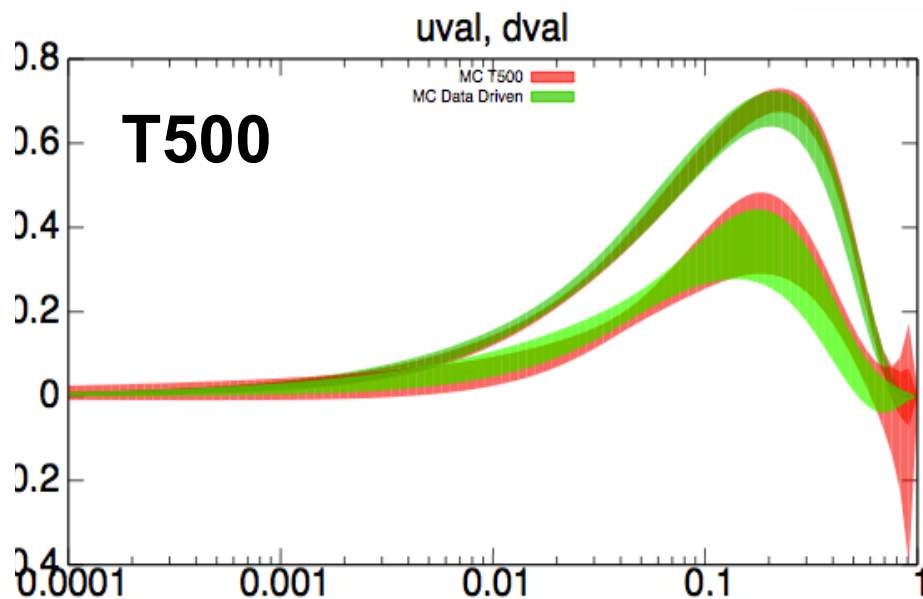
- ◆ External Regularisation is based on penalty term in χ^2

A simple χ^2 penalty term for a deviation from a simple PDF parametrisation form:

$$\chi_{\text{reg}}^2 = T \sum_f \left(\left(\frac{D_f}{\Delta_D} \right)^2 + \left(\frac{E_f}{\Delta_E} \right)^2 \right)$$

- with $\Delta D = \Delta E = 100$, such that when D, E large, approach 1,
- T is the regularisation parameter: $T=0$, no penalty, $T \gg 0$ strong penalty

- ▶ The idea is to compare the **Data Driven Regularisation** method with the external regularisation procedure to tune the **T parameter**.





HERAFitter-0.3.0 release



Functionalities:

◆ The HERAFitter package allows for various types of data uncertainty treatment:

□ Various chisquare representations:

○ **Simple form:**
$$\chi_{\text{exp}}^2(\mathbf{m}, \mathbf{b}) = \sum_i \frac{[m^i - \sum_j \gamma_j^i m^i b_j - \mu^i]^2}{(\delta_{i,\text{stat}} \mu^i)^2 + (\delta_{i,\text{uncor}} \mu^i)^2} + \sum_j b_j^2.$$

○ **Scaled form:**
$$\chi_{\text{exp}}^2(\mathbf{m}, \mathbf{b}) = \sum_i \frac{[m^i - \sum_j \gamma_j^i m^i b_j - \mu^i]^2}{\delta_{i,\text{stat}}^2 \mu^i (m^i - \sum_j \gamma_j^i m^i b_j) + (\delta_{i,\text{uncor}} m^i)^2} + \sum_j b_j^2 + \log \text{ penalty}$$

○ **Mixed form (covariance and nuisance parameter):**

$$\chi_{\text{exp}}^2(\mathbf{m}, \mathbf{b}) = \sum_{ij} \left(m^i - \sum_l \Gamma_l^i(m^i) b_l - \mu^i \right) C_{\text{stat. } ij}^{-1}(m^i, m^j) \left(m^j - \sum_l \Gamma_l^j(m^j) b_l - \mu^j \right) + \sum_l b_l^2.$$

□ Various models for bias corrections:

- ◆ The correlated and uncorrelated systematic uncertainties can be treated as additive or multiplicative
- ◆ The statistical uncertainties can be treated as additive or as Poisson



HERAFitter-0.3.0 release



Functionalities:

- ◆ The HERAFitter package allows for various types of data uncertainty treatment:

- Note: each correlated systematic source can be treated differently via modifiers:

Modifier	Description
	Scaling properties
:M	Multiplicative scaling, m^i
:A	Additive scaling, μ^i
:P	Poisson scaling, $\sqrt{m^i \mu^i}$
	χ^2 treatment
:N	Nuisance parameter treatment
:C	Covariance matrix treatment
:O	Offset method treatment
:E	Nuisance parameter, included in MINUIT (“External”)

- Various models for bias corrections:
 - ◆ The correlated and uncorrelated systematic uncertainties can be treated as additive or multiplicative
 - ◆ The statistical uncertainties can be treated as additive or as Poisson



HERAFitter-0.3.0 release



Other New functionalities:

- ◆ Experimental uncertainties for data:
 - ▶ asymmetric errors, offset method, covariance matrix representation
- ◆ Bayesian PDF reweighting based on eigenvectors
- ◆ **Unintegrated PDFs based on the kT factorisation (CCFM) evolution**
 - ▶ applicable only to ep scattering (NC)
 - ▶ <https://www.herafitter.org/HERAFitter/HERAFitter/HERAFitterMeetings/Meeting2012-Oct-29?action=AttachFile&do=get&target=updf.pdf>
- ◆ Addition of dipole and dipole+DGLAP models
- ◆ Inclusion of more data sets (LHC, Tevatron)
 - ▶ <https://www.herafitter.org/HERAFitter/HERAFitter/HERAFitterMeetings/Meeting2012-Nov-27?action=AttachFile&do=get&target=cms.pdf>



HERAFitter-0.3.0 release



Other New functionalities:

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 - ▶ asymmetric errors, offsets
- ◆ Bayesian PDF reweighting
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 - ▶ <https://www.herafitter.org/Meeting2012-Oct-29?act>
- ◆ Addition of dipole and dipole
- ◆ Inclusion of more data sets
 - ▶ <https://www.herafitter.org/Meeting2012-Nov-27?act>

herafitter for TMD (uPDF): program flow

- TMD (uPDF) fit via: `itheory > 100`
 - applicable only to ep scattering (NC): program stops otherwise
 - calculate kernel grid (external input, from TMD evolution, ask me)
 - `ccfm-grid.dat`

```
~/jung/cvs/h1fitter/h1fitter/theoryfiles/updf> ls
ccfm-final-setA0.dat  ccfm-quark.dat  f2tilde-grid.dat
ccfm-grid.dat        f2qpm-grid.dat
~/jung/cvs/h1fitter/h1fitter/theoryfiles/updf> █
```
- calculate DIS x-section (until now only F_2 used for fit)
- `itheory = 101:`
 - full calculation: for each x, Q^2 calculate:
- `itheory = 102:`

$$\frac{d\sigma}{dx dQ^2} = \int dx_g [dk_{\perp}^2 x_g A_i(x_g, k_{\perp}^2, p)] \hat{\sigma}(x_g, k_{\perp}^2, x, Q^2)$$
 - fit already evolved TMD(uPDF): calculate x-section once and fit normalization
- `itheory = 103:`
 - perform full fit of x-dependent starting distribution using a grid

H. Jung, TMDs (uPDFs) in herafitter, herafitter users meeting, 29 Oct 2012

5

Hannes Jung, Oct 2012 – User's meeting



Low Q^2 F_2

Other

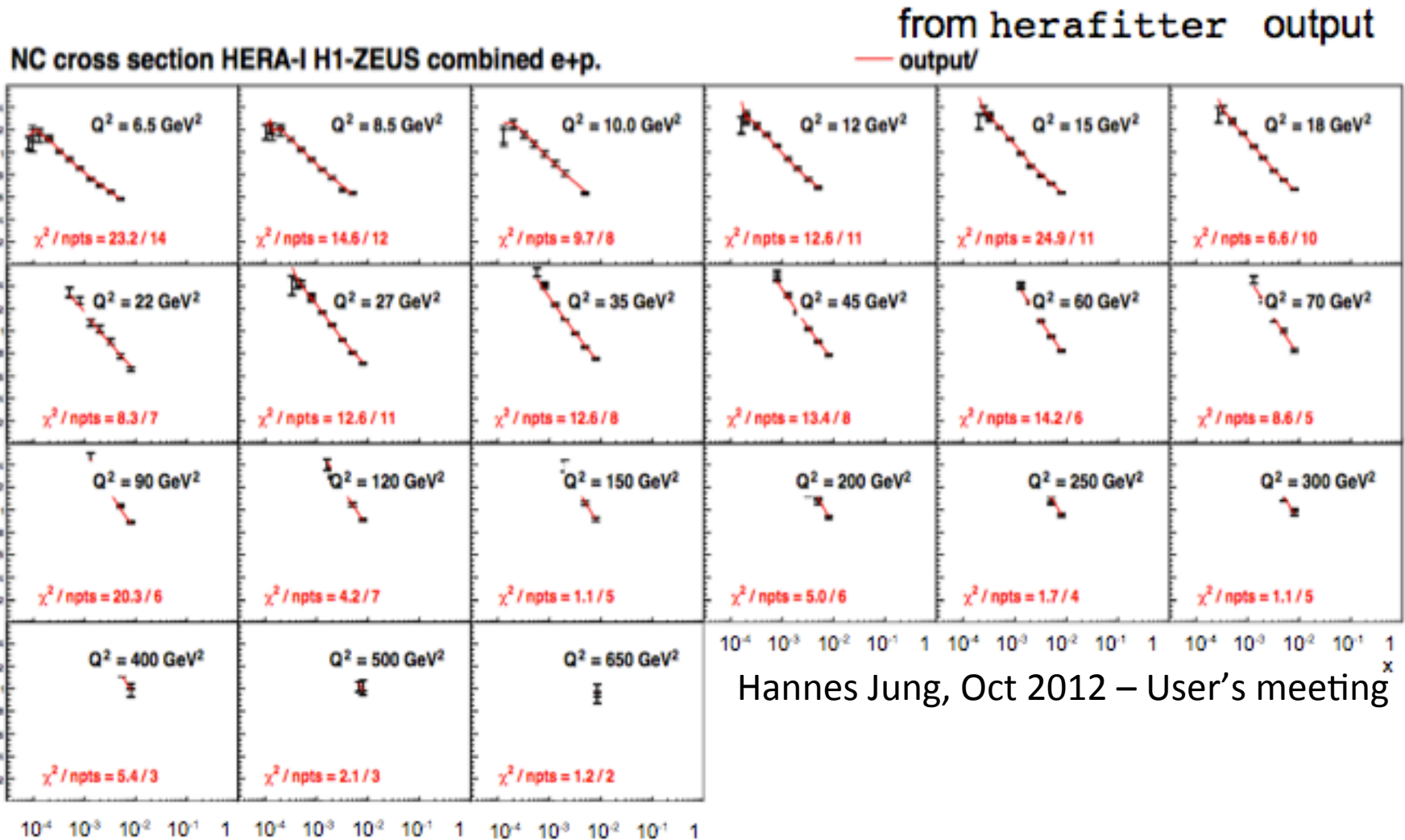
◆ E

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Hannes Jung, Oct 2012 – User's meeting

● Fit performed in $Q^2 > 5 \text{ GeV}^2, x < 0.01$



HERAFitter-0.3.0 release



Other New functionalities:

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 - ▶ <https://www.herafitter.org/HERAFitter/HERAFitter/HERAFitterMeetings/Meeting2012-Nov-27?action=AttachFile&do=get&target=cms.pdf>



Results using HERAFitter



- ◆ ATLAS results obtained using HERAFitter:
 - ▶ Determination of the strange quark density from ATLAS WZ measurements [[Phys.Rev.Lett. 109 \(2012\) 012001](#)]
 - ▶ Measurement of the inclusive jet cross section in pp collisions at 2.76 and 7 TeV [[ATLAS-CONF-2012-128](#)] - see Mark's talk.
- ◆ in CMS several analyses are using HERAFitter for PDF constraints
 - ▶ inclusive jets, s-quark density determination
 - ▶ planned for DY and W+charm data
- ◆ HERA publications:
 - ▶ QCD Analysis to final H1 HERA data [[JHEP 09 \(2012\) 061](#)]
 - ▶ QCD Analysis of Charm Production Cross Section Measurements [[Eur. Phys. J. C73 \(2013\) 2311](#)]
- ◆ LHeC impact studies [[J.Phys. G39 \(2012\)](#)]
- ◆ Theory:
 - ▶ updates of ACOT scheme module (with CTEQ group)
 - ▶ inclusion of photon PDF in QCDNUM (publication is planned)



HERAFitter developments perspectives

A list of planned developments:

◆ Theory (short and long terms):

- ▶ Consistent implementation of scale variations.
- ▶ ACOT NNLO
- ▶ Nuclear PDFs.
- ▶ ACOT in QCDNUM, using fast convolution engine.
- ▶ Improvements in Hathor cross-section calculation for fits, other ttbar codes
- ▶ EW corrections.
- ▶ DYNNLO in APPLGRID.
- ▶ Photon PDF.
- ▶ Different evolution schemes:
 - ✧ e.g. matched to MC showering, mixed Dipole-DGLAP fits.

◆ Data treatments:

- ▶ Additional tools to transform covariance matrix to nuisance parameter representation
- ▶ Alternative to MINUIT minimization package



Summary

- ◆ Successful releases of the HERAFitter package, latest in March 2013.
- ◆ HERAFitter platform has grown into a multi-functional QCD platform:
 - ▶ Various treatments for heavy flavours;
 - ▶ Various treatments for data treatment;
 - ▶ Various parametrisation techniques;
 - ▶ Various physics cases.
- ◆ It can be used for various tests within experimental data analysis as well as for theory studies and advances:
 - ▶ Open to everyone and anyone can contribute.
- ◆ Next release is scheduled for October 2013.
- ◆ Next User's meeting during the DIS 2013 [21-28.04]
<https://indico.cern.ch/conferenceDisplay.py?confId=247363>



HERAFitter organisation and communication

◆ **Steering Group members:**

- ▶ **Conveners:** Voica Radescu, Ringaile Placakyte, Amanda Cooper-Sarkar
- ▶ **Release coordinator:** Sasha Glazov
- ▶ **Contact Persons:**
Klaus Rabbertz (CMS), Bogdan Malaescu (ATLAS),
Gavin Salam (theory), Olaf Behnke (ZEUS), Cristi Diaconu (H1, chair),
Ronan McNulty (LHCb) , Bogdan Malaescu (ATLAS)

◆ **Communication:**

- ▶ **Developers (~30):** HERA, LHC experiments and theory groups
- ▶ Weekly meetings:
<https://herafitter.org/HERAFitter/HERAFitter/HERAFitterInternal/FitForumMeetings>
- ▶ **Users (~100):**
- ▶ Monthly meetings: (next one at DIS, Marseille - Tuesday, 23.04.2013 @ 6PM)
<https://herafitter.org/HERAFitter/HERAFitter/HERAFitterMeetings>



HERAFitter-0.3.0 release



Functionalities:

- ◆ The HERAFitter package allows for various types of data uncertainty treatment:
 - ◆ Different chisquare representations, Various models for bias corrections:

```
! -- Bias corrections for uncertainties --
! 'StatScale'      : 'Poisson', 'NoRescale' ( see also 'ExtraSystRescale' below )
! 'UncorSysScale': 'Poisson', 'Linear', 'NoRescale'
! 'CorSysScale'   : 'Linear', 'NoRescale'
!
! -- Treatment of systematics in chi2 ---
! 'UncorChi2Type': 'Diagonal'
! 'CorChi2Type'  : 'Hessian', 'Matrix', 'Offset'
!
! -- Extra corrections ---
! are given as comma separated list for Chi2ExtraParam, they are off by default.
! 'PoissonCorr'      : extra log correction accounting for changing uncertainties
! 'FirstIterationRescale' : re-scale uncertainties at the first iteration only
! 'ExtraSystRescale' : additional re-scaling of stat. uncertainty to account for syst. shifts.
```

```
CHI2SettingsName = 'StatScale', 'UncorSysScale', 'CorSysScale', 'UncorChi2Type', 'CorChi2Type'
Chi2Settings      = 'Poisson' , 'Linear', 'Linear' , 'Diagonal' , 'Hessian'
! Chi2ExtraParam = 'PoissonCorr'
```

Note: each correlated systematic source can be treated differently via modifiers: