Isolated photons with jets at HERA and proton PDF fit

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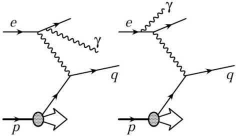
DESY

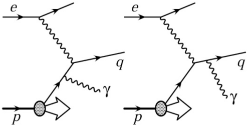
June 26, 2013
HERAFitter User's meeting

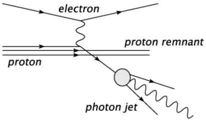
Outline
- Details: data & theory
- Implementation in HERAFitter
- Results of the fits

Isolated photons and proton PDFs

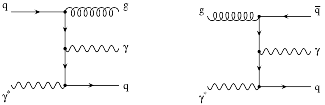
LO, $\mathcal{O}(\alpha^3)$ and fragmentation







NLO, $\mathcal{O}(\alpha^3\alpha_s)$



The information on the proton PDF from measurements of isolated photons could be complementary to measurements from inclusive DIS, since *up*- and *down*- quarks contribute with different weights

Data & Theory

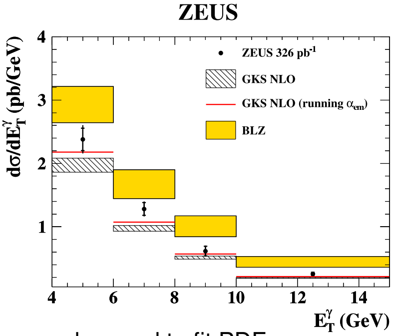
Data: *ZEUS Collaboration (Abramowicz, H. et al.). Measurement of isolated photons accompanied by jets in deep inelastic ep scattering,* Phys Lett B 715 (2012) 88-97

Theory: *A.Gehrmann-De Ridder, G.Kramer, H.Spiesberger. Photon plus jet cross sections in deep inelastic ep collisions at order $\mathcal{O}(\alpha^2\alpha_s)$*, Nucl.Phys. B578 (2000) 326-350

+ running α_{em} from *F. Jegerlehner. Electroweak Effective Couplings for Future Precision Experiments*, DESY 11-117

Phase Space

- $10 < Q^2 < 350 \text{ GeV}^2$
- $4 < E_T^\gamma < 15 \text{ GeV}$
- $-0.7 < \eta^\gamma < 0.9$
- $\frac{E^\gamma}{E^{jet\ containing\ \gamma}} > 0.9$
- $E_T^{jet} > 2.5 \text{ GeV}$
- $-1.5 < \eta^{jet} < 1.8$



Updated theory describes the data well ⇒ can be used to fit PDFs

Fast calculations of the NLO predictions

• original code by H. Spiesberger et al. - 5-8 hours of CPU (Intel(R) Core(TM) i5-2500 CPU @ 3.30GHz) time per bin
$\rightarrow$ for practical reasons calculations need to be done faster

The procedure:
1. Create table of perturbative coefficients in bins of x and μ_F
$p^{\mathrm{LO}}_{a,i,j} = \sigma^{\mathrm{LO}}_{a,i,j}/f_a(x_i, \mu_{F,j})$ for LO (a runs over flavours)
$p^{\mathrm{NLO}}_{a,i,j} = \sigma^{\mathrm{NLO}}_{a,i,j}/f_a(x_i, \mu_{F,j})/\alpha_s(\mu_R = \mu_{F,j})$ for NLO
The tables were created for each subprocess for each bin of the cross sections.
The number of bins in x and μ_F has been chosen in order to have the precision of typically 1-2 ‰
2. Convolve coefficients with PDFs

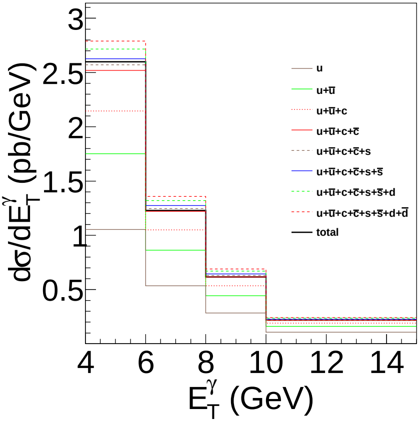
$$\sigma = \sum_{a,i,j} p^{\mathrm{LO}}_{a,i,j} \cdot f_a(x_i, \mu_{F,j}) + \sum_{a,i,j} \alpha_s(\mu_R = \mu_{F,j}) \cdot p^{\mathrm{NLO}}_{a,i,j} \cdot f_a(x_i, \mu_{F,j})$$

< 1 s of CPU time per bin

• the data are included within framework of the HERAFitter program

NLO predictions and PDFs

Cross section at parton level:



Main contribution to the NLO cross section is from $u,\ \bar{u},\ c$ and $\bar{c}$

Including in HERAFitter

Files added:

- `src/epg.f`

(fill THEO array with theoretical cross sections)

- directory `epg/`

(in analogy to Krzysztof Nowak's interface to FastNLO):

`epg/include/EPGHeraFitter.h`,

`epg/src/EPGHeraFitter.cc`,

`epg/src/EPGInterface.cc`

- `epg/src/Makefile.am`
- `datafiles/hera/ZEUS_epg.dat`
- the grids

Files modified:

- `src/theory_dispatcher.f`
- `src/init_theory.f`
- `Makefile.am`
- `src/Makefile.am`
- `configure.am`

Run `autoreconf`,

then install as usual

Results: including E_T^γ cross section (1/3)

Results for:
fit_default_13p_hesse

```
Fitted 13 parameters:
(most reliable available method: none
giving confidence in errors: none)
   1:   'Bg'  = -0.171 ± 0.153
   2:   'Cg'  =  7.468 ± 1.022
   3: 'Aprig' =  1.060 ± 0.561
   4: 'Bprig' = -0.275 ± 0.083
   5:  'Buv'  =  0.660 ± 0.032
   6:  'Cuv'  =  4.681 ± 0.218
   7:  'Euv'  =  9.893 ± 2.311
   8:  'Bdv'  =  0.662 ± 0.078
   9:  'Cdv'  =  4.409 ± 0.723
  10: 'CUbar' =  2.436 ± 0.546
  11: 'ADbar' =  0.161 ± 0.008
  12: 'BDbar' = -0.166 ± 0.007
  13: 'CDbar' =  2.326 ± 0.754
```

First iteration	591.72	579	1.022
After minimisation	570.55	579	0.985

Partial chi2s

1	107.08	145	NC	HERA-I	H1-ZEUS	combined	e-p.
2	413.72	379	NC	HERA-I	H1-ZEUS	combined	e+p.
3	19.95	34	CC	HERA-I	H1-ZEUS	combined	e-p.
4	29.81	34	CC	HERA-I	H1-ZEUS	combined	e+p.

$$
\begin{aligned}
xg(x) &= A_g x^{B_g} \cdot (1-x)^{C_g} - A'_g x^{B'_g} (1-x)^{C'_g} \\
xu_v(x) &= A_{u_v} x^{B_{u_v}} \cdot (1-x)^{C_{u_v}} \cdot (1 + D_{u_v} x + E_{u_v} x^2) \\
xd_v(x) &= A_{d_v} x^{B_{d_v}} \cdot (1-x)^{C_{d_v}} \\
x\bar{U}(x) &= A_{\bar{U}} x^{B_{\bar{U}}} \cdot (1-x)^{C_{\bar{U}}} \\
x\bar{D}(x) &= A_{\bar{D}} x^{B_{\bar{D}}} \cdot (1-x)^{C_{\bar{D}}}
\end{aligned}
$$

Results for:
fit_epg_et_13p_hesse

```
Fitted 13 parameters:
(most reliable available method: none
giving confidence in errors: none)
   1:   'Bg'  = -0.191 ± 0.145
   2:   'Cg'  =  7.300 ± 1.000
   3: 'Aprig' =  1.042 ± 0.506
   4: 'Bprig' = -0.289 ± 0.079
   5:  'Buv'  =  0.659 ± 0.033
   6:  'Cuv'  =  4.681 ± 0.217
   7:  'Euv'  =  9.954 ± 2.326
   8:  'Bdv'  =  0.661 ± 0.078
   9:  'Cdv'  =  4.375 ± 0.711
  10: 'CUbar' =  2.426 ± 0.546
  11: 'ADbar' =  0.161 ± 0.008
  12: 'BDbar' = -0.166 ± 0.007
  13: 'CDbar' =  2.379 ± 0.781
```

First iteration	595.84	583	1.022
After minimisation	574.43	583	0.985

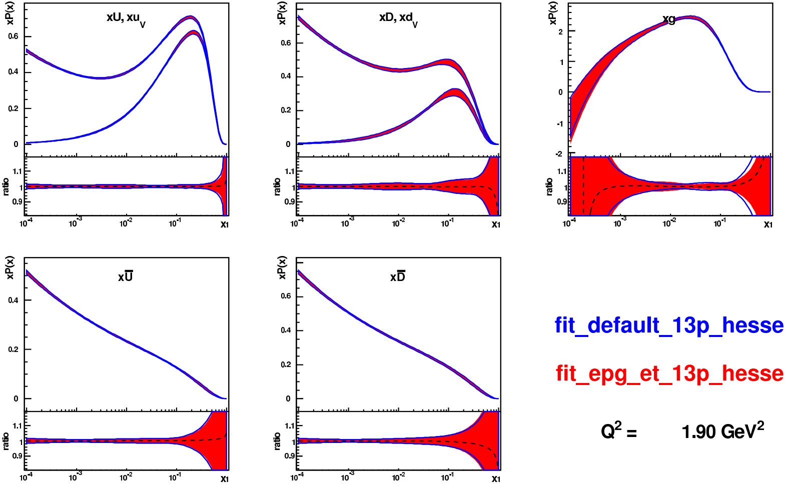
Partial chi2s

1	107.08	145	NC	HERA-I	H1-ZEUS	combined	e-p.
2	413.71	379	NC	HERA-I	H1-ZEUS	combined	e+p.
3	19.99	34	CC	HERA-I	H1-ZEUS	combined	e-p.
4	29.8	34	CC	HERA-I	H1-ZEUS	combined	e+p.
5	2.15	4	ZEUS isolated photons with jets				

Correlated Chi2 1.697
Systematic shifts 2

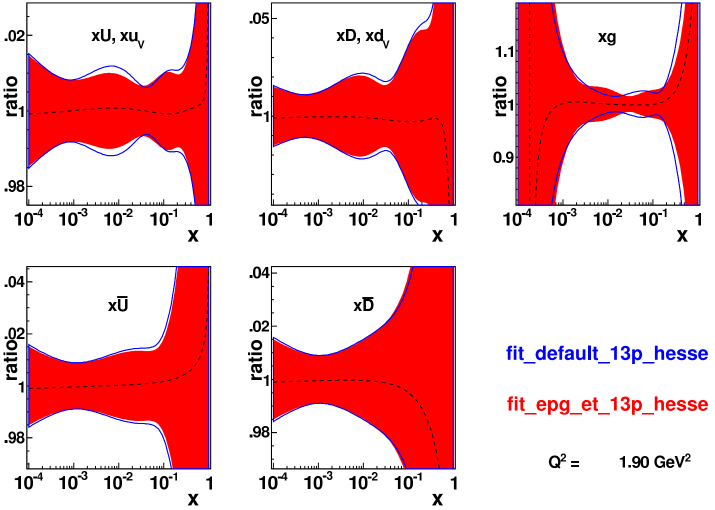
Name	Shift	+/-	Error	Type
1 egjscale	-1.3027	+/-	0.6545	:N:M
2 dzrange	-0.0092	+/-	0.9999	:N:M

Results: including E_T^{γ} cross section (2/3)



- Two fit results are consistent

Results: including E_T^γ cross section: uncertainties (3/3)



- Reduction of the uncertainties mainly in U PDF

Summary

• Data on isolated photon with jets production in DIS are successfully added to the HERAFitter

• Isolated photon data together with inclusive DIS data (as for HERAPDF1.0) have been used in the fit

• The fit with isolated photon data included shows consistent result with inclusive DIS results

• The uncertainties of the PDFs noticeably reduced

More checks to be done:

• free u and d as much as possible in the fit

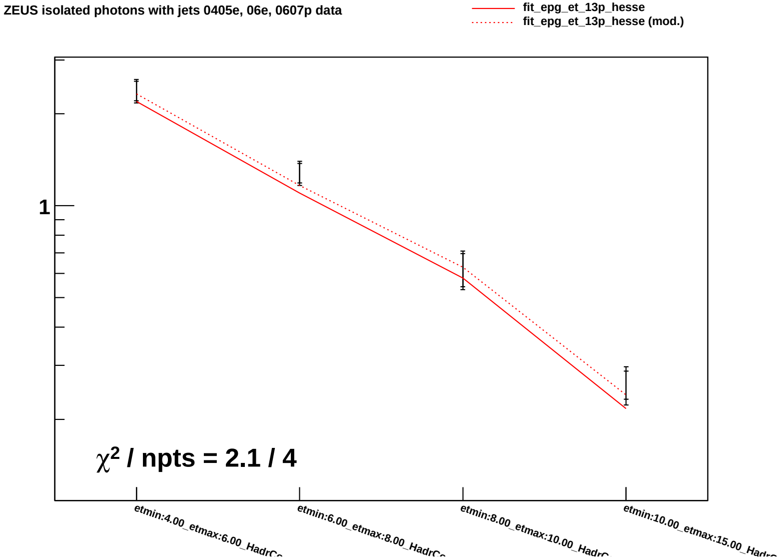
• try different parametrisation styles

• ...

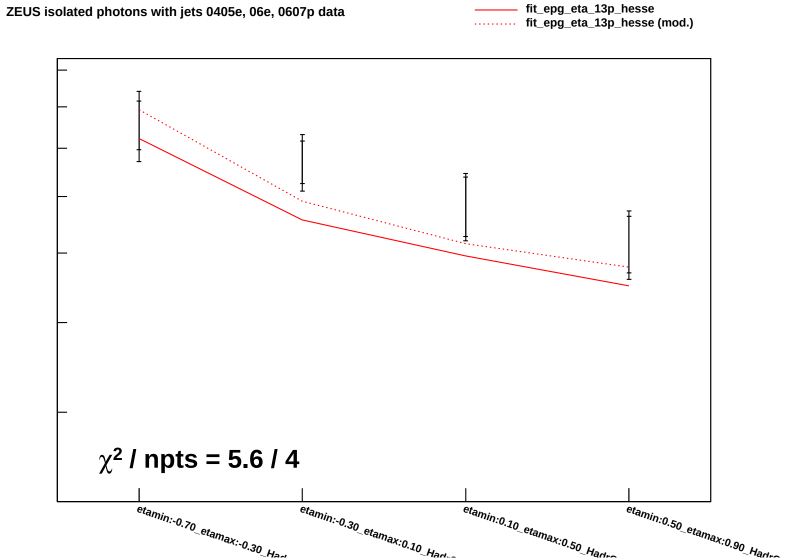
We thank Hubert Spiesberger for kindly providing the codes for the NLO predictions and Voica Radescu for help in implementing new codes and data in the HERAFitter

Backup

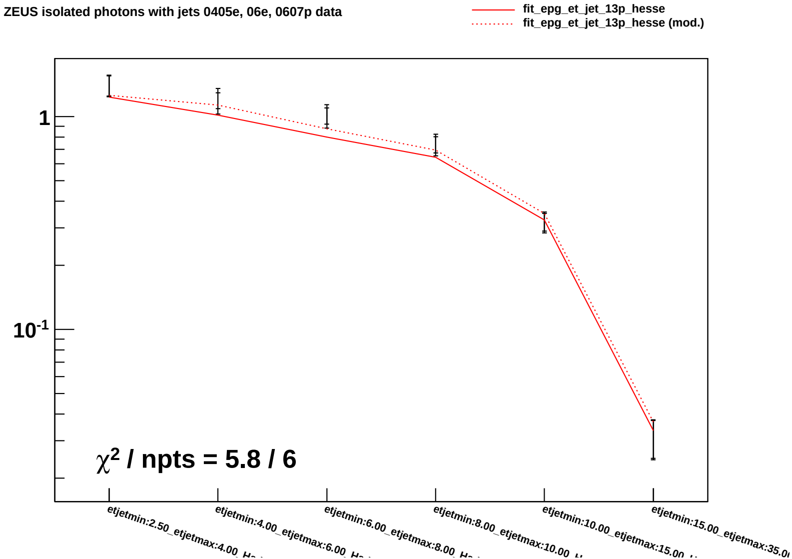
Including E_T^γ cross section: systematics shifts



Including η^γ cross section: systematics shifts



Including η^γ cross section: systematics shifts



Input data: E_T^γ

```
*
* The data are taken from:
*
*"Measurement of isolated photons accompanied by jets in deep inelastic ep scattering"
* By ZEUS Collaboration (H. Abramowicz et al.). DESY-12-089, June 2012. 25pp.
* Published in Phys. Lett. B 715, Issue 1-3:88-97,2012.
* e-Print: arXiv:1206.2270 [hep-ex]
*
* The systematical uncertainties symmetrized in a different way than in paper. Here largest deviation is taken,
* whereas in the paper the mean of upper and bottom uncertainties was taken.

&Data
   Name = 'ZEUS isolated photons with jets 0405e, 06e, 0607p data'
   Reaction  = 'epg'

   NDATA = 4
   NColumn = 8

   ColumnType = 3*'Bin','Sigma',4*'Error'
   ColumnName = 'etmin', 'etmax', 'HadrCorr','Sigma', 'stat', 'egjscale', 'dzrange', 'uncor'

   NInfo    = 4
   DataInfo = 319.,       1.,                 2.,      0.    ! to be updated
   CInfo    = 'sqrt(S)', 'PublicationUnits','MurDef', 'MufDef'

   IndexDataset = 200

   TheoryInfoFile = 'theoryfiles/fnh4002.tab'                   !new light grids
   TheoryType     = 'user_grid'

   Percent    = False, False
&End
4.0  6.0   0.838210272  2.38  0.18    0.11     0.13     0.04
6.0  8.0   0.889243789  1.28  0.10    0.06     0.020    0.03
8.0  10.0  0.935850904  0.62  0.08    0.04     0.029    0.014
10.0 15.0  0.990858773  0.26  0.03    0.022    0.010    0.0005
```