



# *The interplay between PDF fits and heavy New Physics searches*

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In collaboration with:

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Moore, Mark Costantini, Manuel  
Morales, Maeve Madigan, Zahari  
Kassabov

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European Research Council

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# *Motivation*

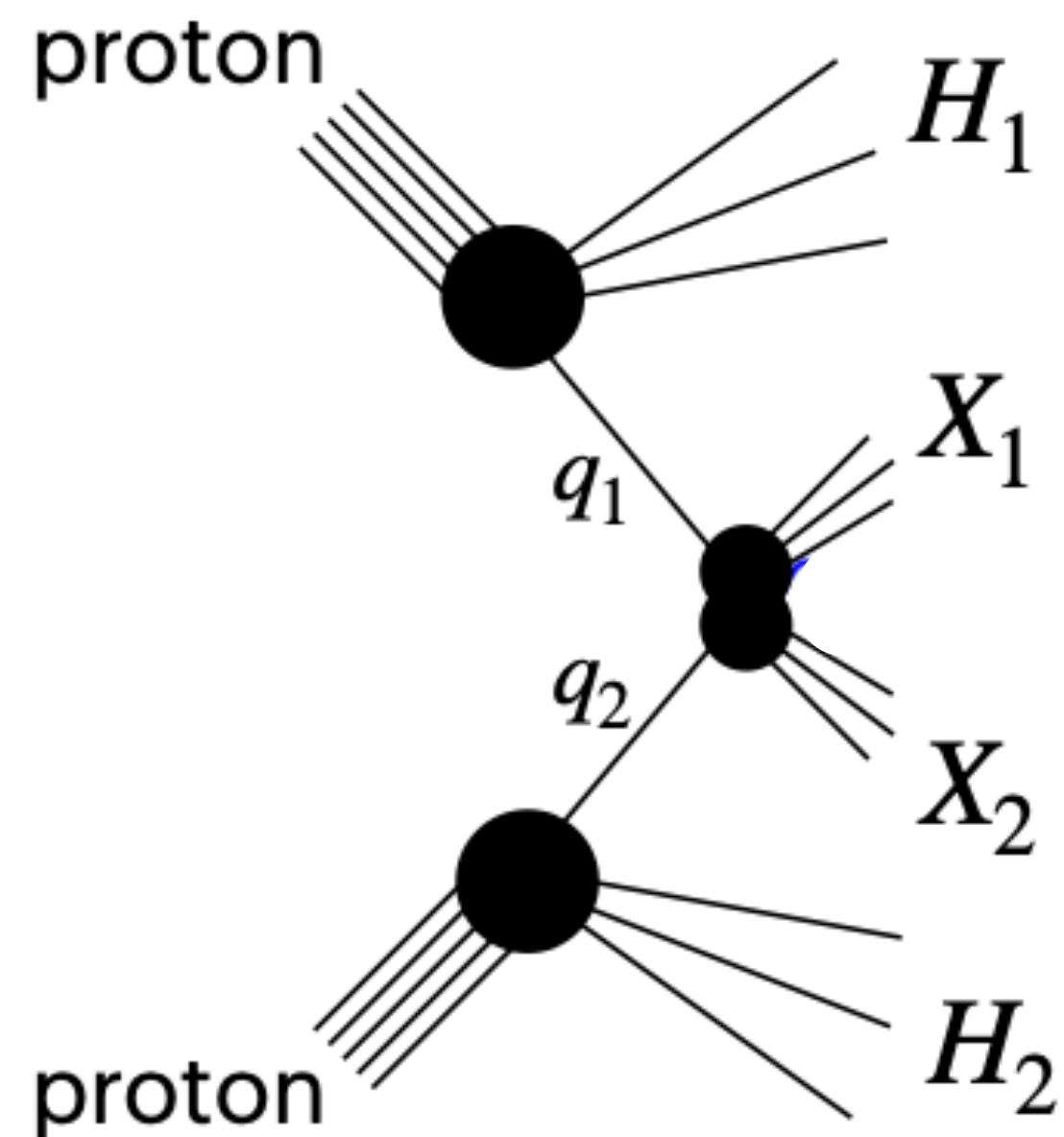


# *The parton model for the proton*

We search for NP at the LHC, where protons are smashed

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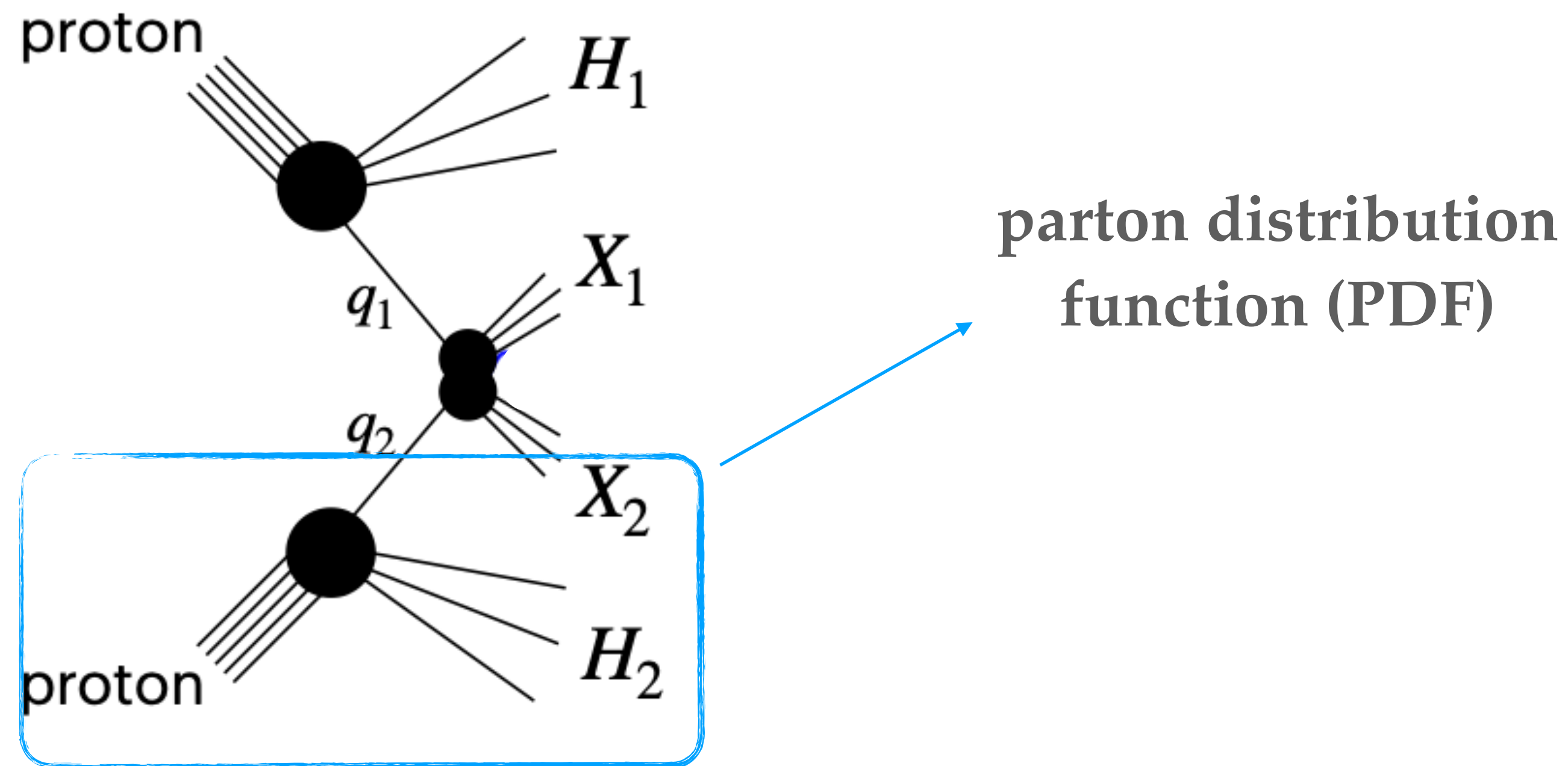
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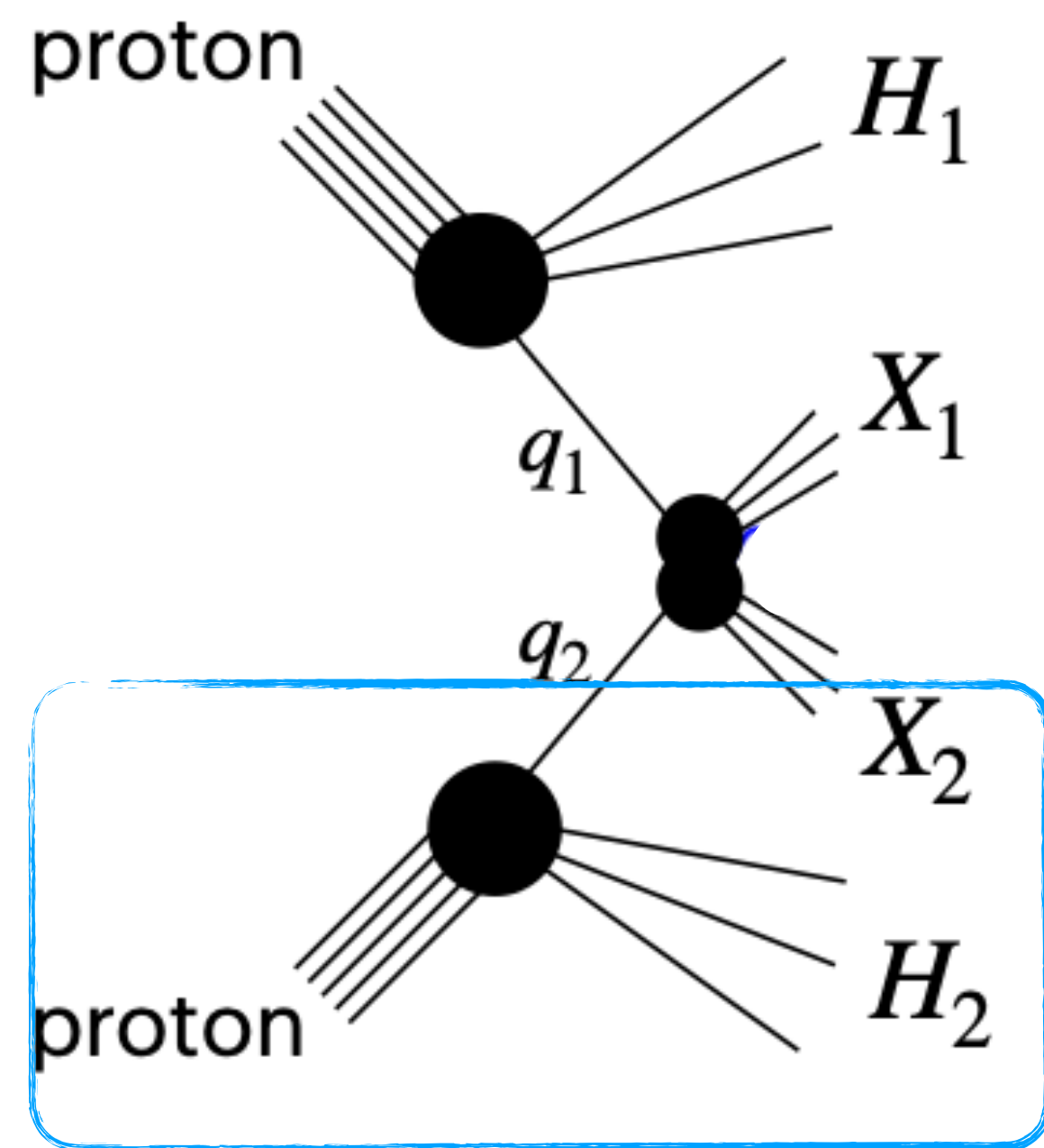
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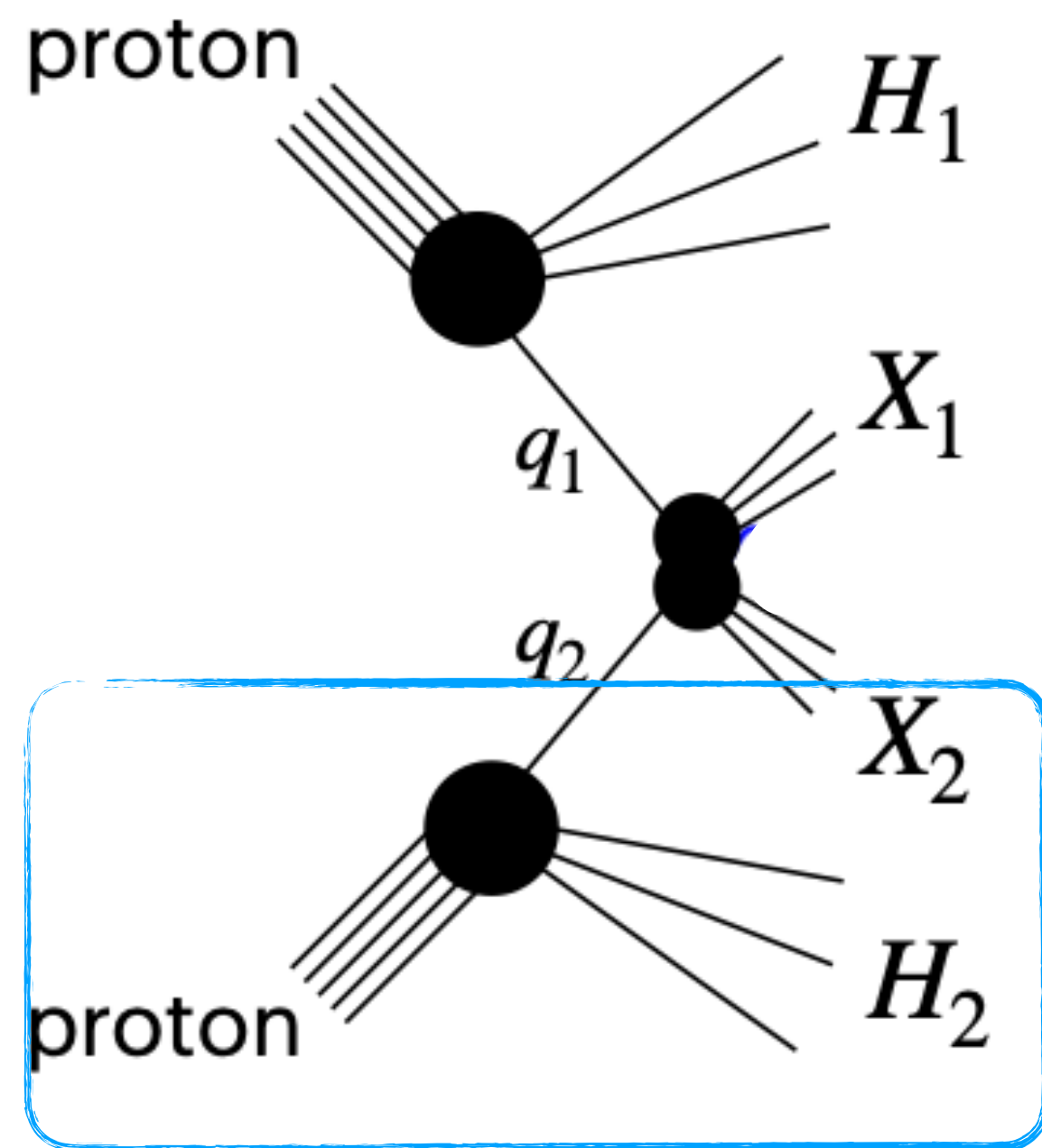
parton distribution  
function (PDF)

Difficult to determine  
on theoretical basis  
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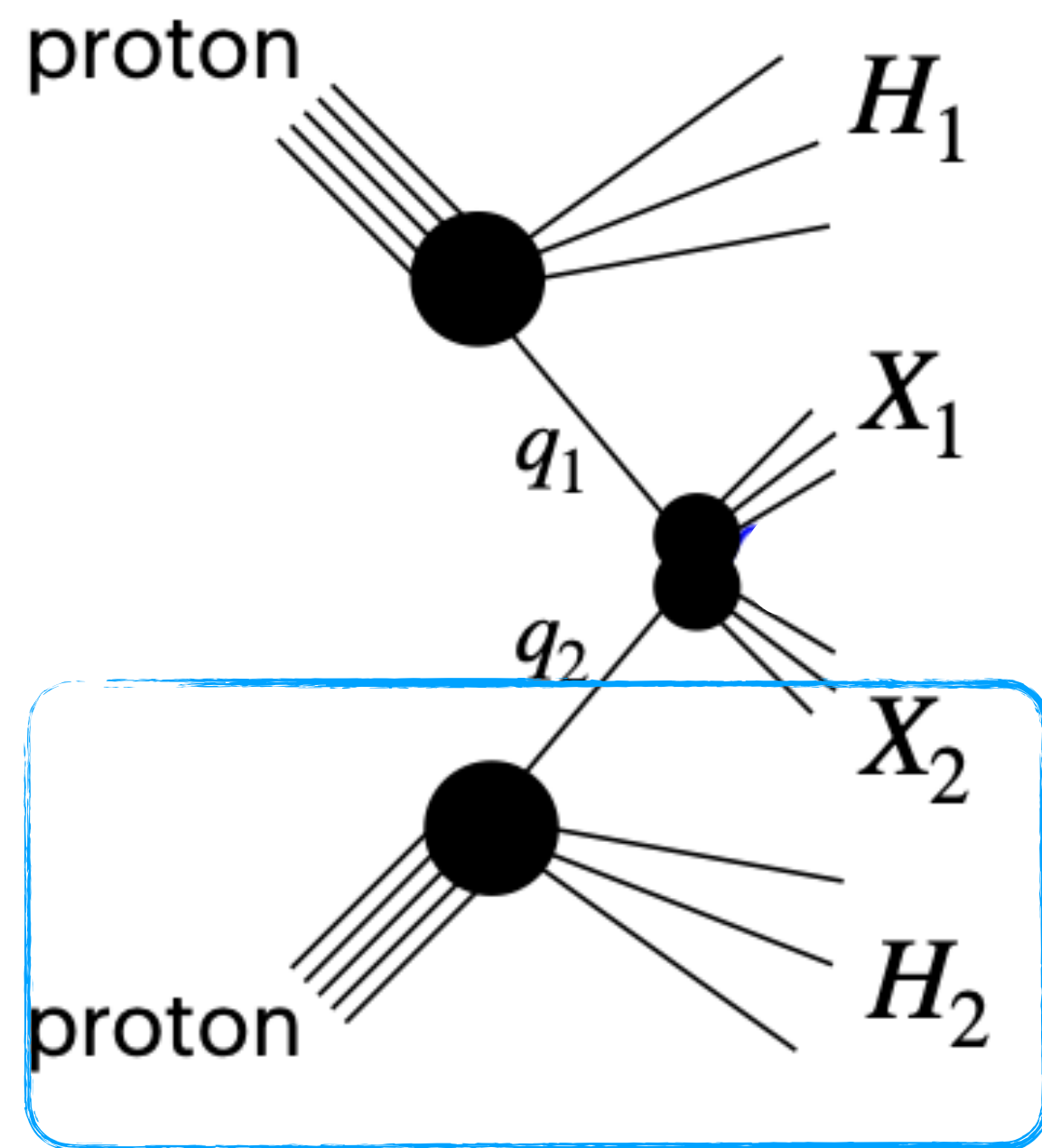
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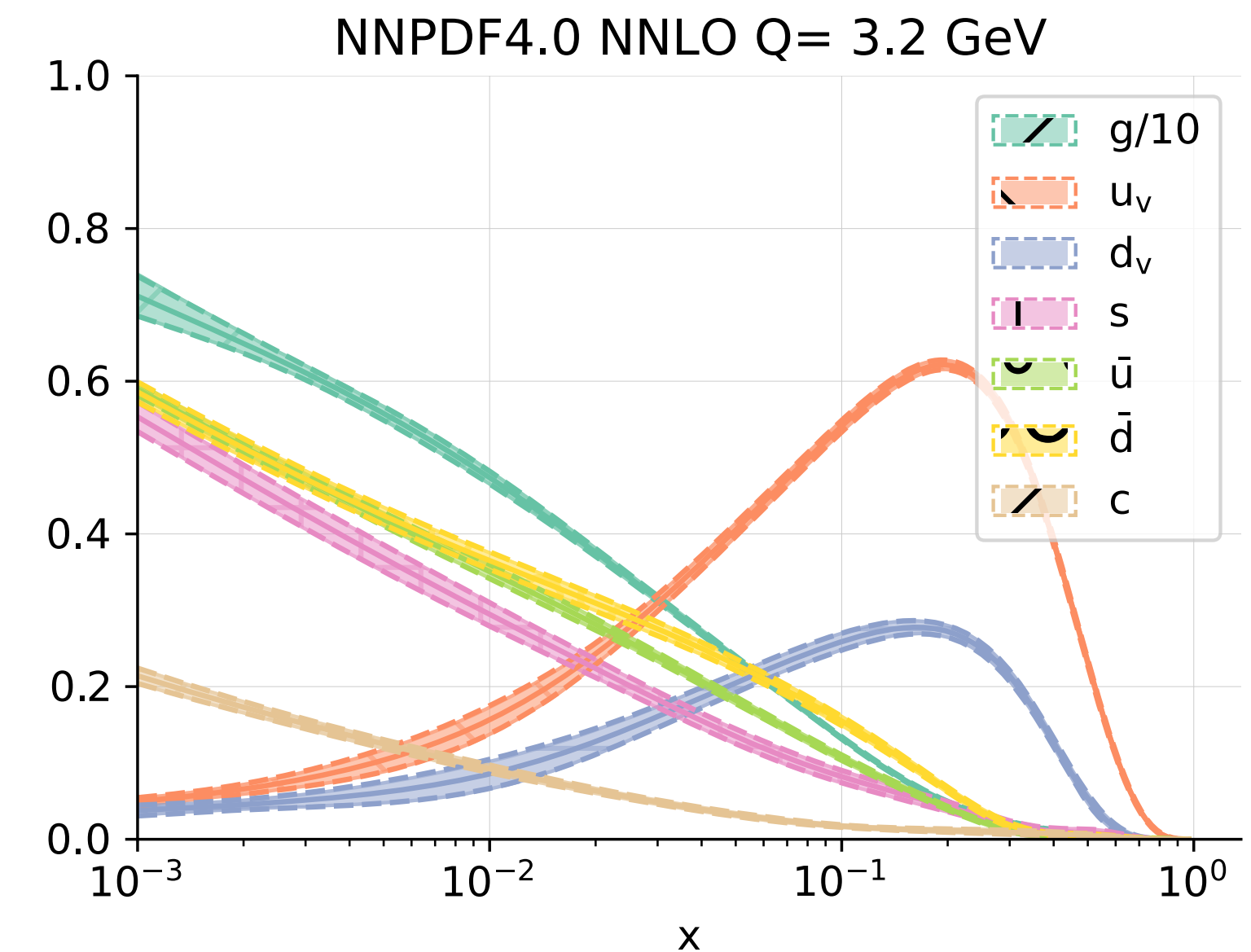
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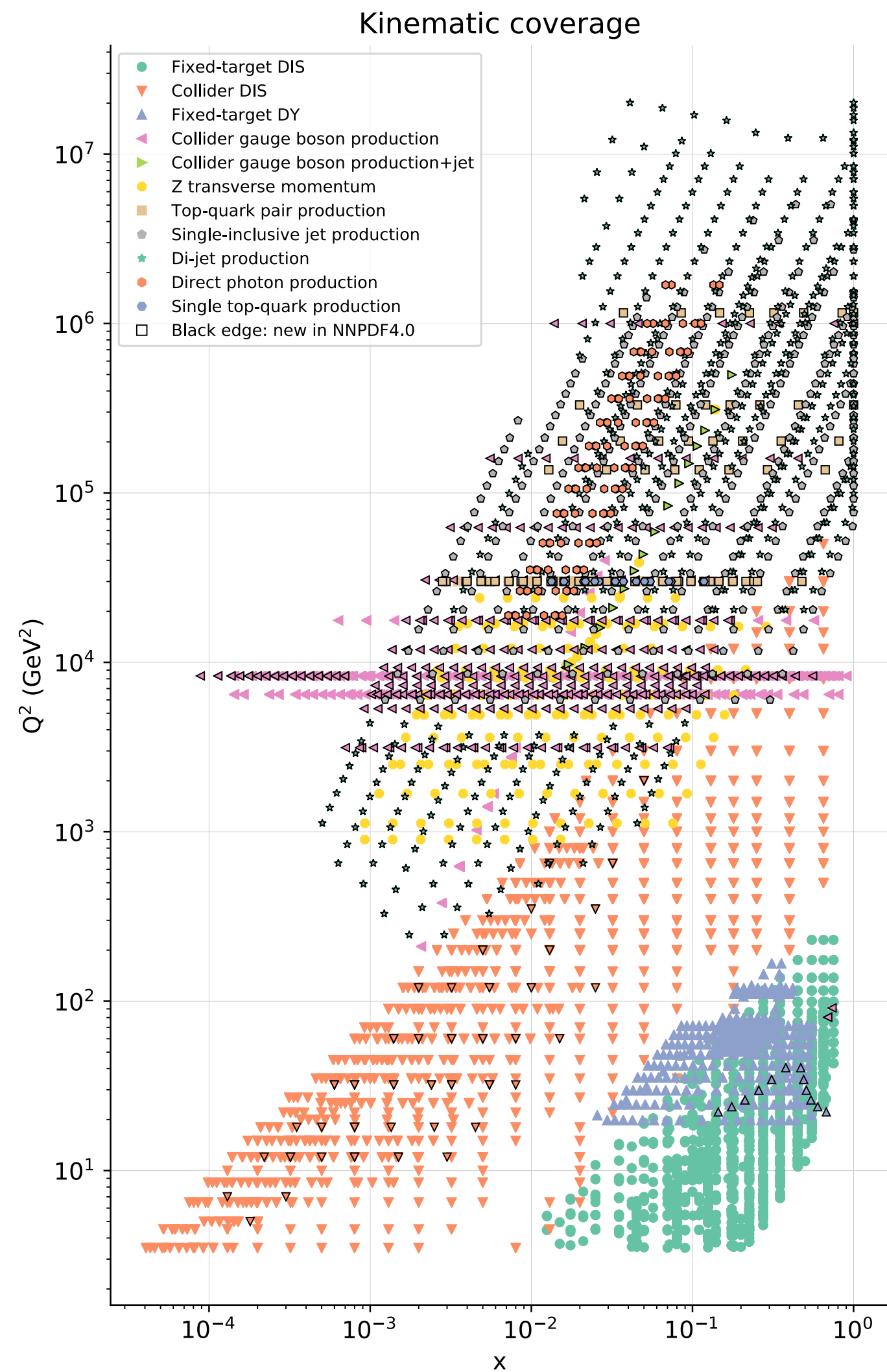
*Ball et. al, NNPDF4.0, 2109.02653*

# PDF determination

Data driven determination

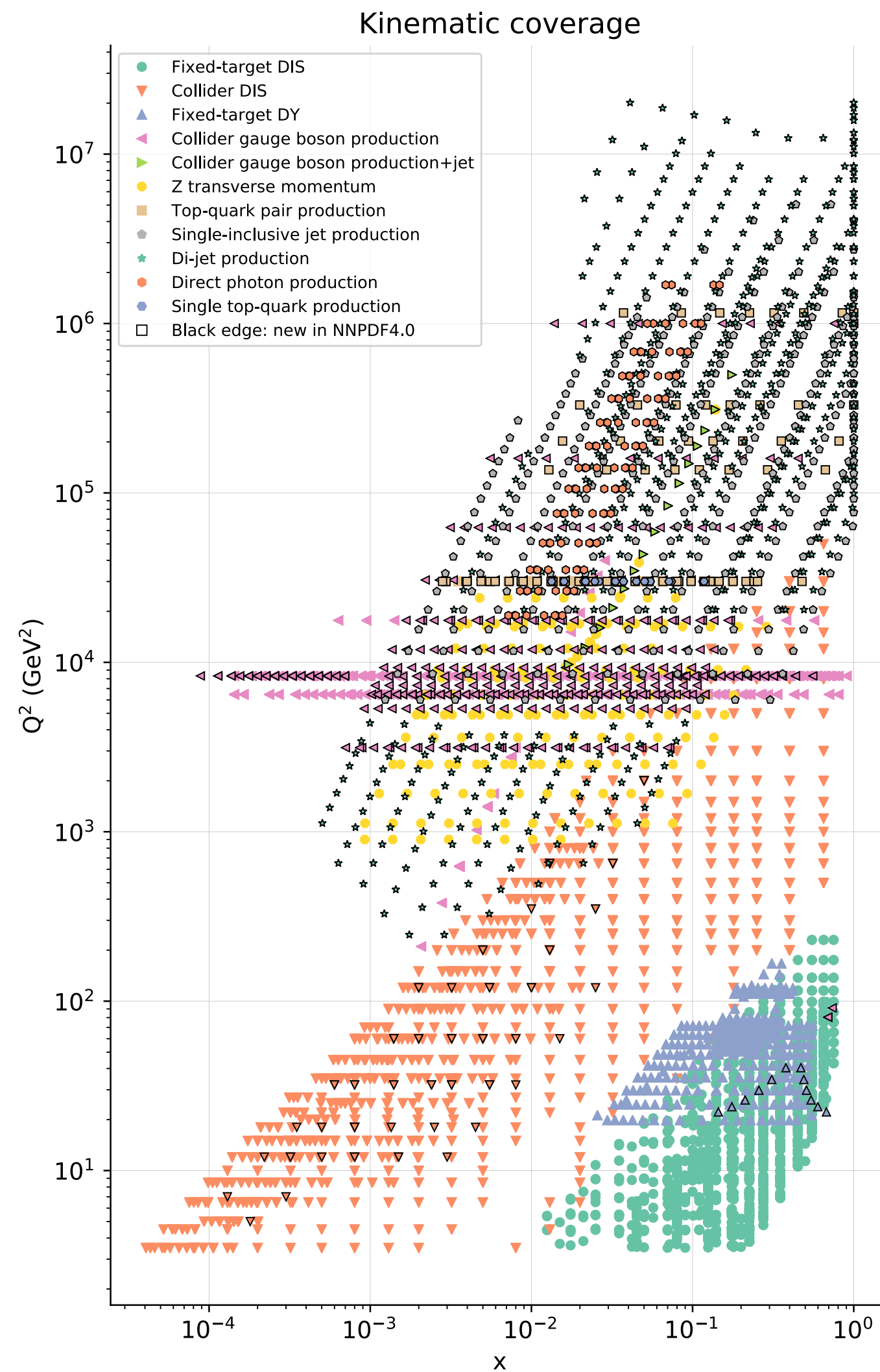
Theory assumptions

Measurements





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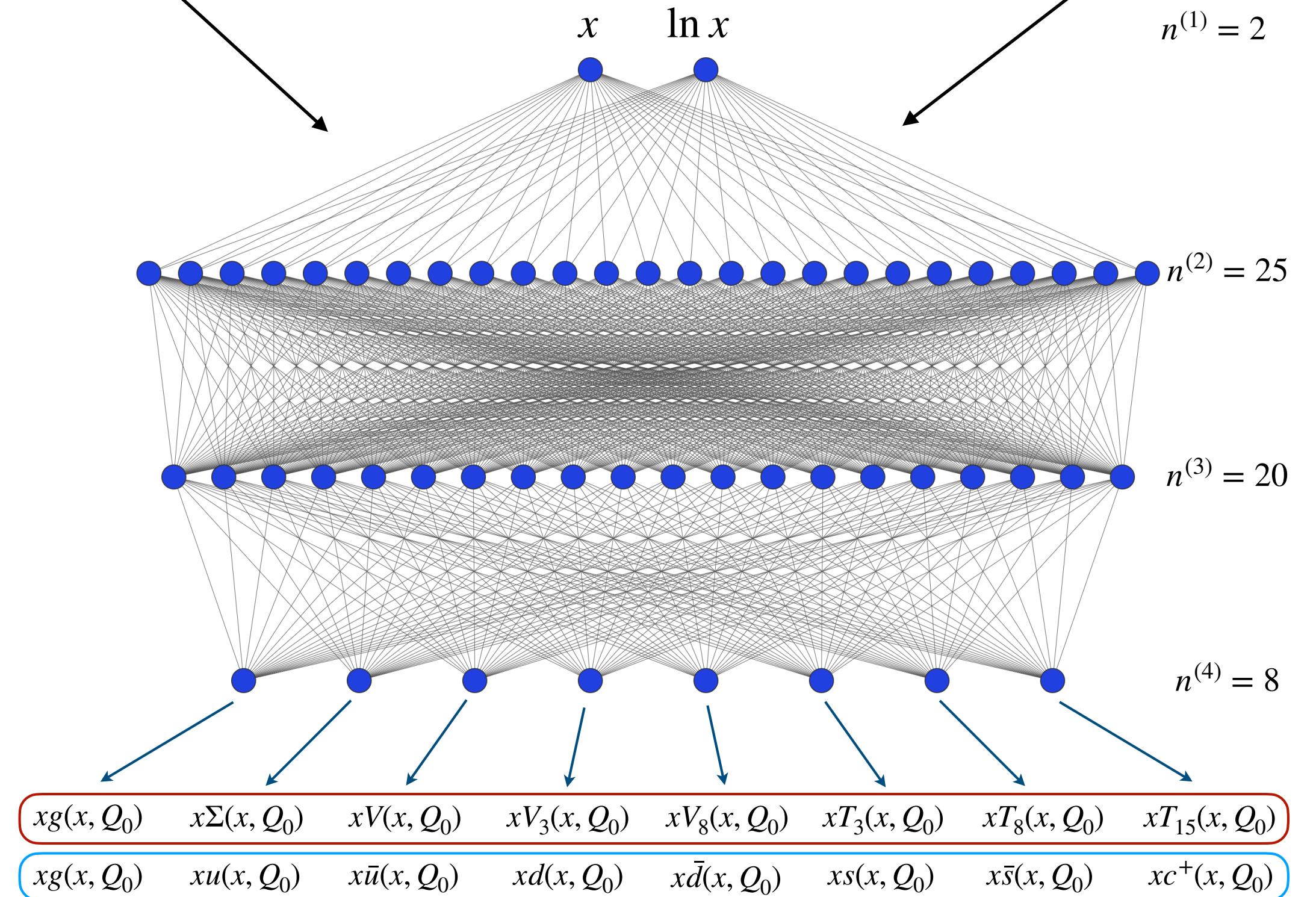


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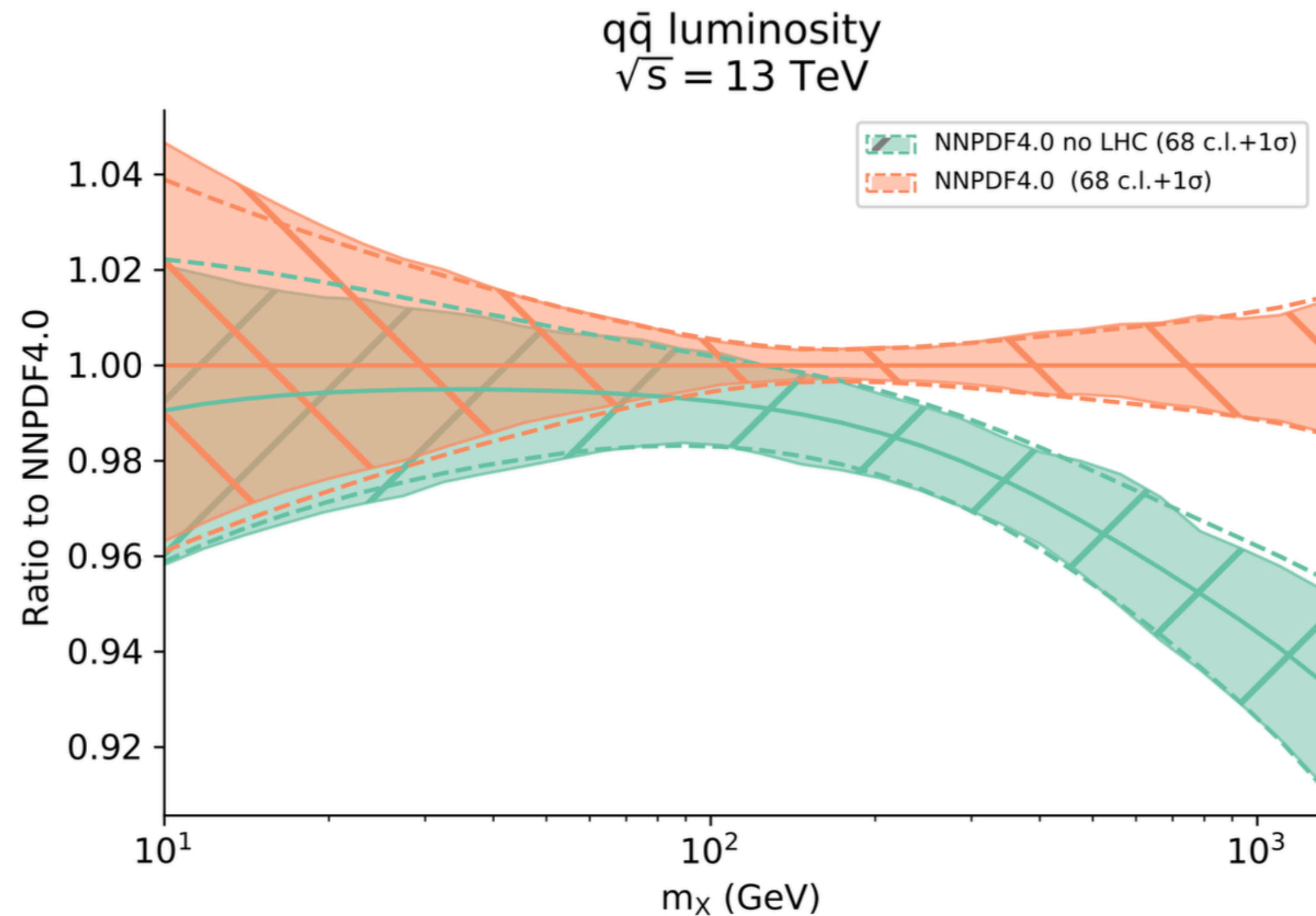
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Neural network





# Could PDFs conceal NP?

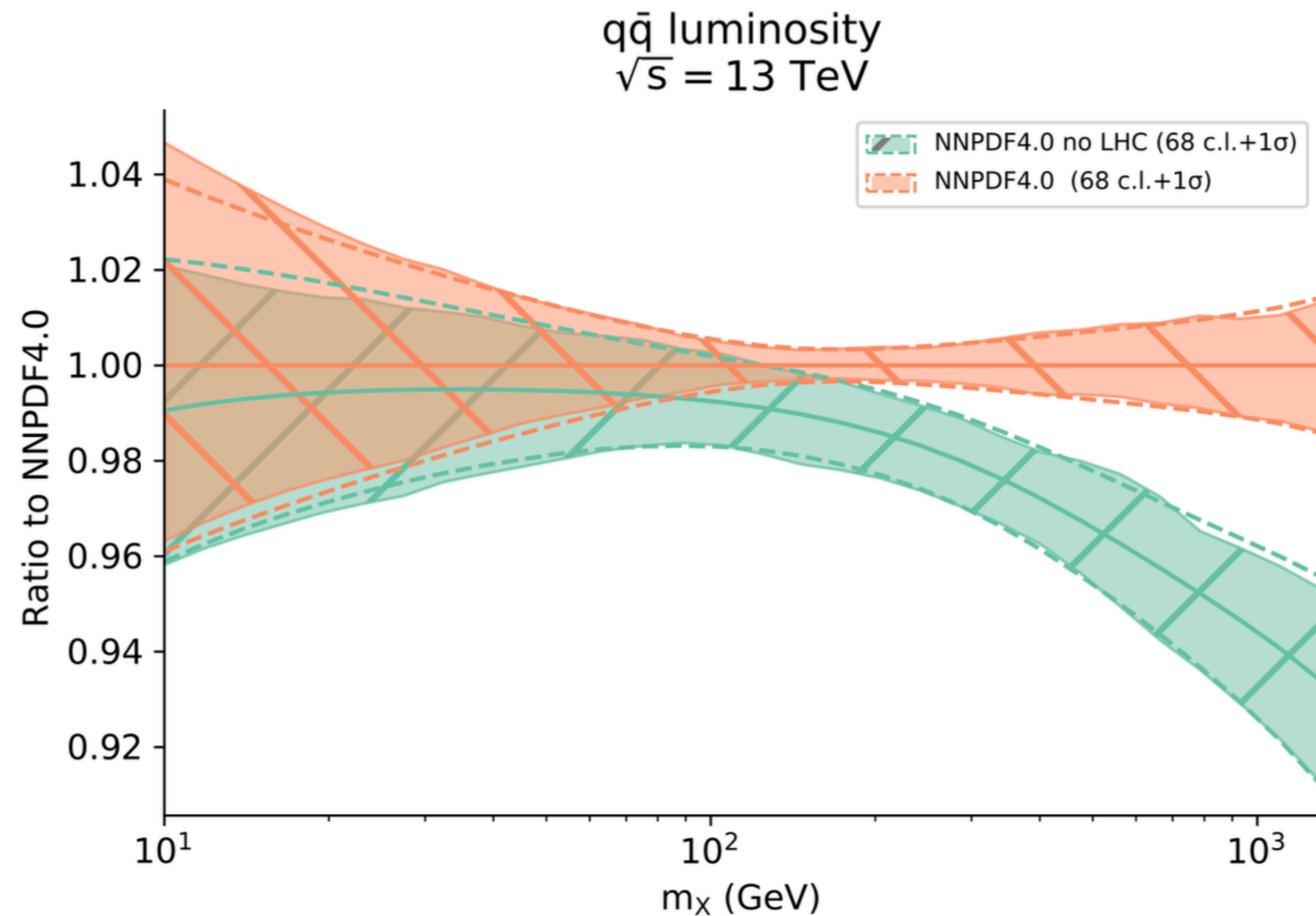


PDF parametrisation  
is flexible... **extrapolation is tricky**

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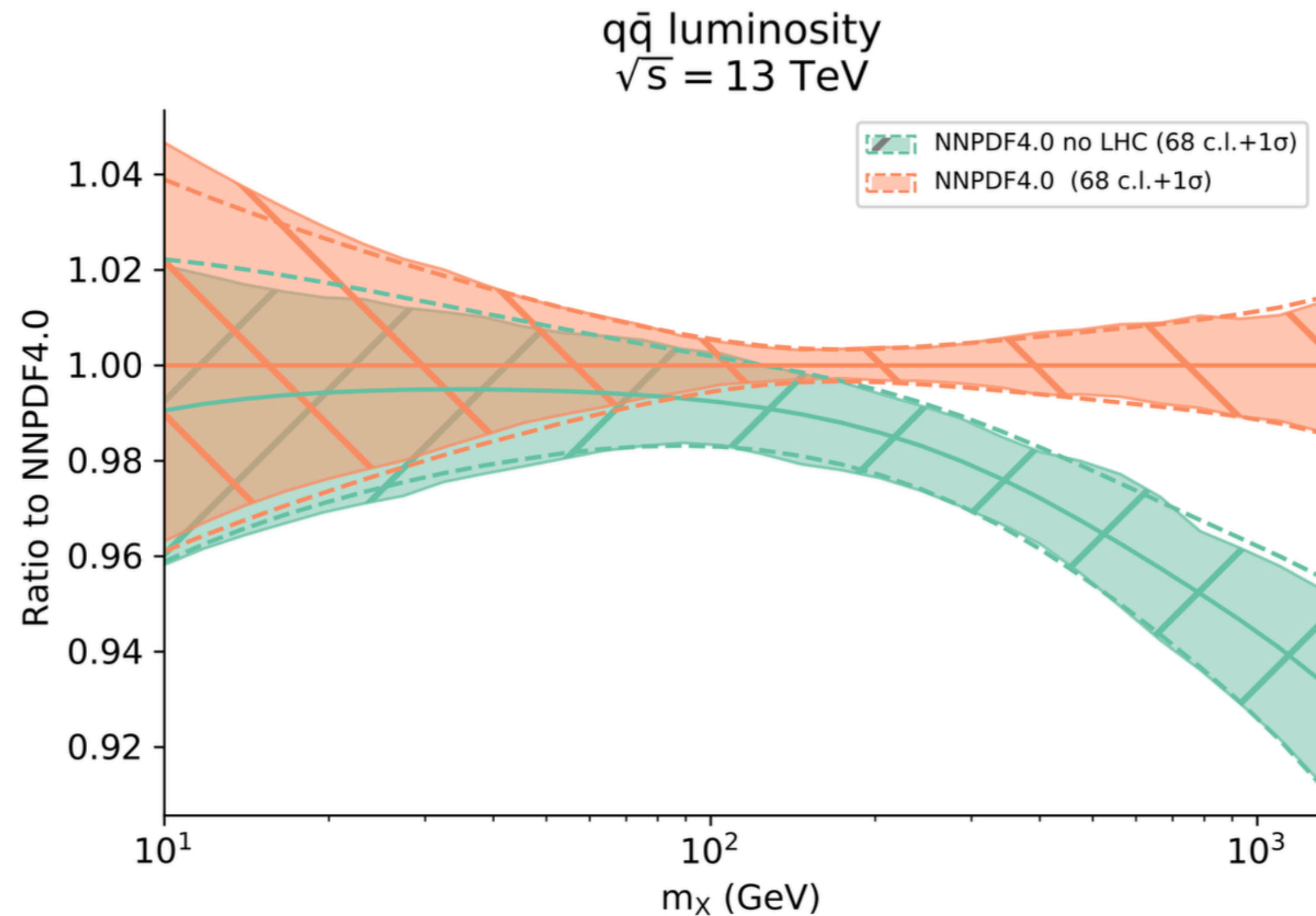
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**Is it possible that NP is being absorbed in the proton?**

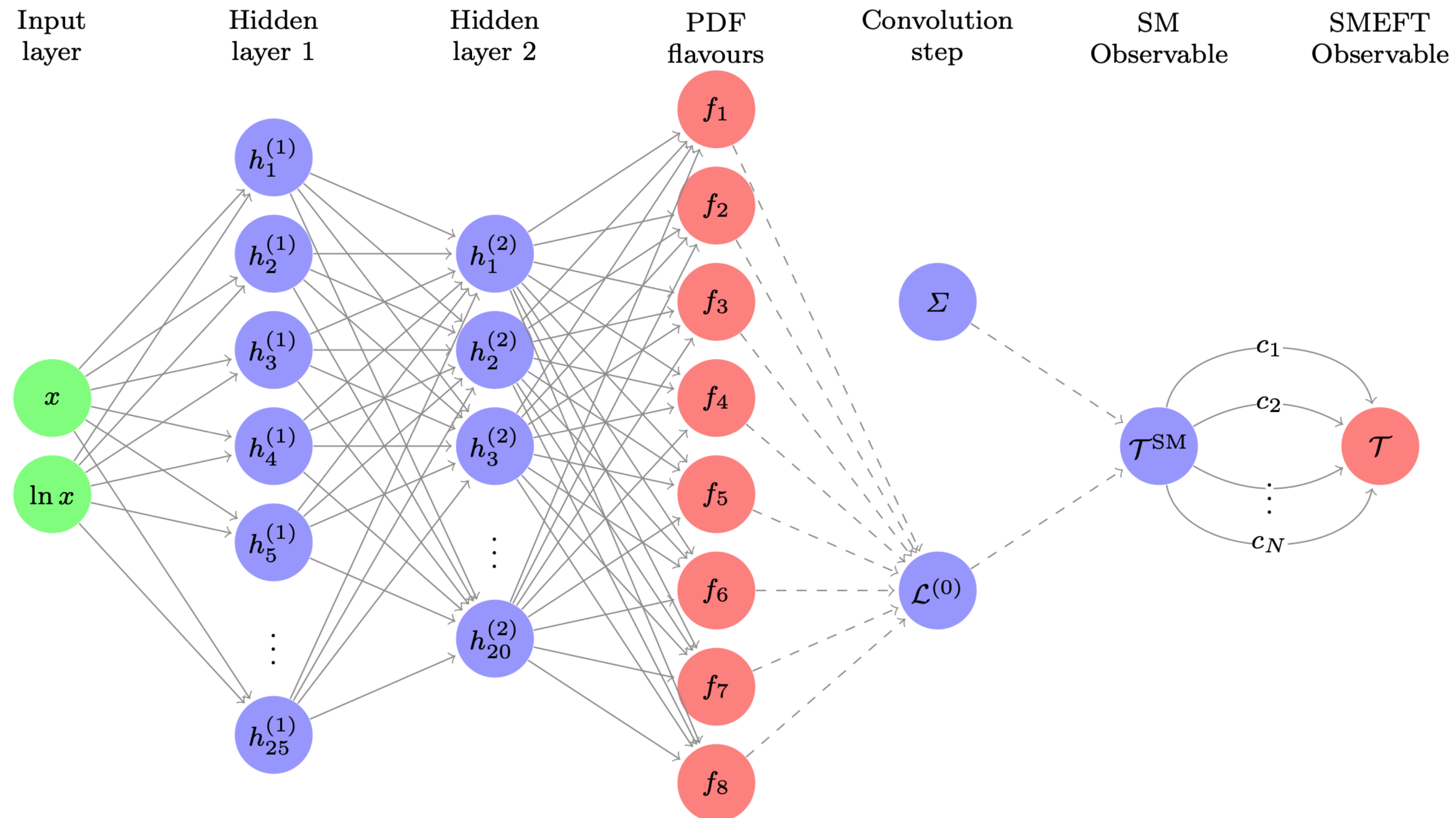


*SIMUnet*



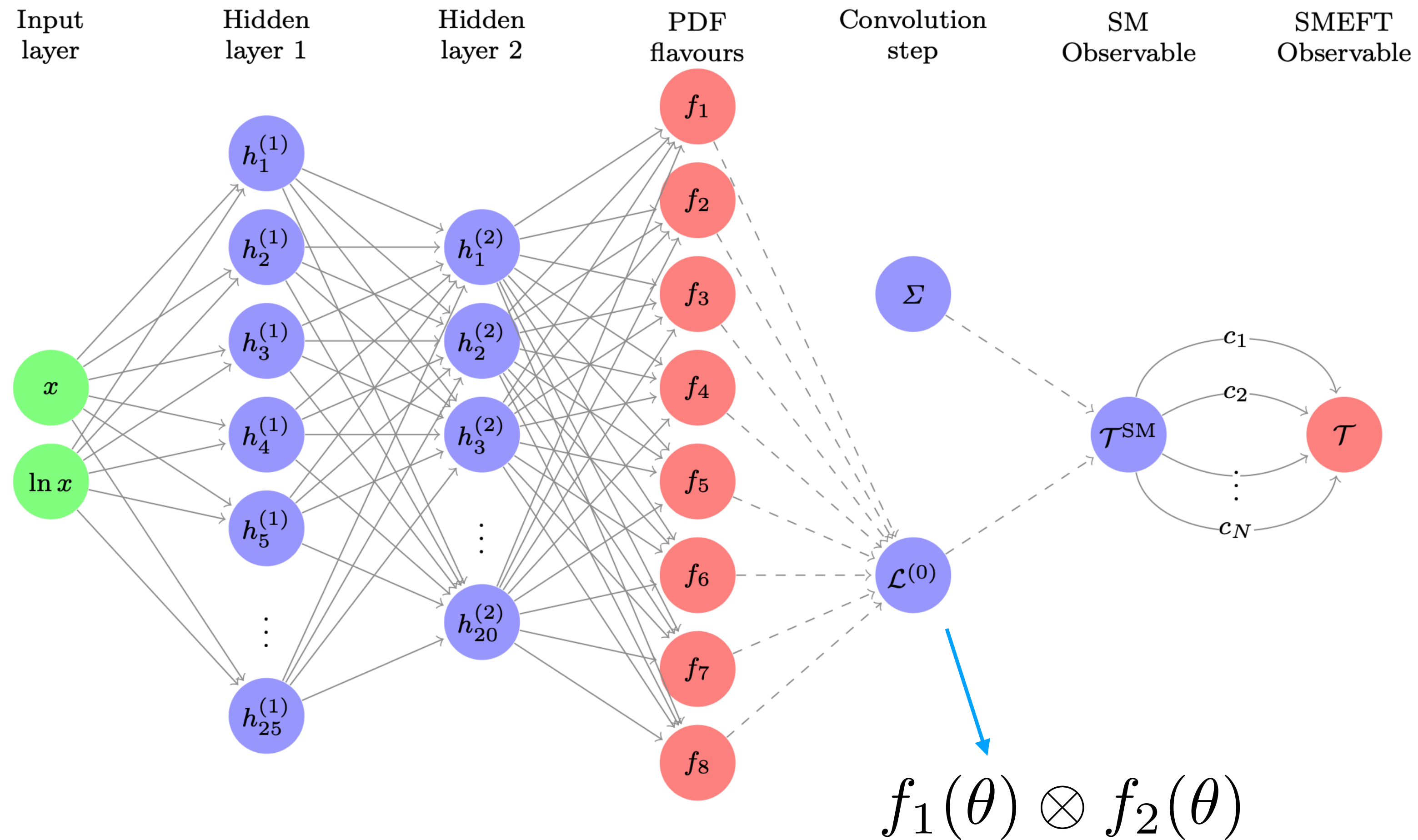
# An extended methodology

## Extension of the NNPDF framework



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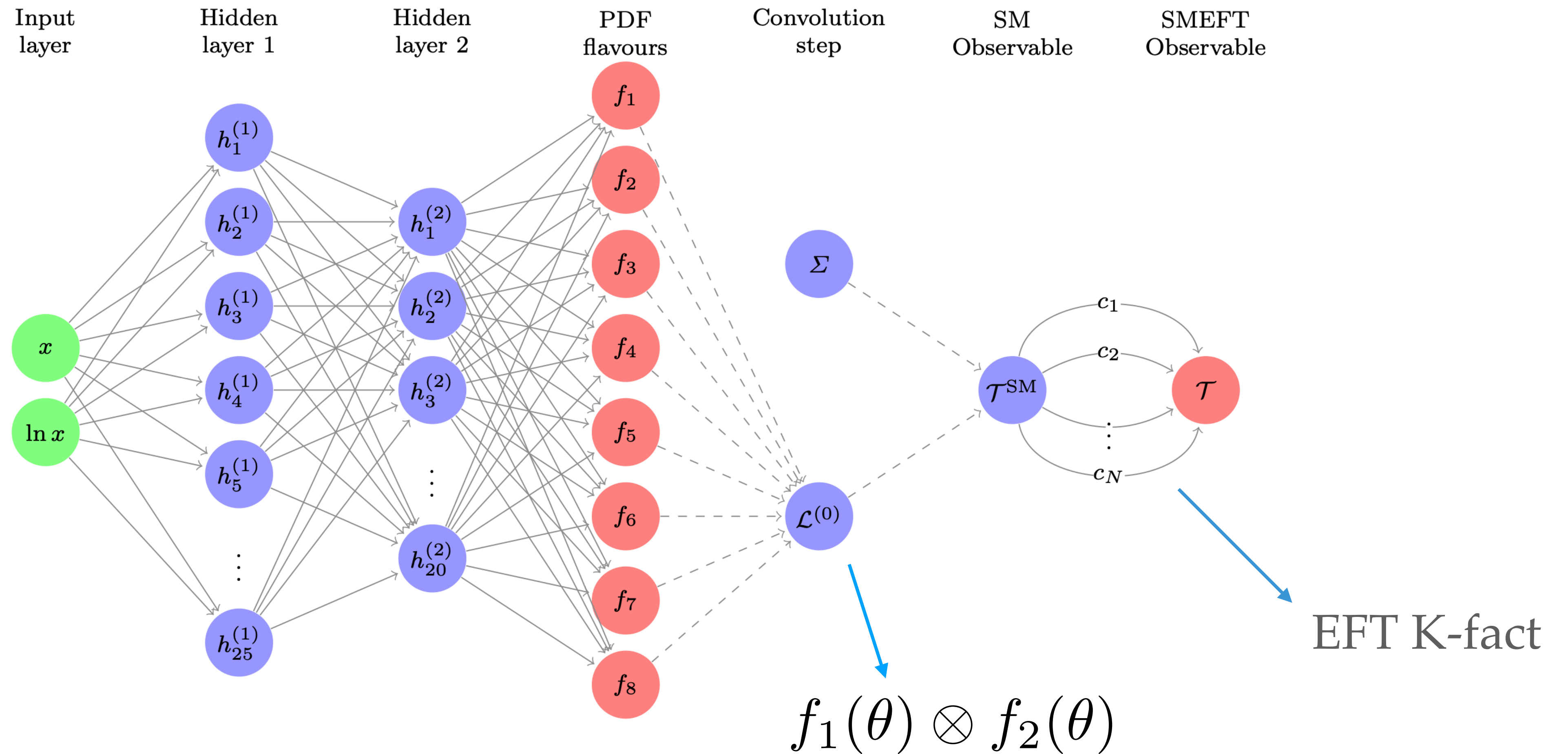
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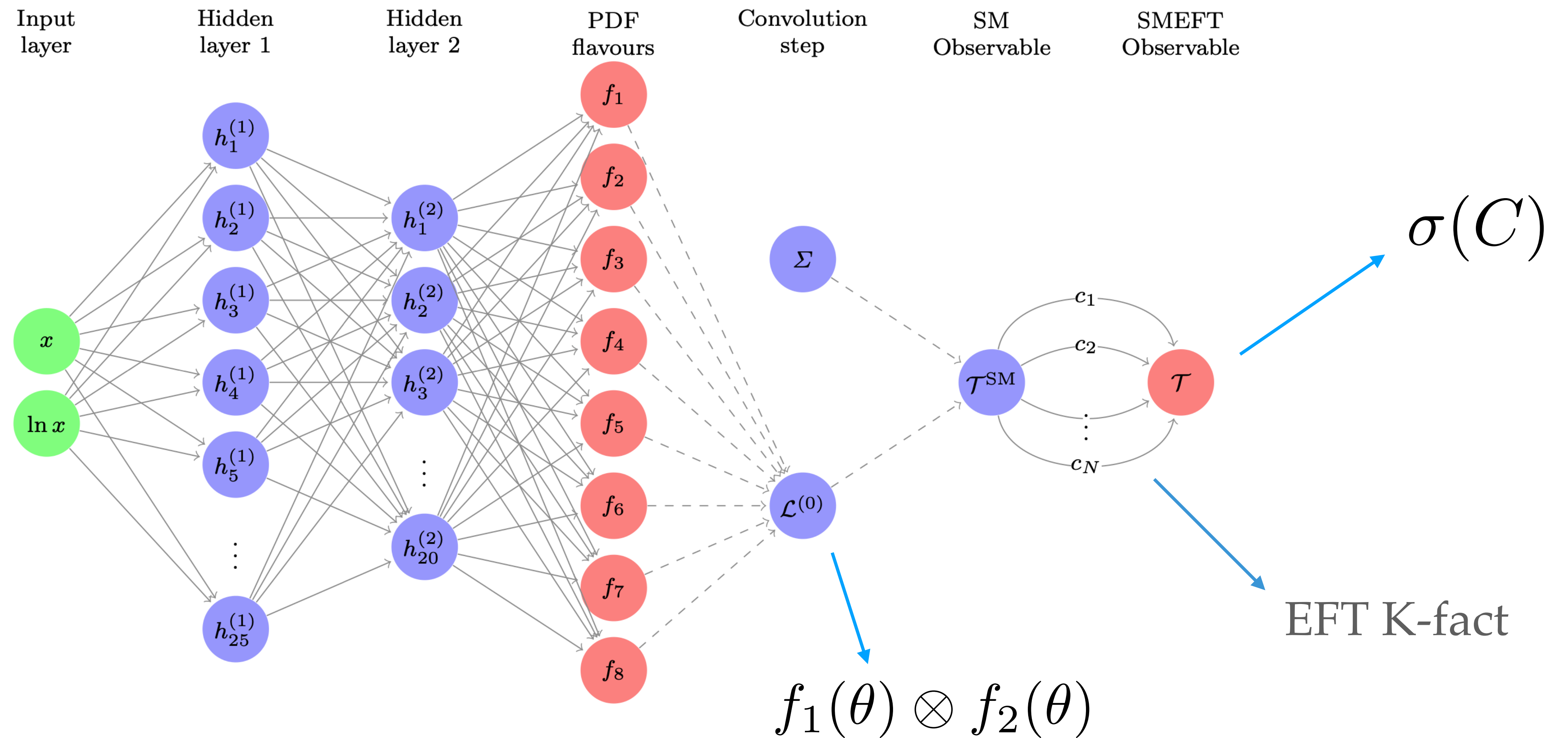
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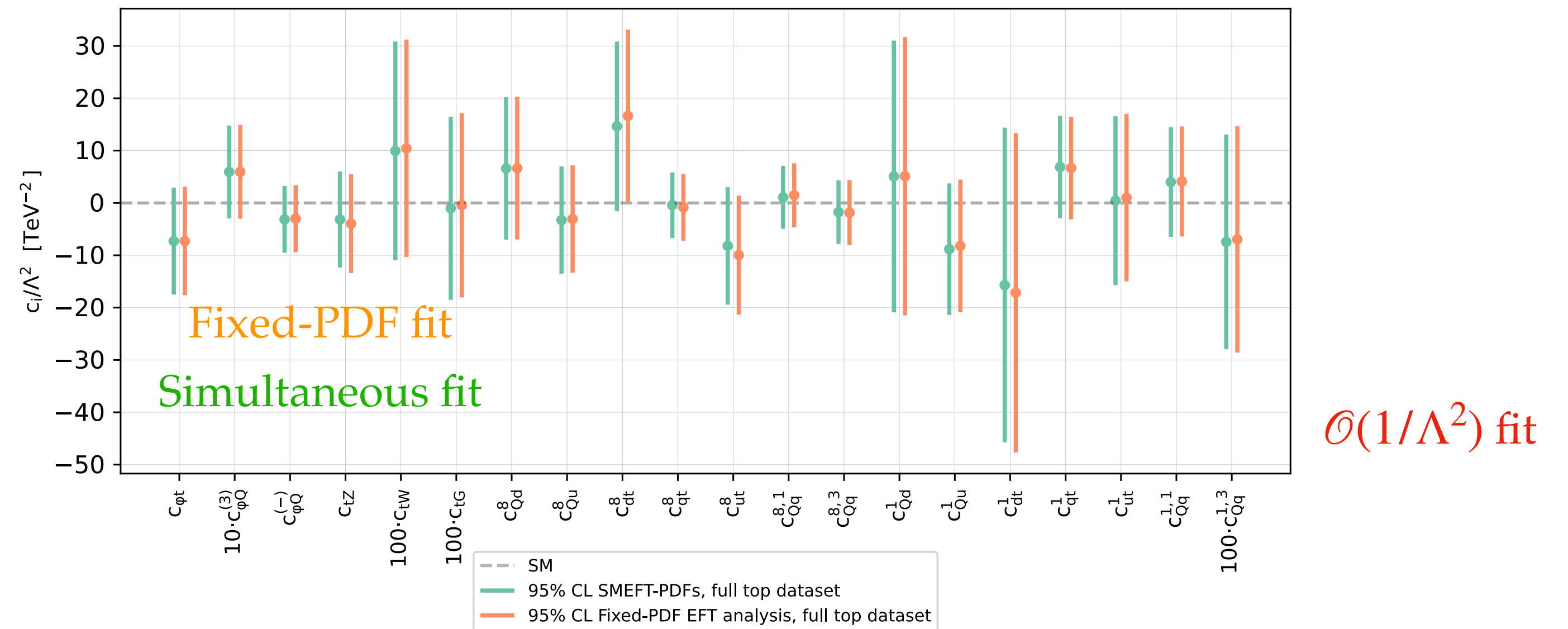
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# Going beyond: simultaneous fits

## SMEFT-PDF interplay in top quark sector

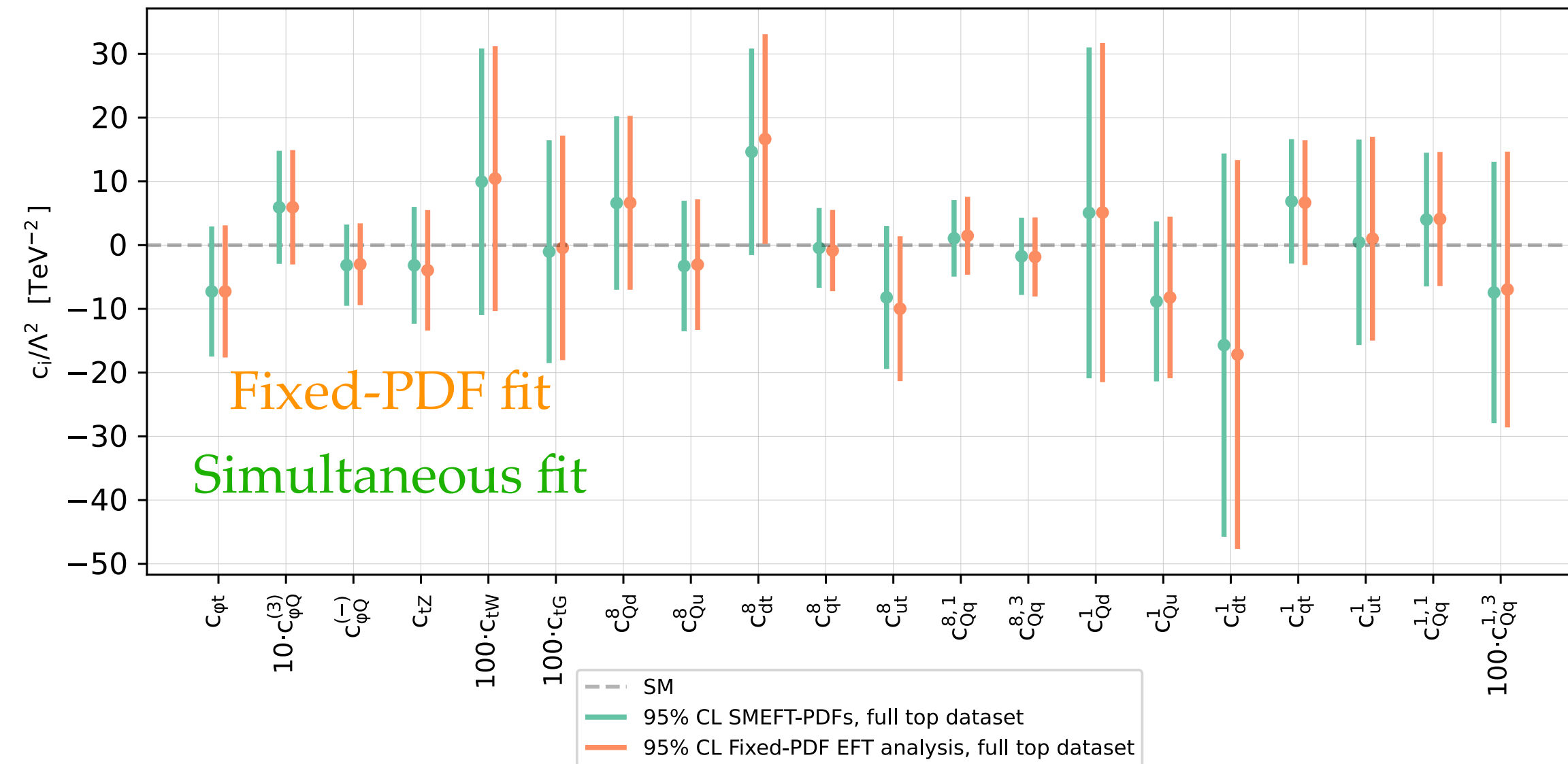
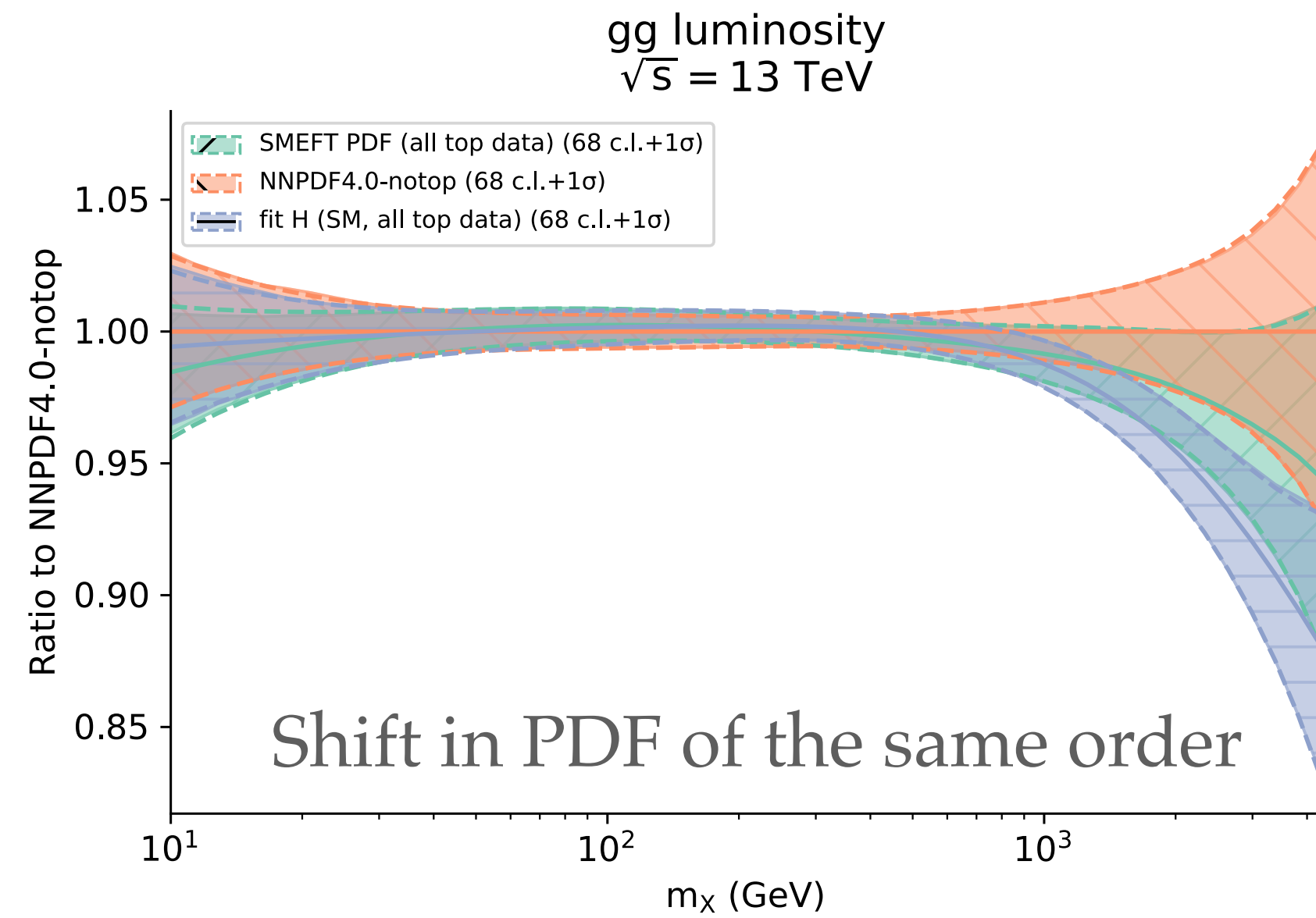
Moderate effect on WC,  $\sim 5-10\%$



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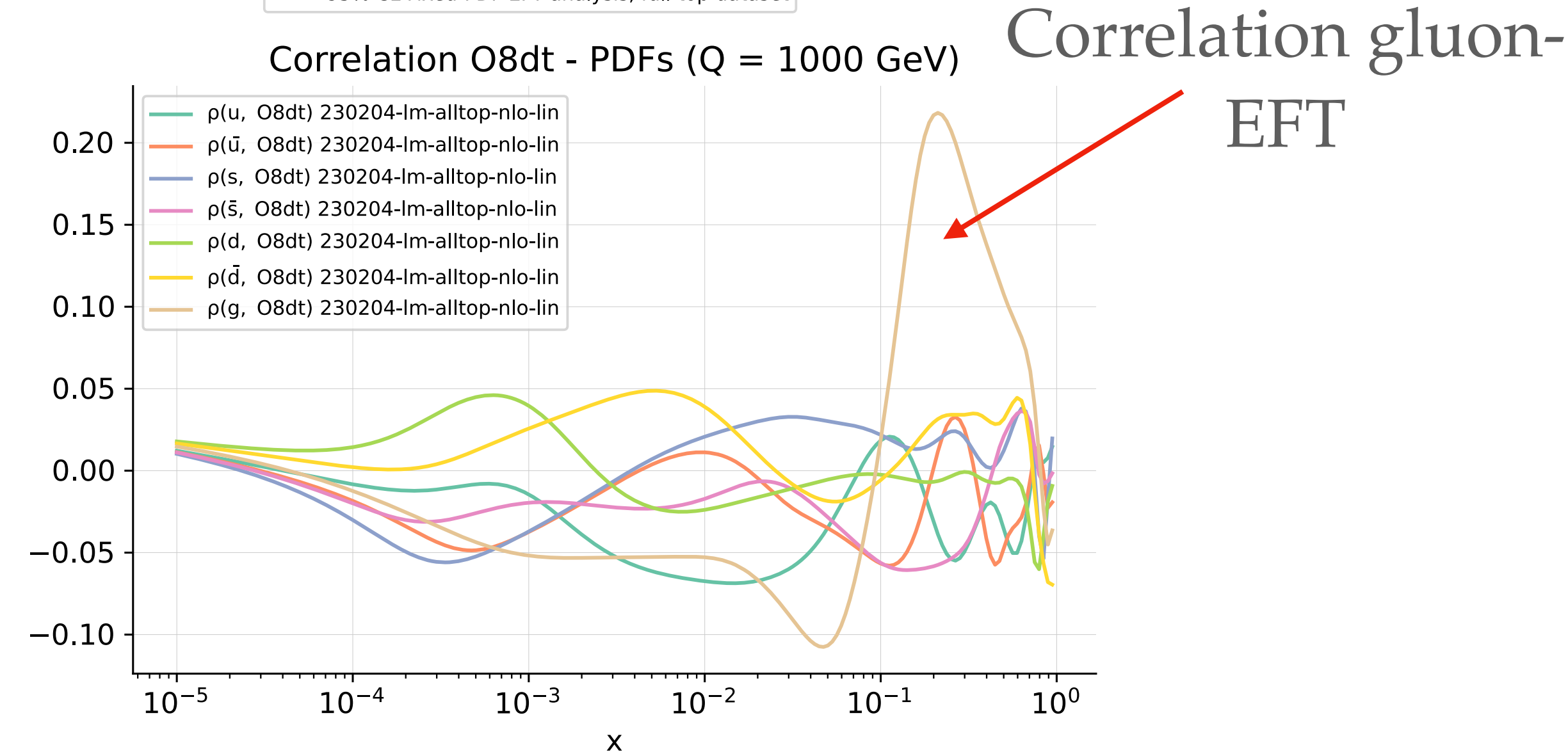
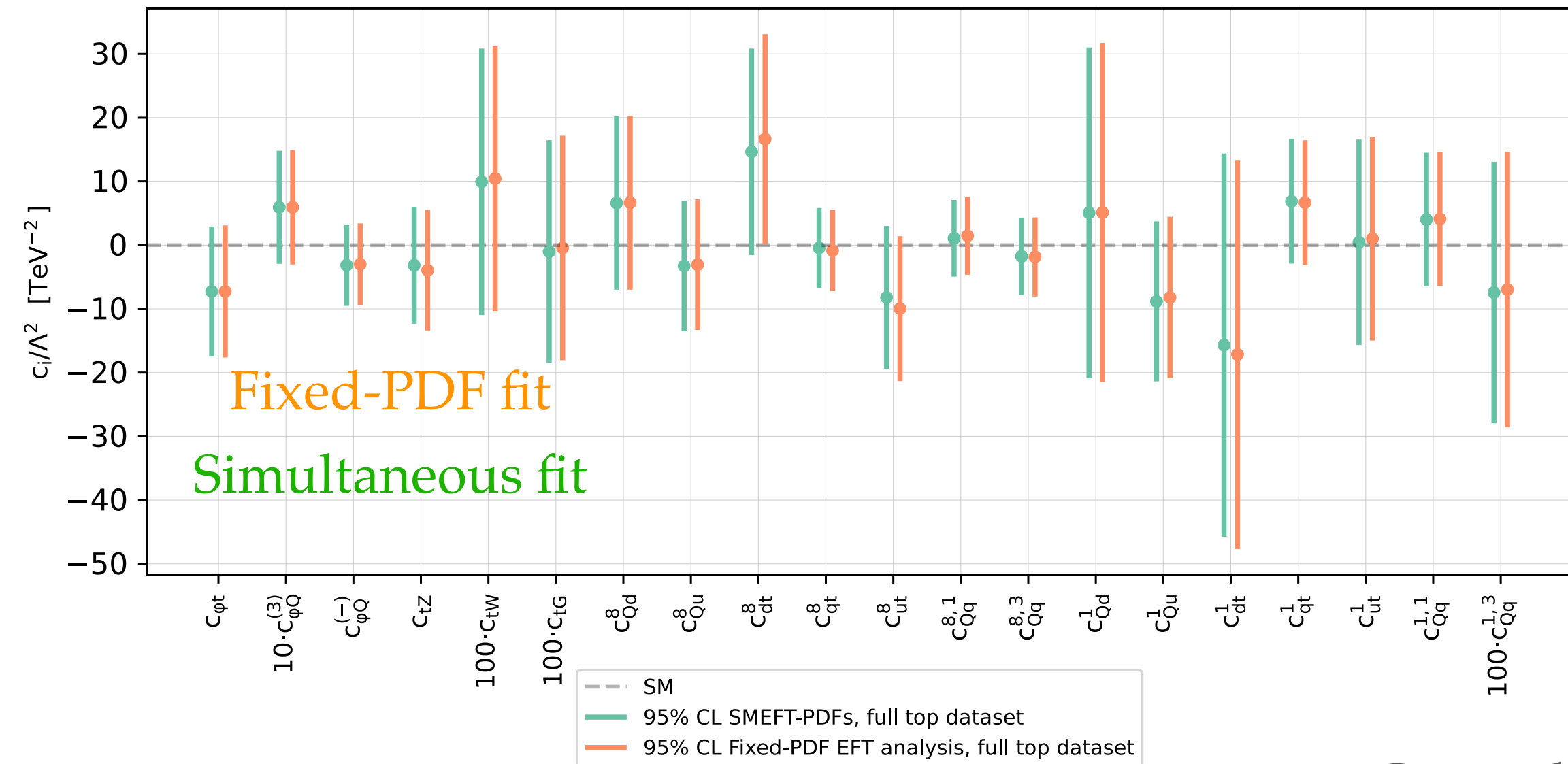
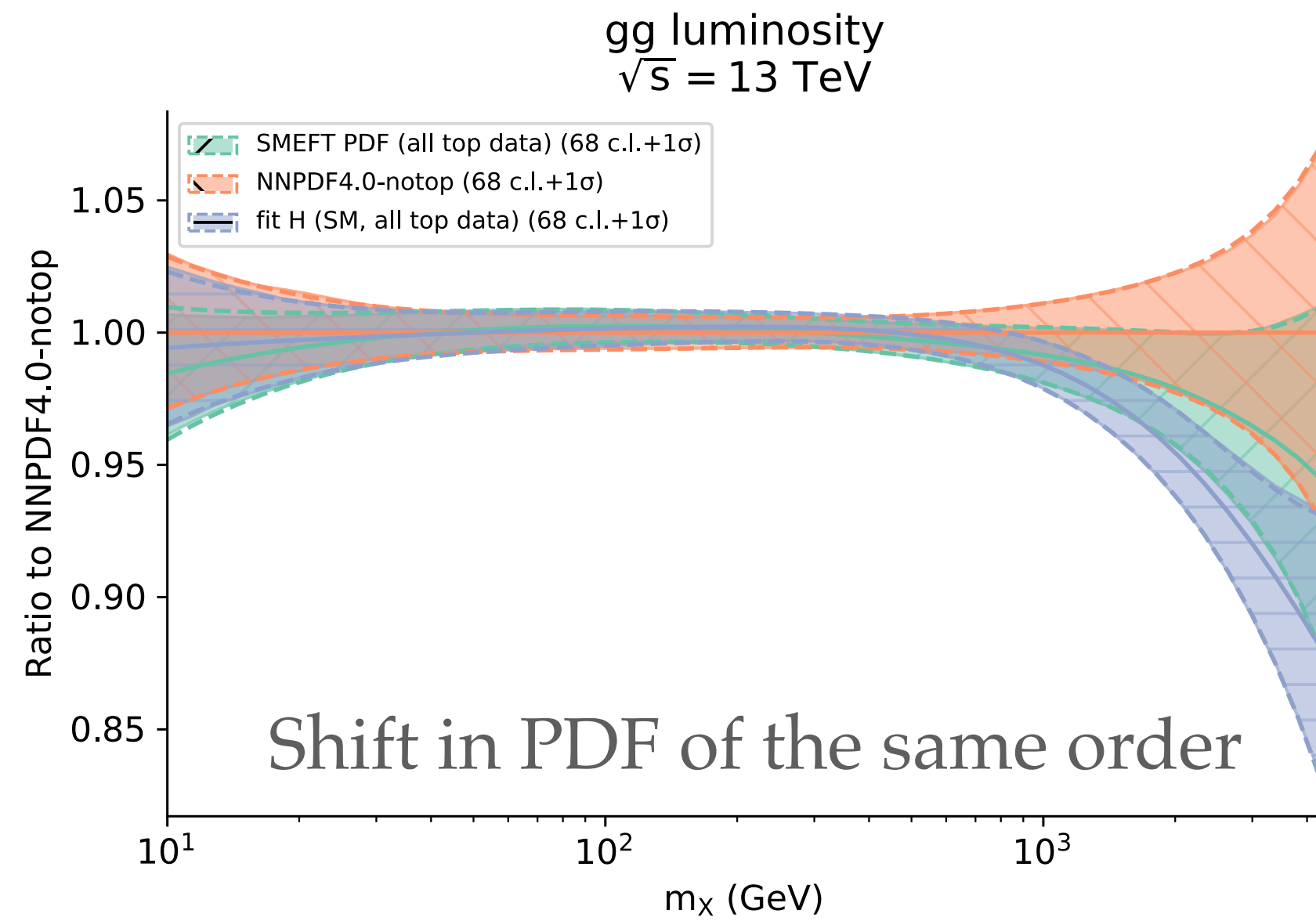
$\mathcal{O}(1/\Lambda^2)$  fit



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# *NP contaminated fits*

SIMUnet allows for generation of pseudodata containing NP

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**Assess whether we can mimic the modified interactions with “wrong” PDFs!**

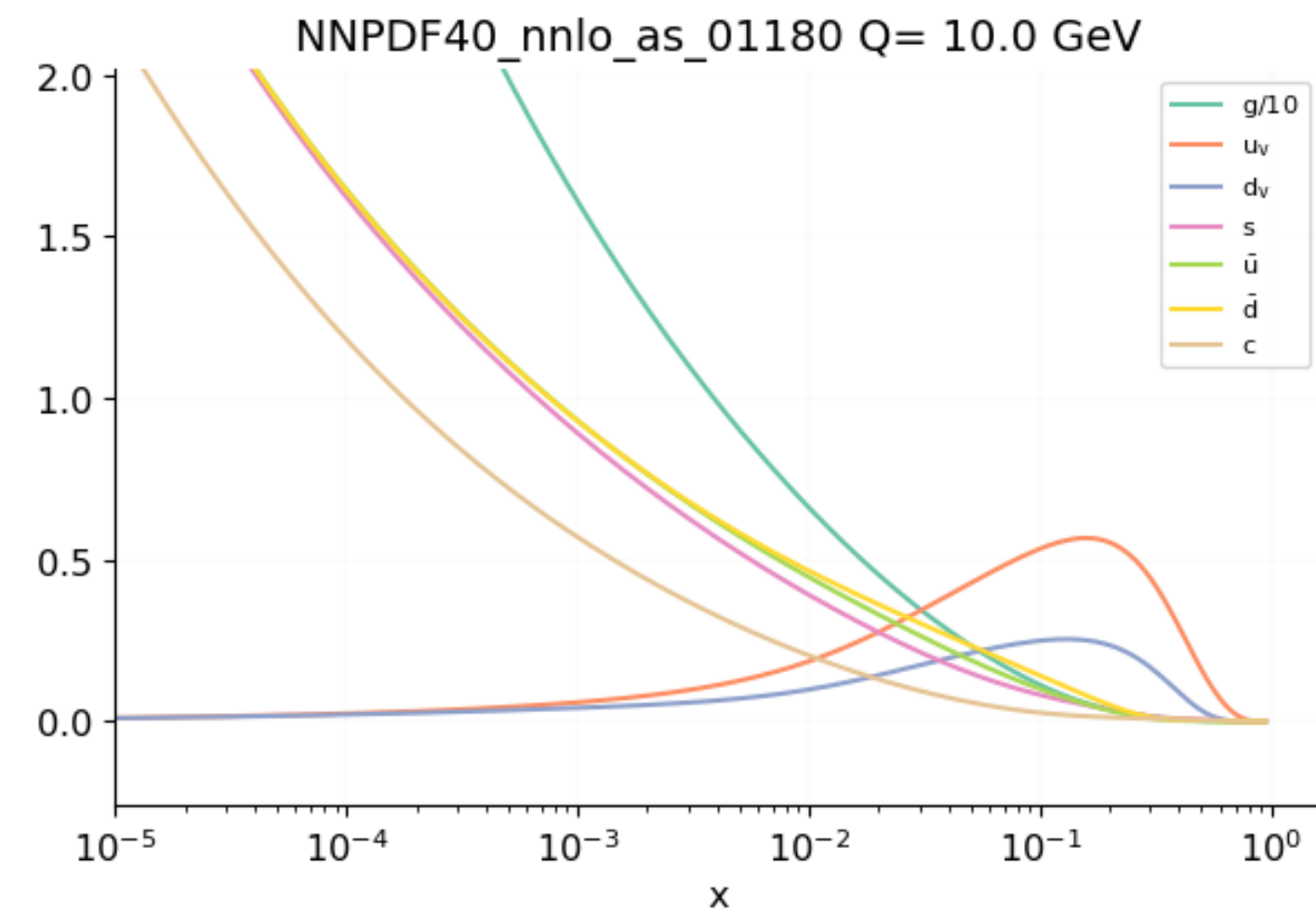


*A case study: heavy  $W'$*

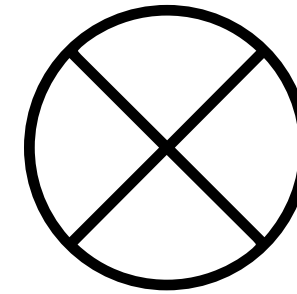


# Can the $W'$ hide in the proton?

Suppose the underlying laws of nature are



“Real” proton structure



$$J_L^{a,\mu} = \sum_{f_L} \bar{f}_L T^a \gamma^\mu f_L$$

$$\mathcal{L}_{\text{SMEFT}}^{W'} = \mathcal{L}_{\text{SM}} - \frac{g^2 \hat{W}}{2m_{W'}^2} J_L^\mu J_{L,\mu}$$

$$\hat{\sigma} = \hat{\sigma}_{\text{SM}} + \hat{\sigma}_{\text{NP}}$$

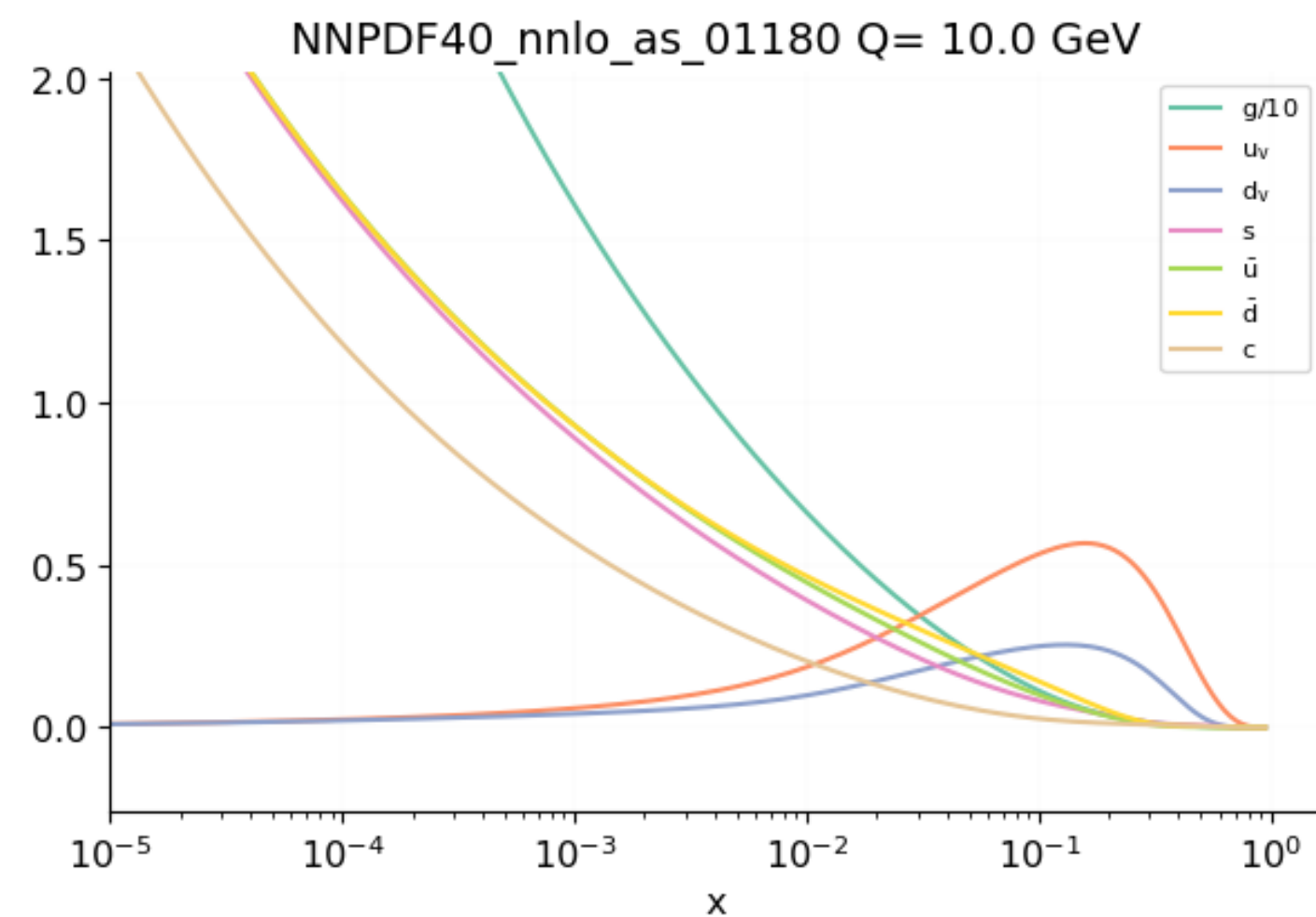
“Real” partonic cross-section



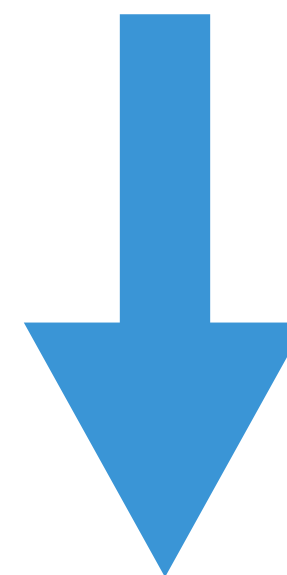
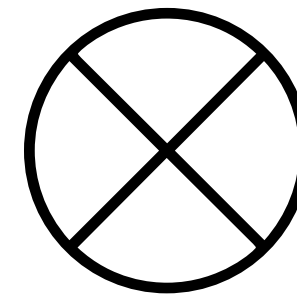
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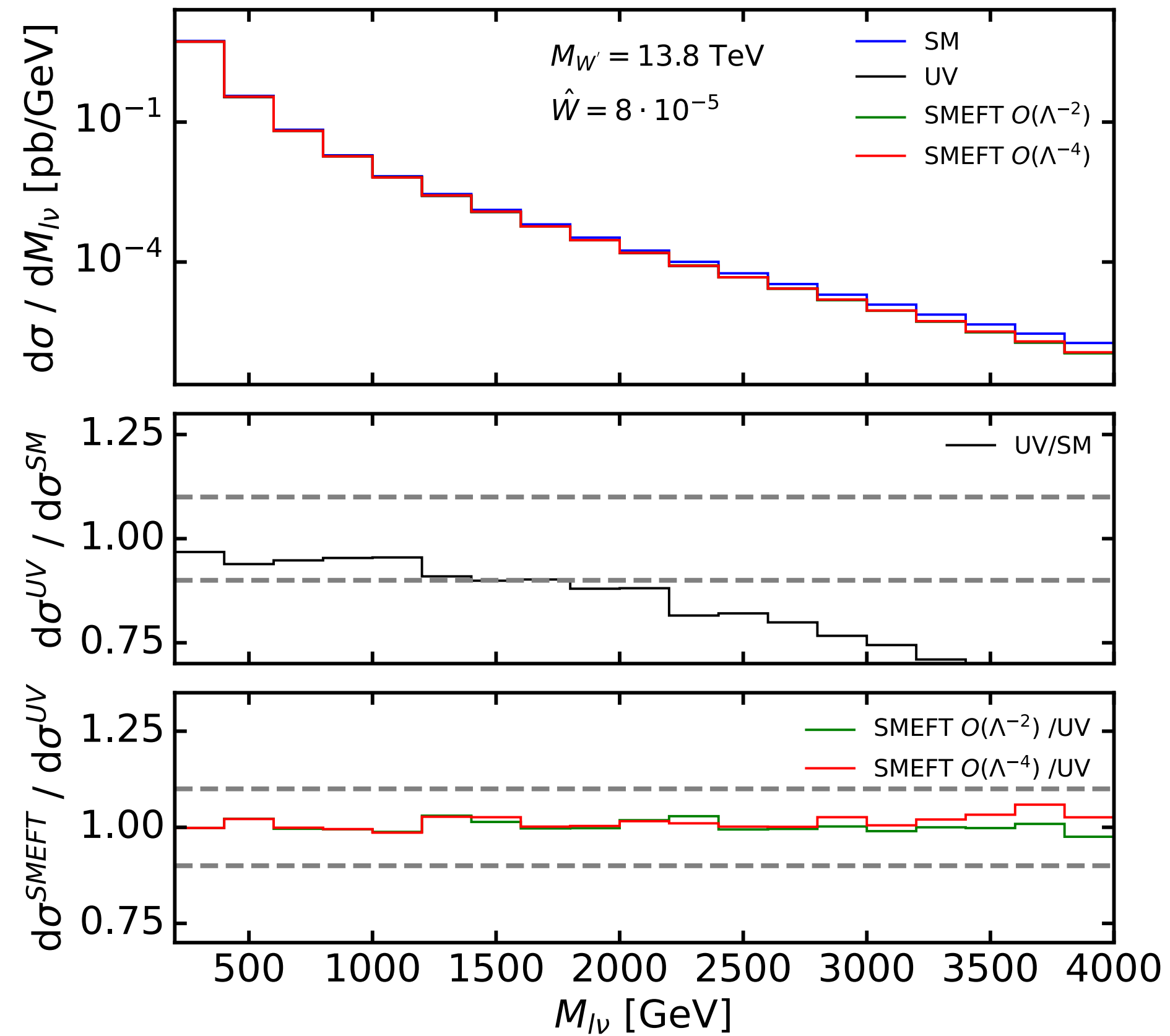
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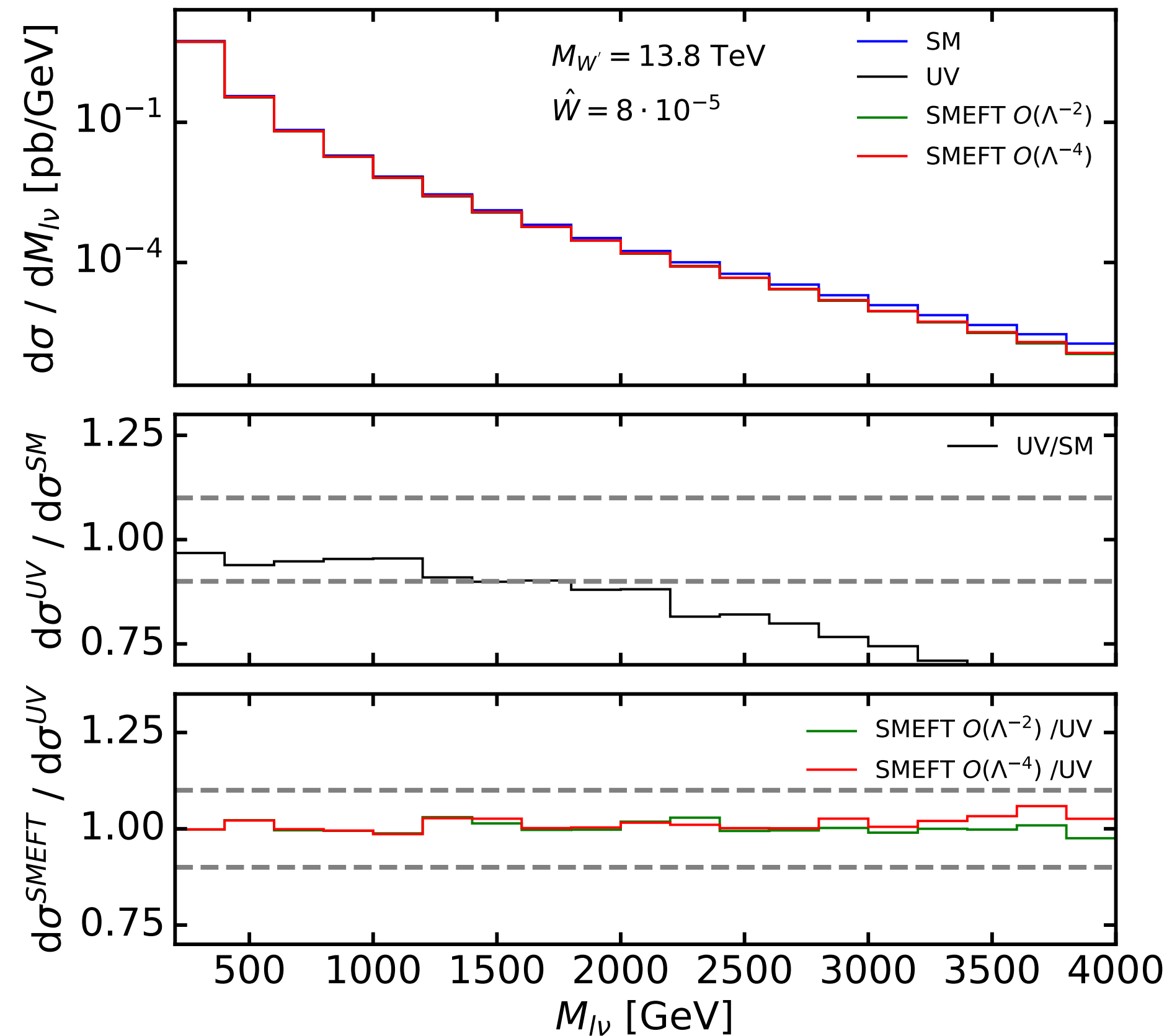


# Kinematic effects



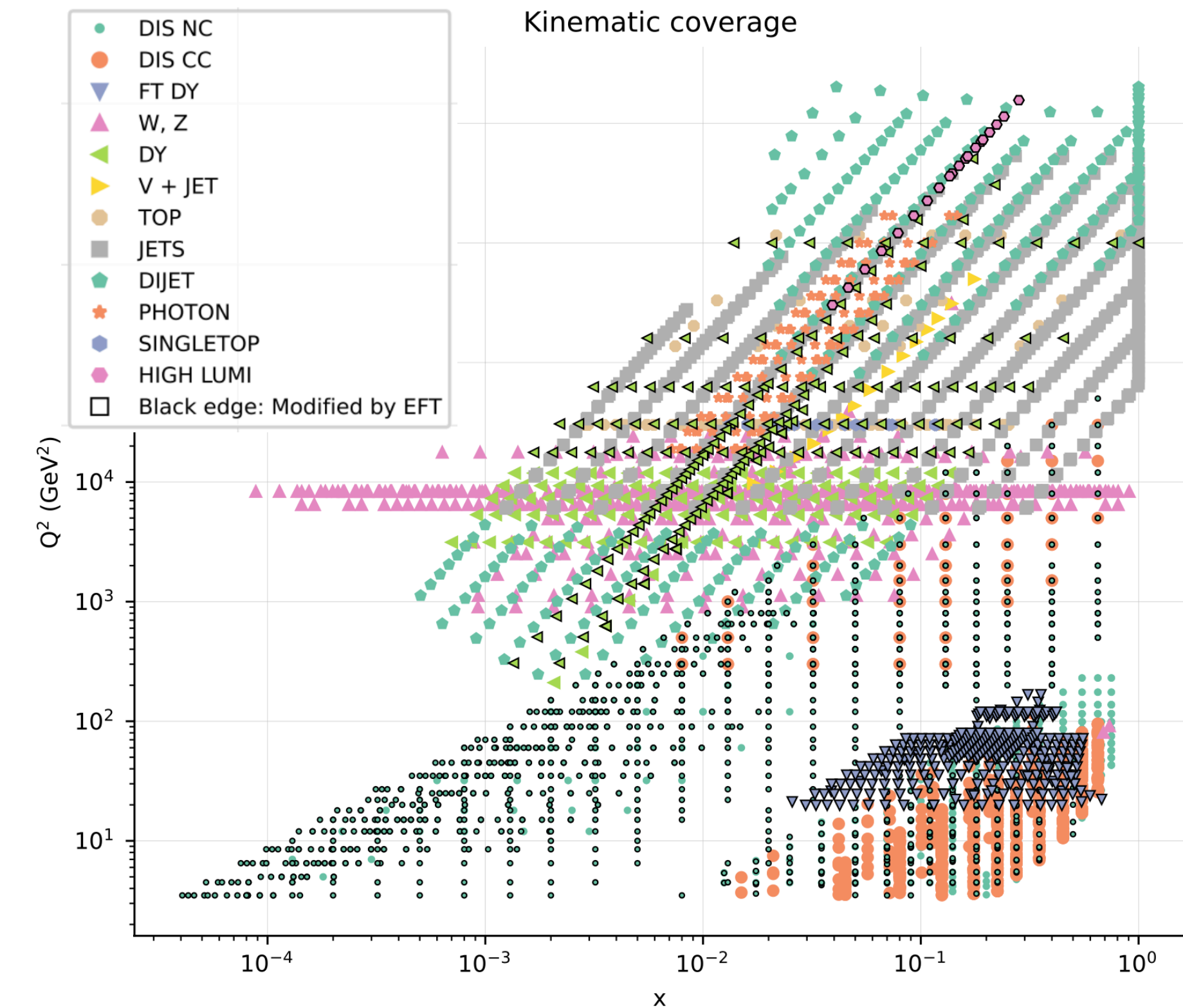
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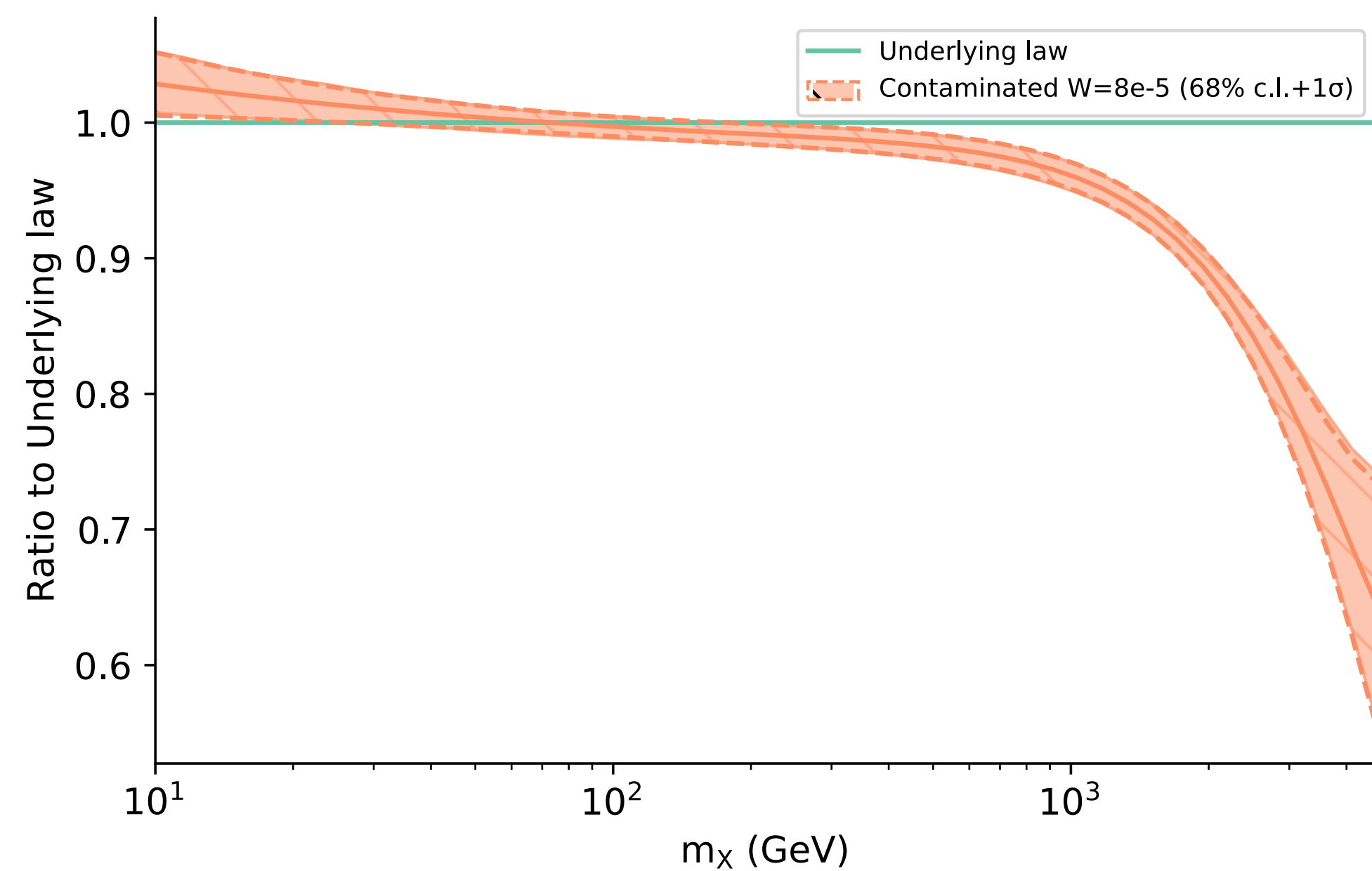
NNPDF4.0 dataset +  
HL-LHC DY projections [[arXiv: 2104.02723](https://arxiv.org/abs/2104.02723)]



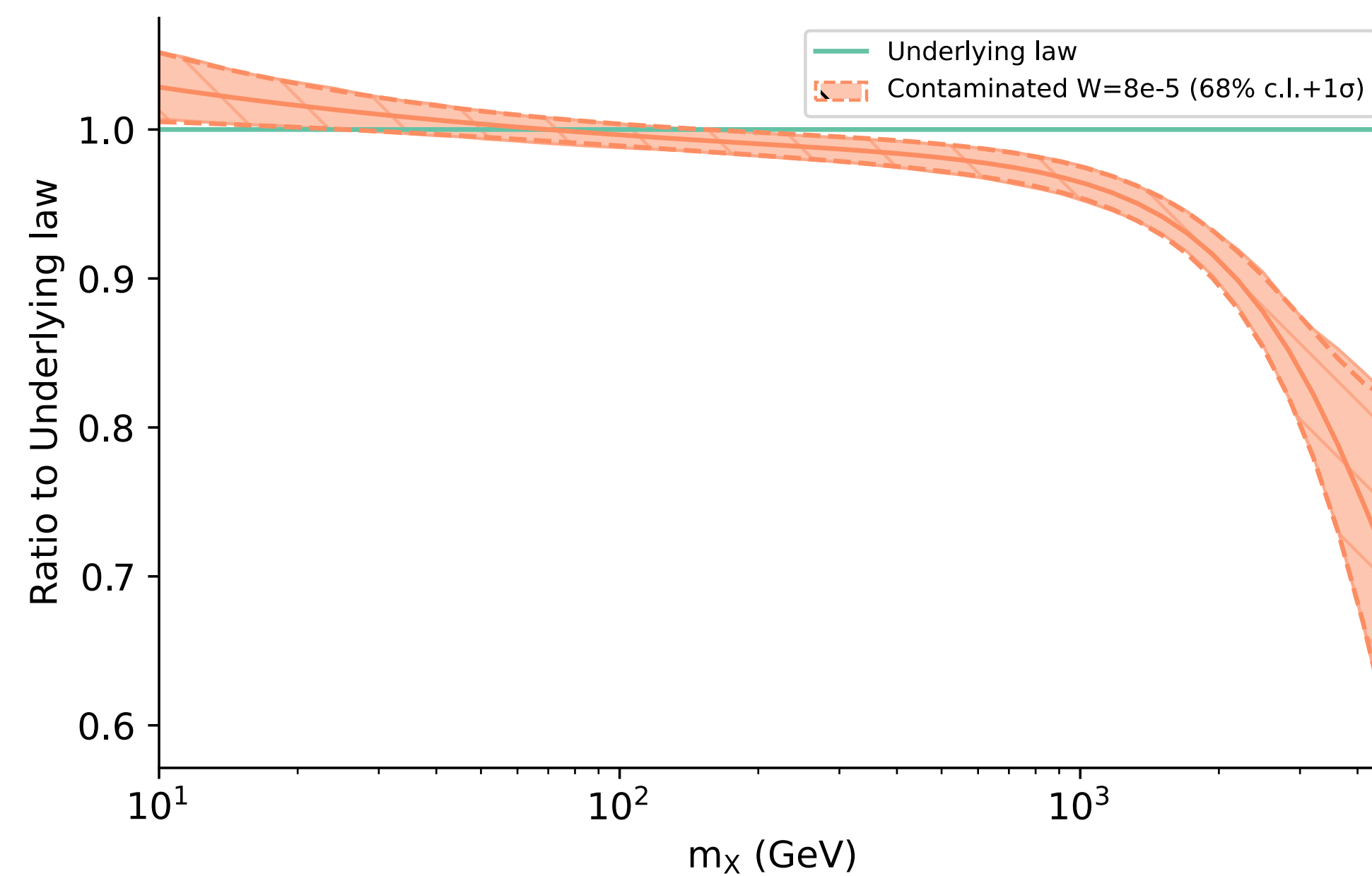
**Data kinematic coverage is wide:**  
 can current PDFs absorb NP  
 while keeping consistency across  
 the whole set of observables?

# Contaminated PDFs

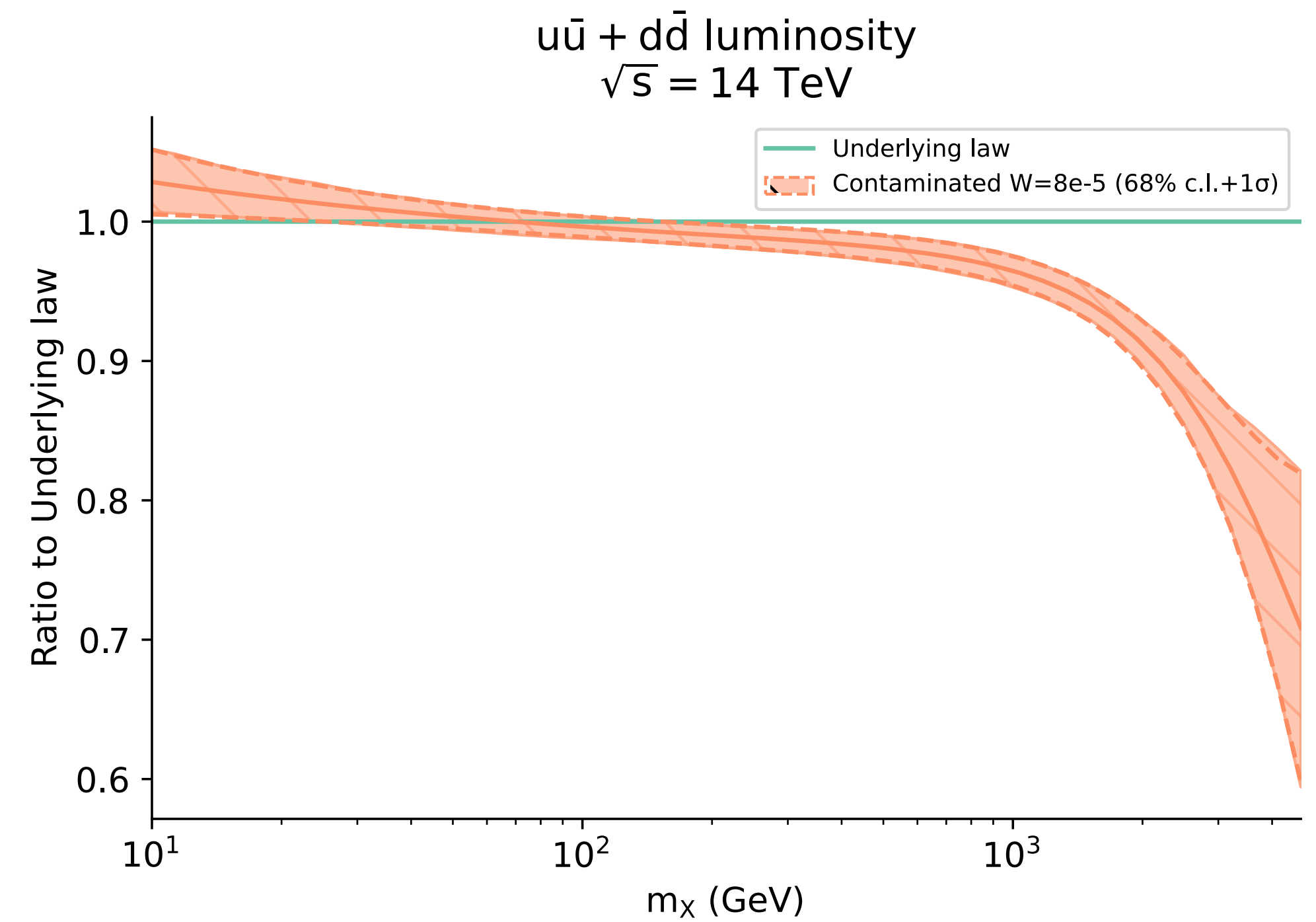
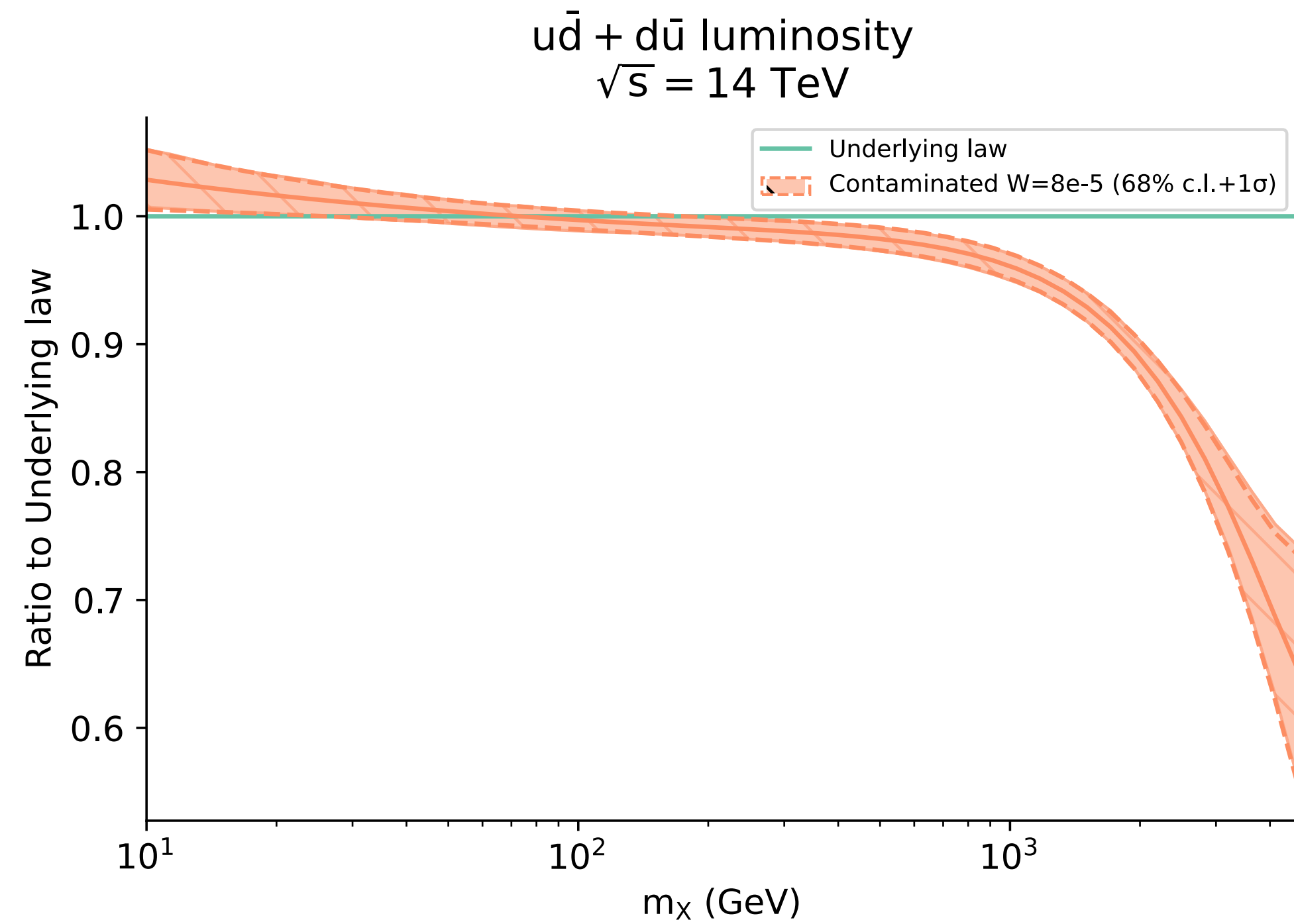
$u\bar{d} + d\bar{u}$  luminosity  
 $\sqrt{s} = 14$  TeV



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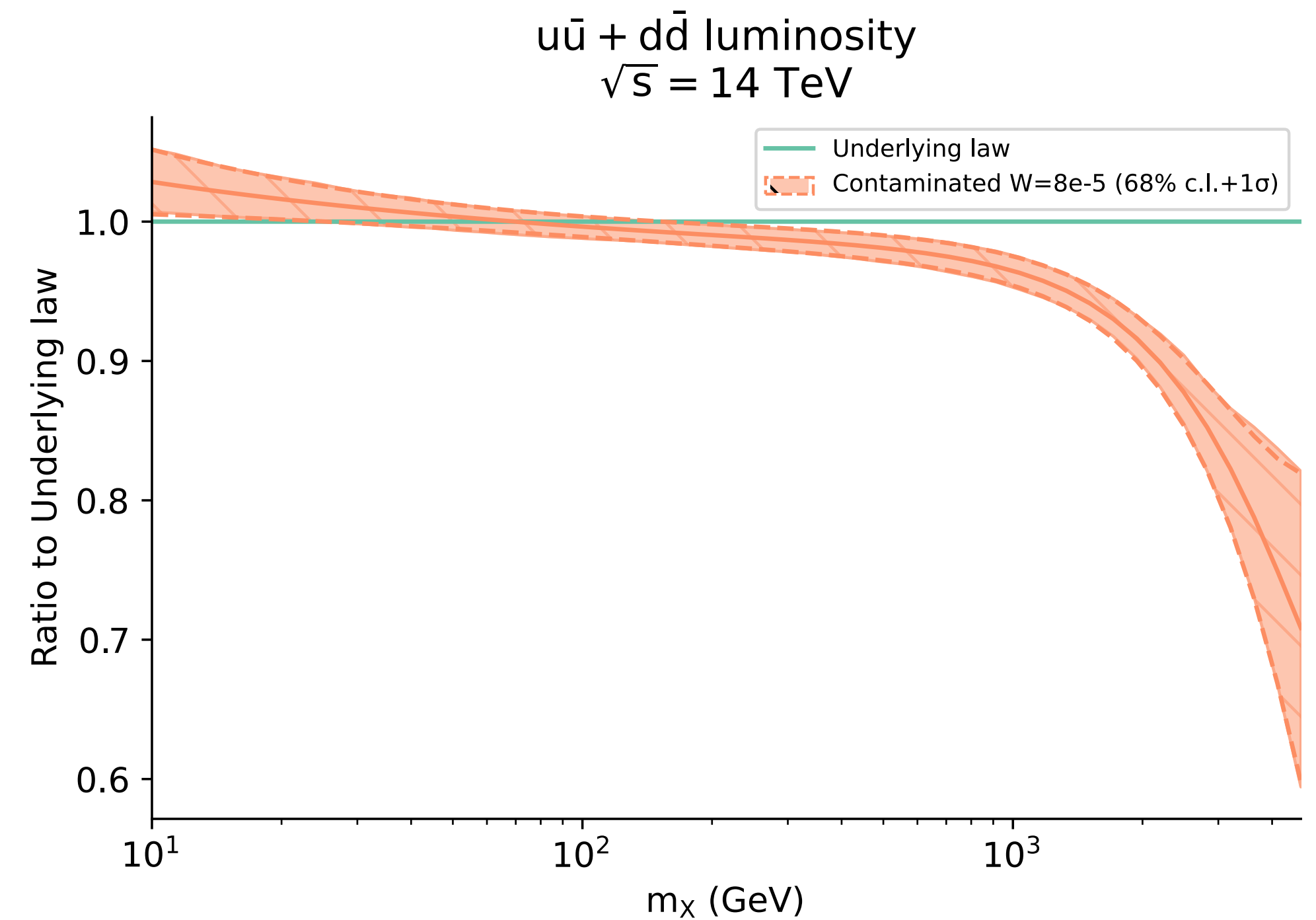
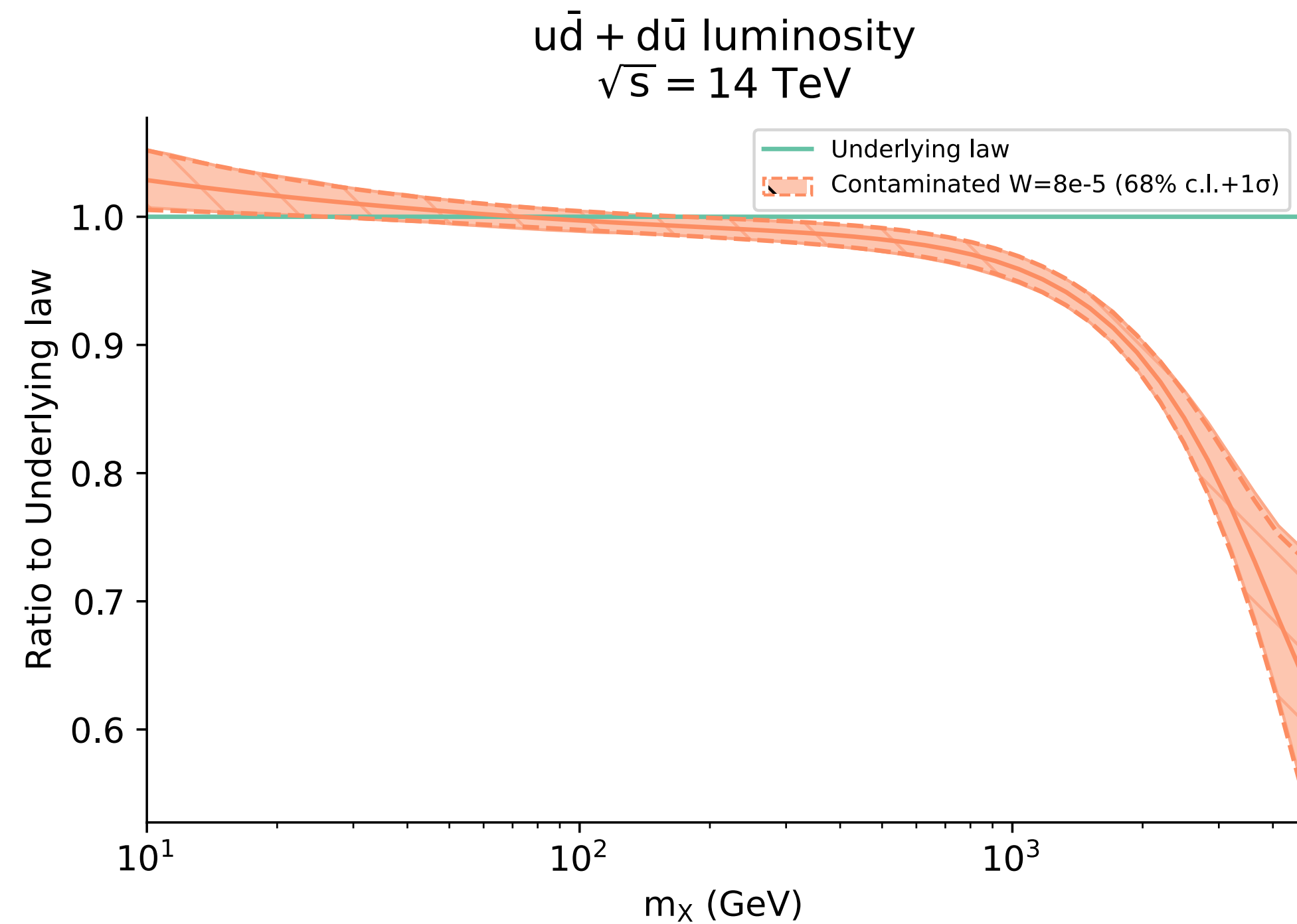


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Huge shift and yet we find a **good fit to the data!**

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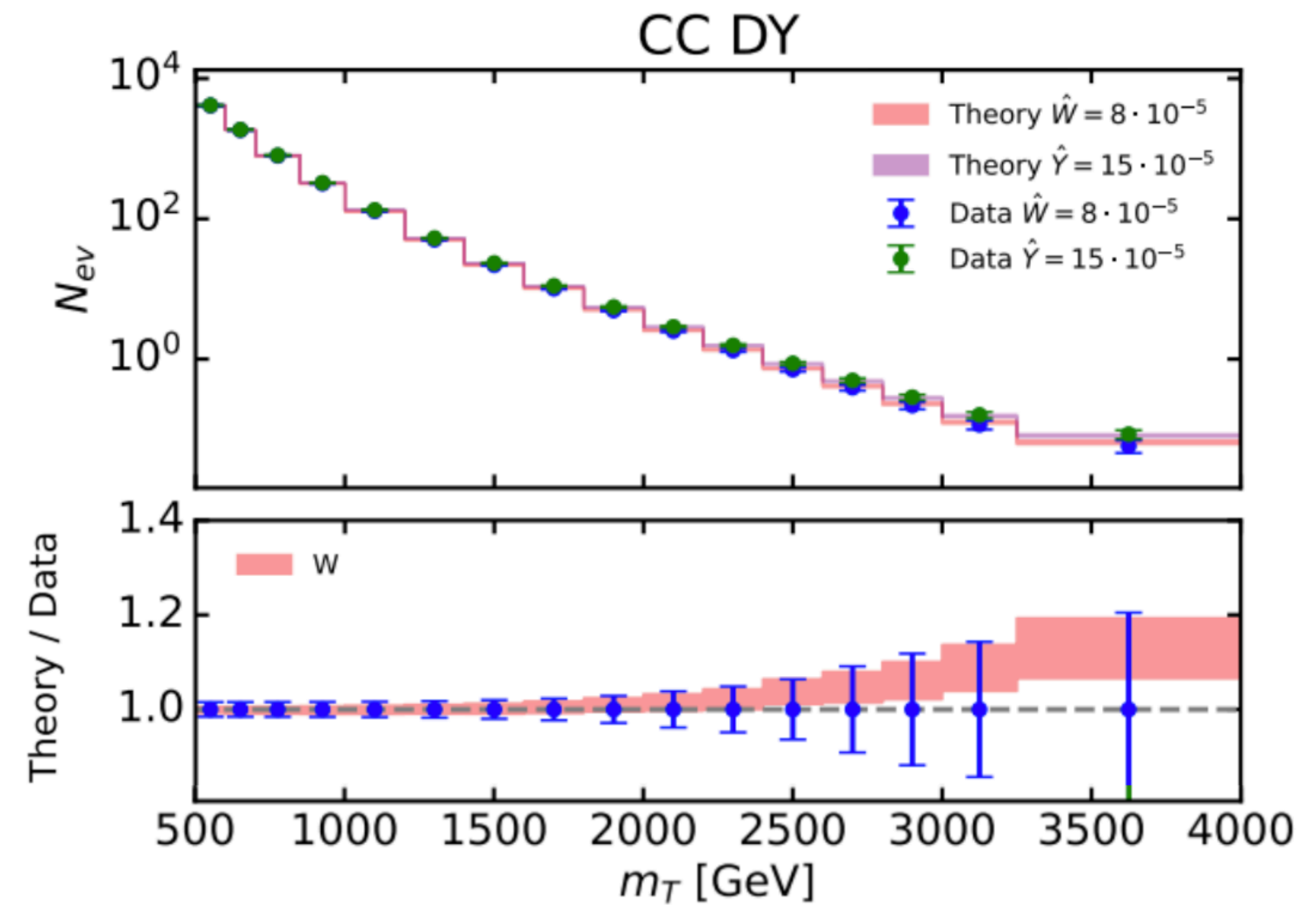
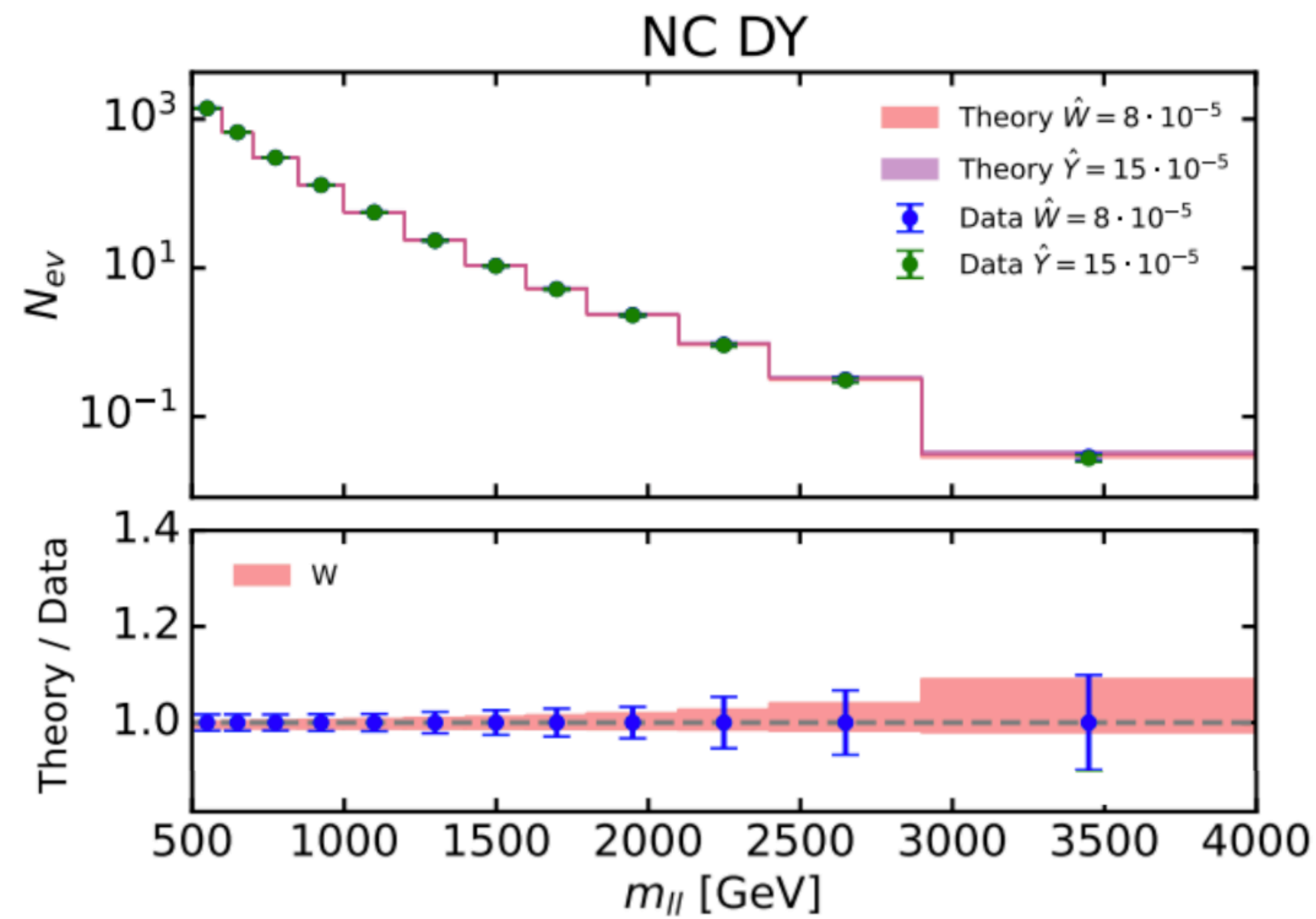
Huge shift and yet we find a **good fit to the data!**

Large- $x$  behaviour in PDFs is not constrained:  
especially **anti-quark PDFs allow for NP absorption**



# Data-theory comparison

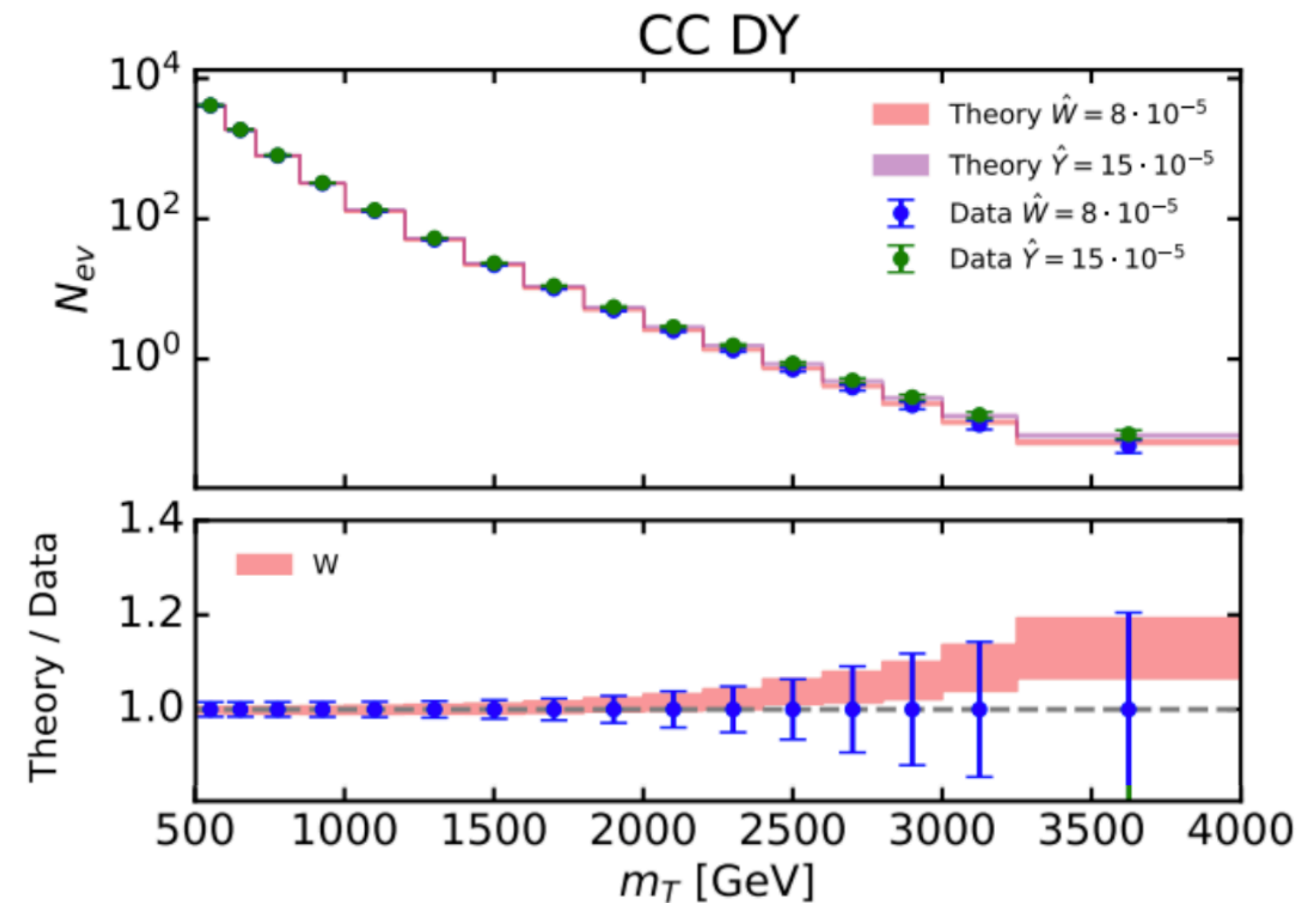
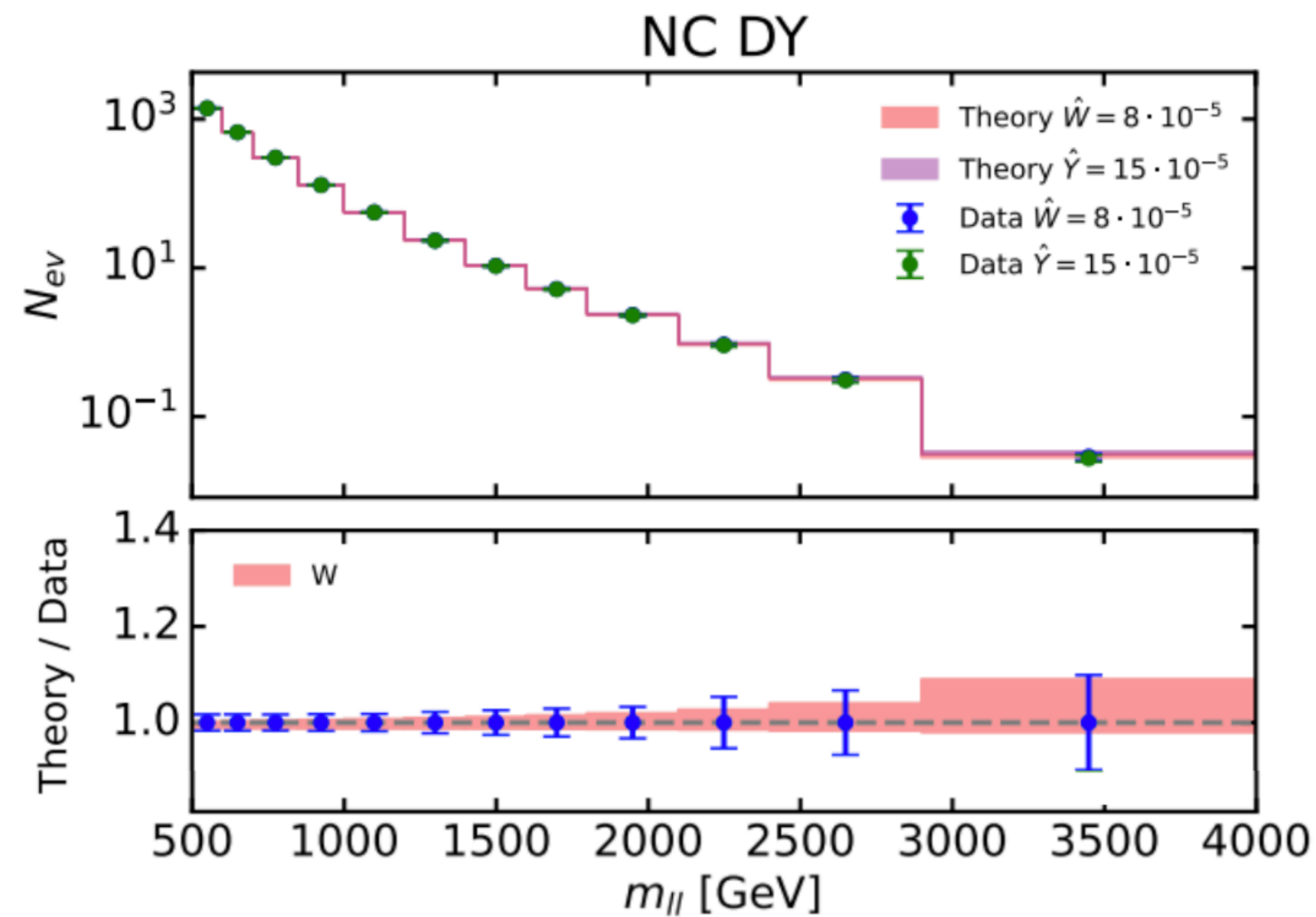
Data:  $f^{true} \otimes \hat{\sigma}_{NP}$   
Theory:  $f^{fit} \otimes \hat{\sigma}_{SM}$



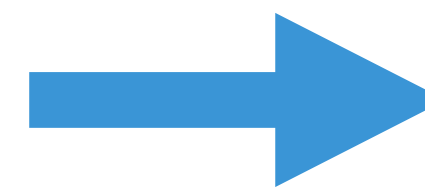
# Data-theory comparison

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PDF shift is completely compensating the NP effect



**NP concealed in the proton!!**

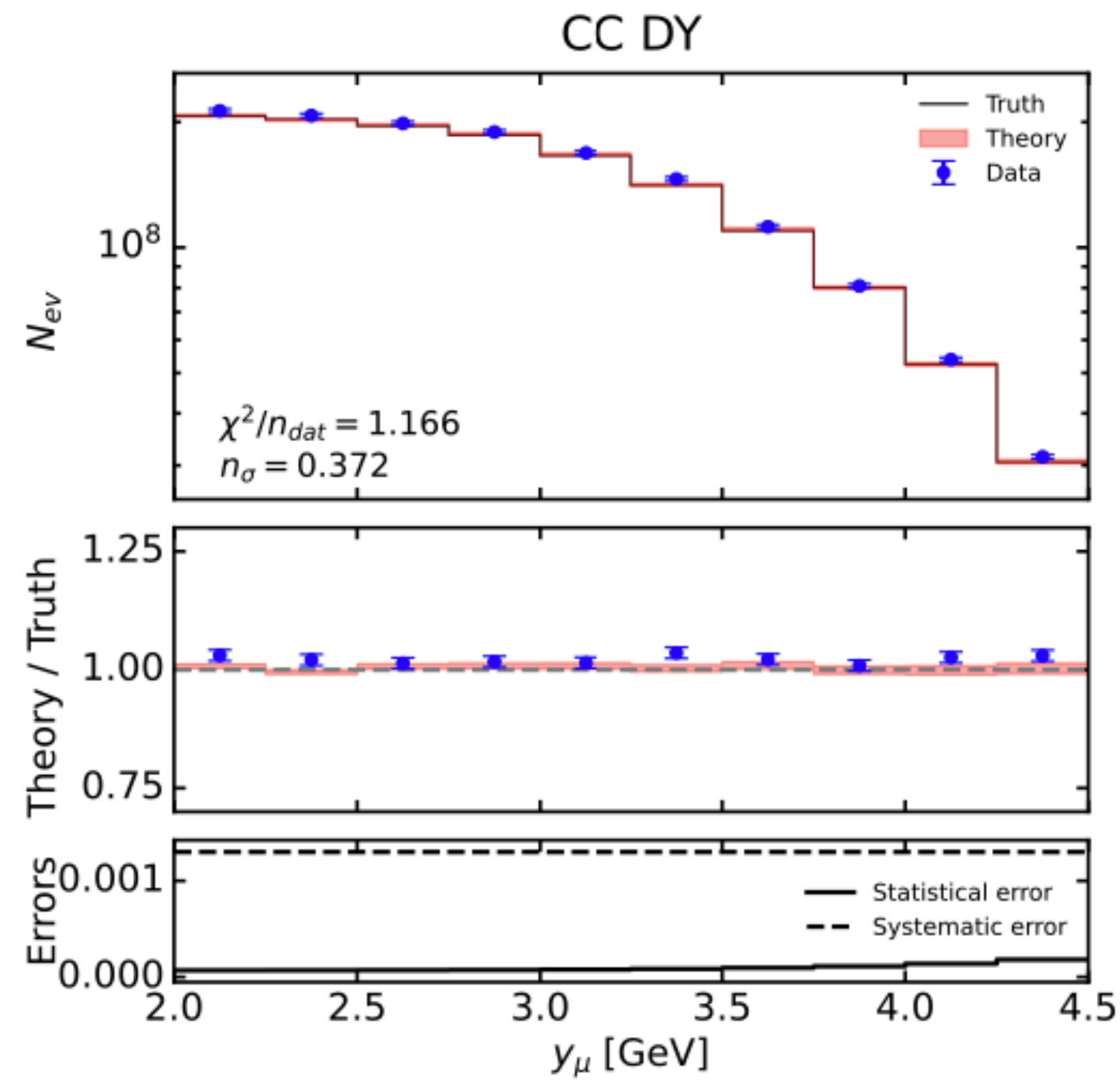
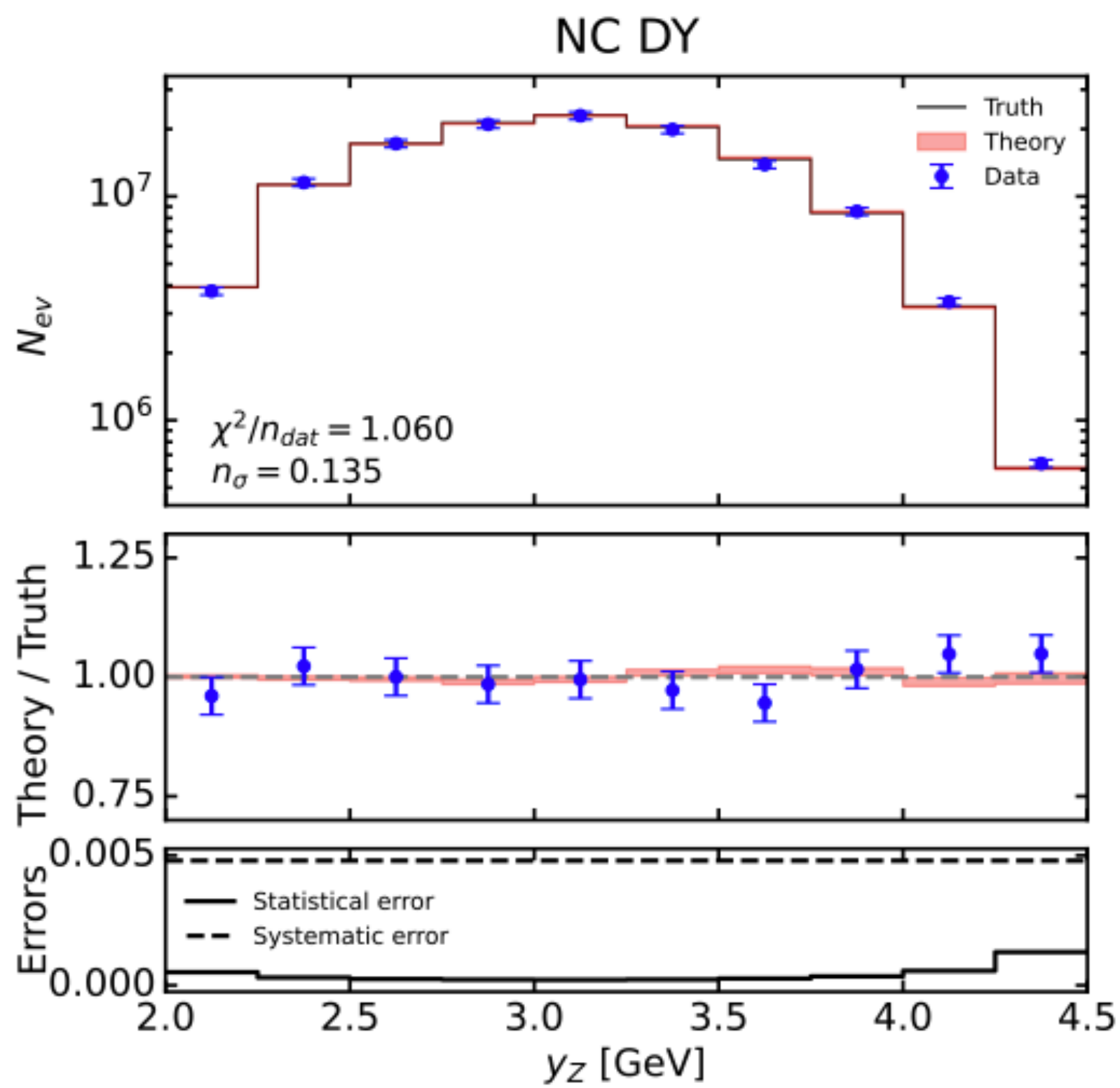
# *Disentangling the effects*

Can we use forward  $V$  production to spot the contamination?



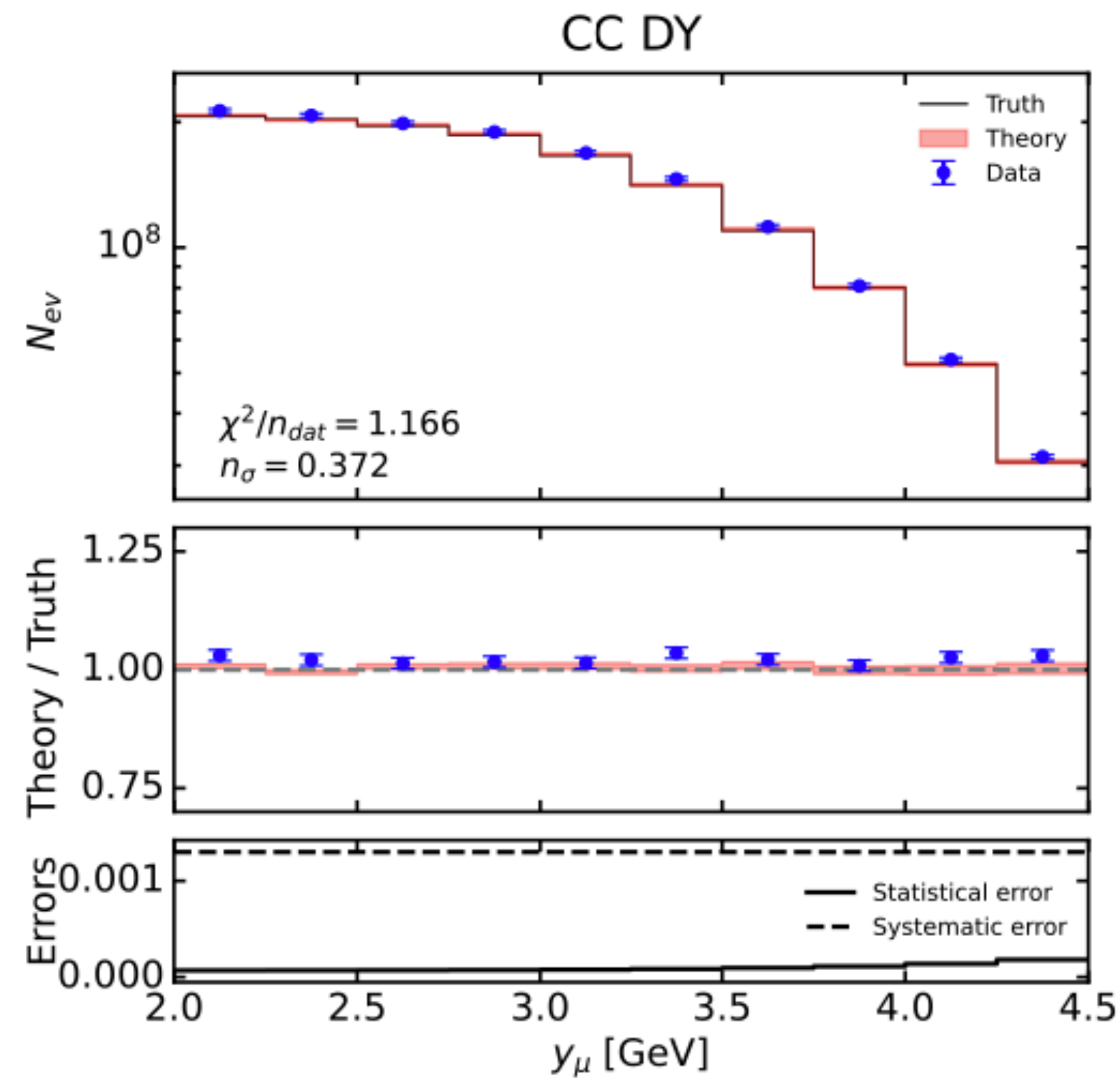
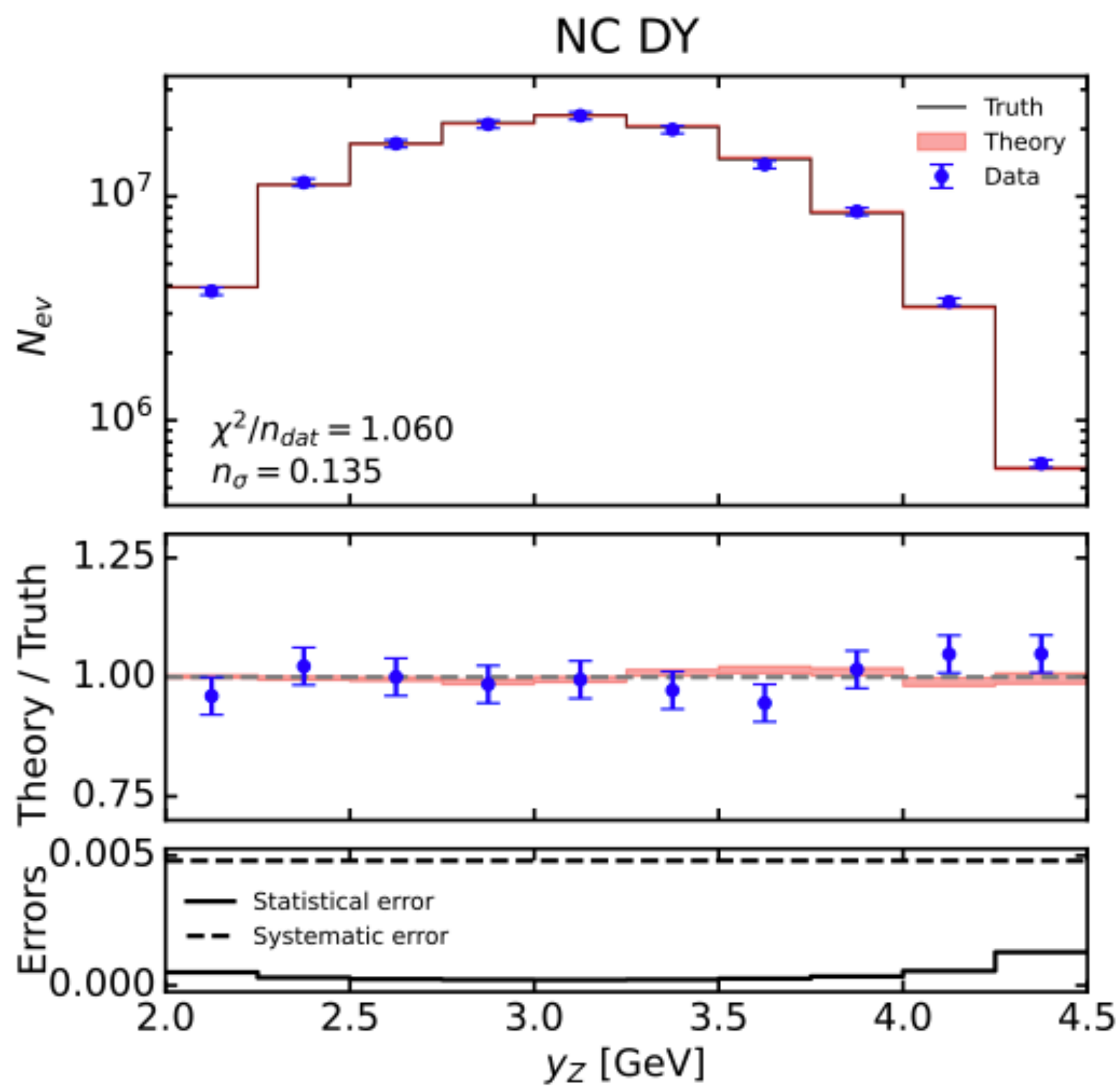
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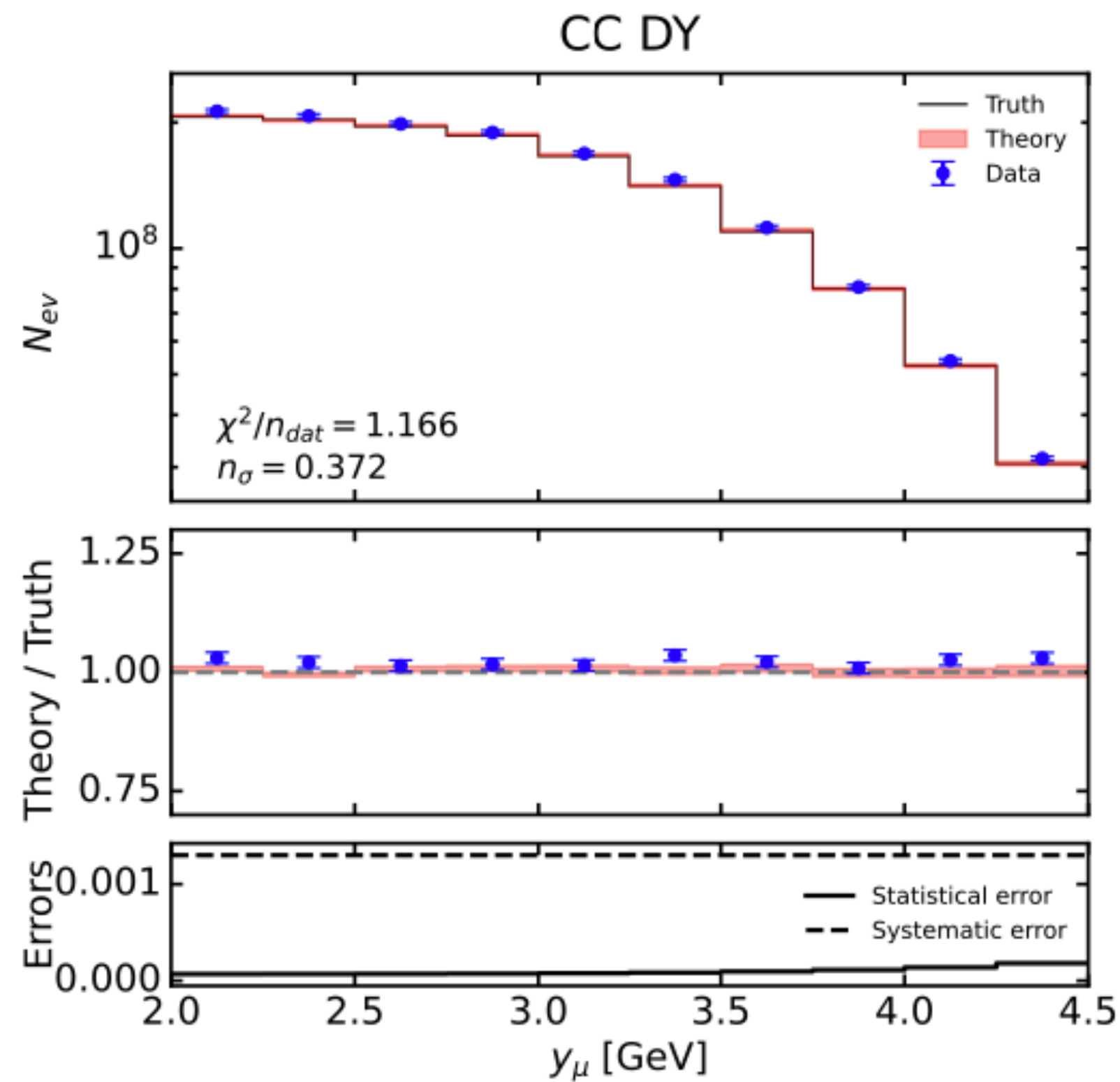
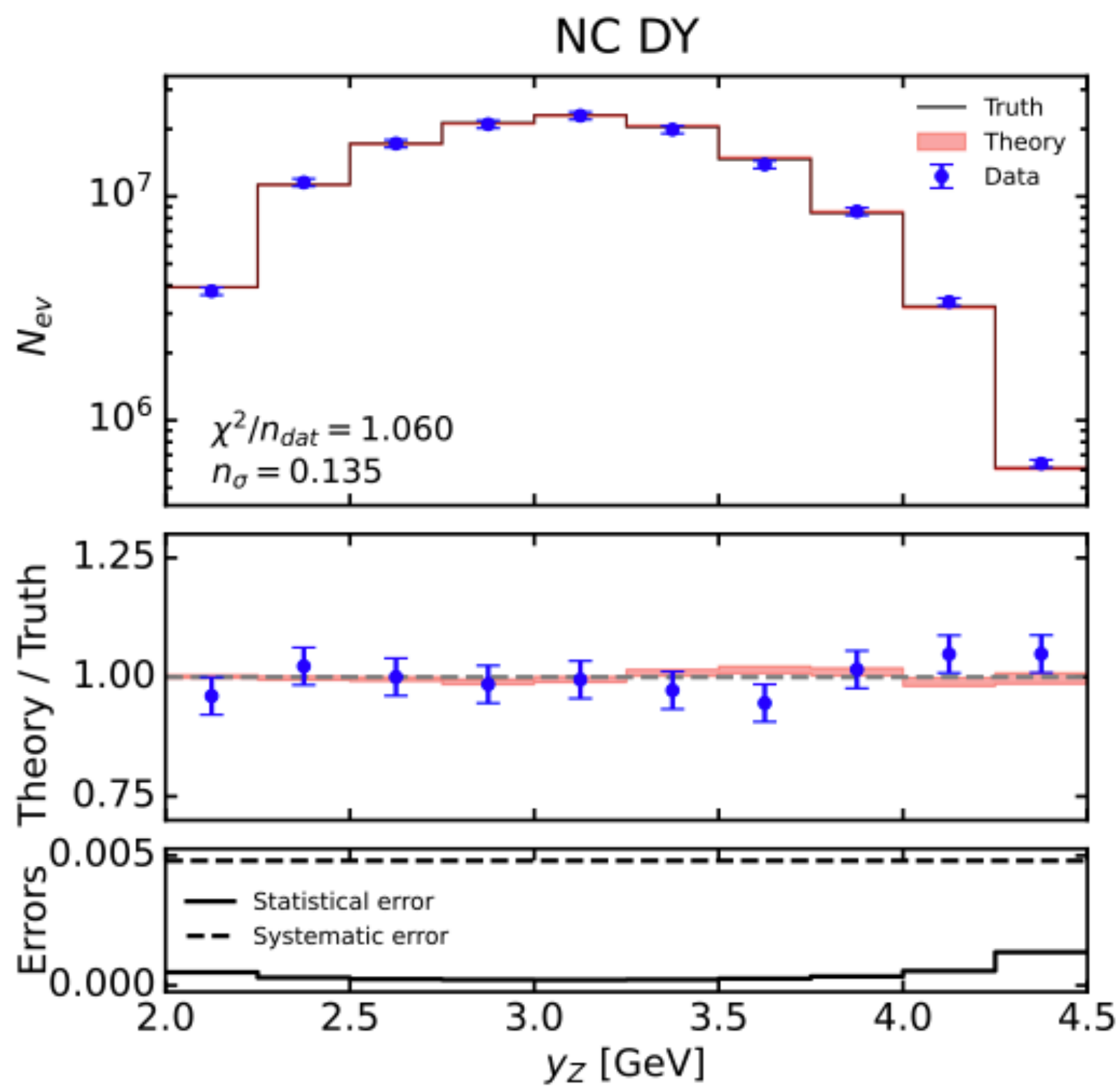
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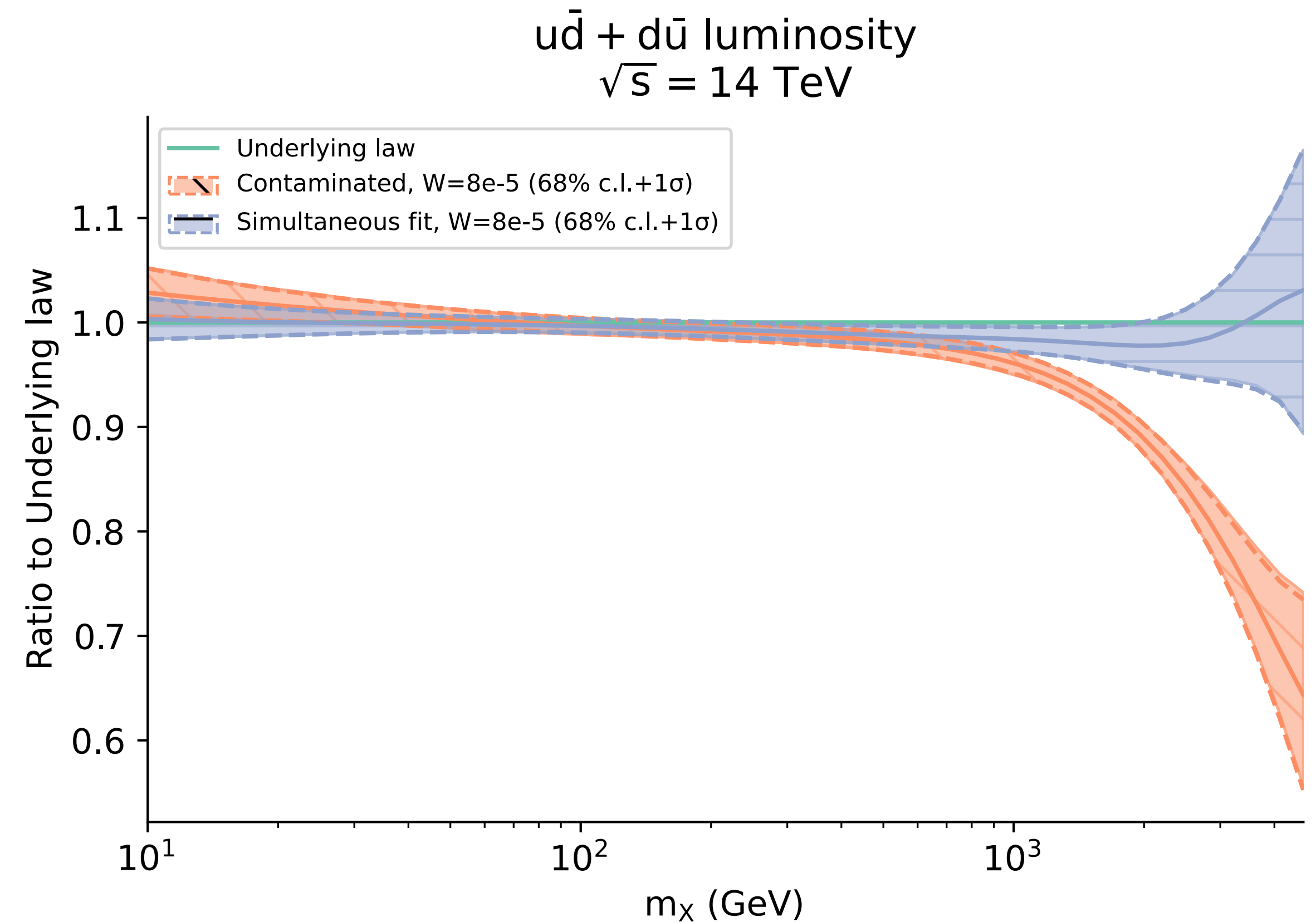
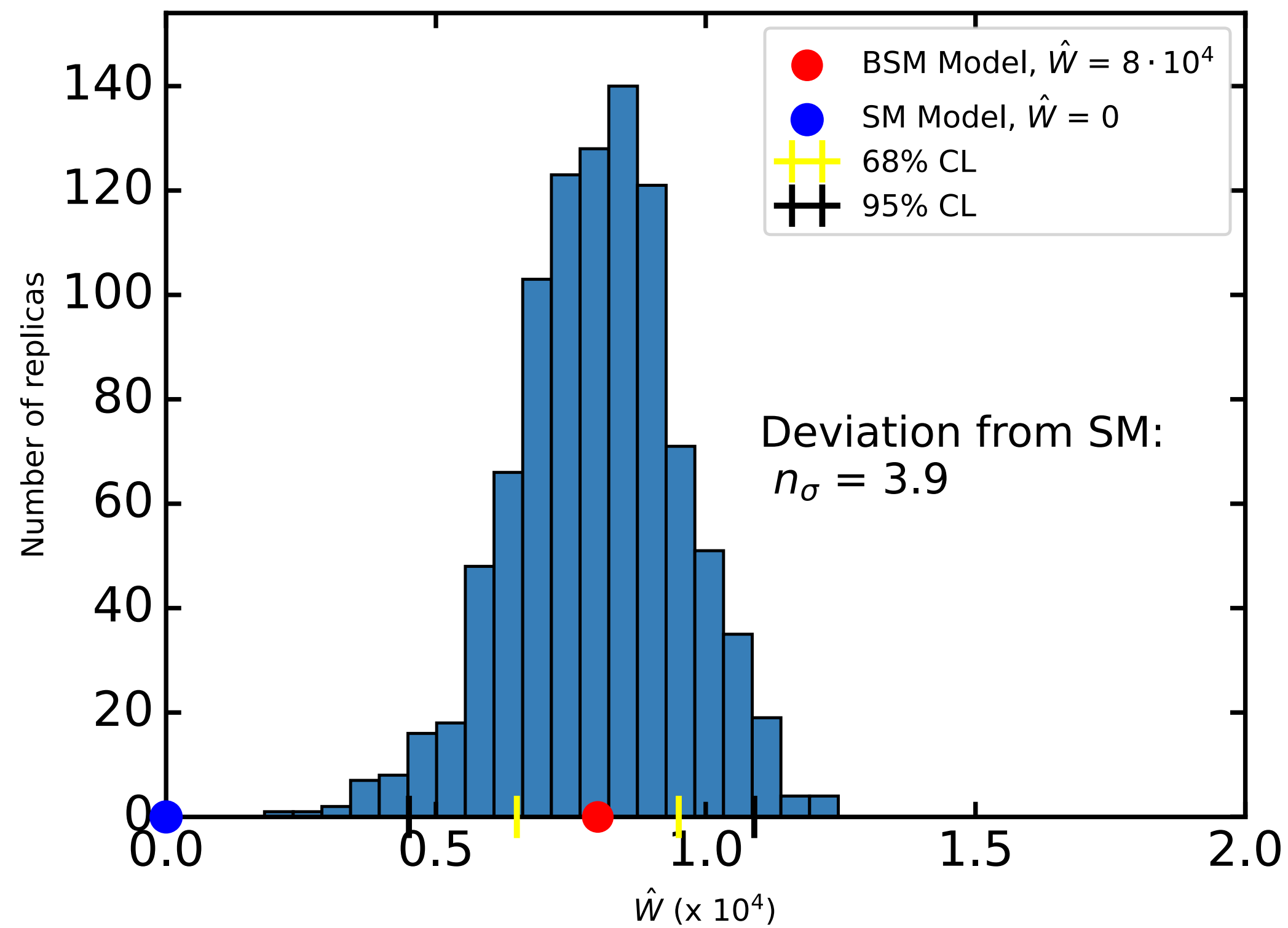


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Future low-energy measurements (e.g. EIC programme) could provide **crucial input for PDFs!**

# Disentangling with a joint fit

Simultaneous fit of PDFs and  $W$  parameter:



# Conclusions


- \* The PDF-EFT interplay could be crucial: wrong PDFs can in principle mimic EFT corrections.
- \* UV completion exist that can be absorbed in the PDF parametrisation.
- \* Current kinematic coverage of PDF datasets is insufficient, forward facilities and DIS experiments will provide vital input.
- \* The SIMUnet methodology offers the possibility to study such scenarios and potentially disentangle the EFT effects in the PDF extraction.






*Thank you*





*Back-up*



# The common approach

Typically fits of physics parameters and PDFs **do not talk**

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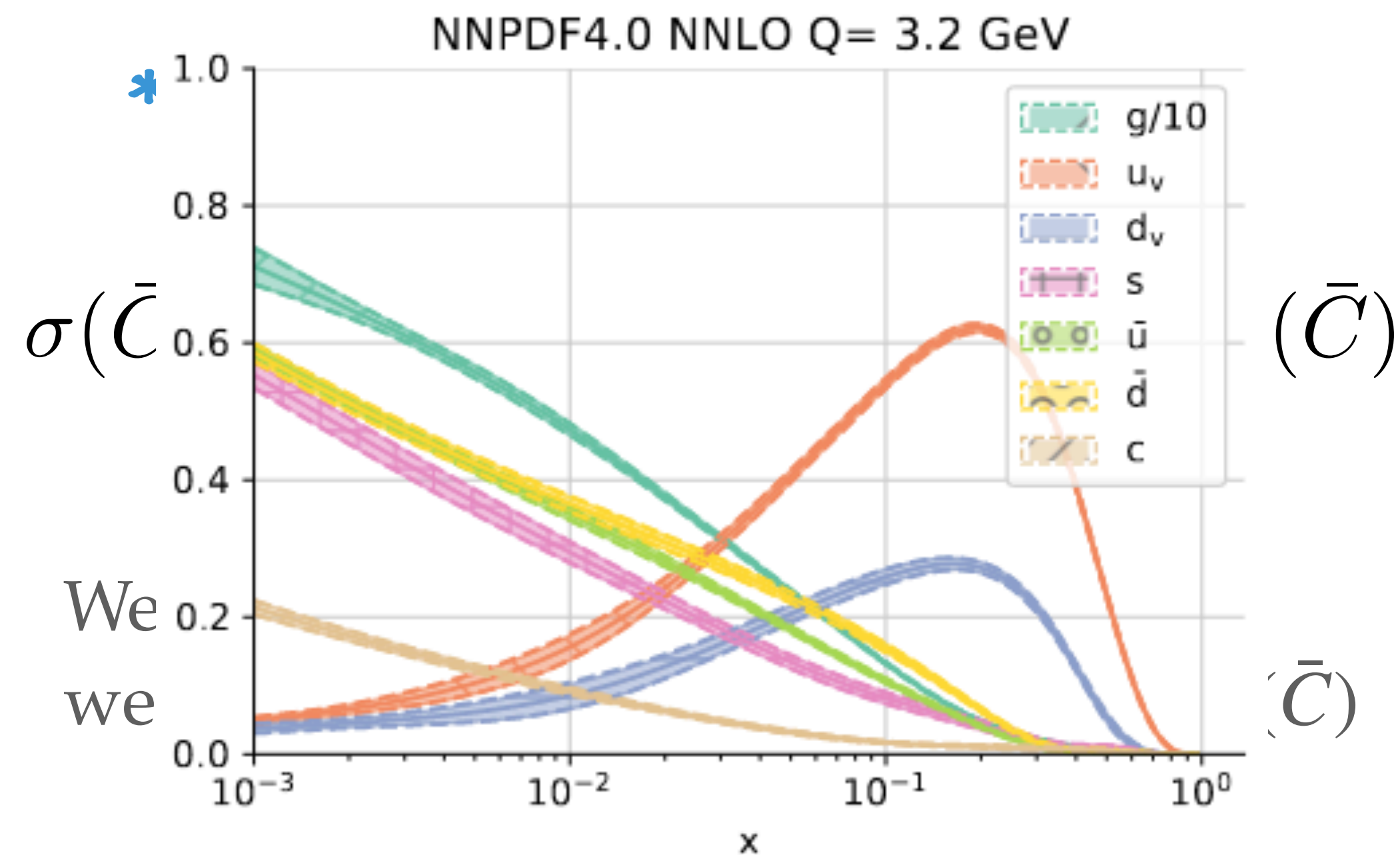


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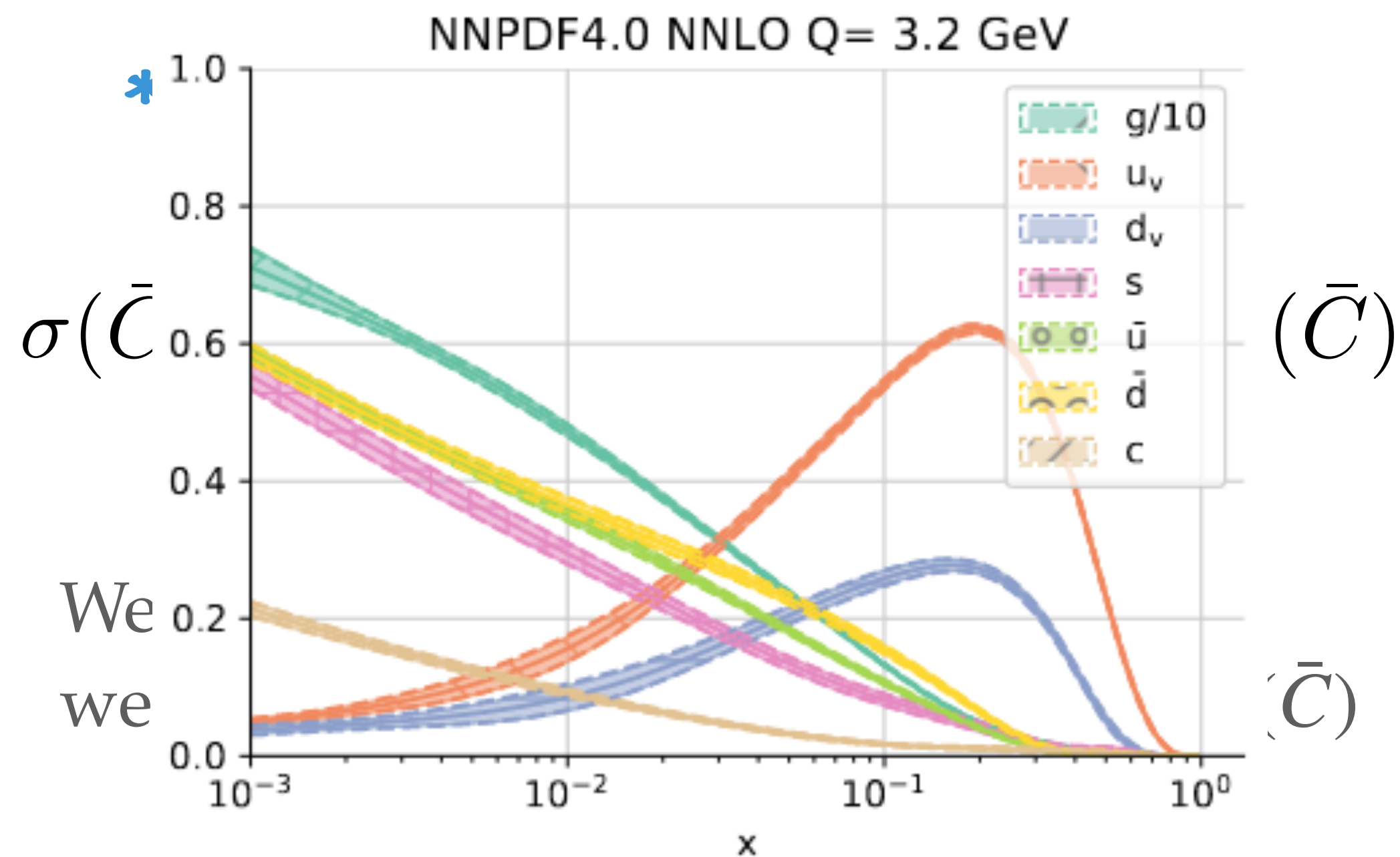
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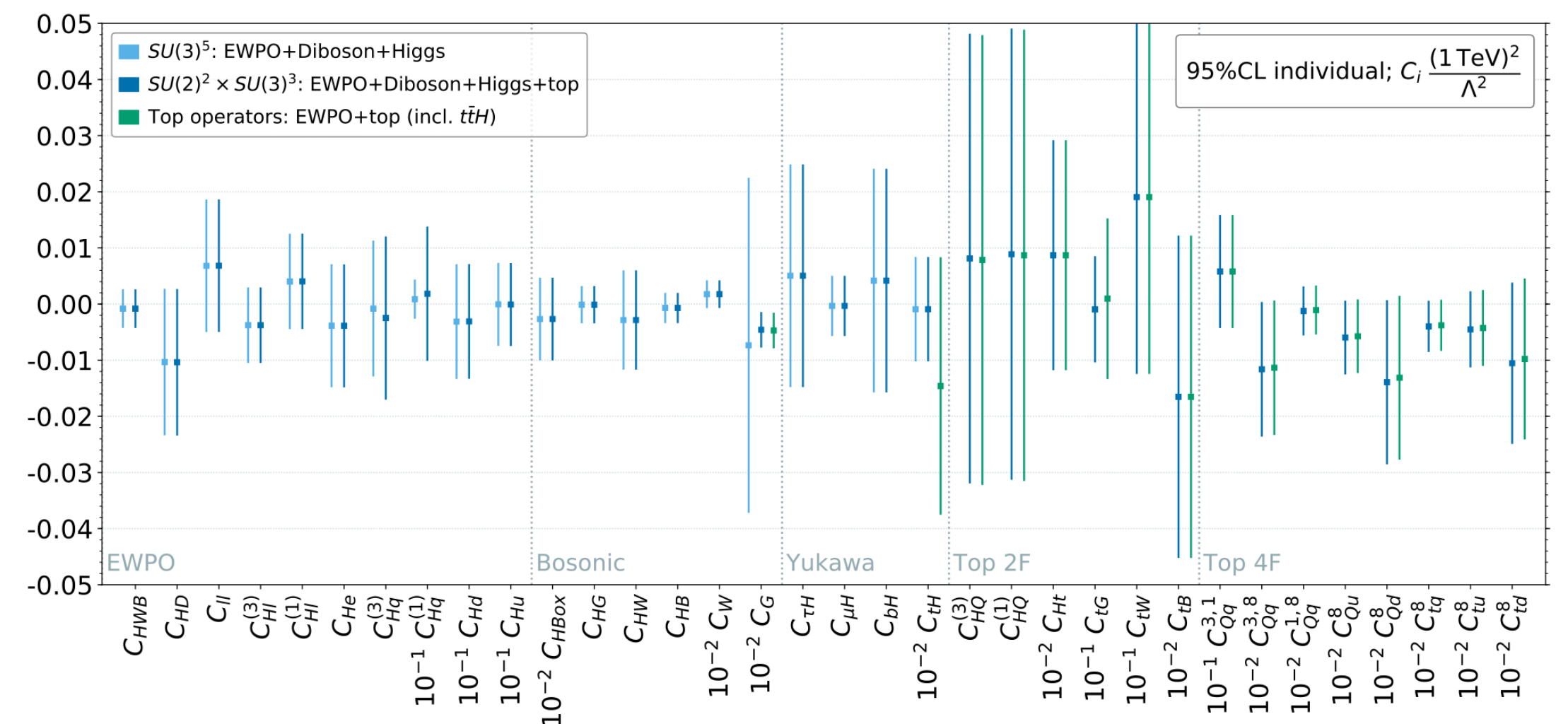
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## PDFs extraction



## Physics parameters



FitMaker [2012:02779]

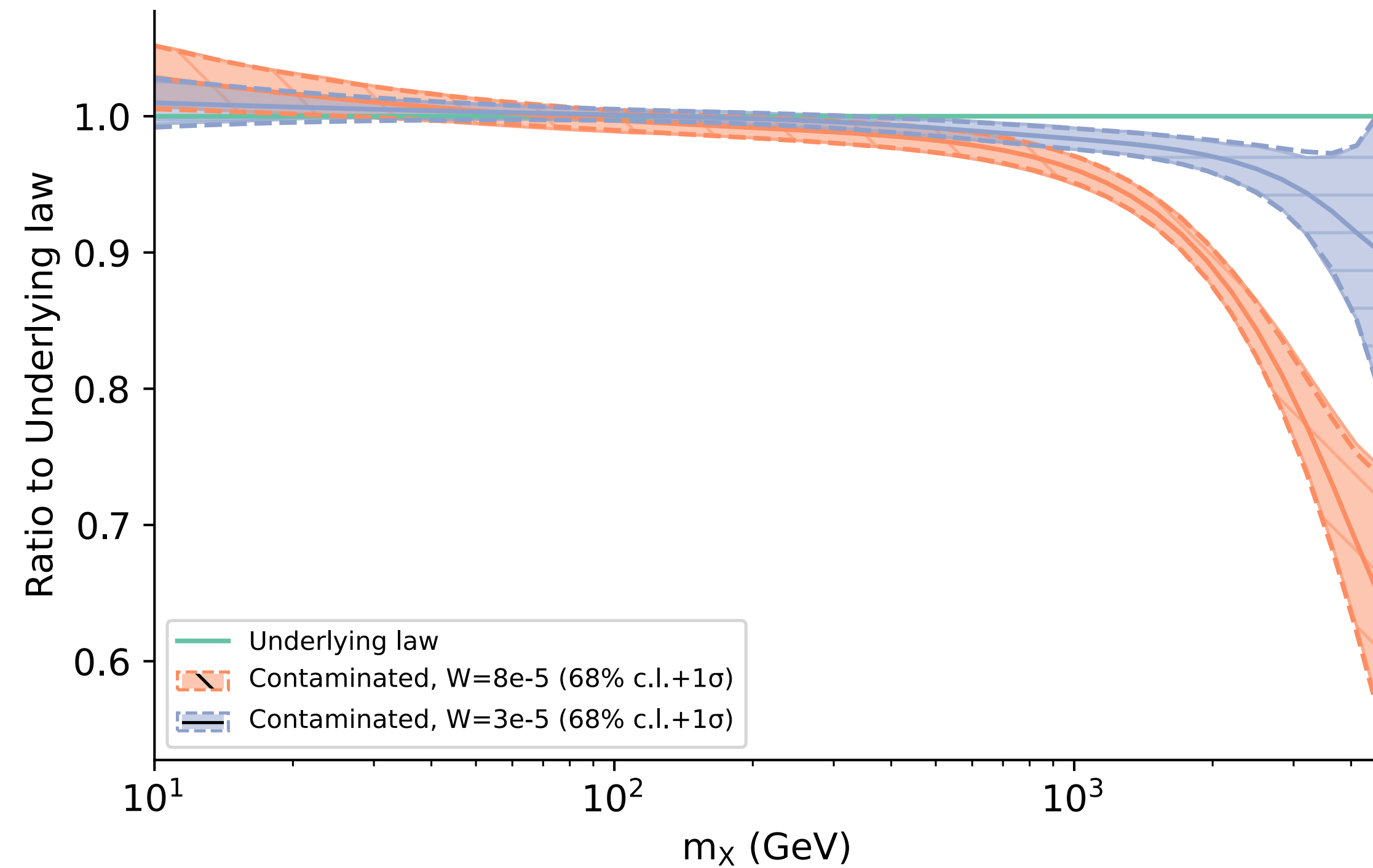
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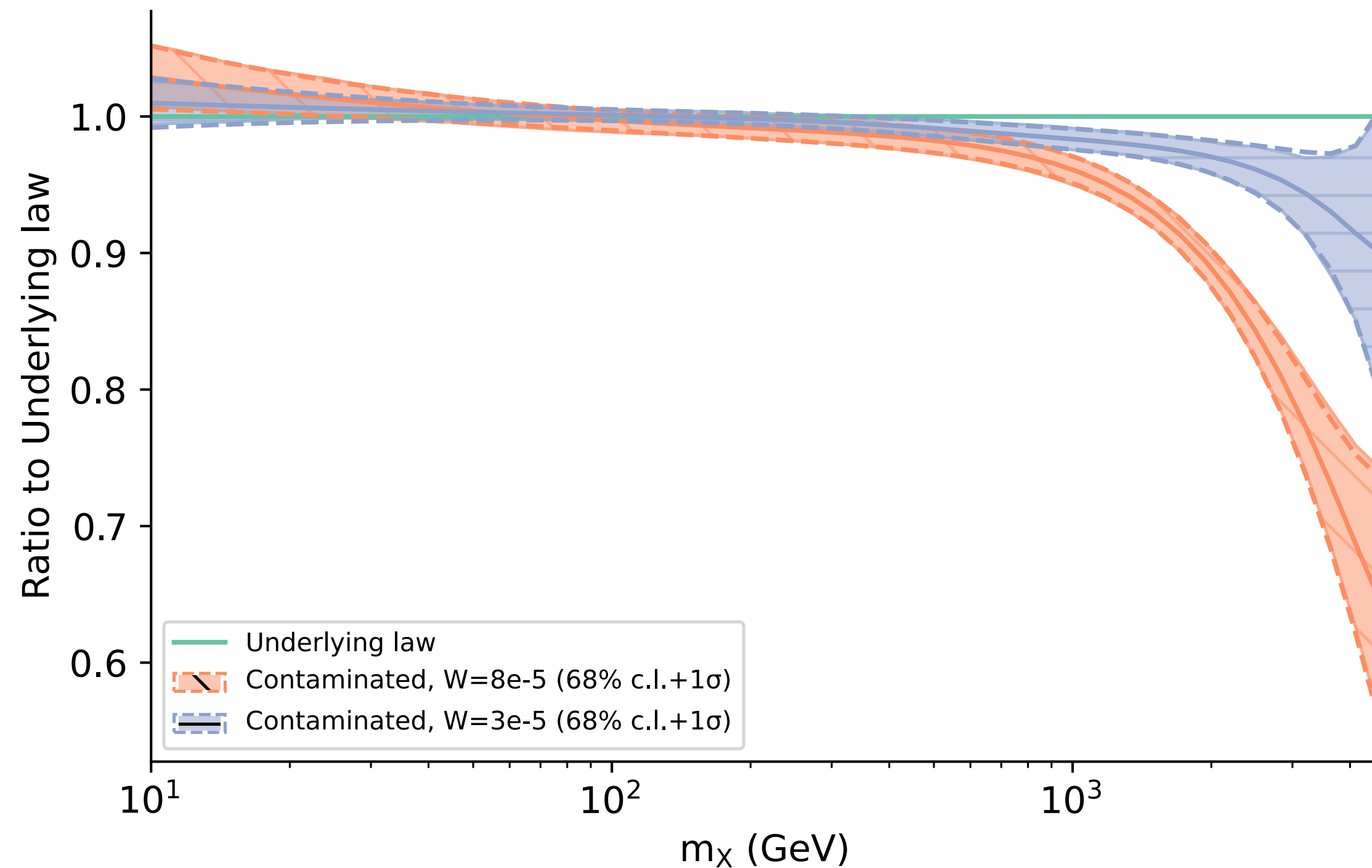
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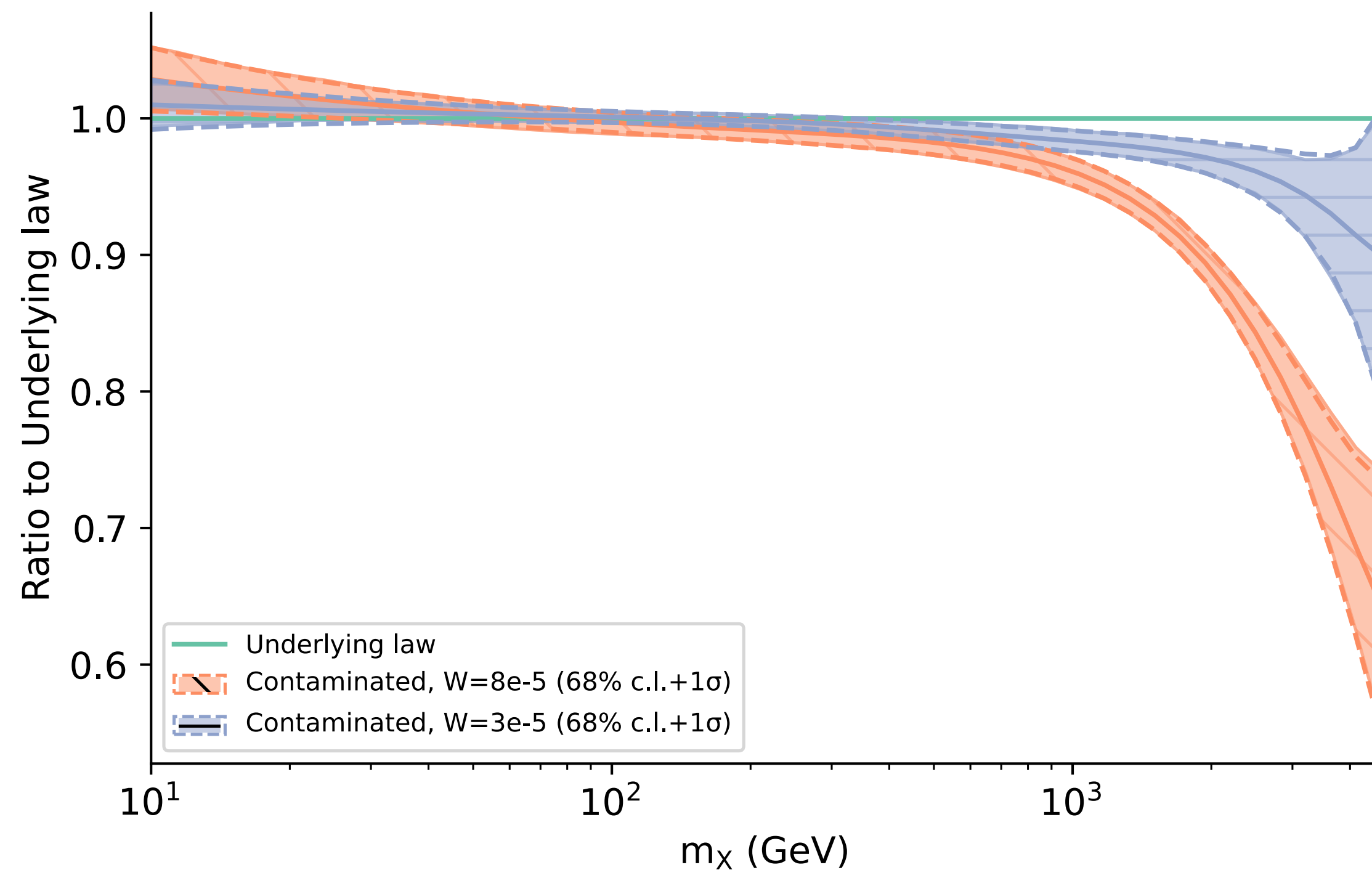
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reduces absorption of NP



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$u\bar{d} + d\bar{u}$  luminosity  
 $\sqrt{s} = 14$  TeV

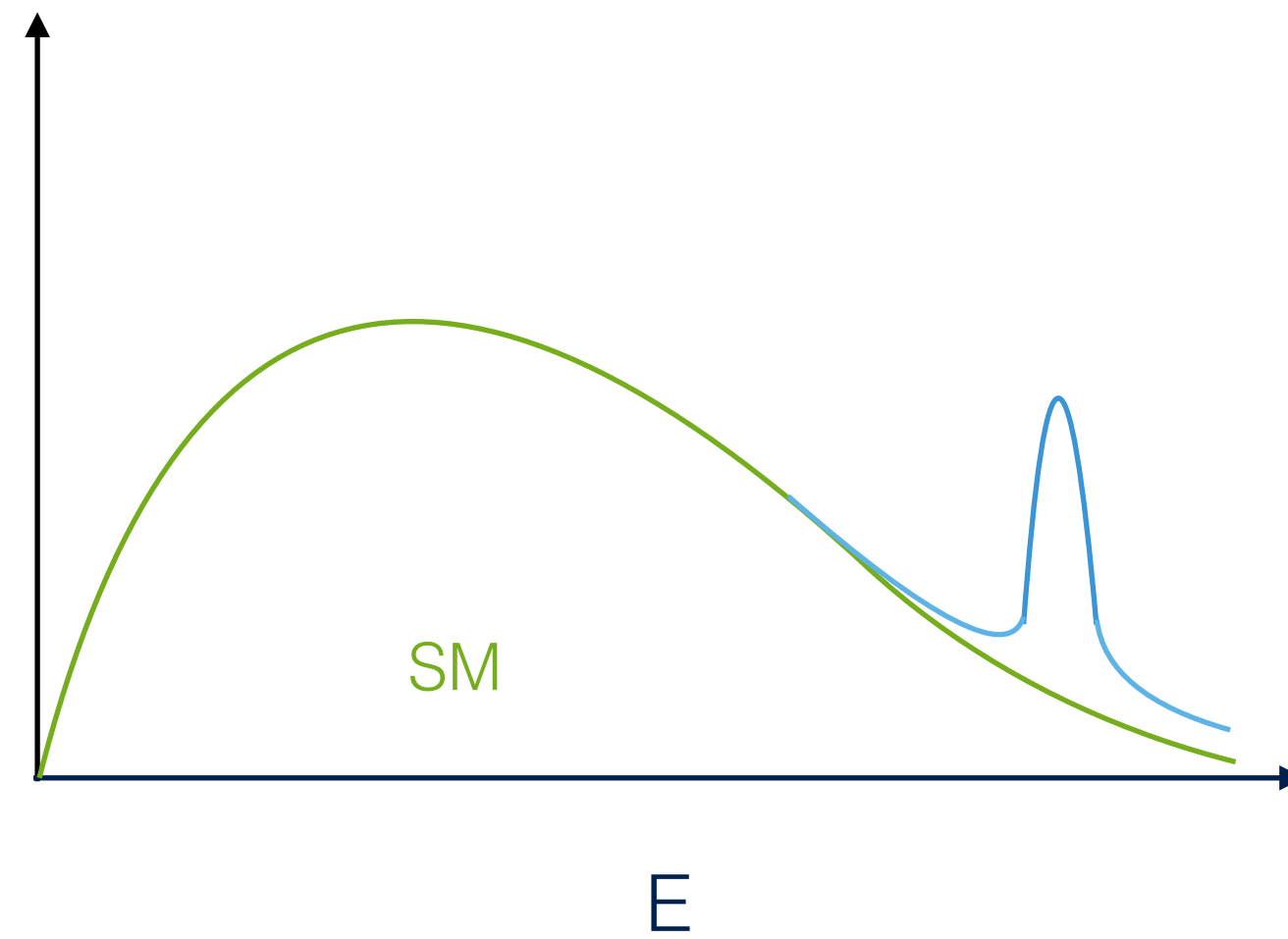


The additional high- $x$ , low- $Q$  data  
reduces absorption of NP

$M_{W'}$  : 14 TeV  $\rightarrow$  23 TeV

# The quest for New Physics

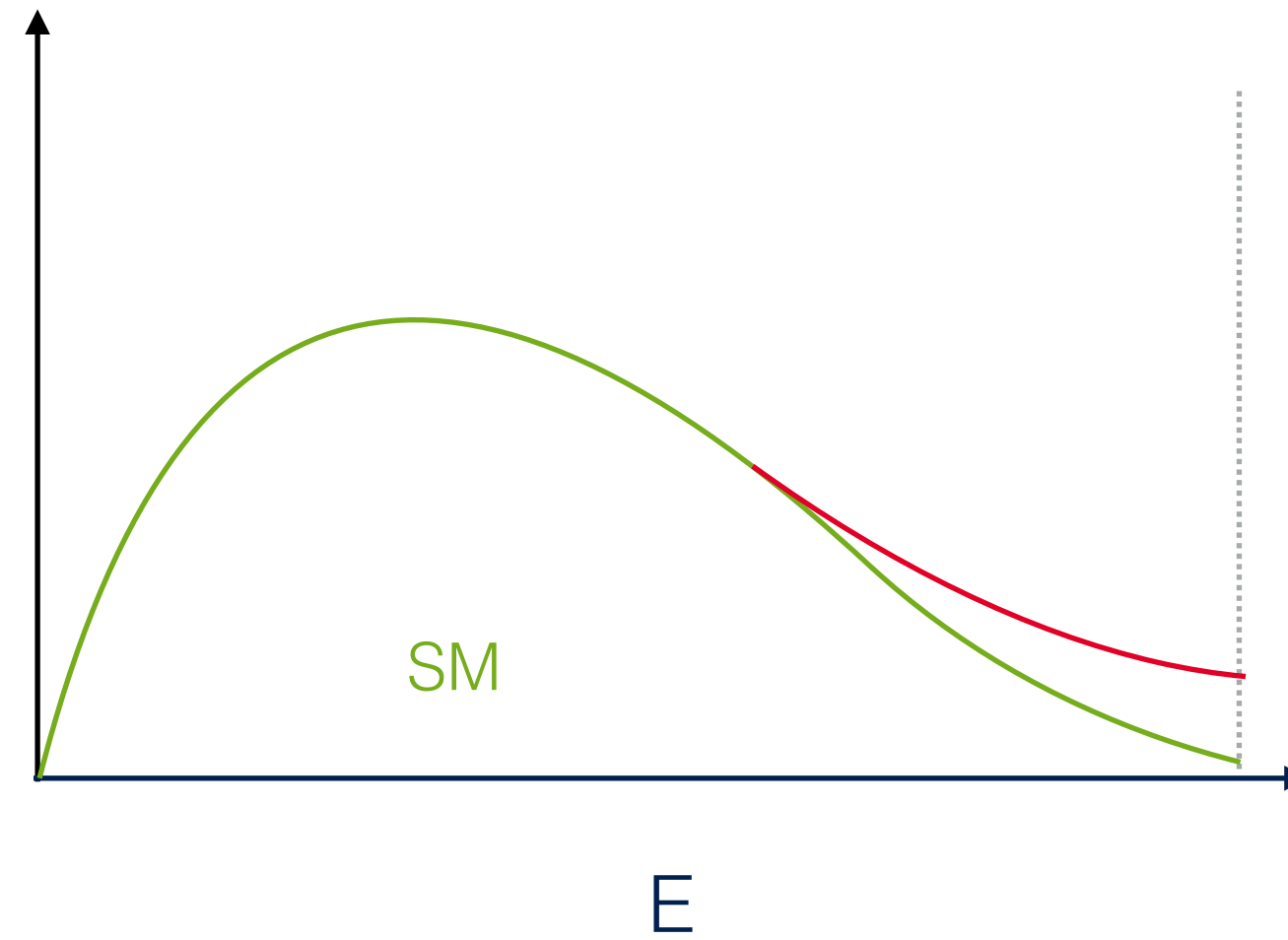
Direct search (Bumps)



# The quest for New Physics

Direct search (Bumps)

Indirect (scouting tails)

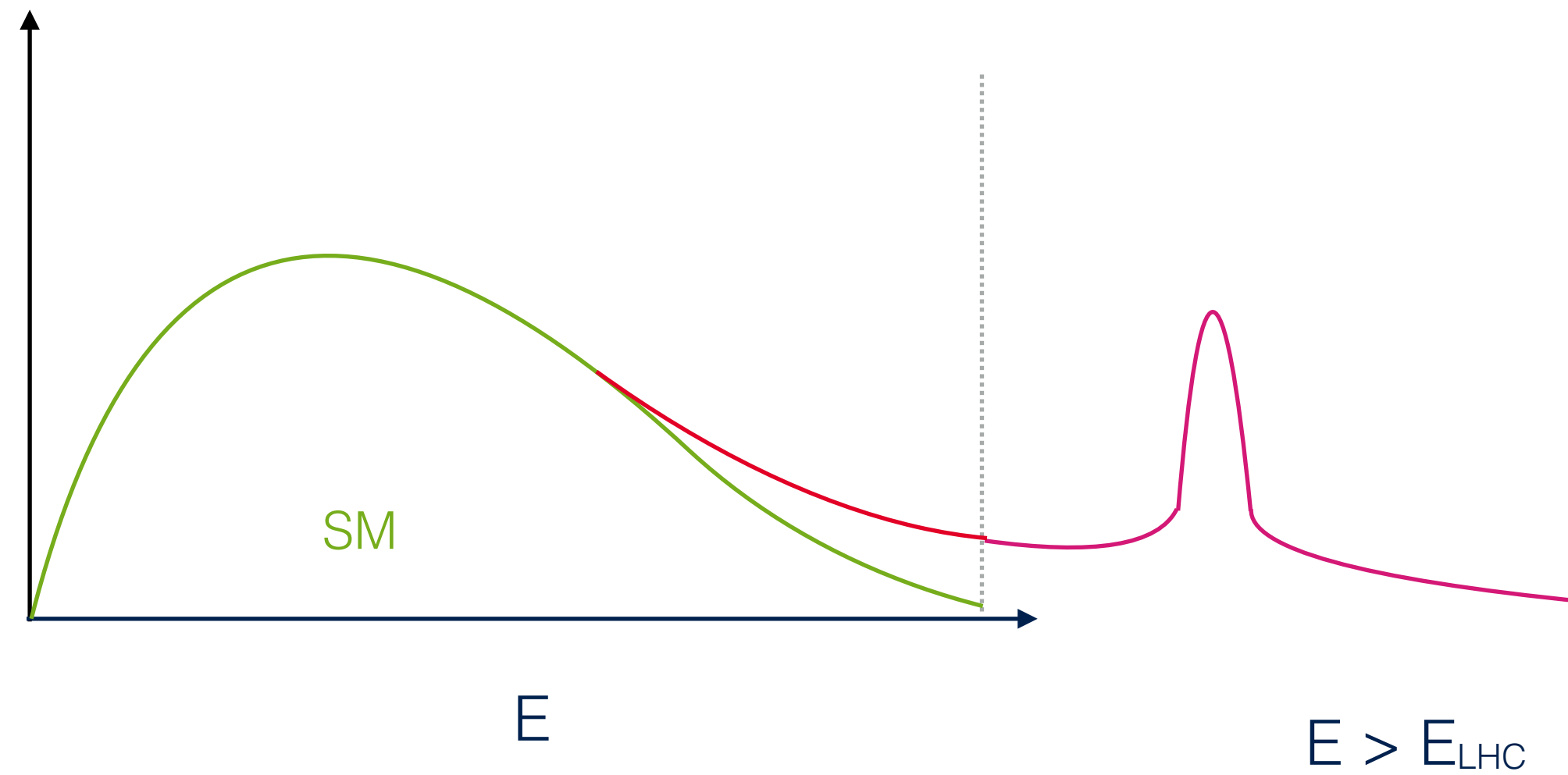


# The quest for New Physics

Direct search (Bumps)

Indirect (scouting tails)

New physics is heavy

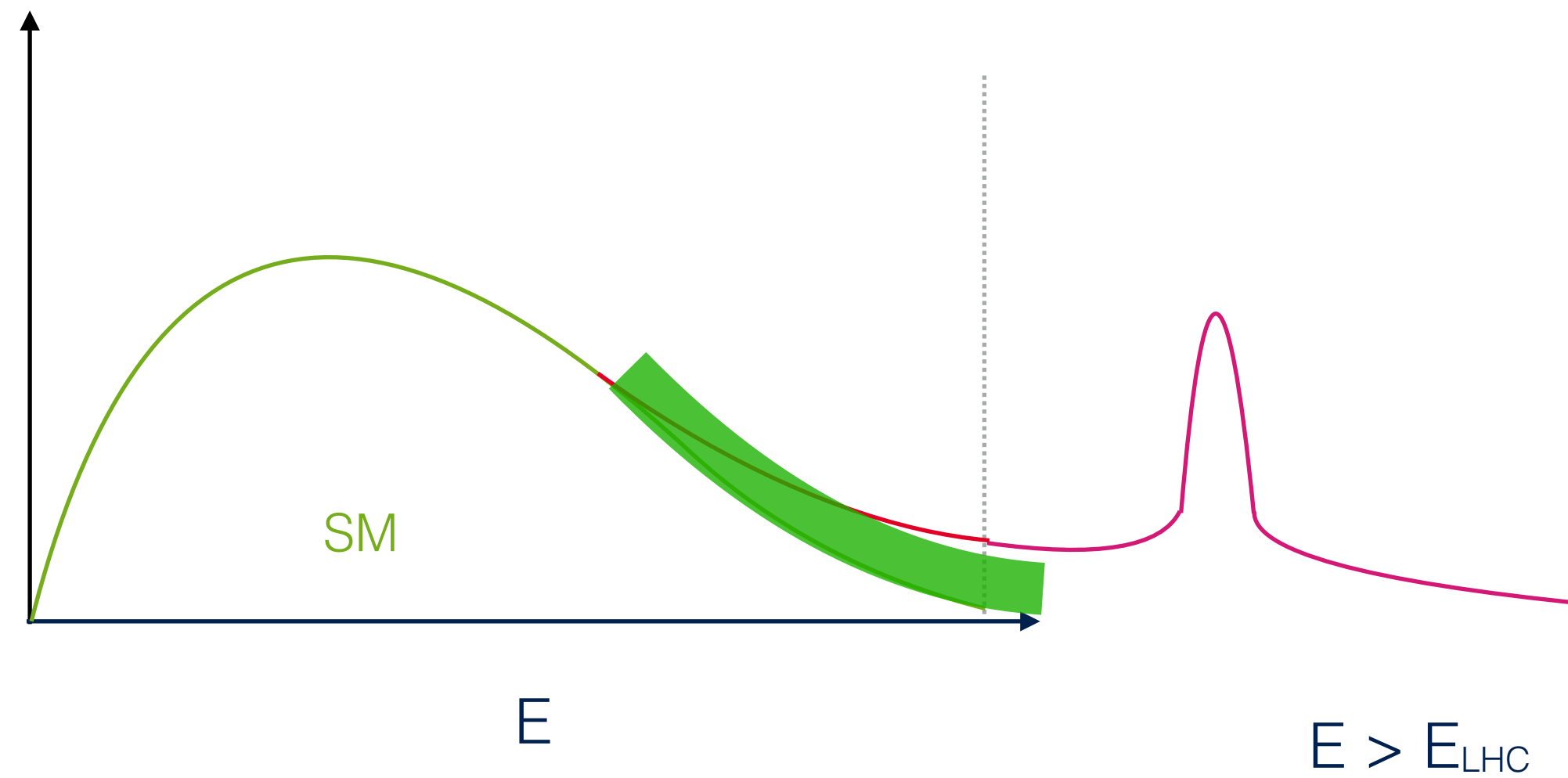


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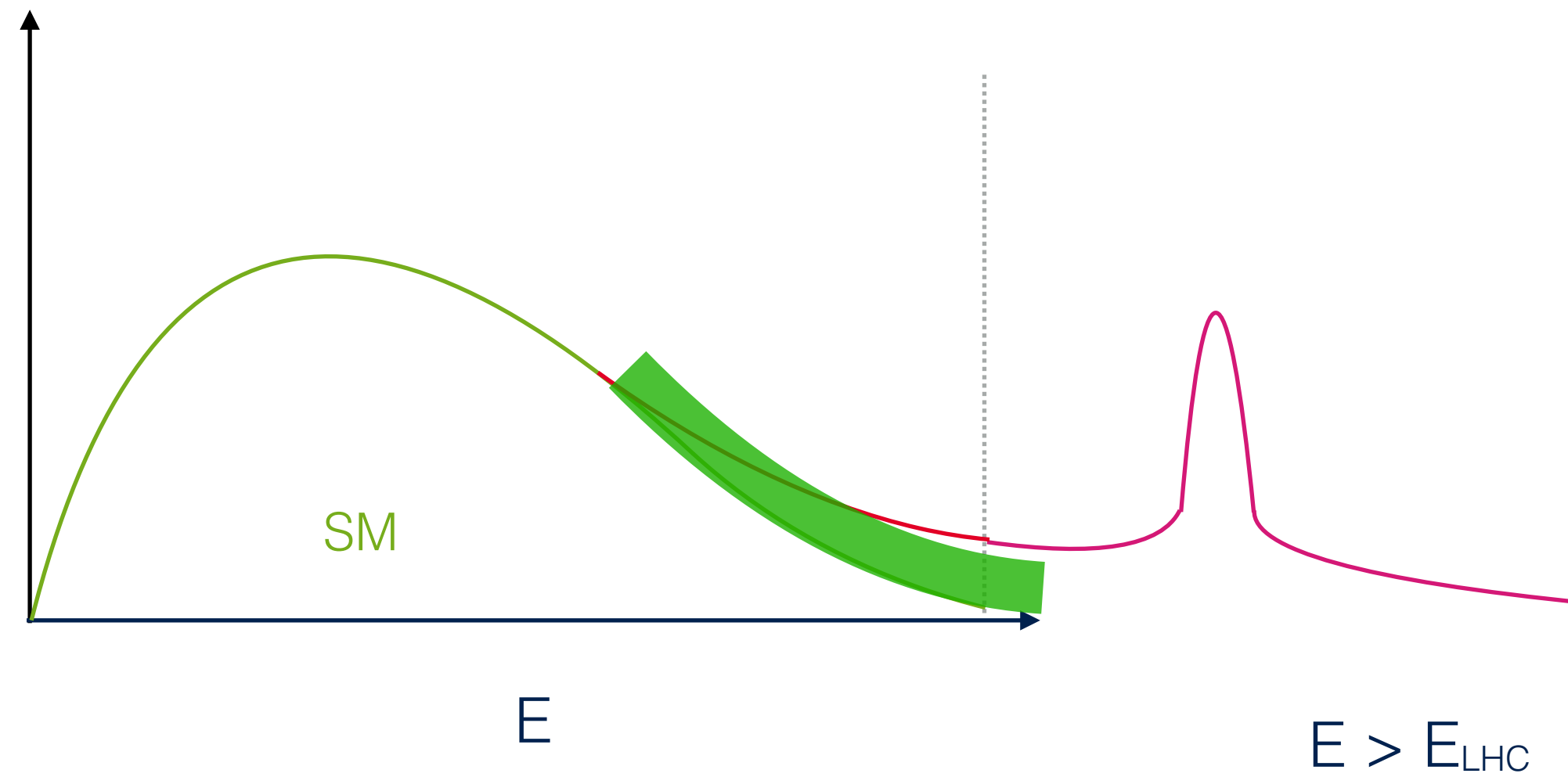


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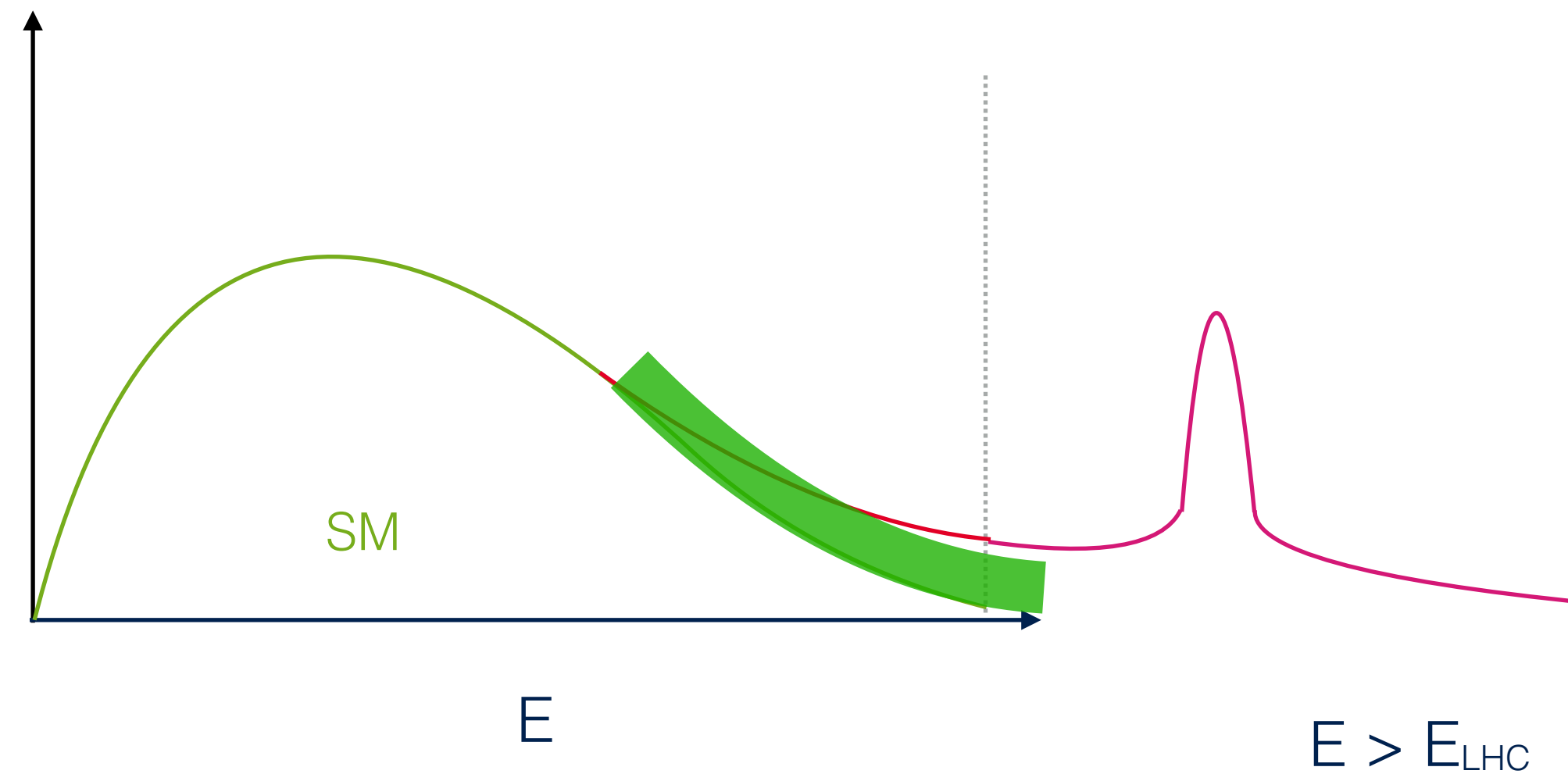
Framework to describe both **precision physics** and **Heavy New Physics**

# The quest for New Physics

Direct search (Bumps)

Indirect (scouting tails)

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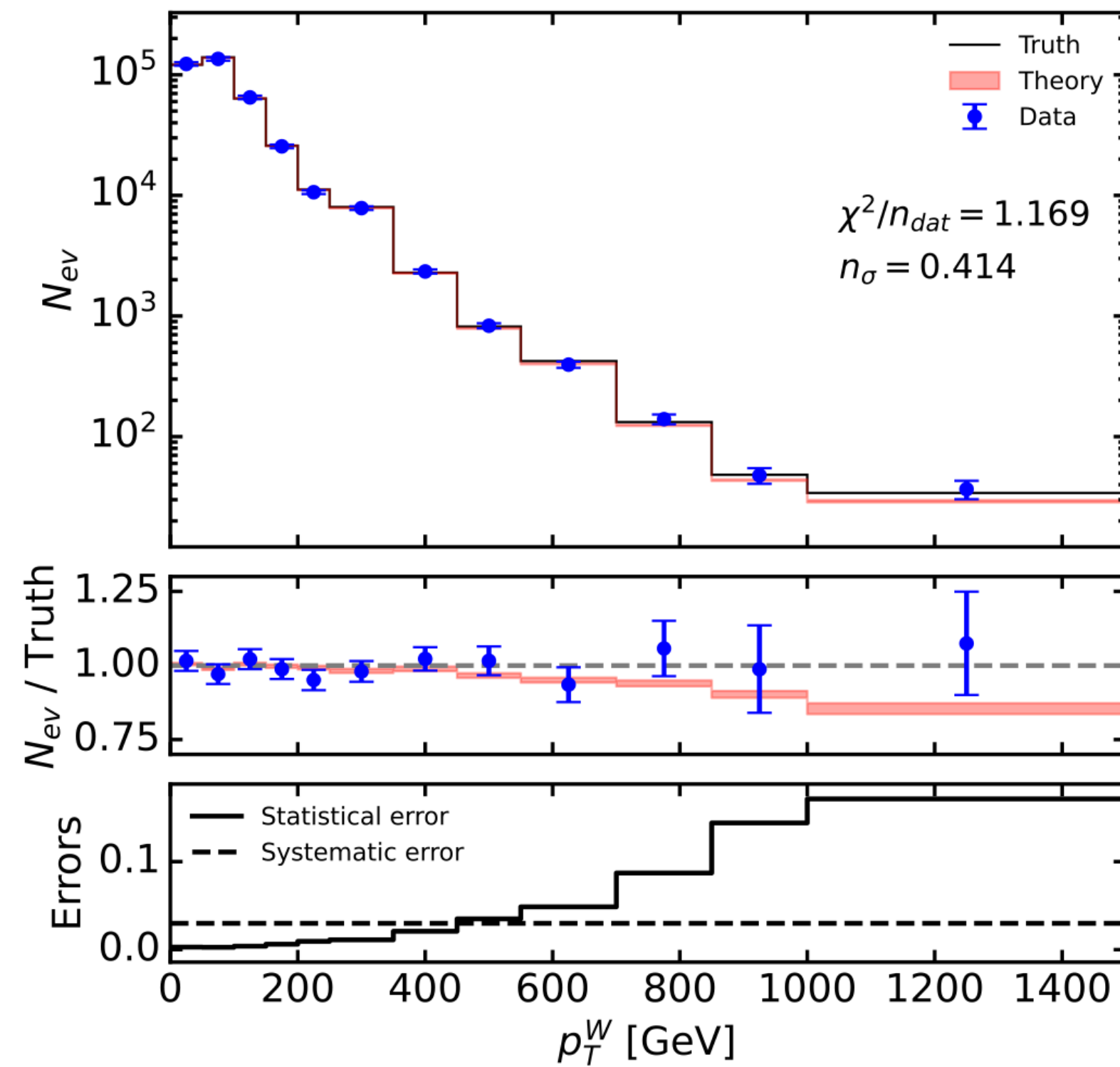


Framework to describe both precision physics and Heavy New Physics

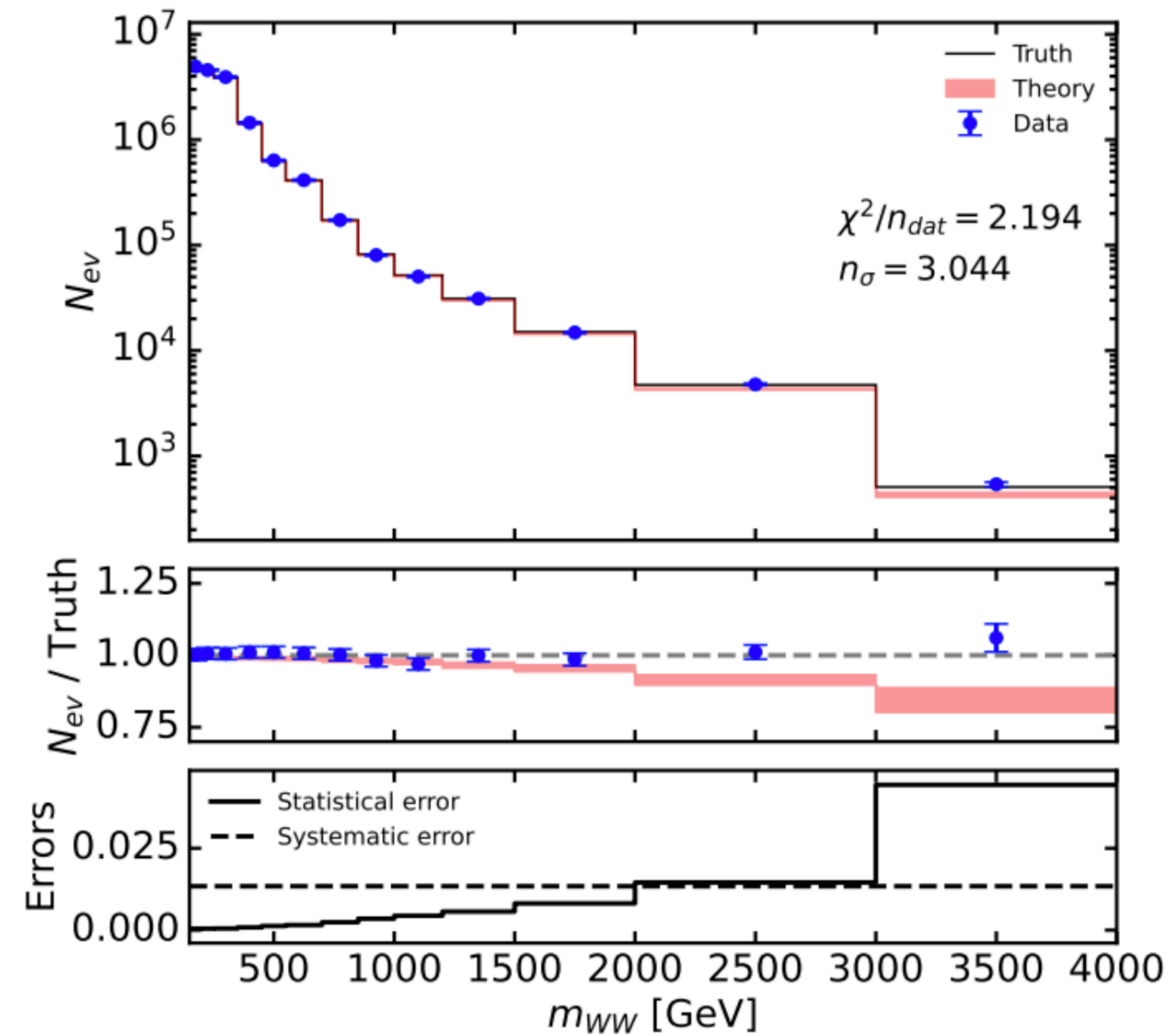
**Standard Model Effective Field Theory (SMEFT)**

# Spurious New Physics

$$pp \rightarrow W^+ H$$



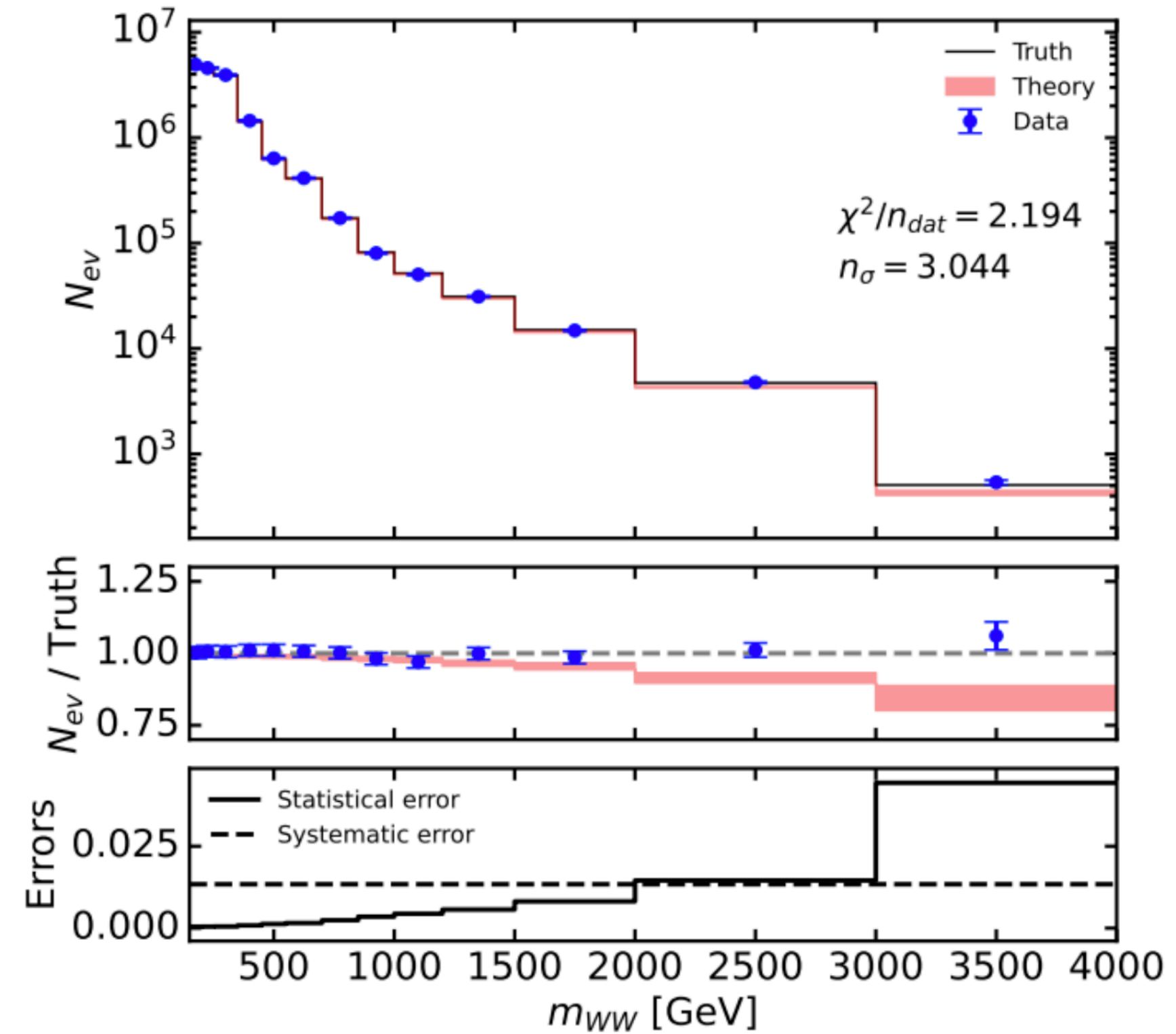
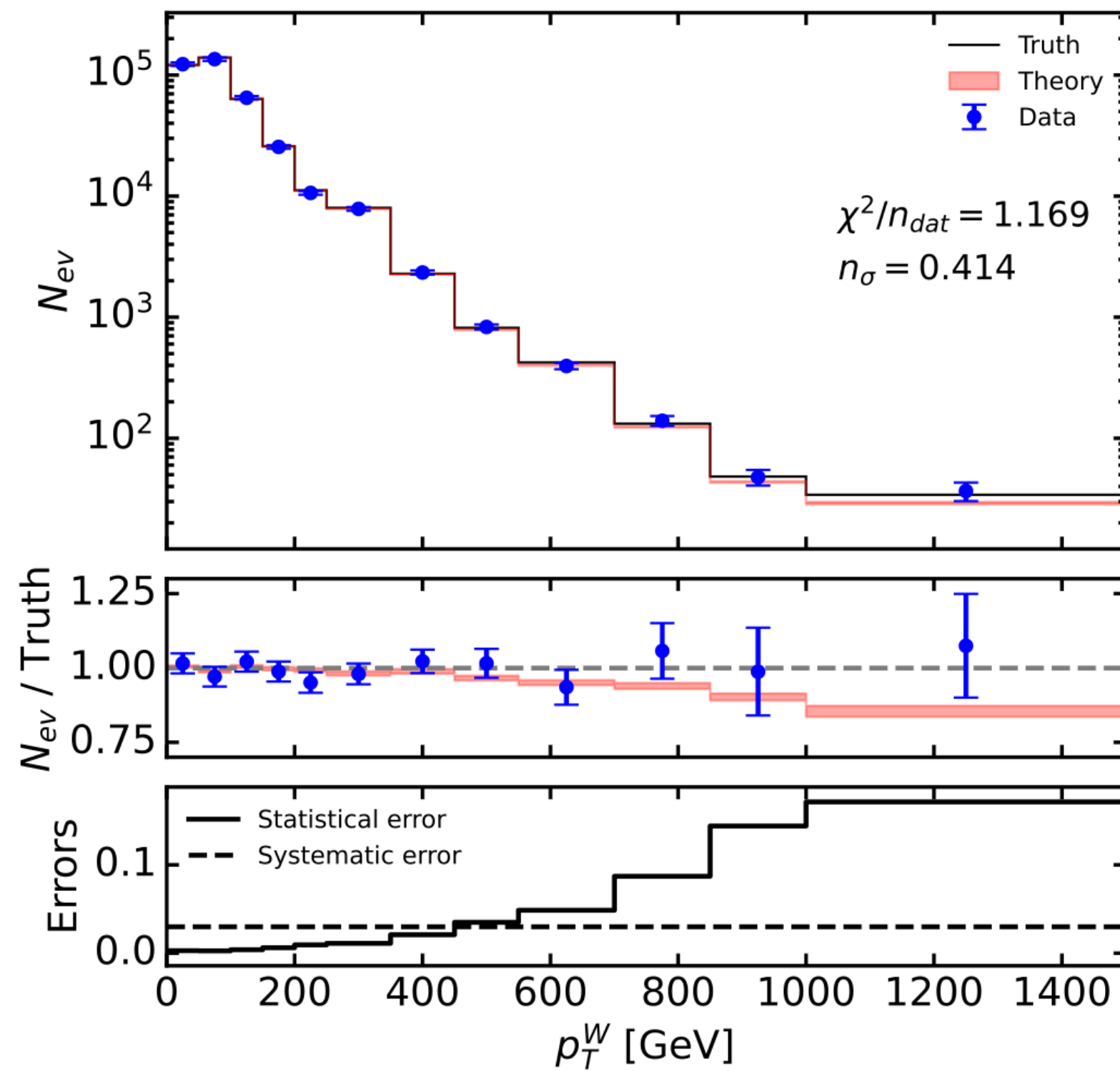
$$pp \rightarrow W^+ W^-$$



# Spurious New Physics

$$pp \rightarrow W^+ H$$

$$pp \rightarrow W^+ W^-$$



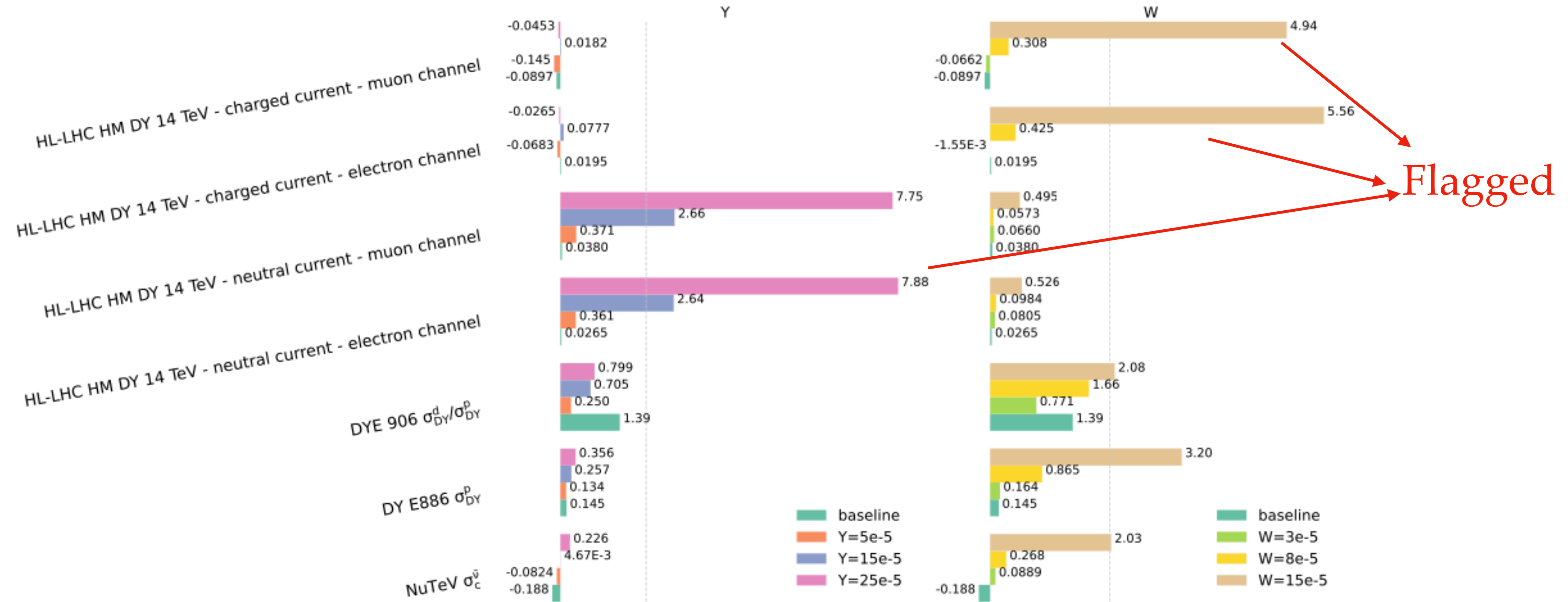
Observables  
not affected by  $W'$



Spurious NP

# Fit metrics

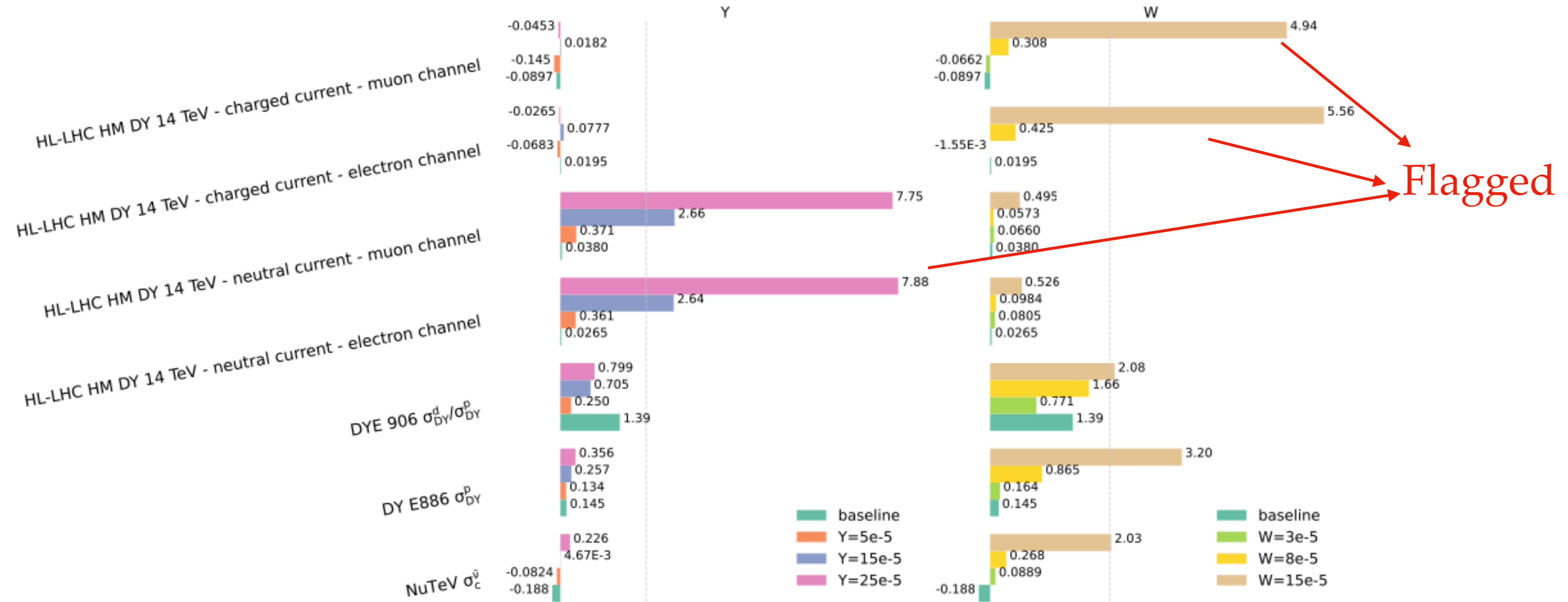
Baseline: SM pseudodata  $n_\sigma = \frac{\chi^2 - 1}{\sigma_{\chi^2}}$





# Fit metrics

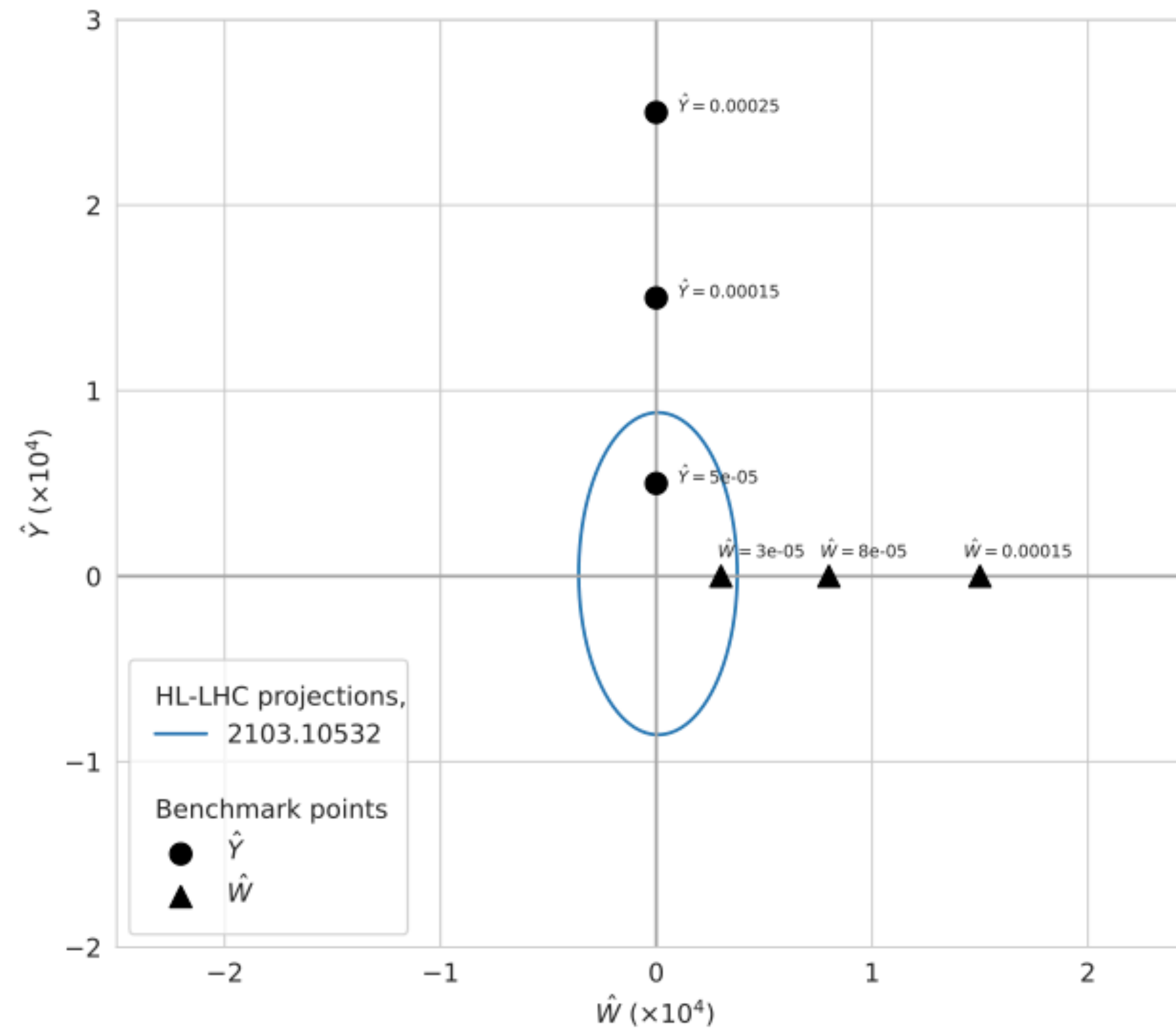
Baseline: SM pseudodata  $n_\sigma = \frac{\chi^2 - 1}{\sigma_{\chi^2}}$



$\hat{W} = 8 \cdot 10^{-5}, M_{W'} \approx 14 \text{ TeV}$

**Absorbed**

# BSM scenarios

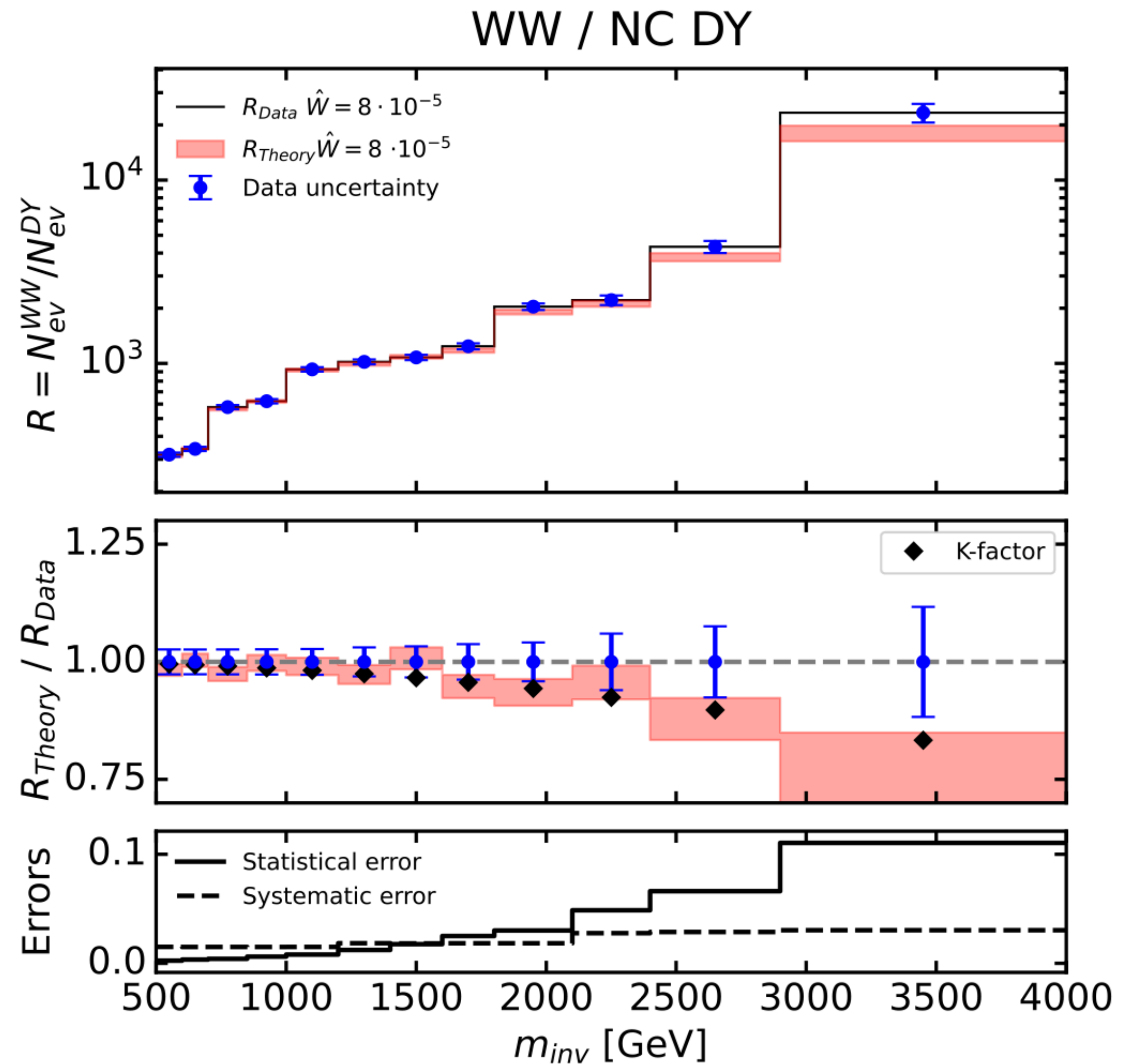


# Ratio observables

Observable which is **independent of PDFs**

# Ratio observables

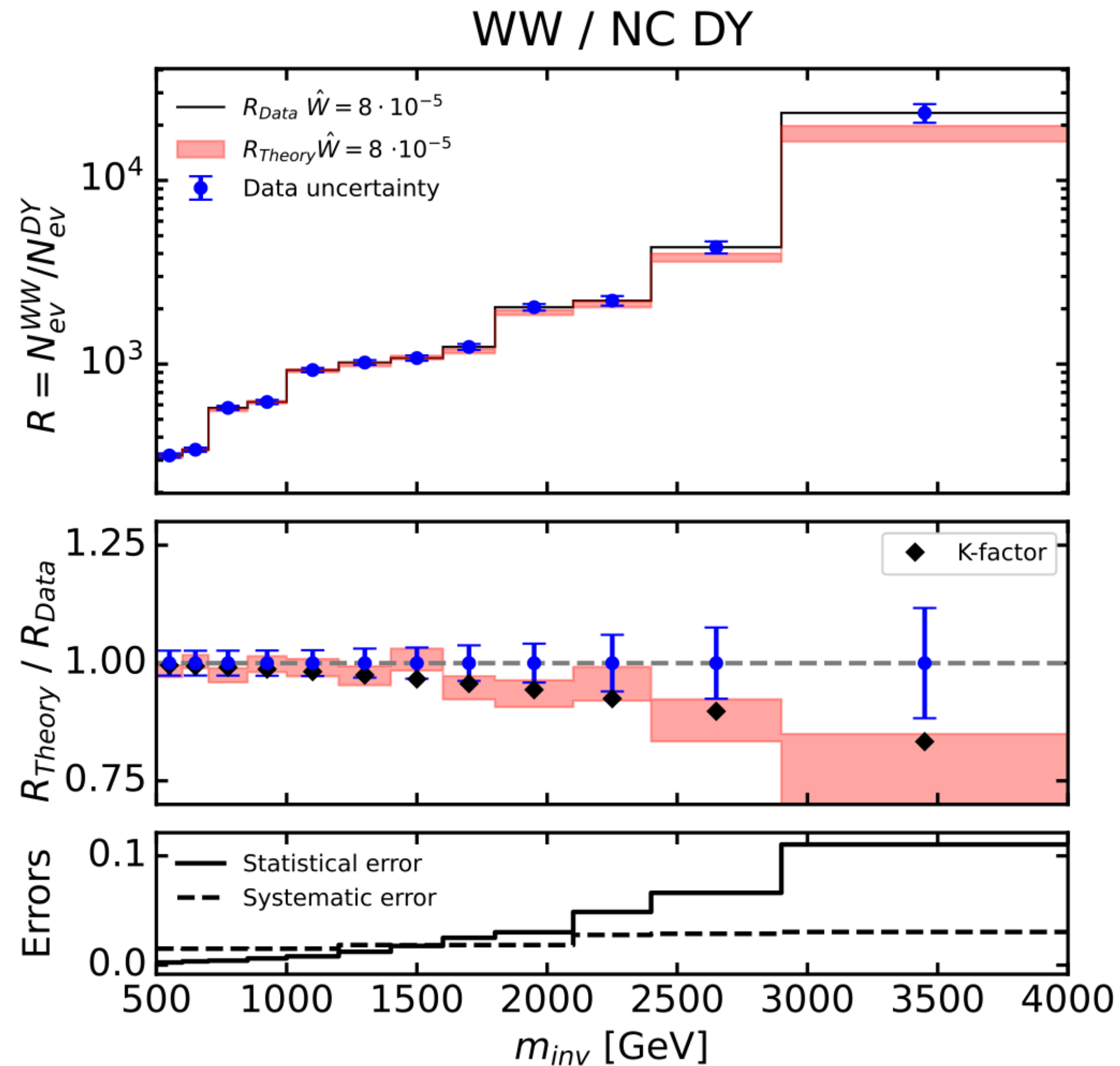
Observable which is **independent of PDFs**



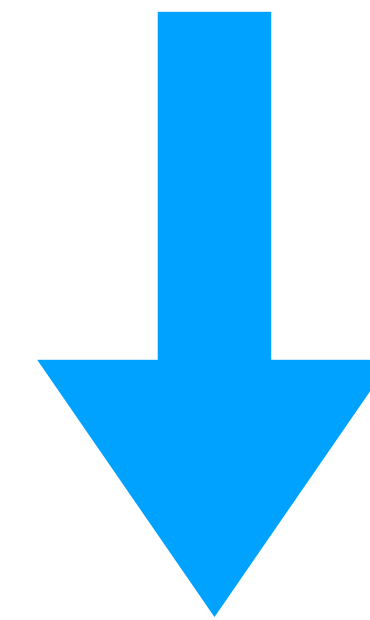
Ratio of WW and DY:  
prediction has suppressed  
dependence on PDF

# Ratio observables

Observable which is **independent of PDFs**



Ratio of WW and DY:  
prediction has suppressed  
dependence on PDF



**NP is there... but where?**