Investigation of parton densities at very high x

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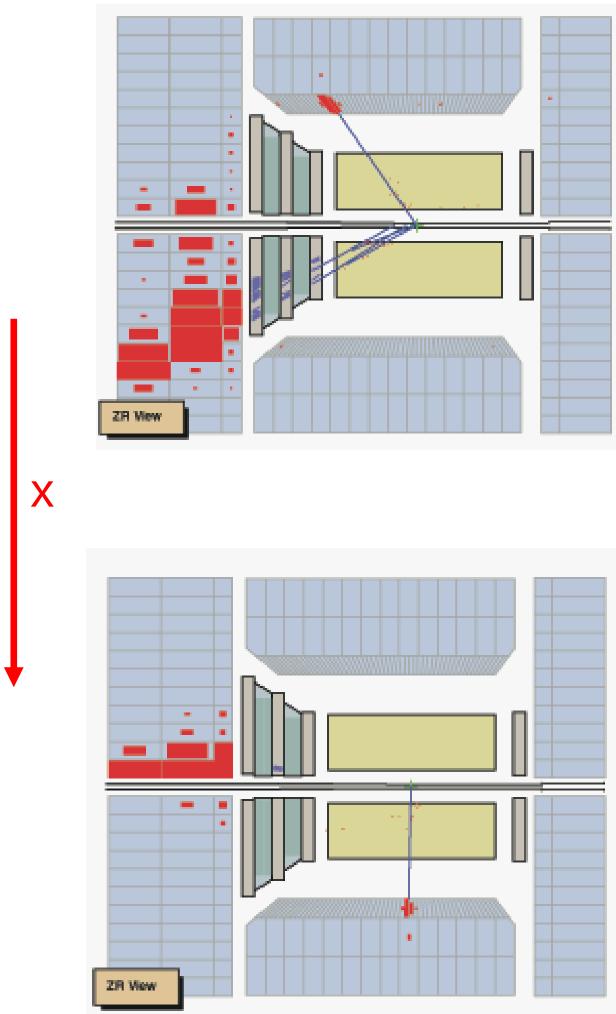
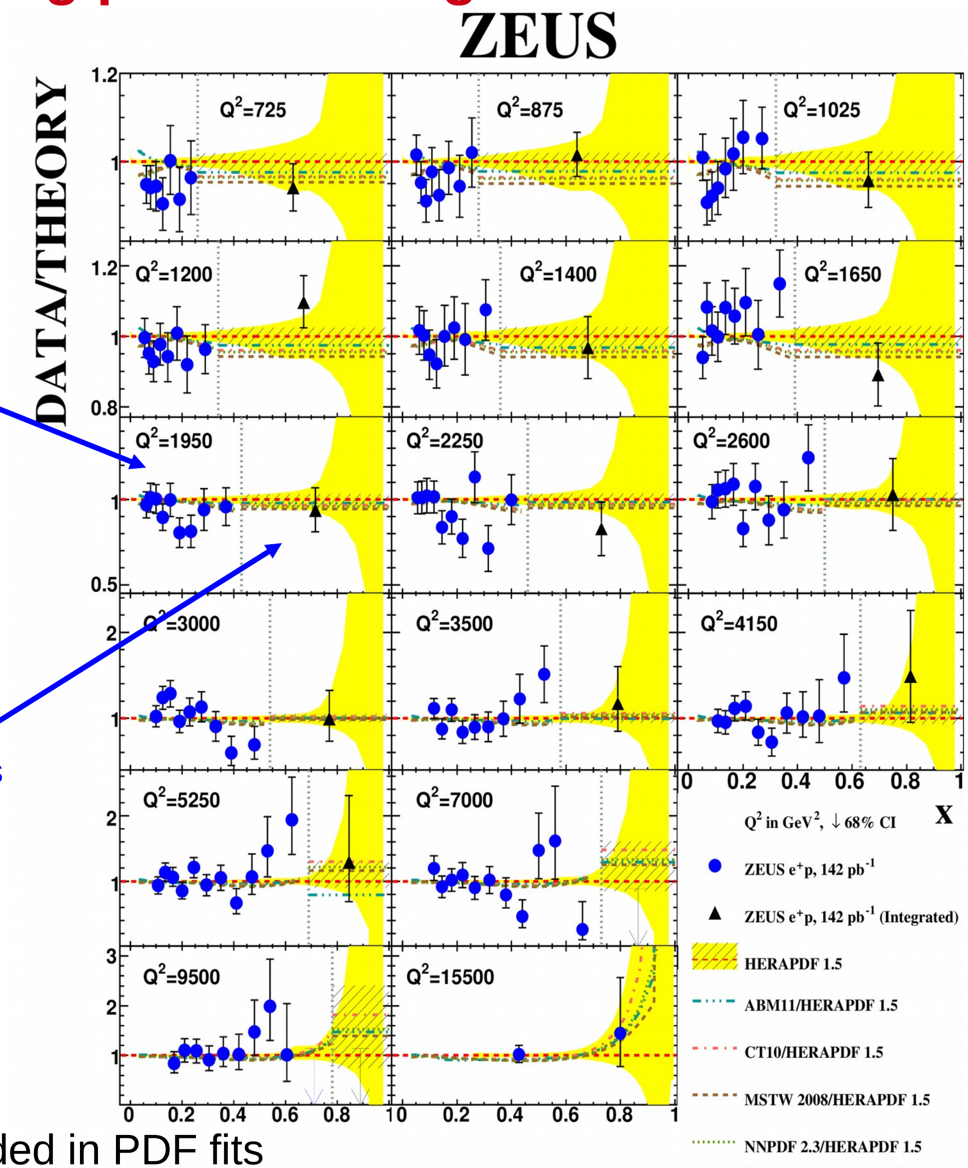
(on the behalf of ZEUS Collaboration)

Overview

- Motivation
- Transfer Matrix for ZEUS detector for high-x data
- Comparison of different PDFs to the high-x data using high-x Transfer Matrix
- p-values for different PDFs when compared to data

Motivation of studying published high-x data





Integrated bins
(cross sections
Integrated in x)

At present x upto 0.65 ZEUS data is included in PDF fits

Note the uncertainity bands above x ~ 0.65, can high-x data impact here

ZEUS Collaboration; H. Abramowicz et al. Measurement of Neutral Current $e^{\pm}p$ Cross-Sections at High Bjorken x with the ZEUS Detector Phys. Rev. D 89 (2014) 072007

High-x data is still not used..

1) Some of the bins have low number of events / few have zero, so poisson errors are quoted.

2) Ofcourse it has a subset of data (high-Q2 ZEUS data) already included in fits, but high-x data has more to say.

Transfer Matrix for the detector is developed using which number of events reconstructed in data can be predicted from any PDF as below.

- Get a prediction for the generator/hadron level number of events, which is luminosity x radiative corrections x Born cross section.

i.e. $$\nu_{i,k} = \mathcal{L} K_{ii} \sigma_{i,k}$$

- Apply transfer matrix a_{ij} to get the number of events in a bin j.

$$\nu_{j,k} \approx \sum_i a_{ij} \nu_{i,k}$$

L : data luminosity
K_{ii} : Radiative corrections (calculated using HERACLES)
$\sigma_{i,k}$: born level cross sections in i^{th} bin for k^{th} PDF
$\boldsymbol{a_{ij}}$ has all detector and analysis effects
(probability of an event reconstructed in j^{th} bin to come from i^{th} true bin)

Transfer Matrix : Probability of an event reconstructed in j^{th} bin to come from i^{th} true bin

Tracing back the path of MC reconstructed events in the generated x-Q^2 phase space

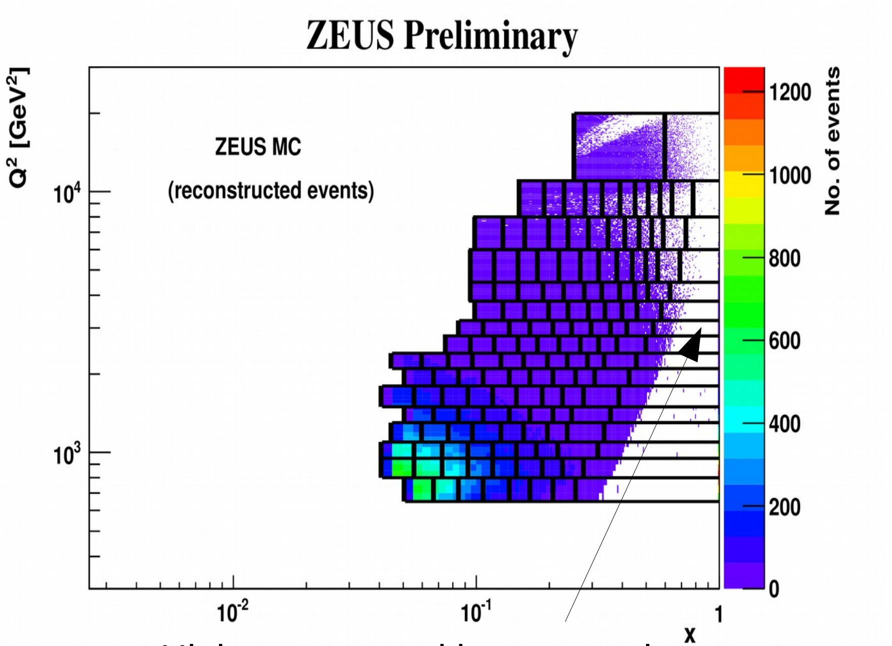
$$a_{ij} = \frac{\sum_{m=1}^{M_i} \omega_m I(m \in j)}{\sum_{m=1}^{M_i} \omega_m^{MC}}$$

a_{ij} = probability of an event reconstructed in j^{th} bin to come from i^{th} bin

ω_m = MC weights given to m^{th} event in bin i

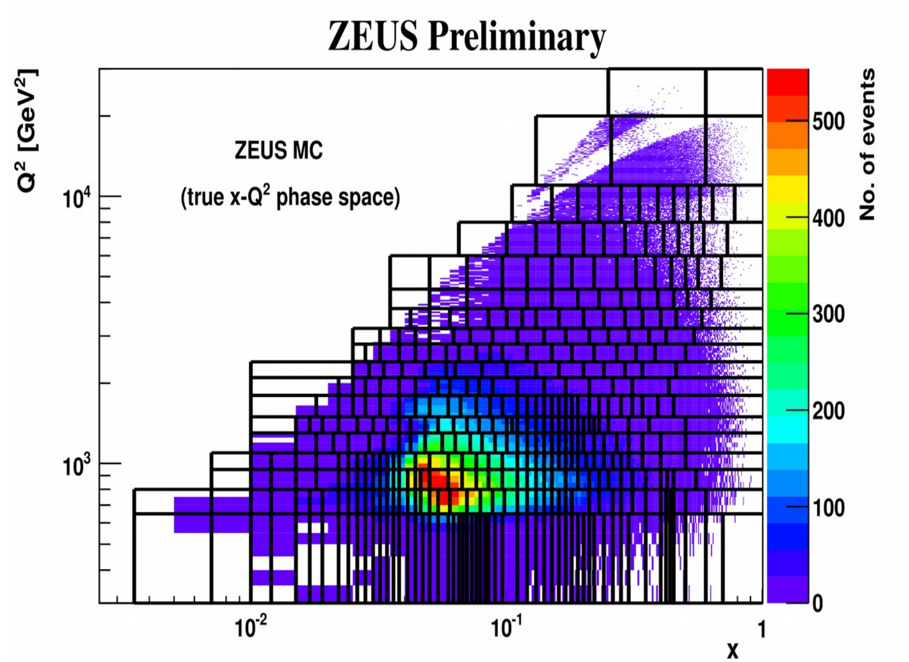
I = 1 if m^{th} event is reconstructed in bin j, else = 0

M_i = total events generated in i^{th} bin



High-x events with x > x_edge

Reconstructed MC events in xsection binning 'N' (total 153 bins)



Generated distribution of these events in extended binning 'M' (total 429 bins)

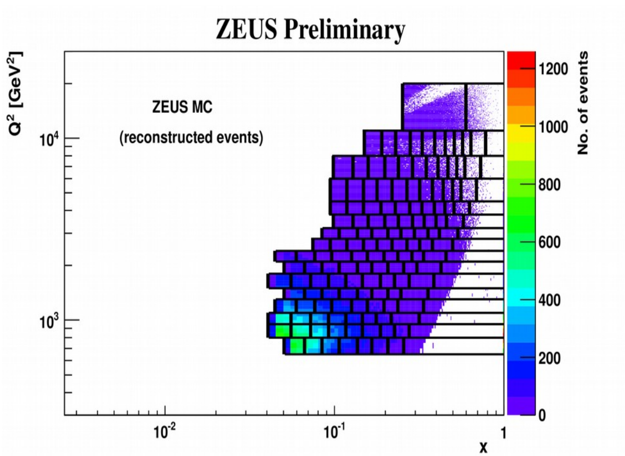
Note : MC samples used as in high-x paper.

Using Transfer matrix to predict no. of events reconstructed in a given cross section bin

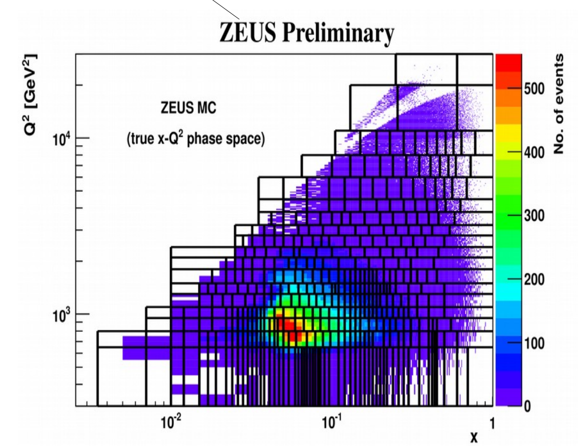
N = T M

Transfer Matrix

(153 X 429 elements)



Predicted x-Q2 events in Cross section binning
(153 elements in N Vector = number of cross section bins)



Generated x-Q2 events in Extended binning

(429 elements in M Vector = number of generated bins)

Comparison of Different PDFs

Two type of comparisons

1) ***Comparison at generator level*** from different PDFs : comparison of the bin integrated born level cross sections in x-Q^2 bins using different PDFs
(next two slides)

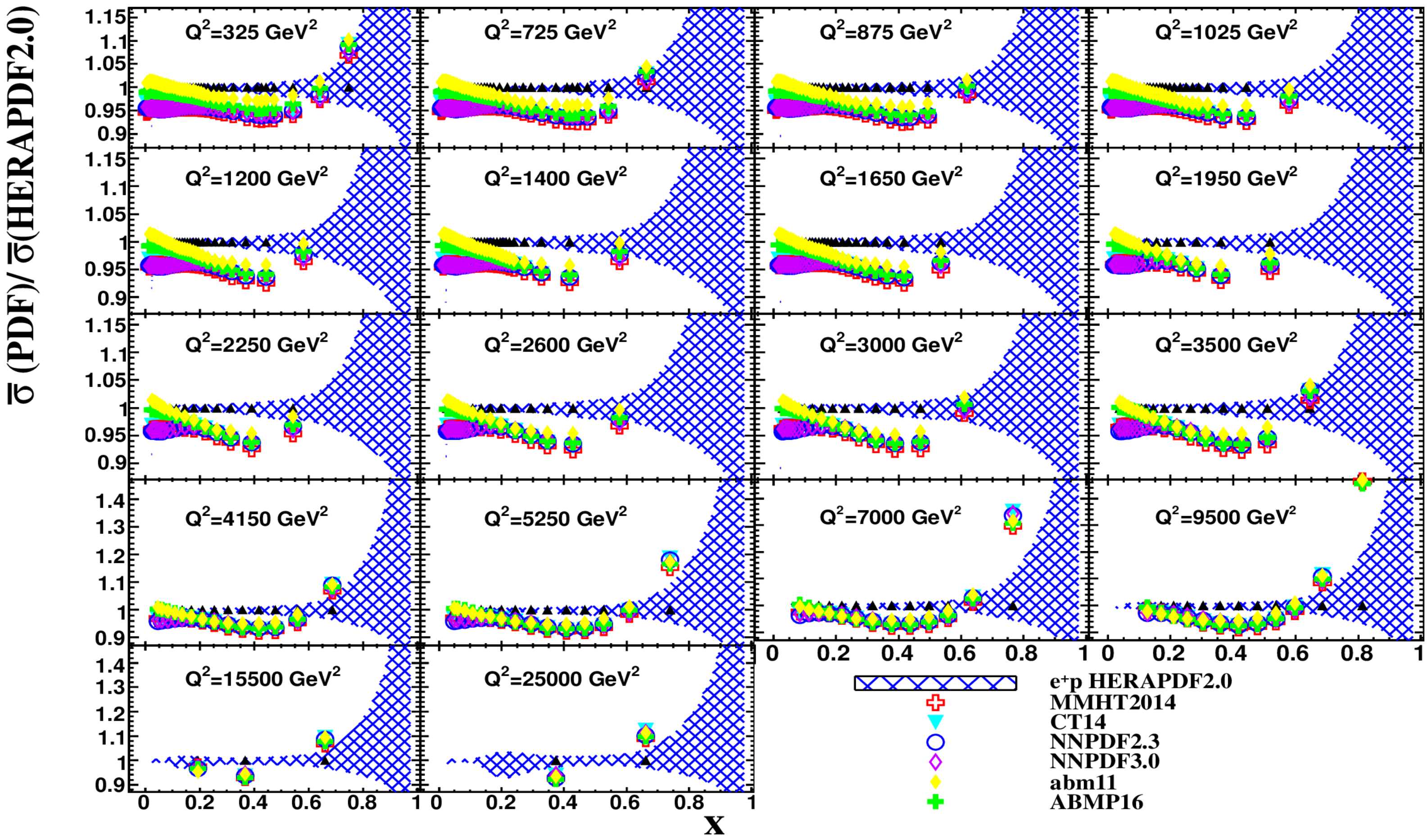
2) ***Comparison at reconstructed level*** from different PDFs : Convolute M with Transfer Matrix to get a prediction of number of events in the cross section Bins (ν) from different PDFs (rest of the talk)

- ν from different PDF is compared to observed events from data and Poisson statistics is used to probe how well given PDF is defining the data.

- p-value is determined for different PDFs

- Comparison of p-values in high-x and lower-x range is shown for different PDFs

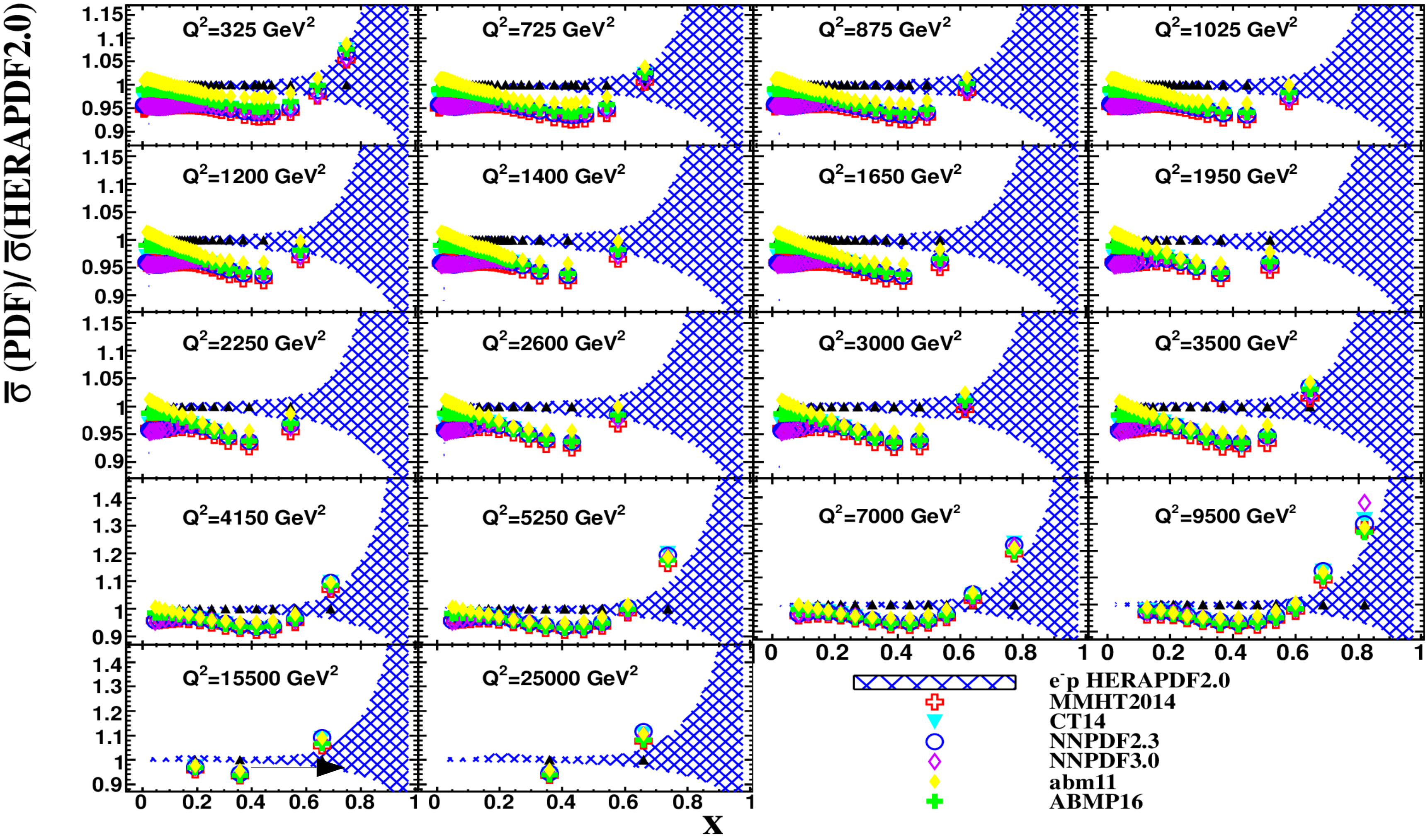
Ratio of generated level cross sections in different PDFs (at NLO) to HERAPDF2.0NLO for M bins (e+p)



Where $\bar{\sigma}$ is the total integrated cross section in a given x-Q^2 bin

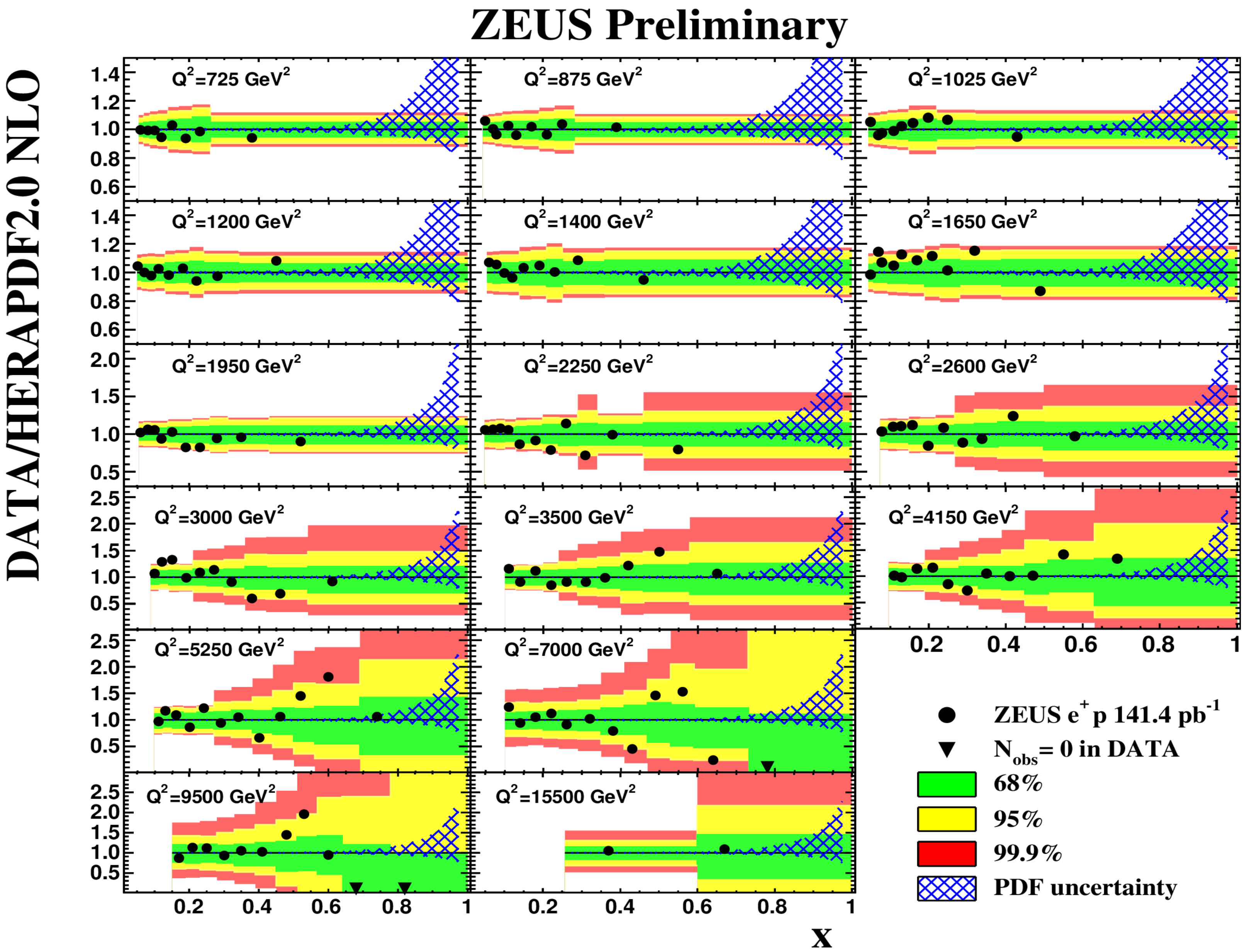
There is a shape difference between HERAPDF & other PDFs, approaches 10% at x ~ 0.4.

Ratio of generated level cross sections in different PDFs (at NLO) to HERAPDF2.0NLO for M bins (e-p)



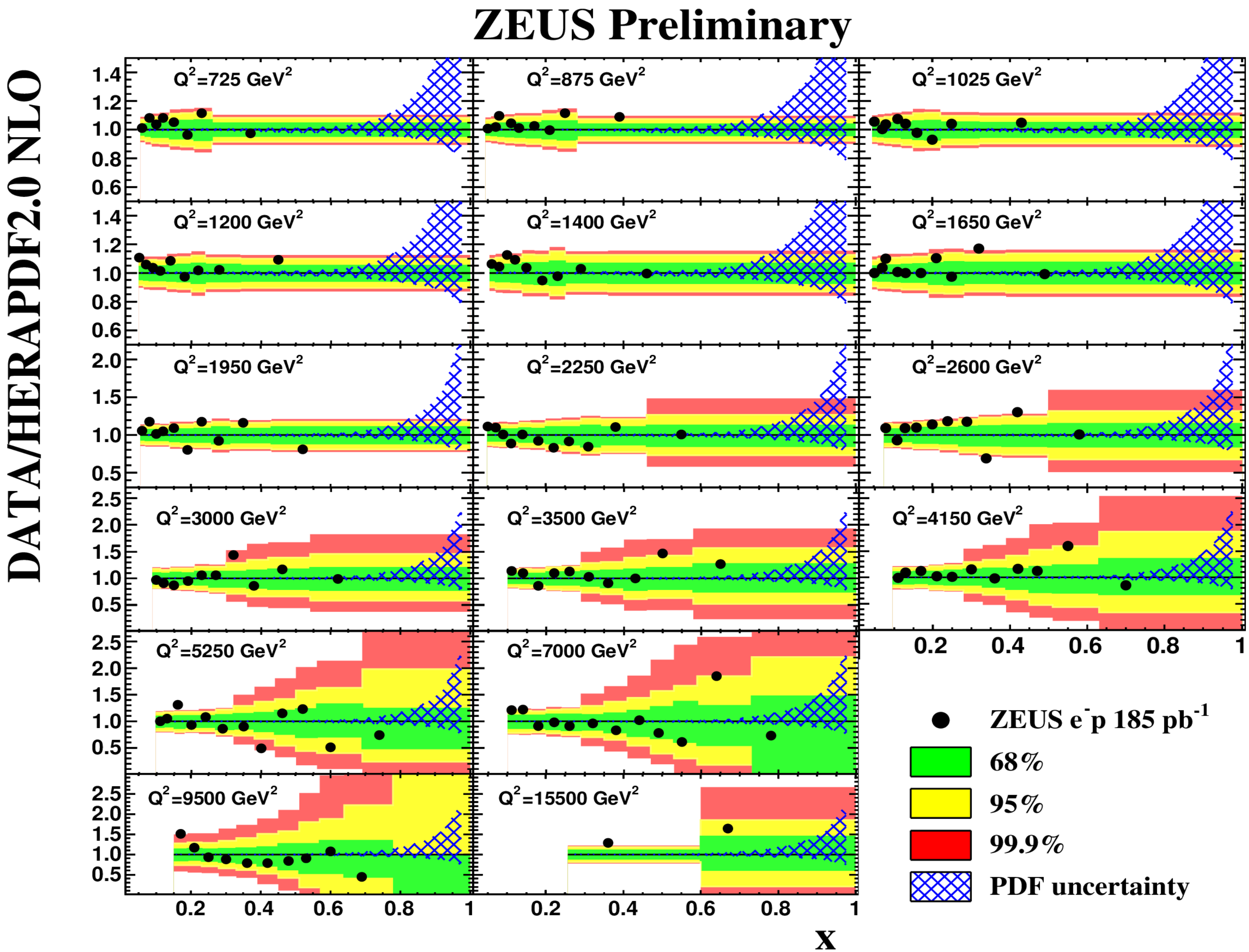
There is a shape difference between HERAPDF & other PDFs, approaches 10% at x ~ 0.4.

Ratio of No. of events in data to HERAPDF2.0 NLO and 1,2,3 sigma bands from Poisson Statistics



R. Aggarwal, A. Caldwell, Error bars for distributions of numbers of events. Eur. Phys. J. Plus 2012, 127, 1–8.

Ratio of No. of events in data to HERAPDF2.0 NLO and 1,2,3 sigma bands from Poisson Statistics



Probability for explaining high-x data from different PDFs

PDF	e^-p	e^+p
$HERAPDF2.0$	0.05	0.5
$CT14$	0.002	0.8
$MMHT2014$	0.002	0.8
$NNPDF2.3$	0.00007	0.6
$NNPDF3.0$	0.0002	0.7
$ABMP16$	0.01	0.8
$ABM11$	0.001	0.6

p-value for e-p and e+p data sets are shown on comparison to different PDFs
(includes only statistical fluctuation from Poisson probabilities).

Conclusions :

- **p-values from MMHT2014, CT14nlo, NNPDF2.3, ABM higher than HERAPDF2.0 for e^+p**
- **Much worse for e^-p**

F. Beaujean et al, p-values for model evaluation, Phys. Rev. D 83, 012004 (2011). arXiv:1011.1674

Probability for explaining high-x data from different PDFs in different x-ranges

	e^-p		e^+p	
PDF	$x < 0.6$	$x \geq 0.6$	$x < 0.6$	$x \geq 0.6$
HERAPDF2.0	0.06	0.2	0.6	0.1
CT14	0.0008	0.2	0.7	0.6
MMHT2014	0.00003	0.1	0.6	0.6
NNPDF2.3	0.00007	0.2	0.6	0.6
NNPDF3.0	0.00003	0.2	0.6	0.6
ABMP16	0.01	0.2	0.8	0.5
ABM11	0.03	0.3	0.7	0.4

p-value for e-p and e+p data sets are shown on comparison to different PDFs for two different x ranges.

Conclusions :

- **Disagreement comes primarily from lower x in e-p**

Statistical and systematic uncertainties

Type of Systematic Uncertainties :

1) Affecting the predictions at generator level (M values)
2) Affecting the Transfer Matrix (T)

Type I :
1) Luminosity uncertainty scaling M values

Type II :
1) MC statistical fluctuations (uncorrelated uncertainty)
2) All correlated and uncorrelated systematic uncertainties as in high-x paper
3) Choice of PDF for building T

Nomalization Error : Vary generated events by 1.8 % up and down and calculate new p-value

+1.8 %				
	e^-p		e^+p	
PDF	$x < 0.6$	$x \geq 0.6$	$x < 0.6$	$x \geq 0.6$
HERAPDF2.0	0.02	0.1	0.2	0.3
CT14	0.02	0.3	0.8	0.5
MMHT2014	0.008	0.2	0.8	0.5
NNPDF2.3	0.009	0.3	0.8	0.4
NNPDF3.0	0.008	0.3	0.8	0.4
ABMP16	0.04	0.3	0.6	0.4
ABM11	0.03	0.3	0.4	0.2
−1.8 %				
	e^-p		e^+p	
PDF	$x < 0.6$	$x \geq 0.6$	$x < 0.6$	$x \geq 0.6$
HERAPDF2.0	0.03	0.3	0.8	0.2
CT14	0.0	0.08	0.4	0.6
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NNPDF2.3	0.0	0.08	0.2	0.6
NNPDF3.0	0.0	0.08	0.2	0.6
ABMP16	0.0003	0.1	0.7	0.6
ABM11	0.004	0.2	0.7	0.5

(Scale M by 1.8% up)

	e^-p		e^+p	
PDF	$x < 0.6$	$x \geq 0.6$	$x < 0.6$	$x \geq 0.6$
HERAPDF2.0	0.06	0.2	0.6	0.1
CT14	0.0008	0.2	0.7	0.6
MMHT2014	0.00003	0.1	0.6	0.6
NNPDF2.3	0.00007	0.2	0.6	0.6
NNPDF3.0	0.00003	0.2	0.6	0.6
ABMP16	0.01	0.2	0.8	0.5
ABM11	0.03	0.3	0.7	0.4

(Scale M by 1.8% down)

Dominant systematics : due to error in normalization of data quoted as 1.8 %

Conclusions :

- **p-values from different PDFs change differently**
- **Similar behavior as when using only statistical fluctuations.**

Summary

Technique of building Transfer Matrix Shown.

--Transfer Matrix can be used to predict number of events in the given cross section bins in MC.

-- Transfer Matrix can be used to compare number of events predicted by different PDFs.

p-values from different PDFs calculated and shown on the basis of their explanation to the high-x data using Transfer Matrix.

-- Differences are seen in different PDFs
-- Differences are also there for e-p and e+p data sets and the high and lower x ranges.

p-values from dominant systematic uncertainty of normalization error shown.

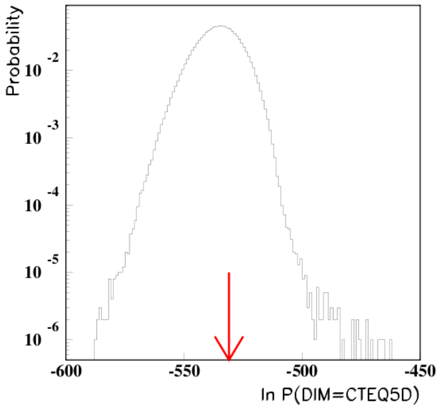
Prescription on how to include high-x data in PDF fits will be provided soon.

Back up

P-value determination

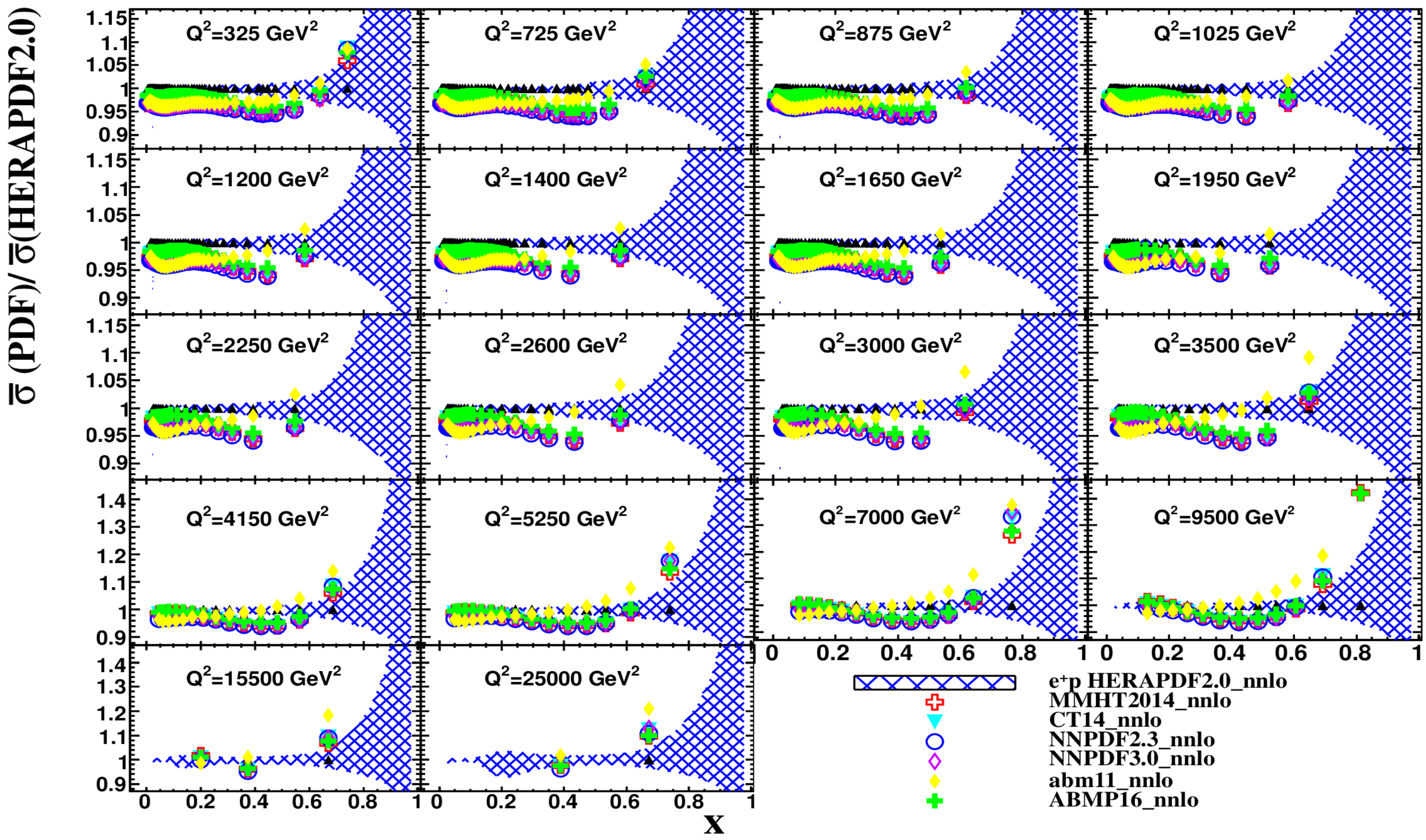
Total probability for each PDF :

$$P(D|M_k) = \prod_j \frac{e^{-\nu_{j,k}} \nu_{j,k}^{n_j}}{n_j!}$$



P-value is calculated by integrating out the probability from the left edge till red for the given PDF

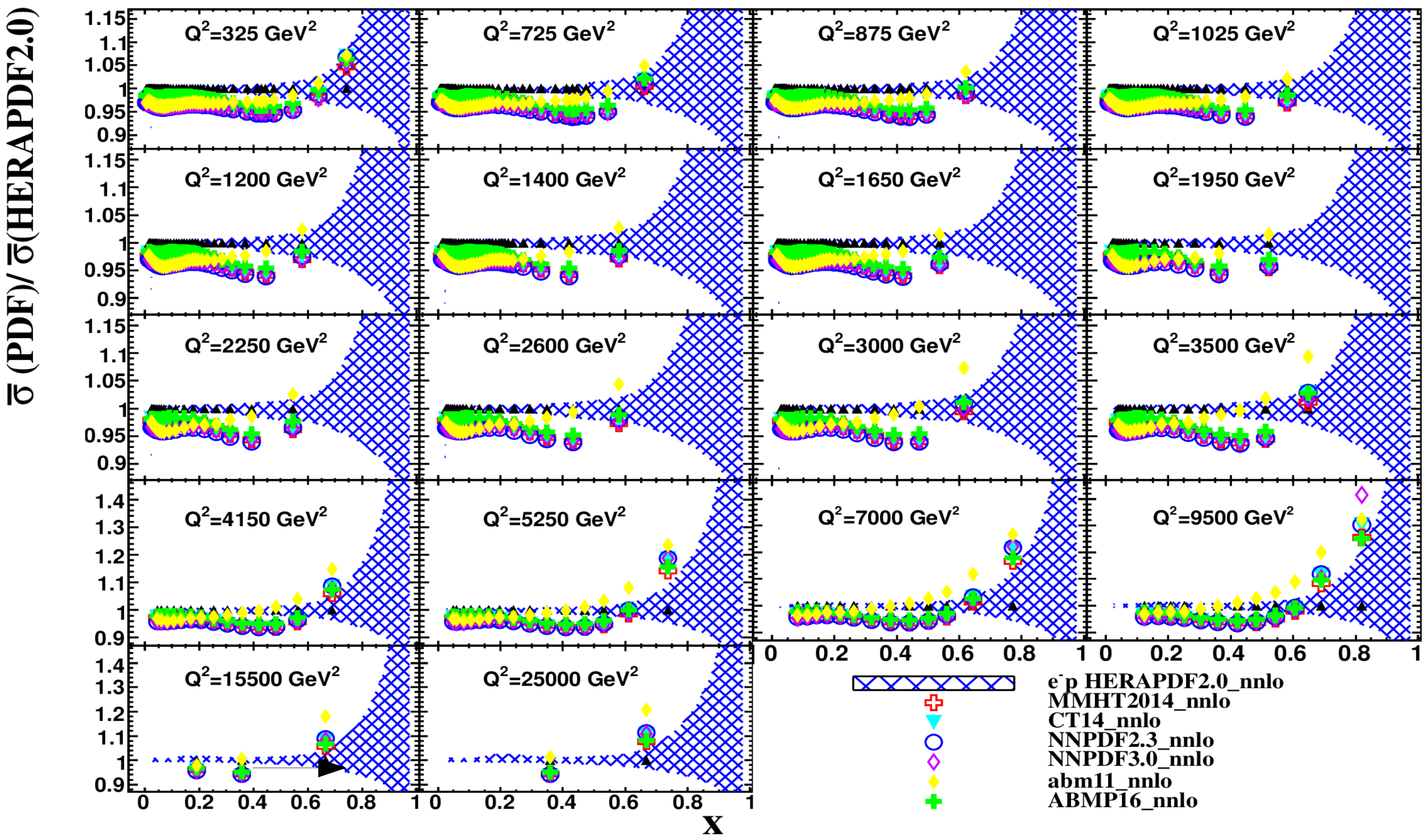
Ratio of generated level cross sections in different PDFs (at NNLO) to HERAPDF2.0NLO for M bins (e+p)



Where $\bar{\sigma}$ is the total integrated cross section in a given x-Q^2 bin

There is a shape difference between HERAPDF & other PDFs, approaches 7% at x ~ 0.4.

Ratio of generated level cross sections in different PDFs (at NNLO) to HERAPDF2.0NNLO for M bins (e-p)



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