PDF Constraint using LHCb data

Z, $W^{\pm}$ and Drell-Yan

F. De Lorenzi[1] R. Mc Nulty[1]

[1]University College Dublin

PDF4LHC, 23th October 2009

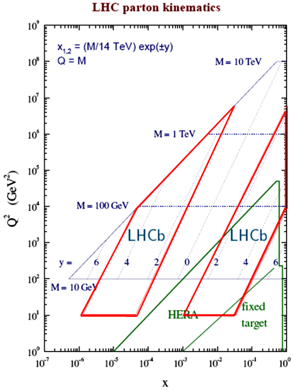
Outline

1. LHCb features
2. Analysis
   - Hessian method
   - NNPDF method
3. Results

Outline

LHCb kinematical region

- Trigger low p_T muons $p_T > 1GeV$
- Unique rapidity coverage $1.9 < \eta < 4.9$
- Possible to reach very small value of x
  - Up to $\sim 5 \cdot 10^{-5}$ with Z and $W^{\pm}$
  - Up to $\sim 10^{-6}$ with low mass drell-yan
- At nominal luminosity it will collect about 2 fb^{-1} of data in 1 year

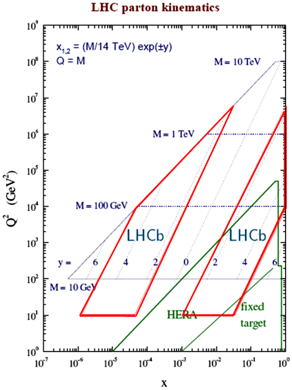


Warning!

All result presented are produced with $E_{cm} = 14\ TeV$

LHCb kinematical region

- Trigger low p_T muons $p_T > 1GeV$
- Unique rapidity coverage $1.9 < \eta < 4.9$
- Possible to reach very small value of x
  - Up to $\sim 5 \cdot 10^{-5}$ with Z and $W^{\pm}$
  - Up to $\sim 10^{-6}$ with low mass drell-yan
- At nominal luminosity it will collect about 2 fb^{-1} of data in 1 year

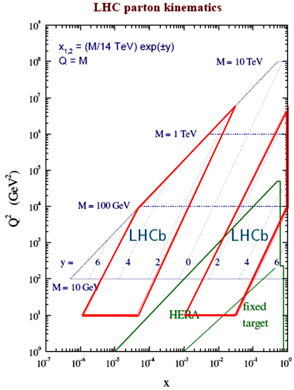


Warning!

All result presented are produced with $E_{cm} = 14\ TeV$

LHCb kinematical region

- Trigger low p_T muons $p_T > 1GeV$
- Unique rapidity coverage $1.9 < \eta < 4.9$
- Possible to reach very small value of x
  - Up to $\sim 5 \cdot 10^{-5}$ with Z and $W^{\pm}$
  - Up to $\sim 10^{-6}$ with low mass drell-yan
- At nominal luminosity it will collect about 2 fb^{-1} of data in 1 year

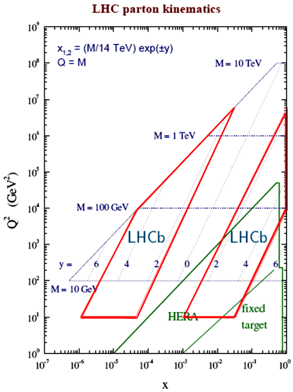


Warning!

All result presented are produced with $E_{cm} = 14\ TeV$

LHCb kinematical region

- Trigger low p_T muons $p_T > 1GeV$
- Unique rapidity coverage $1.9 < \eta < 4.9$
- Possible to reach very small value of x
  - Up to $\sim 5 \cdot 10^{-5}$ with Z and $W^{\pm}$
  - Up to $\sim 10^{-6}$ with low mass drell-yan
- At nominal luminosity it will collect about 2 fb^{-1} of data in 1 year

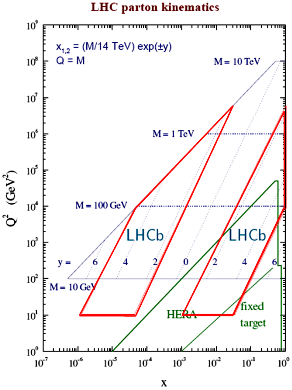


Warning!

All result presented are produced with $E_{cm} = 14\ TeV$

LHCb kinematical region

- Trigger low p_T muons $p_T > 1GeV$
- Unique rapidity coverage $1.9 < \eta < 4.9$
- Possible to reach very small value of x
  - Up to $\sim 5 \cdot 10^{-5}$ with Z and $W^{\pm}$
  - Up to $\sim 10^{-6}$ with low mass drell-yan
- At nominal luminosity it will collect about 2 fb^{-1} of data in 1 year

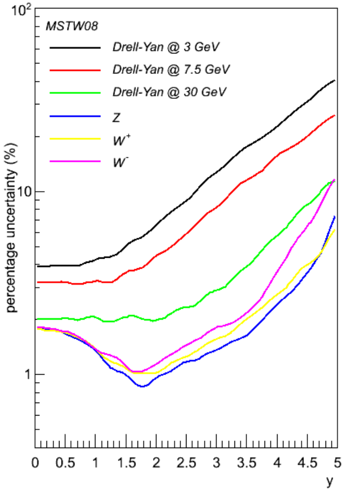


Warning!

All result presented are produced with $E_{cm} = 14\ TeV$

Uncertainties

- Big uncertainties at high rapidity
- Big uncertainties at low mass
- Potentiality for LHCb to constraint PDFs using rapidity distribution for different channels
    - Z
    - $W^{\pm}$
    - D-Y 2.5-5 GeV
      (dominant but difficult experimentally)
    - D-Y 5-10 GeV
    - D-Y 10-20 GeV
    - D-Y 20-40 GeV
    - Combinations
      (i.e. WWZ)

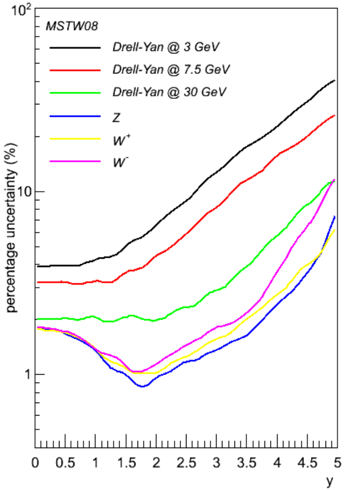


Uncertainties

- Big uncertainties at high rapidity
- Big uncertainties at low mass
- Potentiality for LHCb to constraint PDFs using rapidity distribution for different channels
  - Z
  - $W^{\pm}$
  - D-Y 2.5-5 GeV

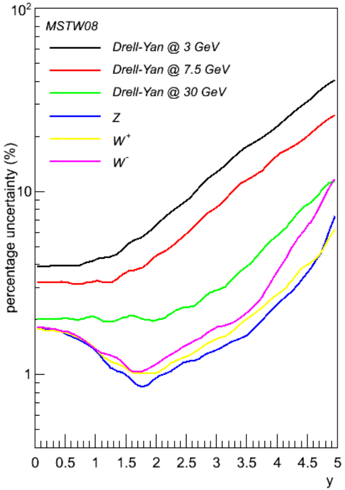
    (dominant but difficult experimentally)
  - D-Y 5-10 GeV
  - D-Y 10-20 GeV
  - D-Y 20-40 GeV
  - Combinations

    (i.e. WWZ)



Uncertainties

- Big uncertainties at high rapidity
- Big uncertainties at low mass
- Potentiality for LHCb to constraint PDFs using rapidity distribution for different channels
  - Z
  - $W^{\pm}$
  - D-Y 2.5-5 GeV
    (dominant but difficult experimentally)
  - D-Y 5-10 GeV
  - D-Y 10-20 GeV
  - D-Y 20-40 GeV
  - Combinations
    (i.e. WWZ)



Outline

Outline

Analysis

- Hessian methods provide a central value and a set of ortogonal eigenvectors
- An observable, f, which is a function of PDF eigenvectors and rapidity, y, can be written:

$$f(y) = f_0(y) + \sum_i \lambda_i \delta_i(y)$$

where f_0 is the observable evaluated at the central value, λ_i are unknown numbers and δ_i are the deviations of f from f_0 obtained when changing the i^{th} eigenvector by one unit of uncertainty. All theoretically consistent values of f can be found by sampling λ_i from a multinormal distribution.

- Since f_0 and δ_i are known it is possible to fit for the λ_i
- Considering rapidity distribution we minimize the χ^2

$$\chi^2 = \sum_{bin} \left(\frac{N_{bin} - \lambda_0 (f_0 + \sum \lambda_i \delta_i)}{\Delta_{bin}} \right)^2 + \sum_{i>0} \lambda_i^2$$

Analysis

- Hessian methods provide a central value and a set of ortogonal eigenvectors
- An observable, f, which is a function of PDF eigenvectors and rapidity, y, can be written:

$$f(y) = f_0(y) + \sum_i \lambda_i \delta_i(y)$$

where f_0 is the observable evaluated at the central value, λ_i are unknown numbers and δ_i are the deviations of f from f_0 obtained when changing the i^{th} eigenvector by one unit of uncertainty. All theoretically consistent values of f can be found by sampling λ_i from a multinormal distribution.
- Since f_0 and δ_i are known it is possible to fit for the λ_i
- Considering rapidity distribution we minimize the χ^2

$$\chi^2 = \sum_{bin} \left(\frac{N_{bin} - \lambda_0 (f_0 + \sum \lambda_i \delta_i)}{\Delta_{bin}} \right)^2 + \sum_{i>0} \lambda_i^2$$

Analysis

- Hessian methods provide a central value and a set of ortogonal eigenvectors
- An observable, f, which is a function of PDF eigenvectors and rapidity, y, can be written:

$$f(y) = f_0(y) + \sum_i \lambda_i \delta_i(y)$$

where f_0 is the observable evaluated at the central value, λ_i are unknown numbers and δ_i are the deviations of f from f_0 obtained when changing the i^{th} eigenvector by one unit of uncertainty. All theoretically consistent values of f can be found by sampling λ_i from a multinormal distribution.

- Since f_0 and δ_i are known it is possible to fit for the λ_i
- Considering rapidity distribution we minimize the χ^2

$$\chi^2 = \sum_{bin} \left(\frac{N_{bin} - \lambda_0 (f_0 + \sum \lambda_i \delta_i)}{\Delta_{bin}} \right)^2 + \sum_{i>0} \lambda_i^2$$

Analysis

- λ_i are the eigenvalues (function of the PDFs)
- Before fit: uncertainty on λ_i is $\Delta\lambda_i = 1$
- After fit: $\Delta\lambda_i < 1 \rightarrow$ better constraint of the PDF
- Uncertainties are calculated:

$$\delta F = \sqrt{\sum_{ij} \frac{\partial F}{\partial \lambda_i} V_{ij} \frac{\partial F}{\partial \lambda_j}}$$

Before:

$$V_{ij} = \begin{pmatrix} 1 & 0 & \cdots & 0 \\ 0 & 1 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & 1 \end{pmatrix}$$

After:

$$V_{ij} = \begin{pmatrix} <1 & \neq 0 & \cdots & \neq 0 \\ \neq 0 & <1 & \cdots & \neq 0 \\ \vdots & \vdots & \ddots & \vdots \\ \neq 0 & \neq 0 & \cdots & <1 \end{pmatrix}$$

Analysis

- λ_i are the eigenvalues (function of the PDFs)
- Before fit: uncertainty on λ_i is $\Delta\lambda_i = 1$
- After fit: $\Delta\lambda_i < 1 \rightarrow$ better constraint of the PDF
- Uncertainties are calculated:

$$\delta F = \sqrt{\sum_{ij} \frac{\partial F}{\partial \lambda_i} V_{ij} \frac{\partial F}{\partial \lambda_j}}$$

Before:

$$V_{ij} = \begin{pmatrix} 1 & 0 & \cdots & 0 \\ 0 & 1 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & 1 \end{pmatrix}$$

After:

$$V_{ij} = \begin{pmatrix} <1 & \neq 0 & \cdots & \neq 0 \\ \neq 0 & <1 & \cdots & \neq 0 \\ \vdots & \vdots & \ddots & \vdots \\ \neq 0 & \neq 0 & \cdots & <1 \end{pmatrix}$$

Outline

Analysis

- NNPDF provides Montecarlo replicas of the PDFs
- Generating rapidity distributions with each replica we can compare the prediction of a single replica with the central value

$$\chi_i^2 = \sum_{bin} \left(\frac{N_{bin}^c - \lambda_0 f_i(y)}{\Delta_{bin}} \right)^2$$

where i is the index of the replica, N_{bin}^c is the prediction of the central value for that rapidity-bin and $f_i(y)$ is the value of the rapidity distribution generated with the i^{th} replica

- We recalculate the central value and the uncertainty rejecting replicas with χ^2 probability smaller than 1%

Analysis

- NNPDF provides Montecarlo replicas of the PDFs
- Generating rapidity distributions with each replica we can compare the prediction of a single replica with the central value

$$\chi_i^2 = \sum_{bin} \left(\frac{N_{bin}^c - \lambda_0 f_i(y)}{\Delta_{bin}} \right)^2$$

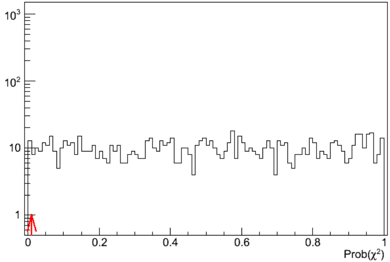
where i is the index of the replica, N_{bin}^c is the prediction of the central value for that rapidity-bin and $f_i(y)$ is the value of the rapidity distribution generated with the i^{th} replica

- We recalculate the central value and the uncertainty rejecting replicas with χ^2 probability smaller than 1%

Analysis

Why selection at 1%

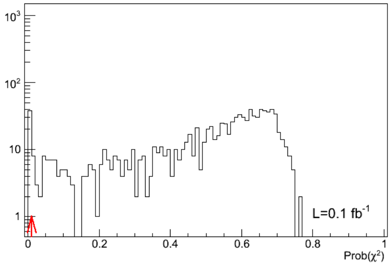
- If we perform 1000 psuedo-experiments generated from a given replica, and calculate the χ^2 compared to the SAME replica, we get a flat probability distribution.
- Only 1% of the time we reject replicas that were actually consistent irrespective of the amount of data.
- On the other hand, incorrect replicas may or may not be consistent. In general, with more data, more incorrect replicas can be rejected.



Analysis

Why selection at 1%

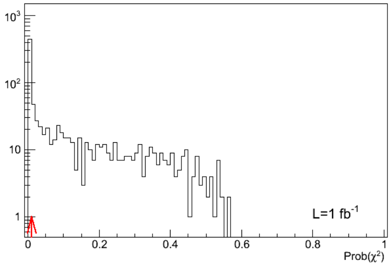
- If we perform 1000 psuedo-experiments generated from a given replica, and calculate the χ^2 compared to the SAME replica, we get a flat probability distribution.
- Only 1% of the time we reject replicas that were actually consistent irrespective of the amount of data.
- On the other hand, incorrect replicas may or may not be consistent. In general, with more data, more incorrect replicas can be rejected.



Analysis

Why selection at 1%

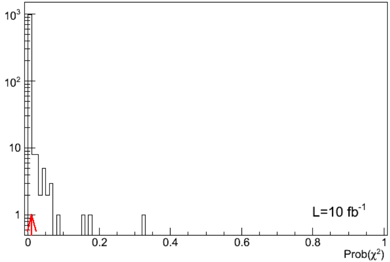
- If we perform 1000 psuedo-experiments generated from a given replica, and calculate the χ^2 compared to the SAME replica, we get a flat probability distribution.
- Only 1% of the time we reject replicas that were actually consistent irrespective of the amount of data.
- On the other hand, incorrect replicas may or may not be consistent. In general, with more data, more incorrect replicas can be rejected.



Analysis

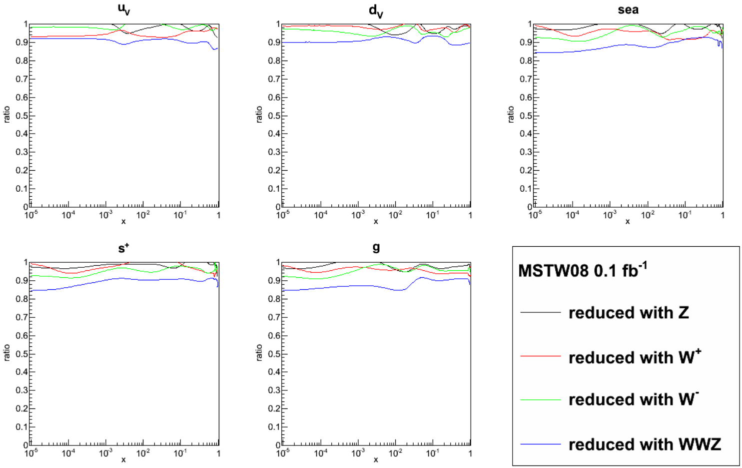
Why selection at 1%

- If we perform 1000 psuedo-experiments generated from a given replica, and calculate the χ^2 compared to the SAME replica, we get a flat probability distribution.
- Only 1% of the time we reject replicas that were actually consistent irrespective of the amount of data.
- On the other hand, incorrect replicas may or may not be consistent. In general, with more data, more incorrect replicas can be rejected.



Outline

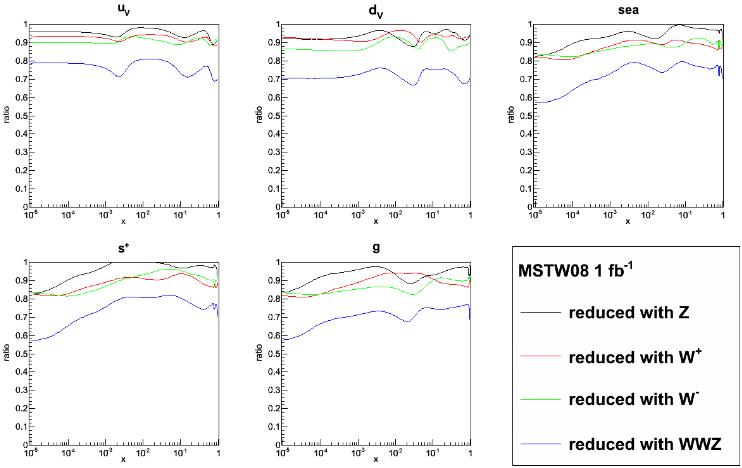
MSTW08
Electroweak



$$ratio = \frac{\delta_{after}}{\delta_{before}}$$

MSTW08

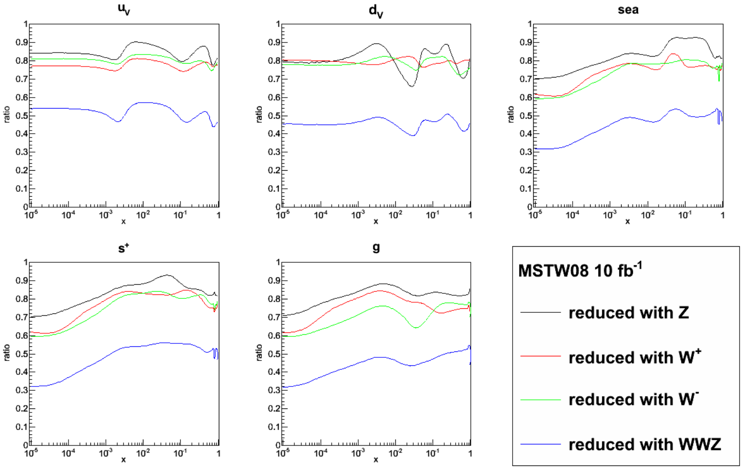
Electroweak



$$ratio = \frac{\delta_{after}}{\delta_{before}}$$

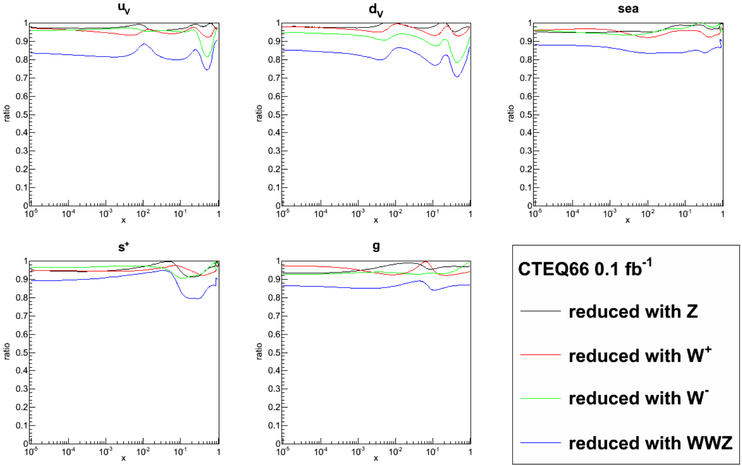
MSTW08

Electroweak



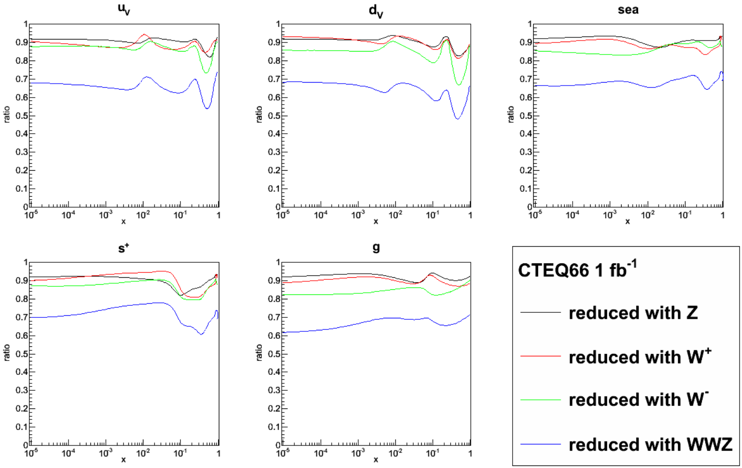
$$ratio = \frac{\delta_{after}}{\delta_{before}}$$

CTEQ66
Electroweak



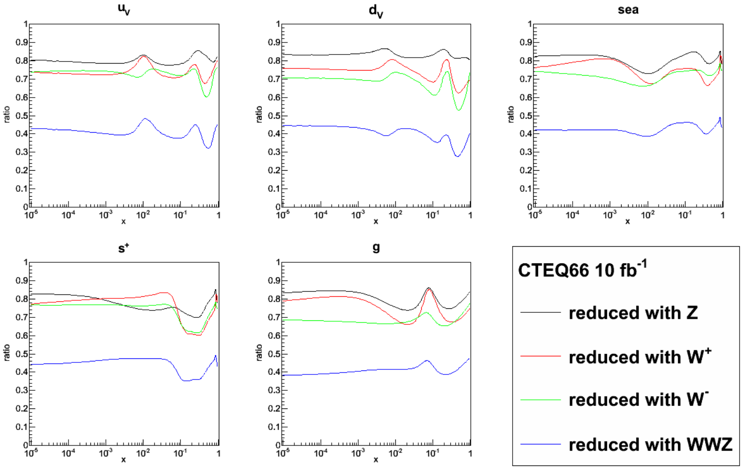
$$ratio = \frac{\delta_{after}}{\delta_{before}}$$

CTEQ66
Electroweak



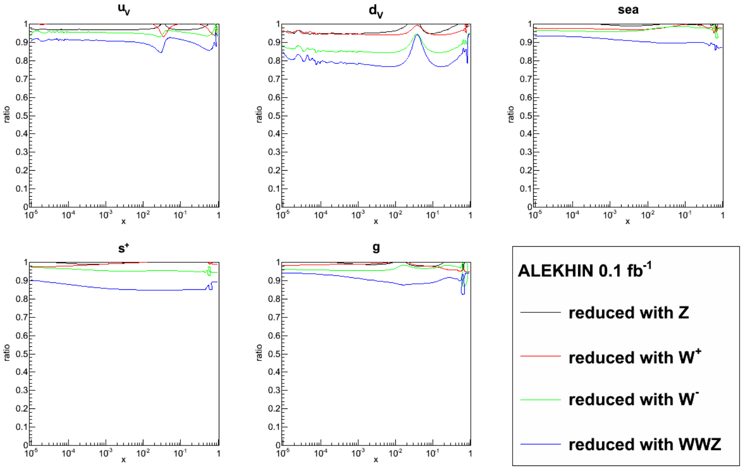
$$ratio = \frac{\delta_{after}}{\delta_{before}}$$

CTEQ66
Electroweak



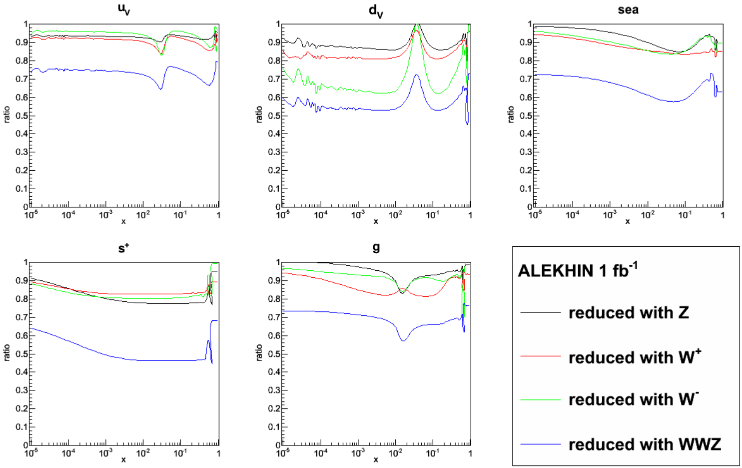
$$ratio = \frac{\delta_{after}}{\delta_{before}}$$

ALEKHIN
Electroweak



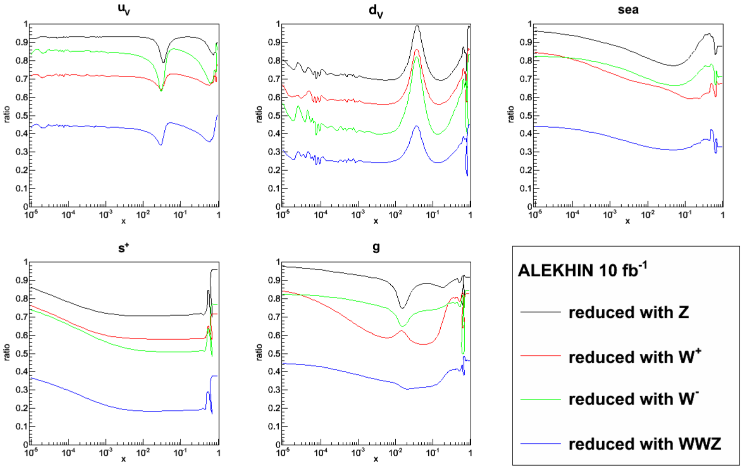
$$ratio = \frac{\delta_{after}}{\delta_{before}}$$

ALEKHIN
Electroweak



$$ratio = \frac{\delta_{after}}{\delta_{before}}$$

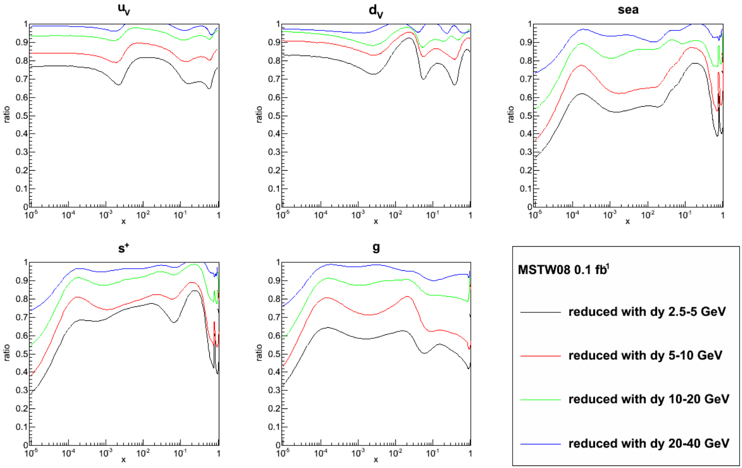
ALEKHIN
Electroweak



$$ratio = \frac{\delta_{after}}{\delta_{before}}$$

MSTW08

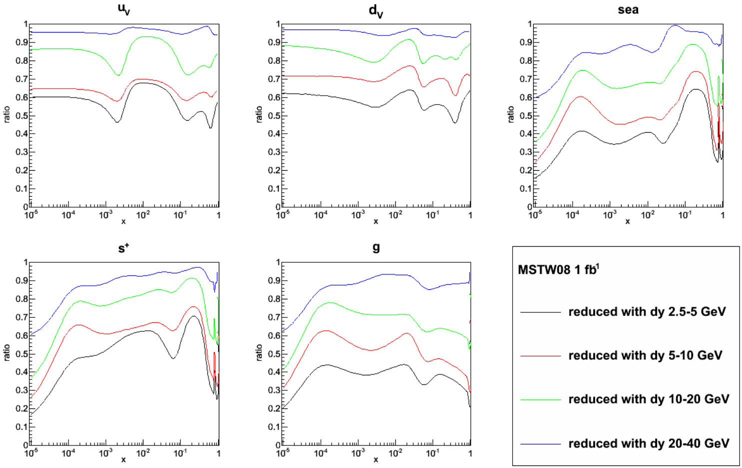
Drell-Yan



$$ratio = \frac{\delta_{after}}{\delta_{before}}$$

MSTW08

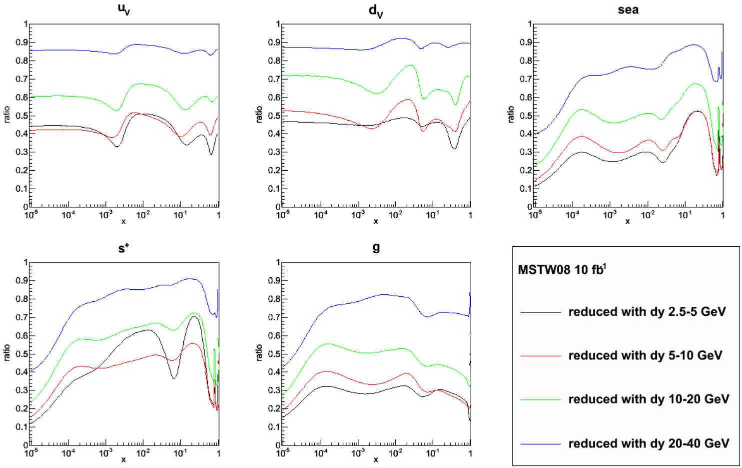
Drell-Yan



$$ratio = \frac{\delta_{after}}{\delta_{before}}$$

MSTW08

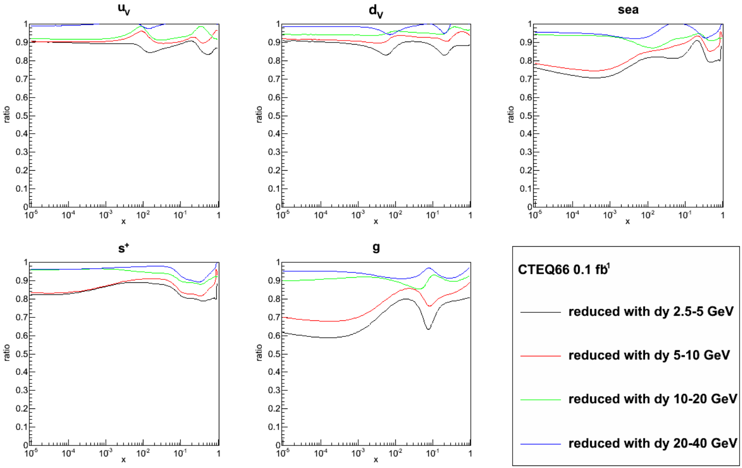
Drell-Yan



$$ratio = \frac{\delta_{after}}{\delta_{before}}$$

CTEQ66

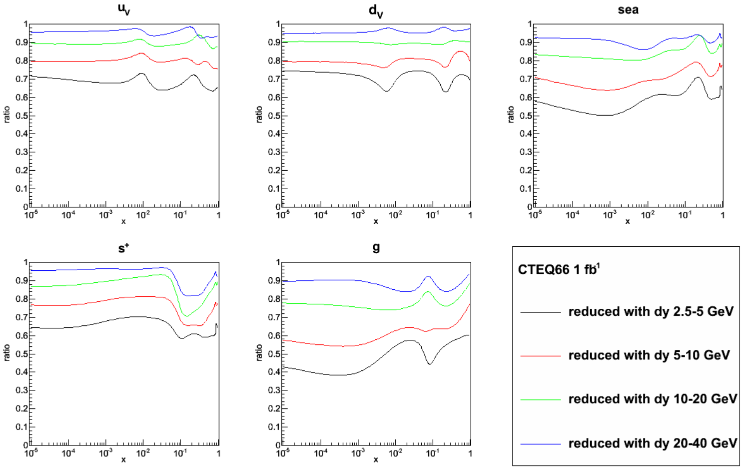
Drell-Yan



$$ratio = \frac{\delta_{after}}{\delta_{before}}$$

CTEQ66

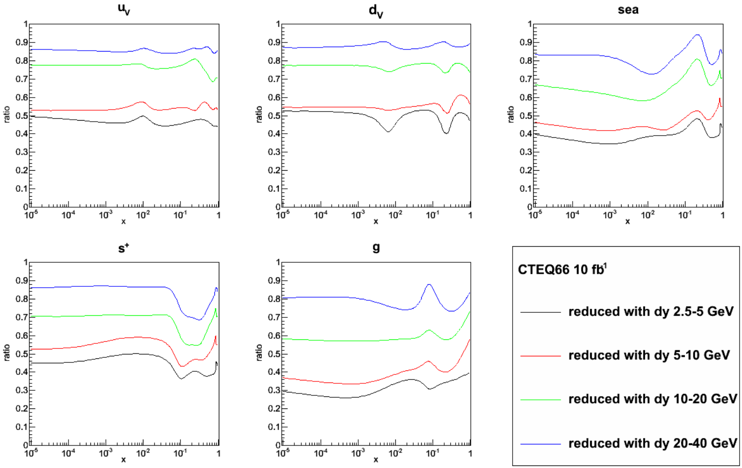
Drell-Yan



$$ratio = \frac{\delta_{after}}{\delta_{before}}$$

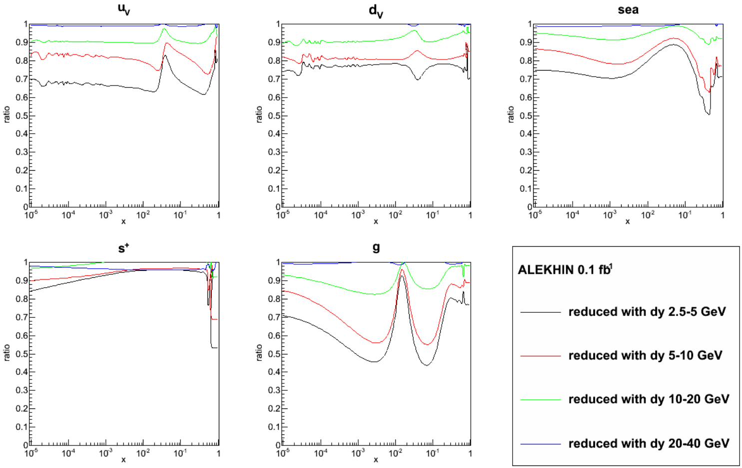
CTEQ66

Drell-Yan



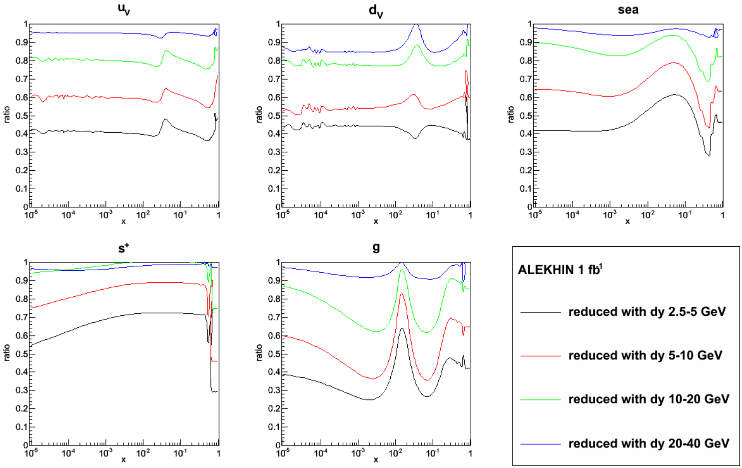
$$ratio = \frac{\delta_{after}}{\delta_{before}}$$

ALEKHIN
Drell-Yan



$$ratio = \frac{\delta_{after}}{\delta_{before}}$$

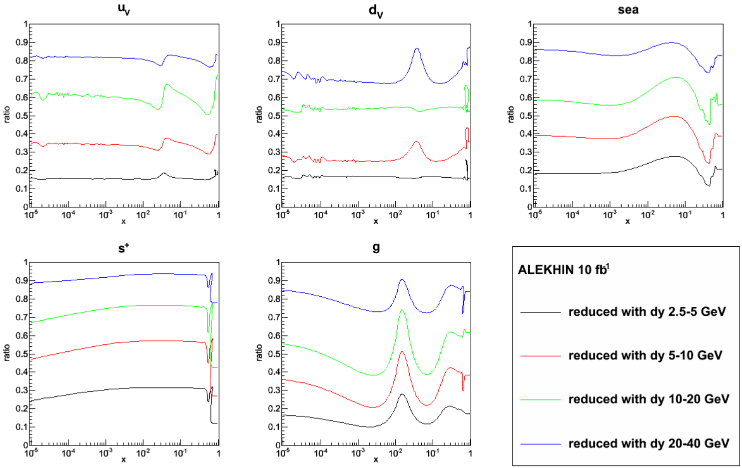
ALEKHIN
Drell-Yan



$$ratio = \frac{\delta_{after}}{\delta_{before}}$$

ALEKHIN

Drell-Yan



$$ratio = \frac{\delta_{after}}{\delta_{before}}$$

Results

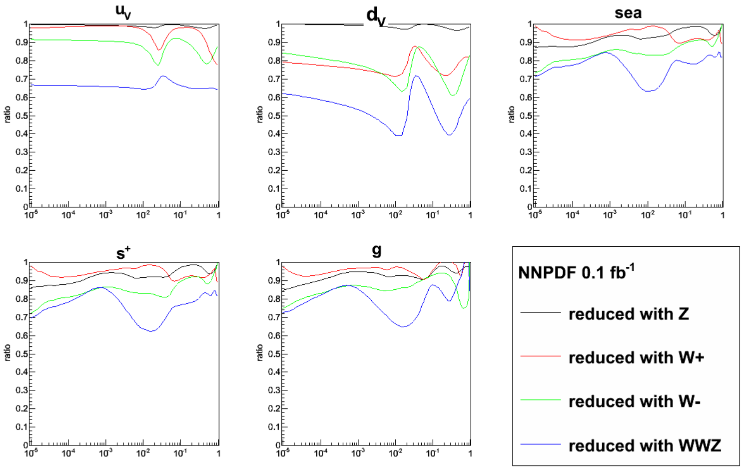
NNPDF1.0

Percentage of replicas with χ^2 probability $> 1\%$

	Lumi (fb^{-1})		
	0.1	1	10
dy 2.5 – 5.0*GeV*	0%	0%	0%
dy 5.0 – 10*GeV*	7.4%	0%	0%
dy 10 – 20*GeV*	77.1%	16.9%	0%
dy 20 – 40*GeV*	98%	75%	0.6%
Z	96.2%	55.3%	3.1%
W^+	67.3%	13.7%	0%
W^-	66.9%	1.1%	0%
WWZ	22.5%	0.1%	0%

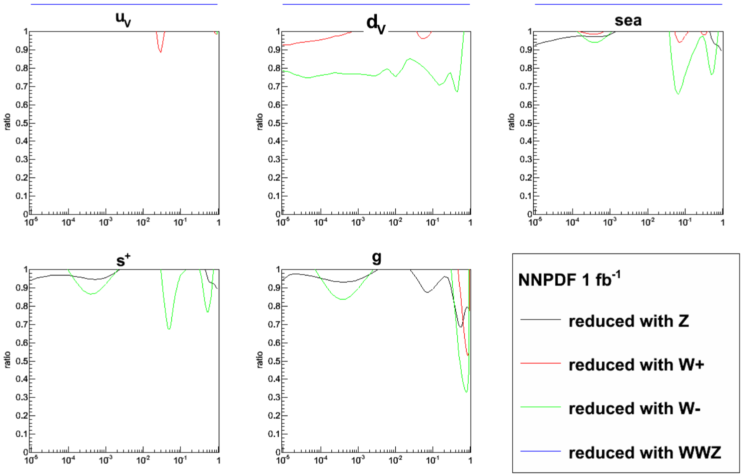
NNPDF1.0

Electroweak



$$ratio = \frac{\delta_{after}}{\delta_{before}}$$

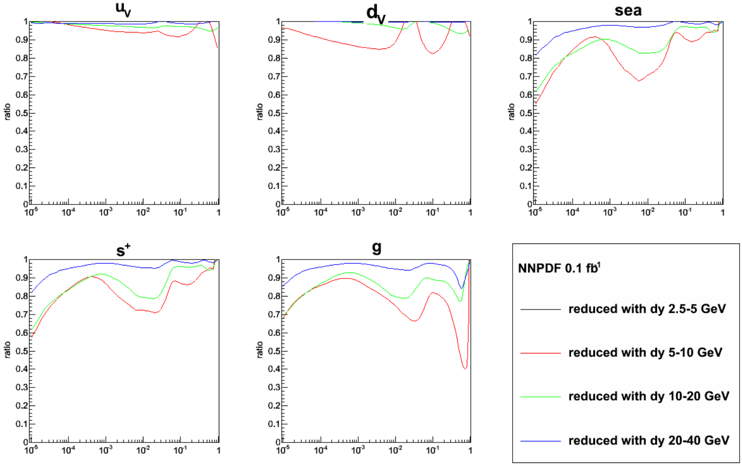
NNPDF1.0
Electroweak



$$ratio = \frac{\delta_{after}}{\delta_{before}}$$

NNPDF1.0

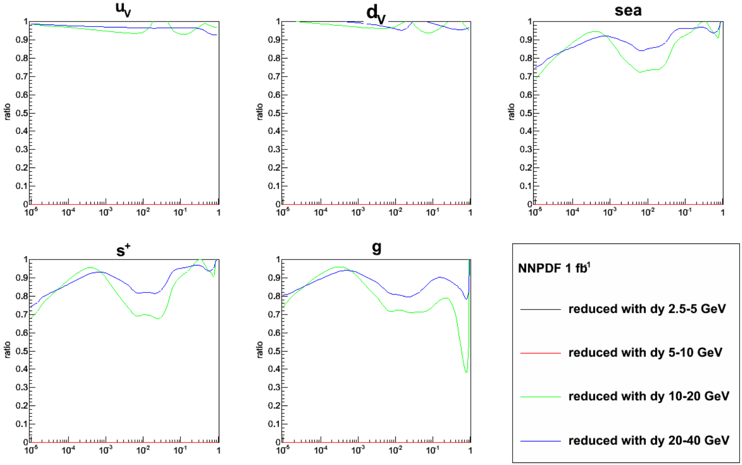
Drell-Yan



$$ratio = \frac{\delta_{after}}{\delta_{before}}$$

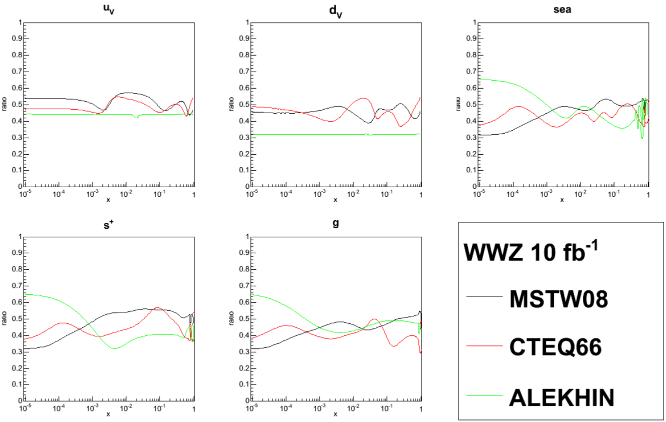
NNPDF1.0

Drell-Yan



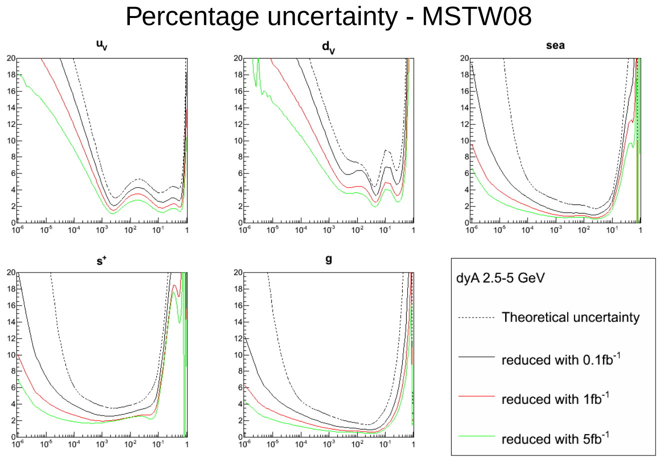
$$ratio = \frac{\delta_{after}}{\delta_{before}}$$

Model comparison



Luminosity dependence

Drell-Yan 2.5 – 5 *GeV*



Conclusion

- LHCb will improve PDF in an unexplored region of (x, Q^2)
- Possible improvement up to 96% in some region with low mass Drell-Yan
- Size of the reduction of uncertainty depends on the model