

# Drell-Yan charged and neutral asymmetries in PDF determination

J. Fiaschi, F. Giuli, F. Hautmann, S. Moretti

[arXiv:2103.10224](https://arxiv.org/abs/2103.10224) [hep-ph]



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# Topics of this talk

- **Drell-Yan data potential in PDF determination**
- **Profiling of PDFs:**
  - Including  $A_W$  pseudodata
  - Complementarity of  $A_W$  and  $A_{FB}$
- **Impact of PDF uncertainty reduction on:**
  - Antimatter in the proton
  - Determinations of  $M_W$
  - Non-resonant  $Z'$  and  $W'$  searches
- **Conclusions**

# The potential of Drell-Yan data

- **Drell-Yan data potential in PDF determination**
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# The potential of Drell-Yan data

Drell-Yan measurements are capable of providing high sensitivity to PDFs as they feature low theoretical and experimental systematics, high statistical precision and good control of correlations.

Recent studies have established the remarkable potential of less traditional observables such as:

- the neutral channel **Forward-Backward Asymmetry** ( $A_{\text{FB}}$ )

[JHEP 10 \(2019\) 176](#)

- the  $A_0$  coefficient of the expanded DY cross section in spherical harmonics

(more details on the latter in Simone Amoroso's talk)

[arXiv:2012.10298](#)

This talk focuses on the potential of the **Lepton-charge asymmetry** ( $A_w$ ) in PDF constraining and its complementarity with respect to the  $A_{\text{FB}}$

# Lepton-charge asymmetry

$$A_W = \frac{d\sigma_{W^+}/d\eta_\ell - d\sigma_{W^-}/d\eta_\ell}{d\sigma_{W^+}/d\eta_\ell + d\sigma_{W^-}/d\eta_\ell}$$

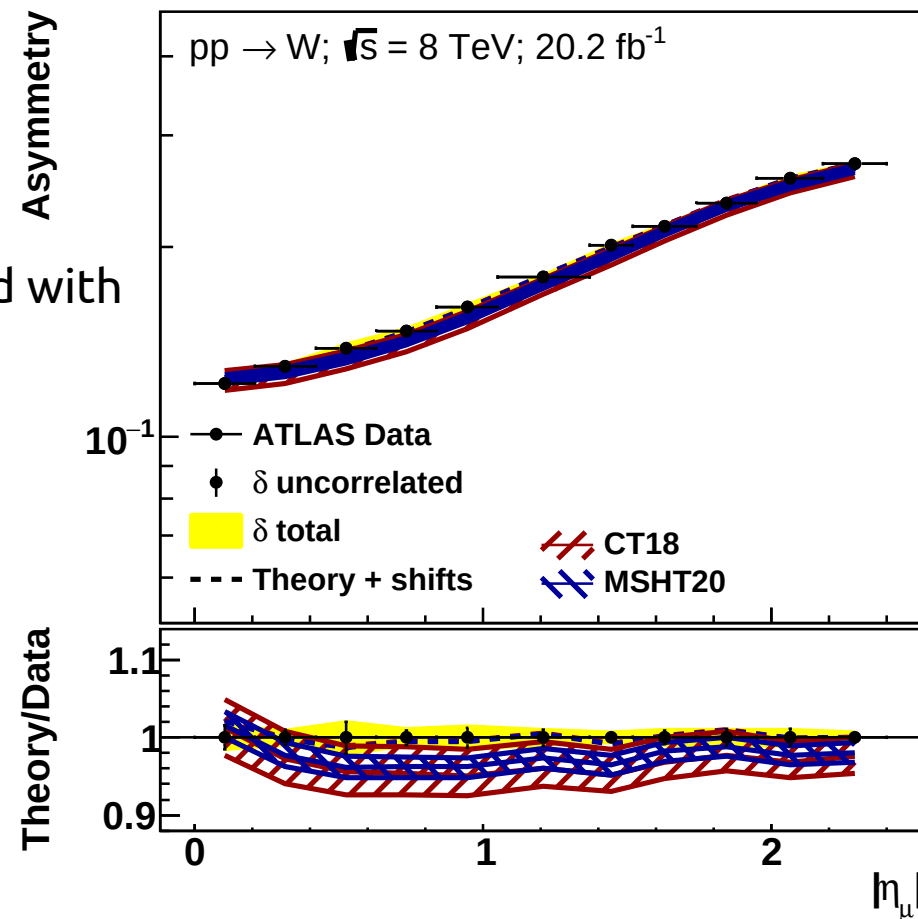
Asymmetry

Calculations at **NLO QCD** accuracy, supplemented with **NNLO QCD** correction through **K-factor**.

Modern PDF sets well describe  $A_W$  data

| PDF set                       | $\chi^2/\text{d.o.f.}$ |
|-------------------------------|------------------------|
| CT18NNLO                      | 10.26/11               |
| CT18ANNLO                     | 11.29/11               |
| MSHT20nnlo_as118              | 12.18/11               |
| NNPDF3.1_nnlo_as_0118_hessian | 14.88/11               |
| PDF4LHC15_nnlo_100            | 9.53/11                |
| ABMP16.5_nnlo                 | 18.21/11               |
| HERAPDF20_NNLO_EIG            | 8.92/11                |

We employed the public code **xFitter** for assessing the impact of  $A_W$  pseudodata on PDFs.



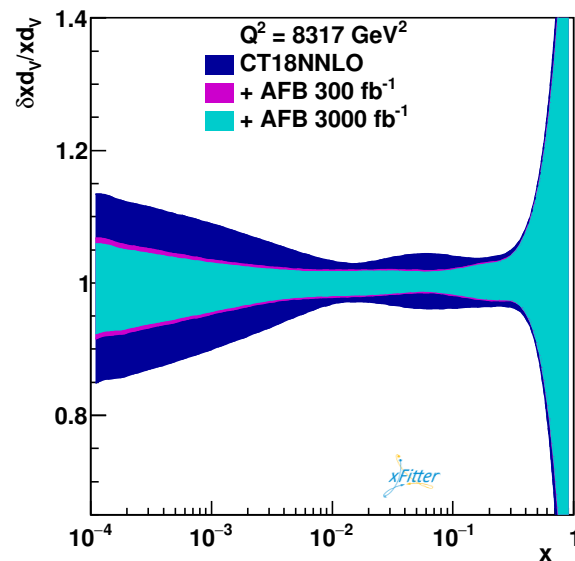
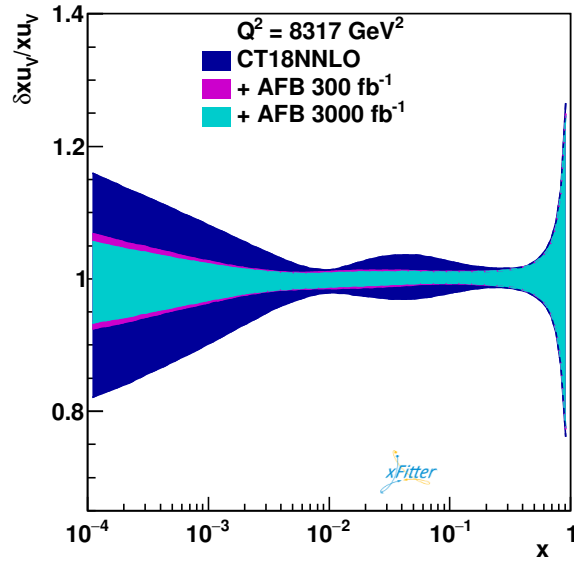
$A_W$  pseudodata for c.o.m. energy of 13 TeV with precision corresponding to:

- $300 \text{ fb}^{-1}$  (end of LHC Run-III)
- $3000 \text{ fb}^{-1}$  (HL-LHC stage)

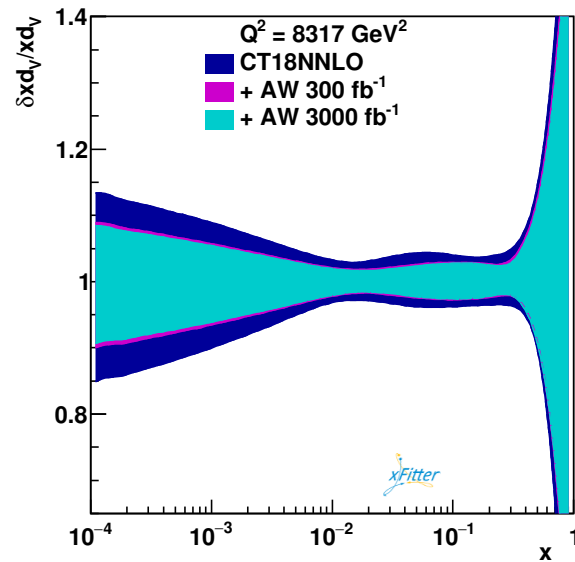
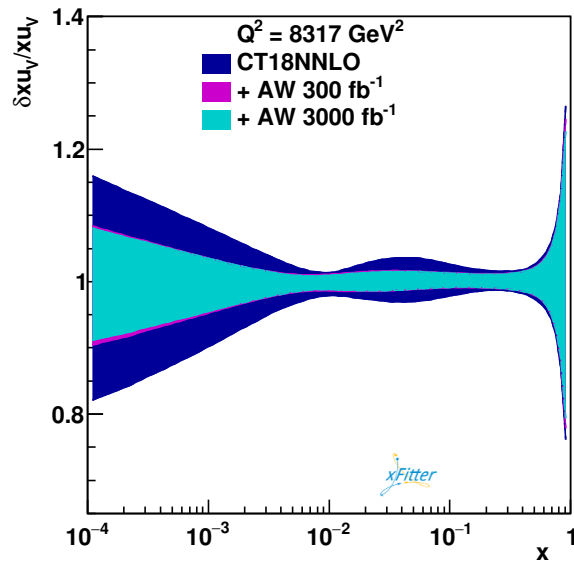
# PDFs profiling

- Drell-Yan data potential in PDF determination
- **Profiling of PDFs:**
  - Including  $A_W$  pseudodata
  - Complementarity of  $A_W$  and  $A_{FB}$
- Impact of PDF uncertainty reduction on:
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# $A_W$ vs $A_{FB}$



**CT18NNLO +  $A_{FB}$**

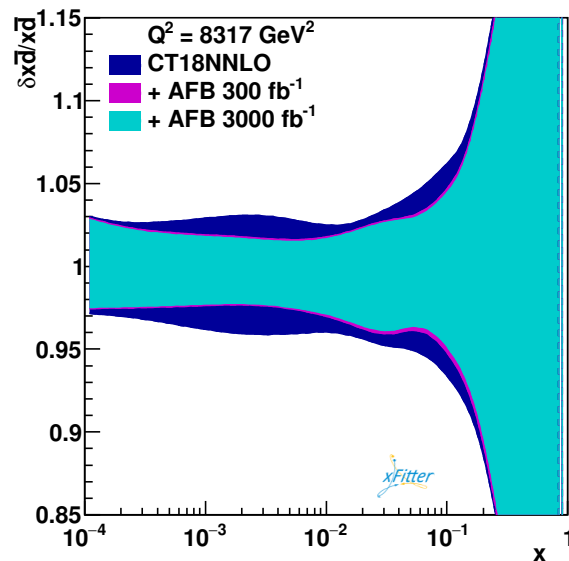
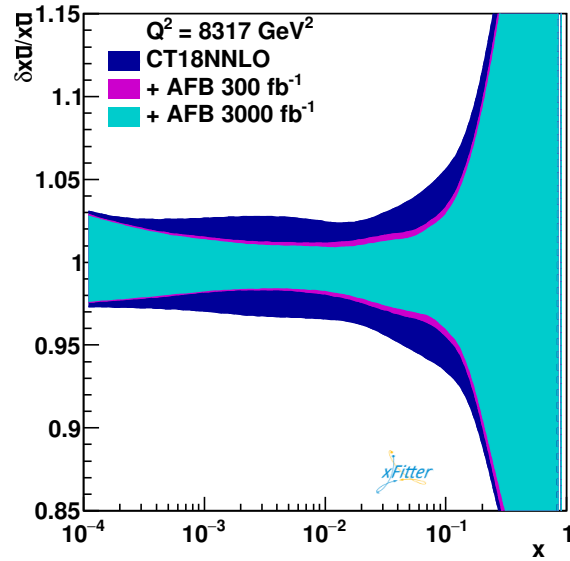


**CT18NNLO +  $A_W$**

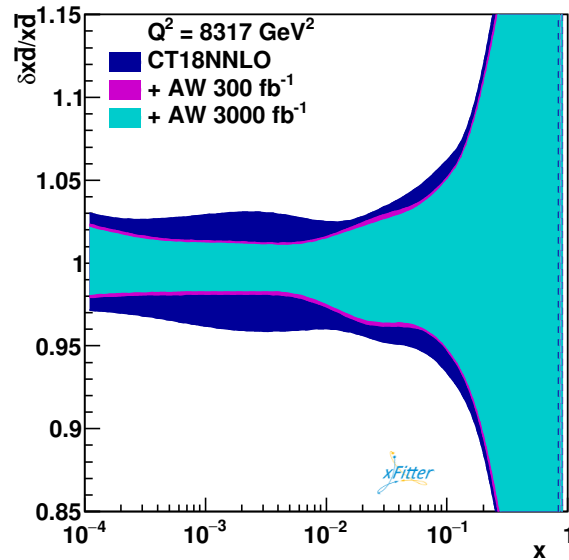
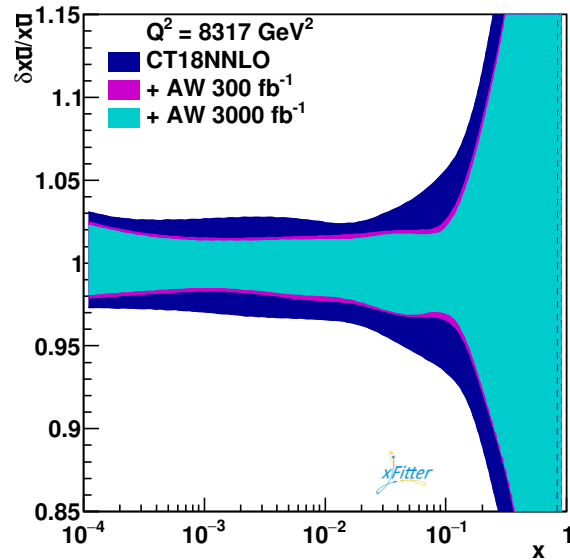
Comparable sensitivity on valence quark PDFs,  
with  $A_{FB}$  providing slightly stronger constraints.

( Saturation of uncertainty reduction  
from 300  $\text{fb}^{-1}$  to 3000  $\text{fb}^{-1}$ . )

# $A_W$ vs $A_{FB}$



**CT18NNLO +  $A_{FB}$**



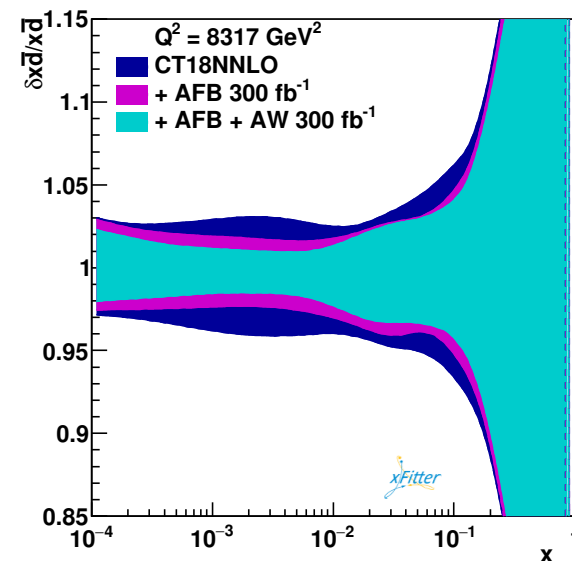
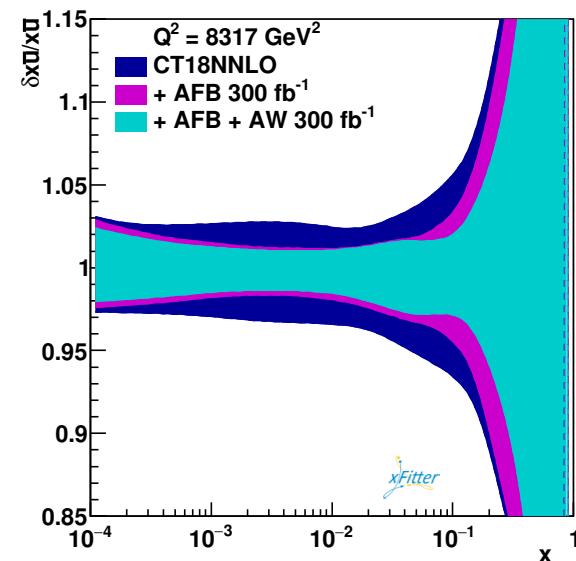
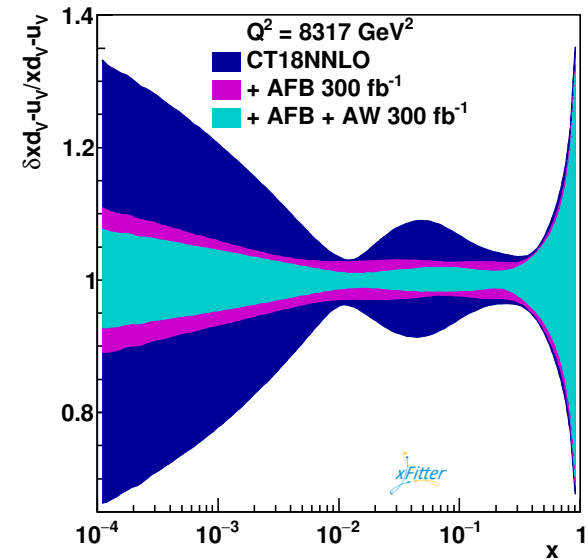
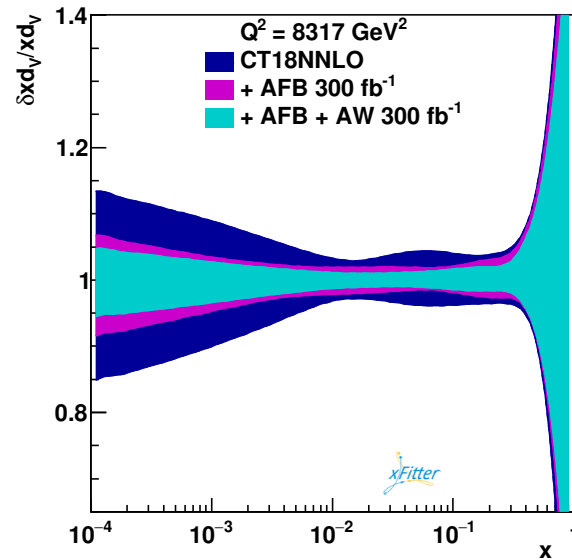
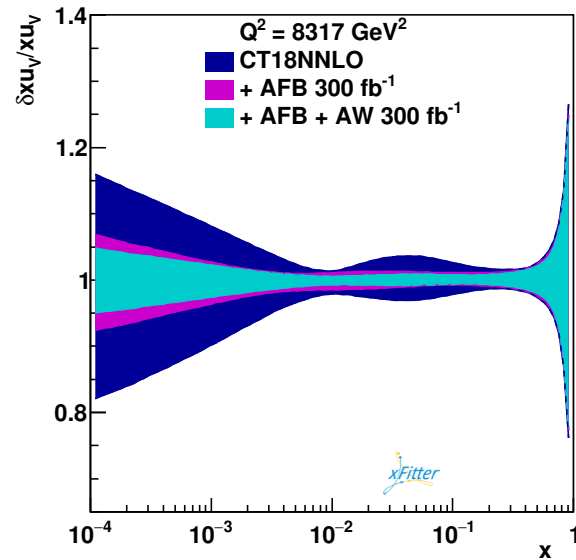
**CT18NNLO +  $A_W$**

$A_W$  provides slightly stronger than  $A_{FB}$  on anti-quark PDFs, particularly for  $\bar{u}$  in the low  $x$  region and for  $\bar{d}$  in the low and intermediate  $x$  range.



# Combining $A_W$ and $A_{FB}$

CT18NNLO +  $A_{FB}$  +  $A_W$



Visible reduction in valence quark PDFs (and their combinations) in low and intermediate  $x$  region.

Large reduction in  $\bar{u}$  PDF in the high  $x$  region and in  $\bar{d}$  PDF in the intermediate  $x$  region.

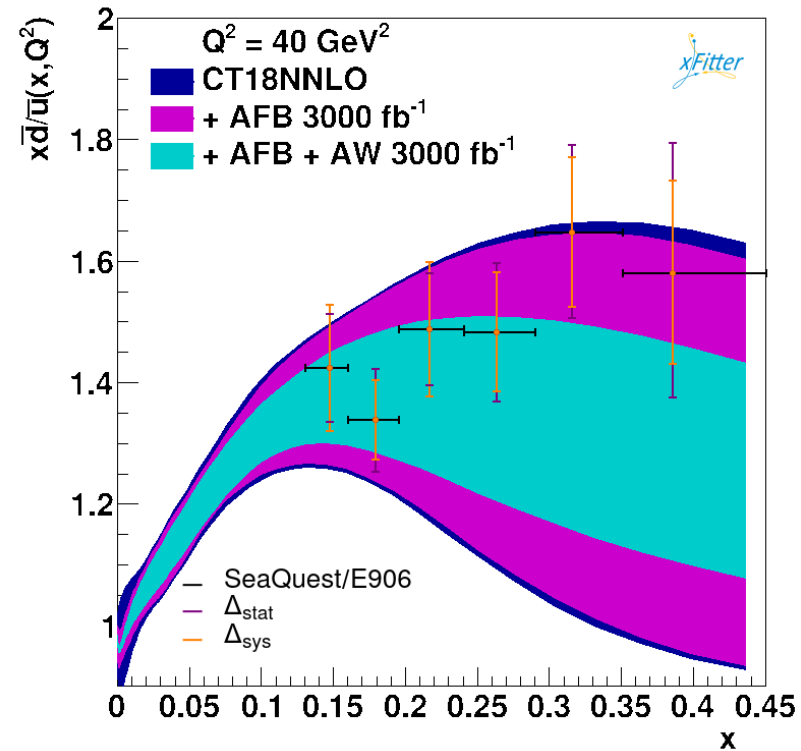
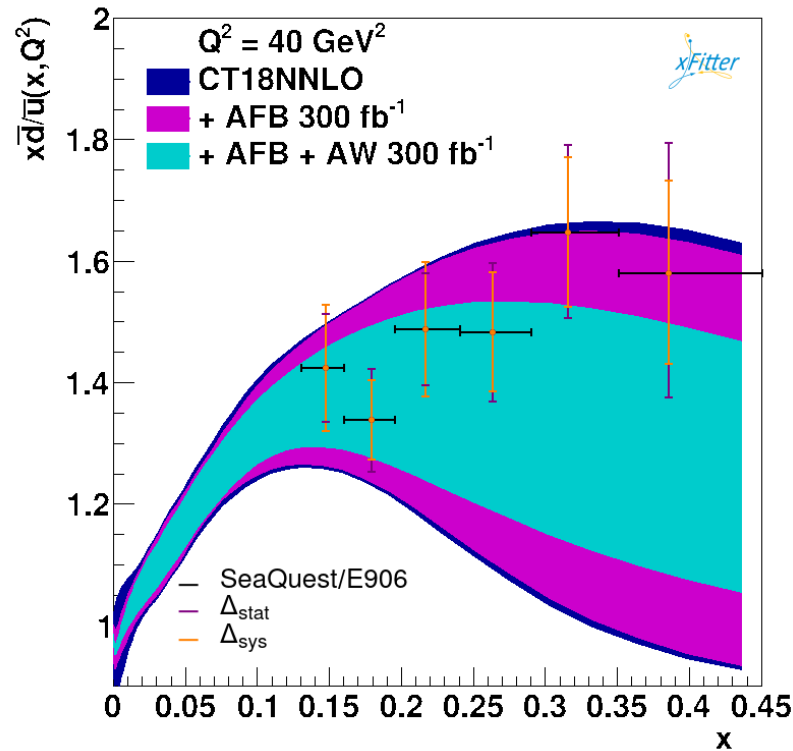
( Saturation of uncertainty reduction from 300  $\text{fb}^{-1}$  to 3000  $\text{fb}^{-1}$ . )

The combination of  $A_W$  and  $A_{FB}$  can further reduce the PDF error bands.

# Impact of PDF uncertainty reduction

- Drell-Yan data potential in PDF determination
- Profiling of PDFs:
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  - Complementarity of  $A_W$  and  $A_{FB}$
- **Impact of PDF uncertainty reduction on:**
  - Antimatter in the proton
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# $A_W$ for antimatter asymmetry



[SeaQuest Collaboration, Nature 590 \(2021\) 7847, 561-565](#)

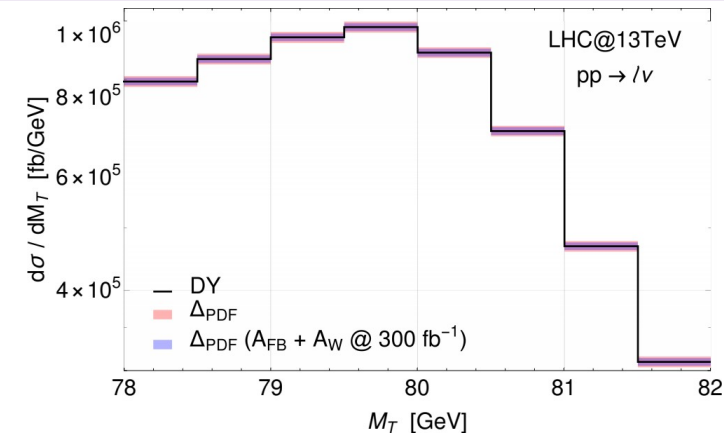
$A_W$  data carries relevant information on the anti-quark PDFs in the high  $x$  region, and would provide a significant reduction of uncertainty bands in the region of interest.

(REMARK: real data would most certainly modify the central values as well)

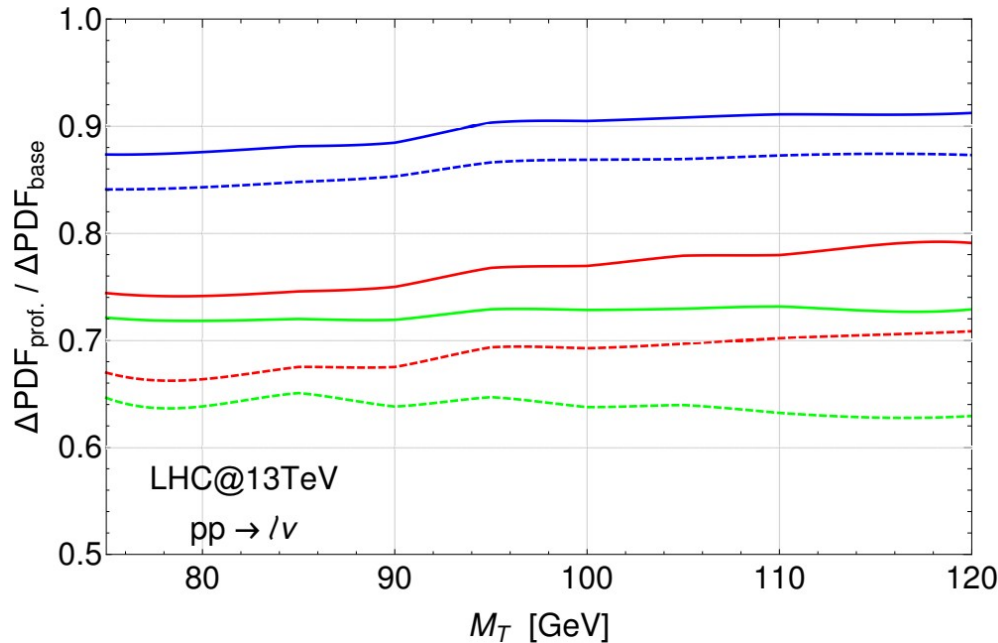
# Application on $M_W$ measurement

Reduction of PDF uncertainties crucial for SM precision measurements.

Lepton + MET transverse mass spectrum for extraction of  $M_W$



PDF uncertainty before profiling about 1.8%



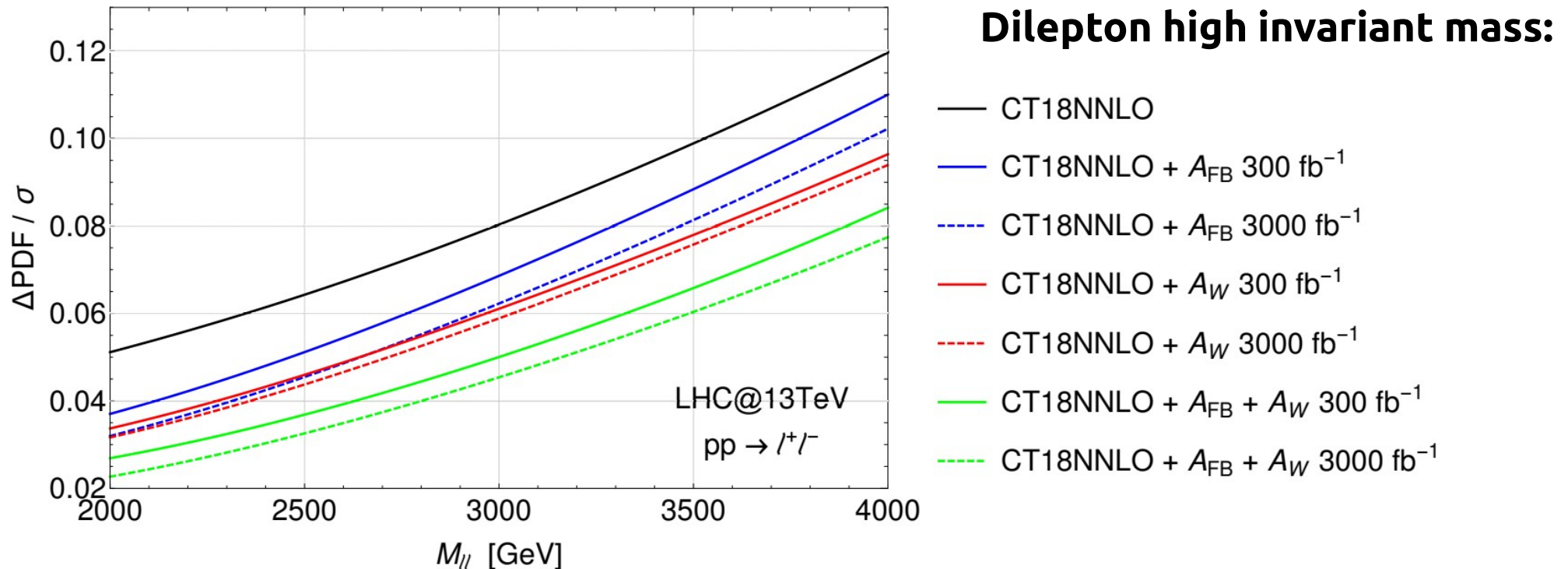
- CT18NNLO +  $A_{FB}$  300 fb $^{-1}$
- - CT18NNLO +  $A_{FB}$  3000 fb $^{-1}$
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- - CT18NNLO +  $A_W$  3000 fb $^{-1}$
- CT18NNLO +  $A_{FB}$  +  $A_W$  300 fb $^{-1}$
- - CT18NNLO +  $A_{FB}$  +  $A_W$  3000 fb $^{-1}$

- $A_{FB}$  300 (3000) fb $^{-1}$  data reduces PDF uncertainty  $\sim 12\%$  ( $\sim 16\%$ )
- $A_W$  300 (3000) fb $^{-1}$  data reduces PDF uncertainty  $\sim 26\%$  (43%)
- Combination of  $A_{FB}$  and  $A_W$  300 (3000) fb $^{-1}$  reduces PDF uncertainty  $\sim 28\%$  ( $\sim 46\%$ )

(REMARK: assessing the improvement on  $M_W$  measurement requires a delicate and refined analysis of normalized distribution, where reduction of uncertainty is far more moderate)

# Application on BSM searches

Relevant reduction of uncertainties in the high transverse/invariant mass spectra for BSM searches.

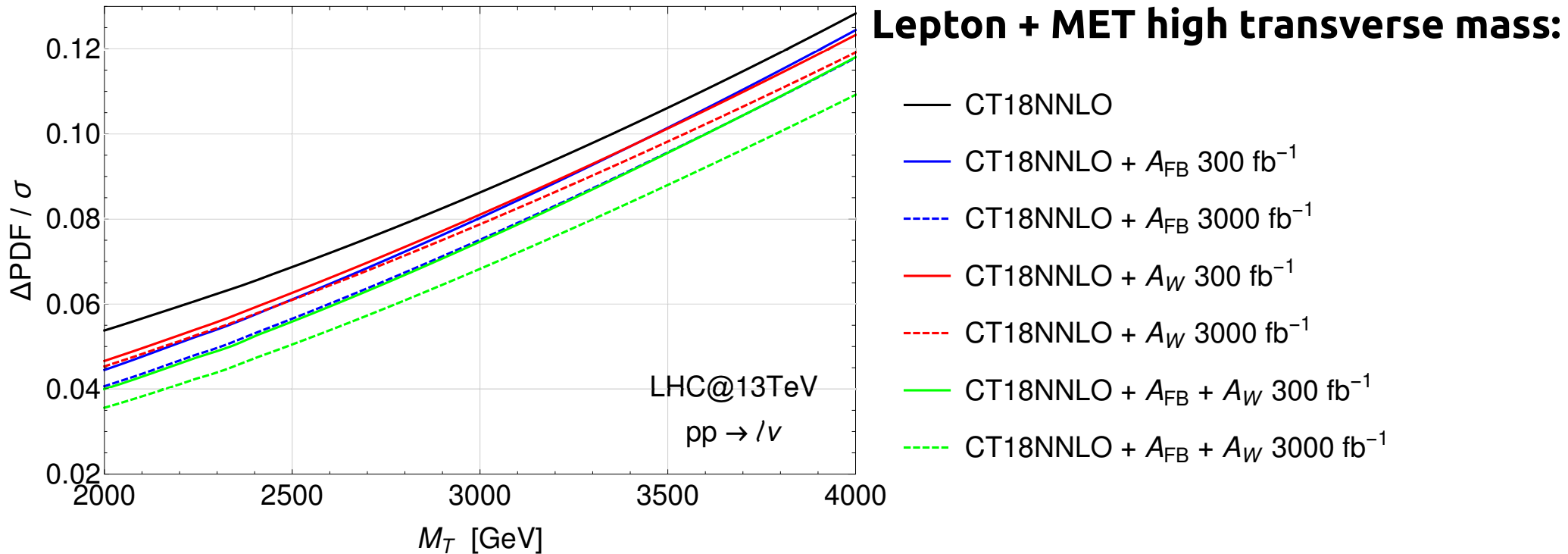


Original PDF uncertainty (i.e.) at 4 TeV from 12% is reduced to:

- 11% (10.2%) by  $A_{\text{FB}}$  300 (3000)  $\text{fb}^{-1}$  data
- 9.6% (9.4%) by  $A_W$  300 (3000)  $\text{fb}^{-1}$  data
- 8.4% (7.8%) by combination of  $A_{\text{FB}}$  and  $A_W$  300 (3000)  $\text{fb}^{-1}$  data

# Application on BSM searches

Relevant reduction of uncertainties in the high transverse/invariant mass spectra for BSM searches.



Original PDF uncertainty (i.e.) at 4 TeV from 12.9% is reduced to:

- 12.5% (11.8%) by  $A_{\text{FB}}$  300 (3000) fb<sup>-1</sup> data
- 12.3% (11.9%) by  $A_W$  300 (3000) fb<sup>-1</sup> data
- 11.8% (10.9%) by combination of  $A_{\text{FB}}$  and  $A_W$  300 (3000) fb<sup>-1</sup> data

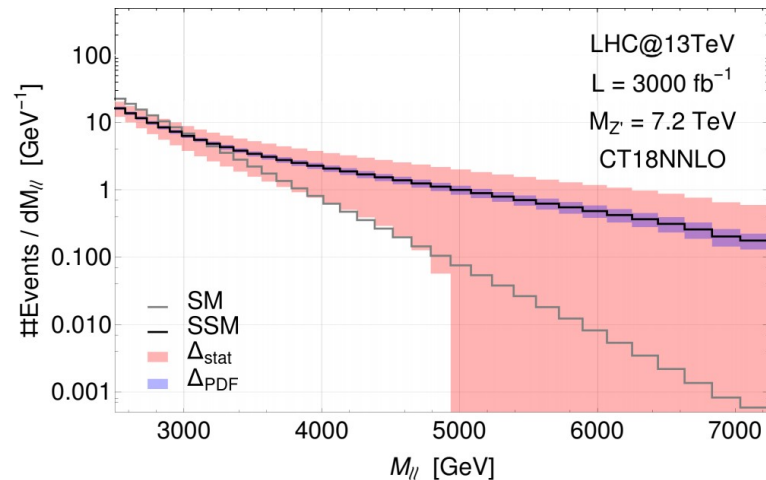
# Effects on Z' searches

PDF uncertainties are relevant in searches for non-resonant objects.

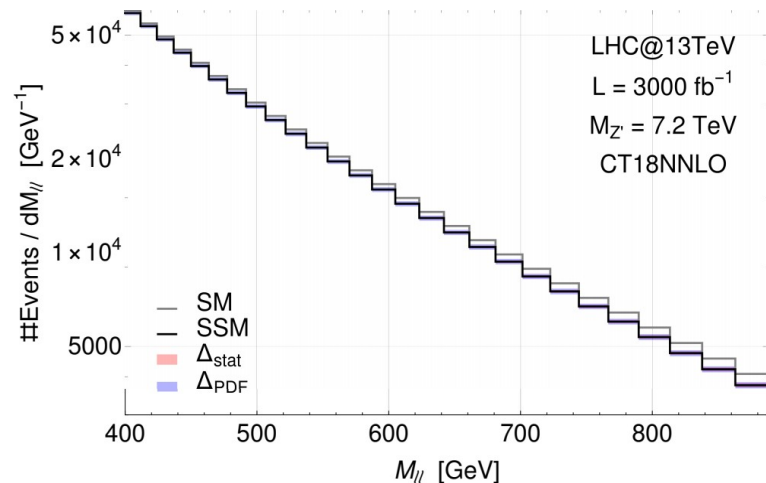
Benchmark: Enhanced SSM model

(same as SSM with BSM gauge coupling augmented by factor 3)

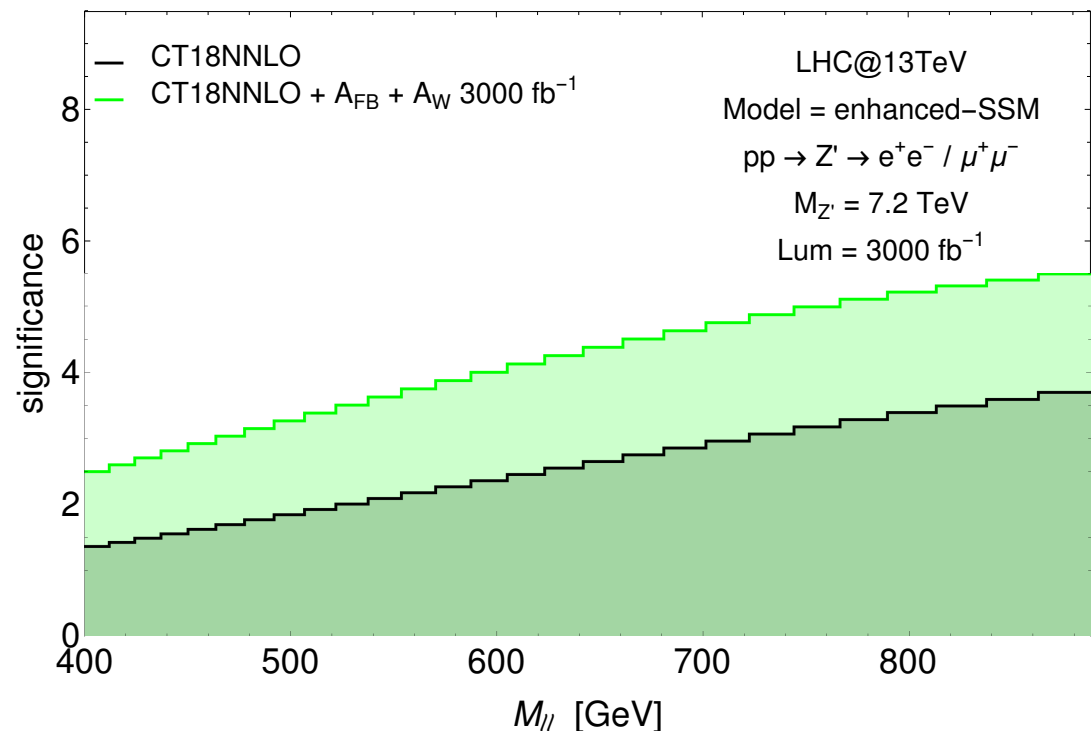
[Phys.Lett.B 803 \(2020\) 135293](#)



High invariant mass excess is non-significant



Significant depletion of events due to interference in the low invariant mass tail



Early evidence of BSM physics significantly improved by reduction of PDF uncertainty

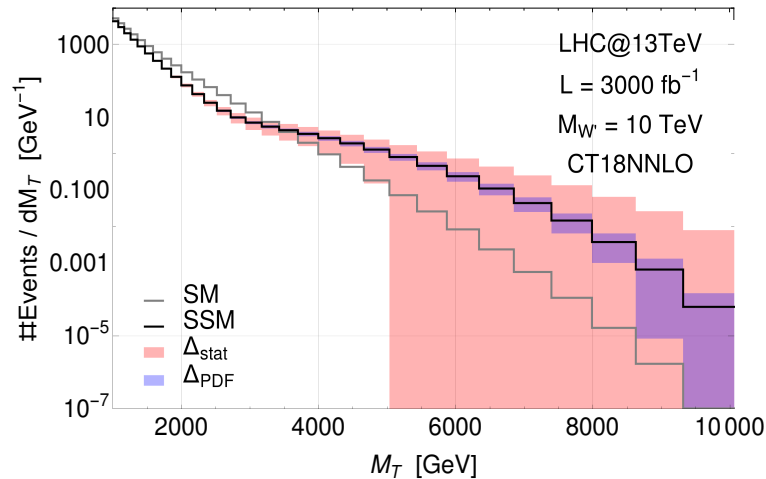
# Effects on $W'$ searches

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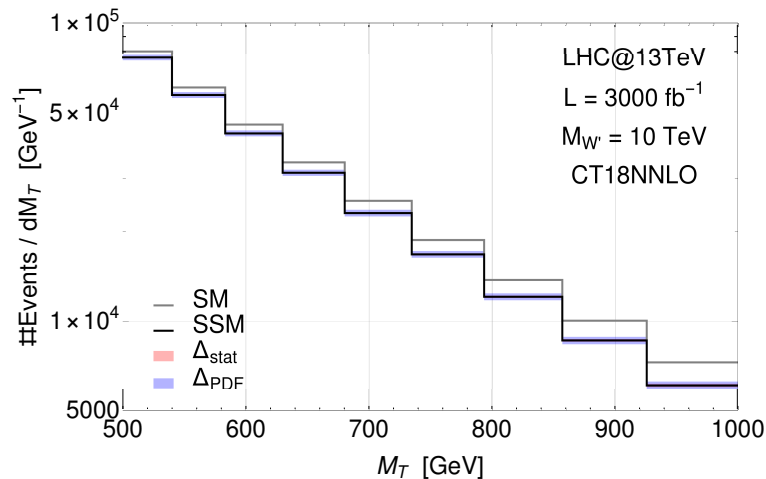
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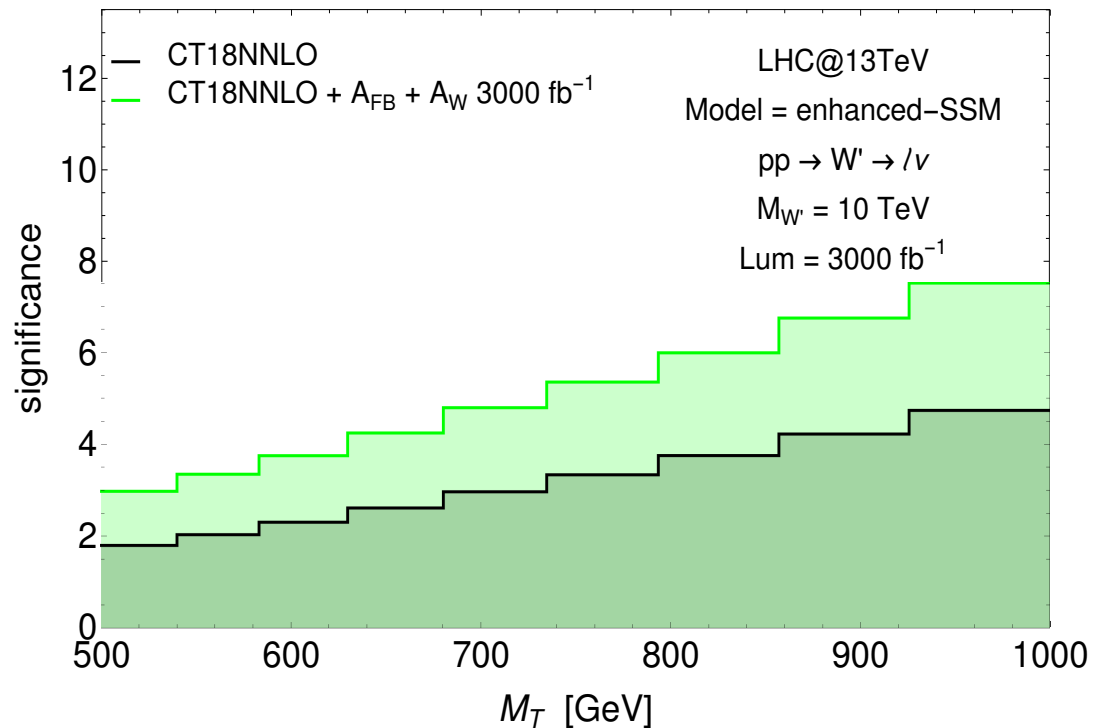
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# Conclusions

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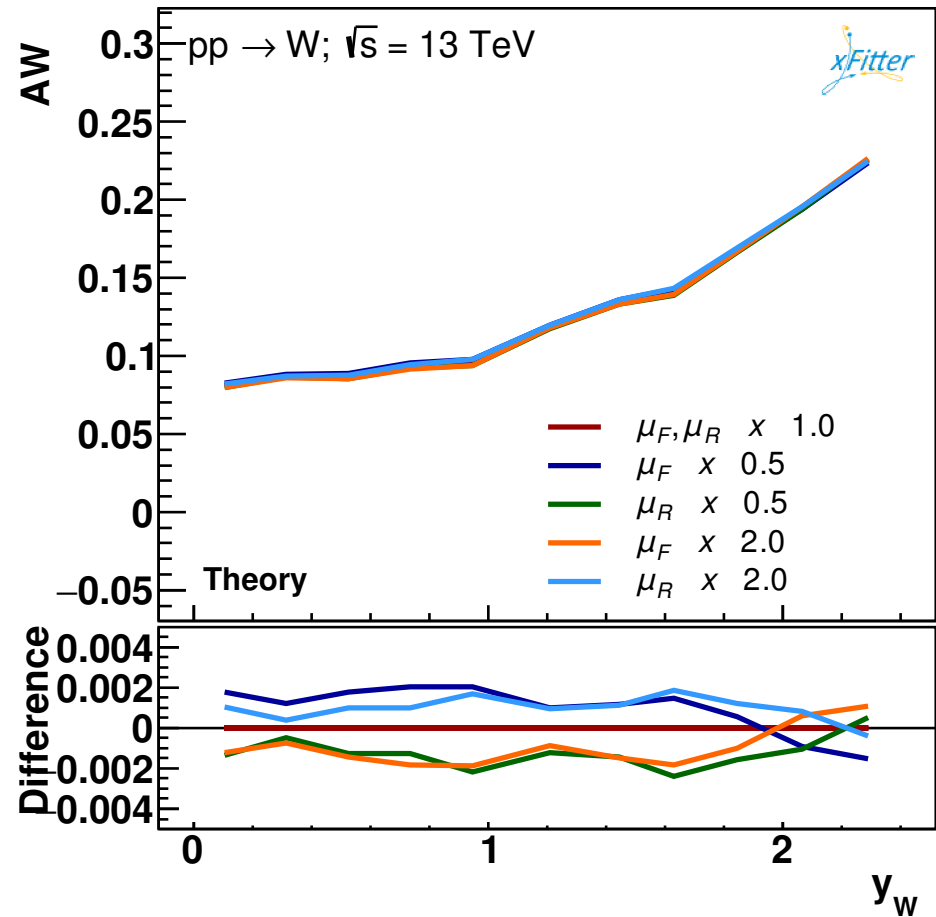
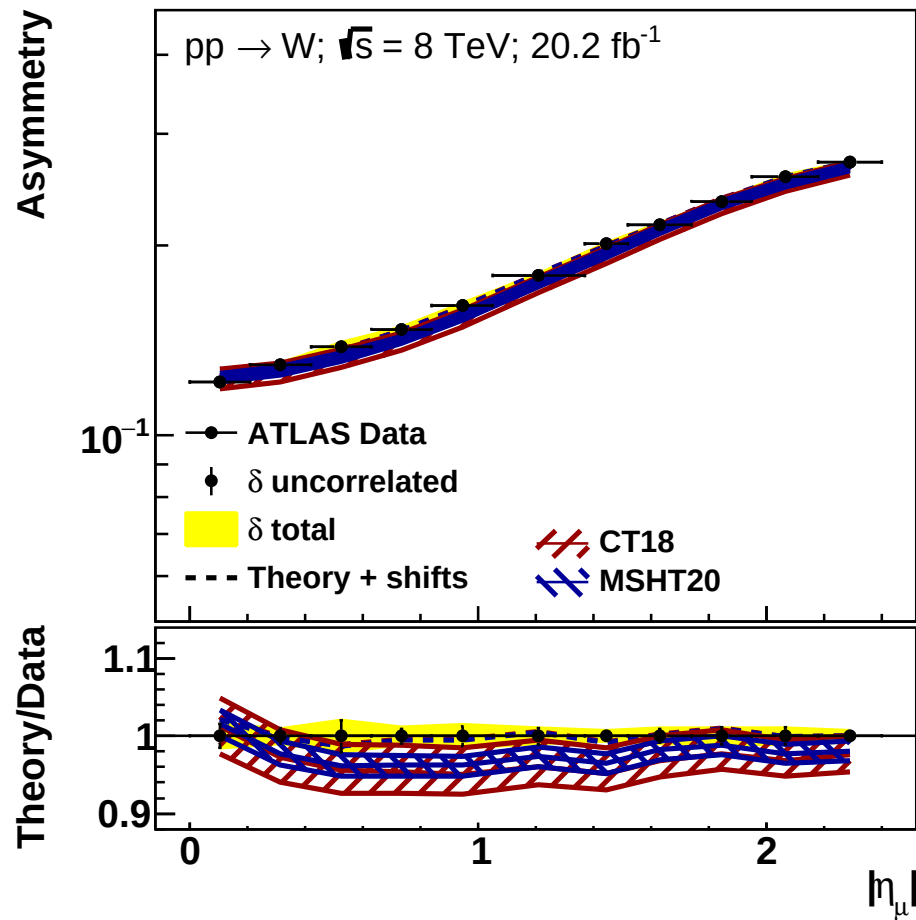
# Conclusions

- We extend our previous work on PDF constraints from Drell-Yan measurements: The high statistical precision of experimental measurements and the high accuracy of theoretical predictions lead to a remarkable constraining potential of this data.
- We have emphasised the complementarity between asymmetry measurements in the charged ( $A_W$ ) and neutral ( $A_{FB}$ ) channels:
  - Strong constraints on valence quark PDFs, comparable sensitivity of  $A_W$  and  $A_{FB}$ .
  - Significant constraints on anti-quark PDFs, particularly from  $A_W$  measurements in the high  $x$  region.
  - Shown the profiling results from the combination of  $A_{FB}$  and  $A_W$  data.
- We have explored the consequences of the reduction of PDF uncertainty from the inclusion of  $A_W$  and  $A_{FB}$  data on:
  - Precision measurements of SM observables, i.e. determination of  $M_W$ .
  - Improvement in the sensitivity of BSM searches on non-resonant objects in both neutral ( $Z'$ ) and charged ( $W'$ ) channels.

# Thank you!

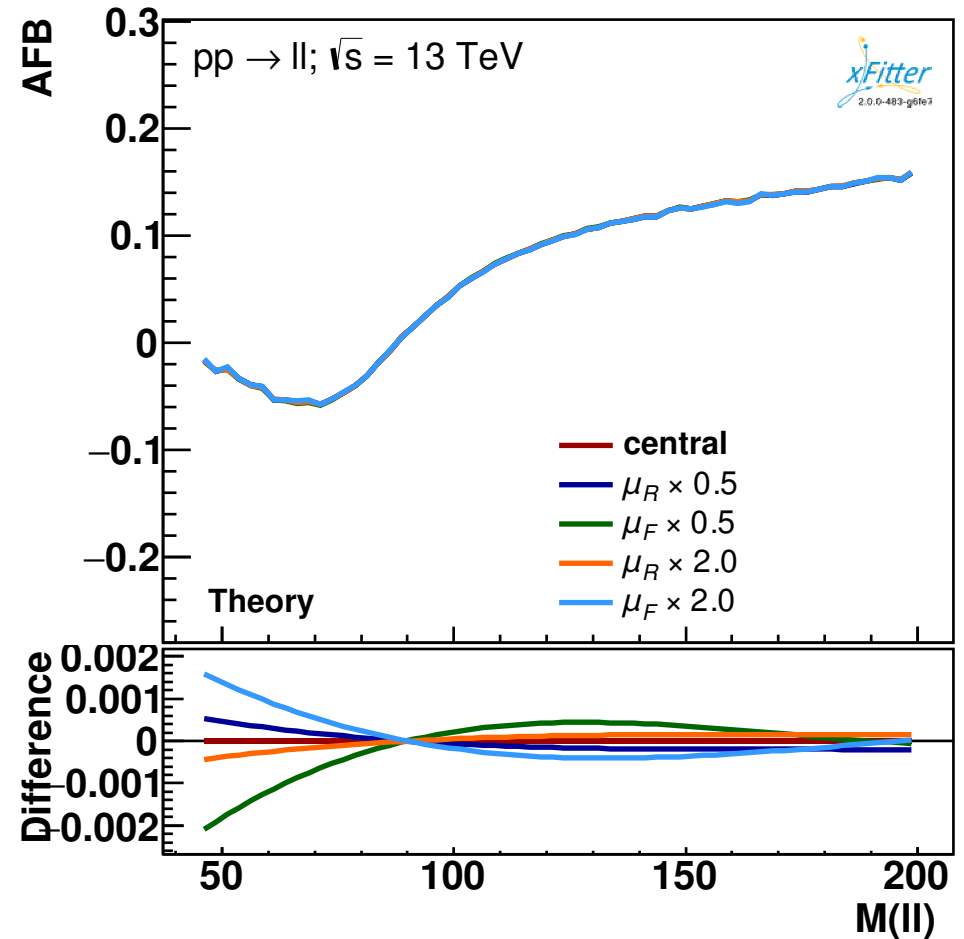
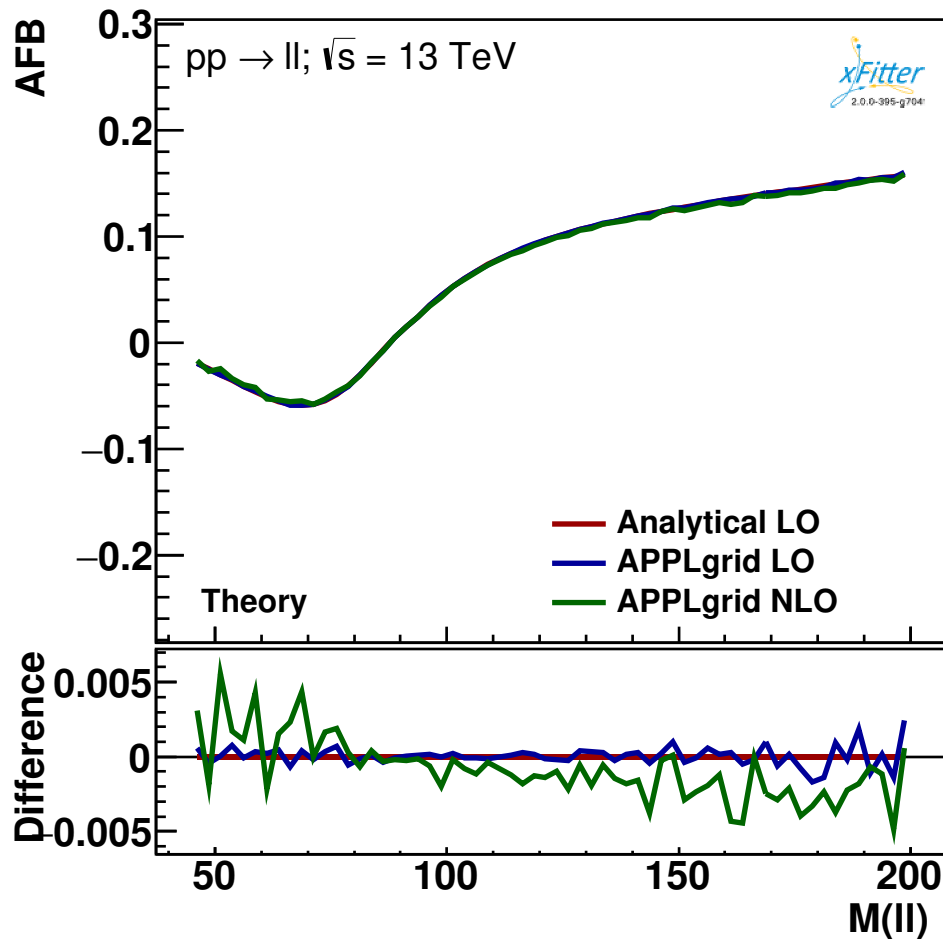
# Backup slides

# Lepton-charge asymmetry



Theory uncertainty from scale variation  
under control, well below PDF uncertainties.

# Neutral channel asymmetry



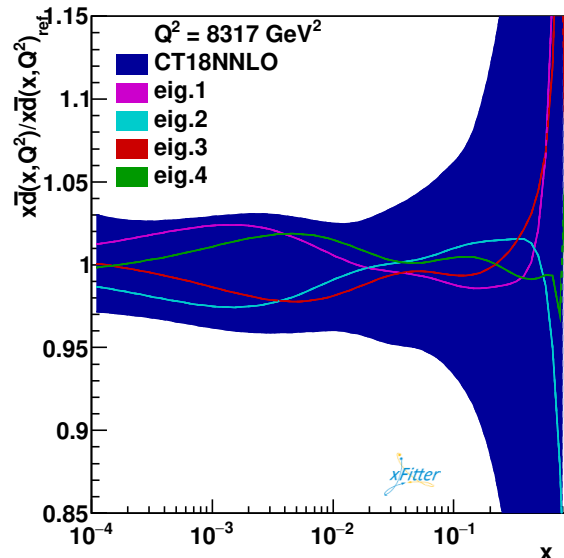
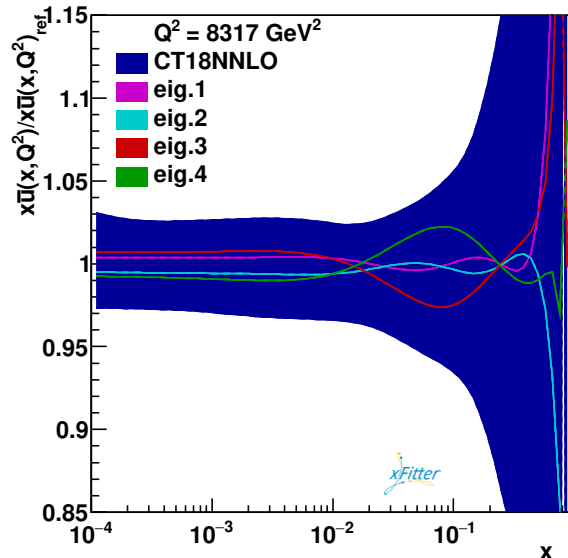
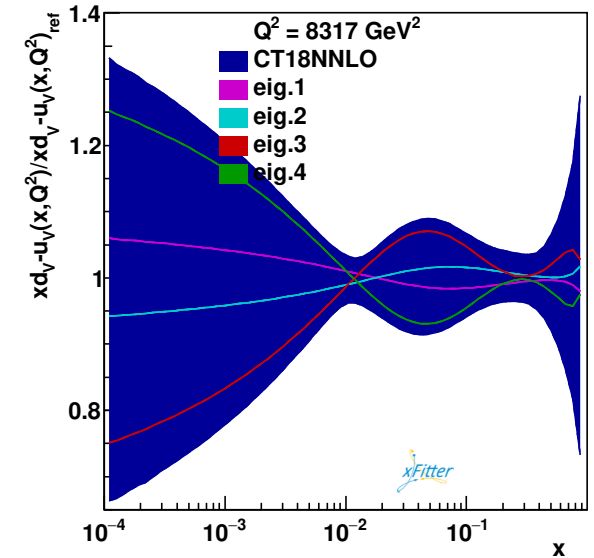
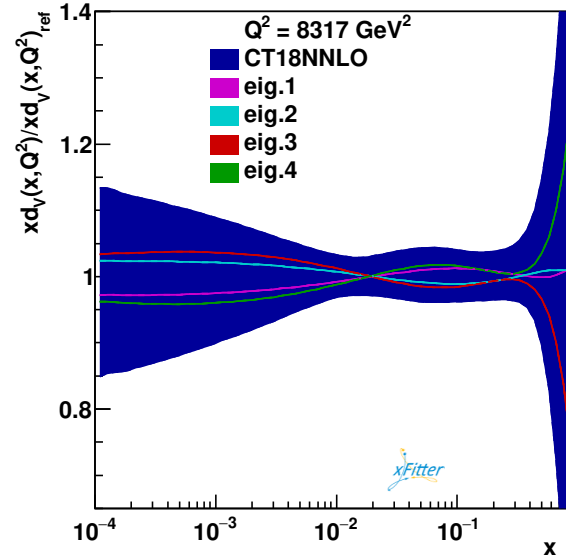
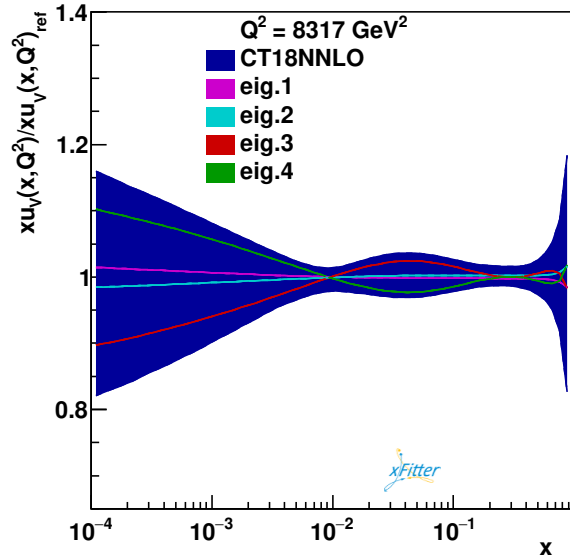
Theory uncertainty from  
scale variation under control.

# Eigenvector rotation

Assess the single PDF sensitivity on  $A_W$  data through eigenvector rotation exercise:

J. Pumplin,

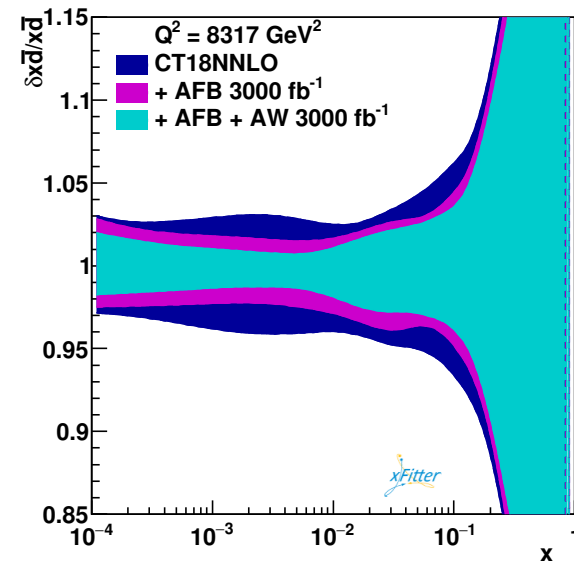
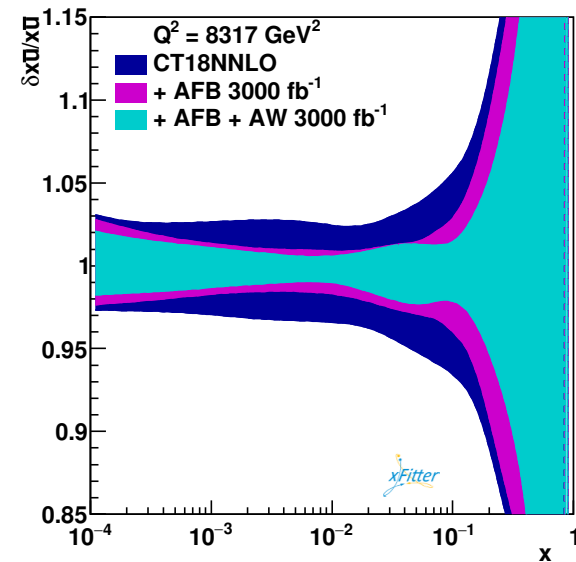
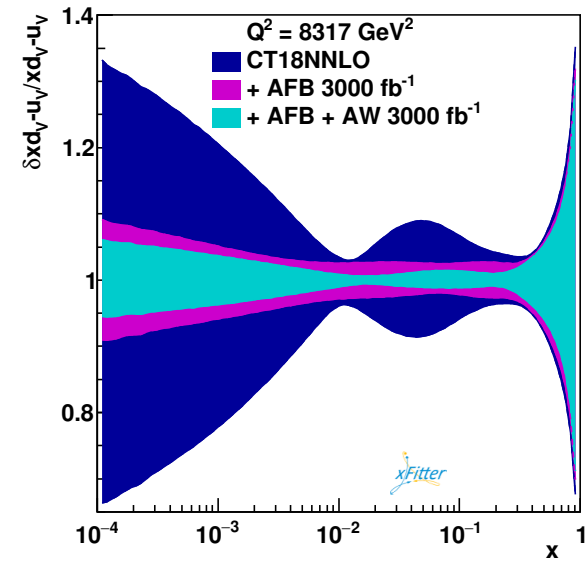
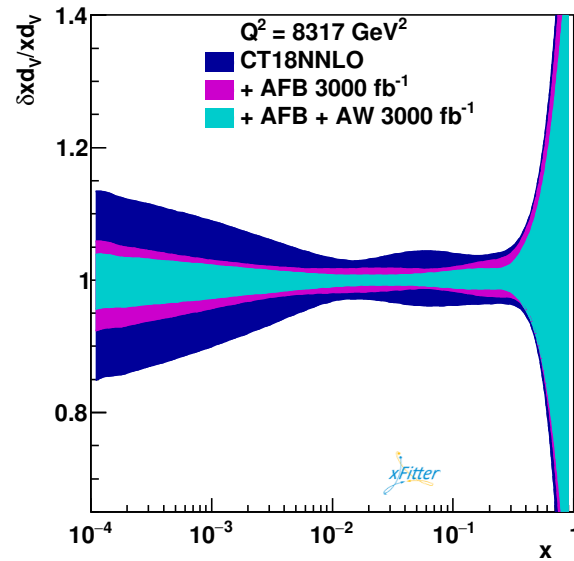
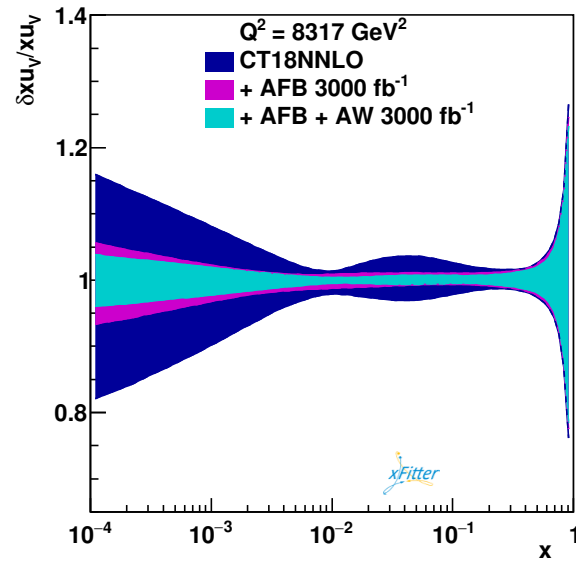
Phys. Rev. D 80 (2009) 034002



Largest sensitivity on valence quarks, particularly on the combination  $(d_V - u_V)$

Complementarity with  $A_{FB}$  most sensitive to  $(1/3 d_V + 2/3 u_V)$

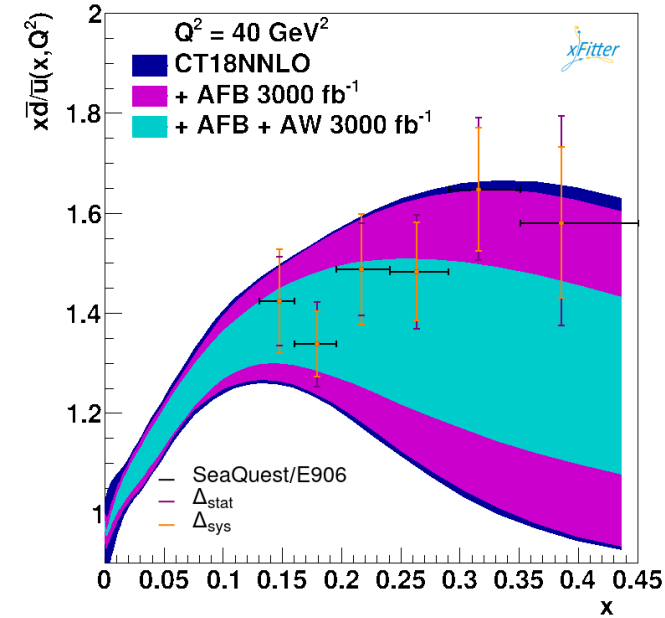
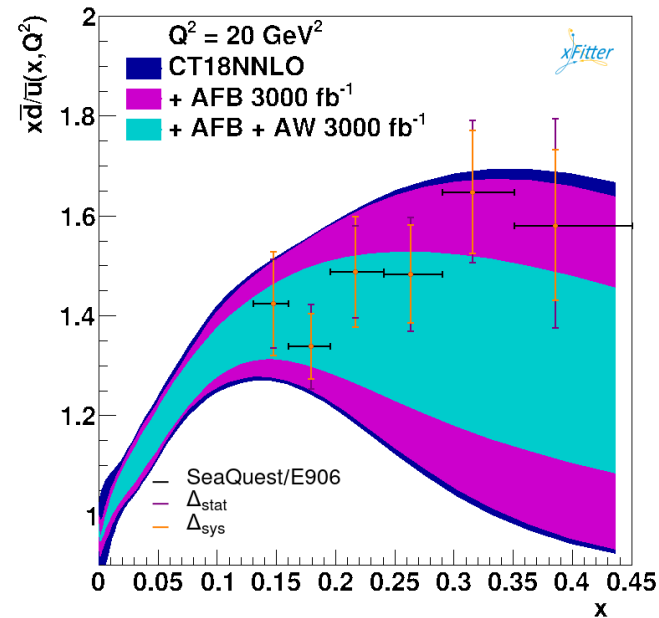
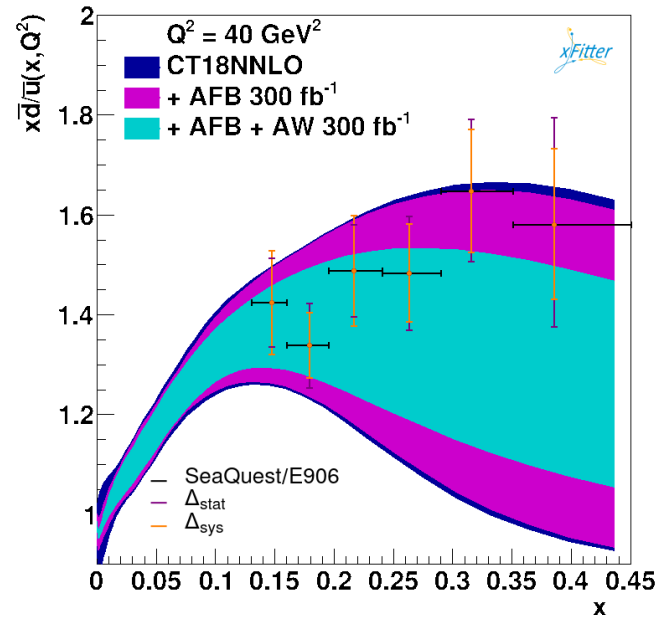
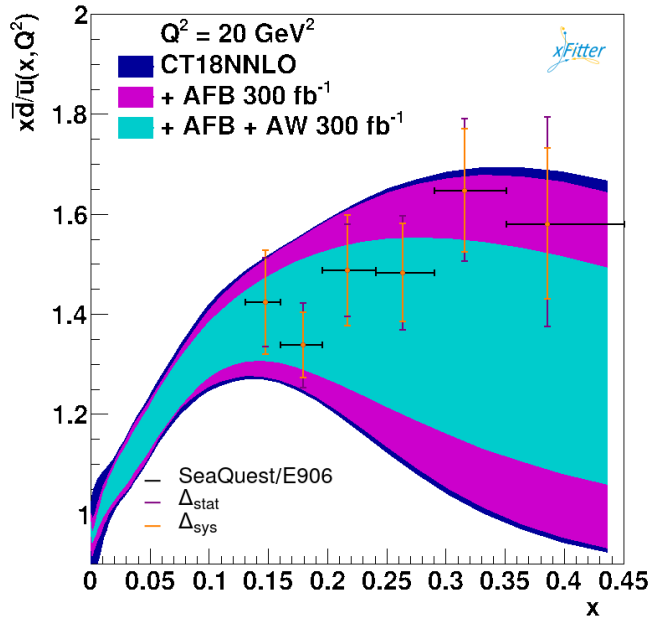
# Combining $A_W$ and $A_{FB}$



At higher luminosity we observe an effect of saturation, i.e. the improvement from  $300 \text{ fb}^{-1}$  to  $3000 \text{ fb}^{-1}$  is small.

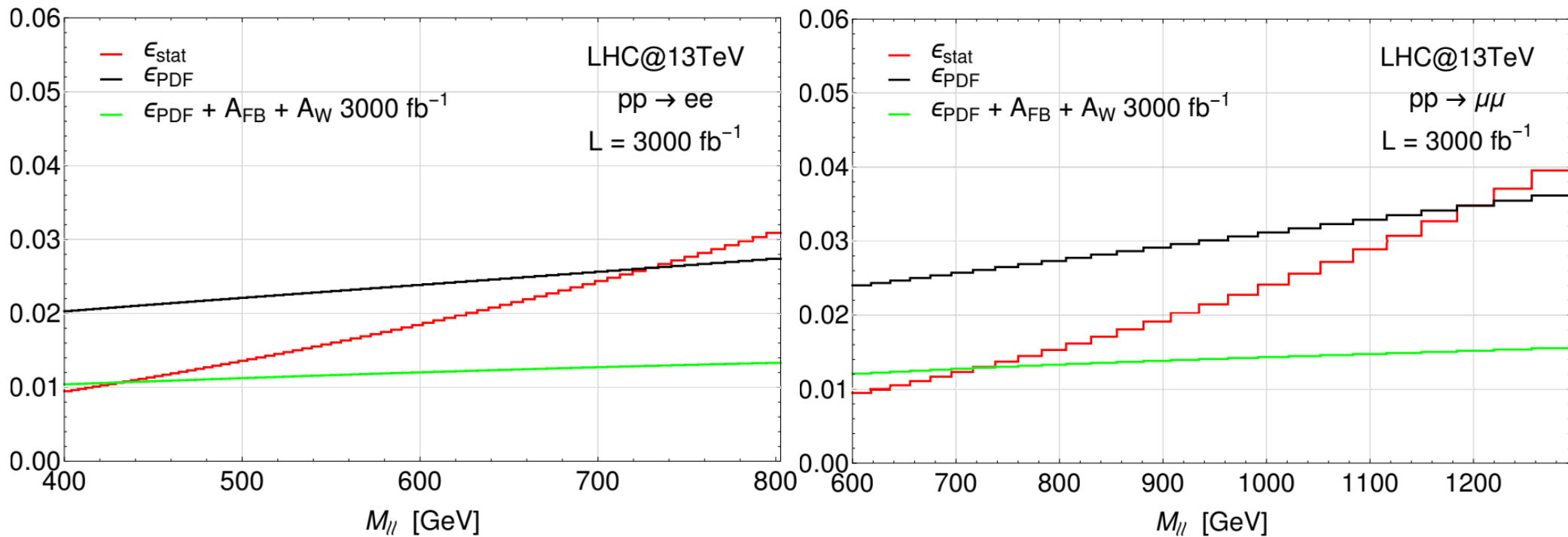


# $A_W$ for antimatter asymmetry



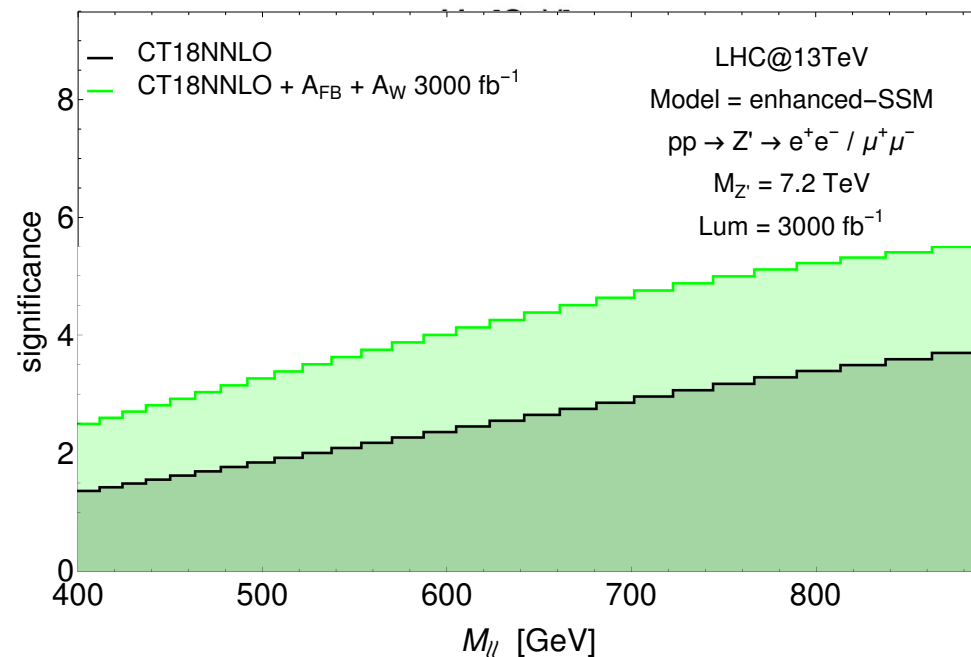
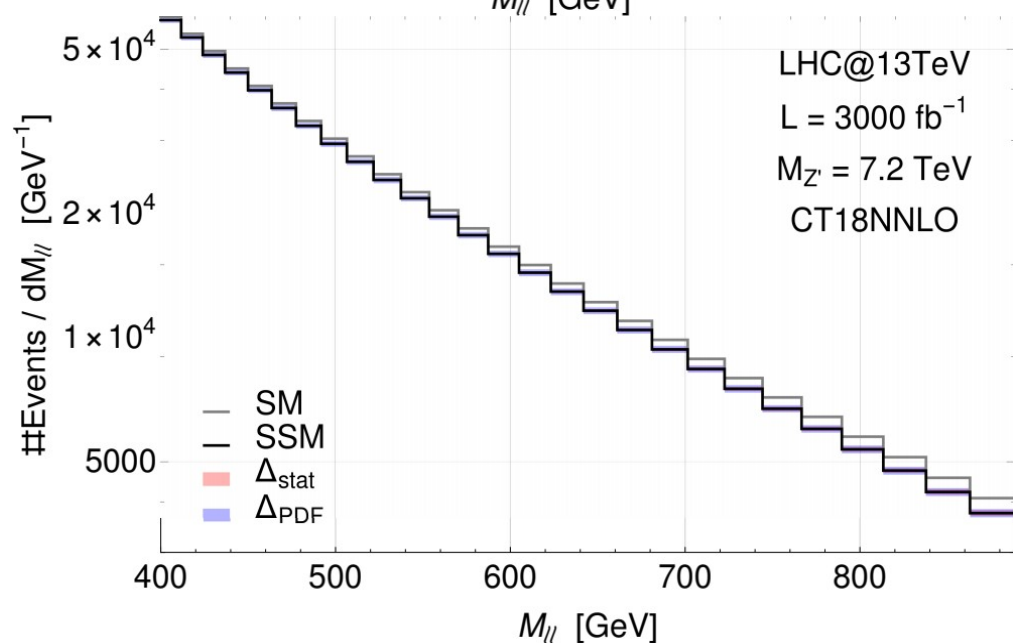
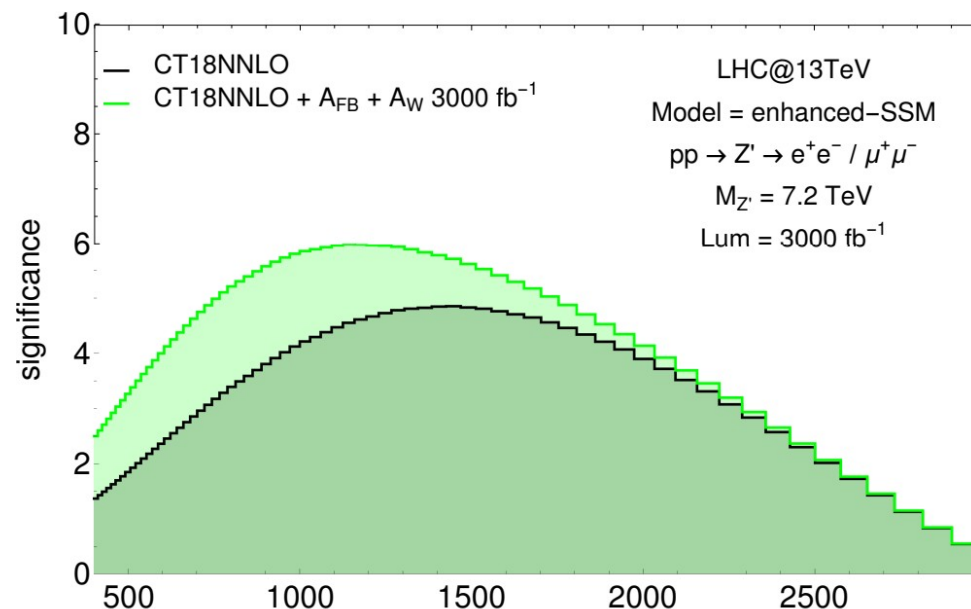
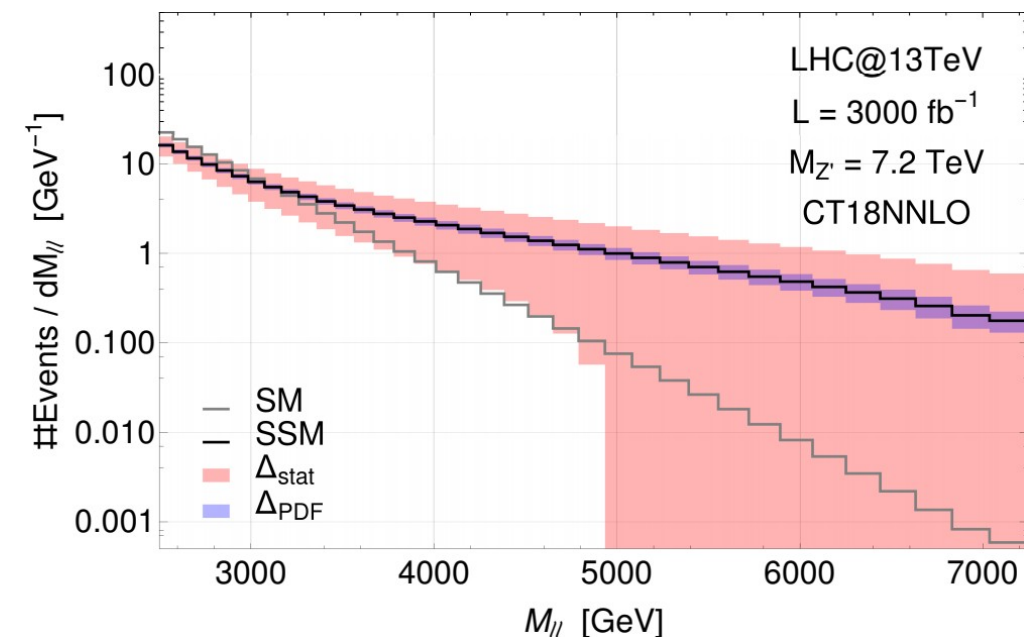
SeaQuest Collaboration,  
Nature 590 (2021) 7847, 561-565

# Uncertainties in the neutral channel



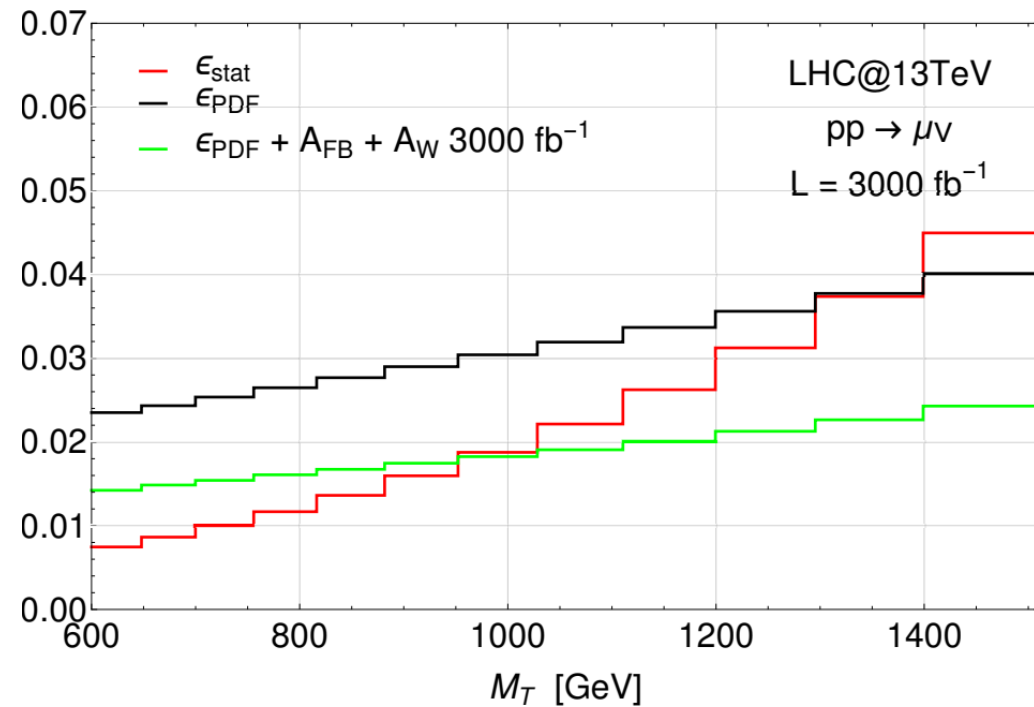
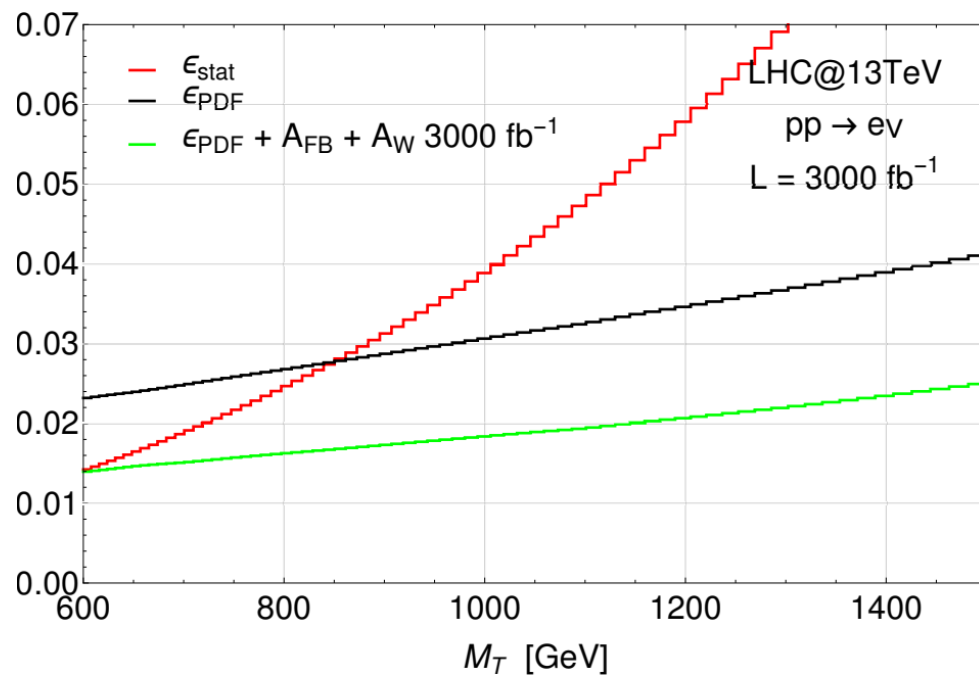
The improvement on PDF determination increases the sensitivity to BSM physics and enables the diagnostic power of experimental analysis.

# Effects on $Z'$ searches



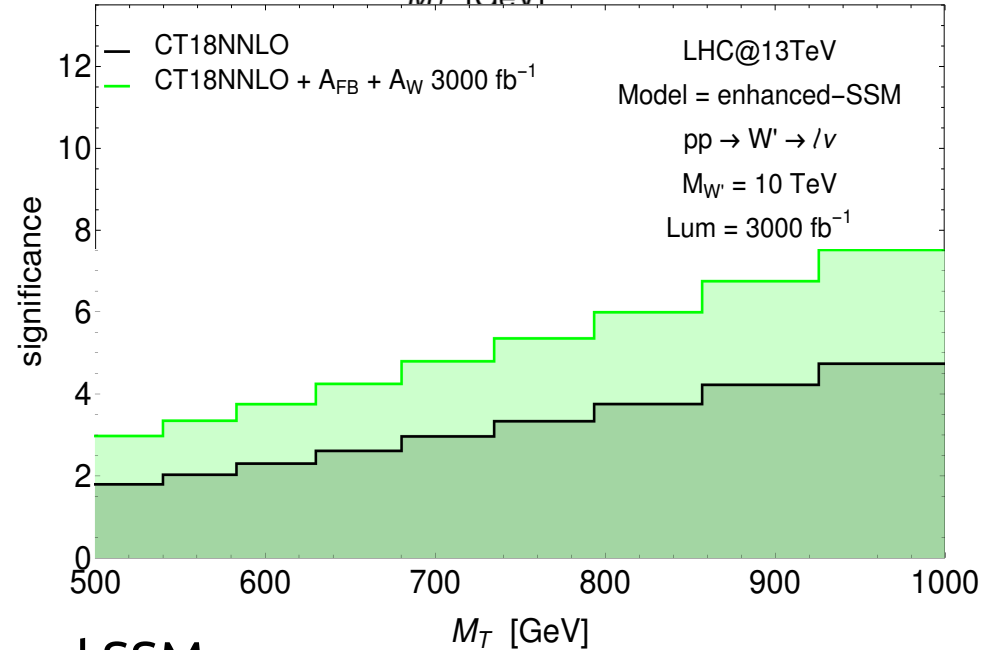
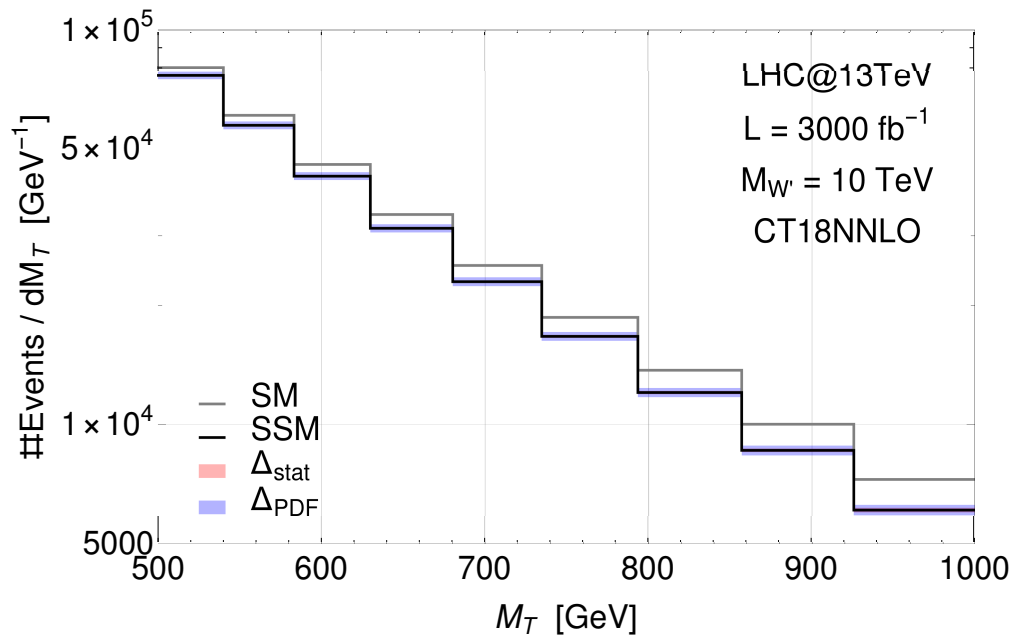
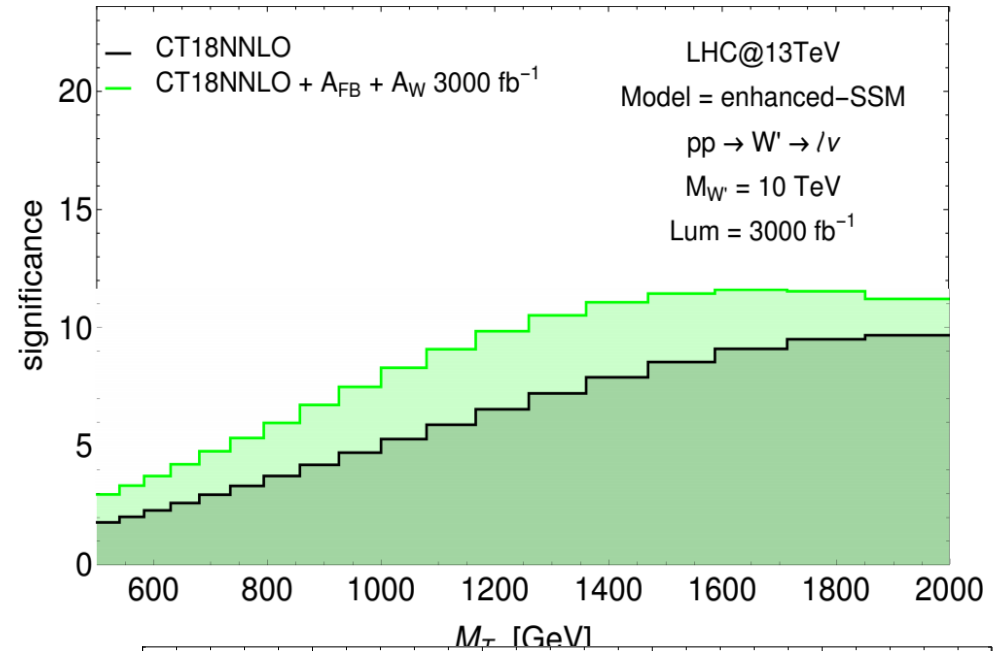
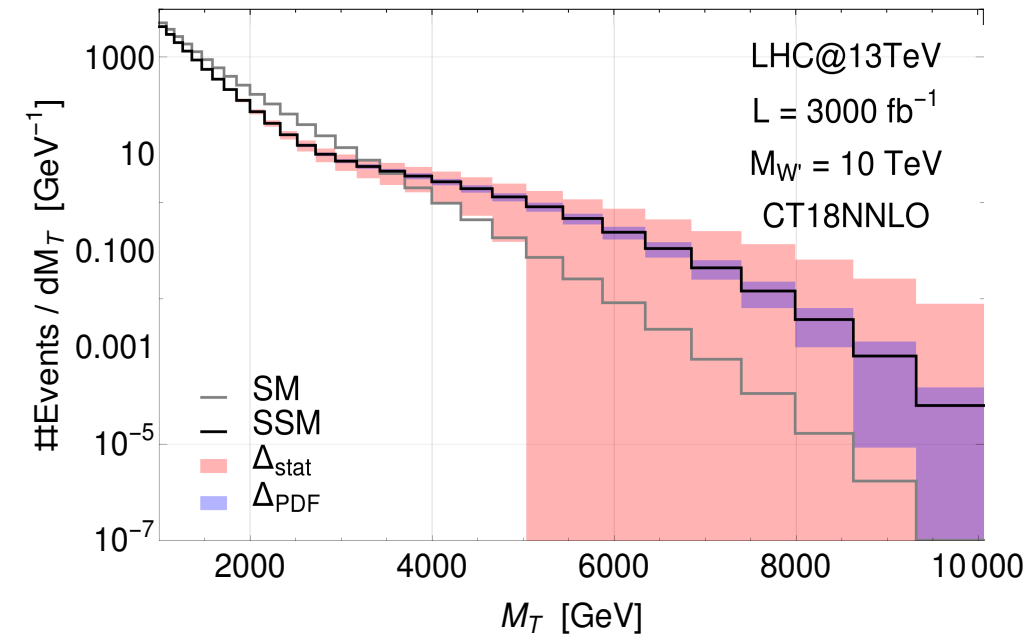
$Z'$  from enhanced SSM

# Uncertainties in the charged channel



The improvement on PDF determination increases the sensitivity to BSM physics and enables the diagnostic power of experimental analysis.

# Effects on $W'$ searches



$W'$  from enhanced SSM