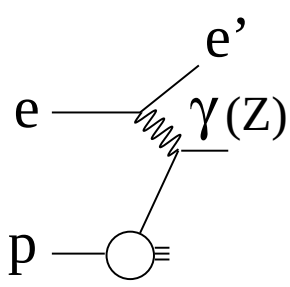

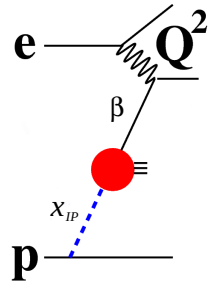

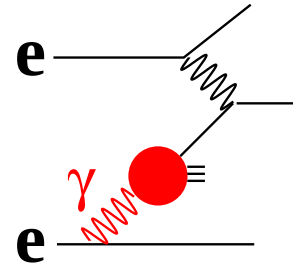

Comparison of the Hadronic Structures in Structure Function Measurements of the Proton, Photon and Diffractive Exchange

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Contents

- Main idea of the analysis and motivation
- Structure function of the proton, photon and diffractive exchange
- Charm contribution to the proton structure function
- Comparison plots
- Summary

Analysis Idea

- Find an intuitive description of structure functions
- Fit structure function distribution using function:

$$F_2(x, Q^2) = a(x) \left[\ln \left(\frac{Q^2}{\Lambda^2} \right) \right]^{\kappa(x)}$$

with $\Lambda = 0.35$ GeV

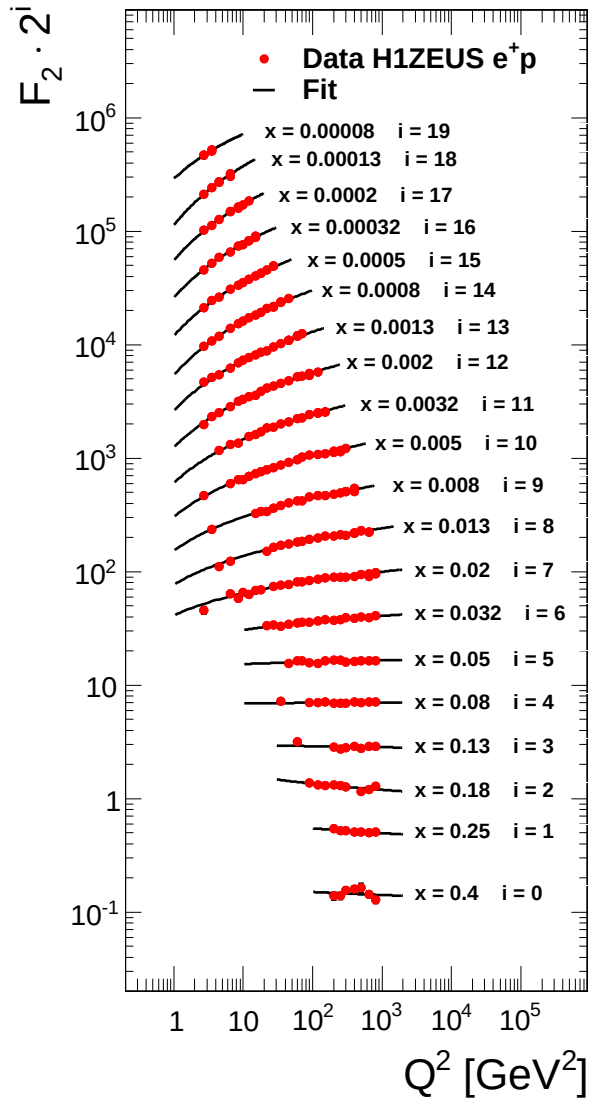
- $a(x)$ shows hadronic structure at low momentum transfer

$$Q^2 = e \cdot \Lambda^2 = 0.3 \text{ GeV}^2$$

$$\Longrightarrow \; F_2(x, e \cdot \Lambda^2) = a(x) \cdot 1$$

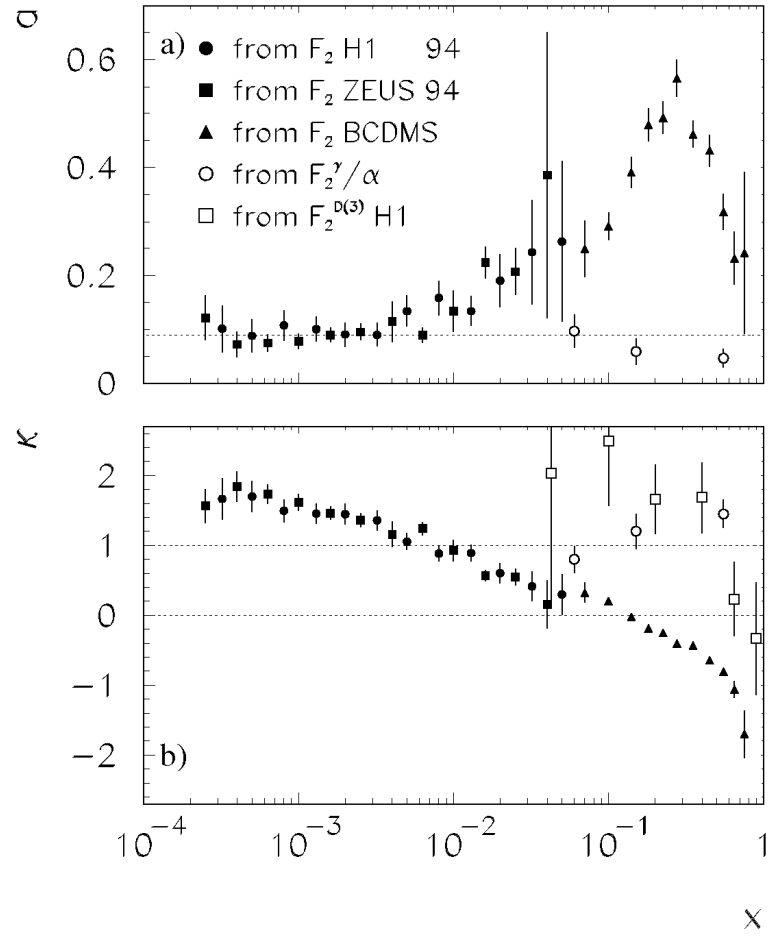
- $\kappa(x)$ shows scaling violations

H1/ZEUS combined e^+p data:



Motivation

- **Extend the Publication:**
  "On the Structure of the Proton, the Photon, and the Colour Singlet Exchange" by M. Erdmann, Phys.Lett.B488:131-137, 2000, hep-ex/0007058
- **Use new more precise data from HERA I (H1, ZEUS)**
  - **for Proton, Diffractive Exchange**
- **New data from LEP since the last publication (L3, ALEPH, OPAL, DELPHI)**
  - **for Photon**
- **New: add charm contribution to proton structure function (HERA I, II)**



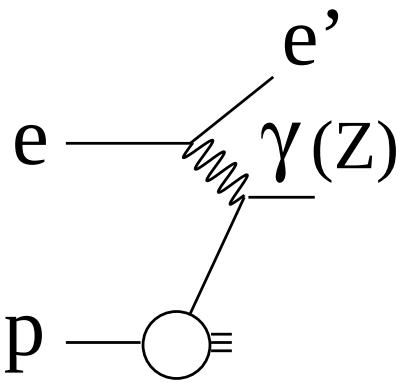
- **Fit model allows intuitive description of hadronic structure**

Analysis Strategy

- Consider all published F_2 data for NC processes
- Restrict analysis for
  - $y < 0.6$
  - $2\,\mathrm{GeV}^2 < \mathrm{Q}^2 < 1000\,\mathrm{GeV}^2$
- Take into account combined statistical and systematic errors
- If only reduced cross section provided: estimate $F_2^{D(3)}$ using $R = 0.25$ (for diffractive data)
- Cut on $x_{IP} < 0.005$ for diffractive data (Pomeron-like region)
- Make x - binning if needed
- Plot a and κ if
  - more than 2 points for a given x-bin available (2 parameters)
  - $\delta a < 0.2$ and $\delta\kappa < 1.0$

Proton Hadronic Structure

NC process at HERA:



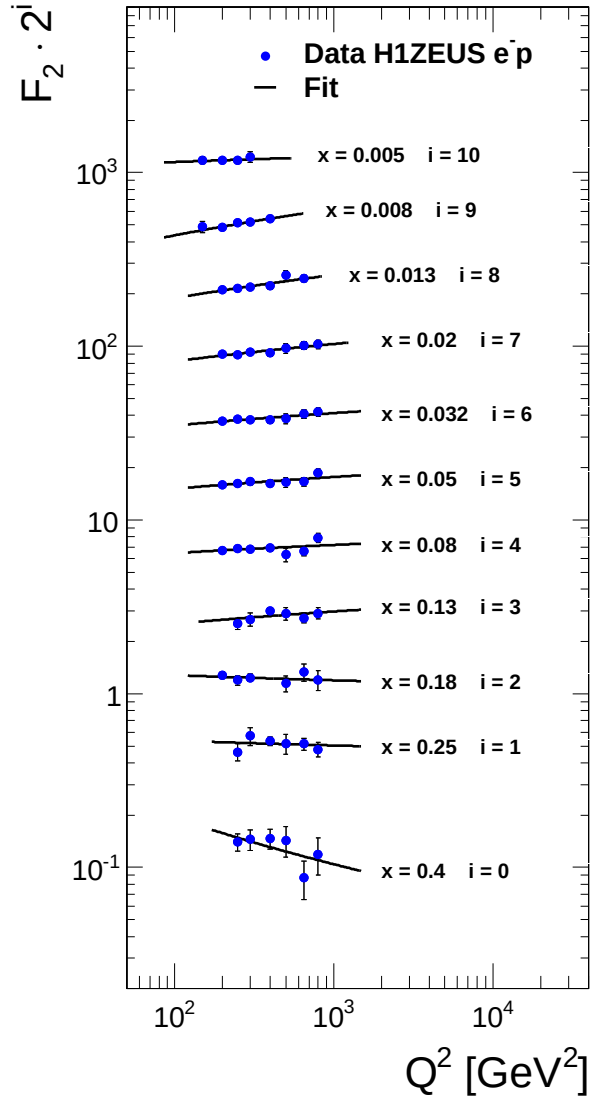
Considered data:

- **Combined H1/ZEUS HERA I e^+p and e^-p data**
- **BCDMS data**
- **EMC data**

Find a and κ from the fit:

$$F_2(x,Q^2) = a(x)\left[\ln\left(\frac{Q^2}{\Lambda^2}\right)\right]^{\kappa(x)}$$

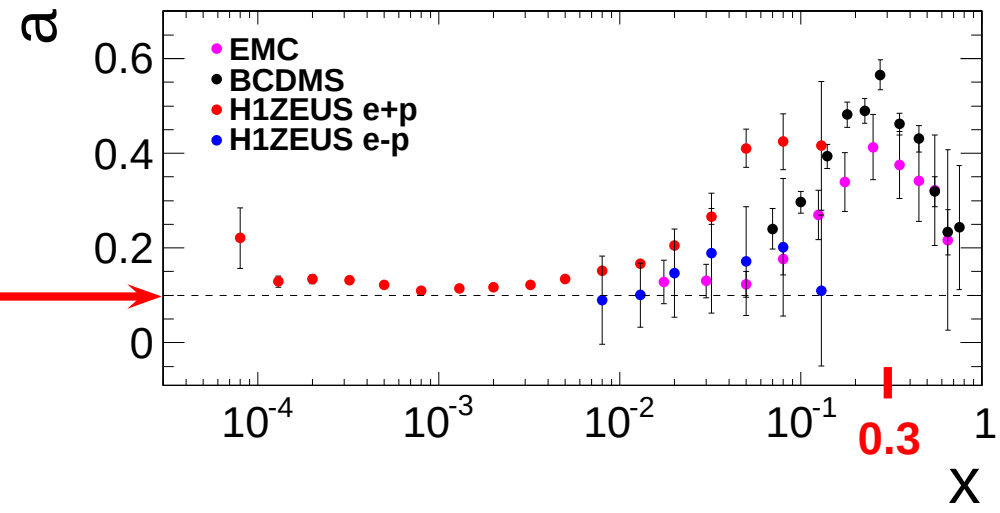
H1/ZEUS combined e^-p data:



Proton Hadronic Structure

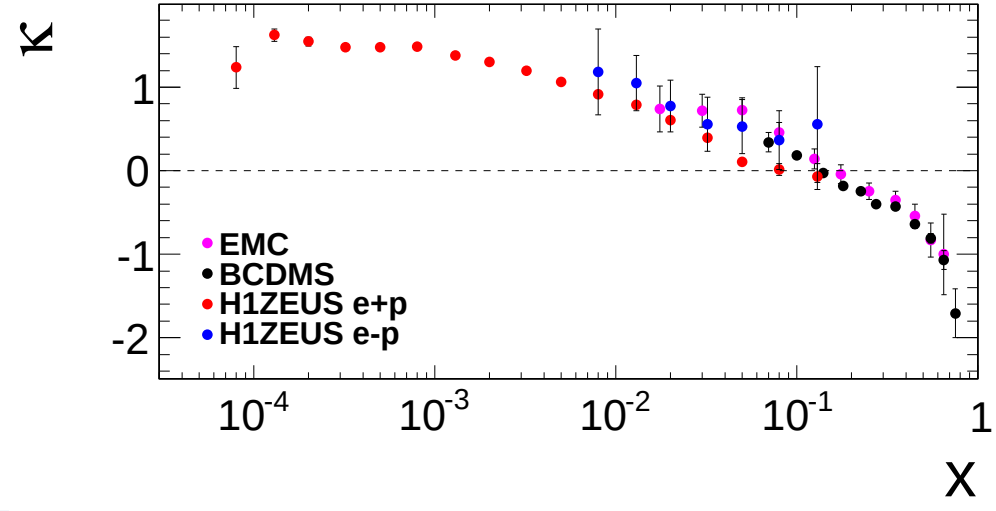
- valence quarks at $x \sim 1/3$
- low x: sea quarks
- typical value for hadronic structure at small x: $a = 0.1$

Hadronic Structure of Proton:



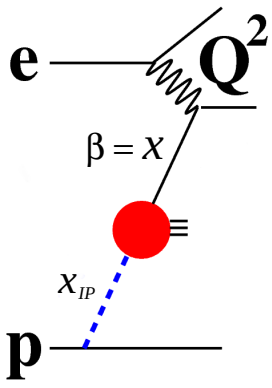
Scaling Violations:

- positive and negative scaling violations



Diffractive Exchange Structure

NC diffractive process at HERA:



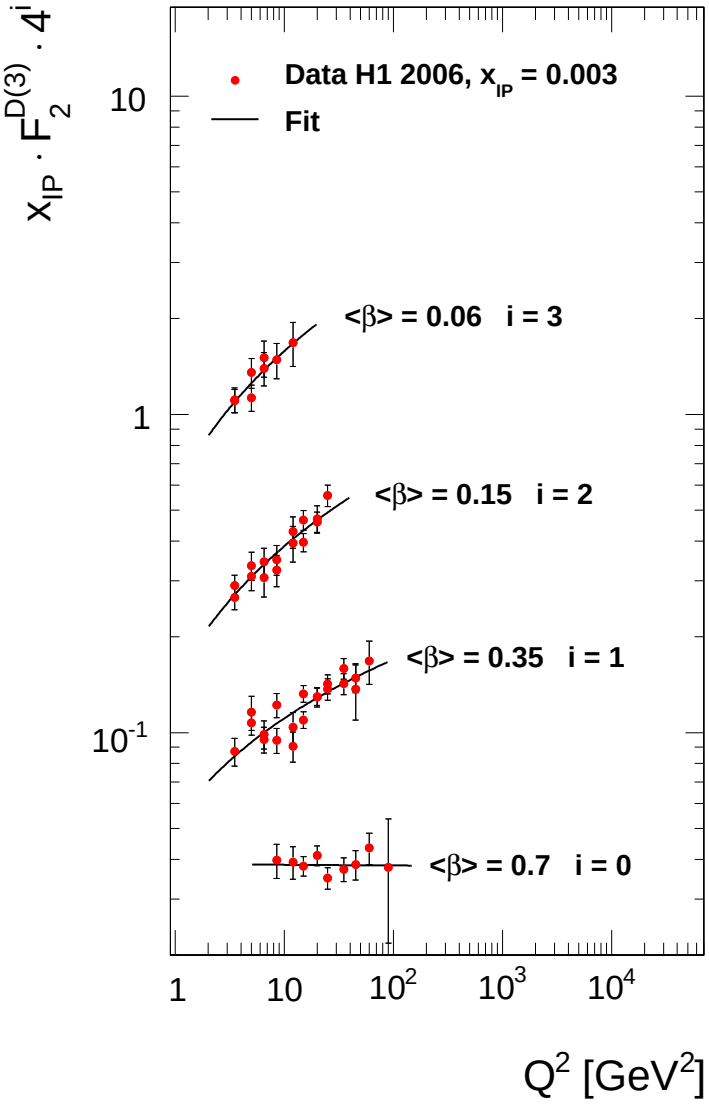
Considered data:

- **H1 and ZEUS HERA I diffractive data for Pomeron-like region:**

$$x_{IP} < 0.005$$

Find a and κ from the fit:

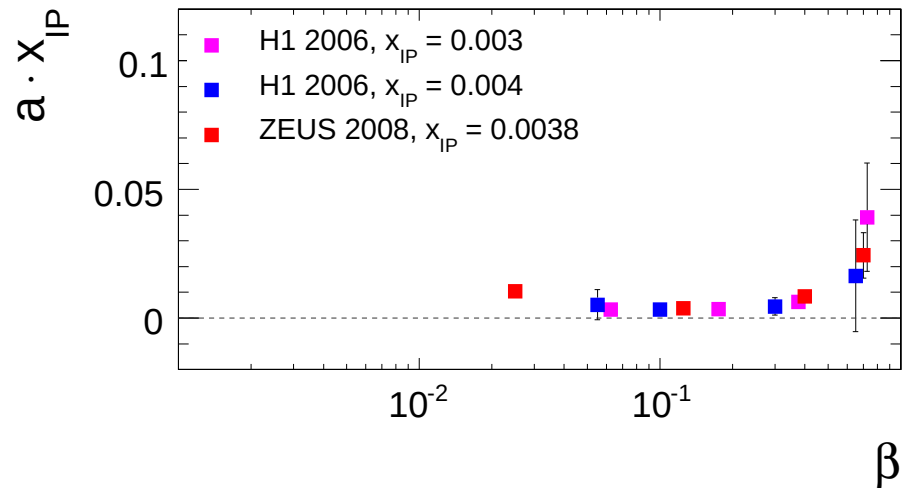
$$F_2(x, Q^2) = a(x) \left[\ln \left(\frac{Q^2}{\Lambda^2} \right) \right]^{\kappa(x)}$$



Diffractive Exchange Structure

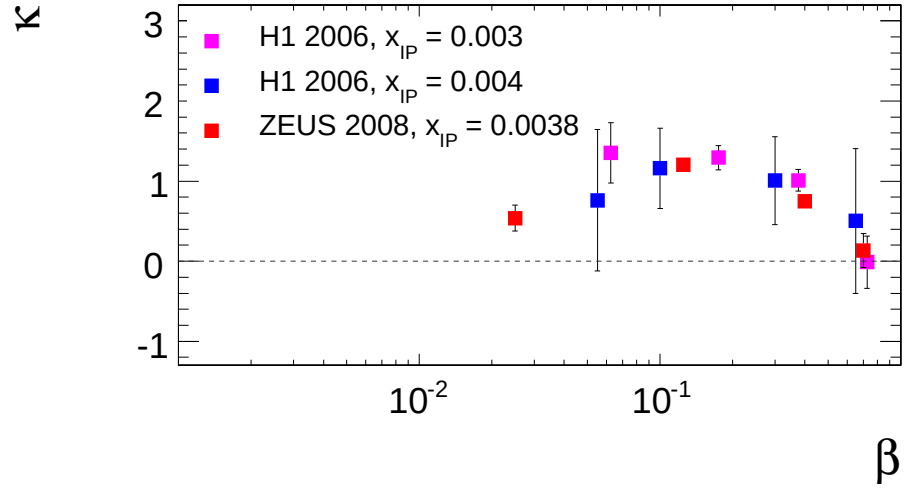
- high density at large parton momentum, for example 2 gluons where one carries a high momentum fraction

Hadronic Structure:



- mostly positive scaling violations

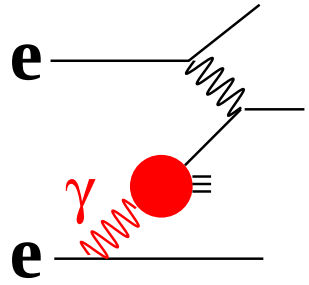
Scaling Violations:



Photon Structure

Photon structure results from fluctuations of a photon into a colour neutral and flavour neutral hadronic state

NC process for photon structure in e^+e^- collider:



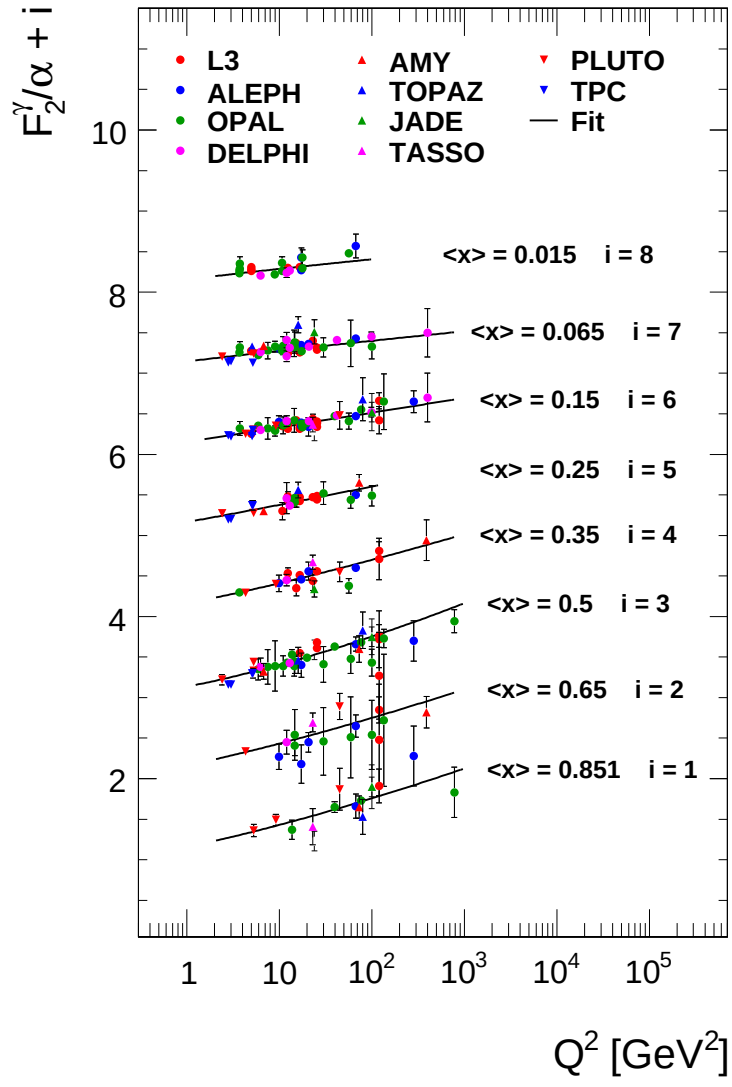
Considered data:

- LEP: L3, ALEPH, OPAL, DELPHI
- JADE, TASSO, etc.

Find a and κ from the fit:

$$F_2(x,Q^2) = a(x)\left[\ln\left(\frac{Q^2}{\Lambda^2}\right)\right]^{\kappa(x)}$$

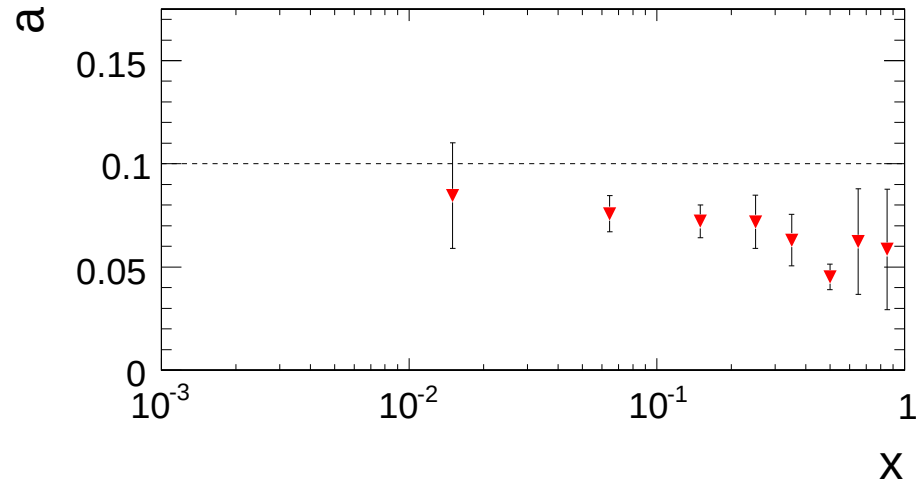
All available e^+e^- data:



Photon Structure

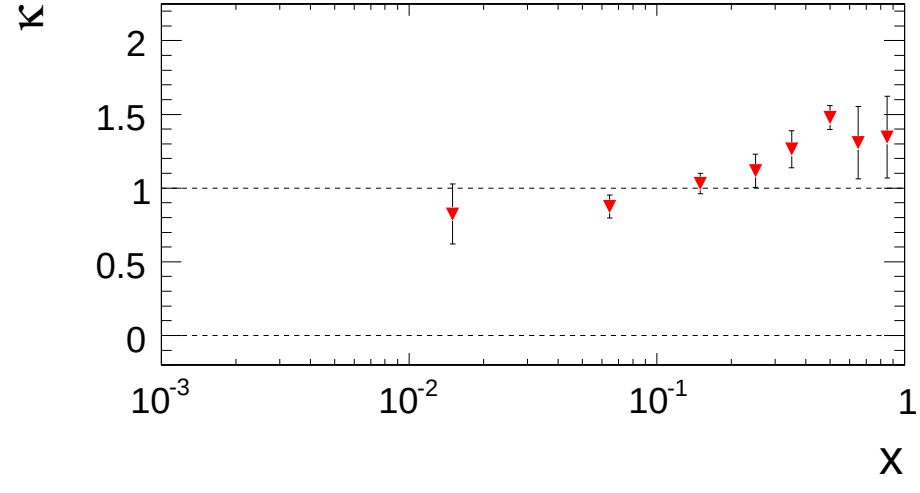
- no evidence of valence quarks
- low x: hadronic-like structure as for proton: $a \sim 0.1$
- hadronic fall plus point-like rise?
- watch out: correlation between a and κ

Hadronic Structure of Photon:



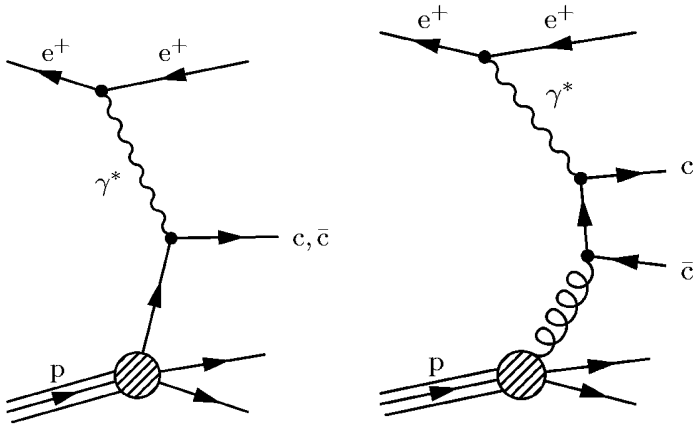
- positive scaling violations
- $\kappa(x) \sim 1$ as expected from QCD calculations

Scaling Violations for Photon:



Charm Contribution to Proton Structure

NC processes at HERA:



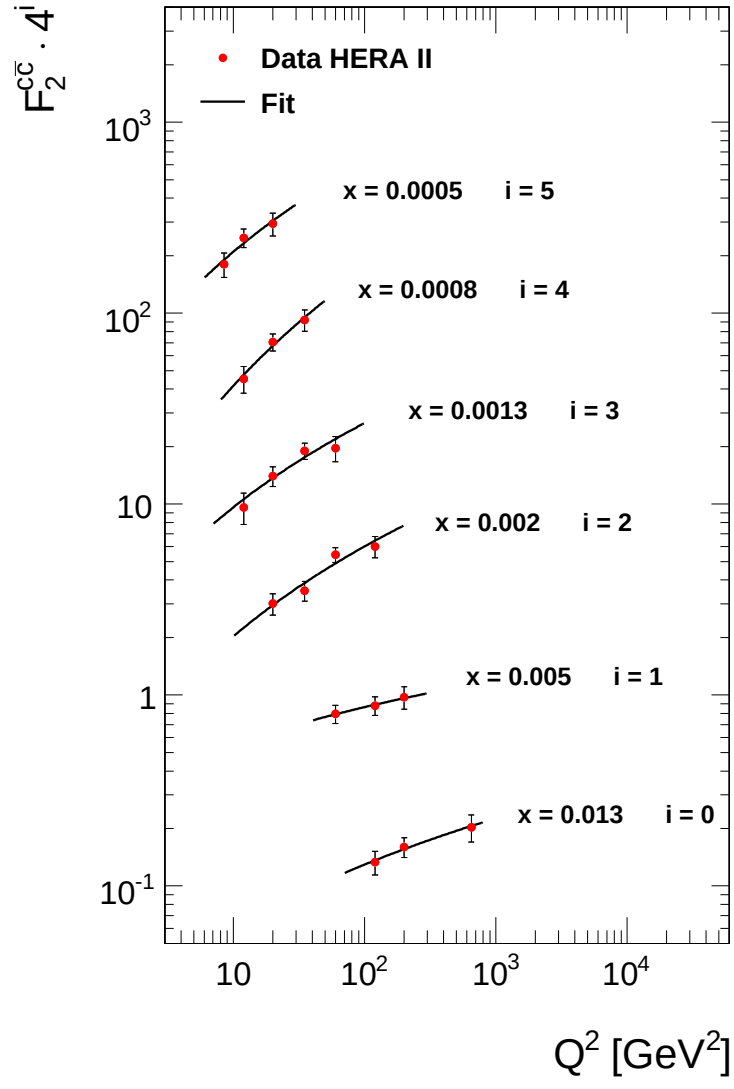
Considered data:

- inclusive H1 HERA I/II data
- D-meson HERA I data from H1 and ZEUS
- EMC charm data

Find a and κ from the fit:

$$F_2(x, Q^2) = a(x) \left[\ln \left(\frac{Q^2}{\Lambda^2} \right) \right]^{\kappa(x)}$$

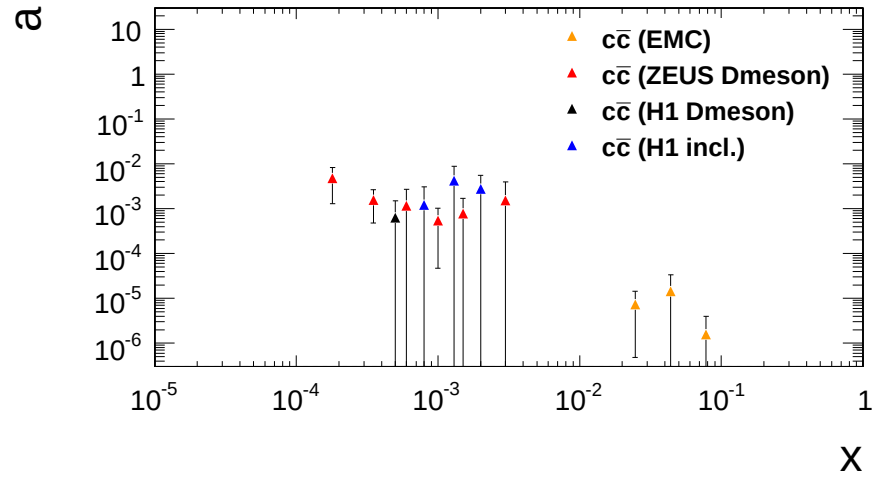
H1 HERA II charm inclusive measurements:



Charm Contribution to Proton Structure

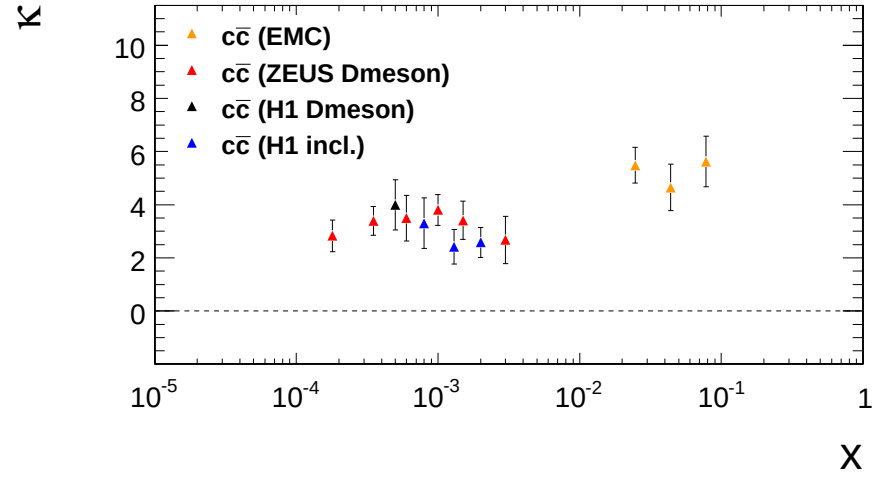
- negligible charm in the proton when probing with static resolution scale of $Q^2 = 0.3\,\mathrm{GeV}^2$

Hadronic Structure:



- strong positive scaling violations
- consistent with charm resulting from fluctuations

Scaling Violations:



Comparison I: Proton and Charm Contribution

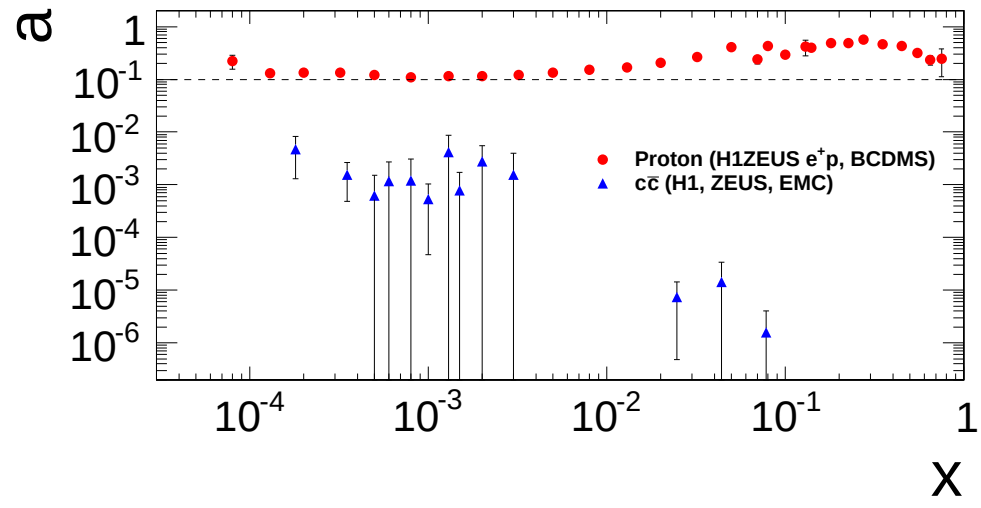
Proton:

- valence quarks at $x \sim 1/3$
- low x: sea quarks
- positive and negative scaling violations

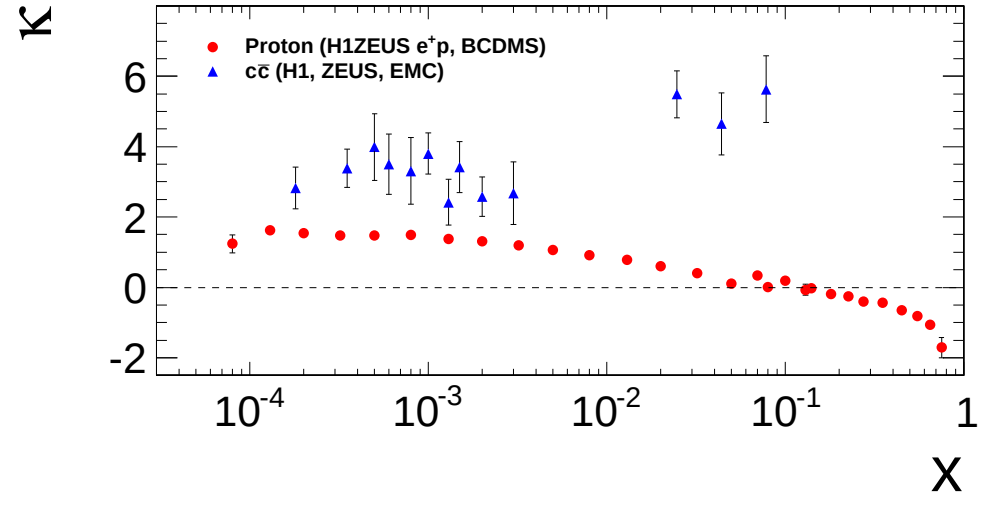
Charm in Proton:

- strong positive scaling violations
- no charm in the proton when probing with static resolution scale of $Q^2 = 0.3\ \mathrm{GeV}^2$
- all charm at higher Q^2 results from fluctuations

Hadronic Structure:



Scaling Violations:



Comparison II: Charm, Colour Singlet, Photon

Charm in Proton:

- strong positive scaling violations
- no charm at $Q^2 = 0.3\ \mathrm{GeV}^2$
- charm from fluctuations at higher Q^2

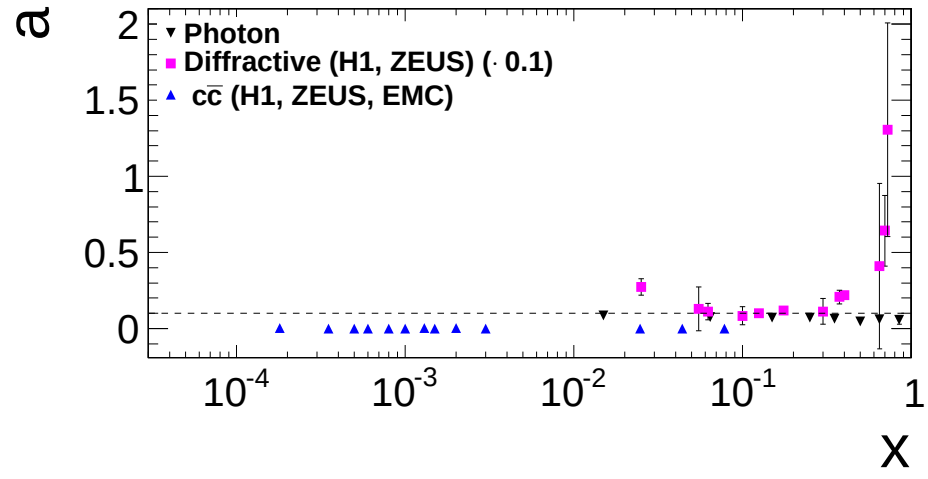
Colour Singlet Exchange:

- a devided by 10 for comparison
- high density at large x: suggestive of gluon-gluon system with 1 gluon carrying most of the momentum
- mostly positive scaling violations

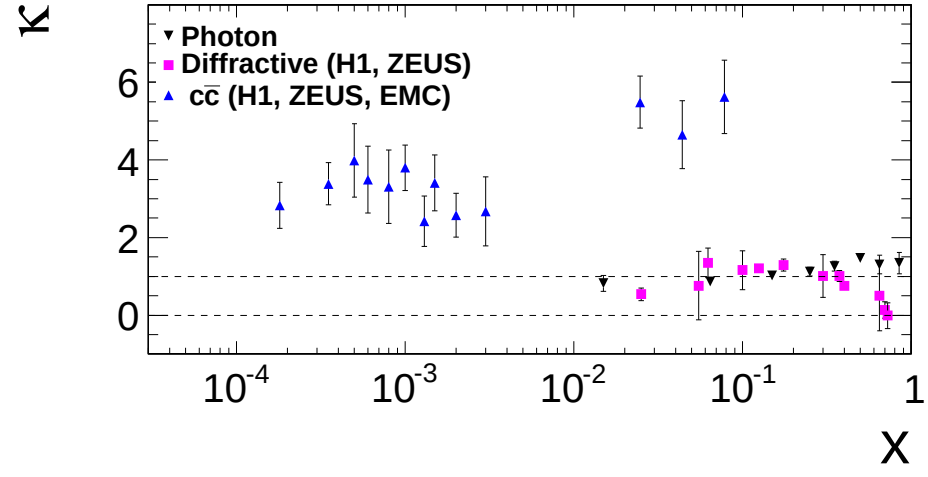
Photon:

- only sea quarks
- $\kappa(x) \sim 1$ as expected from QCD calculations

Hadronic Structure:



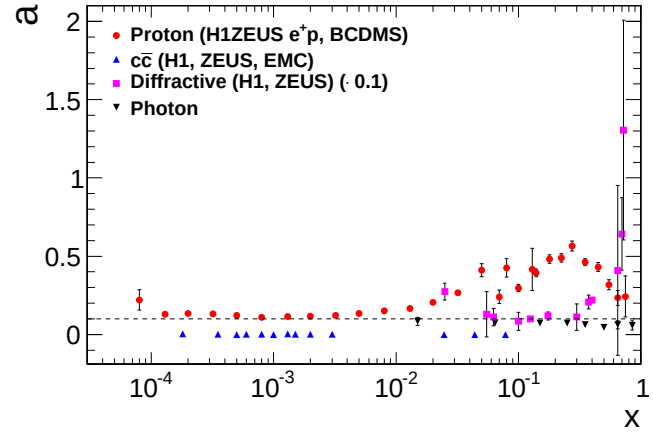
Scaling Violations:



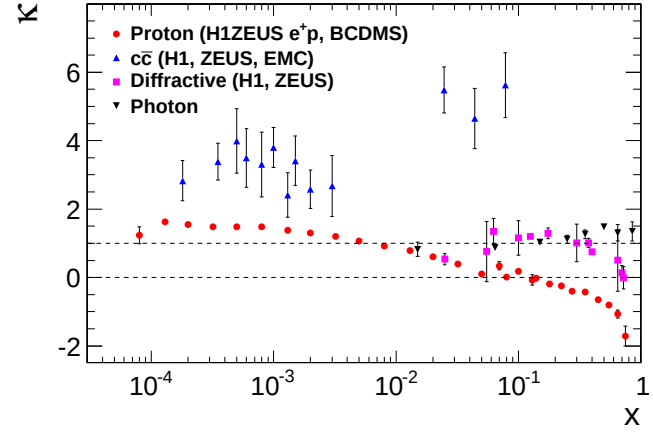
Summary

- Wealth of new data from ep collisions at HERA and e^+e^- collisions at LEP
- Hadronic structures extrapolated to $Q^2 = 0.3\ \mathrm{GeV}^2$:
  - **Proton** shows valence quarks at $x \sim 0.3$, at low x sea quarks with negligible heavy quark contributions
  - **Photon:** similar level of sea quarks as the proton
  - **Diffractive exchange:** similar level of sea contribution at low x, increase towards $x = 1$ (gluons)
- Scaling violations: strongly positive for charm, photon, proton at low x, diffractive exchange (except for $x = 1$), negative for proton at high x

Hadronic Structure:

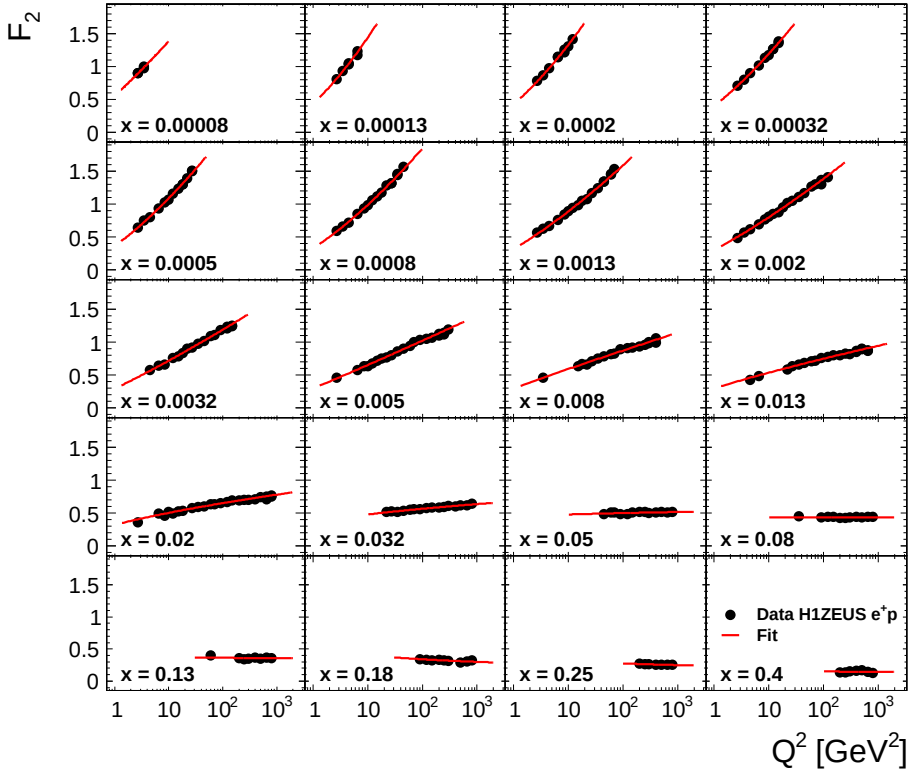


Scaling Violations:



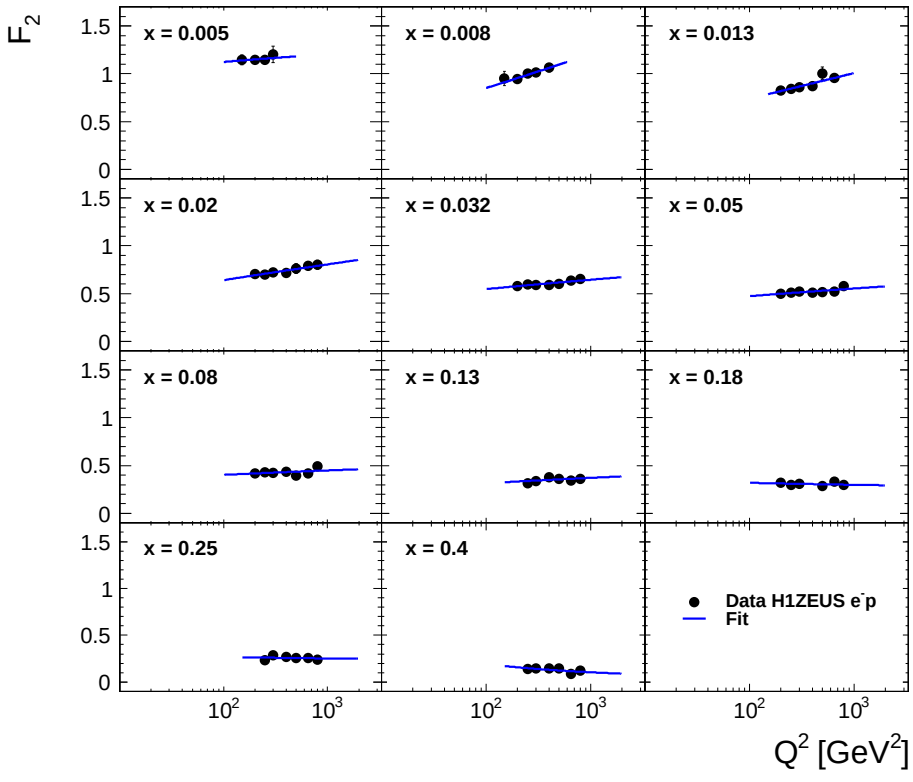
Backup Slides

Fits of combined H1/ZEUS e^+p data



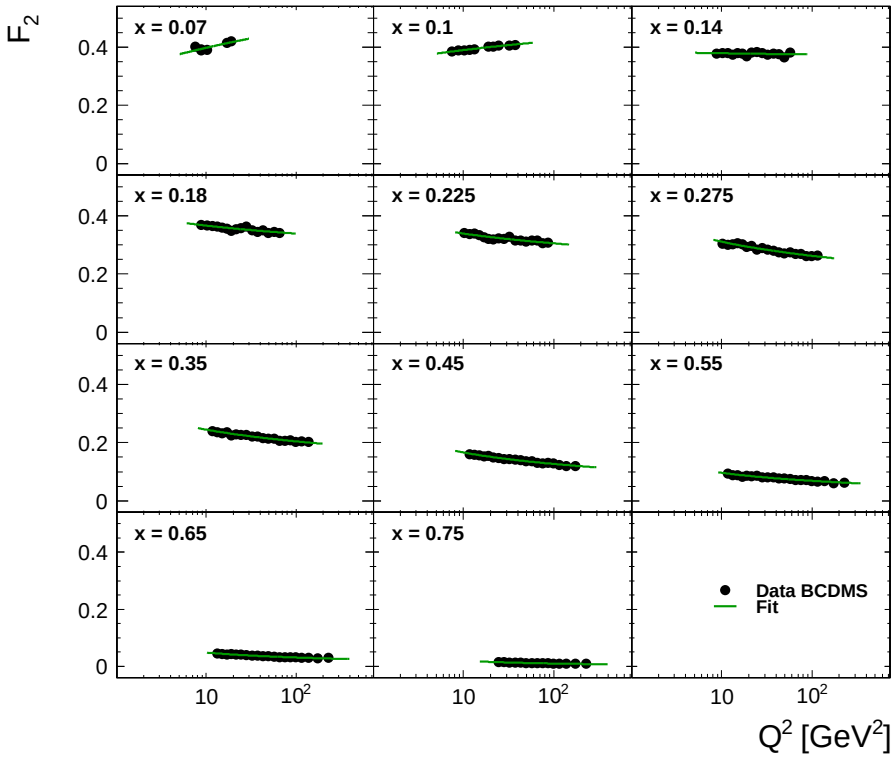
x	a	δa	κ	$\delta\kappa$	χ^2/ndf
0.00008	0.221	0.064	1.237	0.249	0.80/2
0.00013	0.129	0.012	1.624	0.073	3.00/4
0.0002	0.134	0.009	1.547	0.052	4.12/7
0.00032	0.132	0.006	1.482	0.035	3.80/8
0.0005	0.122	0.005	1.477	0.026	9.99/11
0.0008	0.109	0.004	1.486	0.022	9.71/13
0.0013	0.115	0.004	1.381	0.019	20.69/15
0.002	0.116	0.003	1.303	0.017	19.42/16
0.0032	0.122	0.004	1.197	0.020	13.39/15
0.005	0.135	0.004	1.066	0.017	26.16/19
0.008	0.152	0.005	0.919	0.017	23.60/16
0.013	0.167	0.006	0.789	0.020	28.07/18
0.02	0.205	0.007	0.609	0.018	34.72/22
0.032	0.266	0.017	0.398	0.033	7.02/14
0.05	0.411	0.041	0.106	0.050	14.62/11
0.08	0.425	0.059	0.016	0.069	5.24/9
0.13	0.416	0.136	-0.071	0.156	7.20/6
0.18	0.763	0.255	-0.425	0.164	5.18/7
0.25	0.520	0.323	-0.336	0.294	0.62/5
0.4	0.225	0.238	-0.209	0.508	8.15/5

Fits of combined H1/ZEUS e^-p data



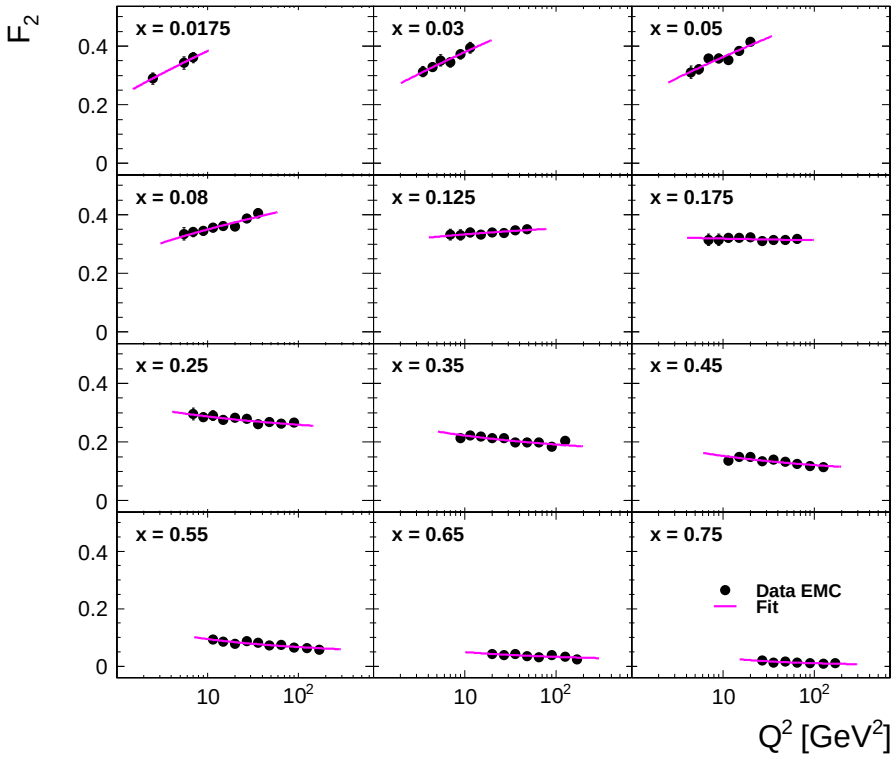
x	a	δa	κ	$\delta\kappa$	χ^2/ndf
0.005	0.717	1.239	0.236	0.862	0.29/2
0.008	0.089	0.093	1.183	0.512	0.68/3
0.013	0.100	0.068	1.049	0.330	2.11/4
0.02	0.147	0.093	0.775	0.308	1.49/5
0.032	0.189	0.126	0.558	0.324	1.21/5
0.05	0.172	0.115	0.531	0.323	2.37/5
0.08	0.201	0.145	0.366	0.351	5.17/5
0.13	0.110	0.160	0.554	0.691	4.04/4
0.18	0.499	0.653	-0.234	0.640	1.55/4
0.25	0.407	0.818	-0.219	0.953	2.63/4
0.4	10.429	46.704	-2.095	2.156	3.33/4

Fits of BCDMS data



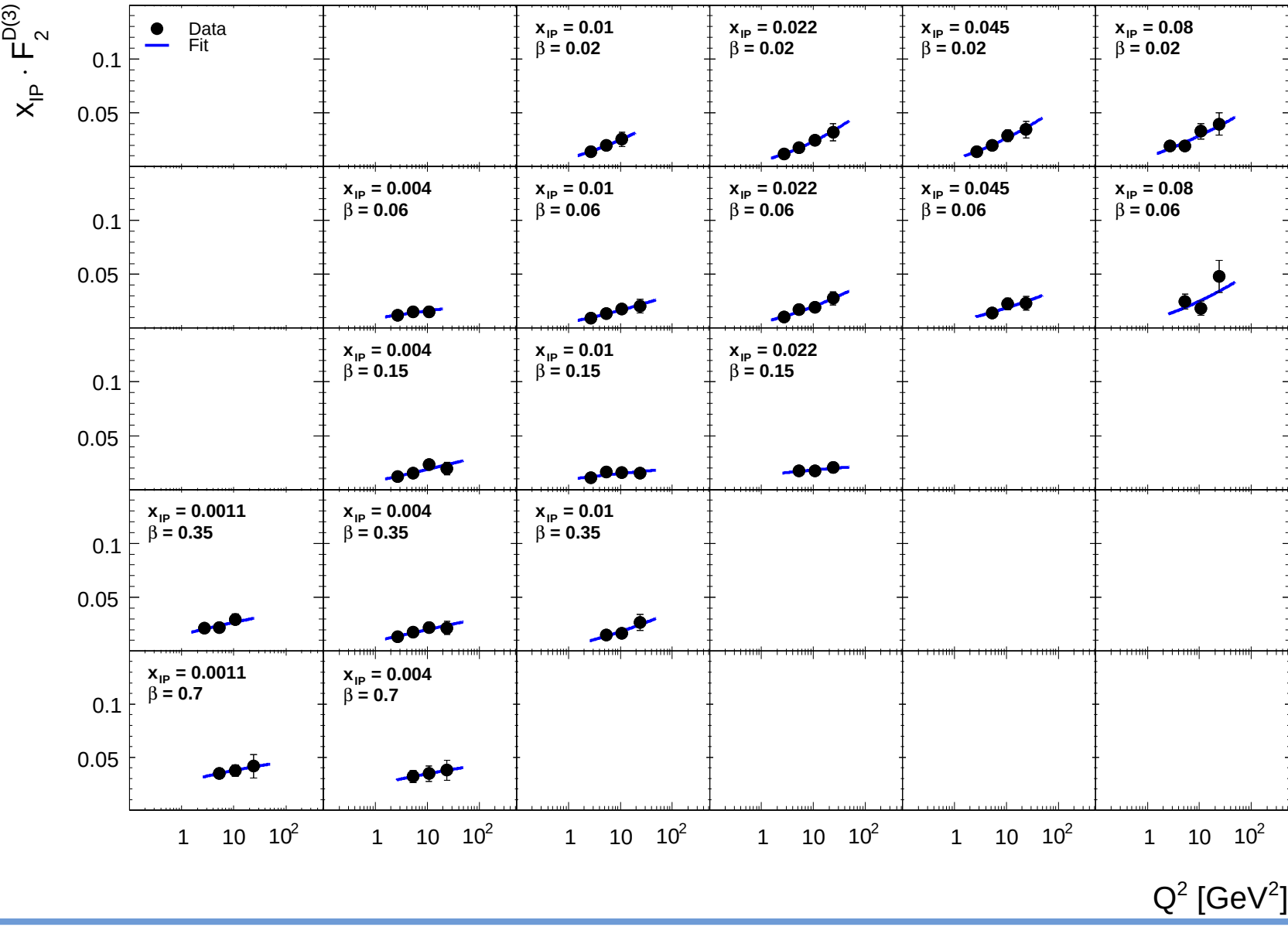
x	a	δa	κ	$\delta\kappa$	χ^2/ndf
0.07	0.240	0.043	0.341	0.118	3.17/4
0.1	0.297	0.023	0.184	0.048	0.66/8
0.14	0.394	0.025	-0.026	0.040	7.80/13
0.18	0.481	0.027	-0.185	0.033	9.11/14
0.225	0.489	0.026	-0.248	0.031	14.09/15
0.275	0.565	0.032	-0.404	0.032	12.69/17
0.35	0.462	0.023	-0.429	0.028	12.62/17
0.45	0.431	0.028	-0.643	0.036	9.79/18
0.55	0.319	0.032	-0.808	0.055	13.66/19
0.65	0.233	0.048	-1.068	0.112	4.55/18
0.75	0.243	0.131	-1.708	0.292	2.96/13

Fits of EMC data



x	a	δa	κ	$\delta\kappa$	χ^2/ndf
0.0175	0.128	0.046	0.741	0.274	0.01/1
0.03	0.131	0.035	0.719	0.196	1.01/4
0.05	0.123	0.027	0.727	0.148	4.81/5
0.08	0.177	0.034	0.459	0.120	2.07/6
0.125	0.270	0.052	0.141	0.117	0.50/6
0.175	0.339	0.062	-0.042	0.110	0.77/7
0.25	0.413	0.068	-0.245	0.097	2.39/8
0.35	0.375	0.070	-0.353	0.109	3.90/8
0.45	0.342	0.086	-0.544	0.144	5.60/7
0.55	0.322	0.116	-0.829	0.204	4.24/8
0.65	0.217	0.190	-1.001	0.484	4.05/6
0.75	1.475	3.878	-2.619	1.467	1.12/5

Fits of diffractive data (H1, DESY 06-048) I



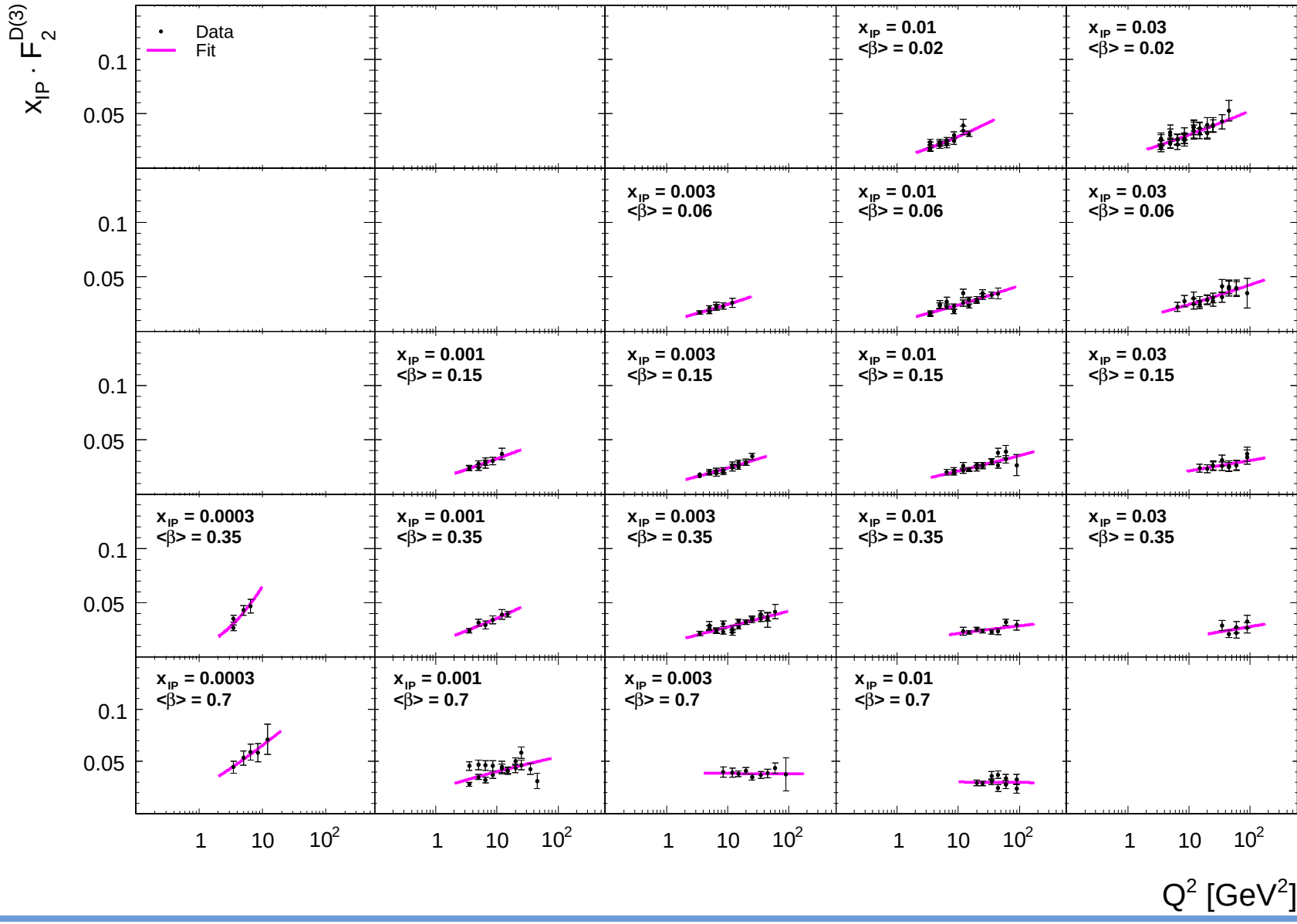
Fits of diffractive data (H1, DESY 06-048) II

x_{IP}	β	a	δa	κ	$\delta\kappa$	χ^2/ndf
0.01	0.02	0.002	0.003	1.602	0.924	0.001/1
0.022	0.02	0.001	0.001	1.945	0.527	0.051/2
0.045	0.02	0.002	0.001	1.754	0.495	0.164/2
0.08	0.02	0.003	0.003	1.523	0.675	1.62/2
0.004	0.06	0.005	0.006	0.762	0.882	0.104/1
0.01	0.06	0.002	0.002	1.49	0.629	0.129/2
0.022	0.06	0.001	0.001	1.757	0.527	0.469/2
0.045	0.06	0.002	0.002	1.553	0.871	0.507/1
0.08	0.06	0.002	0.006	1.726	2.203	2.694/1

Fits of diffractive data (H1, DESY 06-048) III

x_{IP}	β	a	δa	κ	$\delta\kappa$	χ^2/ndf
0.004	0.15	0.003	0.002	1.16	0.503	1.409/2
0.01	0.15	0.006	0.005	0.619	0.571	0.878/2
0.022	0.15	0.009	0.013	0.452	0.961	0.126/1
0.0011	0.35	0.009	0.006	0.748	0.563	0.77/1
0.004	0.35	0.004	0.003	1.006	0.548	0.416/2
0.01	0.35	0.001	0.003	1.697	1.37	0.318/1
0.0011	0.7	0.018	0.021	0.484	0.814	0.006/1
0.004	0.7	0.016	0.022	0.502	0.904	0.0/1

Fits of diffractive data (H1, DESY 06-049) I



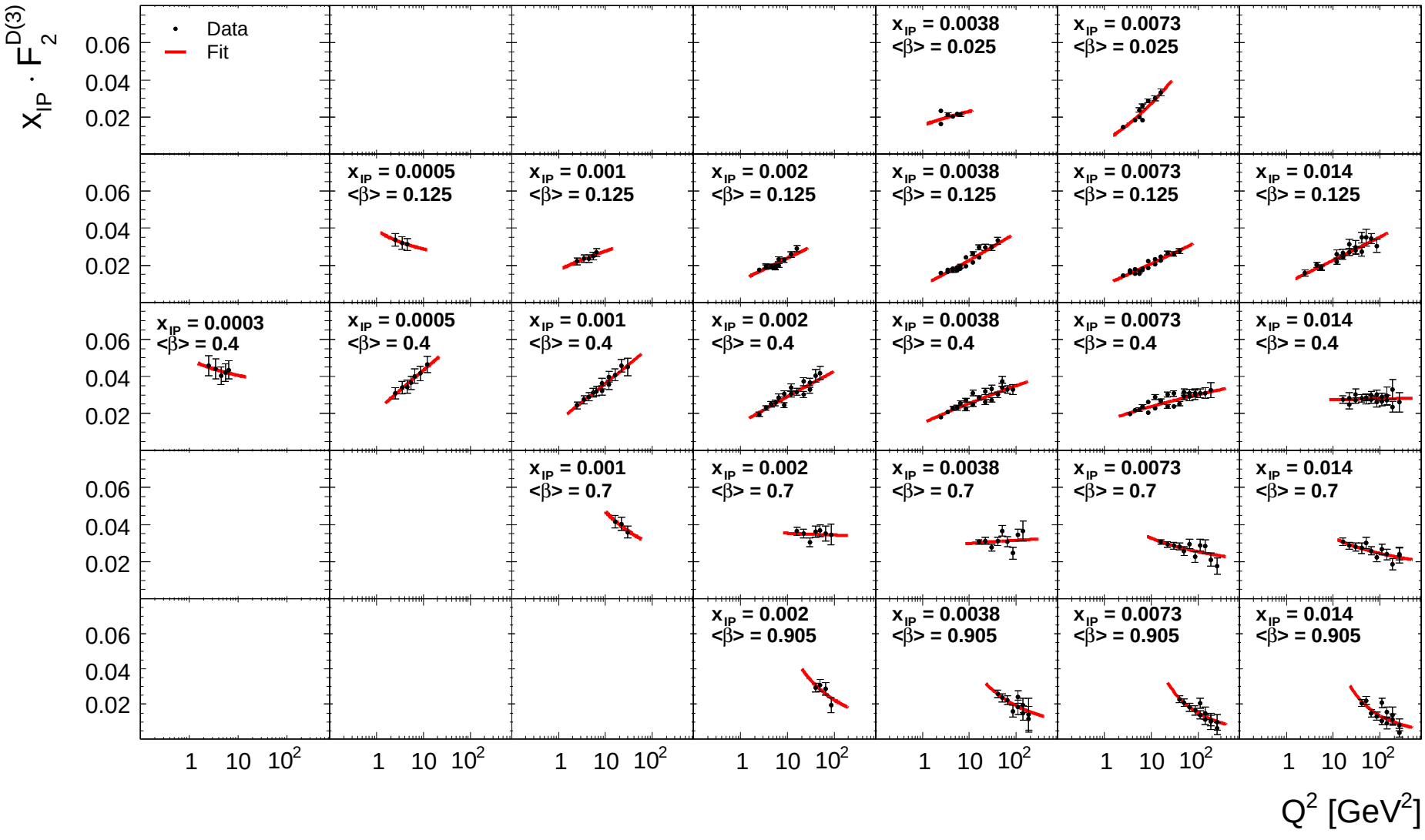
Fits of diffractive data (H1, DESY 06-049) II

x_{IP}	β	a	δa	κ	$\delta\kappa$	χ^2/ndf
0.01	0.02	0.003	0.001	1.59	0.22	14.355/13
0.03	0.02	0.005	0.001	1.285	0.21	11.495/29
0.003	0.06	0.003	0.002	1.351	0.377	2.367/6
0.01	0.06	0.003	0.001	1.308	0.142	27.716/16
0.03	0.06	0.004	0.002	1.31	0.336	5.915/15
0.001	0.15	0.006	0.003	1.194	0.408	1.575/6
0.003	0.15	0.004	0.001	1.292	0.153	8.876/13
0.01	0.15	0.004	0.001	1.207	0.19	13.604/16
0.03	0.15	0.006	0.005	0.888	0.5	3.39/10

Fits of diffractive data (H1, DESY 06-049) III

x_{IP}	β	a	δa	κ	$\delta\kappa$	χ^2/ndf
0.0003	0.35	0.001	0.001	2.729	0.762	4.96/2
0.001	0.35	0.005	0.002	1.293	0.274	1.629/4
0.003	0.35	0.006	0.001	1.01	0.136	24.783/18
0.01	0.35	0.008	0.005	0.657	0.347	5.968/6
0.03	0.35	0.004	0.015	0.999	1.913	3.554/4
0.0003	0.7	0.009	0.008	1.347	0.636	0.312/3
0.001	0.7	0.014	0.003	0.72	0.127	46.23/16
0.003	0.7	0.039	0.021	-0.012	0.325	3.74/7
0.01	0.7	0.032	0.024	-0.043	0.426	13.109/8

Fits of diffractive data (ZEUS 2008 LRG) I



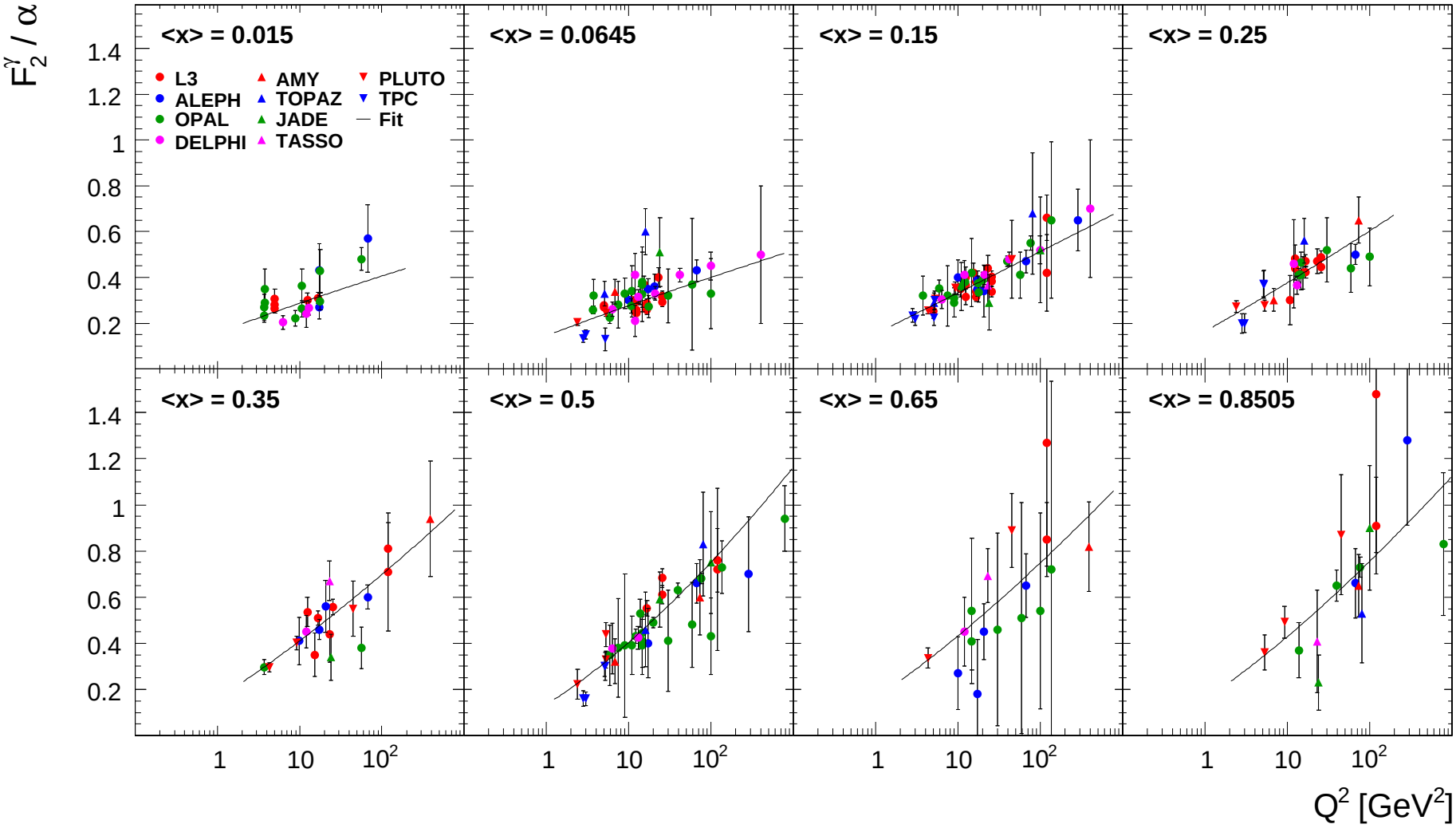
Fits of diffractive data (ZEUS 2008 LRG) II

x_{IP}	β	a	δa	κ	$\delta\kappa$	χ^2/ndf
0.0038	0.025	0.01	0.002	0.538	0.161	40.81/4
0.0073	0.025	0.002	0.0	1.797	0.118	51.755/7
0.0005	0.125	0.053	0.052	-0.41	0.82	0.003/1
0.001	0.125	0.011	0.005	0.62	0.379	0.471/3
0.002	0.125	0.006	0.001	0.965	0.14	14.203/10
0.0038	0.125	0.004	0.0	1.206	0.069	58.196/16
0.0073	0.125	0.004	0.0	1.084	0.057	53.606/16
0.014	0.125	0.005	0.001	1.052	0.1	16.783/15
0.0003	0.4	0.06	0.043	-0.268	0.557	0.422/3
0.0005	0.4	0.011	0.004	0.957	0.285	0.501/5
0.001	0.4	0.007	0.001	1.083	0.138	3.151/10
0.002	0.4	0.007	0.001	0.918	0.076	24.762/14

Fits of diffractive data (ZEUS 2008 LRG) III

x_{IP}	β	a	δa	κ	$\delta\kappa$	χ^2/ndf
0.0038	0.4	0.008	0.001	0.75	0.053	47.777/17
0.0073	0.4	0.01	0.001	0.567	0.051	83.159/21
0.014	0.4	0.026	0.008	0.039	0.166	8.9/17
0.001	0.7	0.253	0.365	-1.135	0.879	0.177/1
0.002	0.7	0.039	0.025	-0.067	0.376	4.028/5
0.0038	0.7	0.024	0.009	0.135	0.212	13.012/7
0.0073	0.7	0.079	0.024	-0.599	0.173	8.49/9
0.014	0.7	0.093	0.033	-0.703	0.198	5.798/10
0.002	0.905	1.358	3.185	-2.158	1.31	2.408/2
0.0038	0.905	0.939	1.196	-2.049	0.697	4.886/8
0.0073	0.905	4.618	4.697	-3.012	0.553	6.837/10
0.014	0.905	6.423	8.048	-3.241	0.68	20.001/10

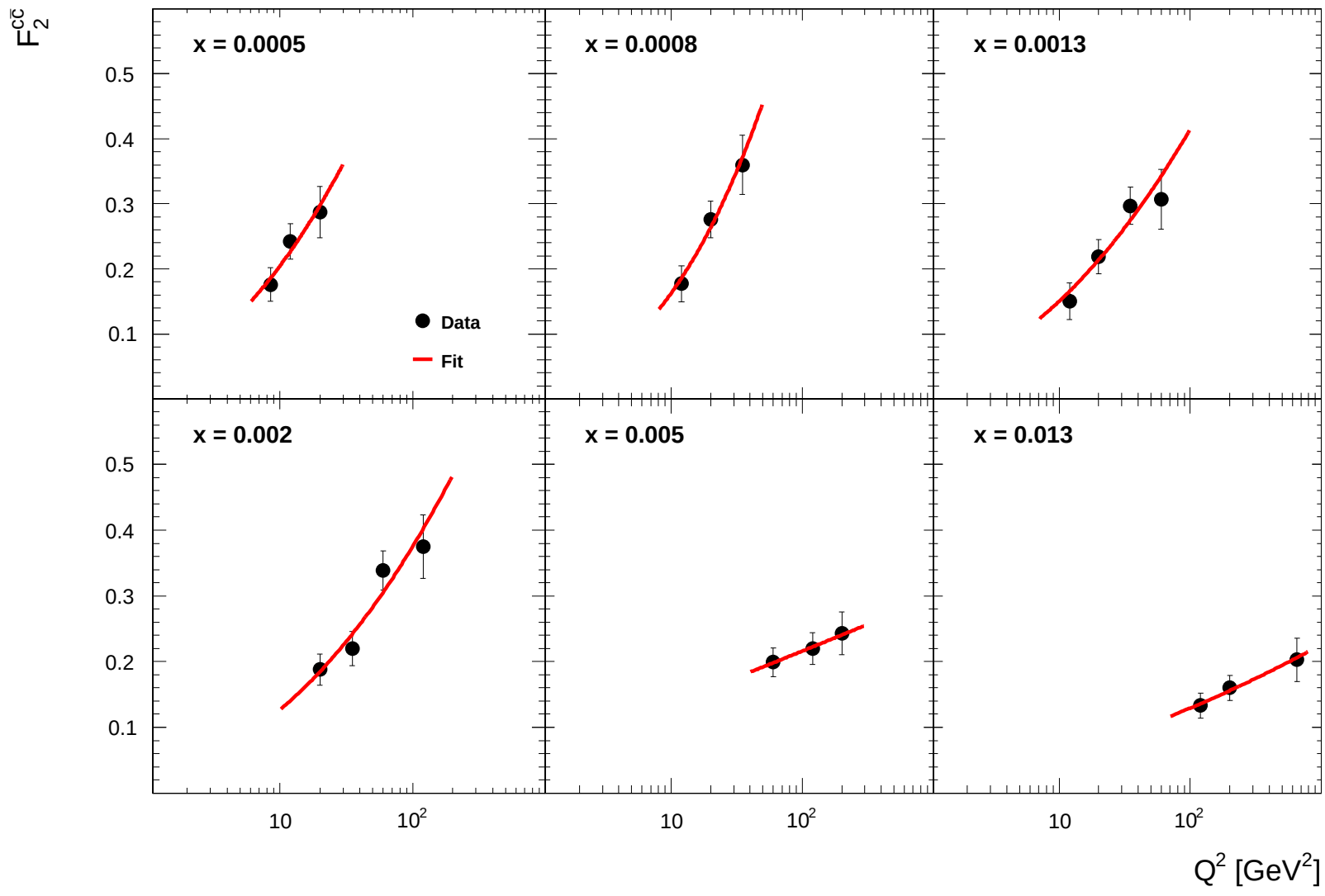
Fits of photon data I



Fits of photon data II

x	a	δa	κ	$\delta\kappa$	χ^2/ndf
0.015	0.085	0.025	0.824	0.204	26.65/19
0.065	0.076	0.009	0.874	0.077	106.539/48
0.15	0.072	0.008	1.031	0.07	57.489/53
0.25	0.072	0.013	1.118	0.114	27.169/25
0.35	0.063	0.012	1.264	0.125	23.623/18
0.5	0.045	0.006	1.477	0.081	56.96/38
0.65	0.062	0.026	1.307	0.245	10.073/15
0.851	0.059	0.029	1.345	0.277	14.723/14

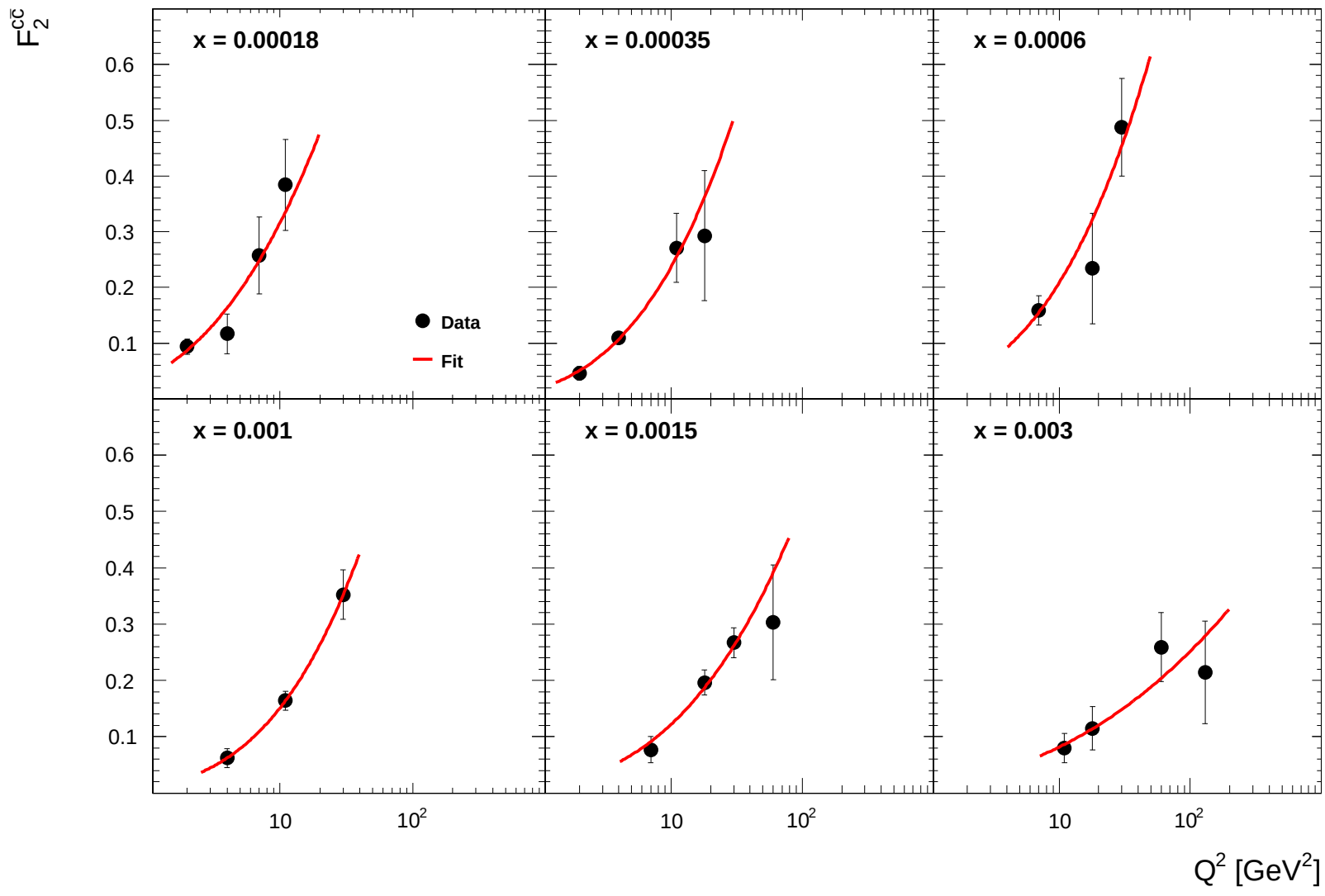
Fits of charm data (H1 inclusive) I



Fits of charm data (H1 inclusive) II

x	a	δa	κ	$\delta\kappa$	χ^2/ndf
0.0005	0.005	0.008	2.561	1.077	0.519/1
0.0008	0.001	0.002	3.305	0.947	0.363/1
0.0013	0.004	0.005	2.416	0.651	1.525/2
0.002	0.003	0.003	2.581	0.563	2.279/2
0.005	0.027	0.052	1.092	1.015	0.017/1
0.013	0.004	0.007	1.89	1.005	0.084/1

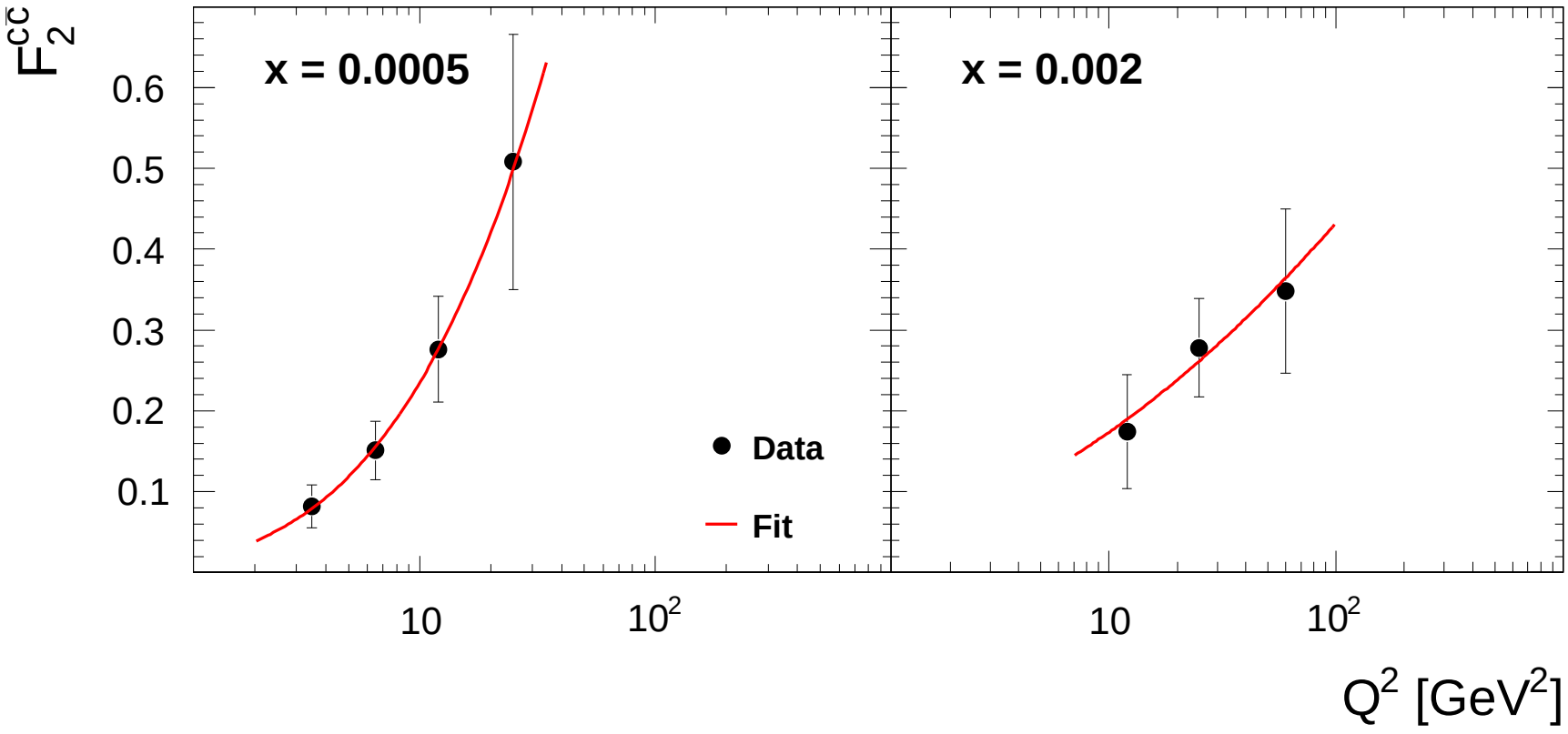
Fits of charm data (ZEUS D meson) I



Fits of charm data (ZEUS D meson) II

x	a	δa	κ	$\delta\kappa$	χ^2/ndf
0.0002	0.005	0.003	2.829	0.591	2.294/2
0.0004	0.002	0.001	3.385	0.542	0.639/2
0.0006	0.001	0.002	3.495	0.859	0.963/1
0.001	0.001	0.0	3.802	0.585	0.0/1
0.0015	0.001	0.001	3.413	0.722	1.345/2
0.003	0.002	0.002	2.677	0.89	1.384/2

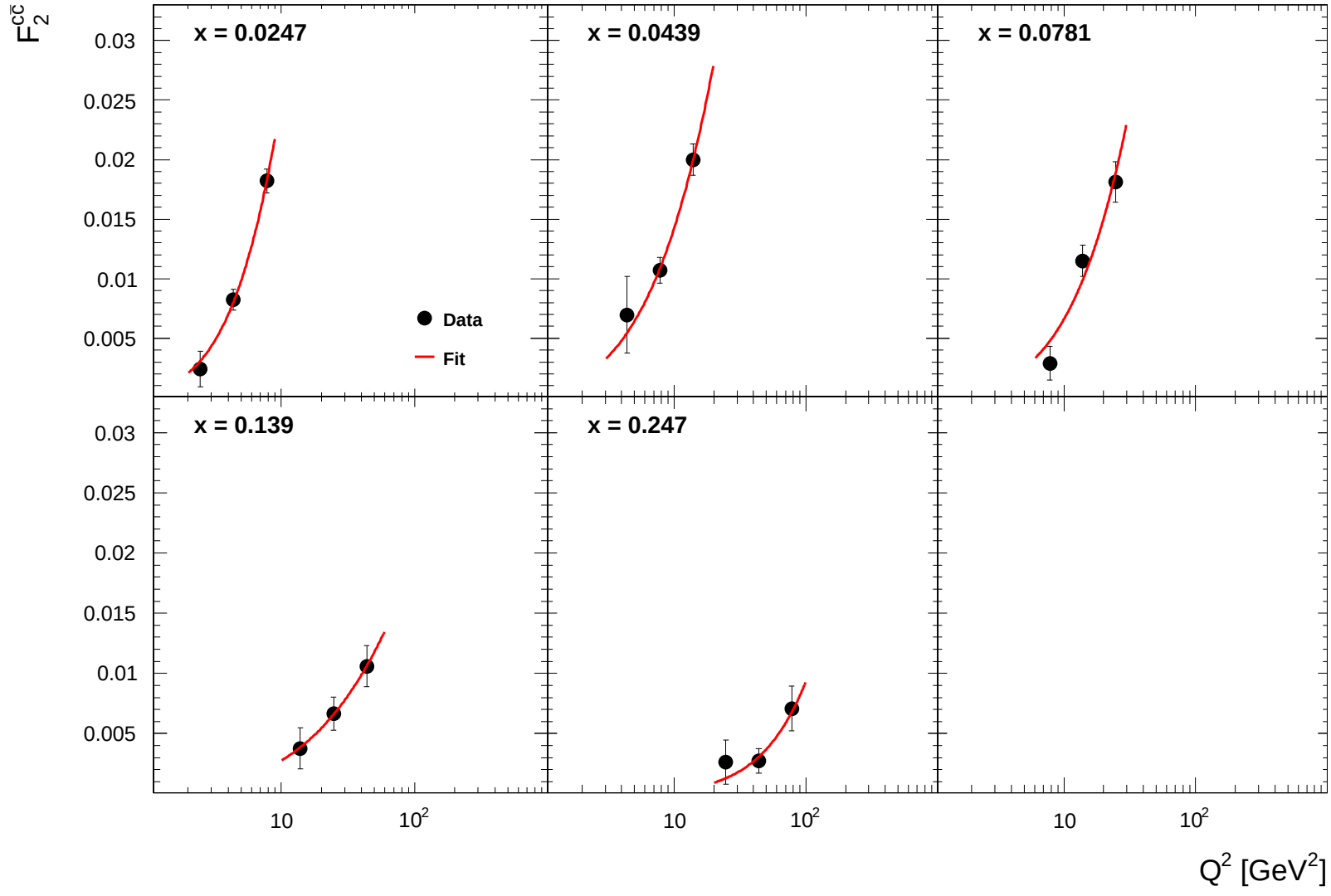
Fits of charm data (H1 D meson) I



Fits of charm data (H1 D meson) II

x	**a**	δ**a**	κ	$\delta\kappa$	χ^2/ndf
0.0005	**0.001**	**0.001**	**3.992**	**0.945**	**0.031/2**
0.002	**0.007**	**0.017**	**2.173**	**1.465**	**0.147/1**

Fits of charm data (EMC) I



Fits of charm data (EMC) II

x	a	δa	κ	$\delta\kappa$	χ^2/ndf
0.0247	0.0	0.0	5.486	0.671	0.239/1
0.0439	0.0	0.0	4.65	0.878	0.253/1
0.0781	0.0	0.0	5.626	0.947	3.448/1
0.139	0.0	0.0	4.668	1.815	0.005/1
0.247	0.0	0.0	8.497	4.54	0.678/1

Used Publications I

Proton:

- **J. J. Aubert *et al.* [European Muon Collaboration], Nucl. Phys. B 259 (1985) 189.**
- **A. C. Benvenuti *et al.* [BCDMS Collaboration], Phys. Lett. B 223 (1989) 485.**
- **F. D. Aaron *et al.* [H1 Collaboration and ZEUS Collaboration], JHEP 1001 (2010) 109 [arXiv:0911.0884 [hep-ex]].**

Diffractive Exchange:

- **S. Chekanov *et al.* [ZEUS Collaboration], Nucl. Phys. B 816 (2009) 1 [arXiv:0812.2003 [hep-ex]].**
- **S. Chekanov [ZEUS Collaboration], Nucl. Phys. B 800 (2008) 1 [arXiv:0802.3017 [hep-ex]].**
- **A. Aktas *et al.* [H1 Collaboration], Eur. Phys. J. C 48 (2006) 749 [arXiv:hep-ex/0606003].**
- **A. Aktas *et al.* [H1 Collaboration], Eur. Phys. J. C 48 (2006) 715 [arXiv:hep-ex/0606004].**

Used Publications II

Photon:

- **M. Acciarri** *et al.* **[L3 Collaboration], Phys. Lett. B 436 (1998) 403.**
- **M. Acciarri** *et al.* **[L3 Collaboration], Phys. Lett. B 447 (1999) 147.**
- **M. Acciarri** *et al.* **[L3 Collaboration], Phys. Lett. B 483 (2000) 373 [arXiv:hep-ex/0004005].**
- **P. Achard** *et al.* **[L3 Collaboration], Phys. Lett. B 622 (2005) 249 [arXiv:hep-ex/0507042].**
- **R. Akers** *et al.* **[OPAL Collaboration], Z. Phys. C 61 (1994) 199.**
- **K. Ackerstaff** *et al.* **[OPAL Collaboration], Z. Phys. C 74 (1997) 33.**
- **K. Ackerstaff** *et al.* **[OPAL Collaboration], Phys. Lett. B 411 (1997) 387 [arXiv:hep-ex/9708019].**
- **K. Ackerstaff** *et al.* **[OPAL Collaboration], Phys. Lett. B 412 (1997) 225 [arXiv:hep-ex/9708028].**
- **G. Abbiendi** *et al.* **[OPAL Collaboration], Eur. Phys. J. C 18 (2000) 15 [arXiv:hep-ex/0007018].**
- **R. Barate** *et al.* **[ALEPH Collaboration], Phys. Lett. B 458 (1999) 152.**
- **A. Heister** *et al.* **[ALEPH Collaboration], Eur. Phys. J. C 30 (2003) 145.**
- **P. Abreu** *et al.* **[DELPHI Collaboration], Z. Phys. C 69 (1996) 223.**
- **T. Sasaki** *et al.* **[AMY Collaboration], Phys. Lett. B 252 (1990) 491.**
- **S. K. Sahu** *et al.* **[AMY Collaboration], Phys. Lett. B 346 (1995) 208.**

Used Publications III

Photon (continued):

- **T. Kojima** *et al.* **[AMY Collaboration], Phys. Lett. B 400 (1997) 395.**
- **K. Muramatsu** *et al.* **[TOPAZ Collaboration], Phys. Lett. B 332 (1994) 477.**
- **M. Althoff** *et al.* **[TASSO Collaboration], Z. Phys. C 31 (1986) 527.**
- **W. Bartel** *et al.* **[JADE Collaboration], Z. Phys. C 24 (1984) 231.**
- **W. Bartel** *et al.* **[JADE Collaboration], Phys. Lett. B 121 (1983) 203.**
- **C. Berger** *et al.* **[PLUTO Collaboration], Phys. Lett. B 142 (1984) 111.**
- **C. Berger** *et al.* **[PLUTO Collaboration], Nucl. Phys. B 281 (1987) 365.**
- **H. Aihara** *et al.* **[TPC/Two Gamma Collaboration], Z. Phys. C 34 (1987) 1.**
- **H. Aihara** *et al.* **[TPC/Two Gamma Collaboration], Phys. Rev. Lett. 58 (1987) 97.**

Used Publications IV

Charm Structure Function:

- **C. Adloff** *et al.* **[H1 Collaboration], Phys. Lett. B 528 (2002) 199 [arXiv:hep-ex/0108039].**
- **F. D. Aaron** *et al.* **[H1 Collaboration], Eur. Phys. J. C 65 (2010) 89 [arXiv:0907.2643 [hep-ex]].**
- **S. Chekanov** *et al.* **[ZEUS Collaboration], Phys. Rev. D 69 (2004) 012004 [arXiv:hep-ex/0308068].**
- **A. Aktas** *et al.* **[H1 Collaboration], Eur. Phys. J. C 40 (2005) 349 [arXiv:hep-ex/0411046].**
- **A. Aktas** *et al.* **[H1 Collaboration], Eur. Phys. J. C 45 (2006) 23 [arXiv:hep-ex/0507081].**
- **J. J. Aubert** *et al.* **[European Muon Collaboration], Nucl. Phys. B 213 (1983) 31.**