Hide and seek: how PDFs can conceal New Physics

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arXiv: 2307.10370

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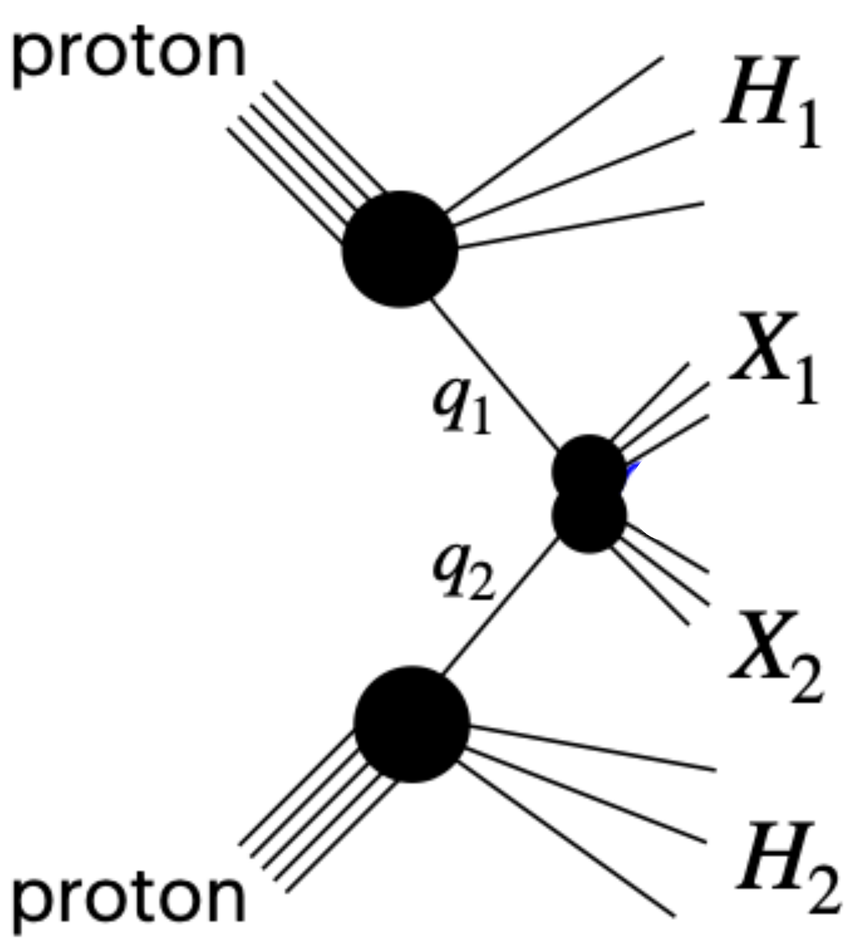

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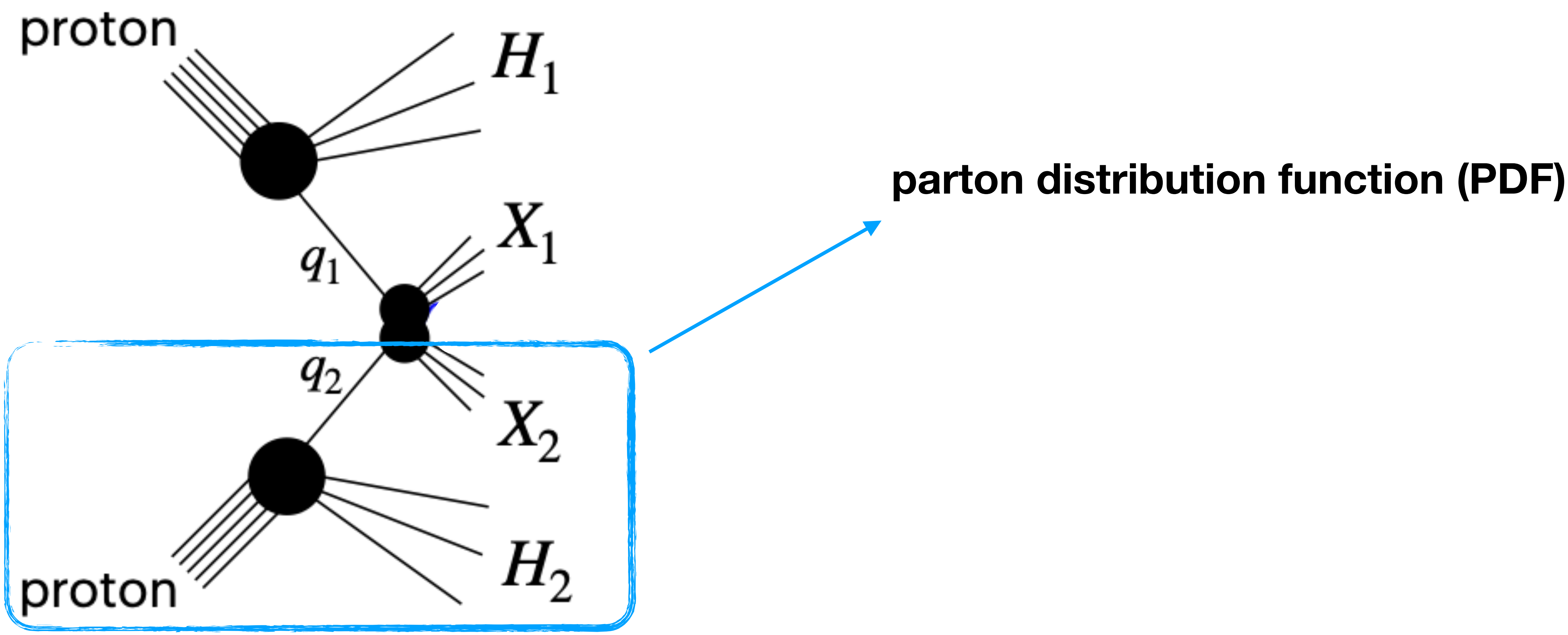

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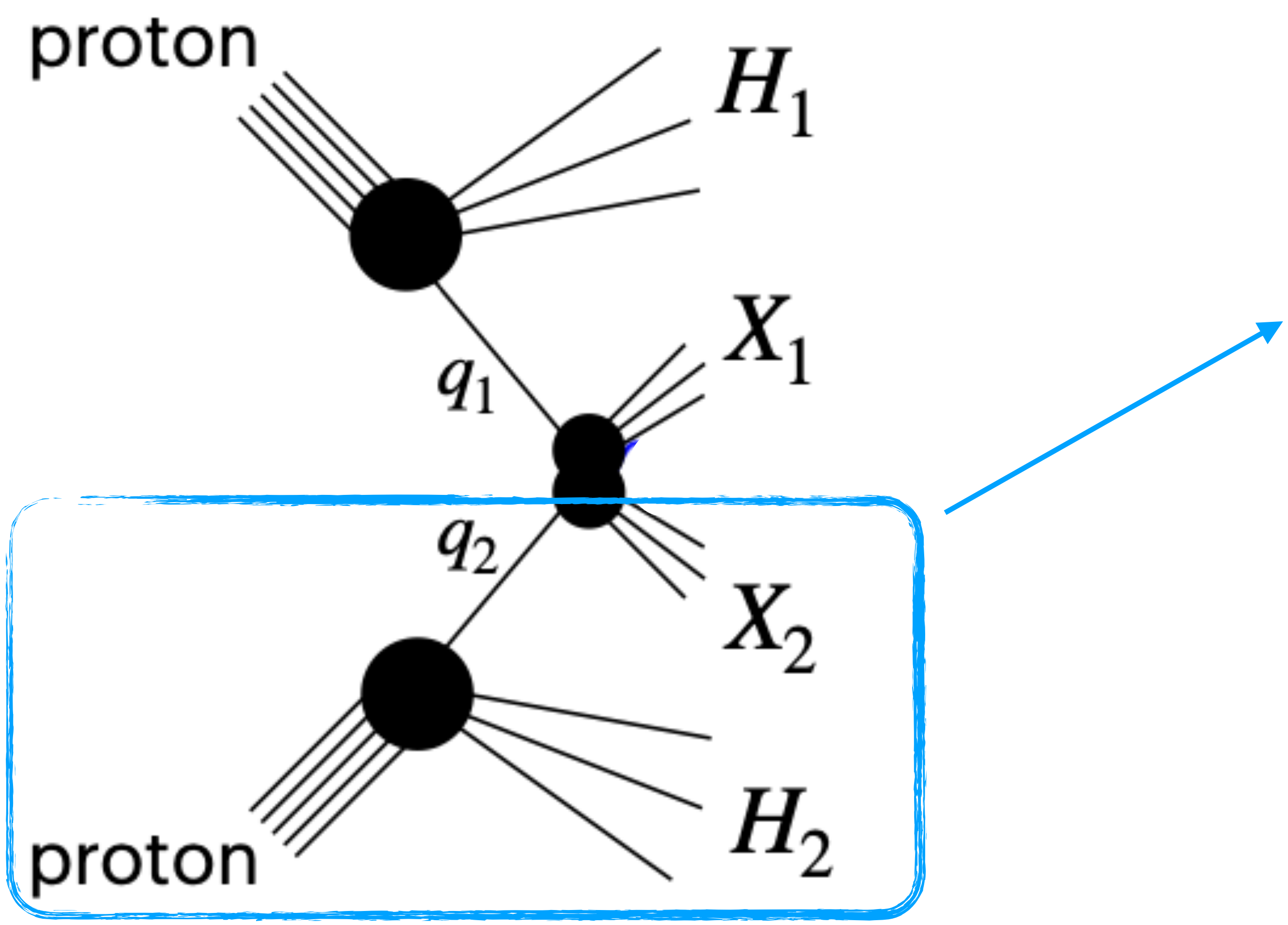

parton distribution function (PDF)

Difficult to determine
on theoretical basis
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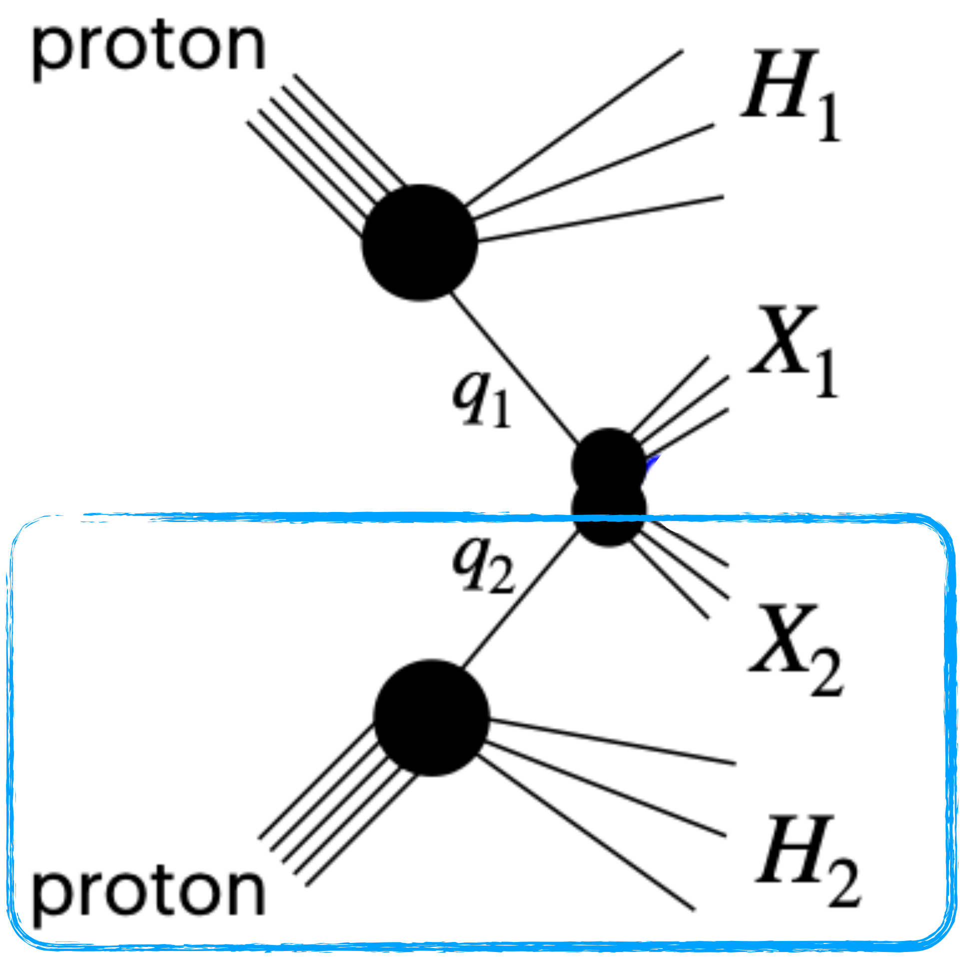

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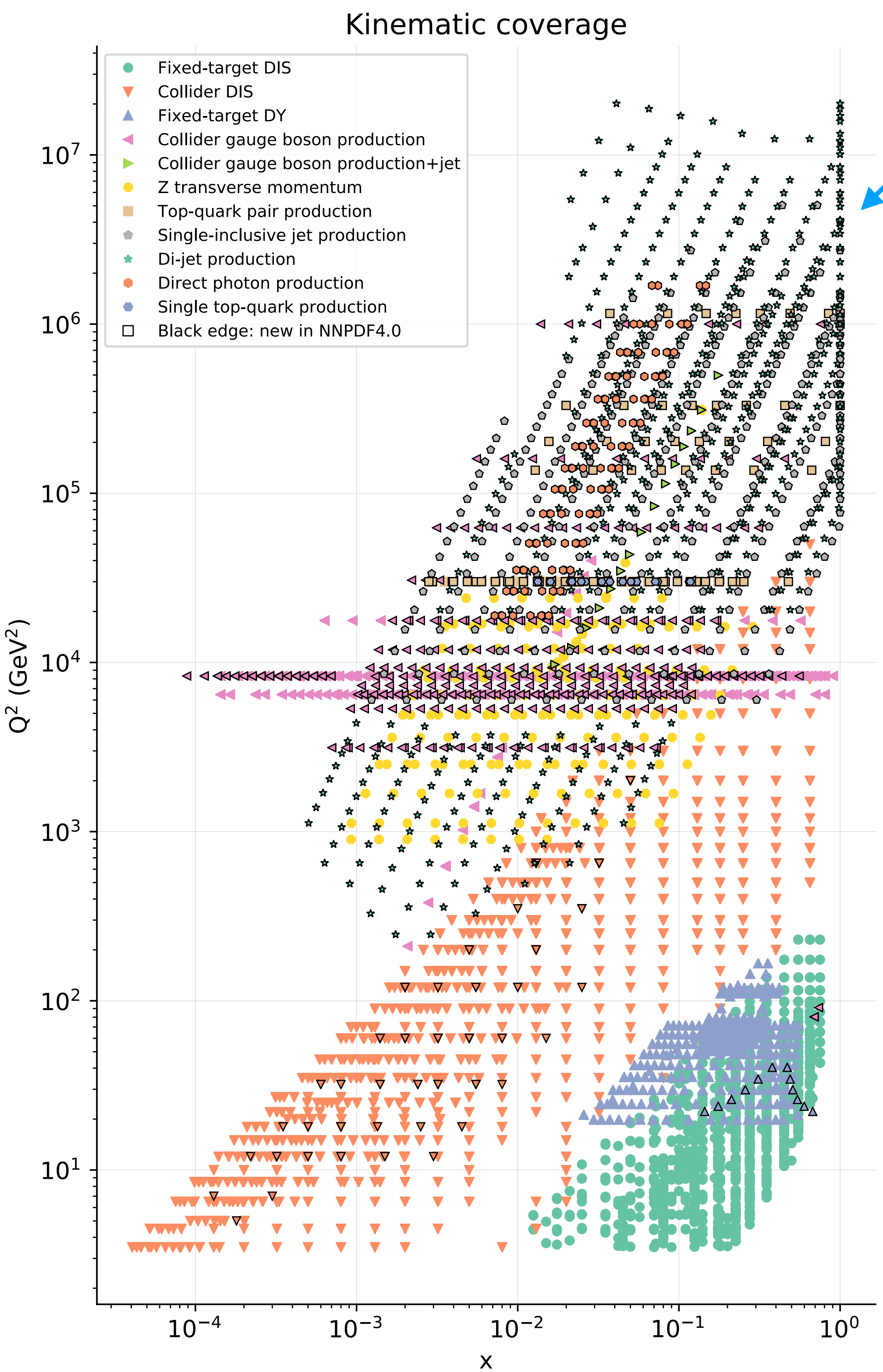

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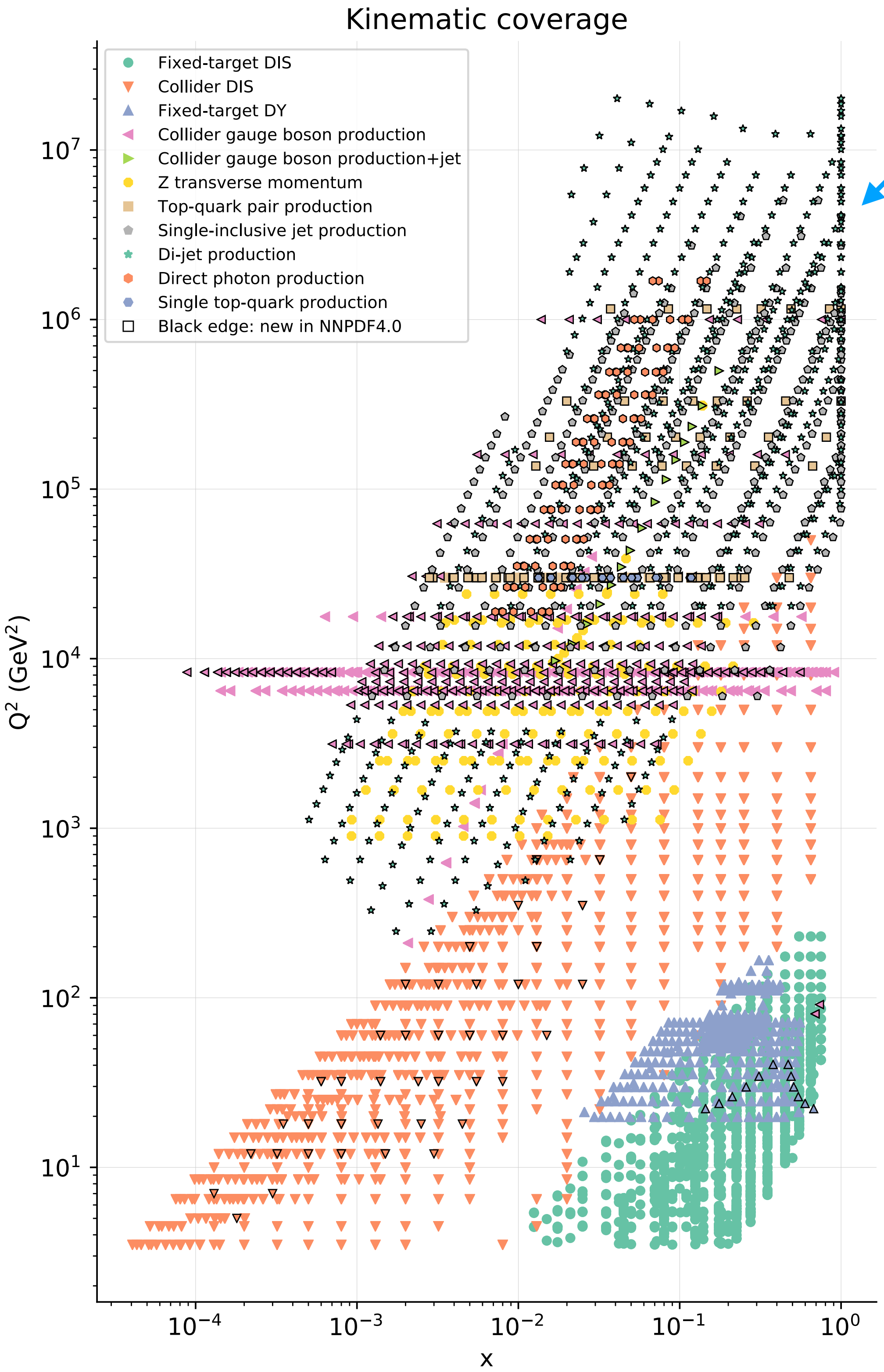

DGLAP equations

$$\frac{\partial}{\partial \log(\mu^2)} \begin{pmatrix} q(x,\mu^2) \\ g(x,\mu^2) \end{pmatrix} = \frac{\alpha_S(\mu^2)}{2\pi} \int_x^1 \frac{dz}{z} \begin{pmatrix} P_{qq}(z) & P_{qg}(z) \\ P_{gq}(z) & P_{gg}(z) \end{pmatrix} \begin{pmatrix} q(x/z,\mu^2) \\ g(x/z,\mu^2) \end{pmatrix}$$

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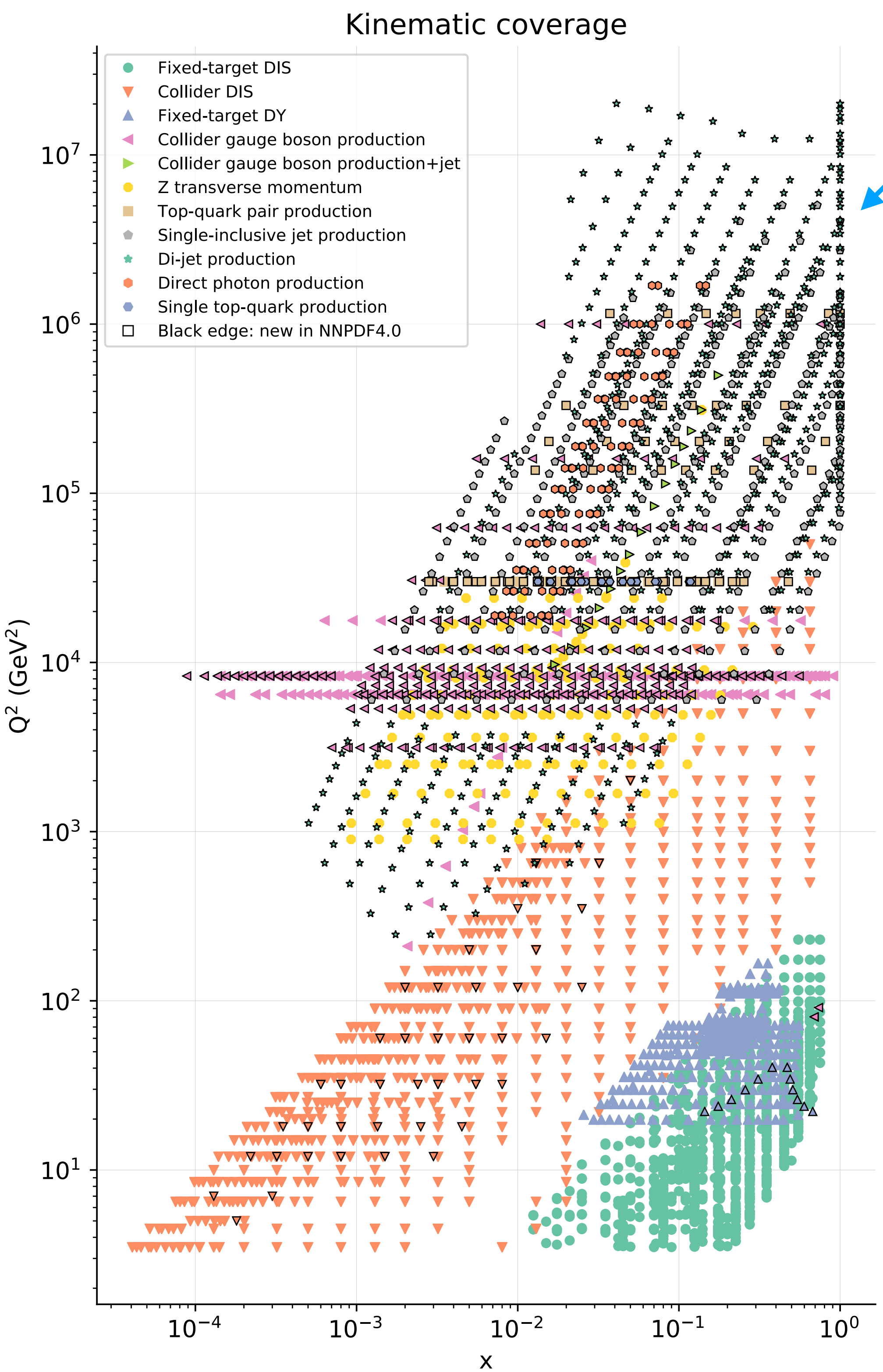

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We just need a functional form for the PDFs

Data driven determination

Theory assumptions

Measurements

Data driven determination

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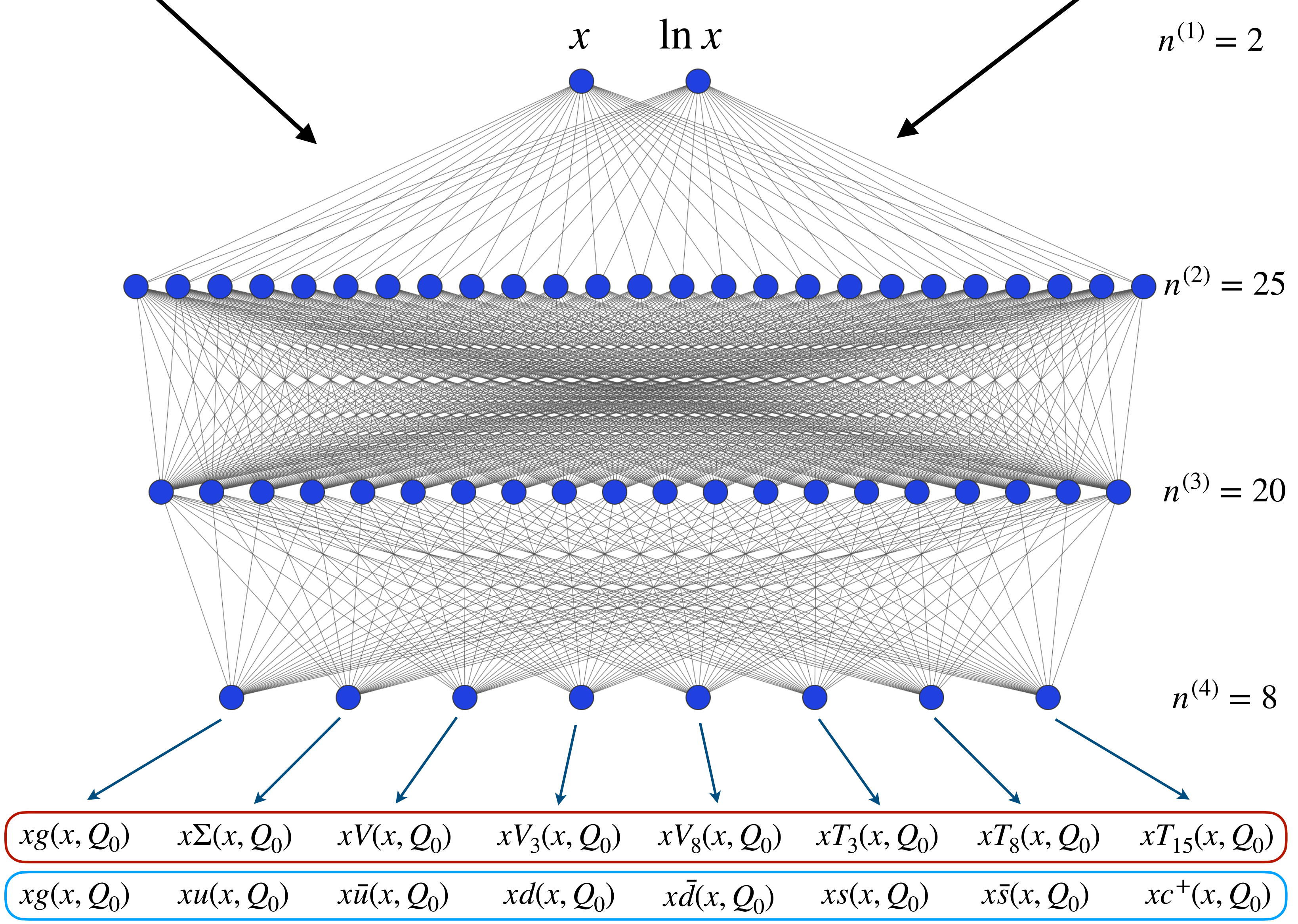
Neural network



Typically fits of physics parameters and PDFs do not talk

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PDFs extraction

- Fix physics parameters $\bar{C}$

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We extract the PDFs from data,
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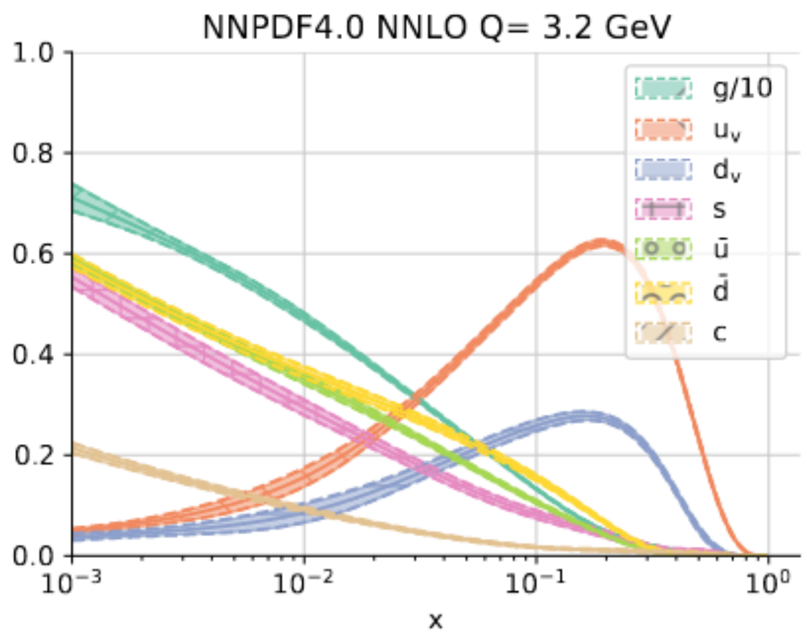

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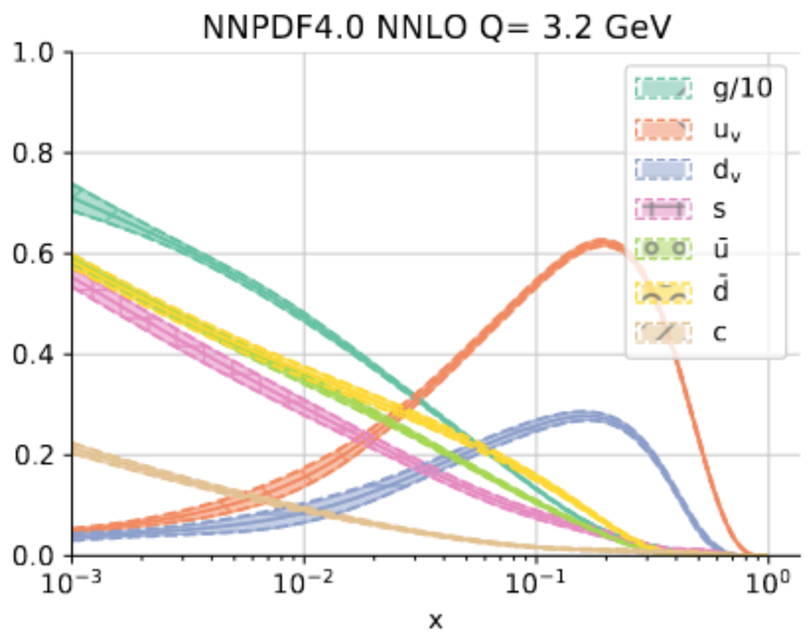

Physics parameters

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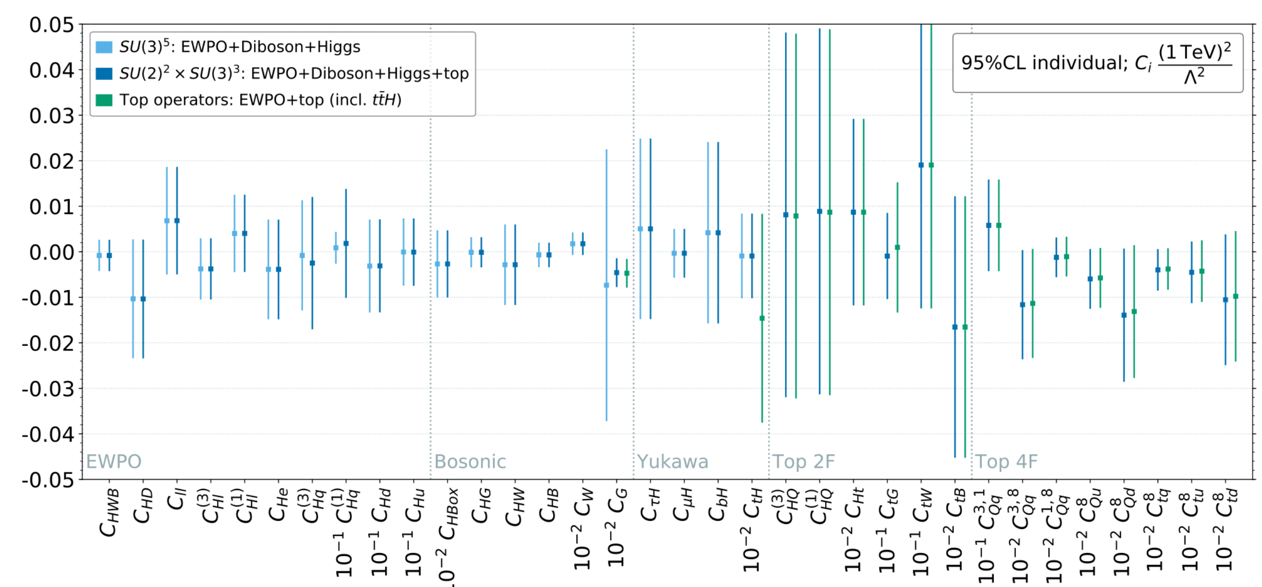
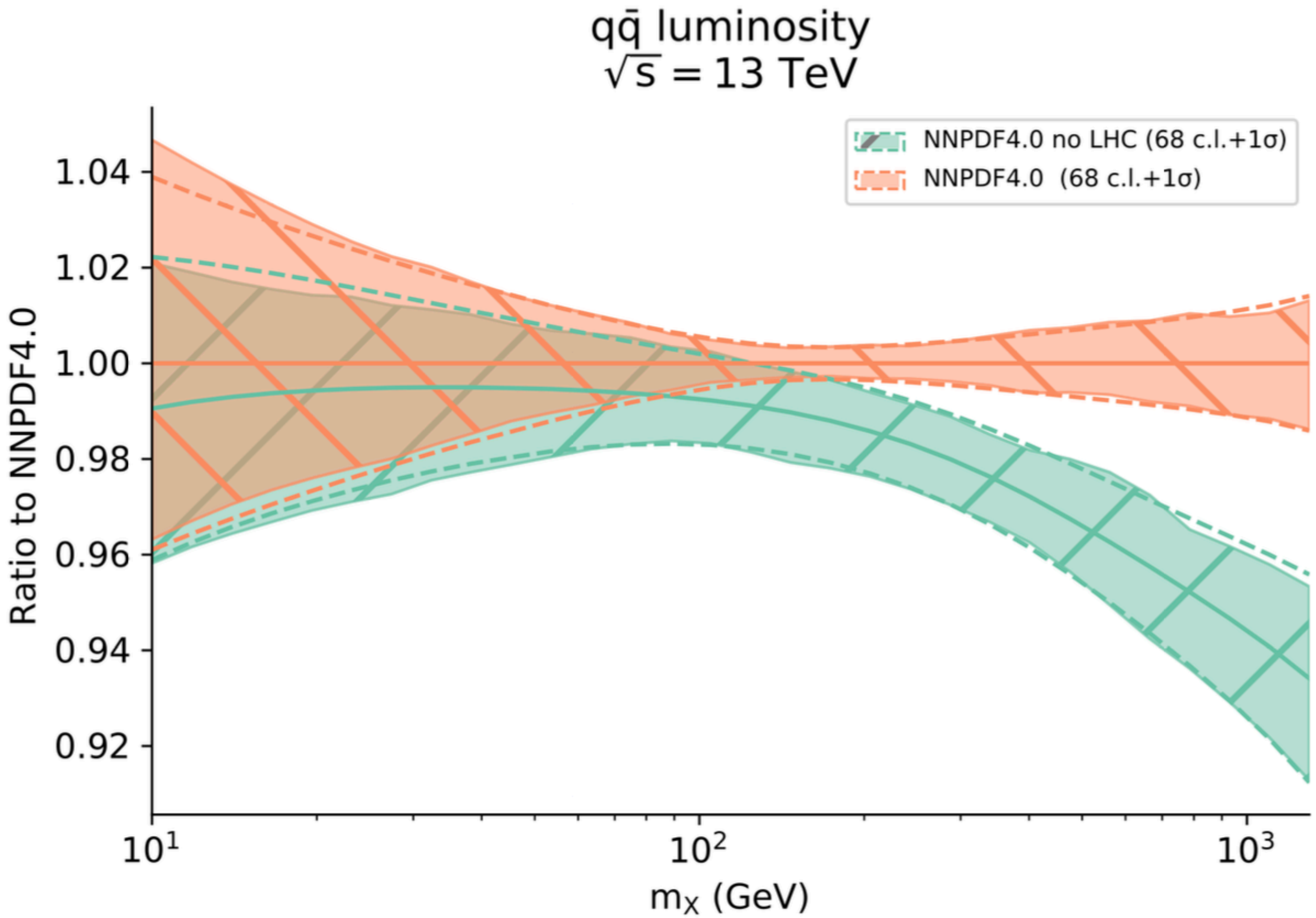


FitMaker [2012:02779]

PDF parametrisation
is flexible… extrapolation is tricky



Central value/uncertainty
pre-LHC badly estimated

Separating datasets
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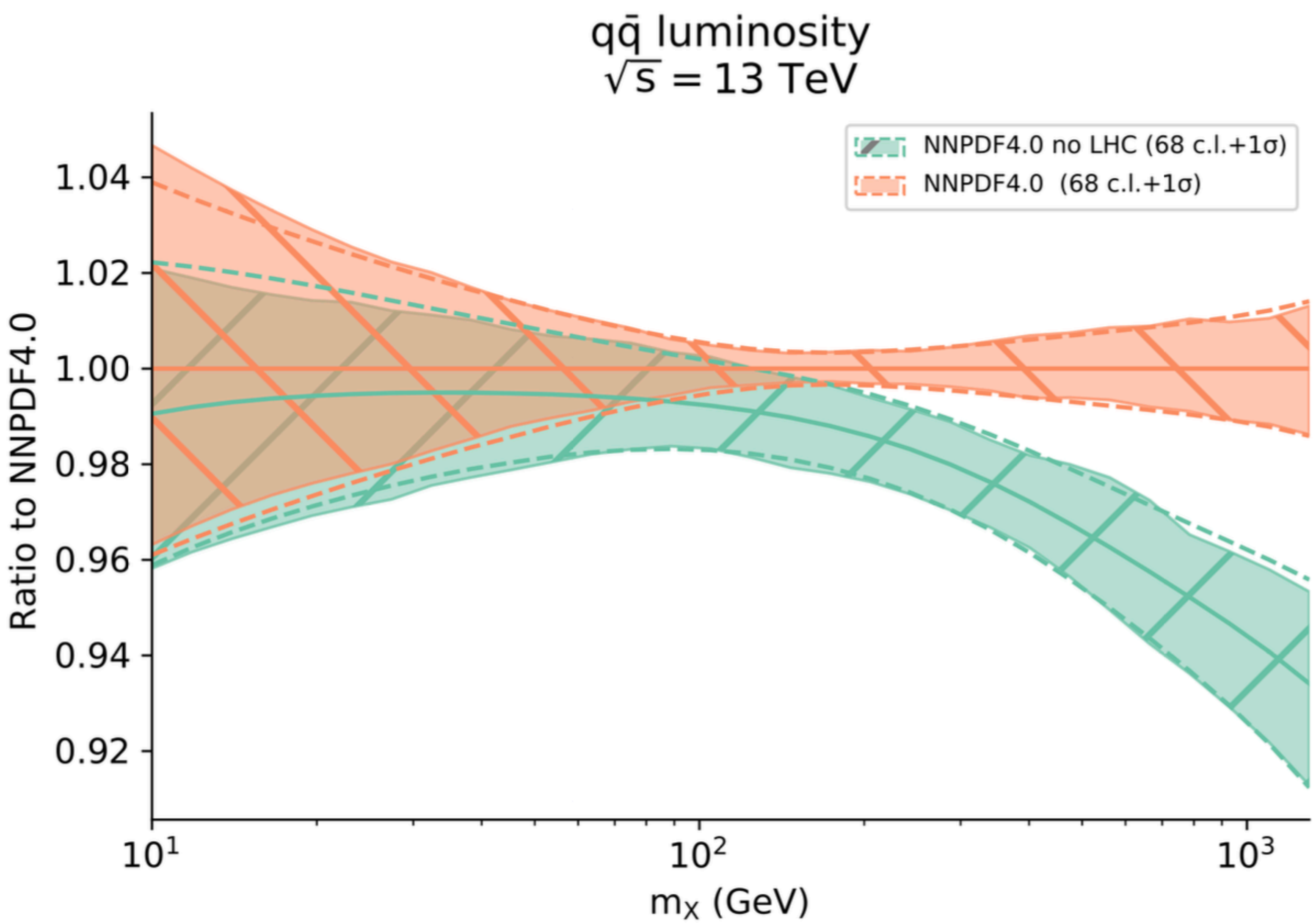

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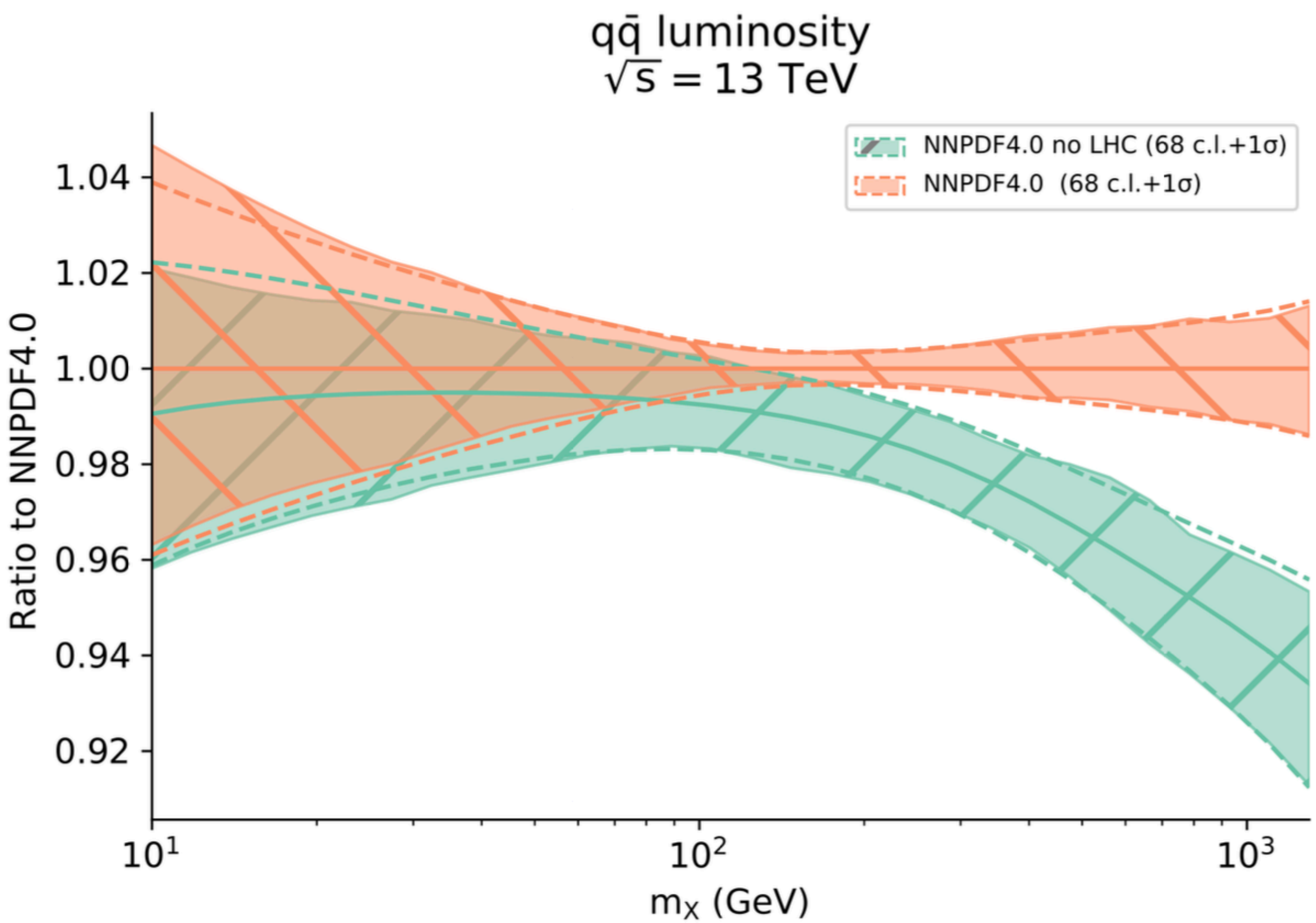

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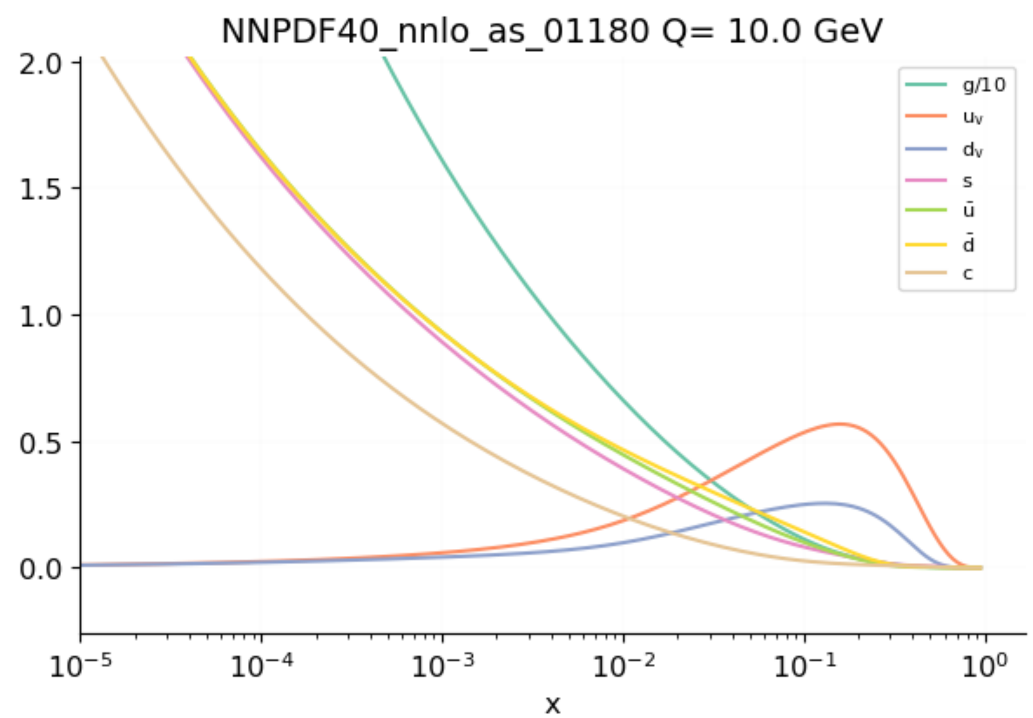
We want to have as much kinematic coverage as possible, but…

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

Suppose the underlying laws of nature are



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

“Real” proton structure

“Real” partonic cross-section

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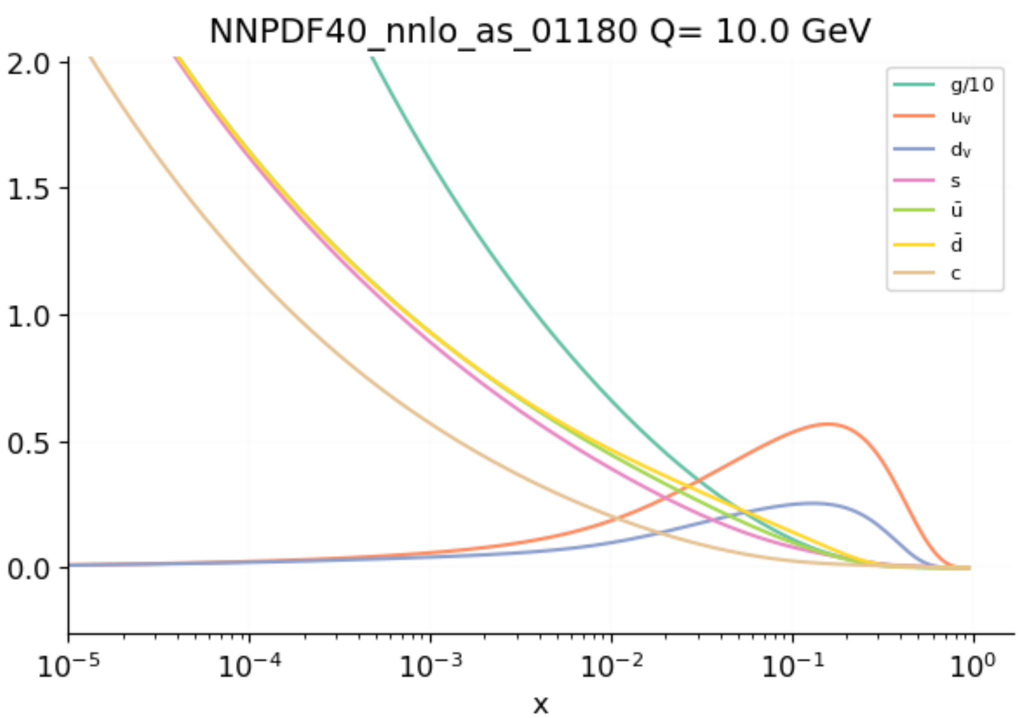

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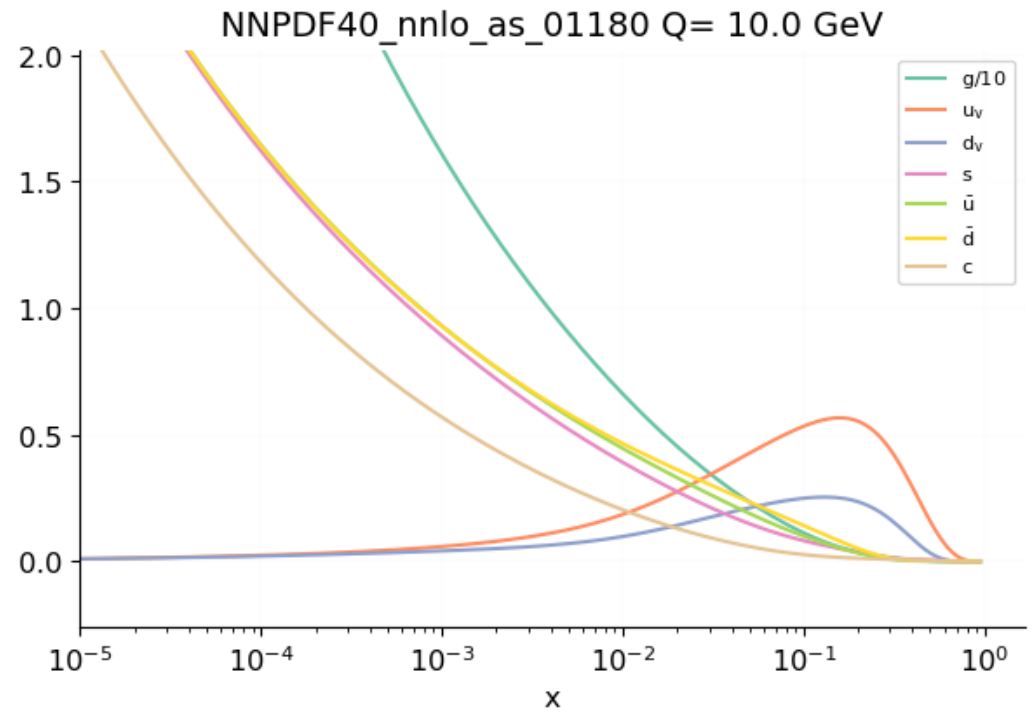

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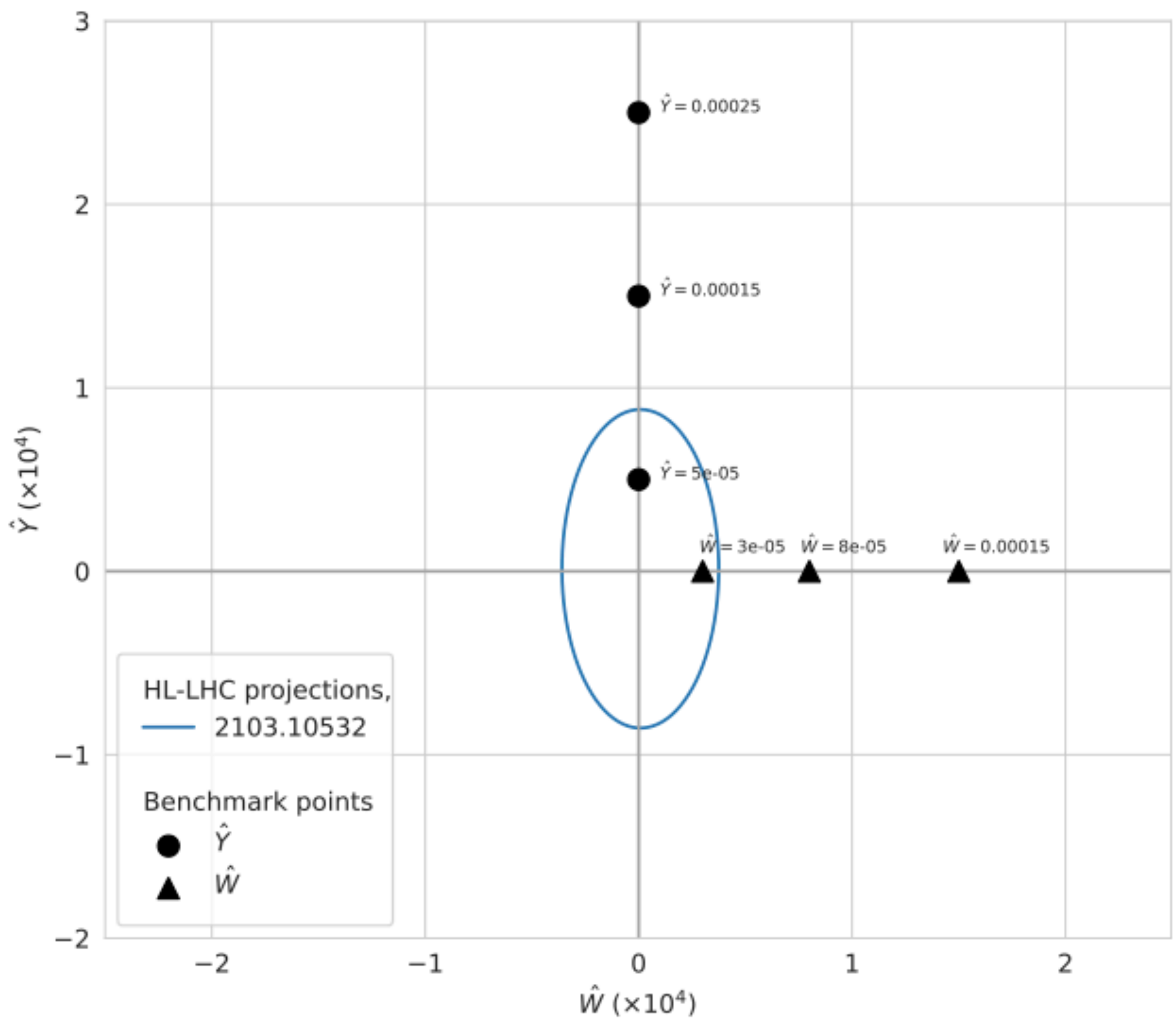
With these assumptions, we produce pseudo-data for benchmark NP scenarios

Benchmark scenarios in terms of flavour universal Y and W parameters



Correspond to Z’ and W’ extensions

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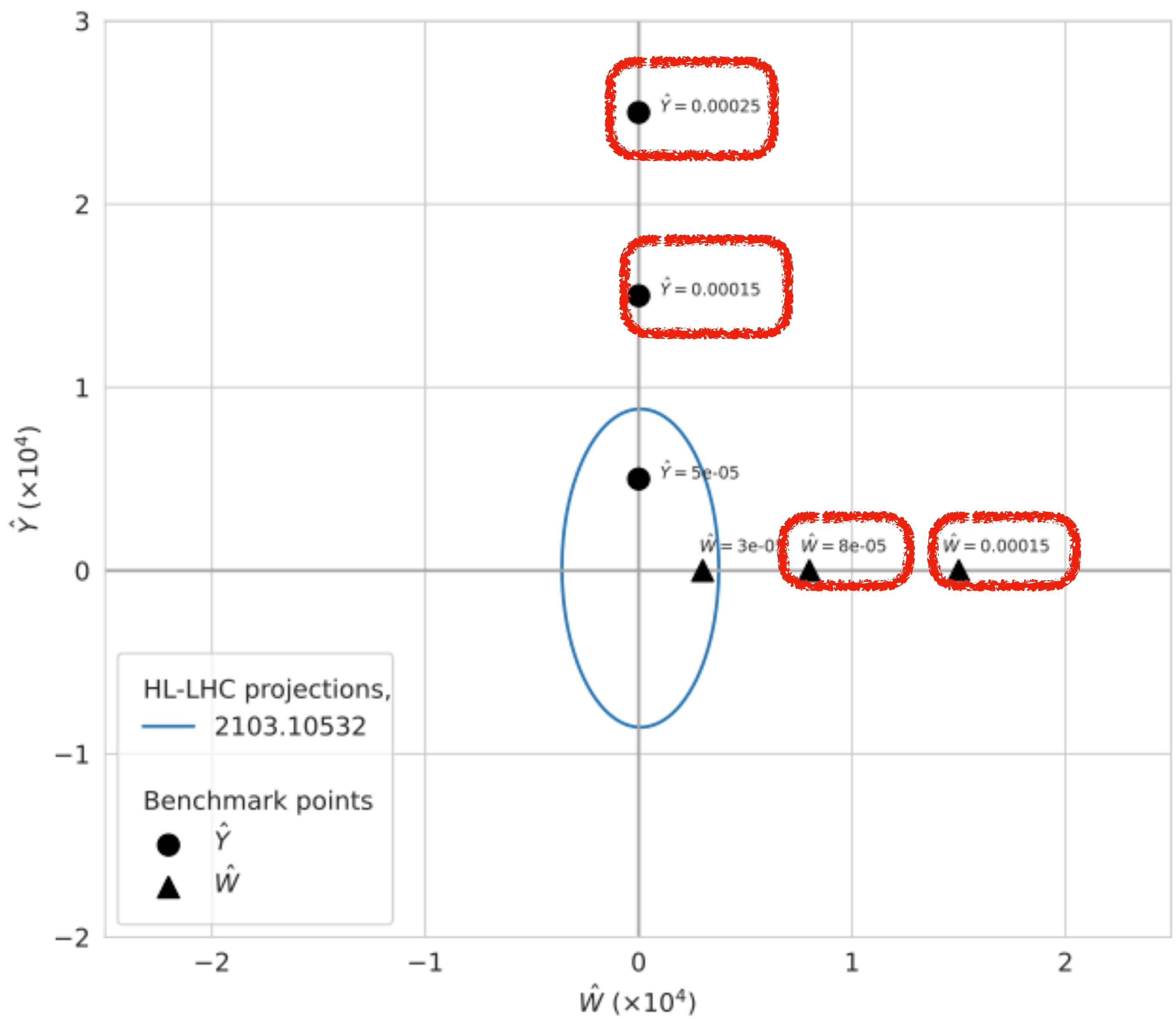

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Discoverable BSM scenarios

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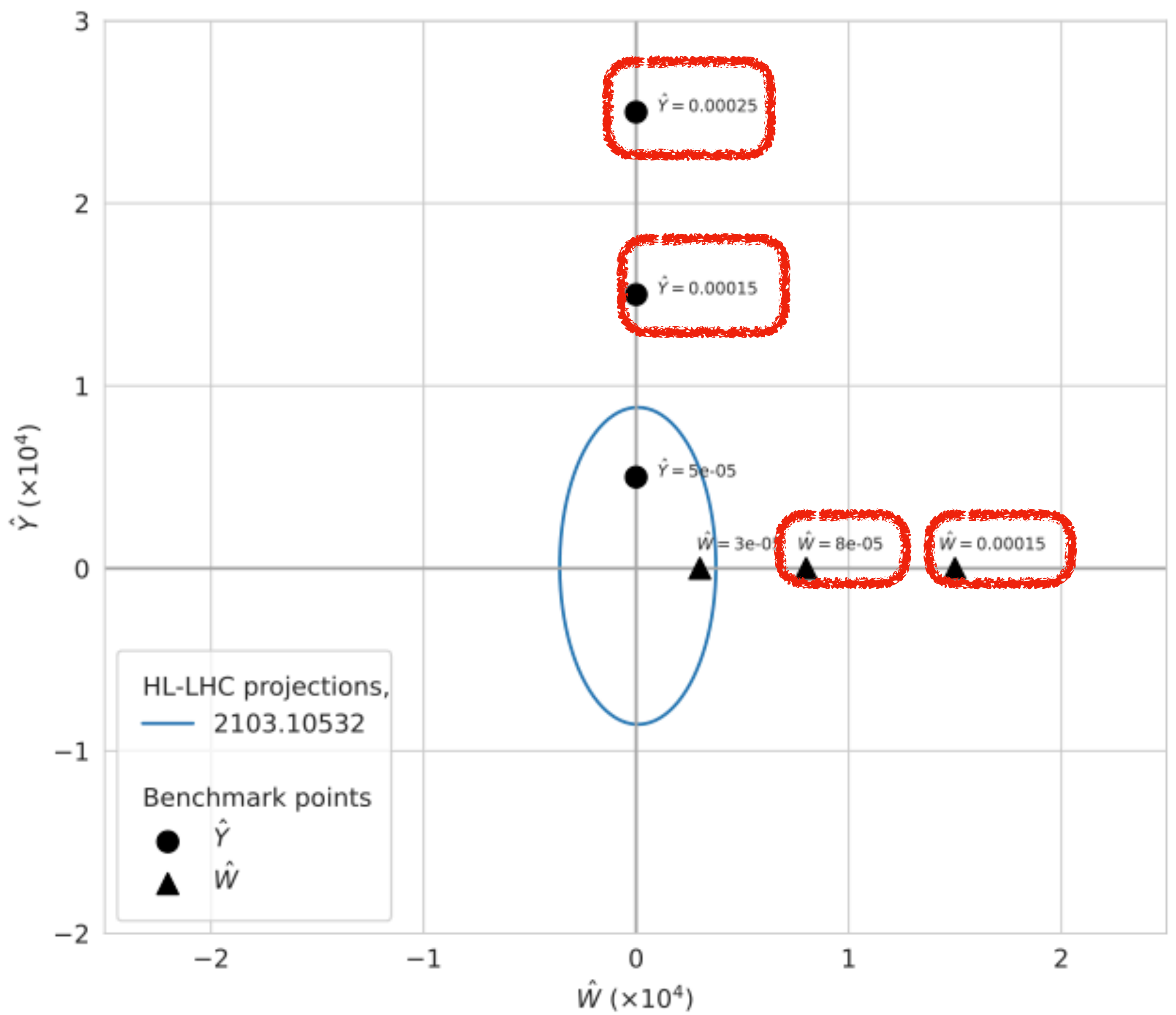
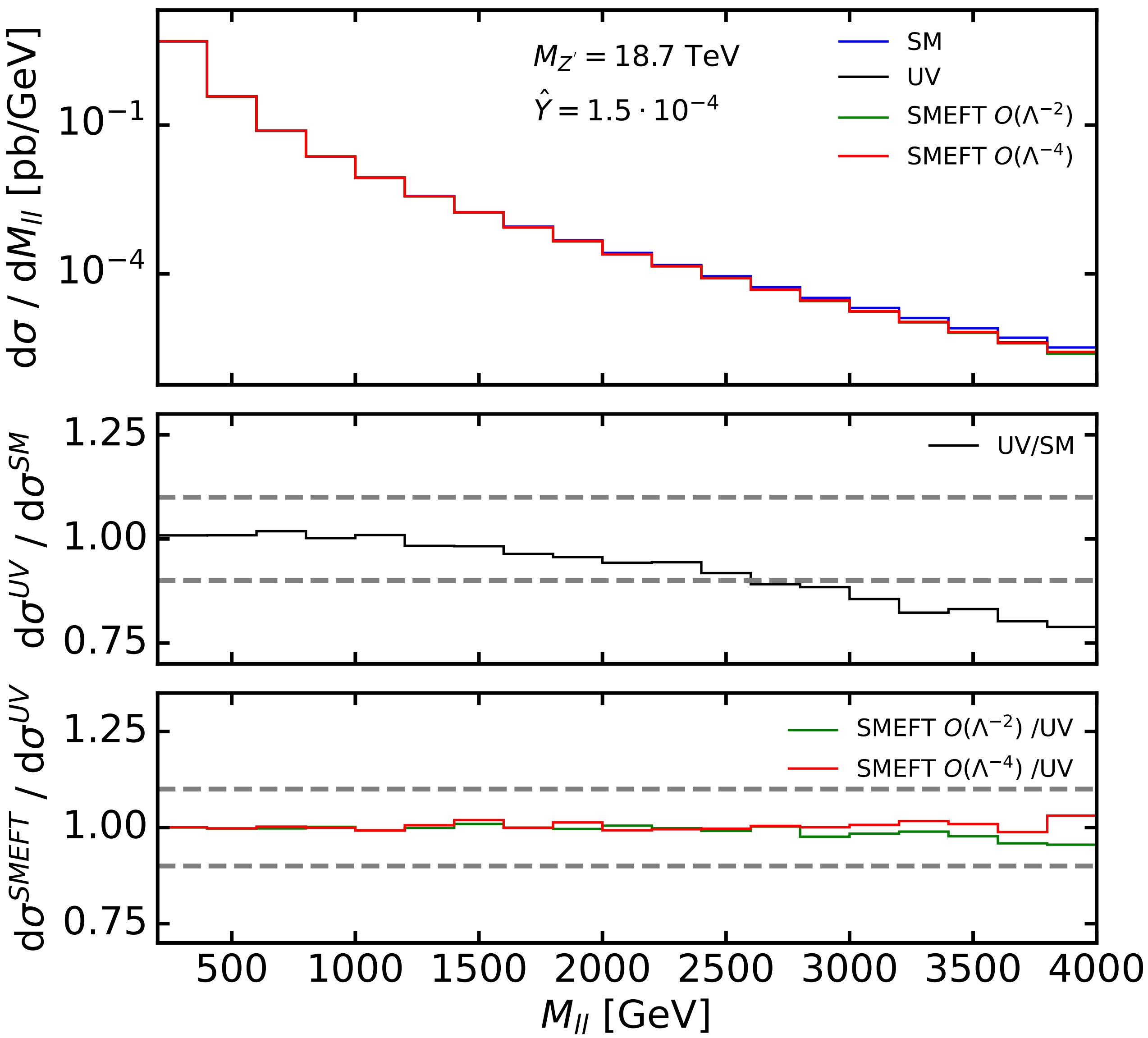


Correspond to Z’ and W’ extensions

Discoverable BSM scenarios → If we have the “correct” PDFs, we would have exp. precision for a discovery

$$\mathcal{L}_{\mathrm{SMEFT}}^{Z'} = \mathcal{L}_{\mathrm{SM}} - \frac{g'^2 \hat{Y}}{2m_W^2} J_Y^\mu J_{Y,\mu}$$



Only NC affected

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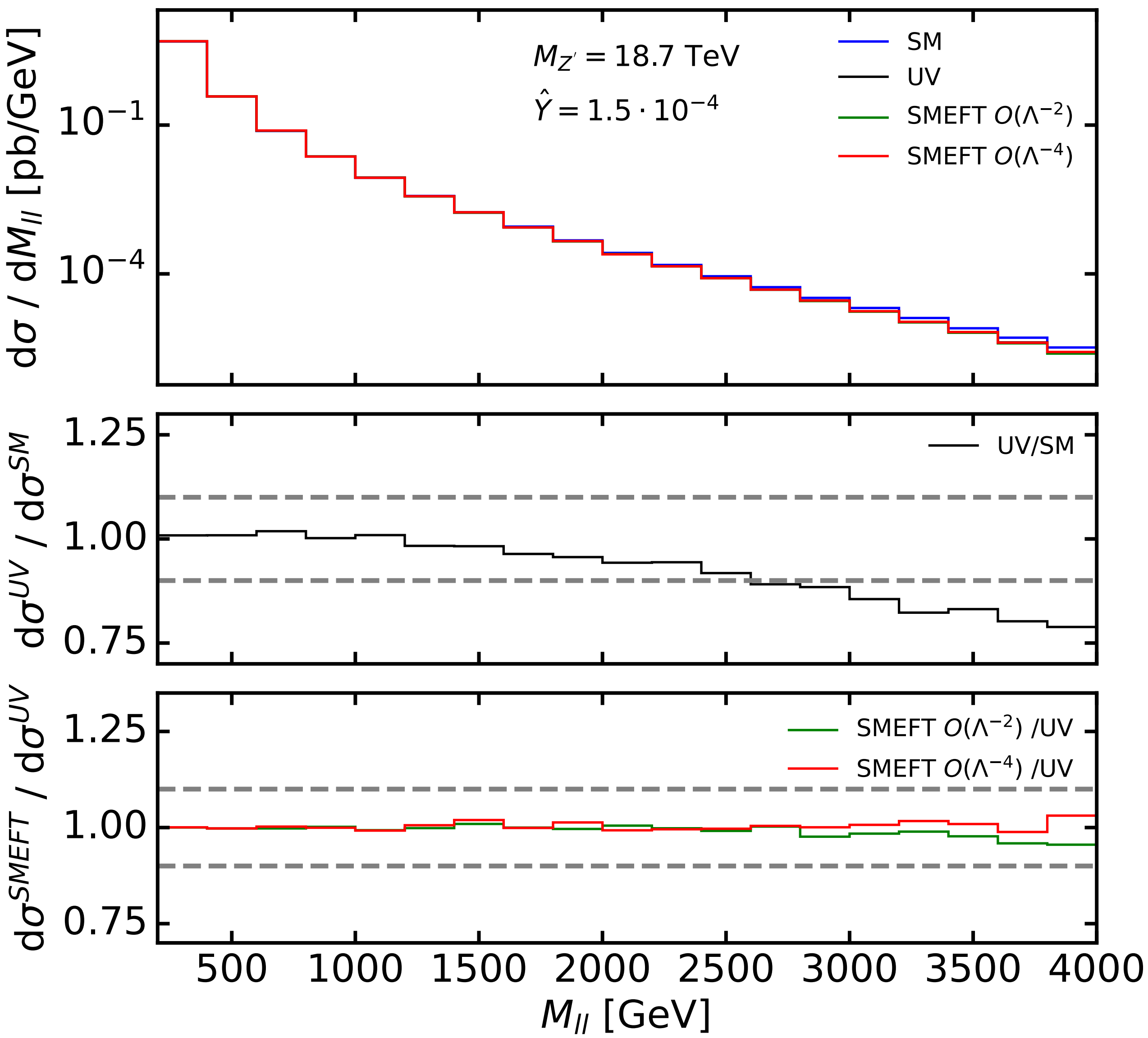

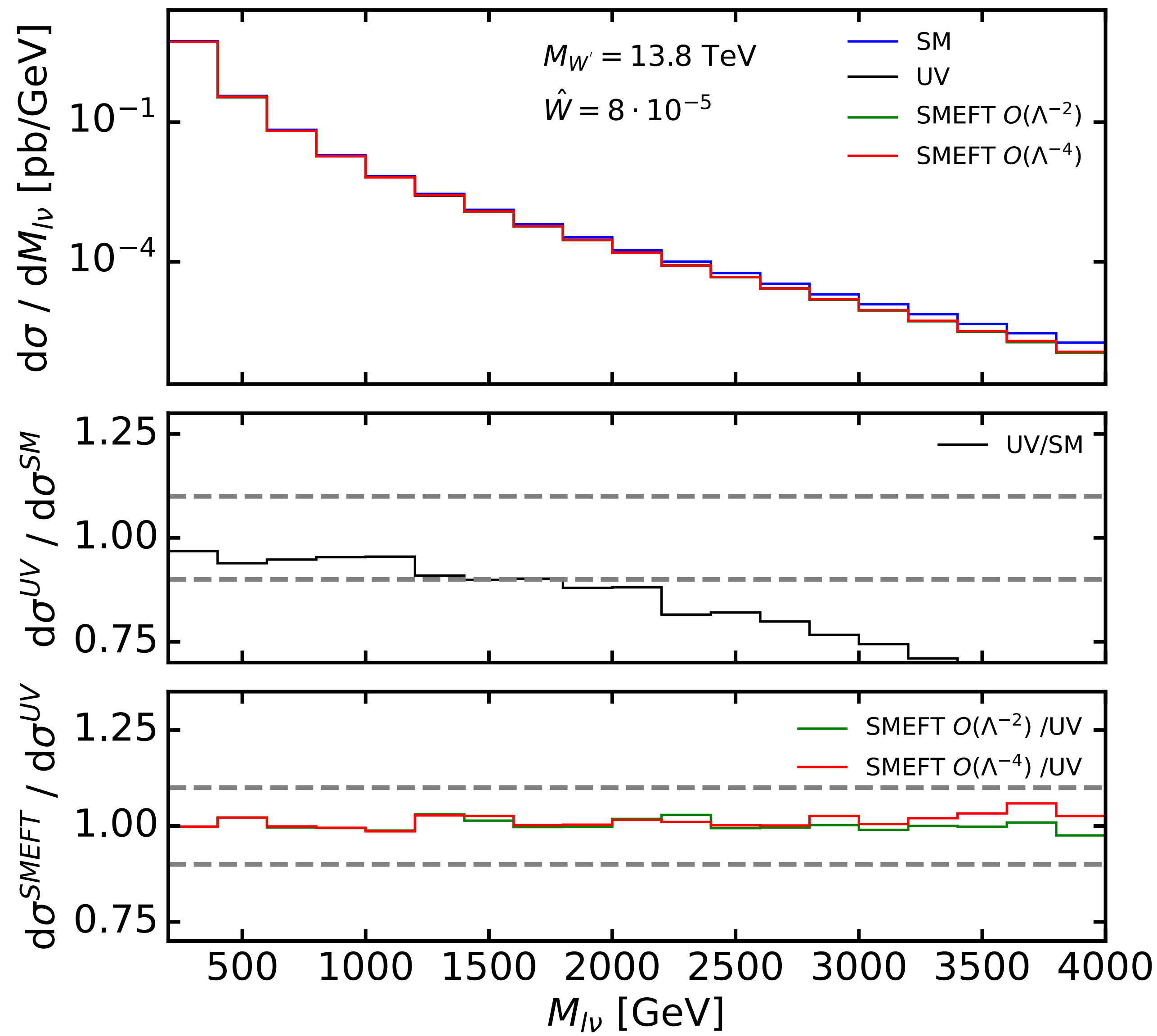

Only NC affected

Both NC and CC affected:
easier for PDFs to accommodate

We now want to perform a "standard" PDF fit:

$$f_1(\theta) \otimes f_2(\theta) \otimes \hat{\sigma}_{SM} \sim f_1^{true} \otimes f_2^{true} \otimes \hat{\sigma}$$

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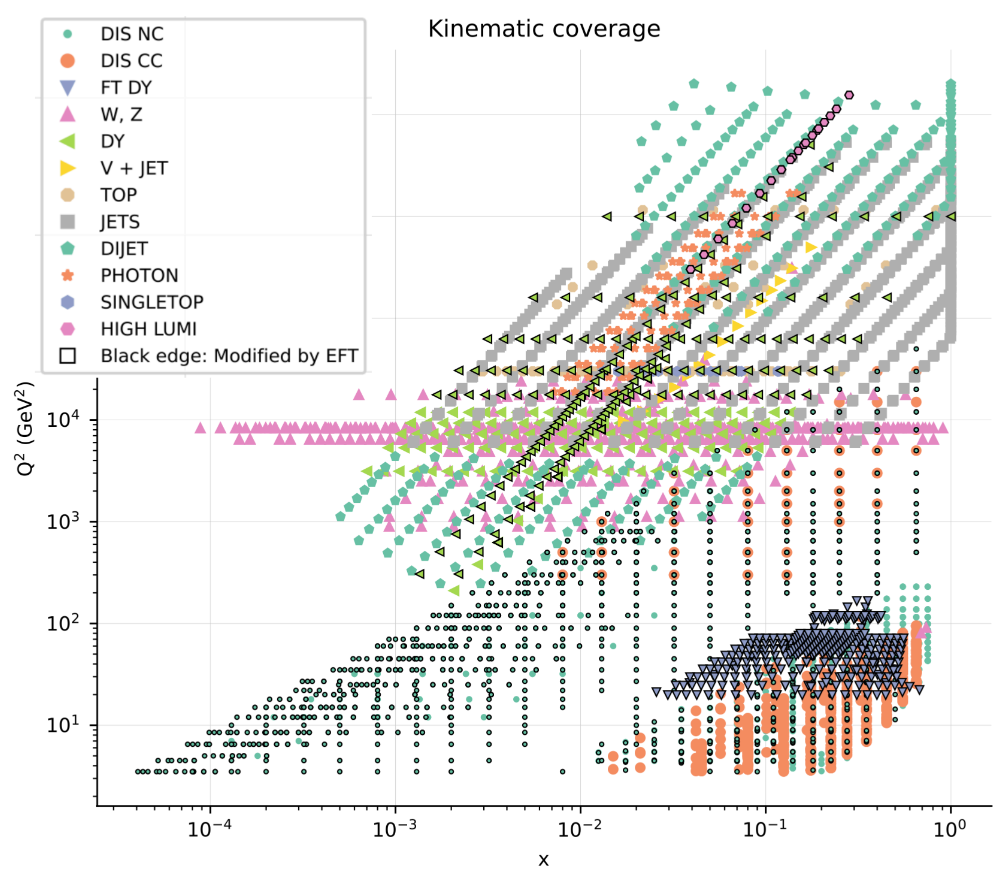
NNPDF4.0 dataset + **HL-LHC** DY projections [arXiv: 2104.02723]



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

arXiv: 2307.10370

We define a true underlying law of nature: PDFs + discoverable BSM scenario

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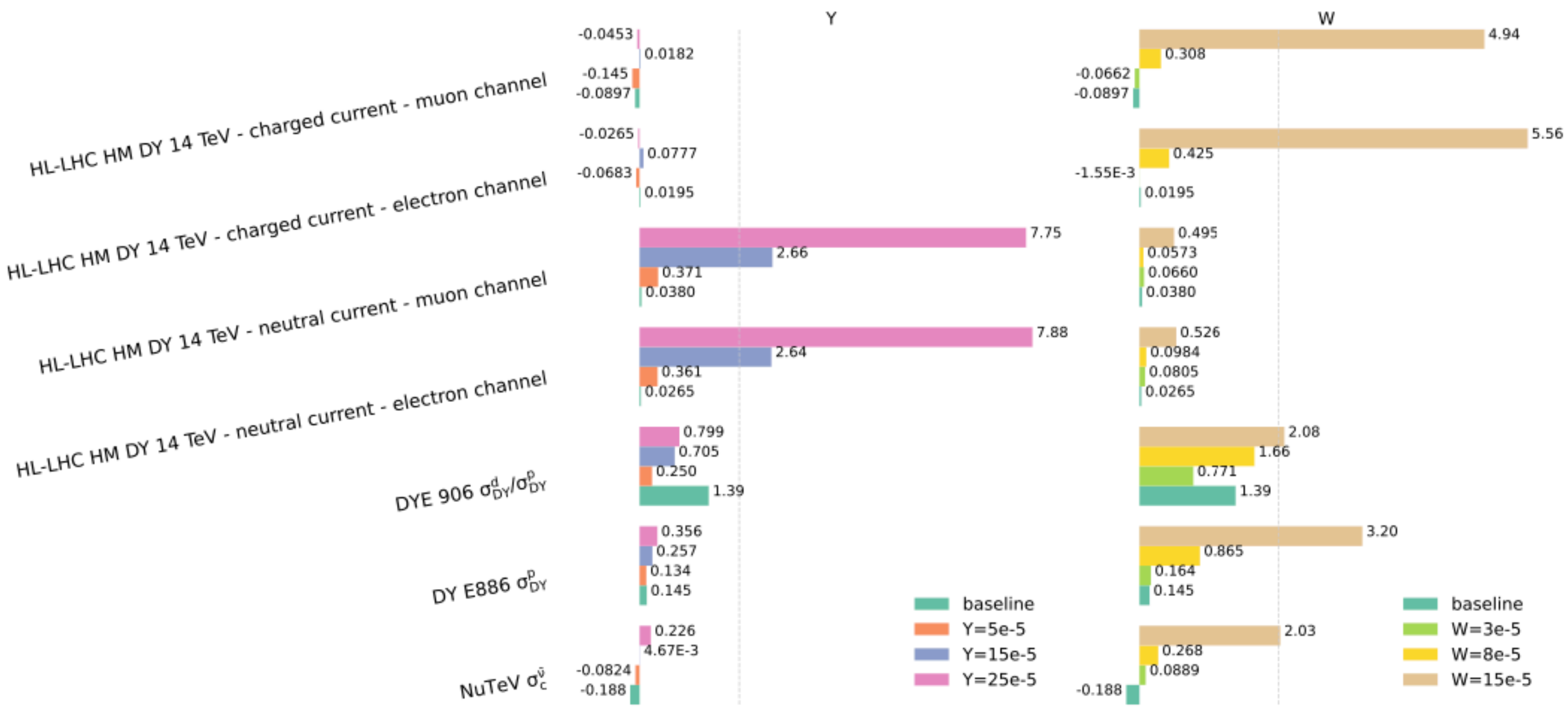
We compare results with a baseline obtained with a consistent fit of SM pseudodata generated with $\theta_{NP} = 0$

$$n_\sigma = \frac{\chi^2 - 1}{\sigma_{\chi^2}}$$

Baseline: SM pseudodata



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Baseline: SM pseudodata

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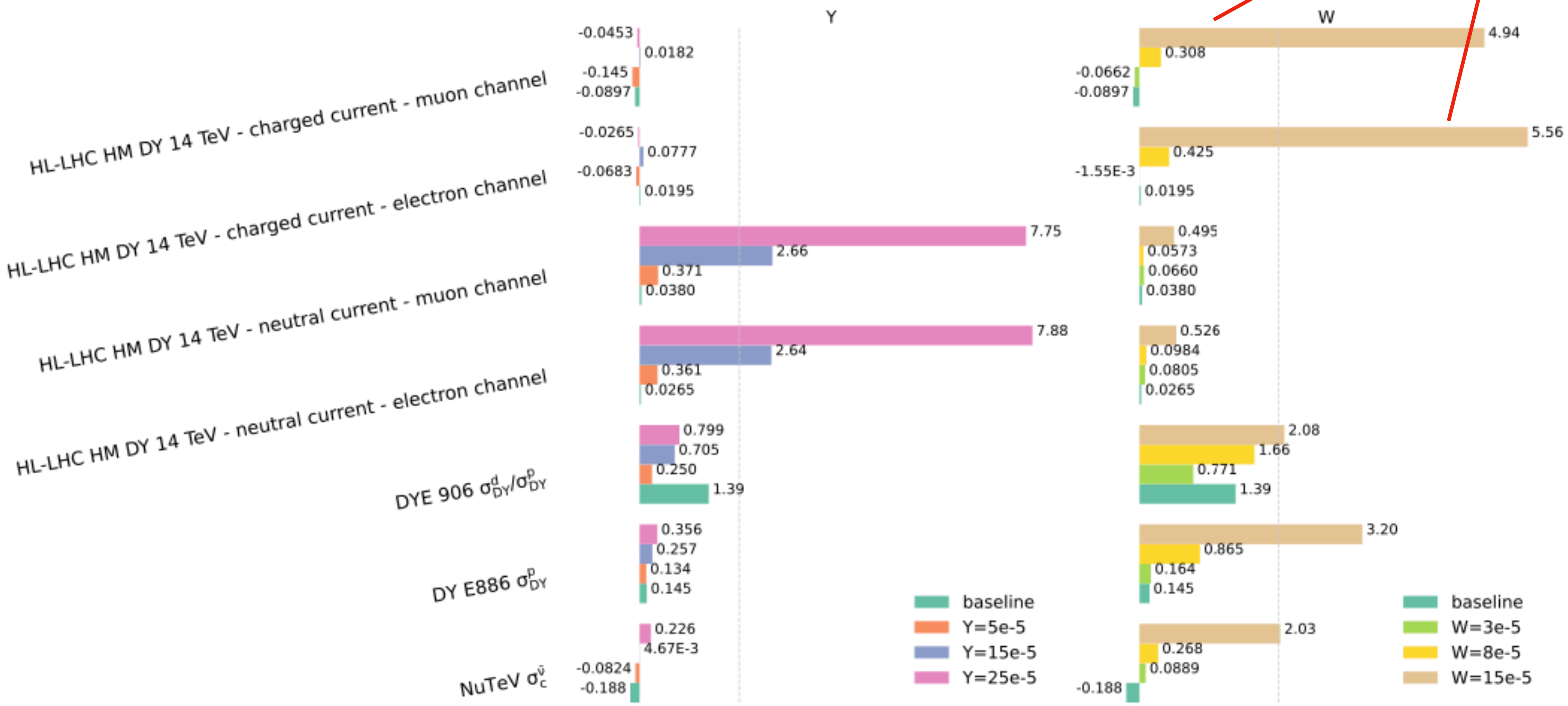

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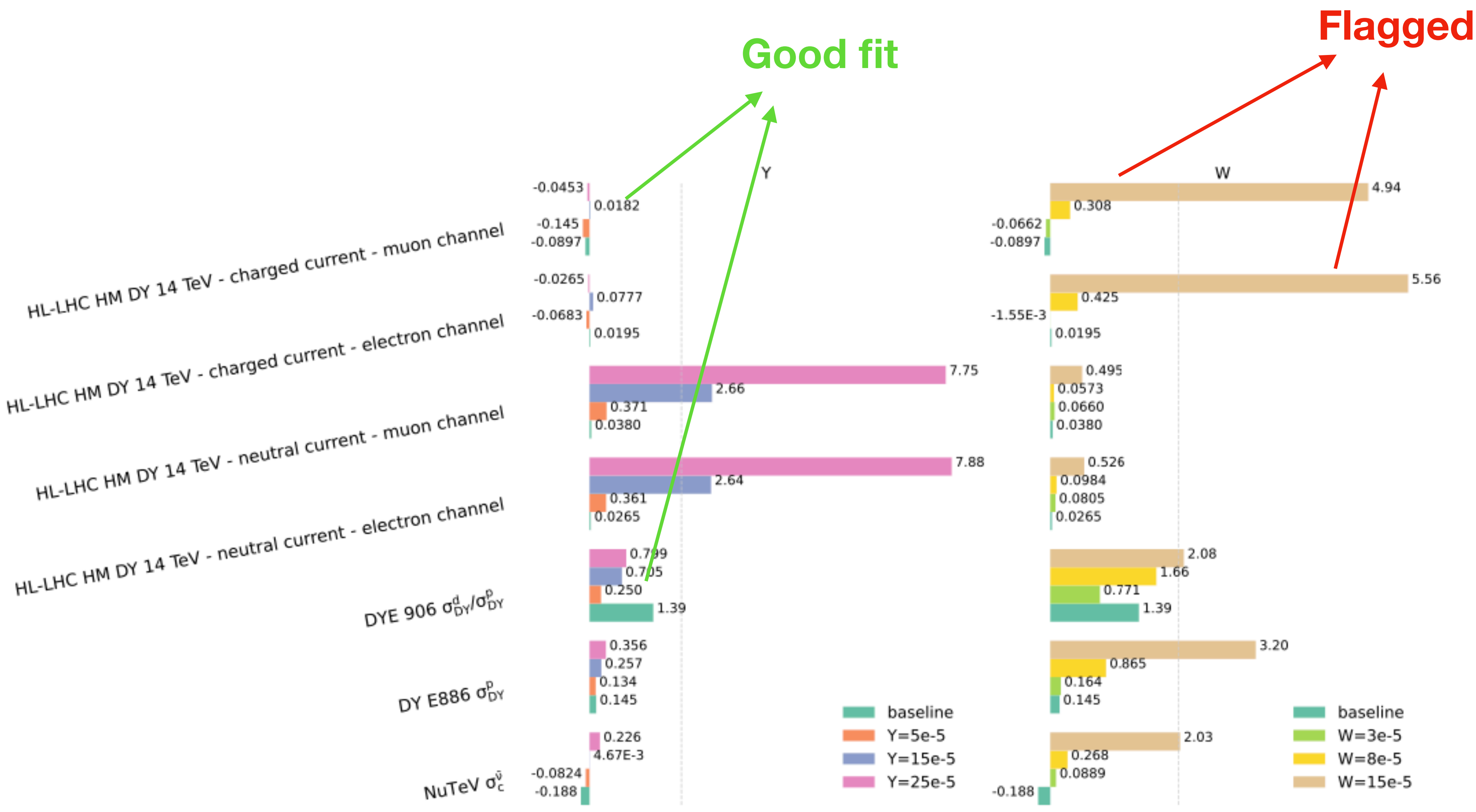

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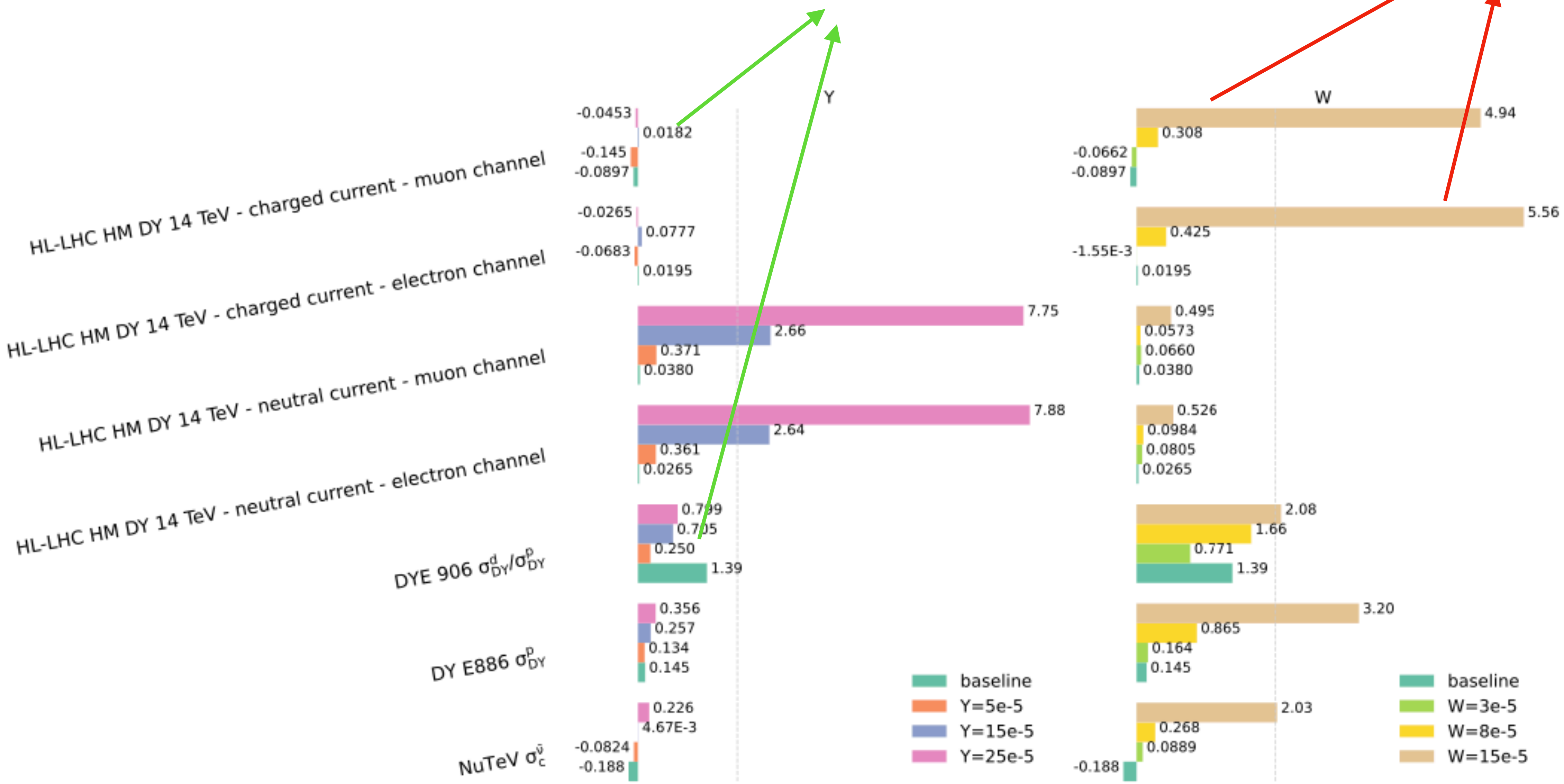
Baseline: SM pseudodata

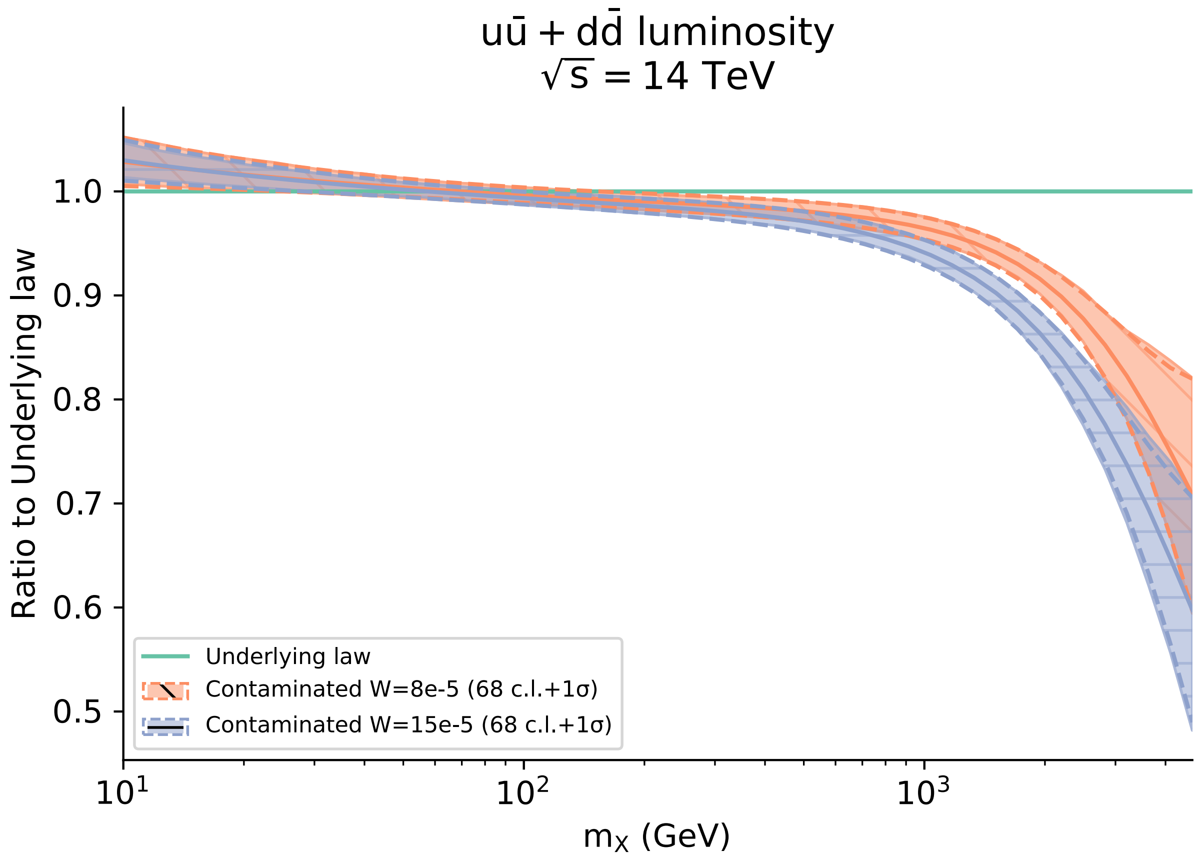
Good fit

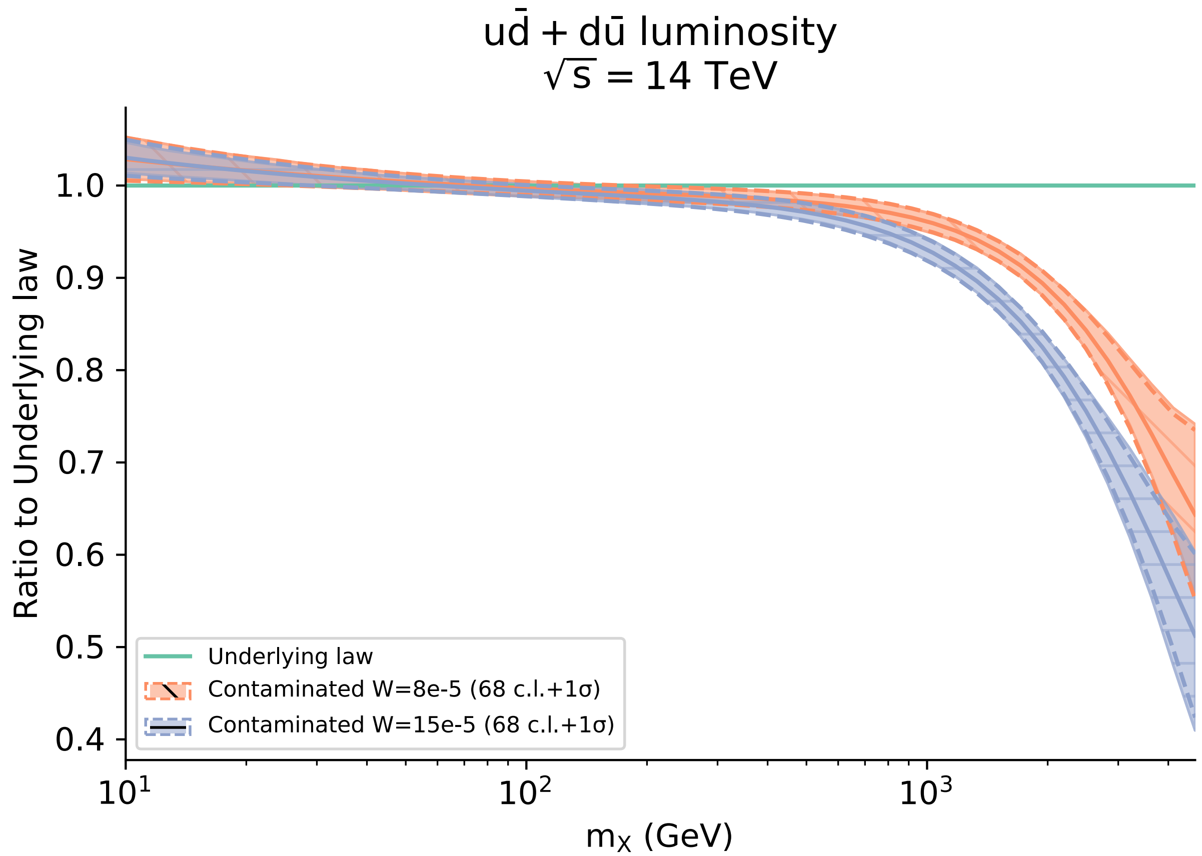
Flagged



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

Absorbed


$u\bar{u} + d\bar{d}$ luminosity
$\sqrt{s} = 14$ TeV
Ratio to Underlying law
m_X (GeV)
Underlying law
Contaminated W=8e-5 (68 c.l.+1σ)
Contaminated W=15e-5 (68 c.l.+1σ)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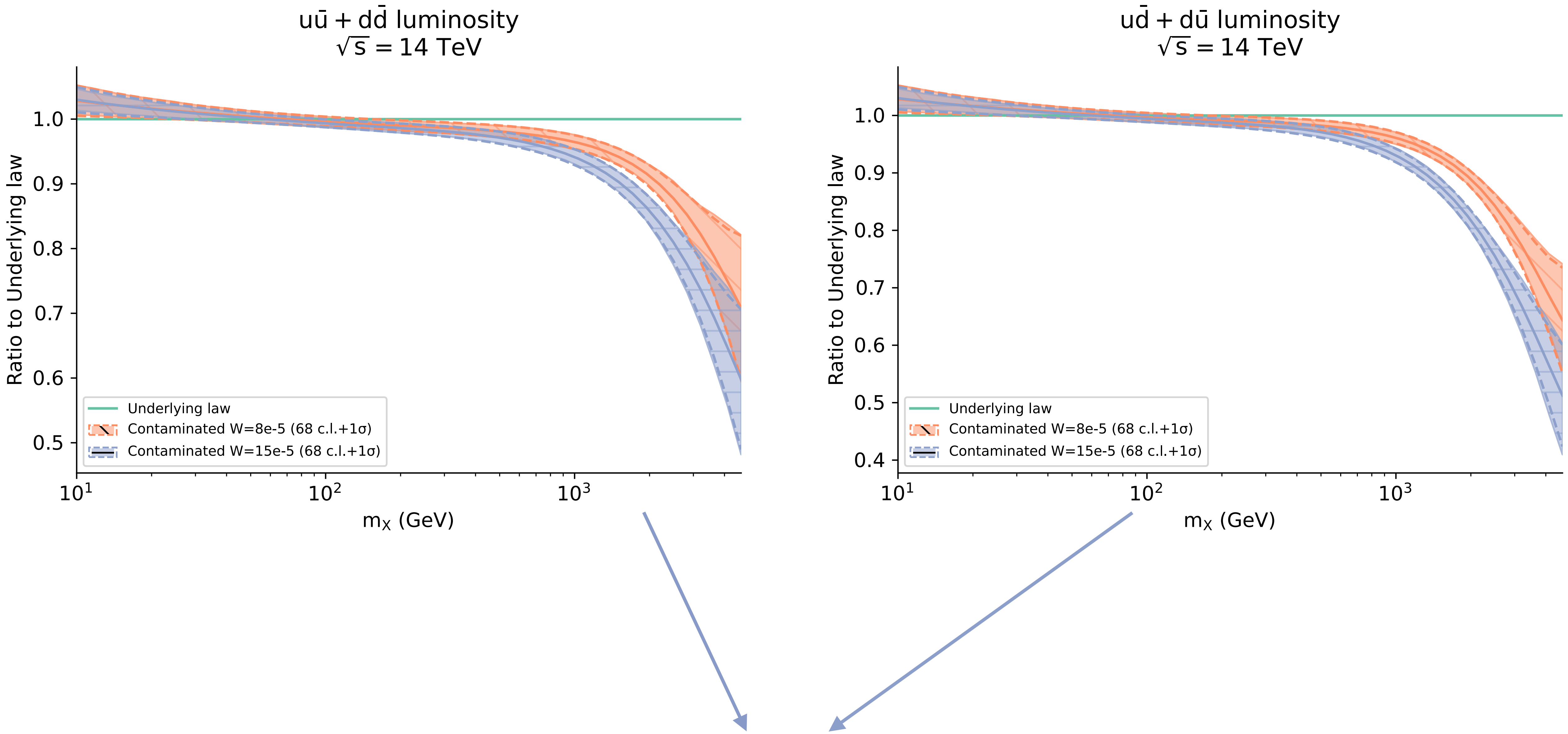
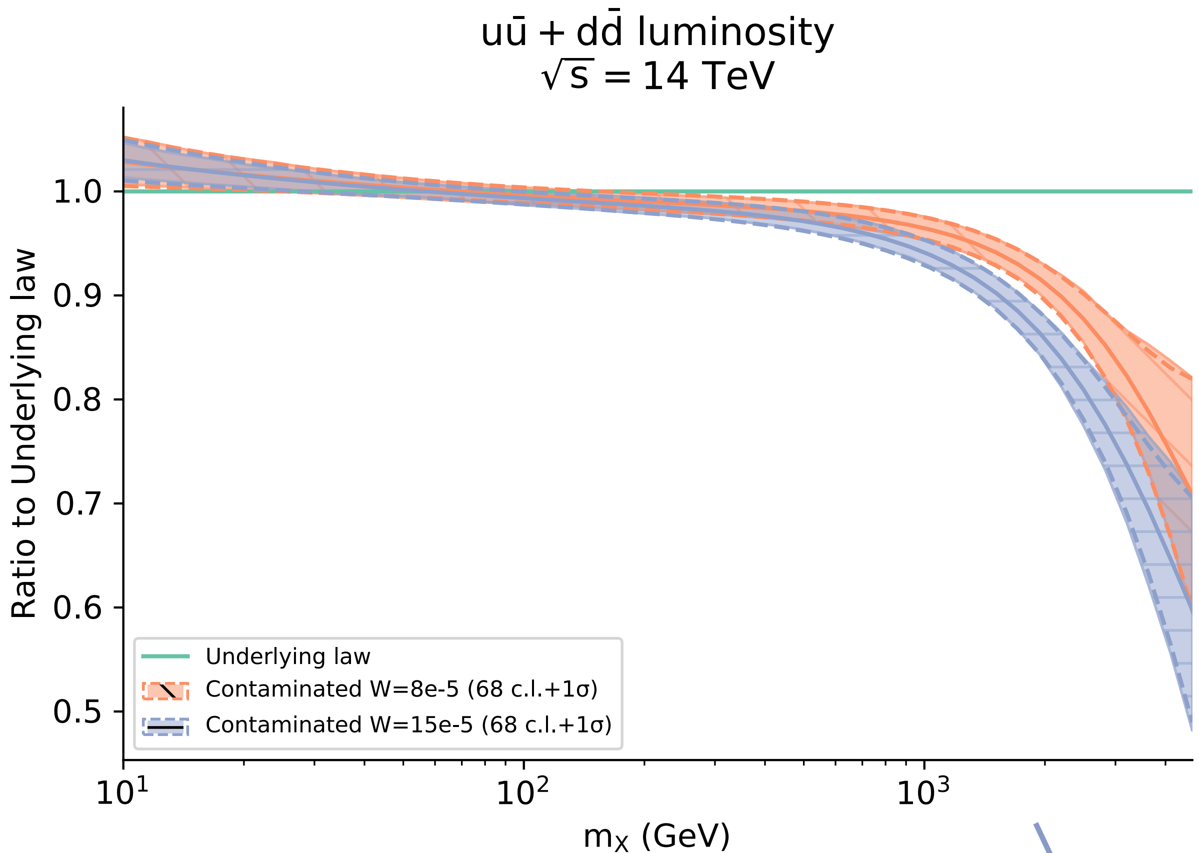
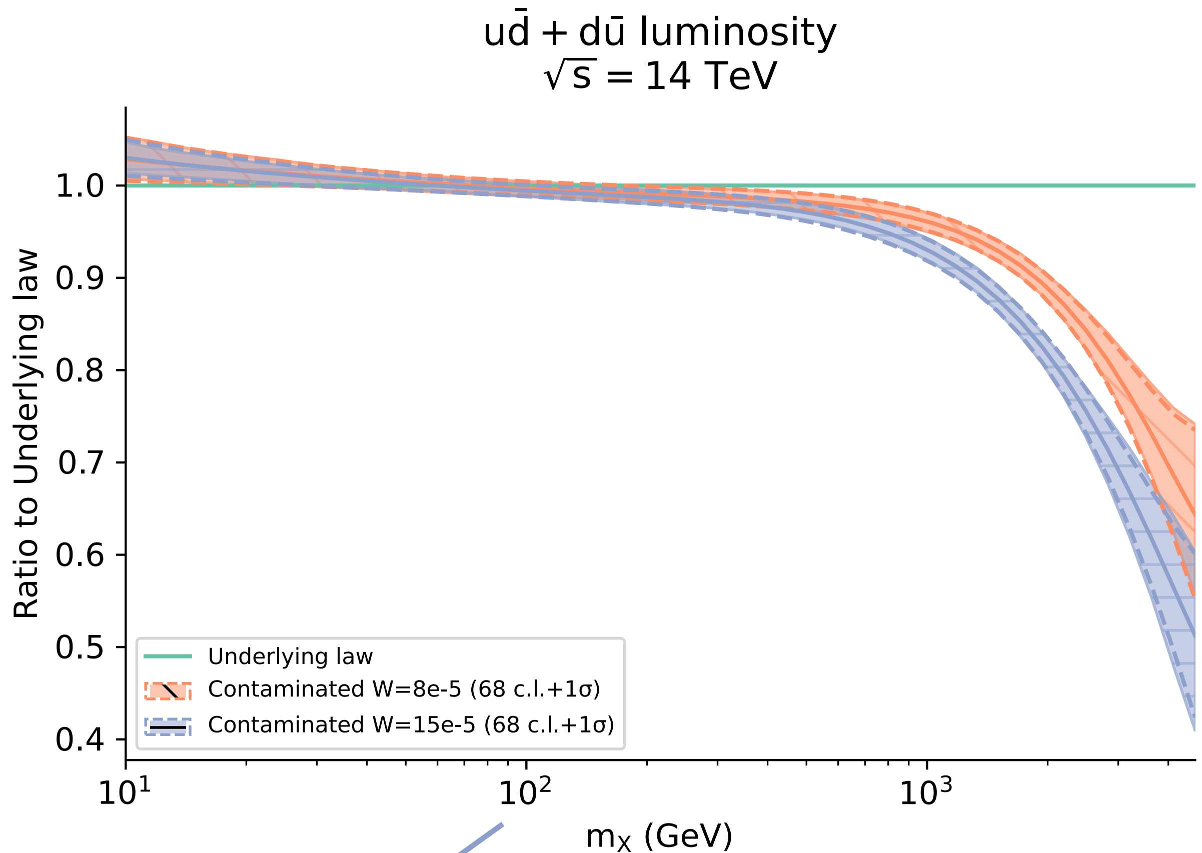


Huge shift, yet good fit for W=8e-5





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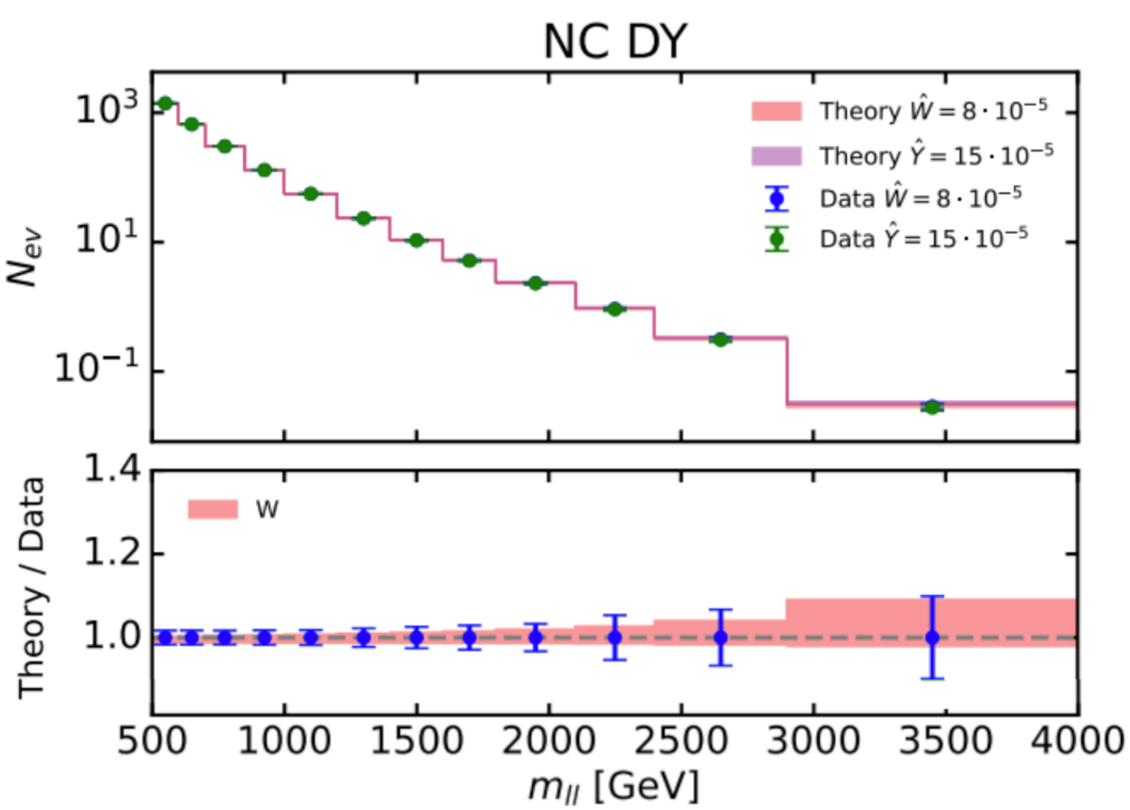
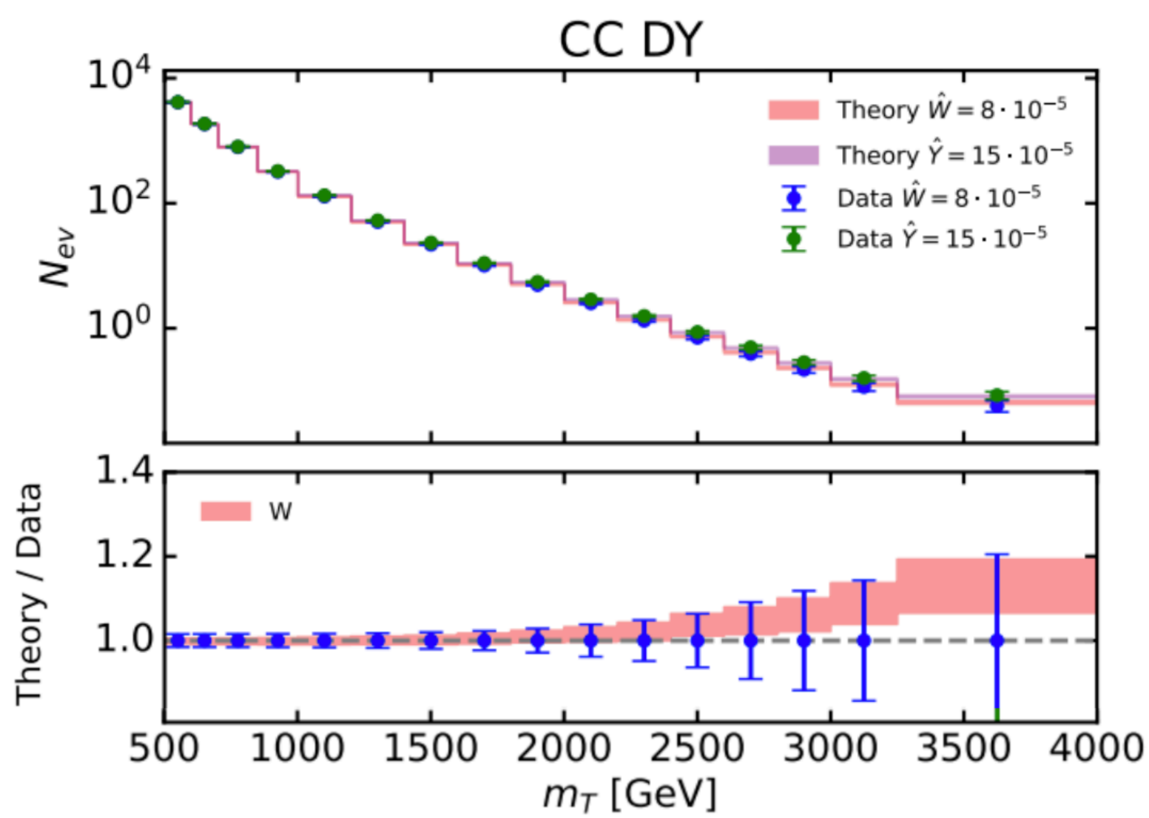
Large-x behaviour in PDFs is not constrained:
especially anti-quark PDFs allow for NP absorption

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

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





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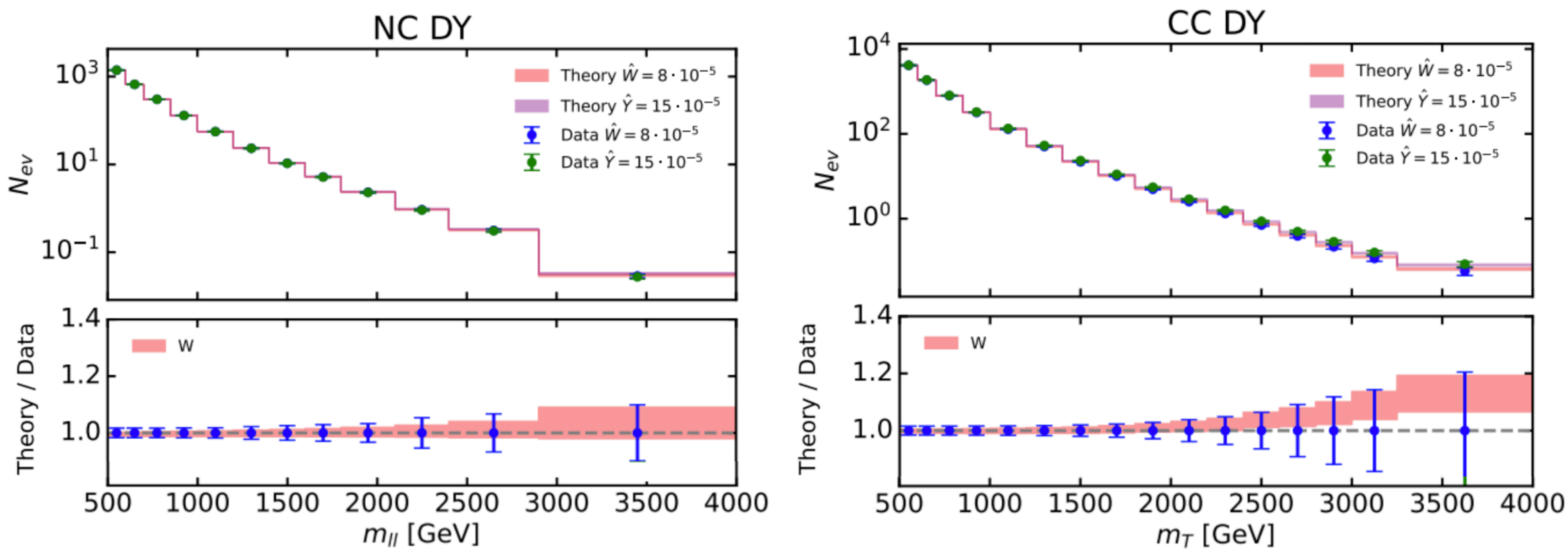
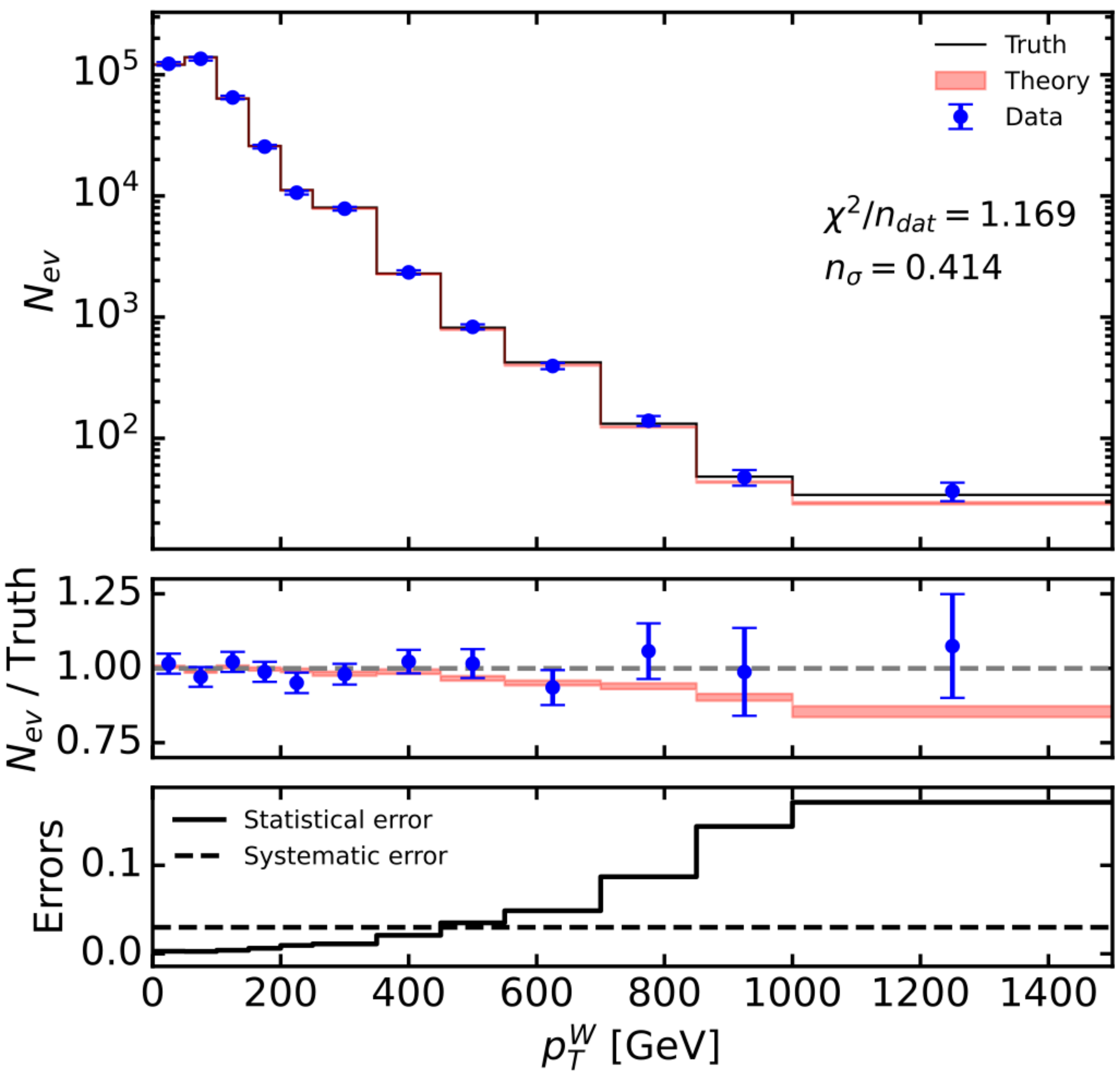
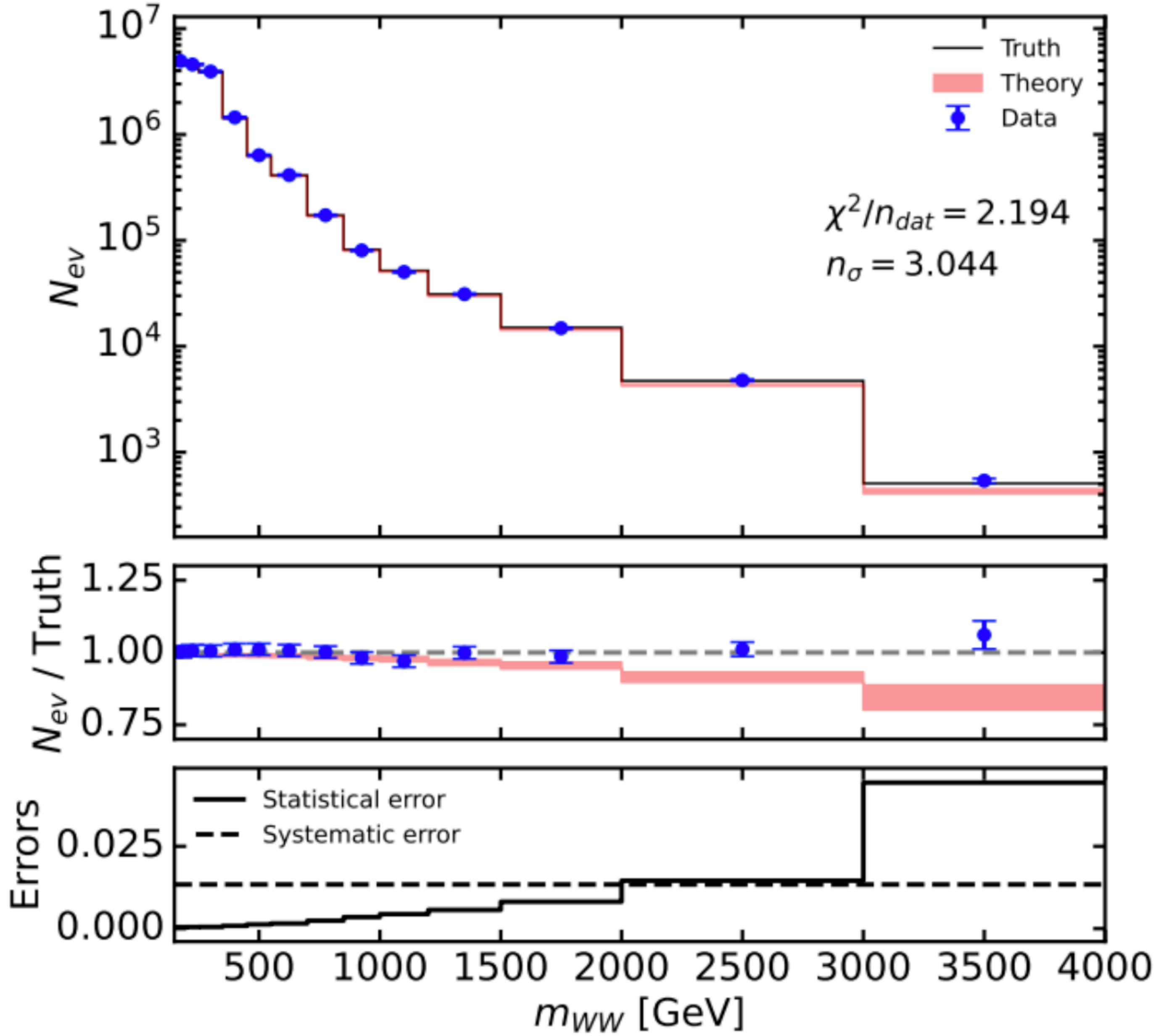


PDF shift is completely compensating the NP effect → **NP concealed in the proton!!**

$pp \to W^+H$ $pp \to W^+W^-$





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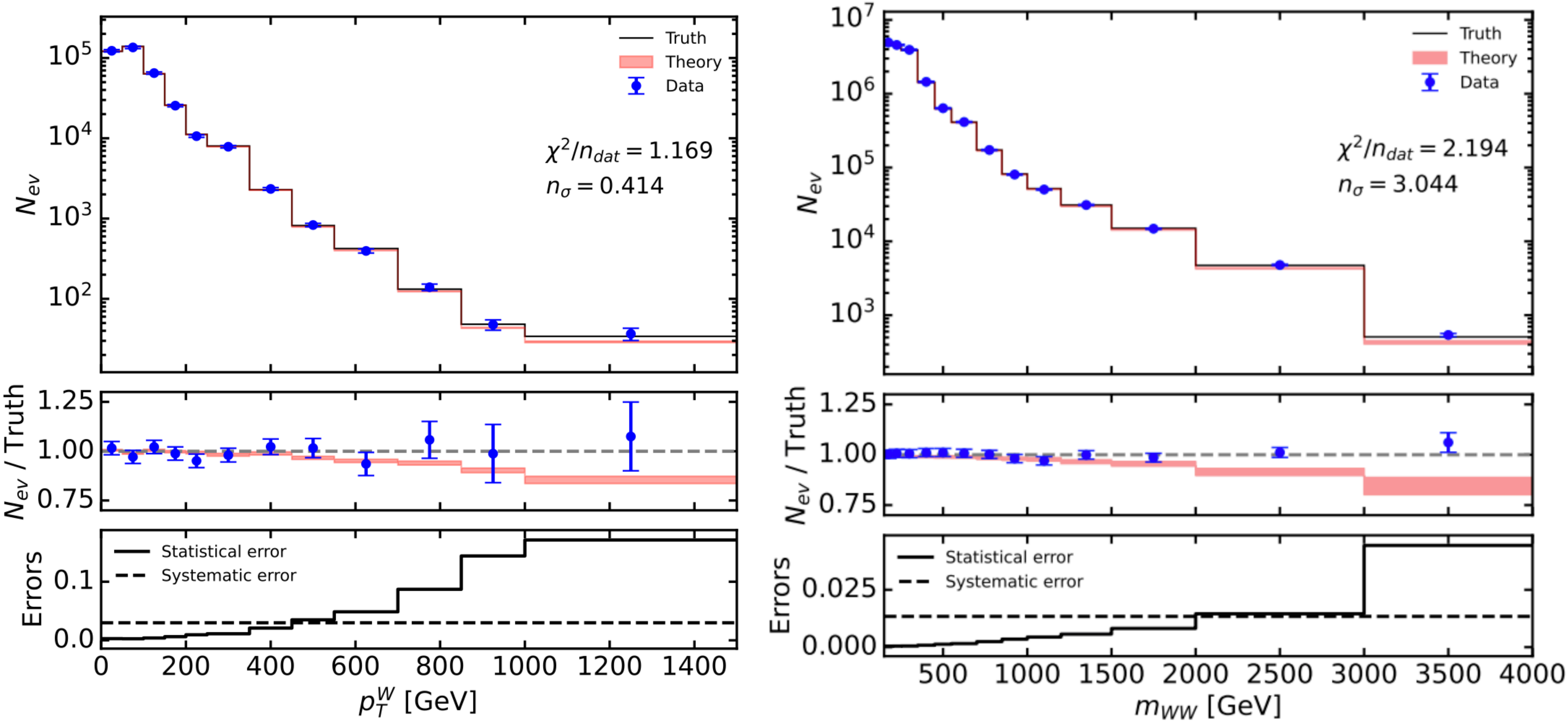

Observables
not affected by W’

Spurious NP

Can we devise an observable which is independent of PDFs?

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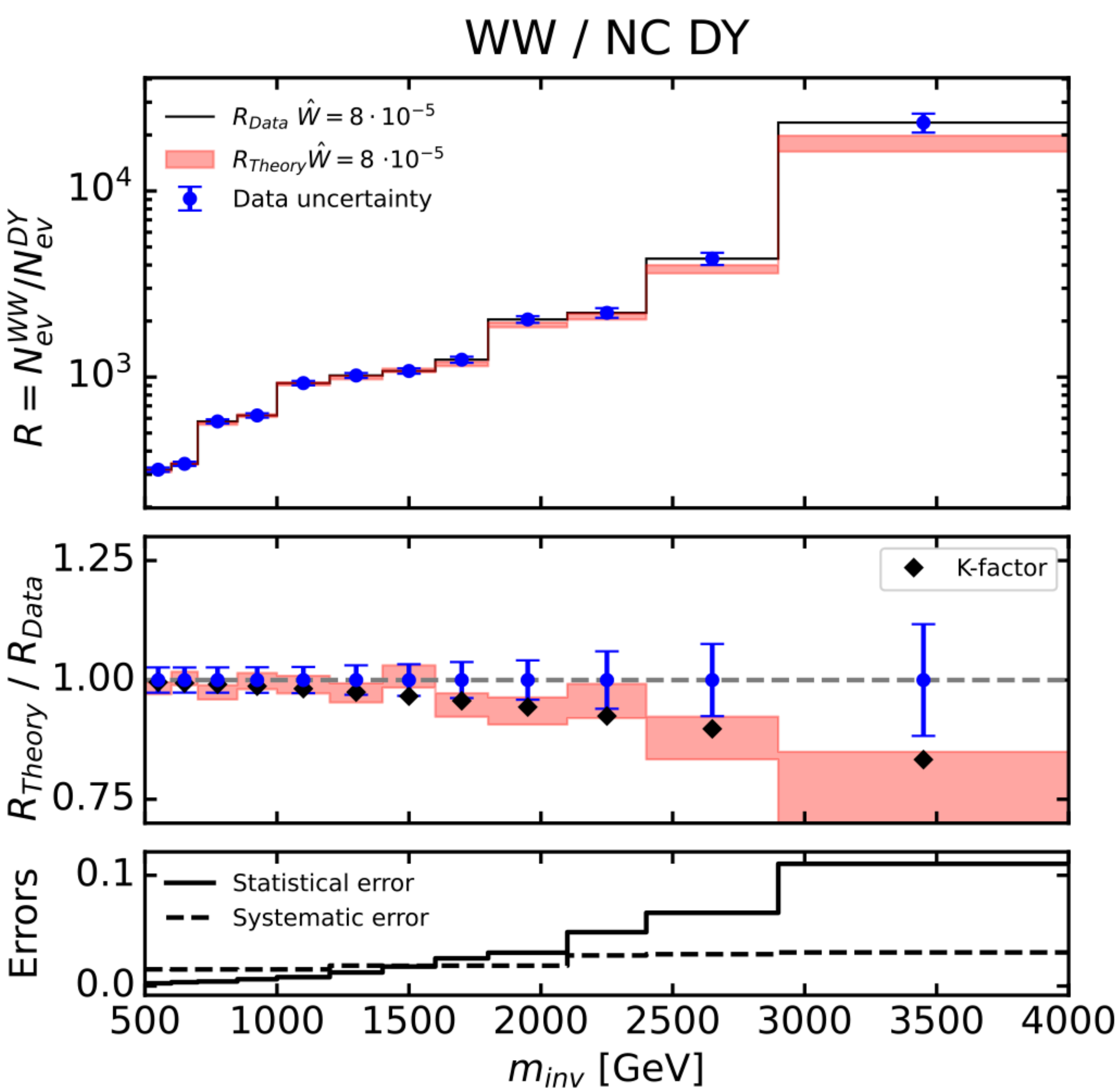

Ratio of WW and DY:
prediction has suppressed
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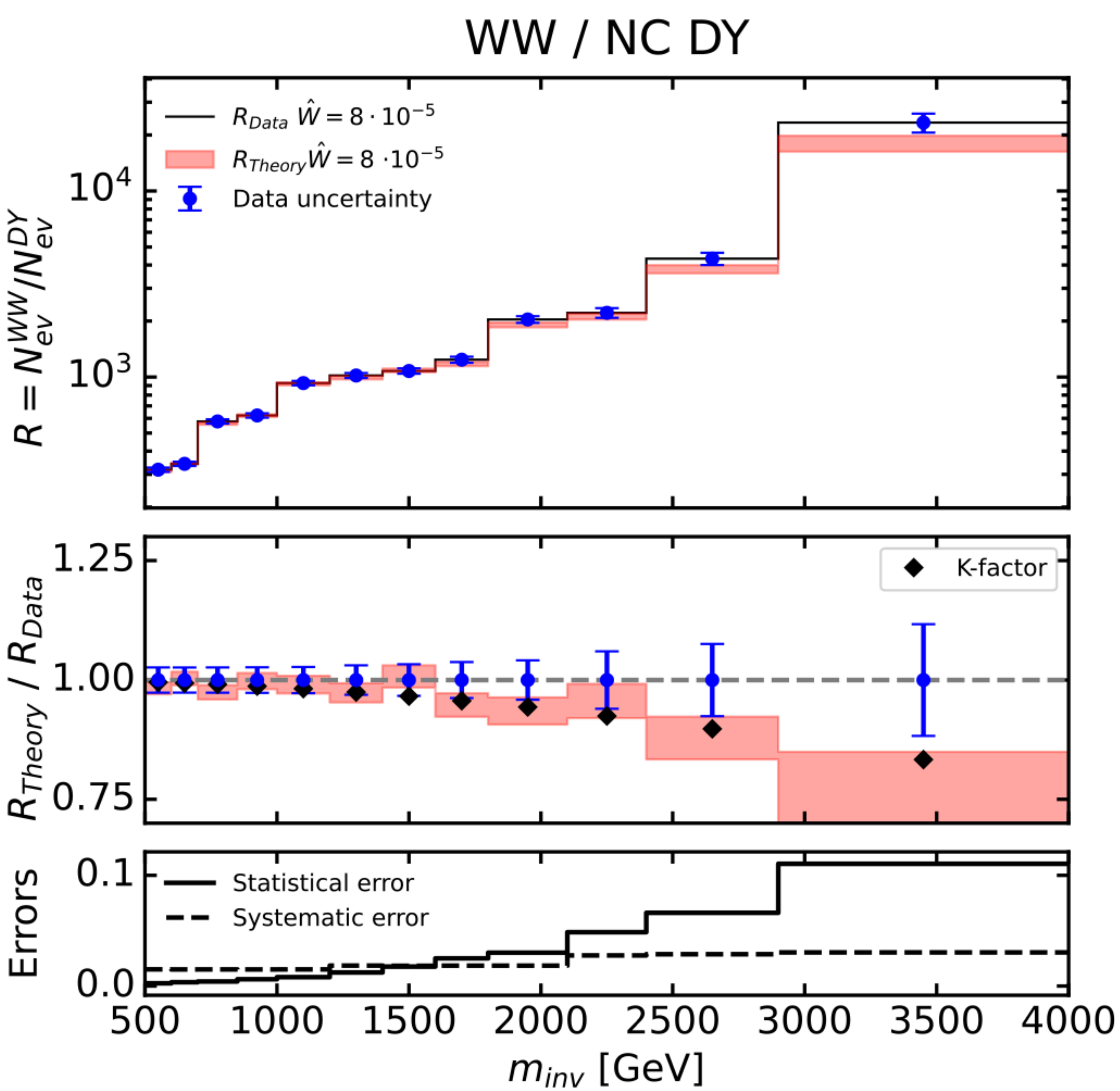
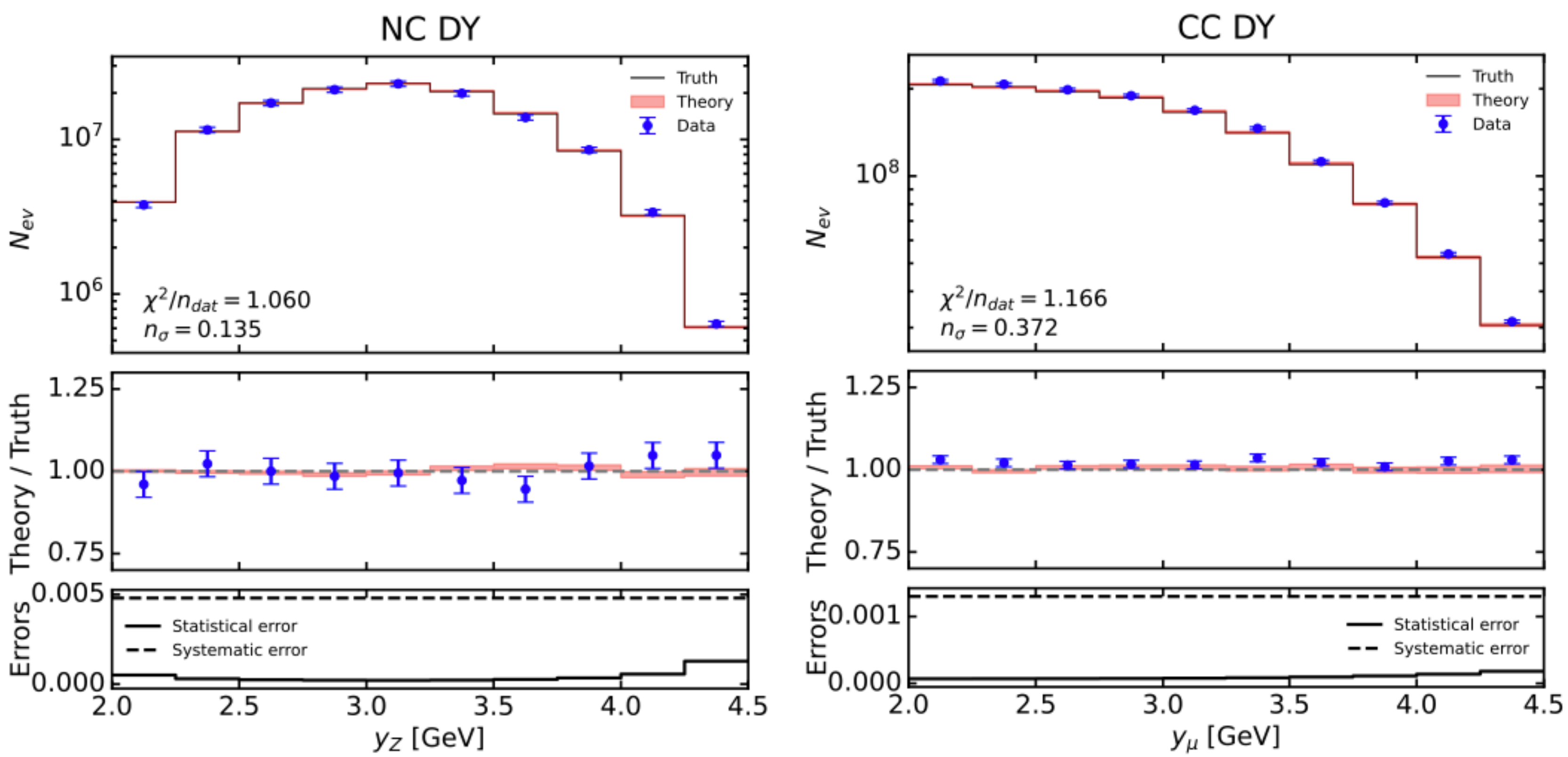


Ratio of WW and DY: prediction has suppressed dependence on PDF

NP is there… but where?

Can we use forward V production to spot the contamination?



Kinematics covered is different: **need for larger x**

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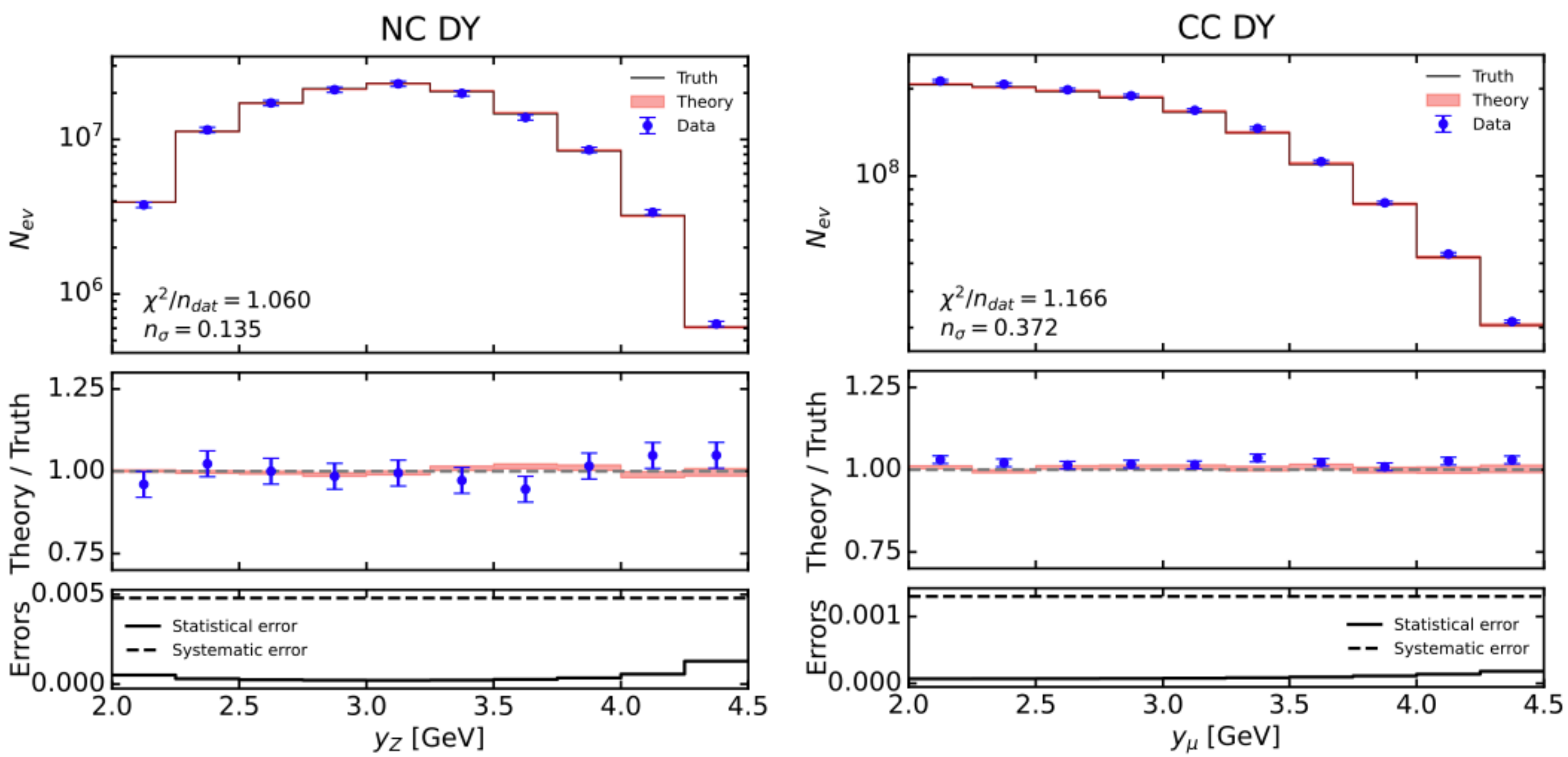

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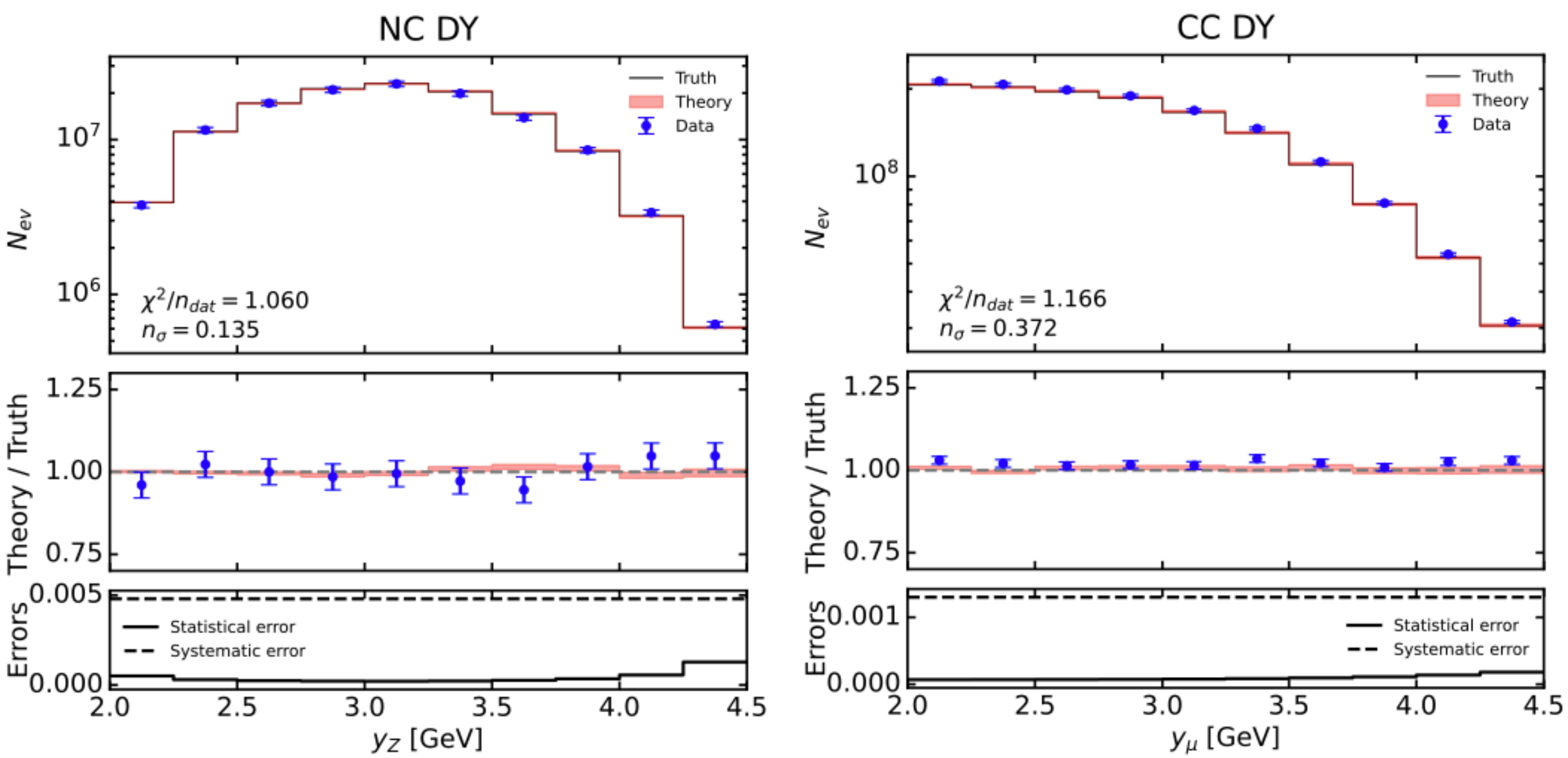

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Other idea: can a simultaneous fit of PDF-SMEFT offer a solution?

- An assessment of NP contamination in the PDFs has been performed considering flavour universal Z' and W' scenarios
- Discoverable W' scenarios exist that are absorbed in the proton parametrisation.
- Kinematic coverage of the current dataset of PDF fits is insufficient.
- There is need to explore NP scenarios more systematically in contaminated PDFs, devising strategies to disentangle the effects.
- Stay tuned: public release of new SIMUnet tool + global fit (top, higgs, DY, EWPO) and with possibility of performing contaminated fits

- An assessment of NP contamination in the PDFs has been performed considering flavour universal Z' and W' scenarios
- Discoverable W' scenarios exist that are absorbed in the proton parametrisation.
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Thanks!

Backup

- Develop new methodology to perform quadratic SMEFT + PDF fits (bayesian)
- Understand better the pitfalls of the MC replica method and whether PDF fits are affected
- Explore NP scenarios more systematically in contaminated PDFs, devising strategies to disentangle the effects
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Thanks!

The SMEFT proton

Zahari Kassabov[1], Maeve Madigan[1], Luca Mantani[1], James Moore[1], Manuel Morales Alvarado[1], Juan Rojo[2,3], and Maria Ubiali[1]

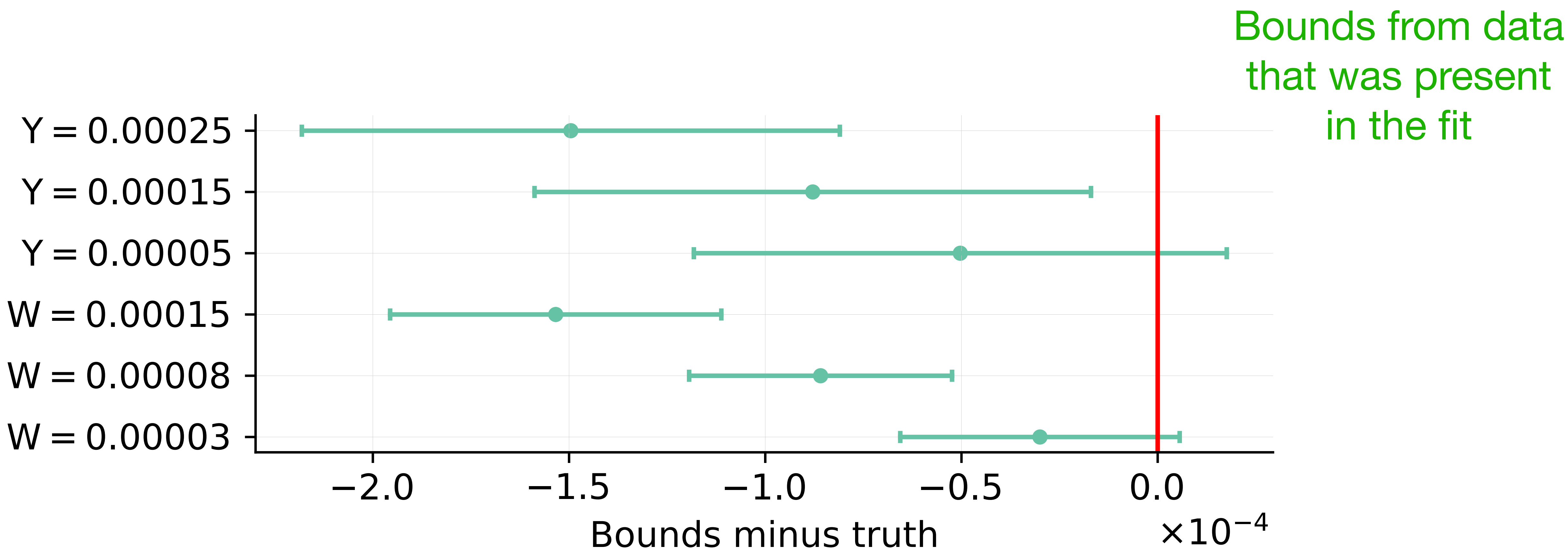
arXiv:2303.06159

Can PDFs conceal NP?

Elie Hammou[a] , **Zahari Kassabov**[a] , **Maeve Madigan**[b] , **Michelangelo L. Mangano**[c] , **Luca Mantani**[a] , **James Moore**[a] , **Manuel Morales Alvarado**[a] and **Maria Ubiali**[a]

arXiv: 2307.10370

What do we find if we put bounds
on Y and W parameters from Drell-Yan?



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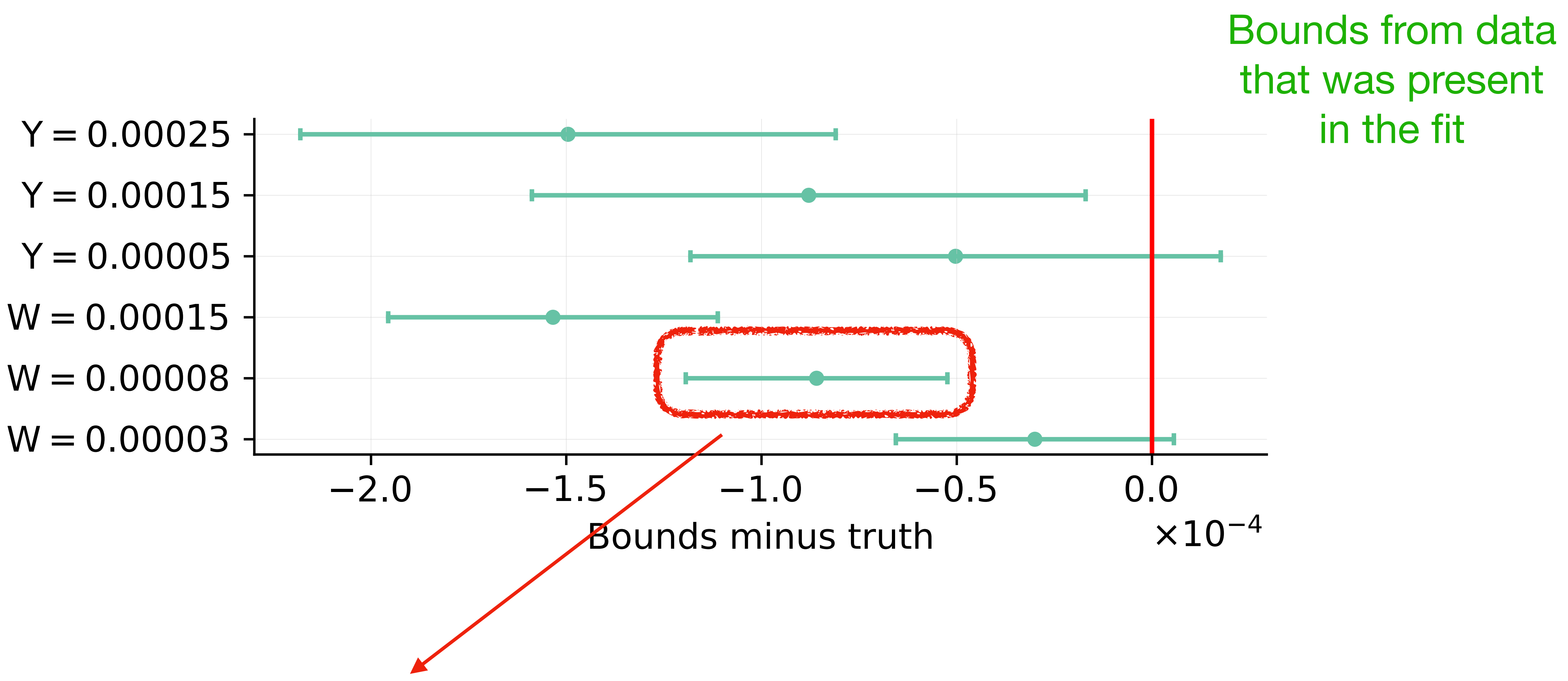
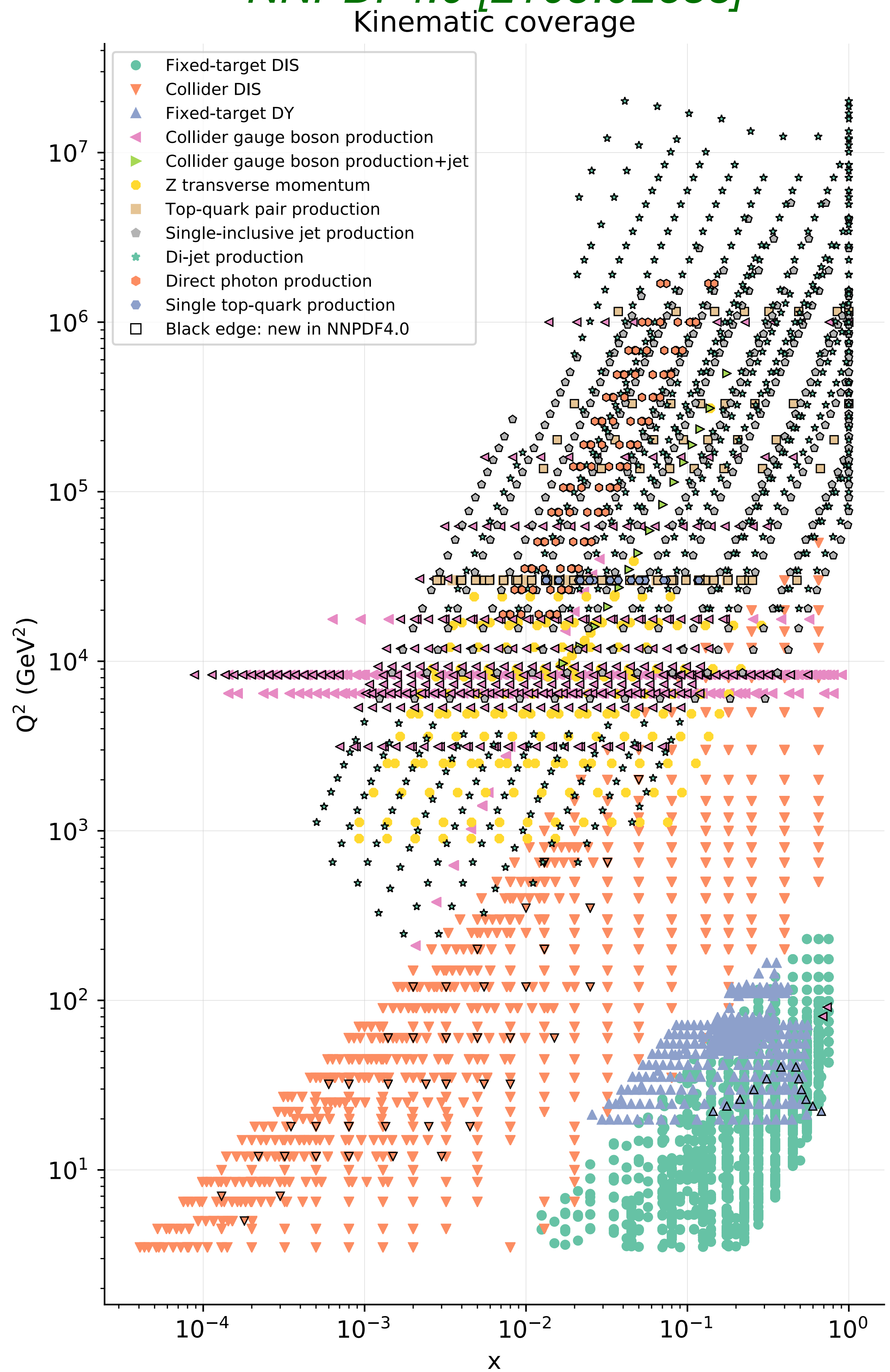


NP is missed + PDF looks fine:
The SM seem to be working fine

Often data used in SMEFT interpretations and PDF extraction coincide

NNPDF4.0 [2109.02653]



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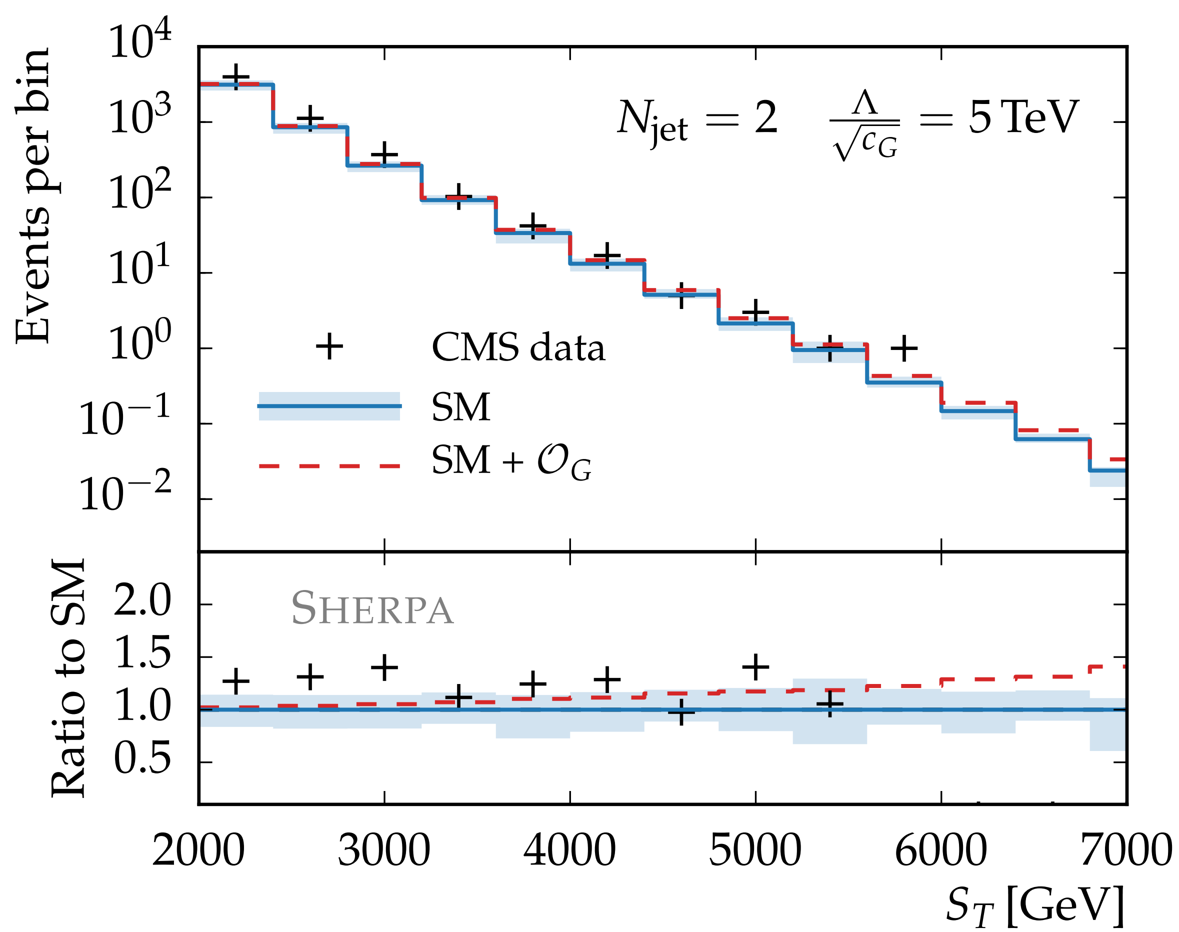
e.g. Dijet data used to fit the SMEFT operator in *F. Krauss et. al, 1611.00767*



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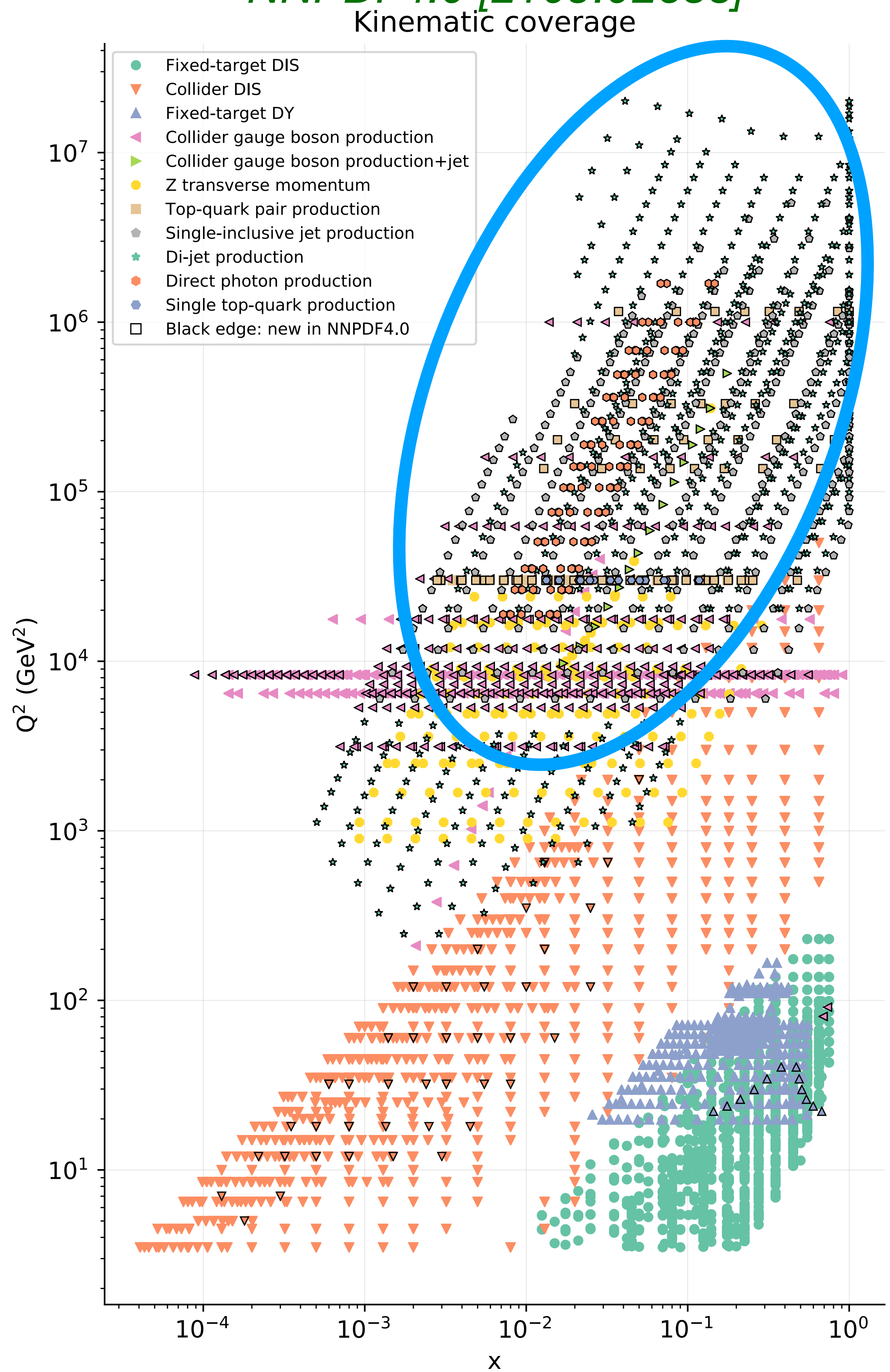
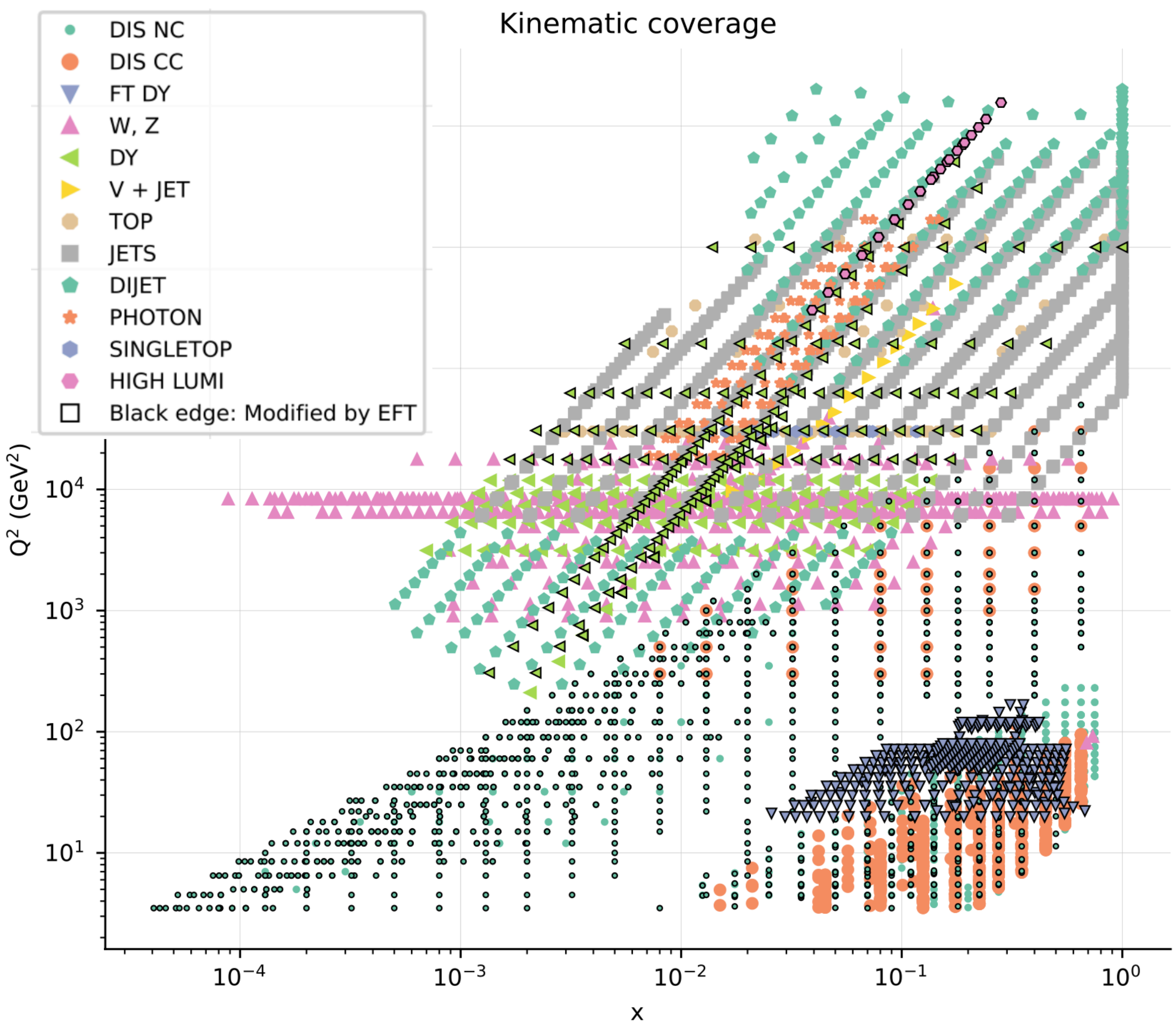


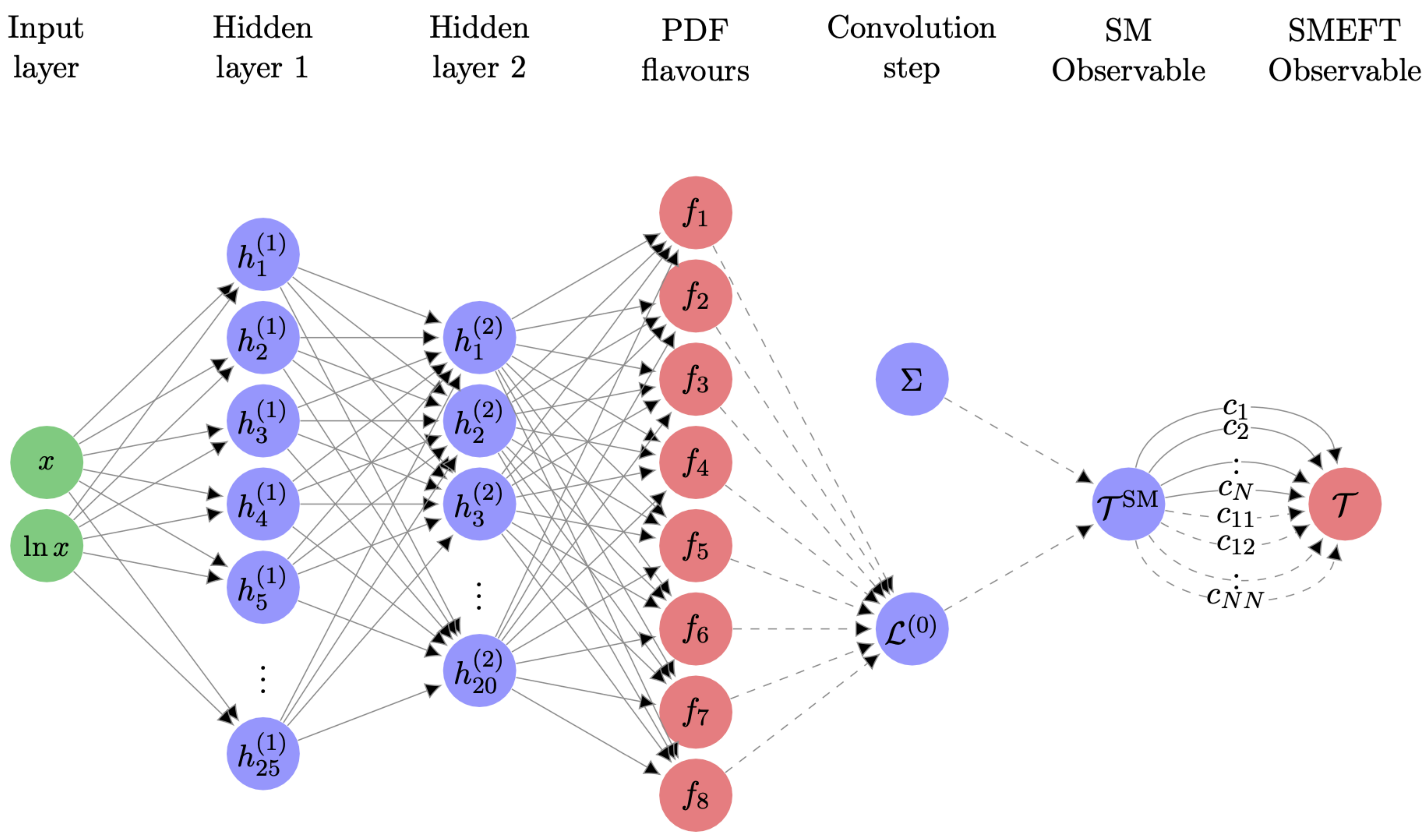
NNPDF4.0 dataset + **HL-LHC** DY projections [arXiv: 2104.02723]



SIMUnet

S. Iranipour, M. Ubiali, [2201.07240]

"A new methodology that is able to yield a simultaneous determination of the PDFs alongside **any set of parameters that determine the theory predictions**"



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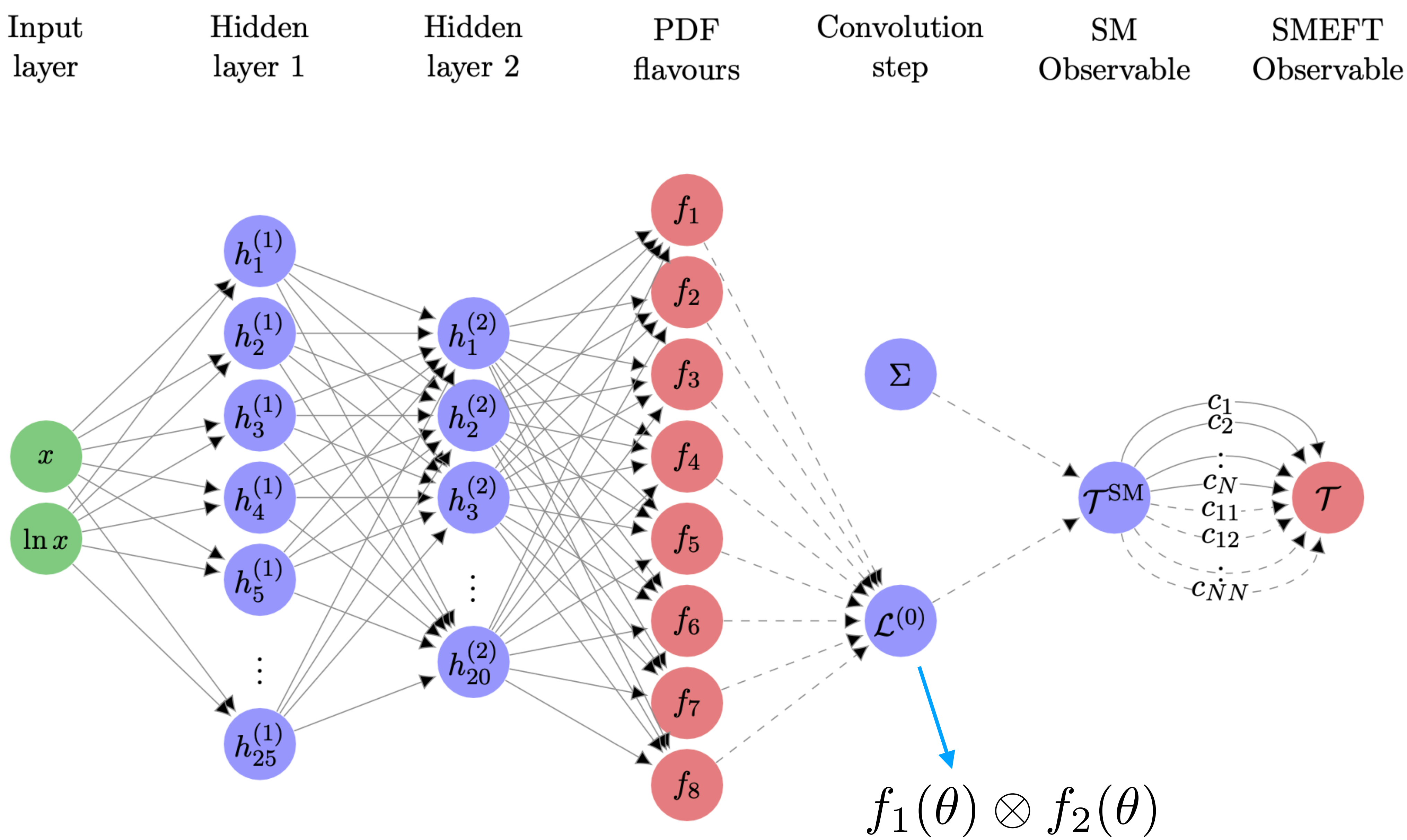

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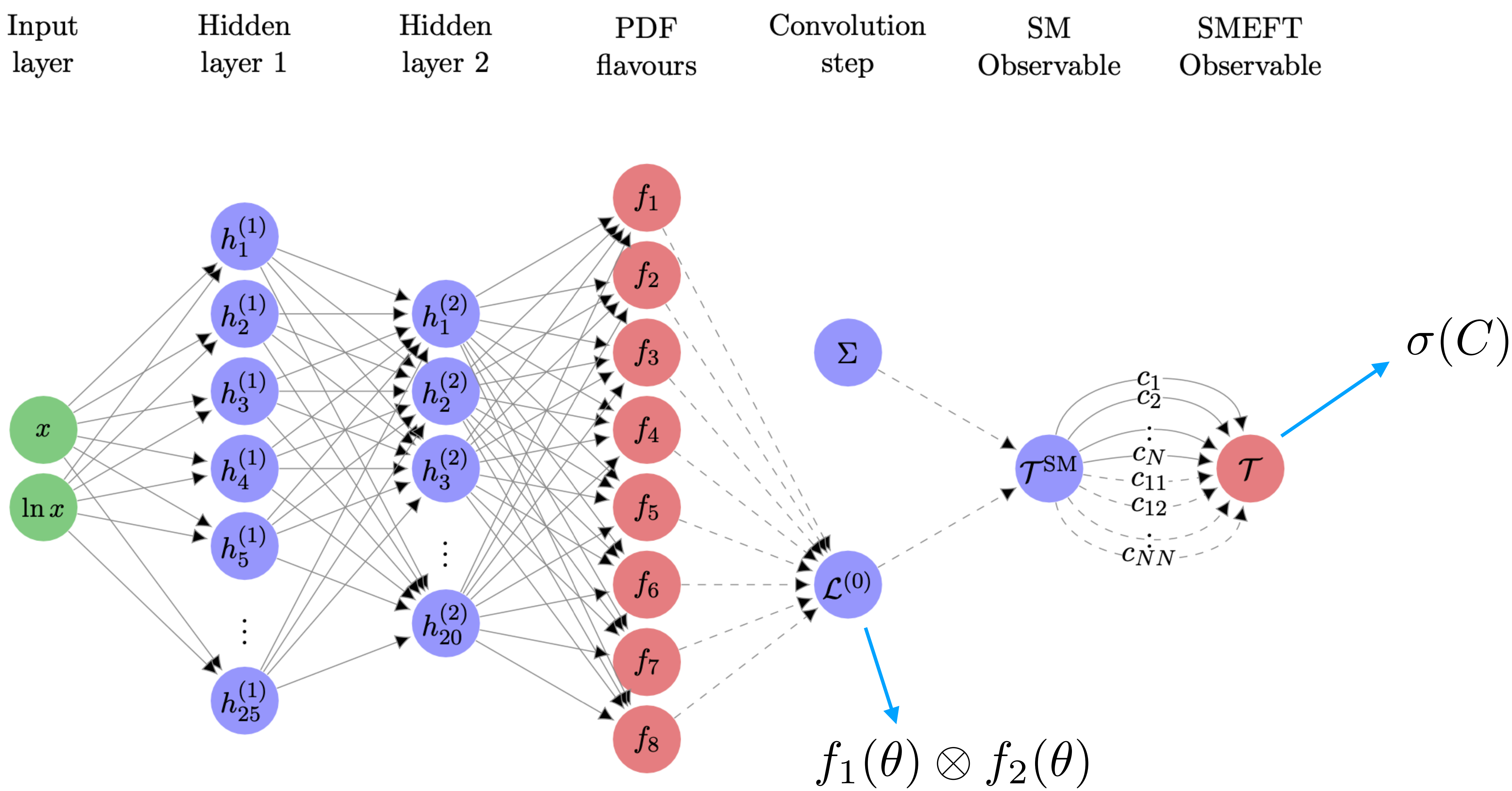


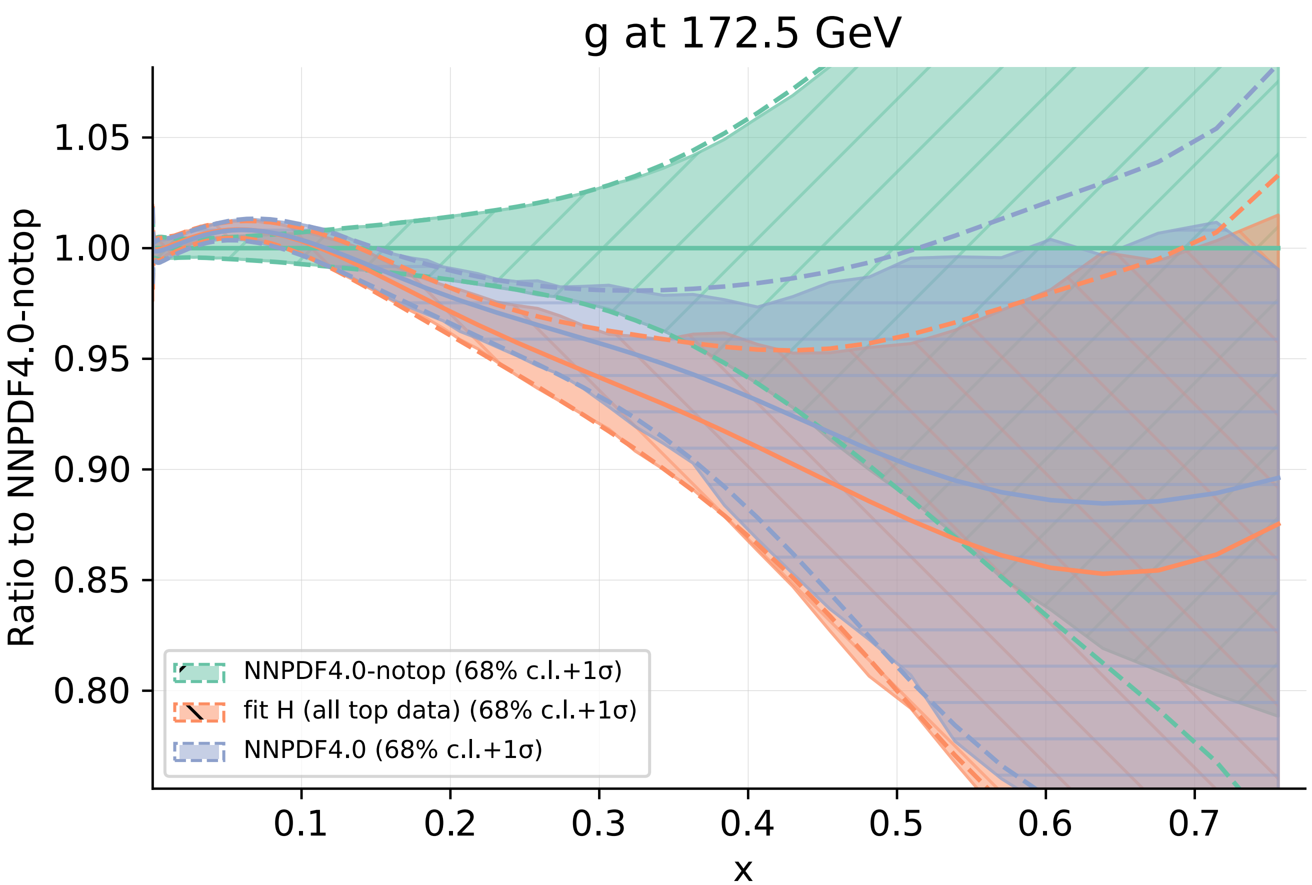
Top data is important especially for the gluon PDF

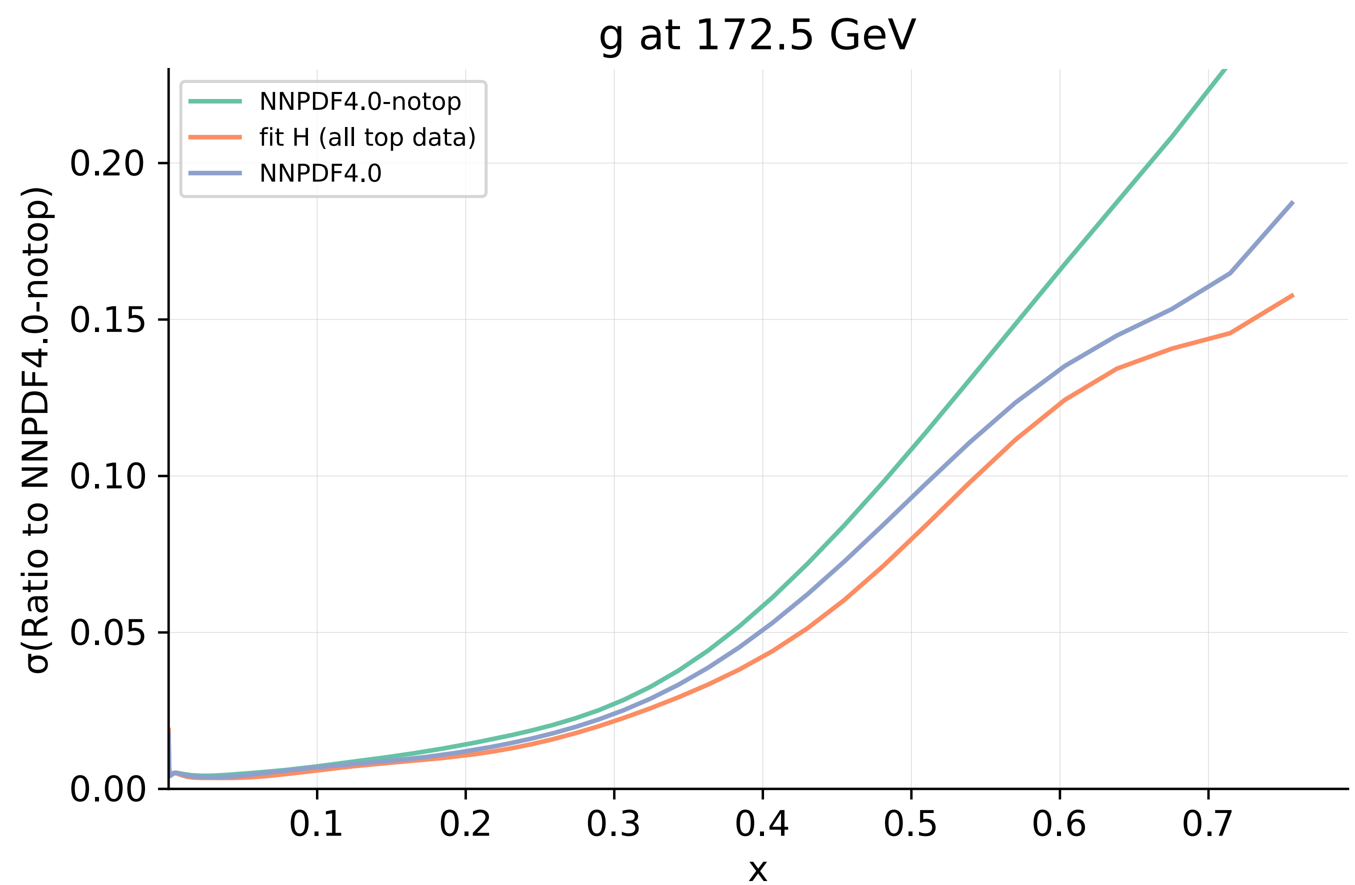
SM PDF fit, all top data

SM PDF fit, no top data

NNPDF 4.0

Additional data include: DIS, DY, jets, V + jets





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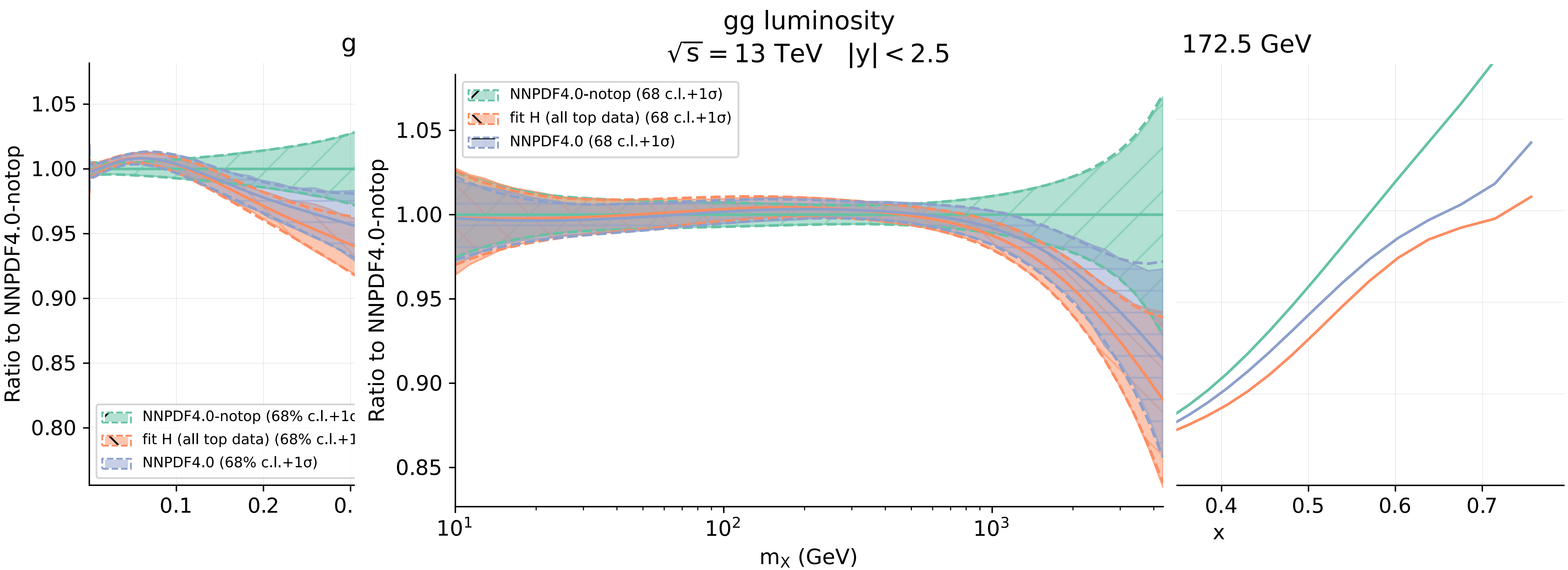

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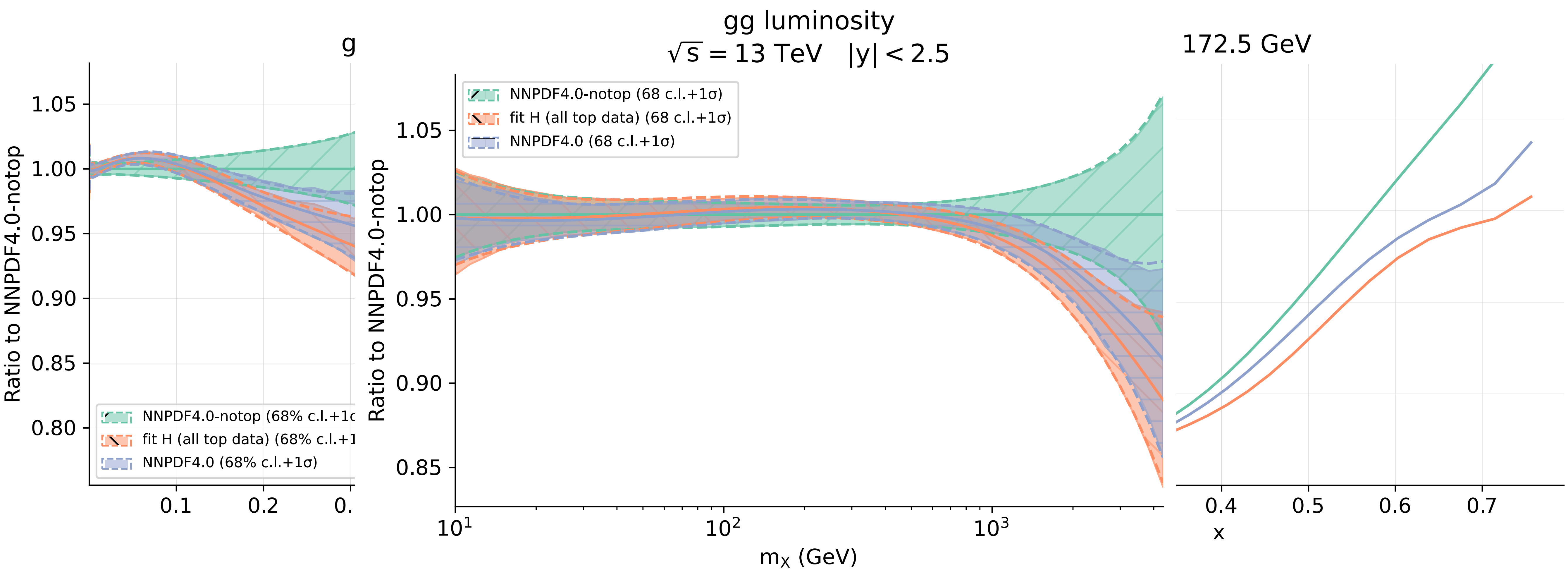

Impact mostly from ttbar data

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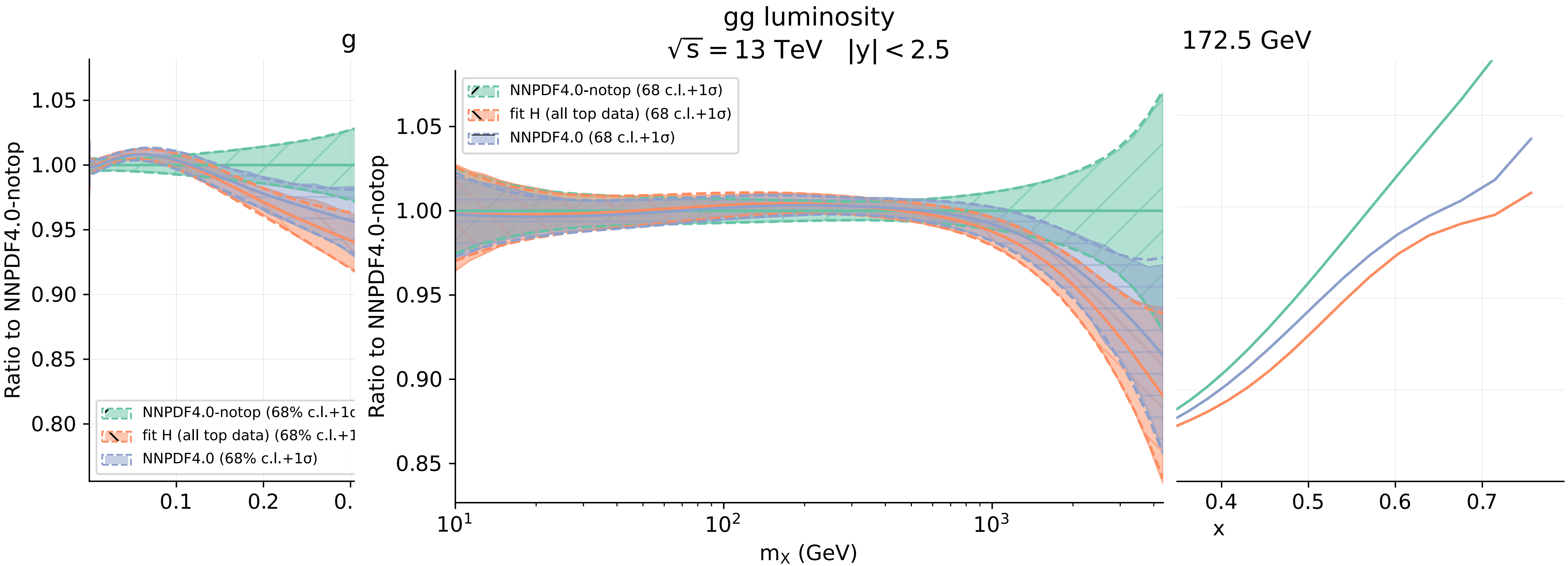
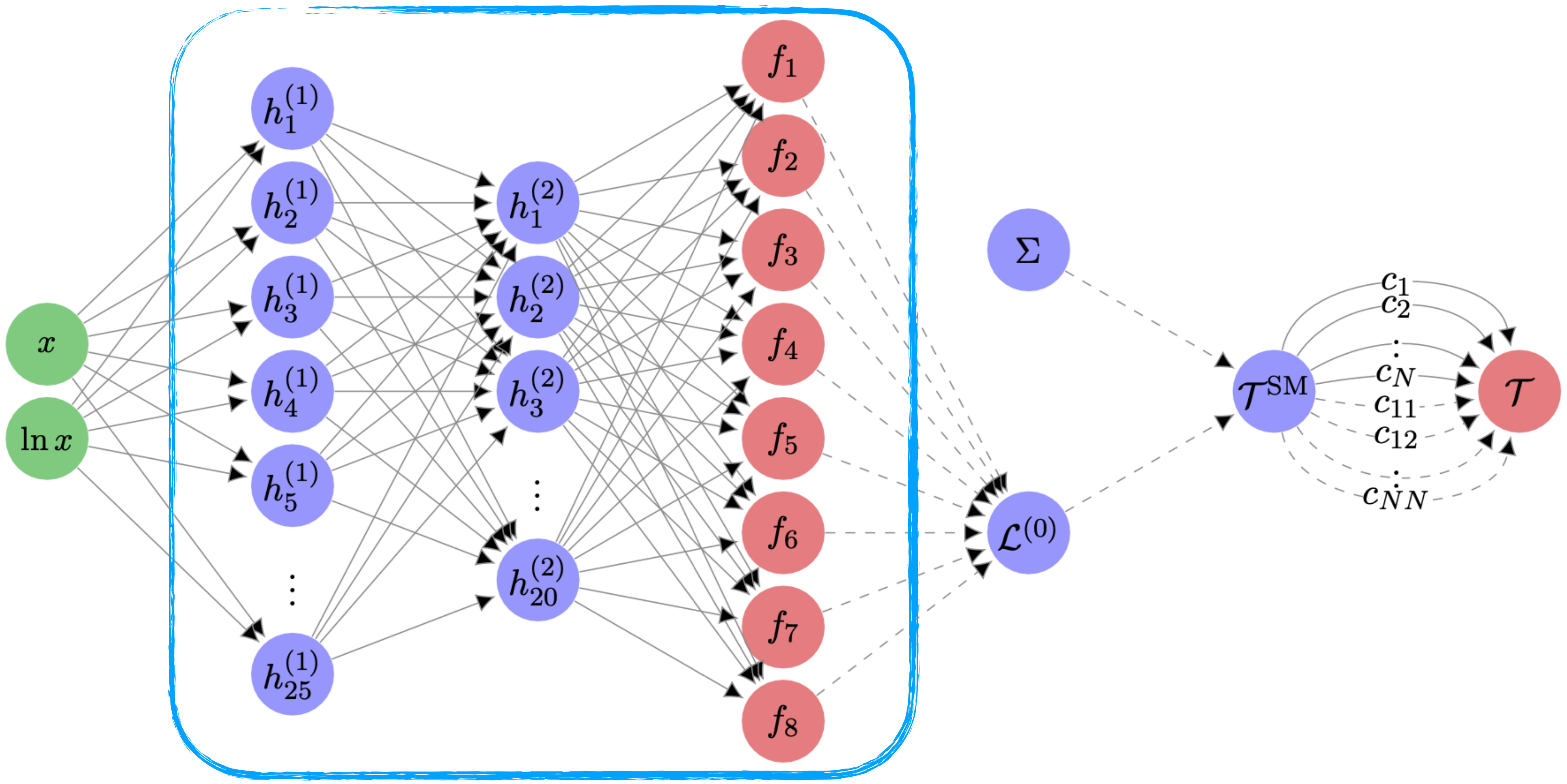


Impact mostly from ttbar data → Likely interplay gluon PDF - EFT operators

Conservative fixed PDF fit

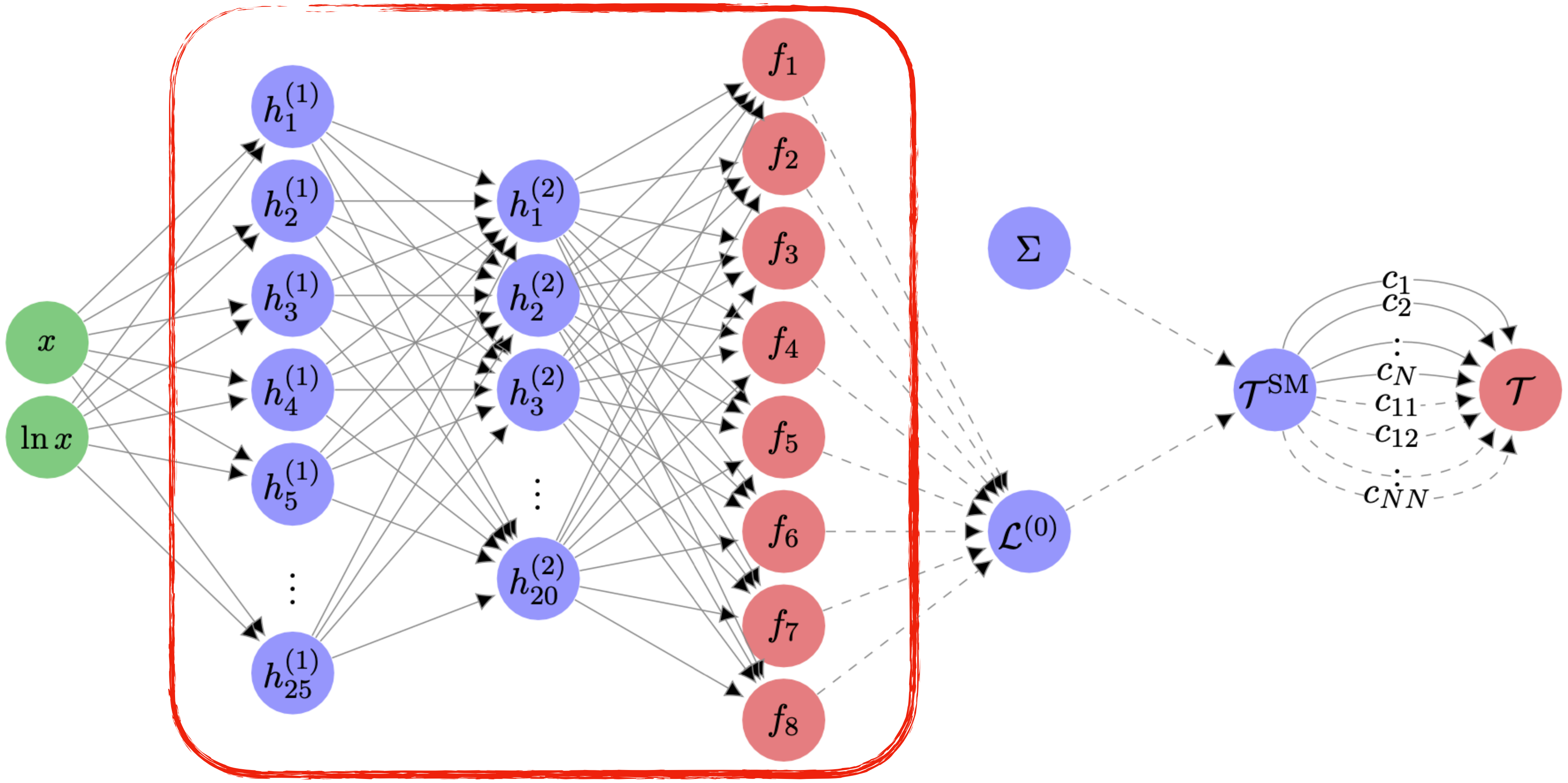
NN weights fixed, no top PDF



Conservative fixed PDF fit

Improper fixed PDF fit

NN weights fixed,
all top PDF

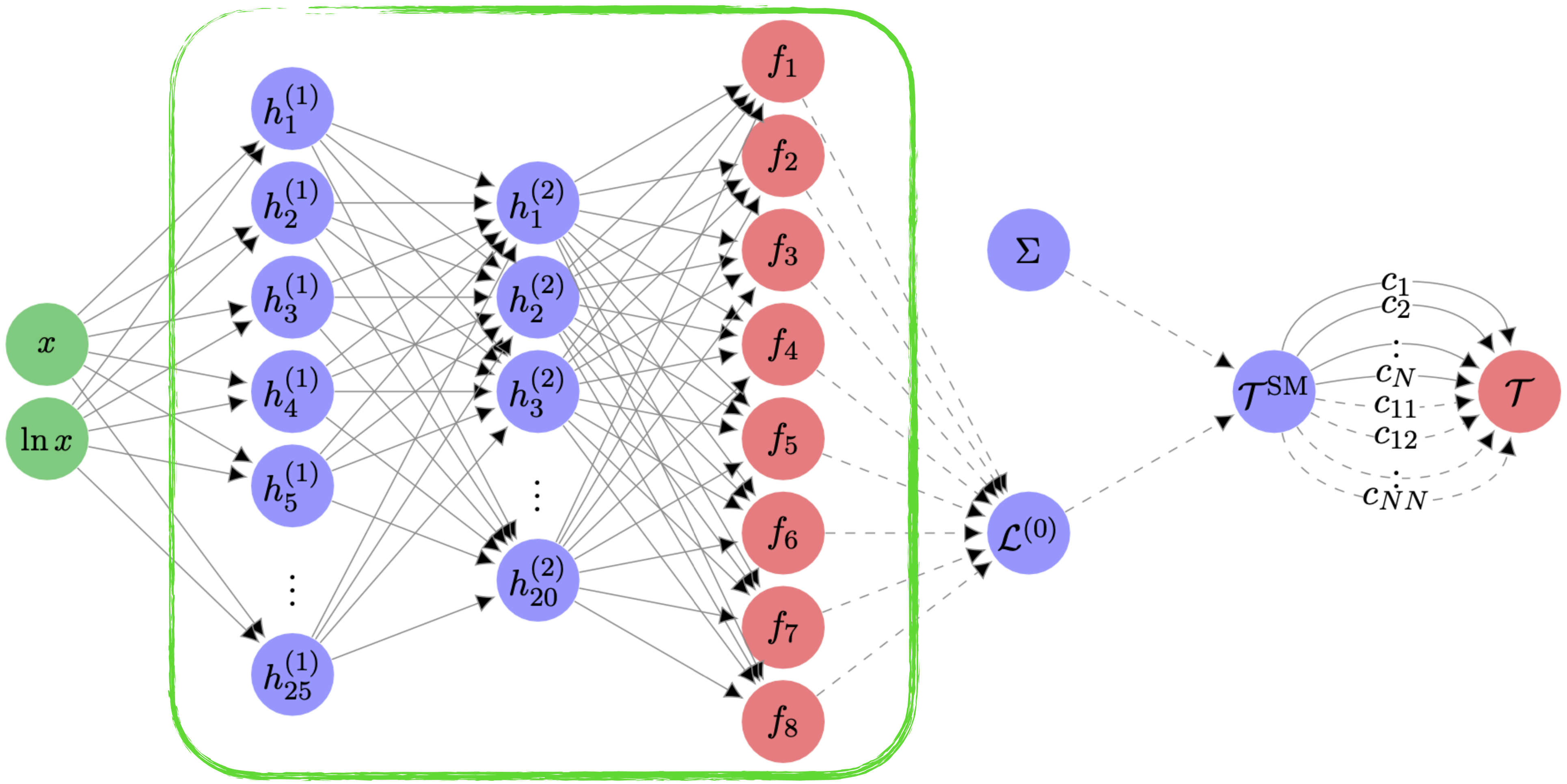


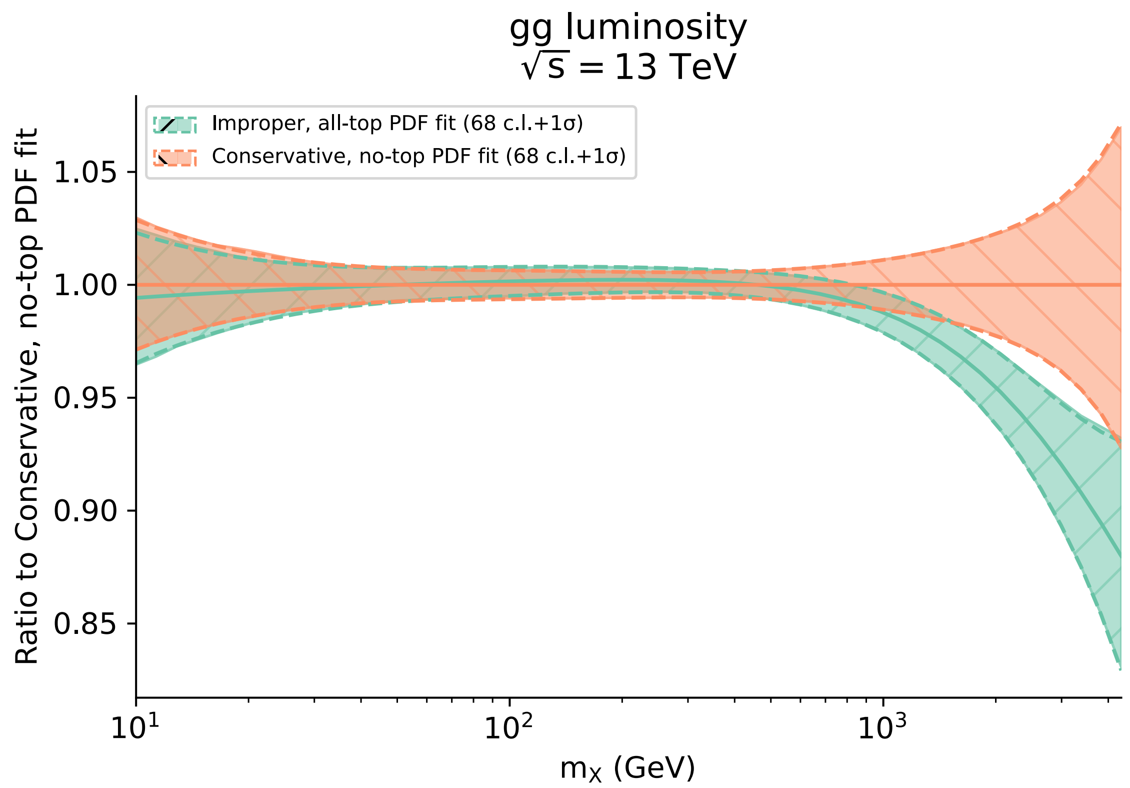
Conservative fixed PDF fit

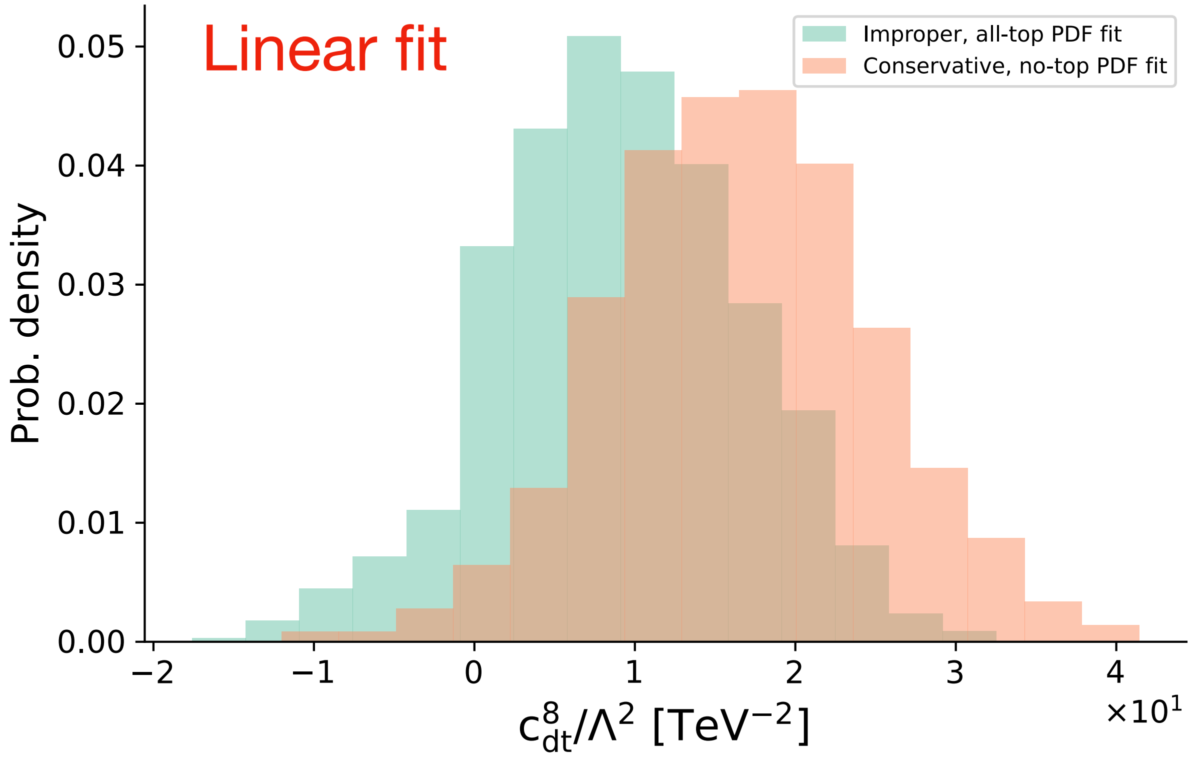
Improper fixed PDF fit

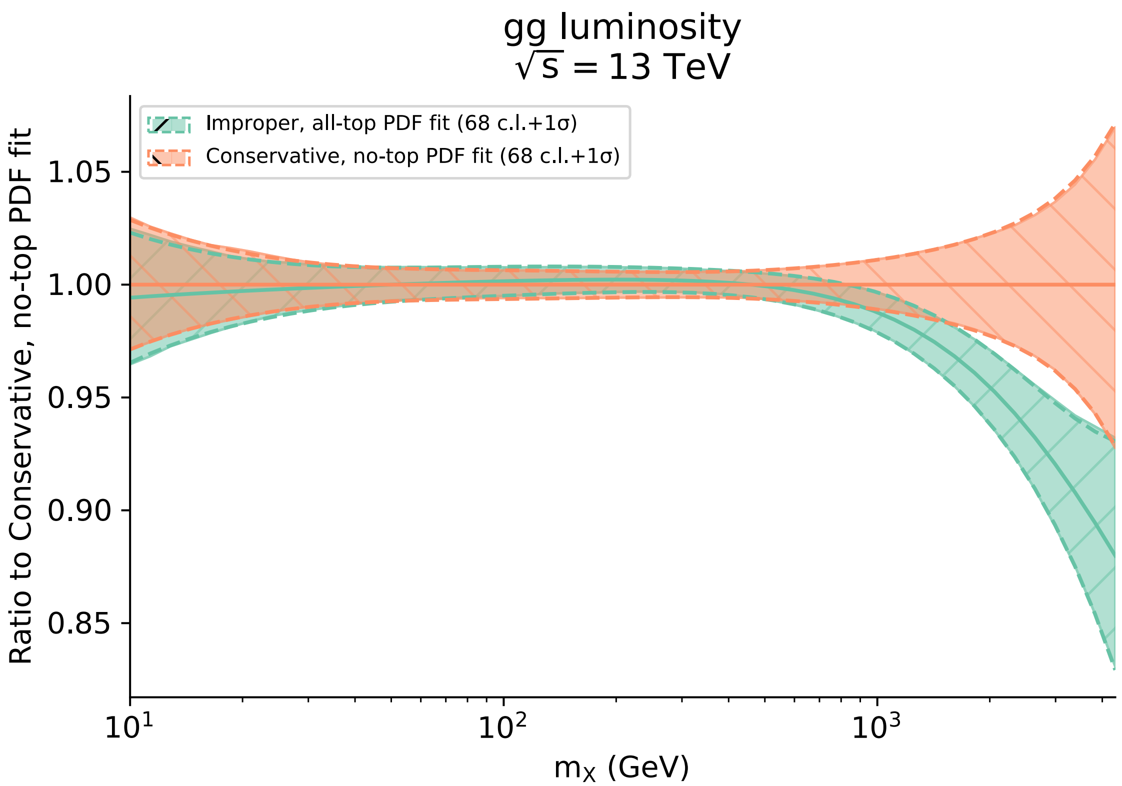
Simultaneous PDF-EFT fit

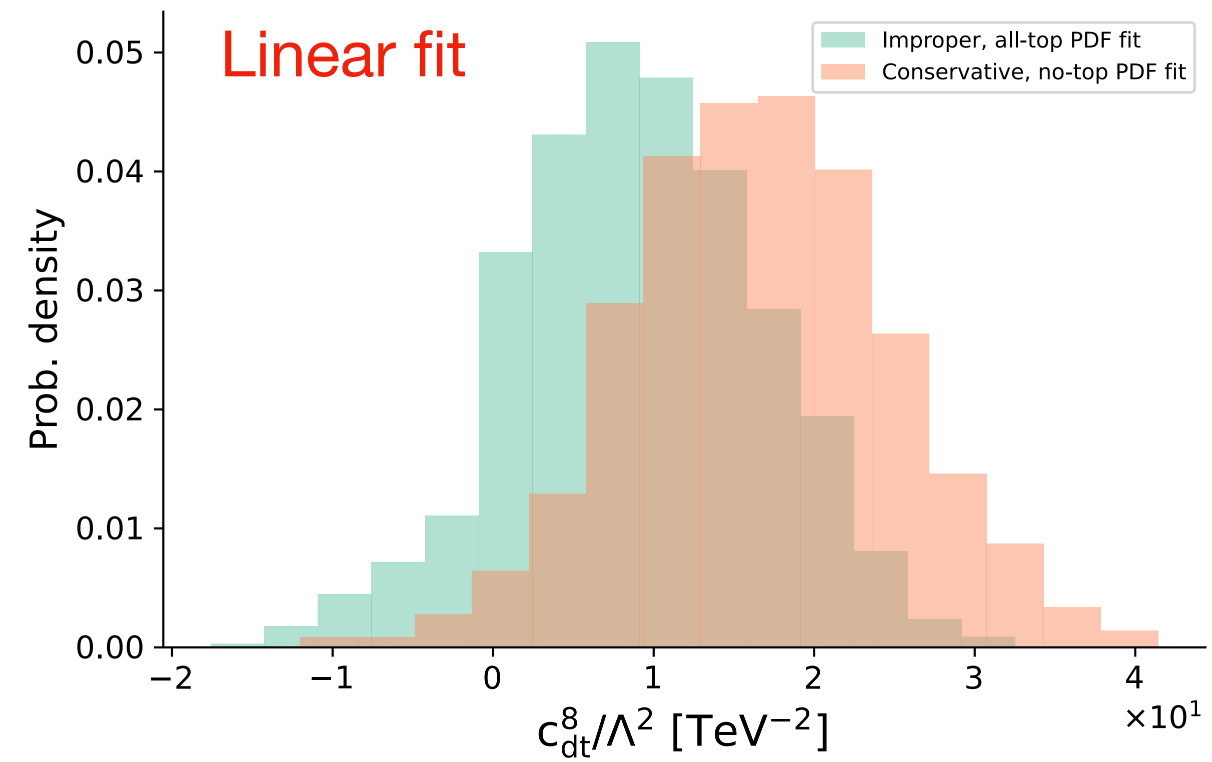
NN weights trainable



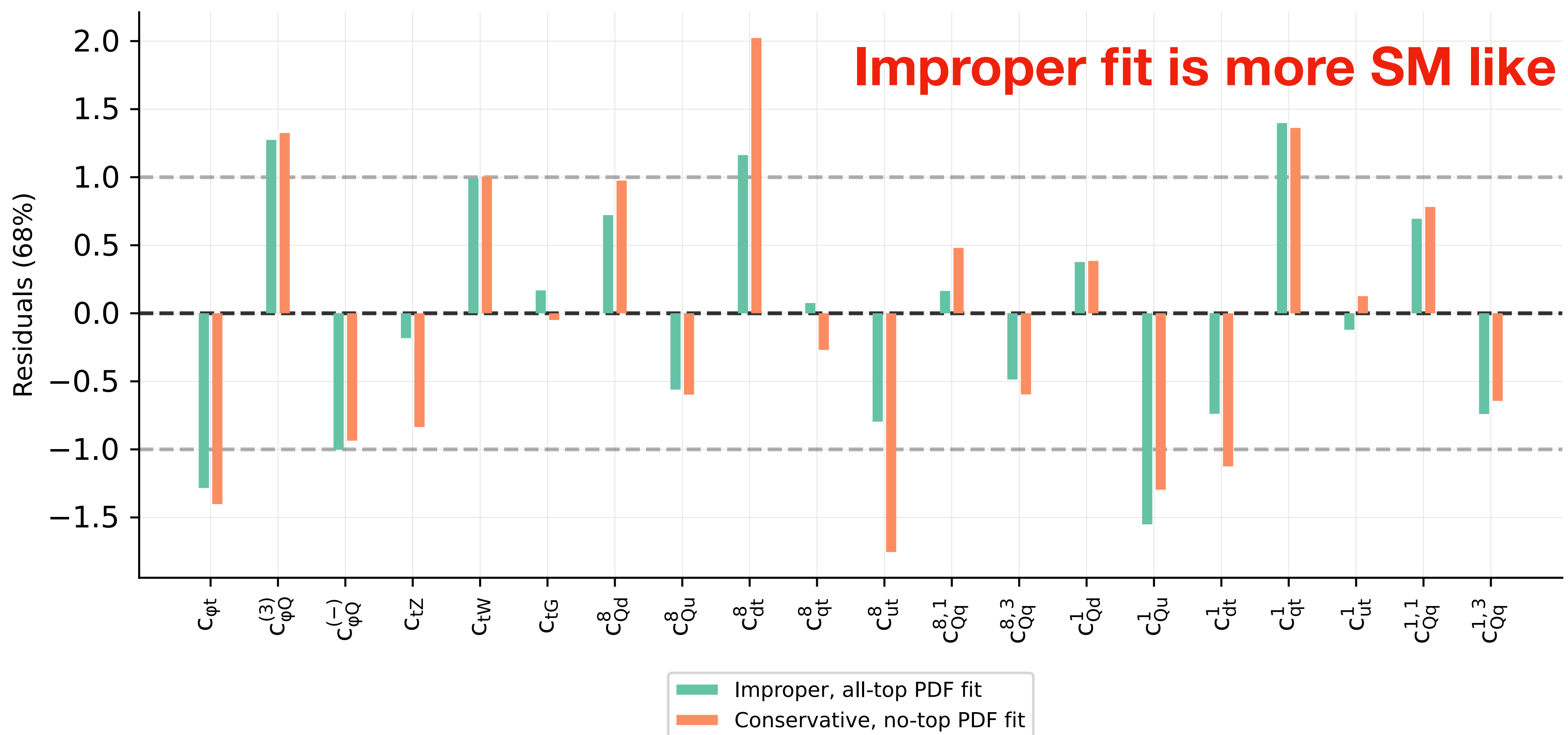

gg luminosity
$\sqrt{s} = 13$ TeV
Improper, all-top PDF fit (68 c.l.+1σ)
Conservative, no-top PDF fit (68 c.l.+1σ)
Ratio to Conservative, no-top PDF fit
1.05
1.00
0.95
0.90
0.85
10^1
10^2
10^3
m_X (GeV)


Linear fit
Improper, all-top PDF fit
Conservative, no-top PDF fit
Prob. density
0.05
0.04
0.03
0.02
0.01
0.00
−2
−1
0
1
2
3
4
$\times 10^1$
c^8_{dt}/Λ^2 [TeV^{-2}]





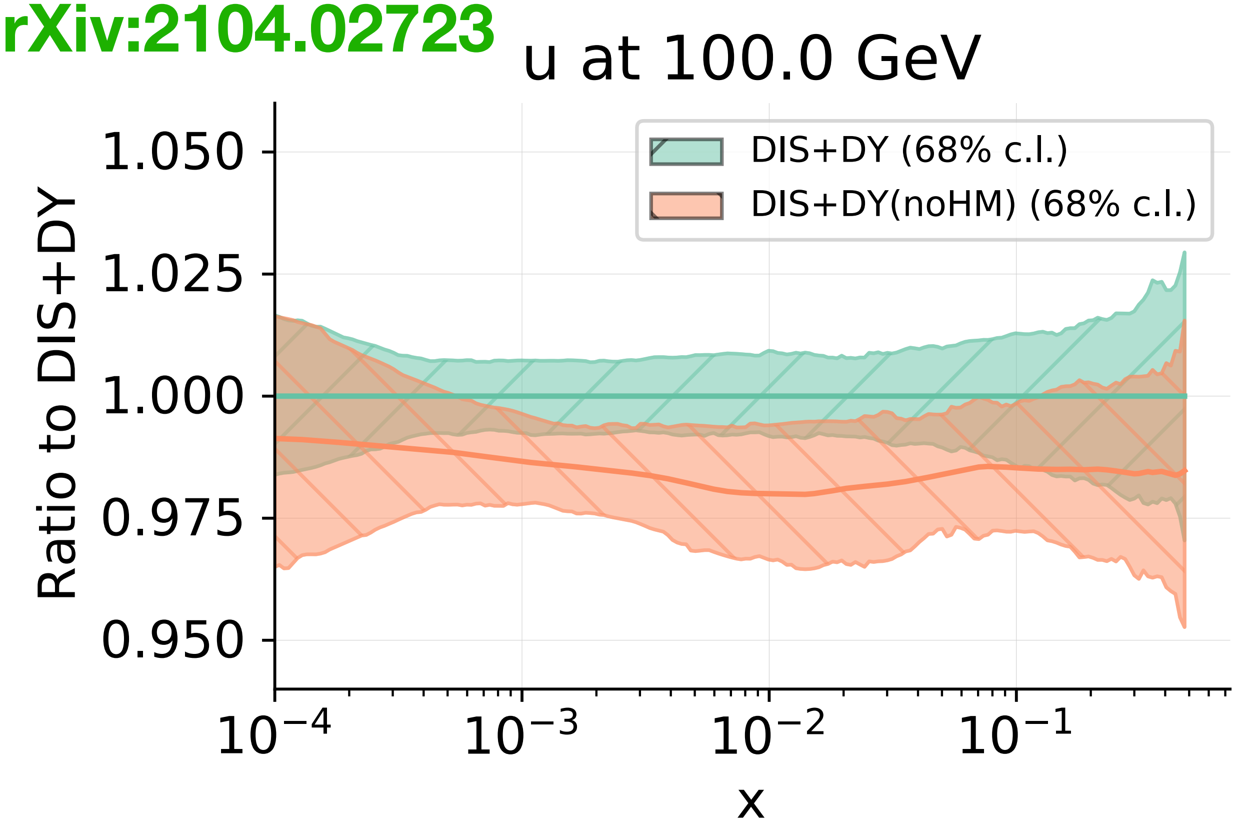
$$R_n = \frac{c_n^*}{\sigma_n}$$

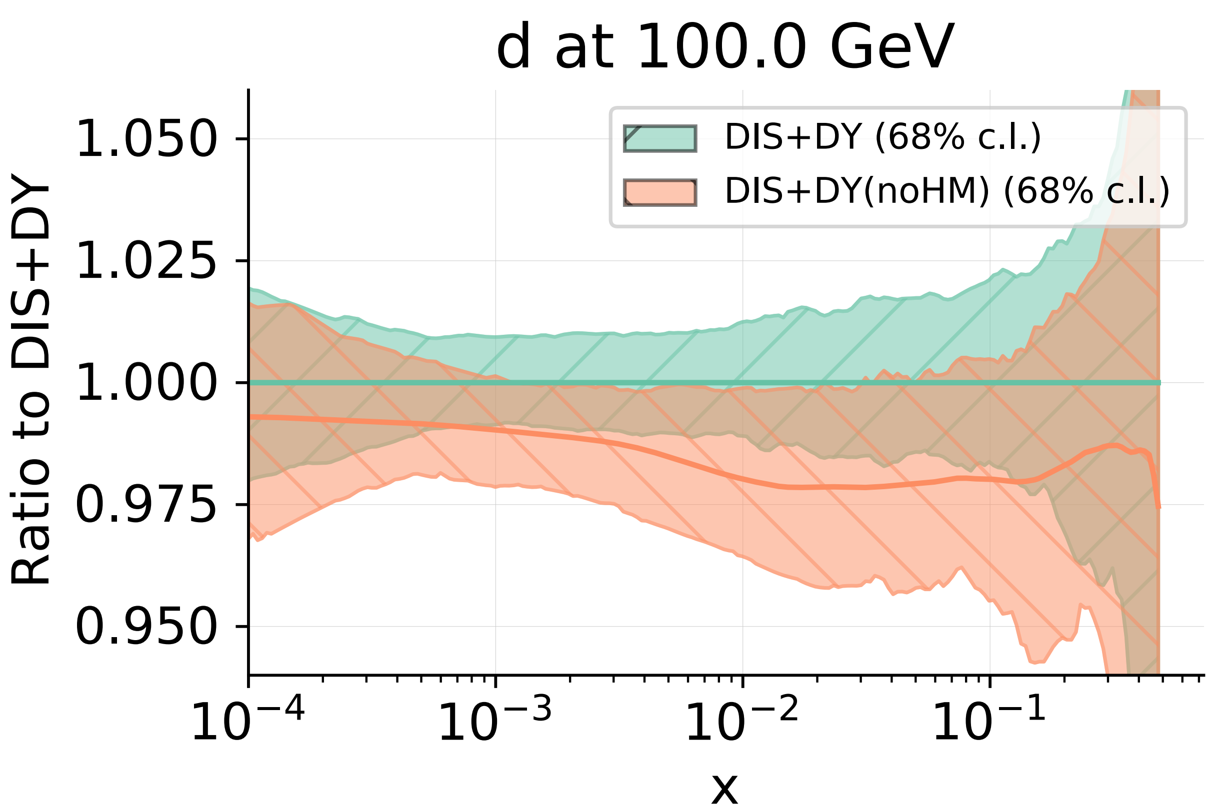


Why not simply use a conservative PDF fit?

Why not simply use a conservative PDF fit?

arXiv:2104.02723





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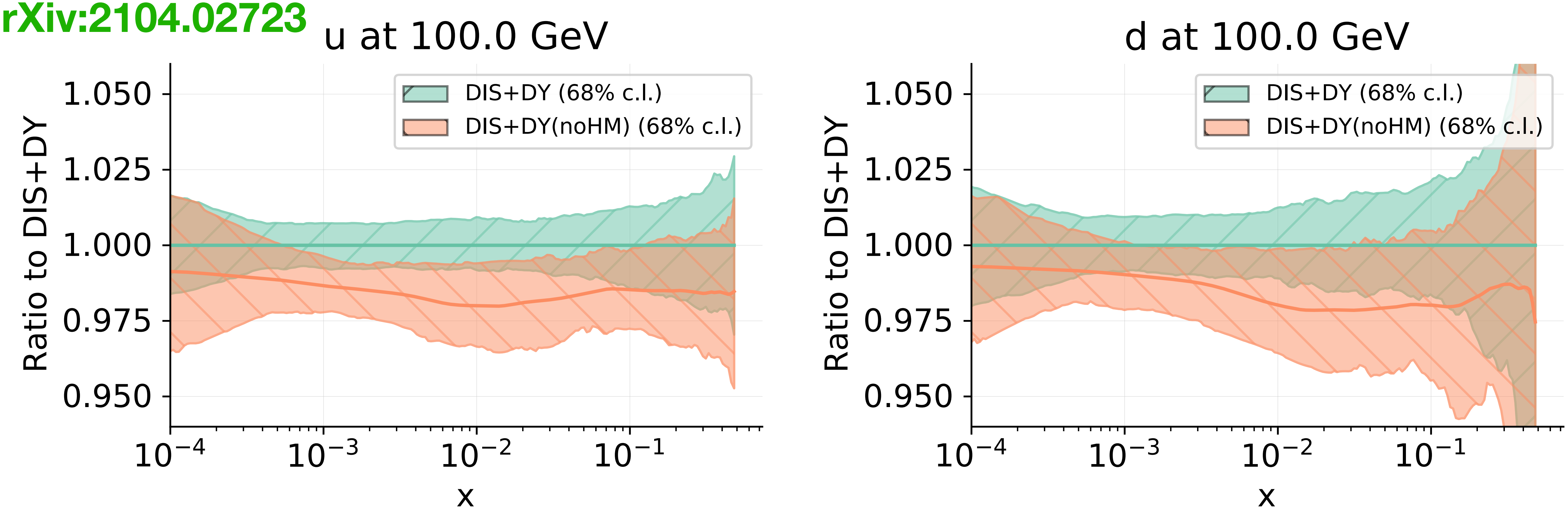

Increased PDF uncertainties in high-x region for several processes interesting for NP:

- diboson
- VBF
- high mass ttbar
- high mass jets
- etc..

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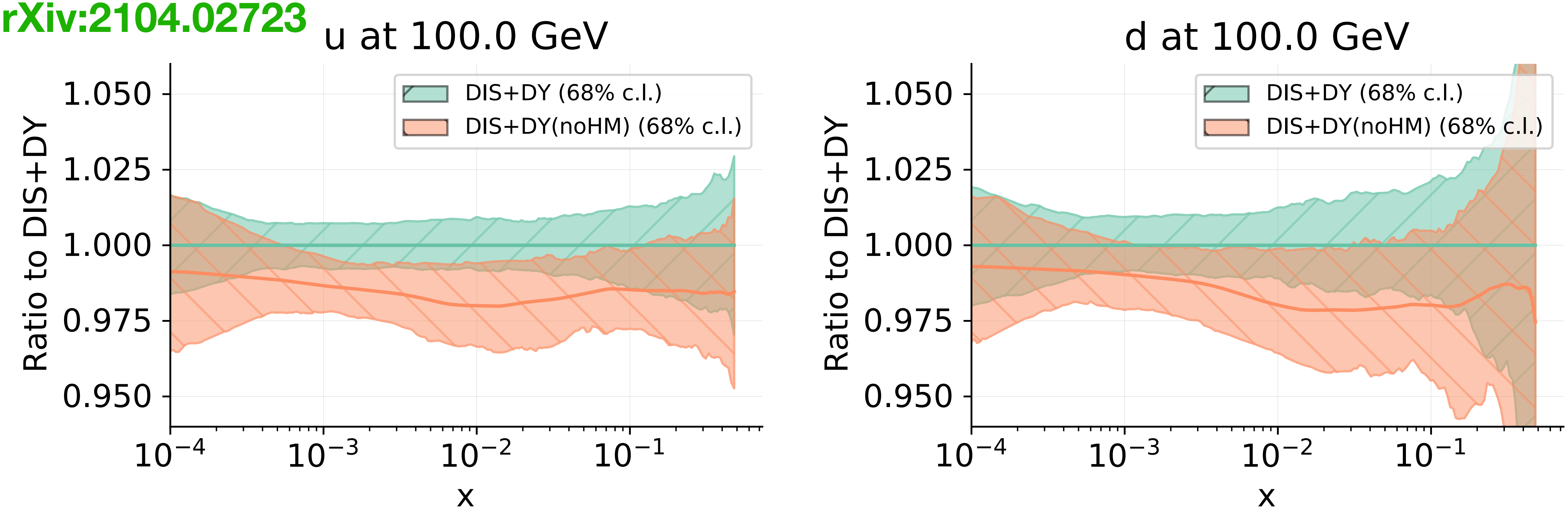

Increased PDF uncertainties in high-x region for several processes interesting for NP:

- diboson
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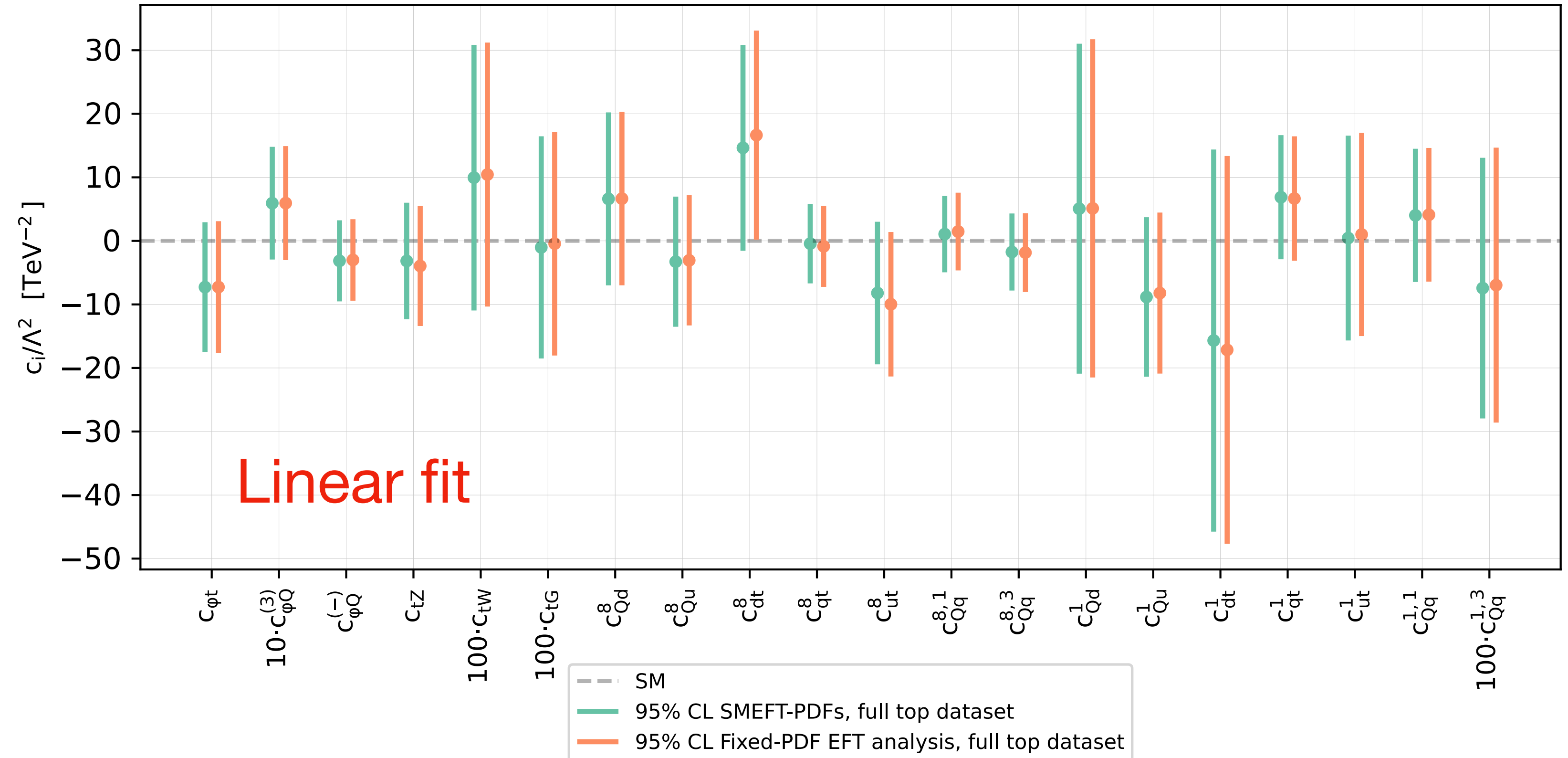
- high mass jets
- etc..

Also: NN good at interpolating, bad in extrapolation

Conservative fit

Simultaneous fit

Moderate effect on WC, ~ 5-10%



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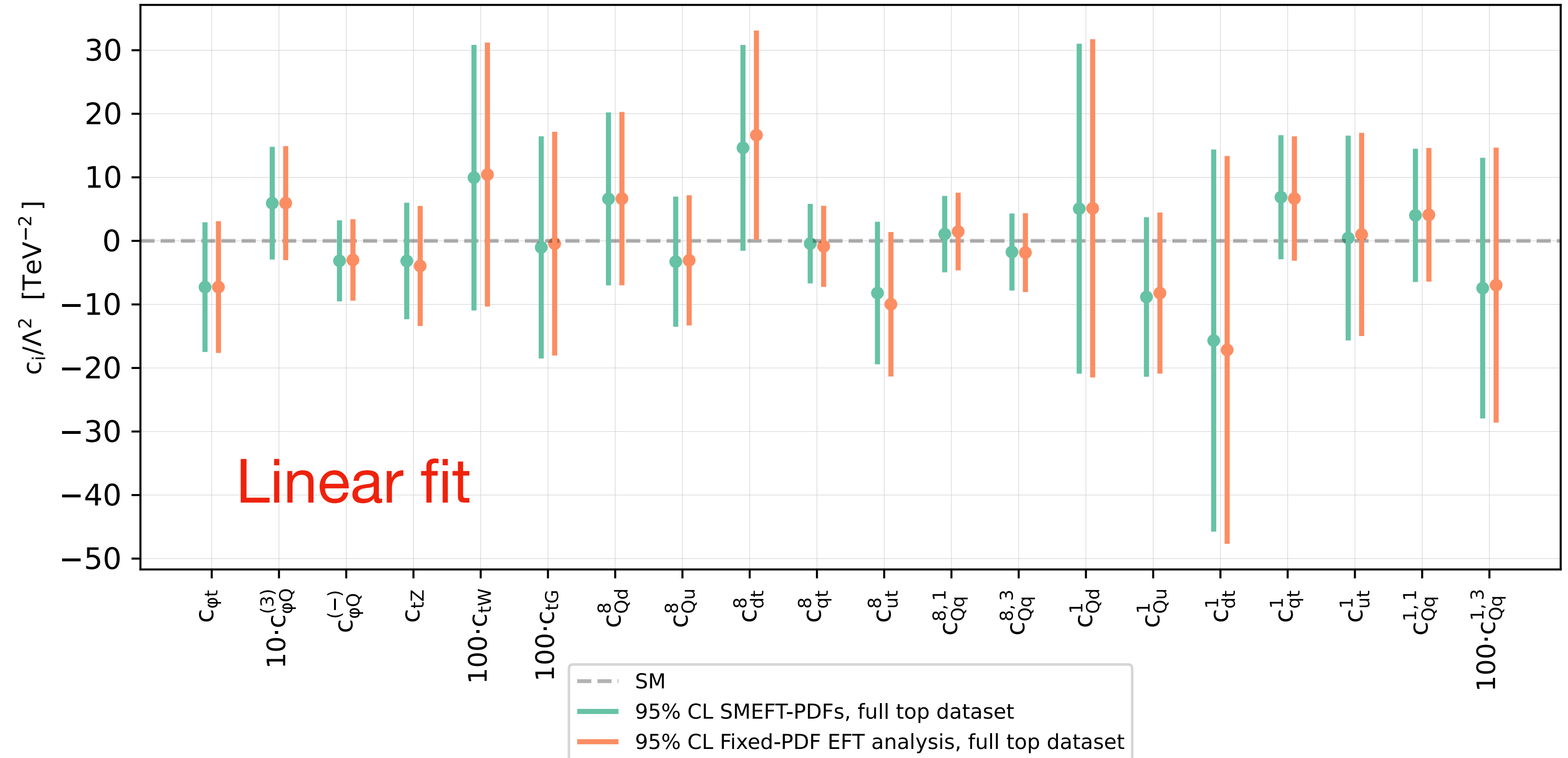
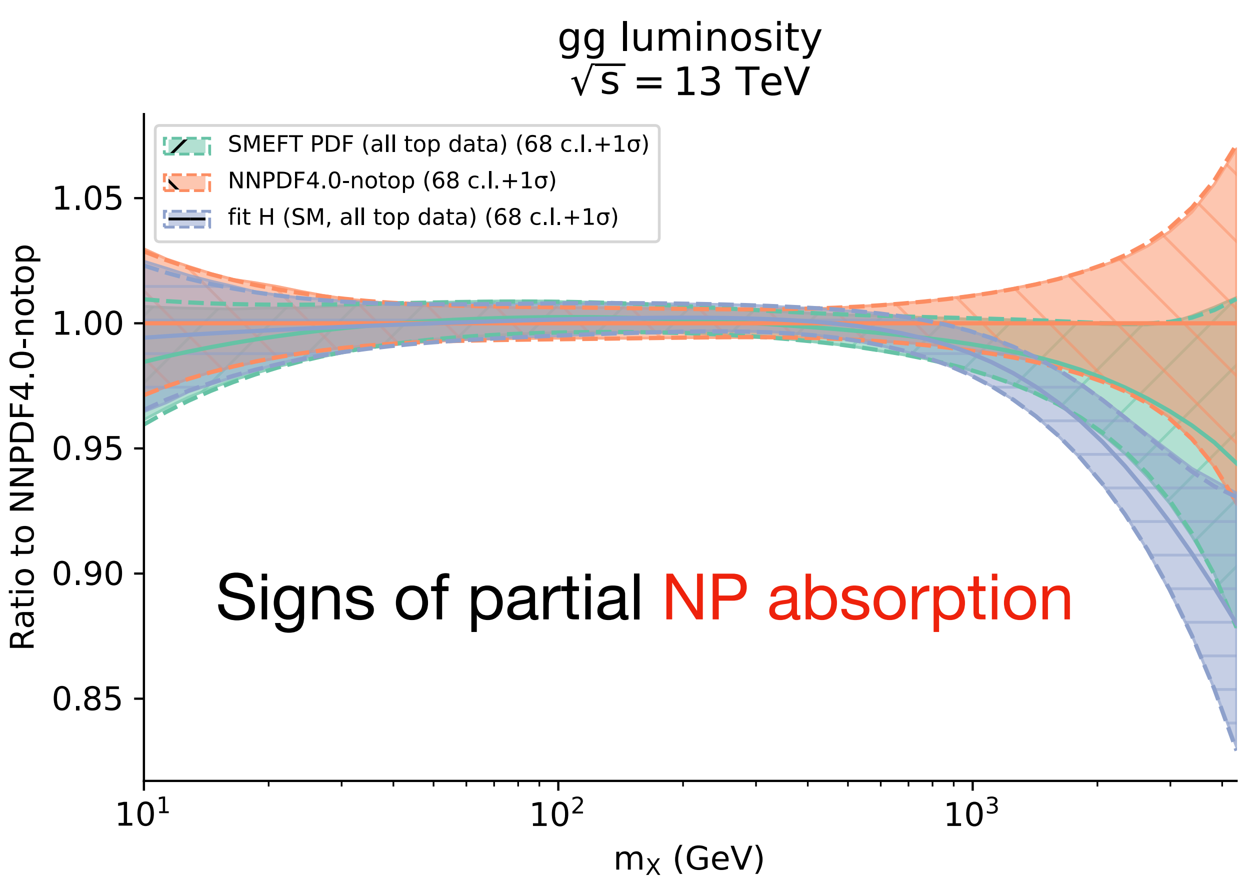


Shift in PDF not as dramatic as SM



Signs of partial NP absorption

Conservative fit

Simultaneous fit

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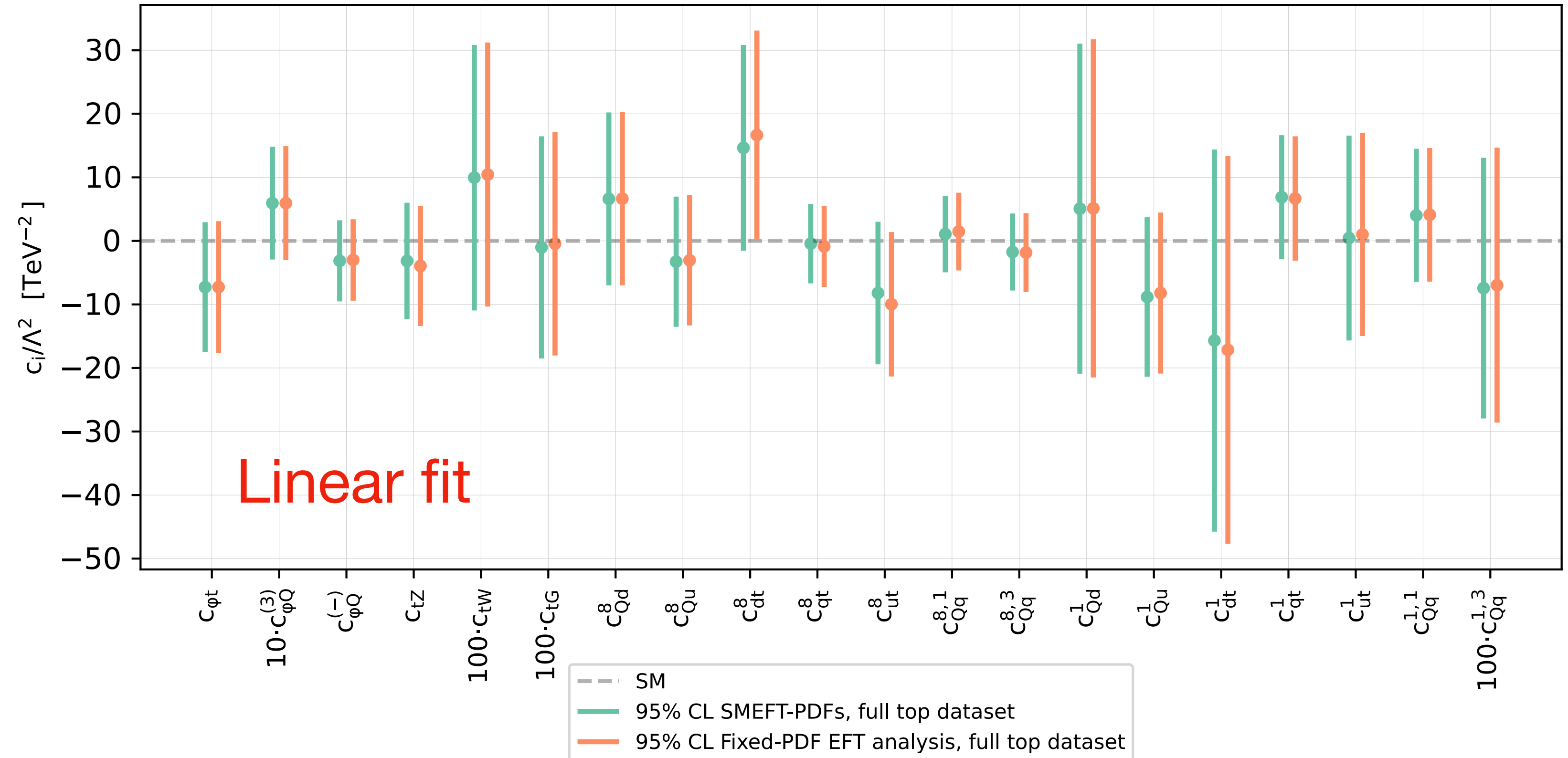

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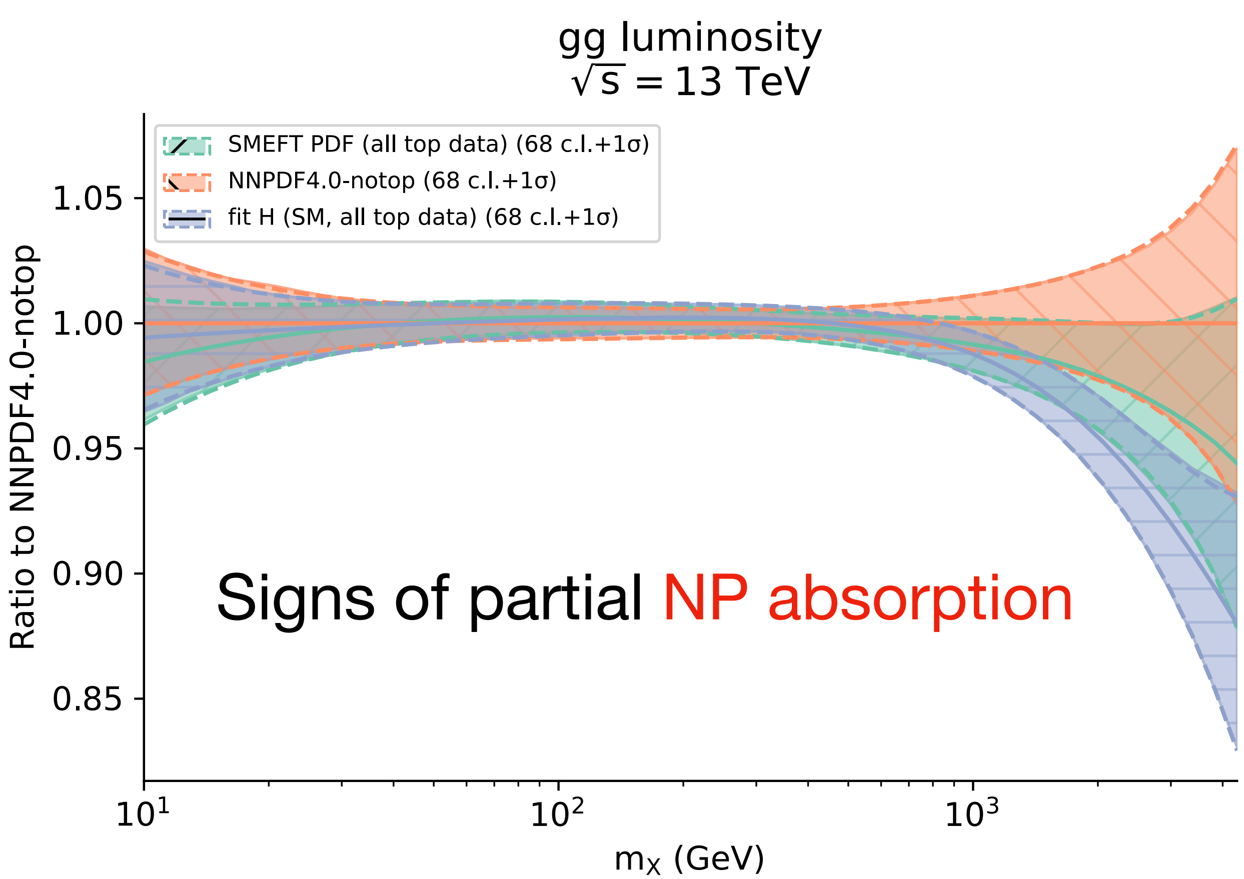
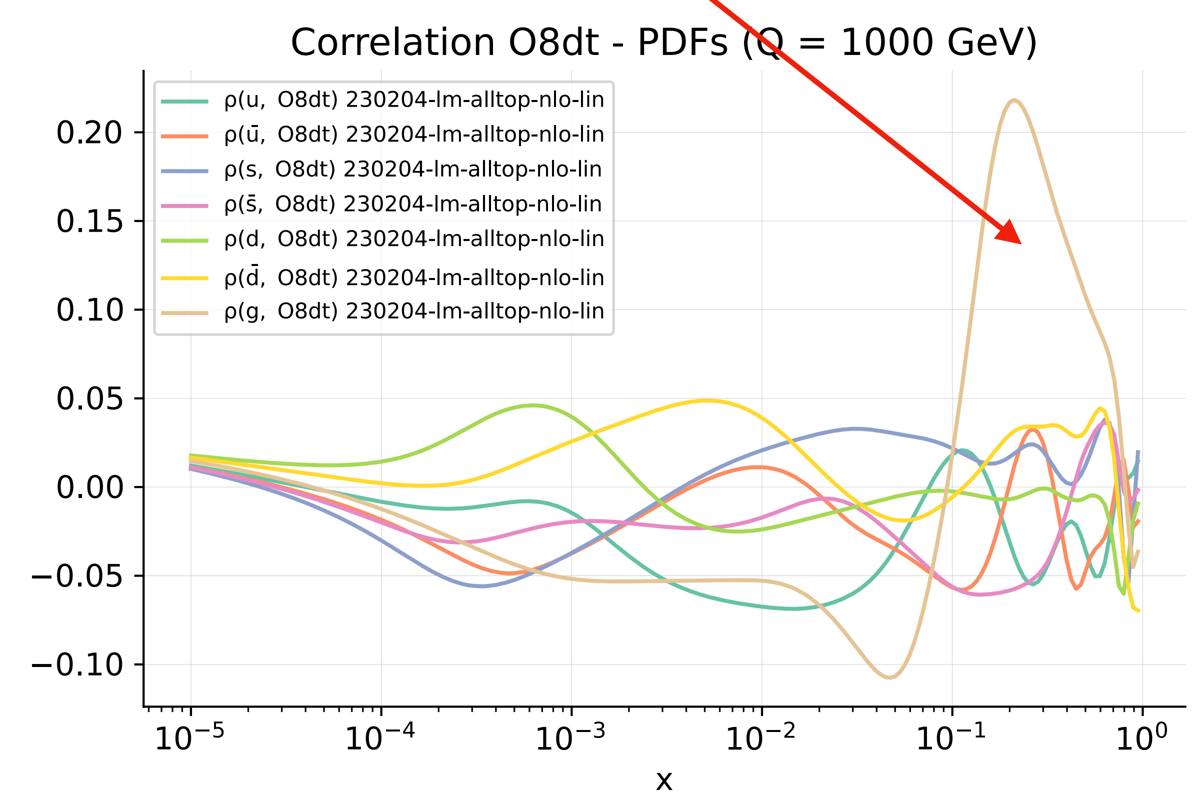


Correlation gluon-EFT



We now have a 4th option to perform a SMEFT fit

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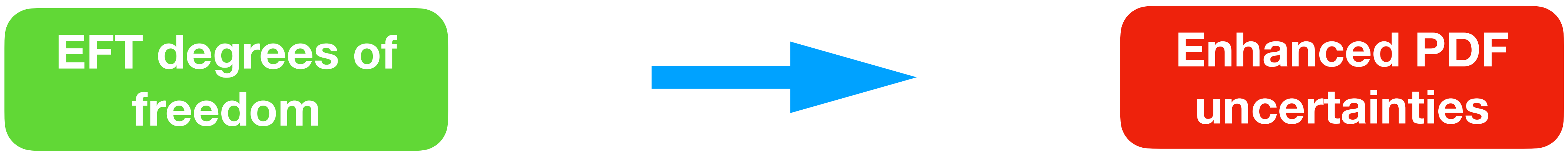


We now have a 4th option to perform a SMEFT fit

From the simultaneous fits we now have a SMEFT PDF

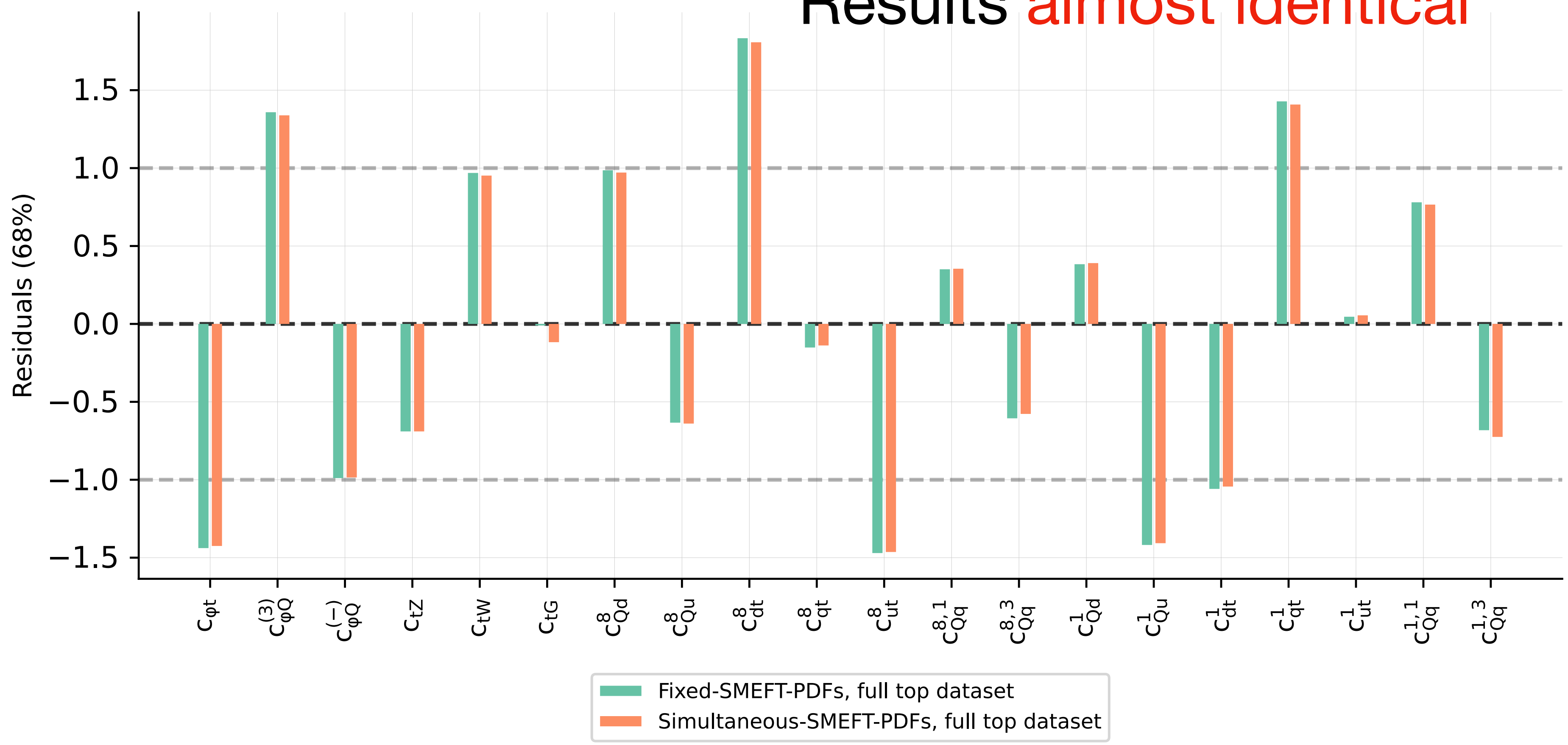
EFT degrees of freedom → **Enhanced PDF uncertainties**

Results almost identical

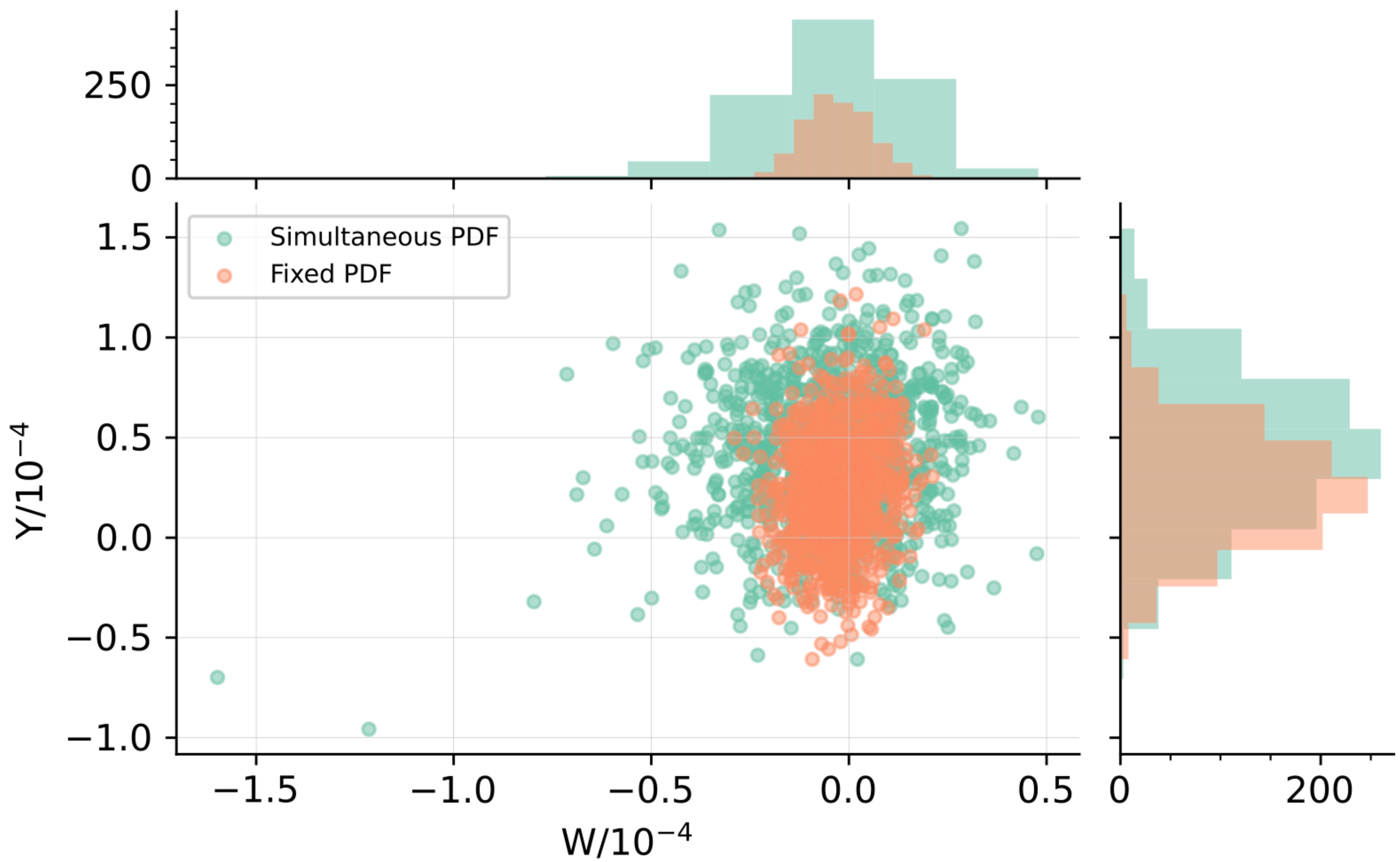
Simultaneous fit

fixed-SMEFT PDF fit

$$R_n = \frac{c_n^*}{\sigma_n}$$



arXiv:2104.02723 Things become more relevant at HL-LHC



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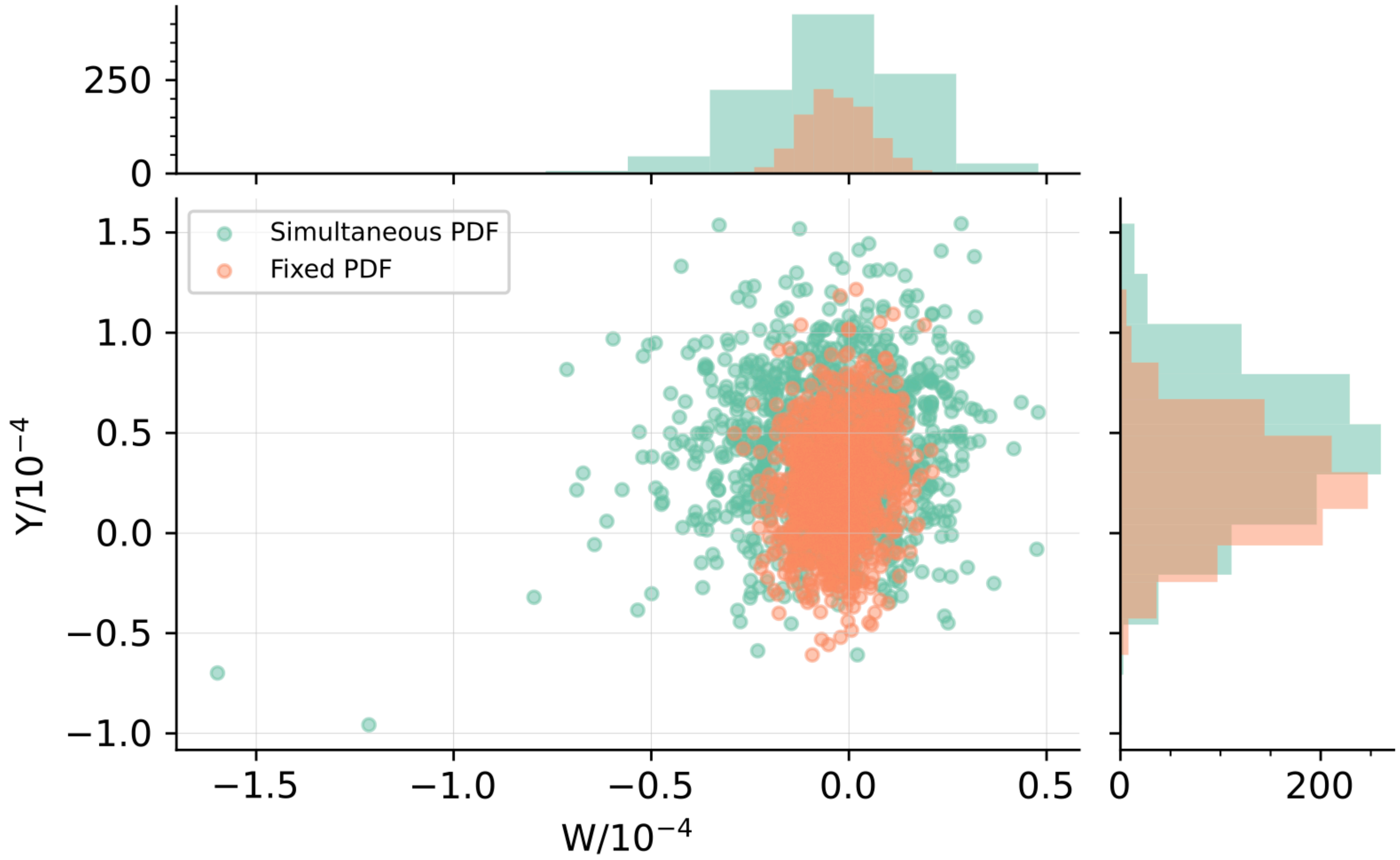

	SM PDFs	SMEFT PDFs	best-fit shift	broadening
$W \times 10^5$ (68% CL)	$[-1.1, 0.5]$	$[-2.4, 1.5]$	-0.2	$+144\%$
$W \times 10^5$ (95% CL)	$[-2.0, 1.4]$	$[-4.3, 3.4]$	-0.2	$+126\%$
$Y \times 10^5$ (68% CL)	$[-0.4, 5.2]$	$[0.6, 8.0]$	$+1.9$	$+32\%$
$Y \times 10^5$ (95% CL)	$[-3.2, 8.1]$	$[-3.1, 11.7]$	$+1.9$	$+31\%$

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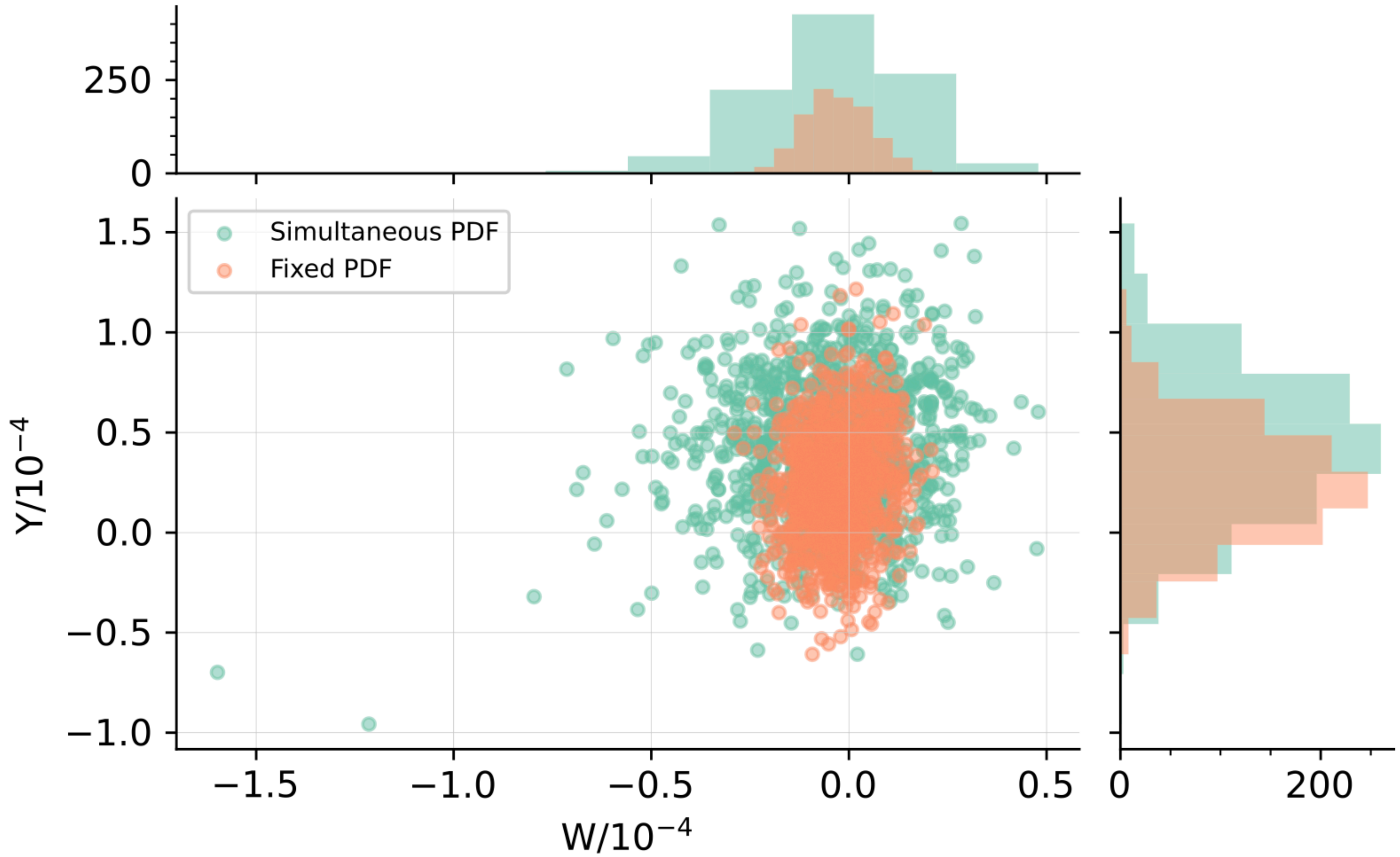

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Introduction

PDF extraction

SMEFT

SIMUnet

Simultaneous fit of PDFs and SMEFT: top quark sector

Outlook and conclusions

Proton structure

Experimental uncertainties are propagated to the PDFs via Monte Carlo

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$$p(x_i) = e^{-\frac{1}{2}(x_i - \bar{x}_i)^T C^{-1} (x_i - \bar{x}_i)}$$

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→

N pseudodata samples $\{x_i\}$

$N \sim 1000$

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Each sample is a “parallel universe” in which central data has been fluctuated

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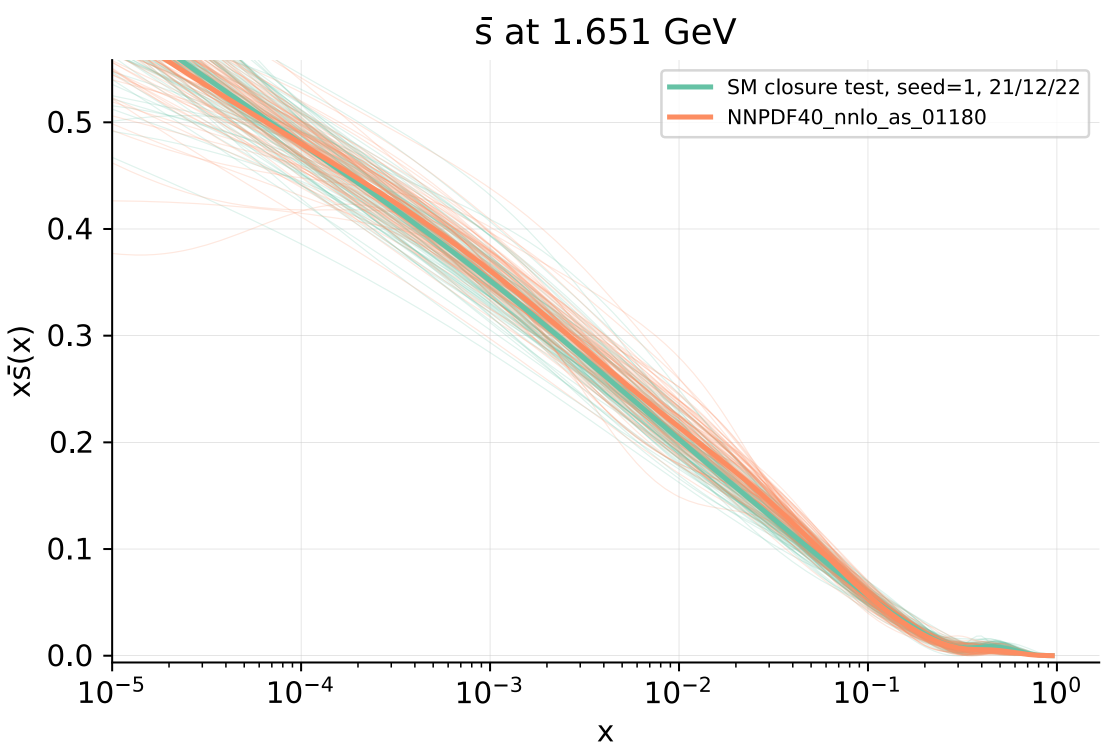

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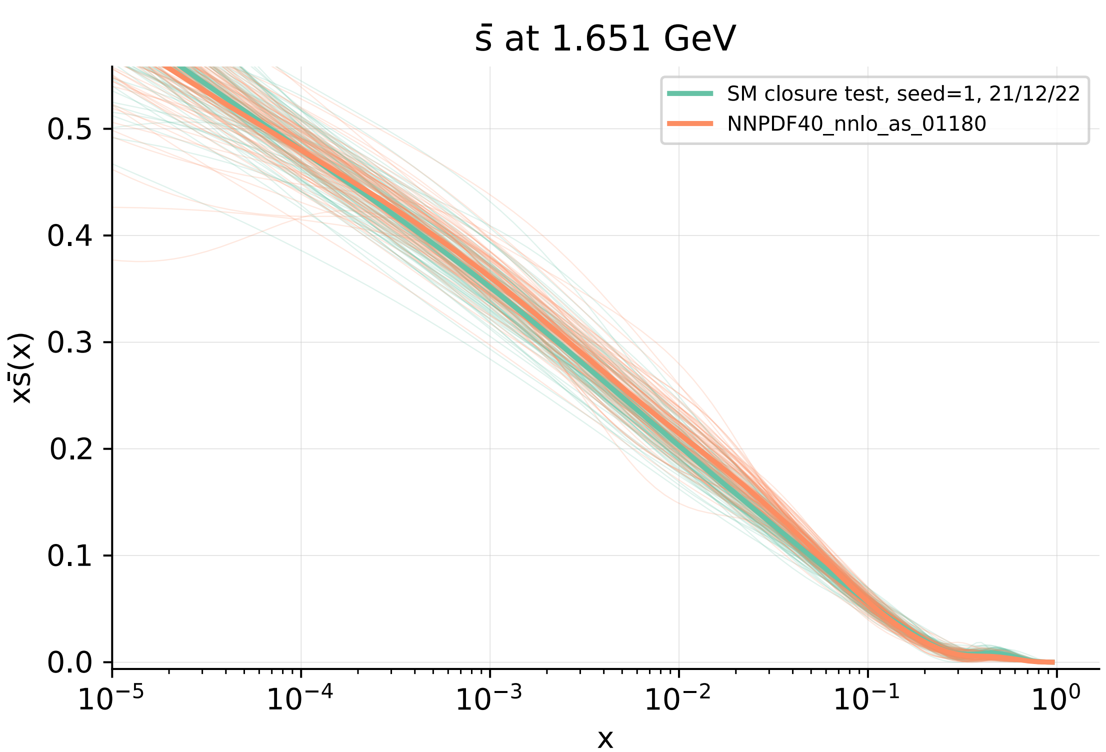
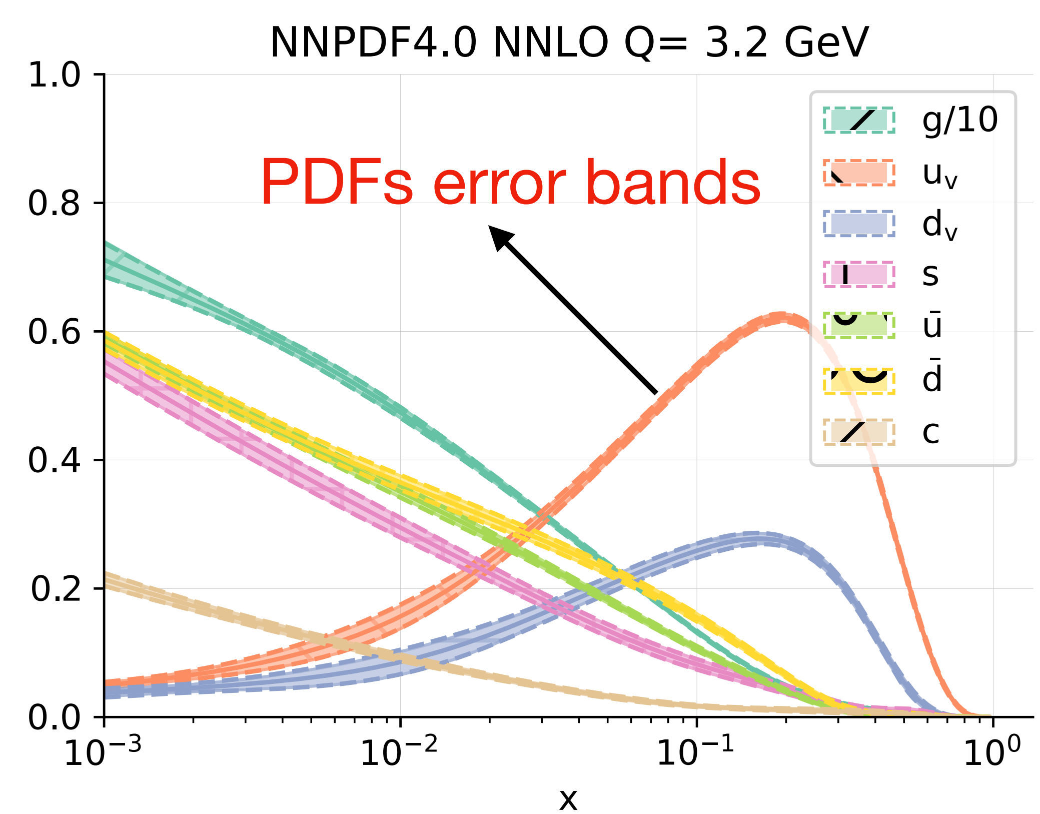
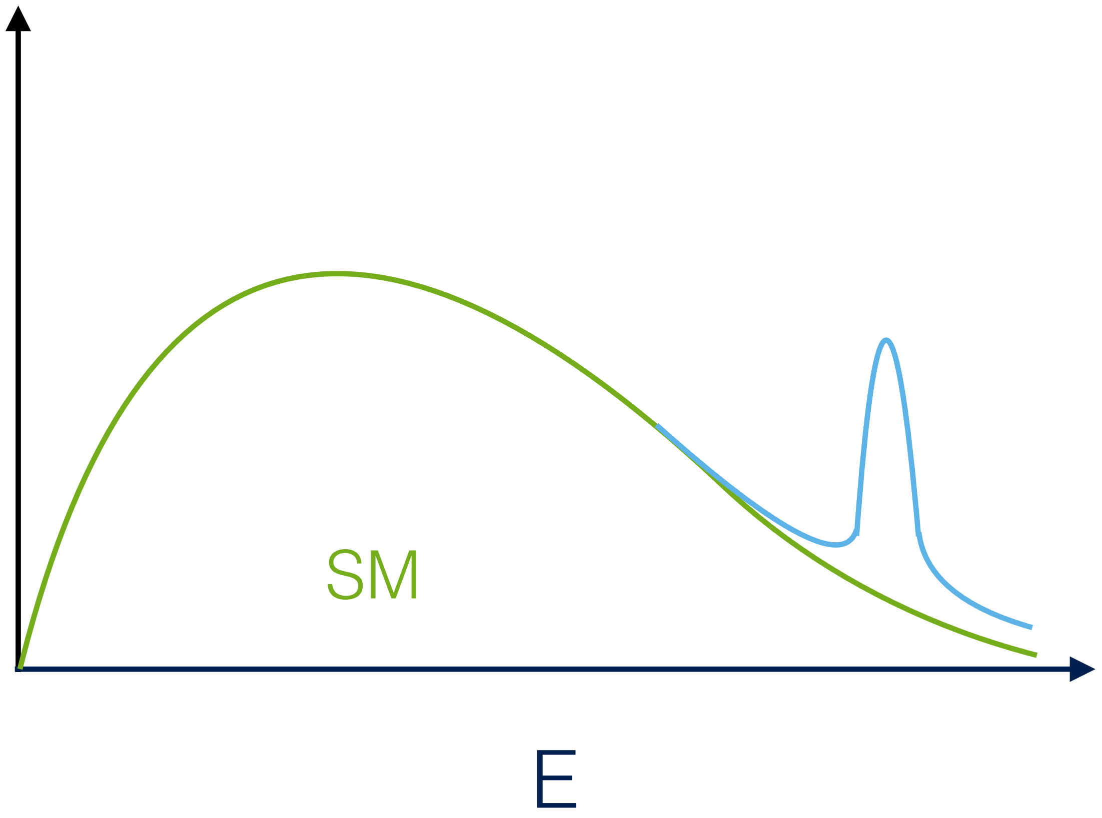




Ball et. al, NNPDF4.0, 2109.02653

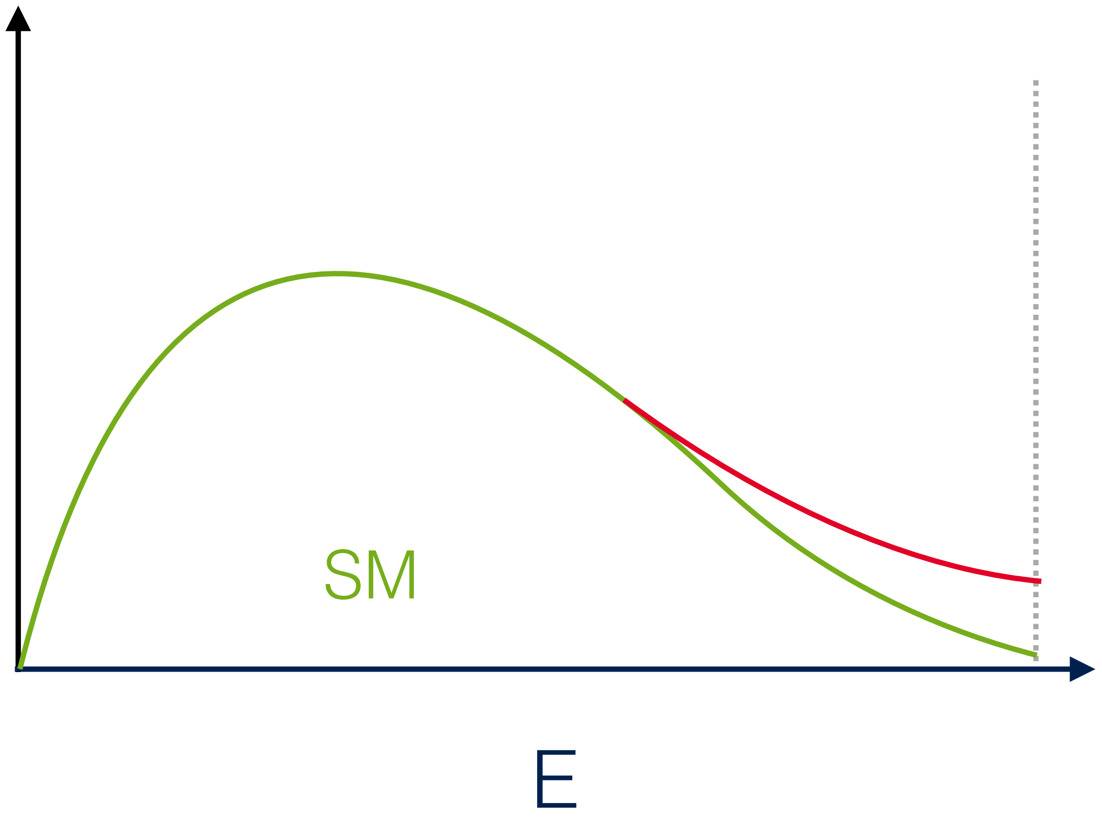
The Standard Model Effective Field Theory

Direct search (Bumps)



Direct search (Bumps)

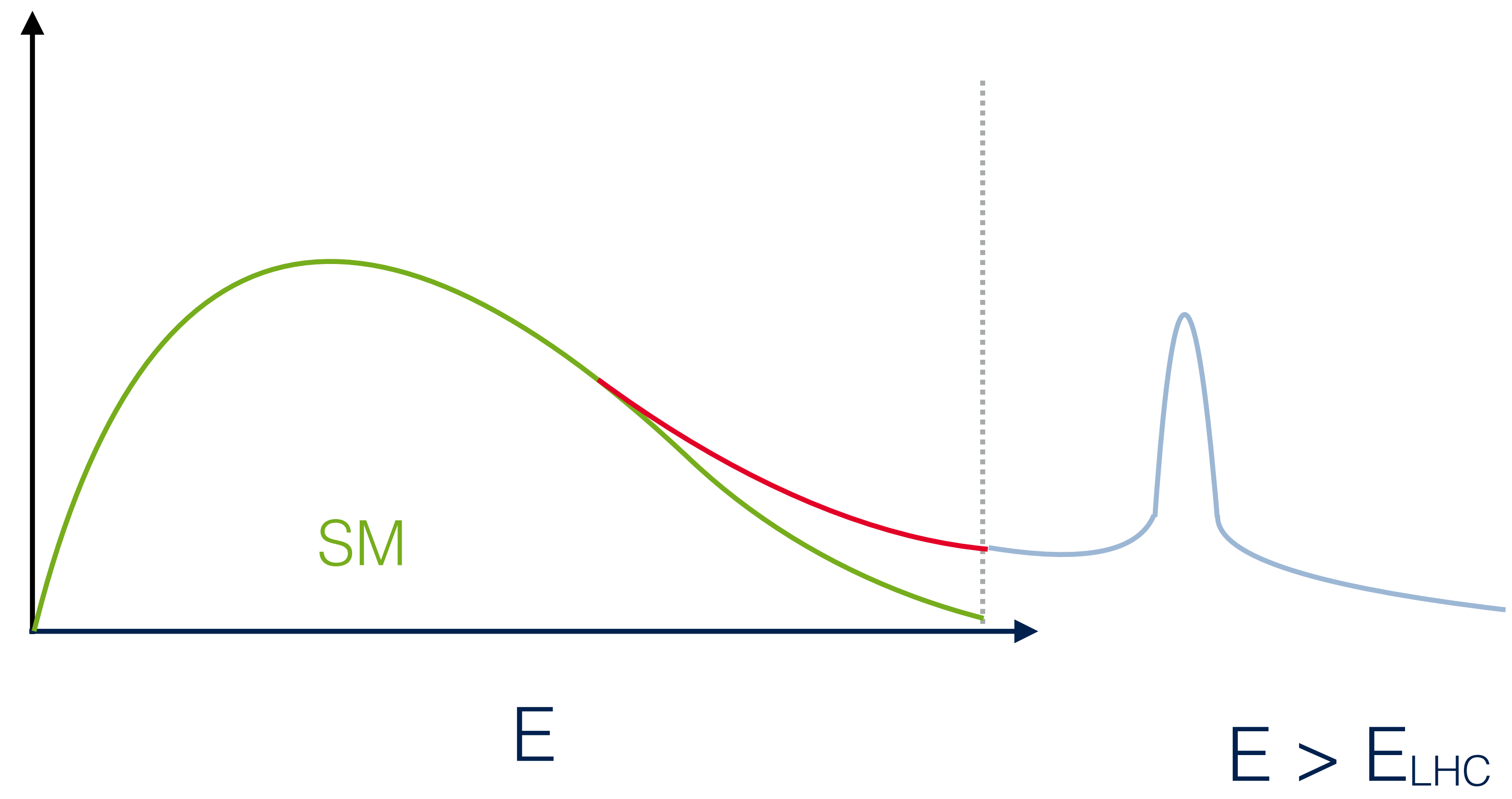
Indirect (scouting tails)



Direct search (Bumps)

Indirect (scouting tails)

⇒ New physics is heavy



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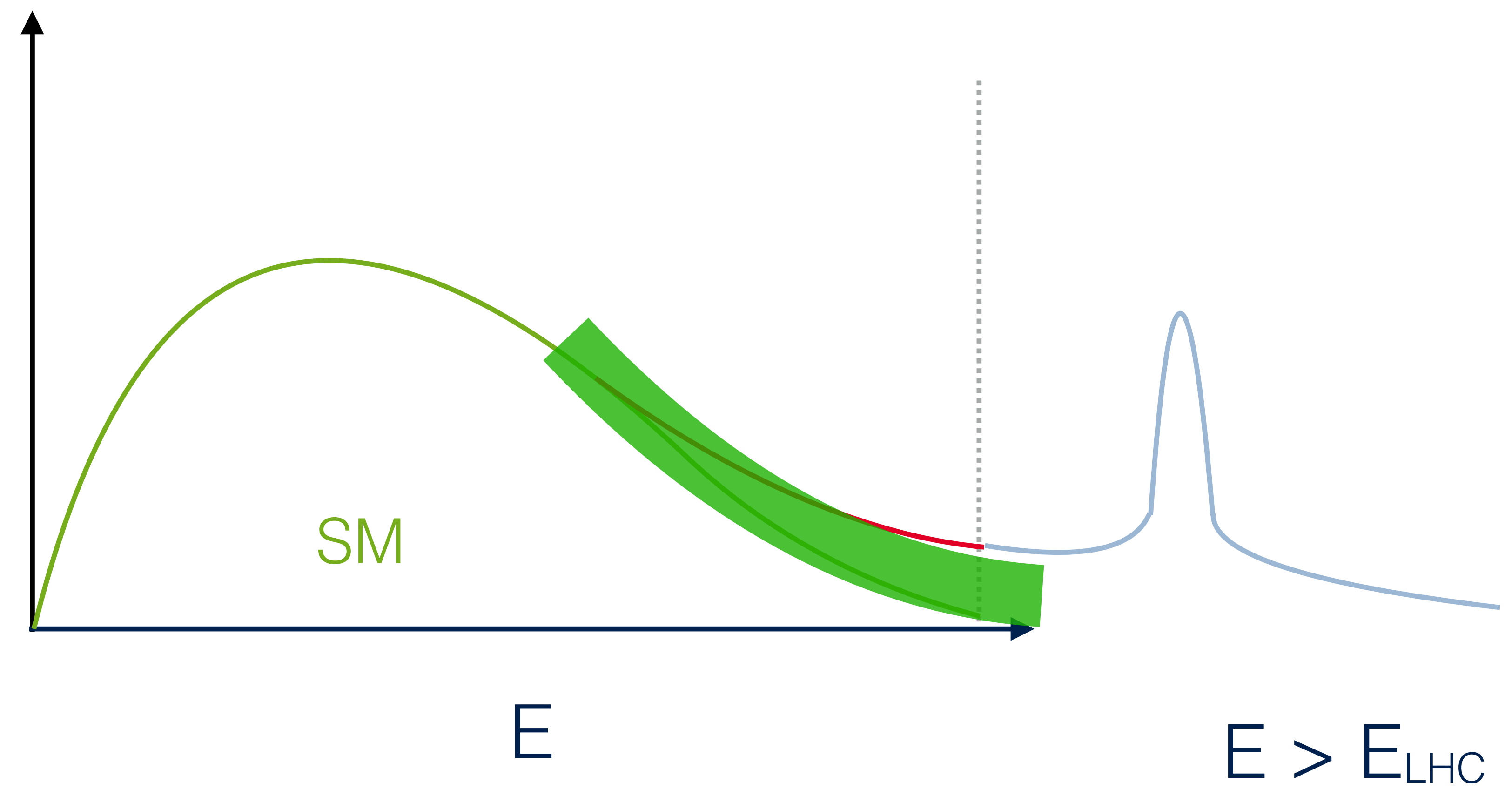

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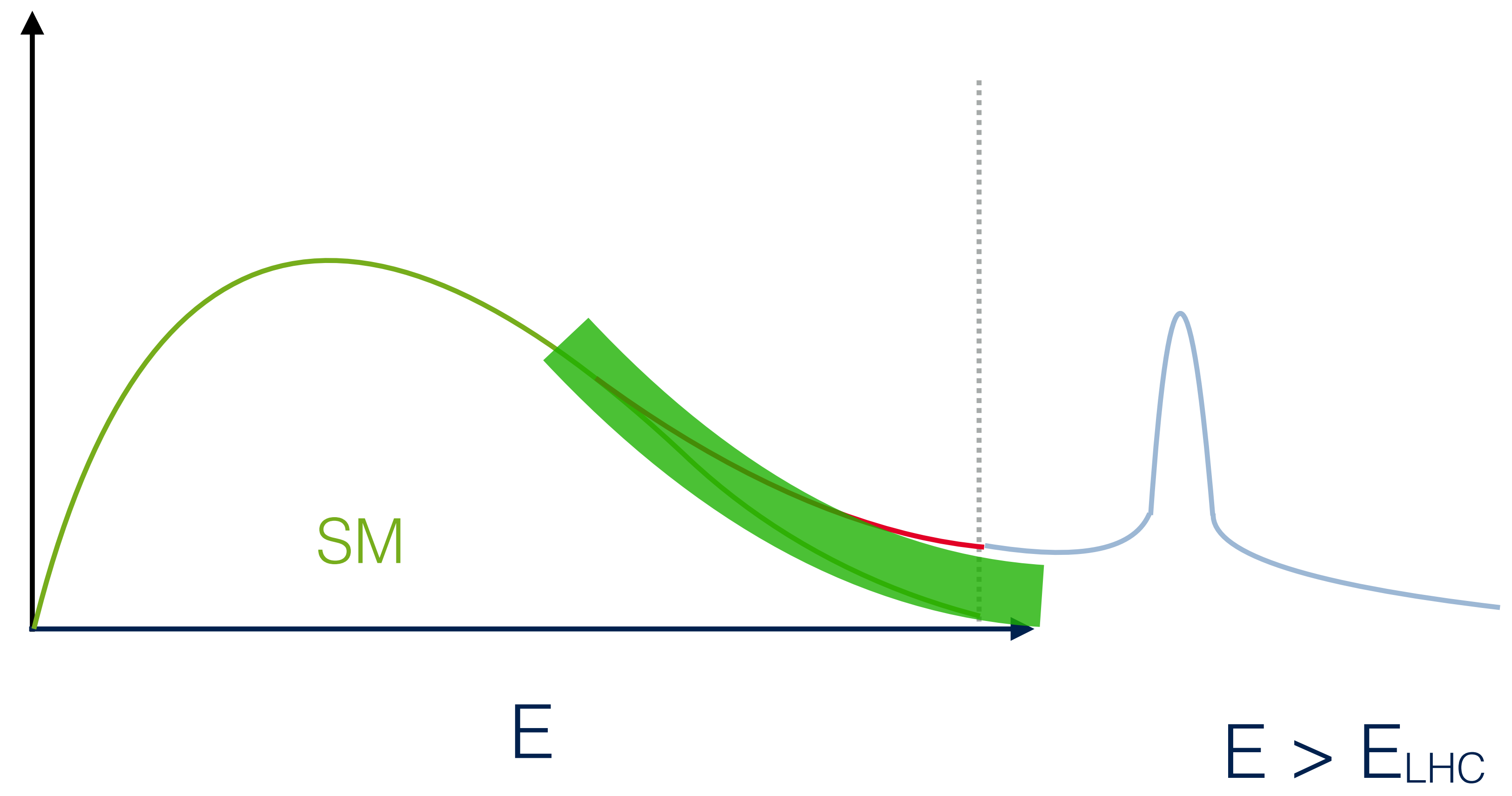

Framework to describe both precision physics and Heavy New Physics.

Direct search (Bumps)

Indirect (scouting tails)

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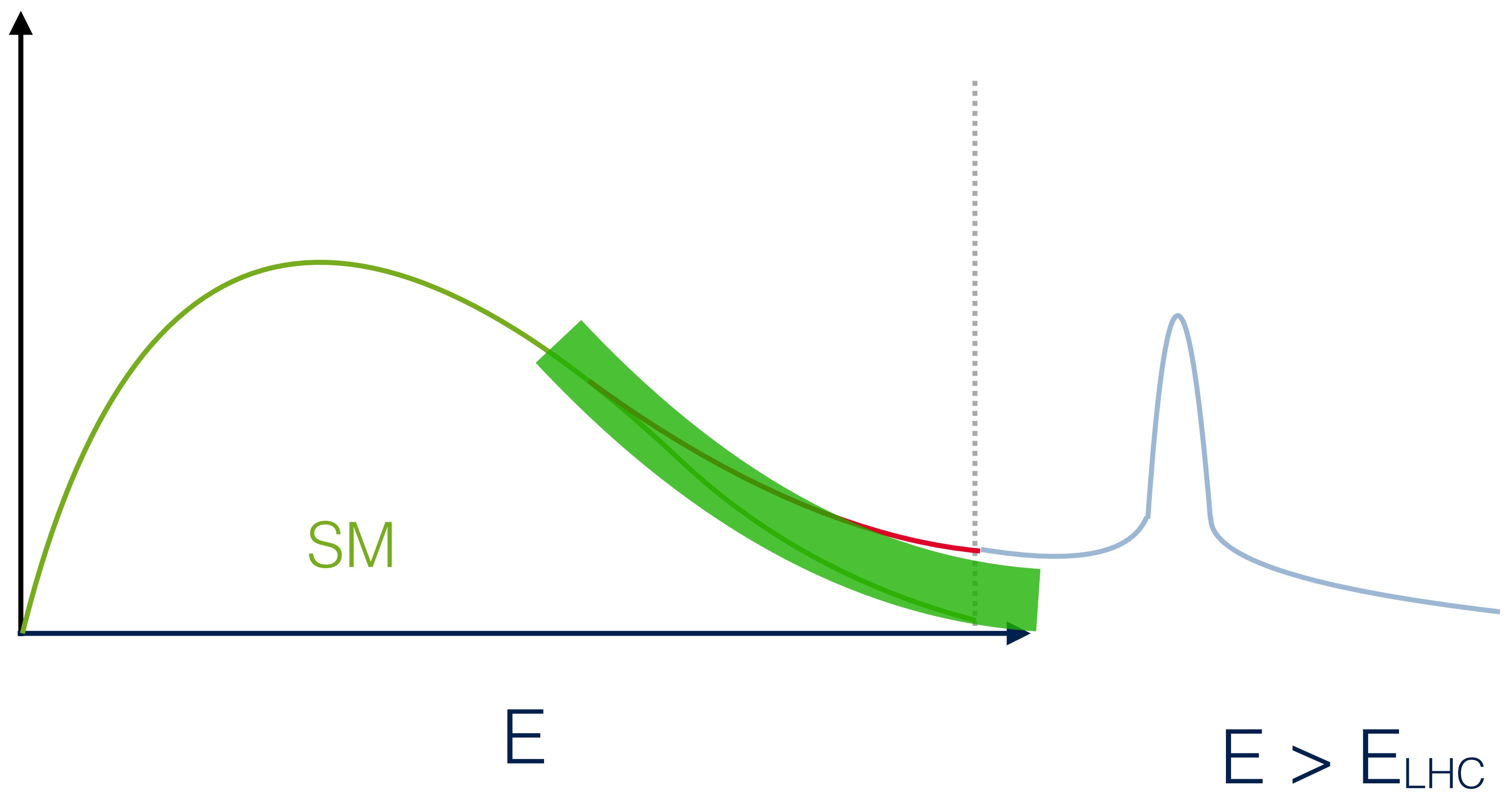

Framework to describe both precision physics and Heavy New Physics.

Standard Model Effective Field Theory (SMEFT)

$$\mathcal{L} = \mathcal{L}_{SM} + \sum_i \frac{1}{\Lambda}\mathcal{O}_i^5 + \sum_i \frac{1}{\Lambda^2}\mathcal{O}_i^6 + \ldots$$

- **Modified interactions among SM particles**
- **Higher dimensional operators preserve SM symmetries.**
- **Mappable to a large class of BSM models.**
- **Truncate at dim 6: leading corrections**

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Scale of NP

- **Modified interactions among SM particles**
- **Higher dimensional operators preserve SM symmetries.**
- **Mappable to a large class of BSM models.**
- **Truncate at dim 6: leading corrections**

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EFT to-do list

- **Define target operators: e.g. top-philic EFT** [arXiv:1802.07237]
- **Find optimal observables to probe them**
- **Compute with precision theoretical predictions (both SM and EFT)**
- **Make accurate measurements**

59 operators flavour universal

2499 operators flavour general

X^3		φ^6 and $\varphi^4 D^2$		$\psi^2\varphi^3$	
Q_G	$f^{ABC}G_\mu^{A\nu}G_\nu^{B\rho}G_\rho^{C\mu}$	Q_φ	$(\varphi^\dagger\varphi)^3$	$Q_{e\varphi}$	$(\varphi^\dagger\varphi)(\bar{l}_p e_r \varphi)$
$Q_{\widetilde{G}}$	$f^{ABC}\widetilde{G}_\mu^{A\nu}G_\nu^{B\rho}G_\rho^{C\mu}$	$Q_{\varphi\Box}$	$(\varphi^\dagger\varphi)\Box(\varphi^\dagger\varphi)$	$Q_{u\varphi}$	$(\varphi^\dagger\varphi)(\bar{q}_p u_r \widetilde{\varphi})$
Q_W	$\varepsilon^{IJK}W_\mu^{I\nu}W_\nu^{J\rho}W_\rho^{K\mu}$	$Q_{\varphi D}$	$\left(\varphi^\dagger D^\mu\varphi\right)^\star\left(\varphi^\dagger D_\mu\varphi\right)$	$Q_{d\varphi}$	$(\varphi^\dagger\varphi)(\bar{q}_p d_r \varphi)$
$Q_{\widetilde{W}}$	$\varepsilon^{IJK}\widetilde{W}_\mu^{I\nu}W_\nu^{J\rho}W_\rho^{K\mu}$				
$X^2\varphi^2$		$\psi^2 X\varphi$		$\psi^2\varphi^2 D$	
$Q_{\varphi G}$	$\varphi^\dagger\varphi\, G_{\mu\nu}^A G^{A\mu\nu}$	Q_{eW}	$(\bar{l}_p\sigma^{\mu\nu}e_r)\tau^I\varphi W_{\mu\nu}^I$	$Q_{\varphi l}^{(1)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{l}_p\gamma^\mu l_r)$
$Q_{\varphi\widetilde{G}}$	$\varphi^\dagger\varphi\, \widetilde{G}_{\mu\nu}^A G^{A\mu\nu}$	Q_{eB}	$(\bar{l}_p\sigma^{\mu\nu}e_r)\varphi B_{\mu\nu}$	$Q_{\varphi l}^{(3)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu^I\varphi)(\bar{l}_p\tau^I\gamma^\mu l_r)$
$Q_{\varphi W}$	$\varphi^\dagger\varphi\, W_{\mu\nu}^I W^{I\mu\nu}$	Q_{uG}	$(\bar{q}_p\sigma^{\mu\nu}T^A u_r)\widetilde{\varphi}\, G_{\mu\nu}^A$	$Q_{\varphi e}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{e}_p\gamma^\mu e_r)$
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$Q_{\varphi B}$	$\varphi^\dagger\varphi\, B_{\mu\nu}B^{\mu\nu}$	Q_{uB}	$(\bar{q}_p\sigma^{\mu\nu}u_r)\widetilde{\varphi}\, B_{\mu\nu}$	$Q_{\varphi q}^{(3)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu^I\varphi)(\bar{q}_p\tau^I\gamma^\mu q_r)$
$Q_{\varphi\widetilde{B}}$	$\varphi^\dagger\varphi\, \widetilde{B}_{\mu\nu}B^{\mu\nu}$	Q_{dG}	$(\bar{q}_p\sigma^{\mu\nu}T^A d_r)\varphi\, G_{\mu\nu}^A$	$Q_{\varphi u}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{u}_p\gamma^\mu u_r)$
$Q_{\varphi WB}$	$\varphi^\dagger\tau^I\varphi\, W_{\mu\nu}^I B^{\mu\nu}$	Q_{dW}	$(\bar{q}_p\sigma^{\mu\nu}d_r)\tau^I\varphi\, W_{\mu\nu}^I$	$Q_{\varphi d}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{d}_p\gamma^\mu d_r)$
$Q_{\varphi\widetilde{W}B}$	$\varphi^\dagger\tau^I\varphi\, \widetilde{W}_{\mu\nu}^I B^{\mu\nu}$	Q_{dB}	$(\bar{q}_p\sigma^{\mu\nu}d_r)\varphi\, B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\widetilde{\varphi}^\dagger D_\mu\varphi)(\bar{u}_p\gamma^\mu d_r)$

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$(\bar LL)(\bar LL)$		$(\bar RR)(\bar RR)$		$(\bar LL)(\bar RR)$	
Q_{ll}	$(\bar l_p\gamma_\mu l_r)(\bar l_s\gamma^\mu l_t)$	Q_{ee}	$(\bar e_p\gamma_\mu e_r)(\bar e_s\gamma^\mu e_t)$	Q_{le}	$(\bar l_p\gamma_\mu l_r)(\bar e_s\gamma^\mu e_t)$
$Q_{qq}^{(1)}$	$(\bar q_p\gamma_\mu q_r)(\bar q_s\gamma^\mu q_t)$	Q_{uu}	$(\bar u_p\gamma_\mu u_r)(\bar u_s\gamma^\mu u_t)$	Q_{lu}	$(\bar l_p\gamma_\mu l_r)(\bar u_s\gamma^\mu u_t)$
$Q_{qq}^{(3)}$	$(\bar q_p\gamma_\mu \tau^I q_r)(\bar q_s\gamma^\mu \tau^I q_t)$	Q_{dd}	$(\bar d_p\gamma_\mu d_r)(\bar d_s\gamma^\mu d_t)$	Q_{ld}	$(\bar l_p\gamma_\mu l_r)(\bar d_s\gamma^\mu d_t)$
$Q_{lq}^{(1)}$	$(\bar l_p\gamma_\mu l_r)(\bar q_s\gamma^\mu q_t)$	Q_{eu}	$(\bar e_p\gamma_\mu e_r)(\bar u_s\gamma^\mu u_t)$	Q_{qe}	$(\bar q_p\gamma_\mu q_r)(\bar e_s\gamma^\mu e_t)$
$Q_{lq}^{(3)}$	$(\bar l_p\gamma_\mu \tau^I l_r)(\bar q_s\gamma^\mu \tau^I q_t)$	Q_{ed}	$(\bar e_p\gamma_\mu e_r)(\bar d_s\gamma^\mu d_t)$	$Q_{qu}^{(1)}$	$(\bar q_p\gamma_\mu q_r)(\bar u_s\gamma^\mu u_t)$
		$Q_{ud}^{(1)}$	$(\bar u_p\gamma_\mu u_r)(\bar d_s\gamma^\mu d_t)$	$Q_{qu}^{(8)}$	$(\bar q_p\gamma_\mu T^A q_r)(\bar u_s\gamma^\mu T^A u_t)$
		$Q_{ud}^{(8)}$	$(\bar u_p\gamma_\mu T^A u_r)(\bar d_s\gamma^\mu T^A d_t)$	$Q_{qd}^{(1)}$	$(\bar q_p\gamma_\mu q_r)(\bar d_s\gamma^\mu d_t)$
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Dim 6: Large number of operators and therefore degrees of freedom

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Many observables and final states → **Break degeneracies in parameter space**

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NLO-QCD with SMEFT@NLO

Degrande et al, arXiv:2008.11743

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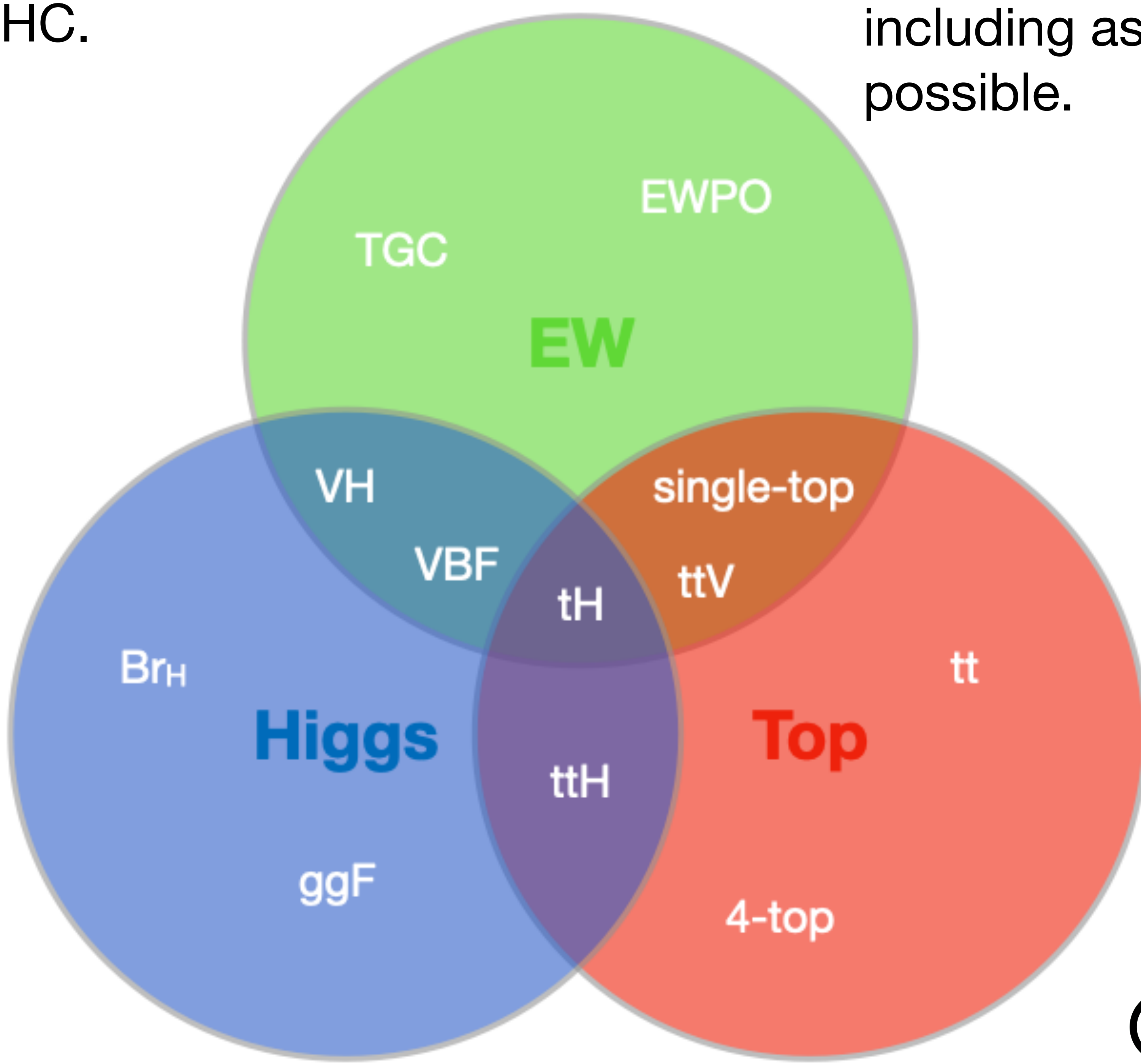
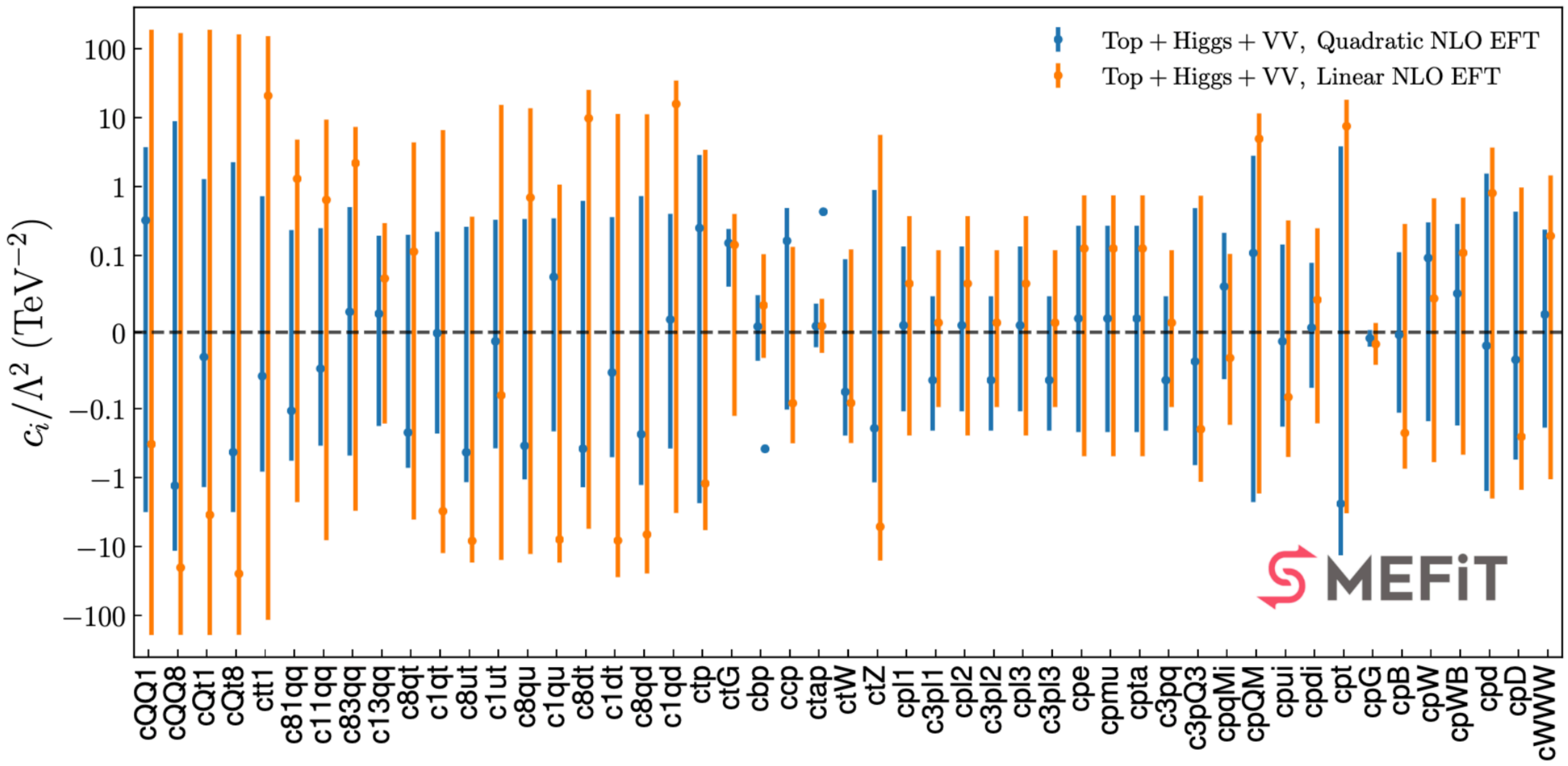
Linear contribution: leading correction

Quadratic contribution: useful information in many instances

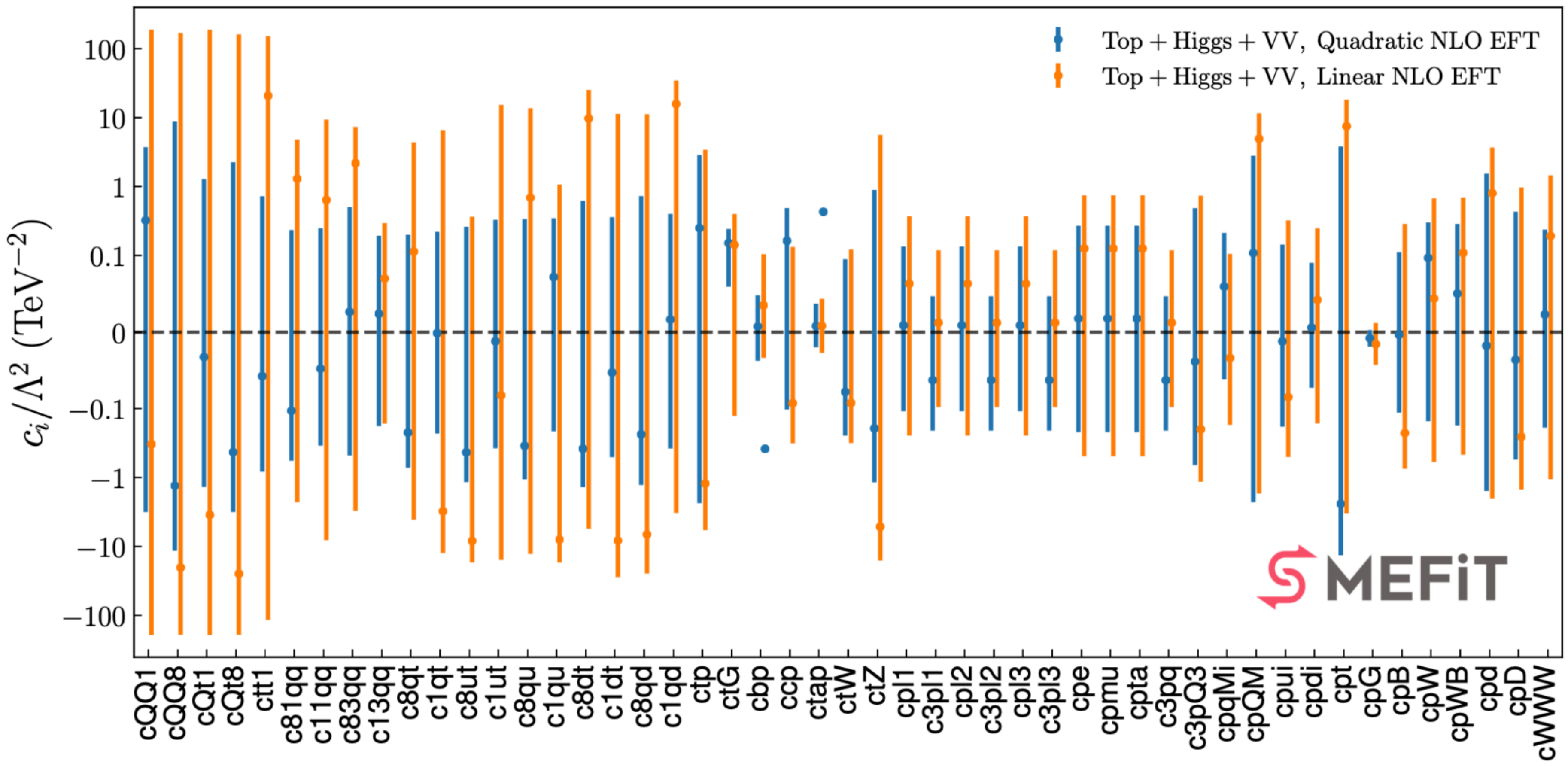
The SMEFT framework connects different sectors of observables measured at the LHC.

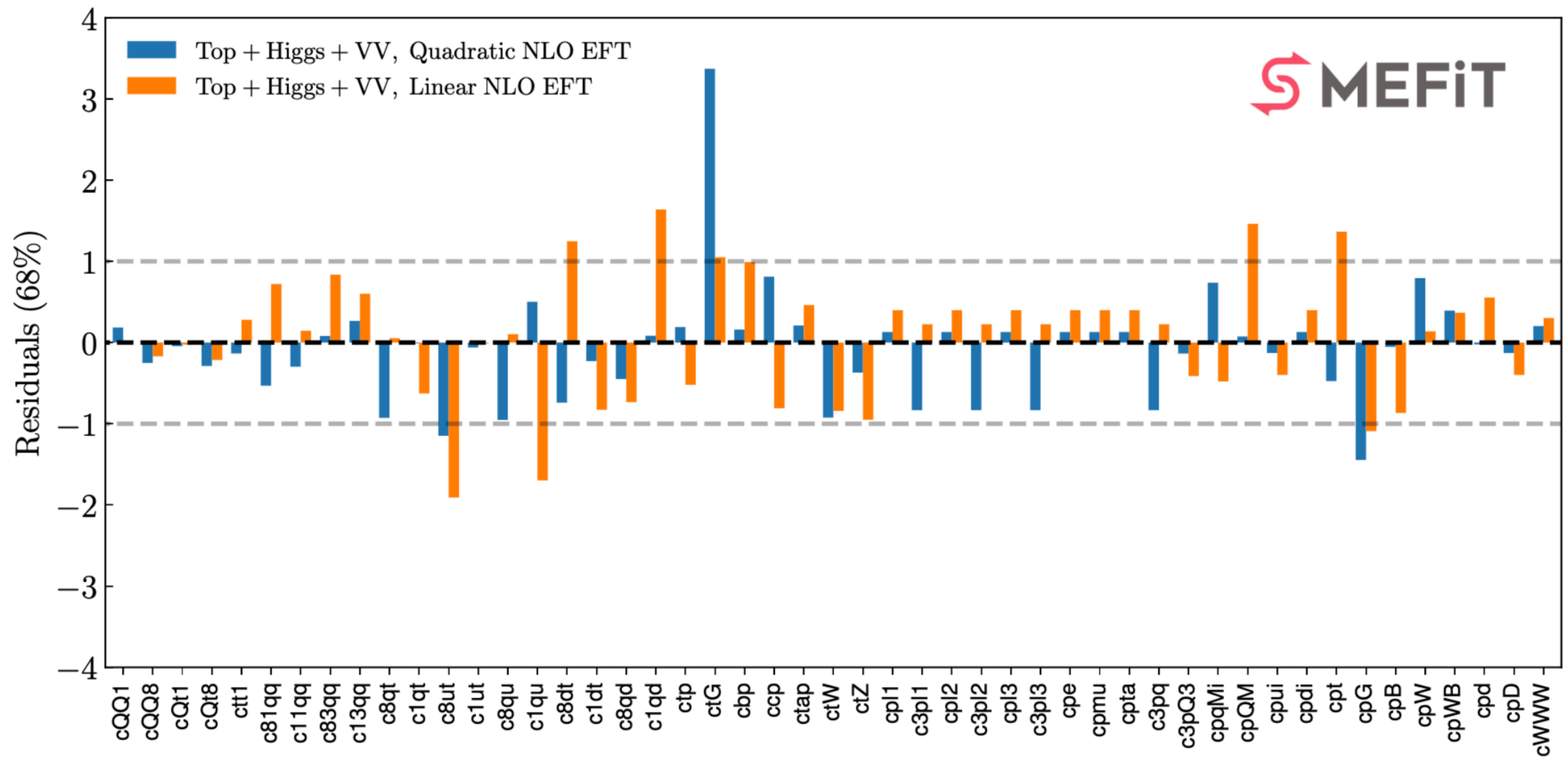
We can probe the SMEFT by taking a **global approach,** including as many datasets as possible.




Top + Higgs + VV, Quadratic NLO EFT
Top + Higgs + VV, Linear NLO EFT
c_i/Λ^2 (TeV^{-2})
100
10
1
0.1
0
−0.1
−1
−10
−100
cQQ1
cQQ8
cQt1
cQt8
ctt1
c81qq
c11qq
c83qq
c13qq
c8qt
c1qt
c8ut
c1ut
c8qu
c1qu
c8dt
c1dt
c8qd
c1qd
ctp
ctG
cbp
ccp
ctap
ctW
ctZ
cpl1
c3pl1
cpl2
c3pl2
cpl3
c3pl3
cpe
cpmu
cpta
c3pq
c3pQ3
cpqMi
cpQM
cpui
cpdi
cpt
cpG
cpB
cpW
cpWB
cpd
cpD
cWWW
SMEFiT

Global fit result

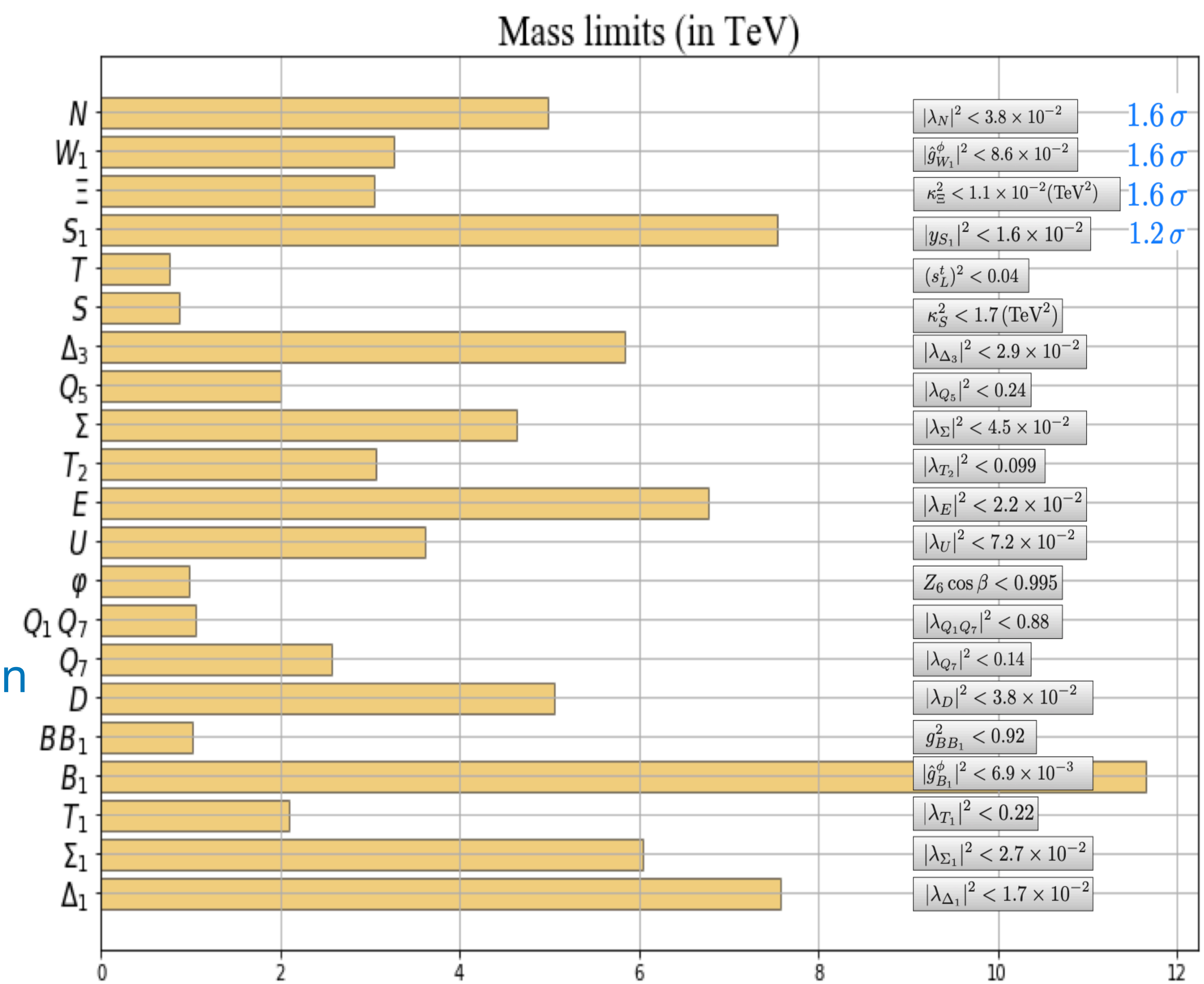




❖ Fits can be interpreted in UV completion models

❖ Bounds on coefficient translate on bounds on mass or couplings

❖ Simple case: single field extension



Ellis et al: arXiv:2012.02779

Process	$n_{\rm dat}$	$\chi^2_{\rm exp+th}$ [SM]	$\chi^2_{\rm exp+th}$ [SMEFT $\mathcal{O}(\Lambda^{-2})$]	$\chi^2_{\rm exp+th}$ [SMEFT $\mathcal{O}(\Lambda^{-4})$]
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$t\bar{t}$ AC	18	0.58	0.50	0.60
W helicities	4	0.71	0.45	0.47
$t\bar{t}Z$	12	1.19	1.17	0.94
$t\bar{t}W$	4	1.71	0.46	1.66
$t\bar{t}\gamma$	2	0.47	0.03	0.59
$t\bar{t}t\bar{t}$ & $t\bar{t}b\bar{b}$	8	1.32	1.06	0.49
single top	30	0.504	0.33	0.37
tW	6	1.00	0.82	0.82
tZ	5	0.45	0.30	0.31
Total	**175**	**1.24**	**0.84**	**1.14**

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For a quadratic fit, χ^2 improves only mildly

EFT quality of fit

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→ **Model is less flexible and unable to accomodate deviations**

The SM does not explain everything.

ν masses

Gravity

Dark Matter

Baryon asymmetry

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ν masses

Gravity

Dark Matter

Baryon asymmetry

We look for New Physics or BSM to explain the deficiencies.

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Gravity **Dark Matter**

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So far, the SM is undefeated: not been able to discover new particles at the LHC.

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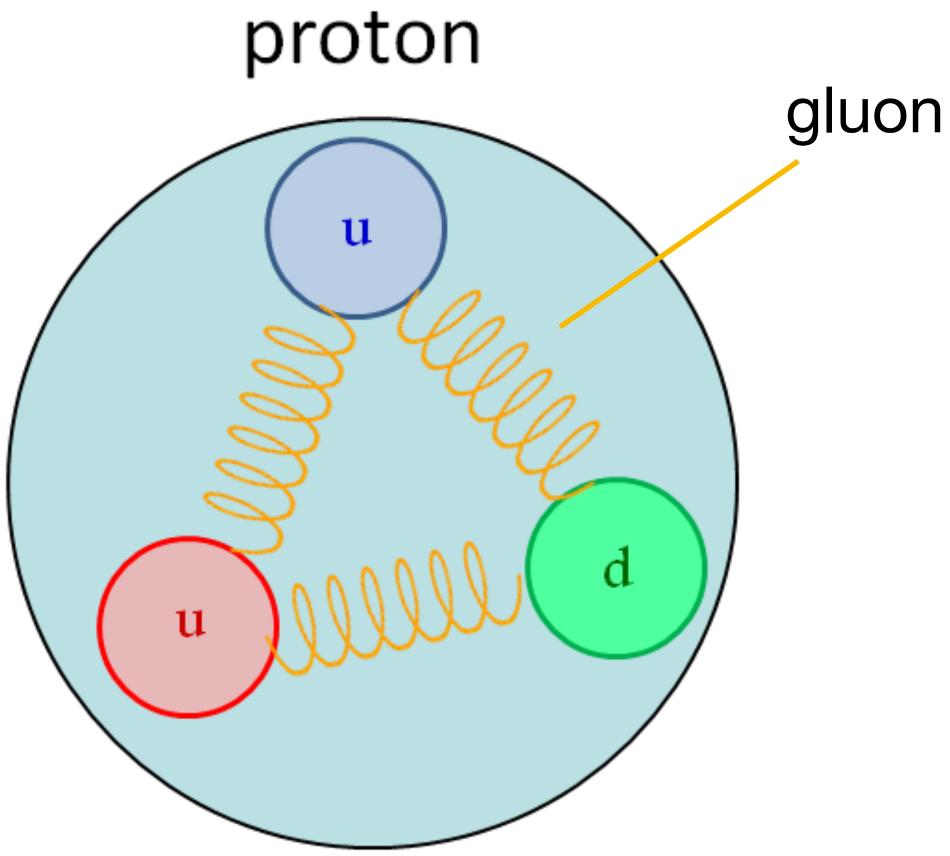
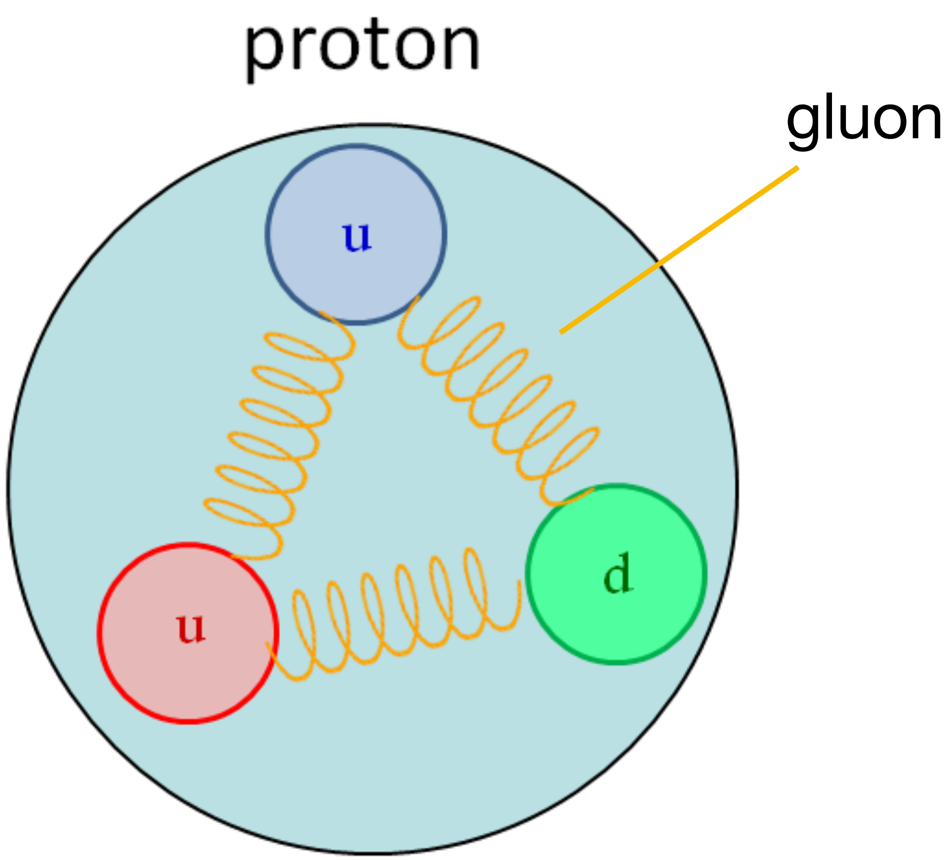
Where do we go from here?


proton
gluon
u
u
d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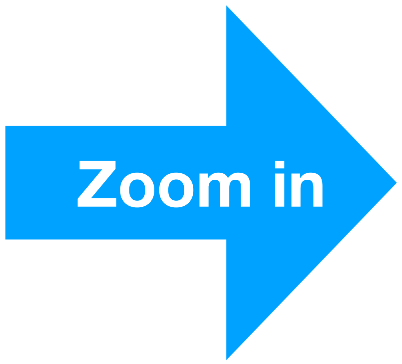
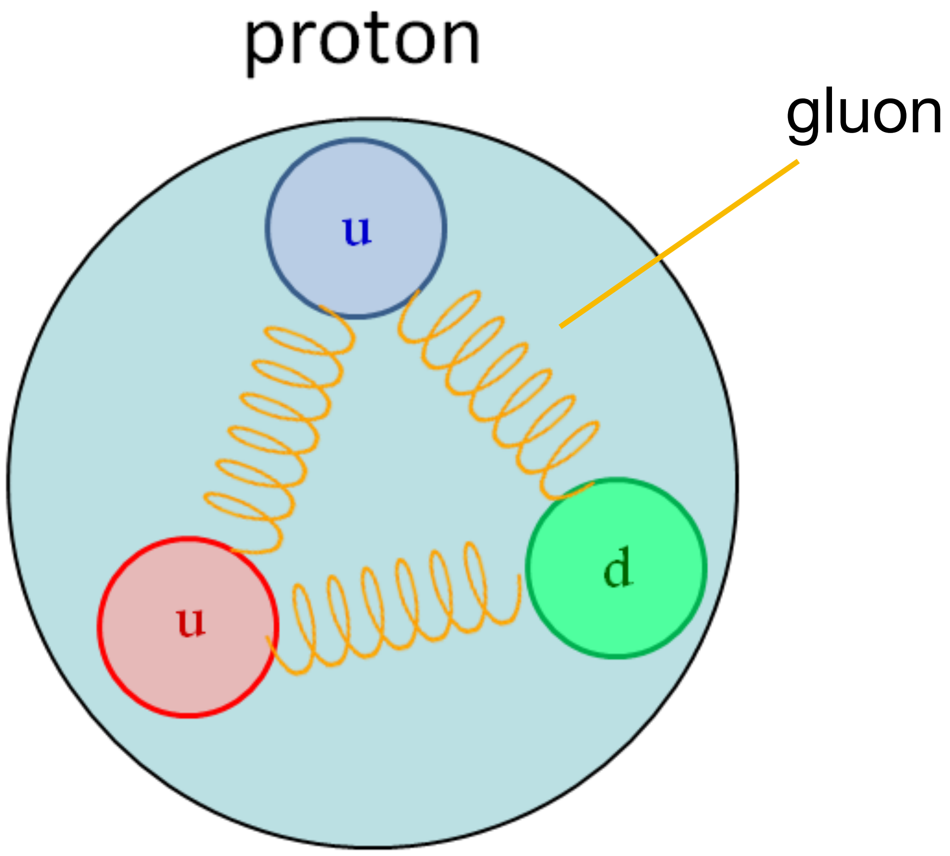

Zoom in



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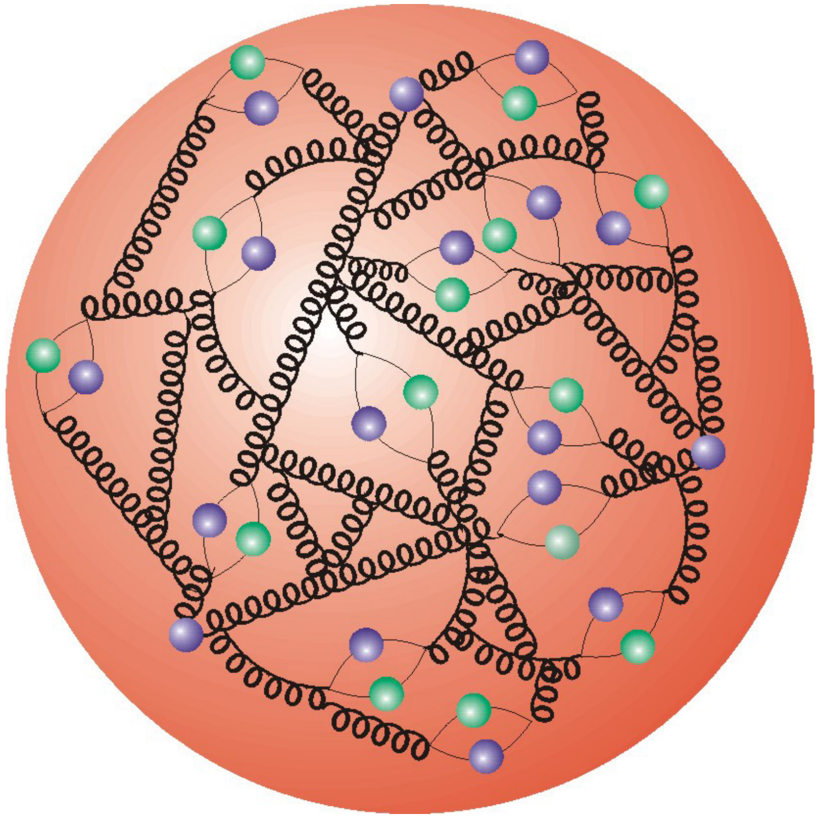

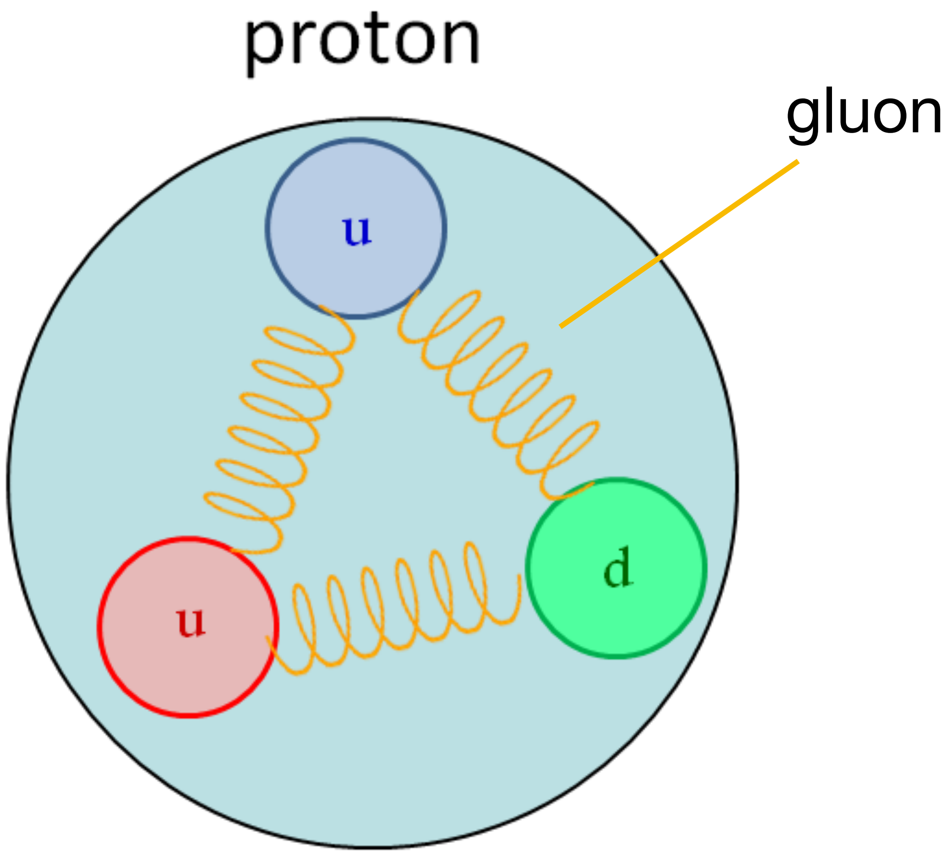

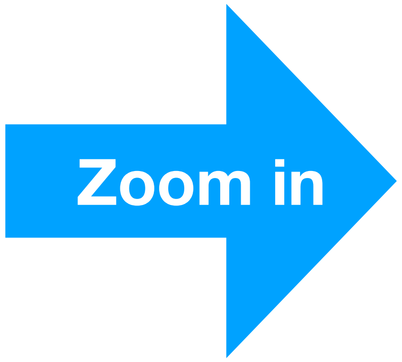

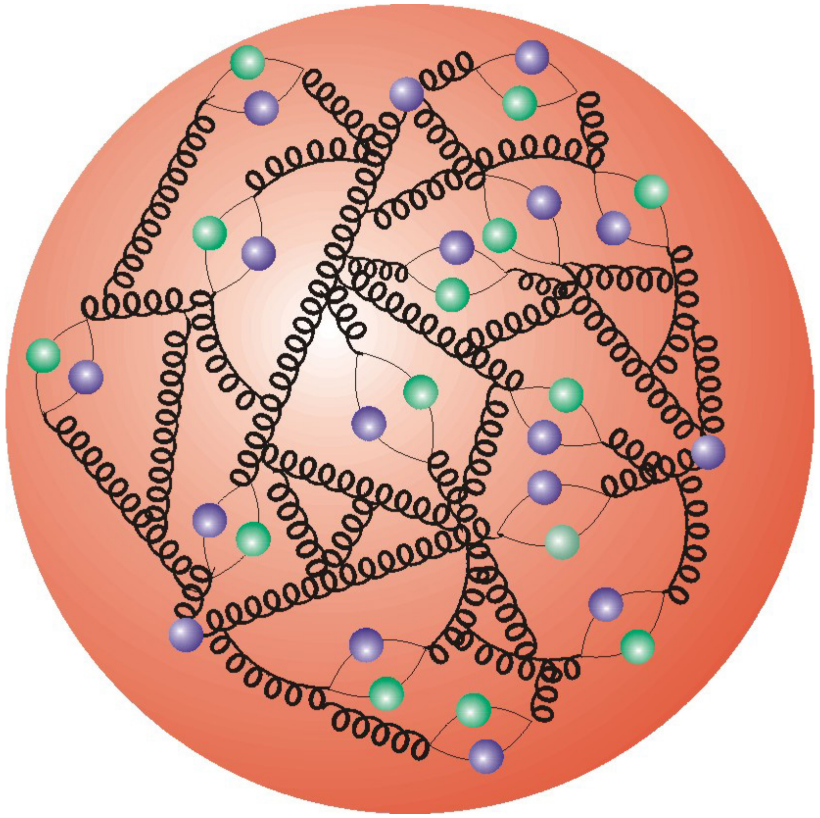

There is A LOT of dynamics inside a proton!

(16 zeros)

LHC operations started around 2010 → 10000000000000000 proton collisions!!

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No clear sign of new particles so far…

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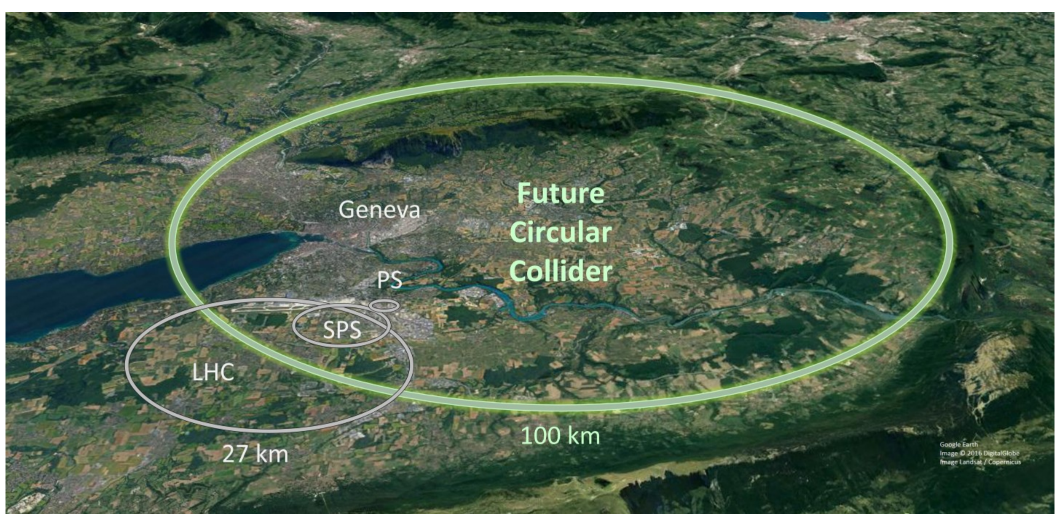

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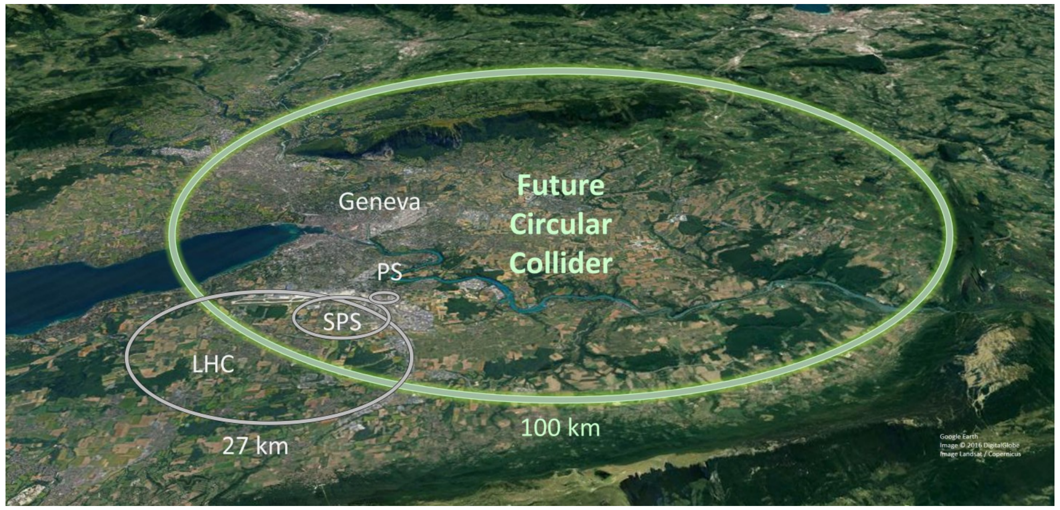

Many years to wait…
We are impatient

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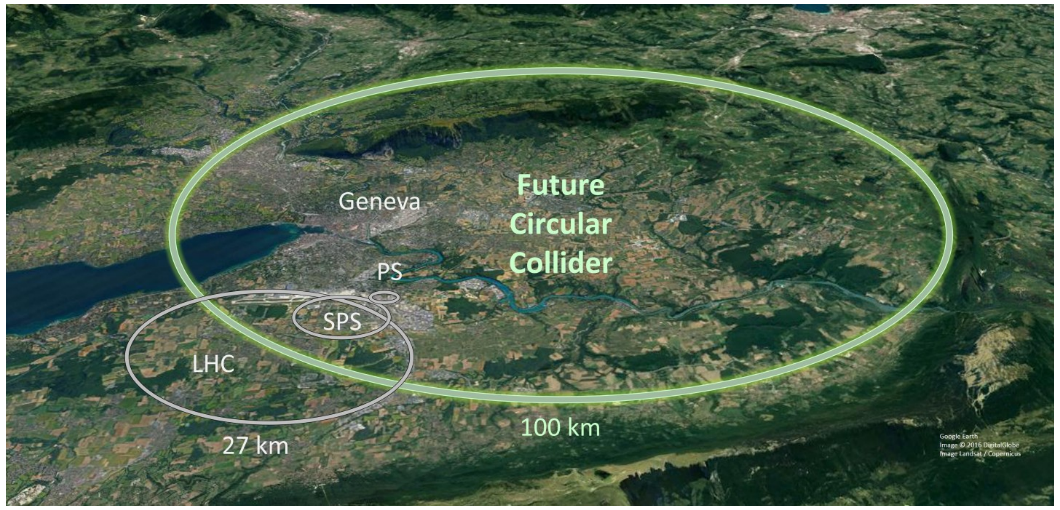
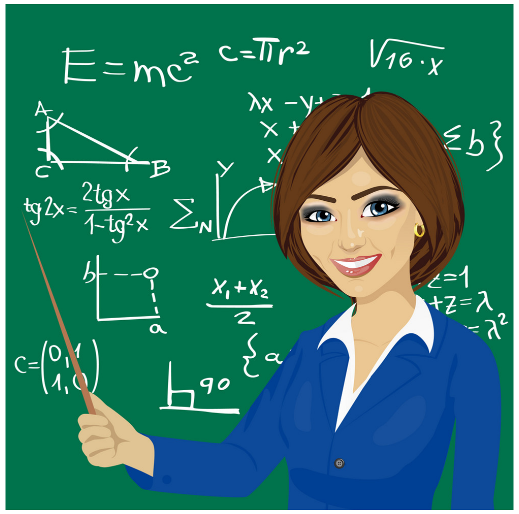
Precision



Precise measurements



Accurate calculations

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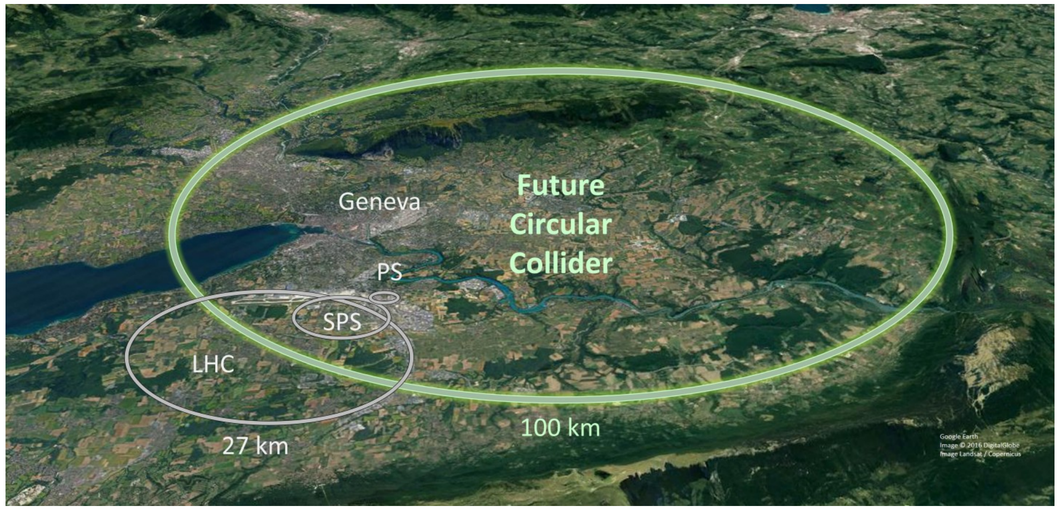

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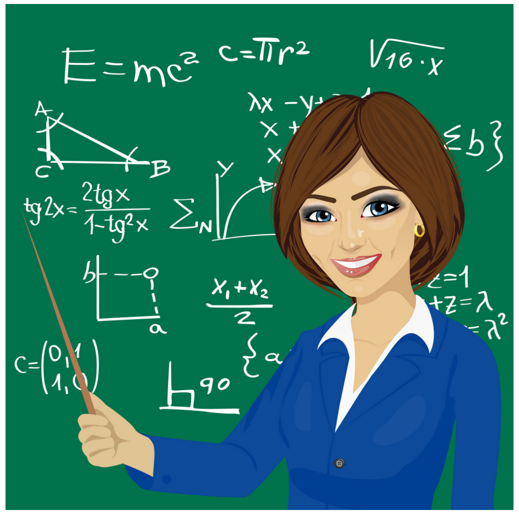

Accurate calculations

Indirect discovery!

How can we describe the presence of new interactions?

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New particles being exchanged in collisions

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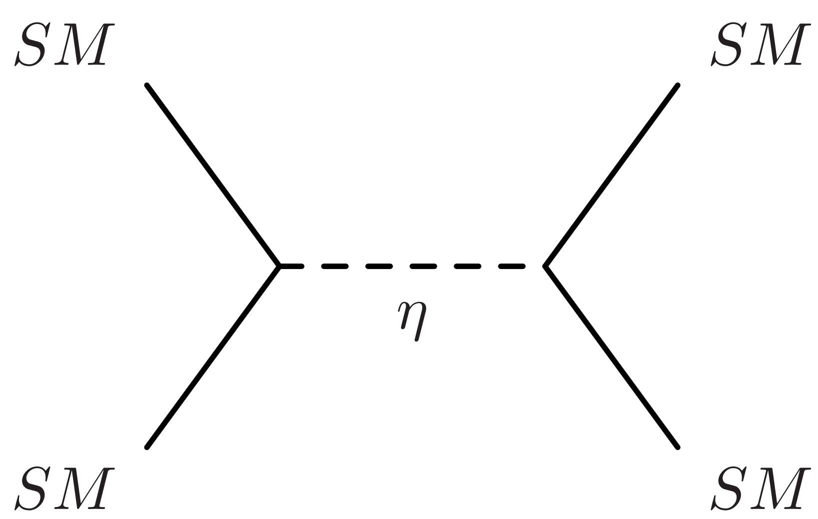
New particles being exchanged in collisions

$$\frac{g^2}{p^2 - M^2}$$



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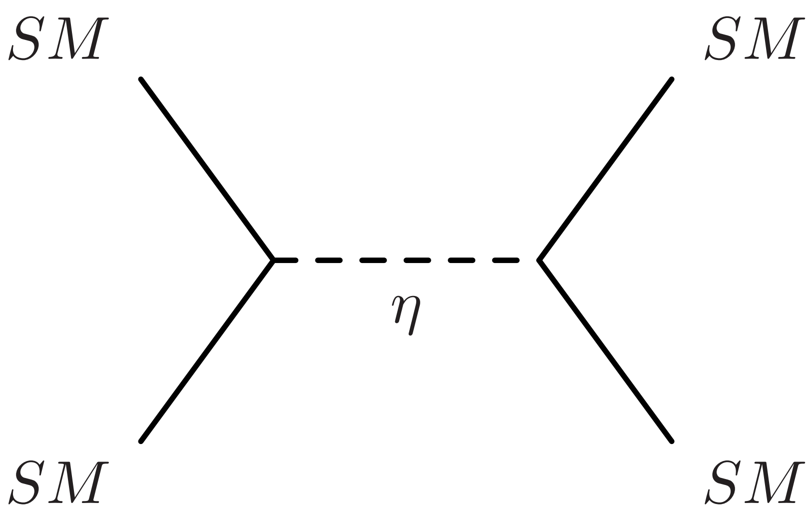

$$M \equiv \Lambda$$
$$p^2 \ll \Lambda^2$$

How can we describe the presence of new interactions?

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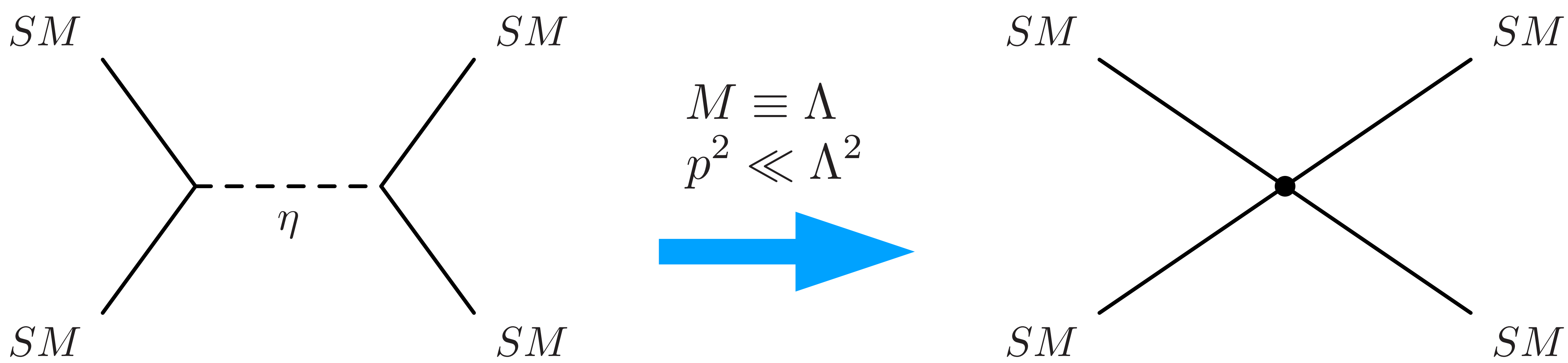

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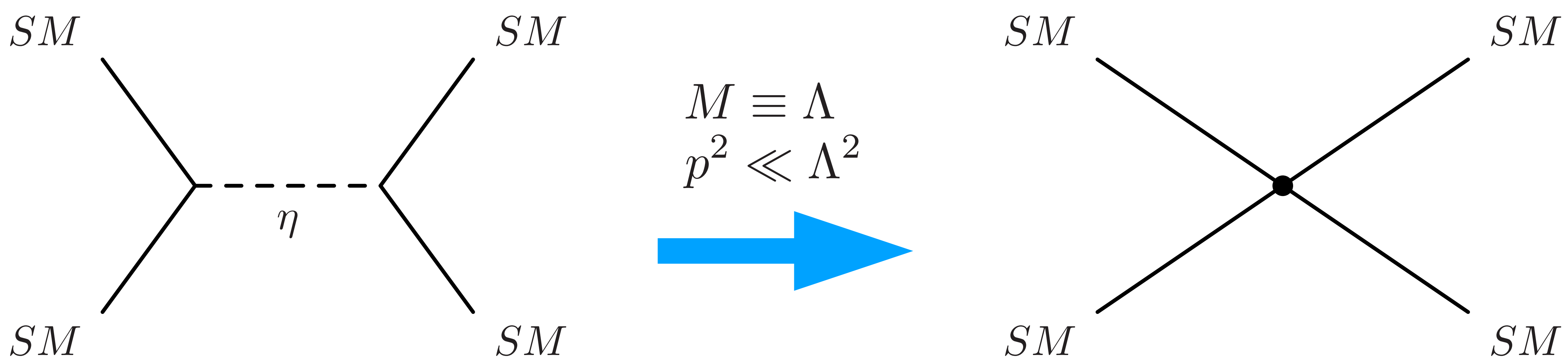

Interaction can be described without explicit presence of new states!

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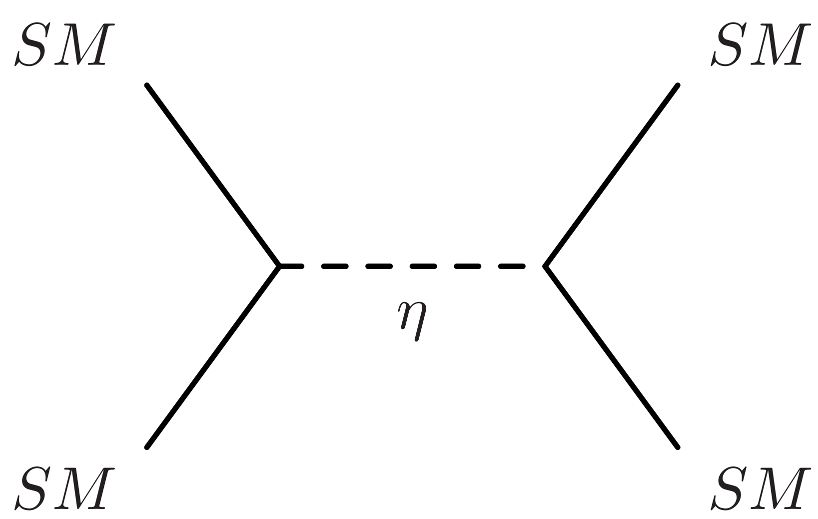

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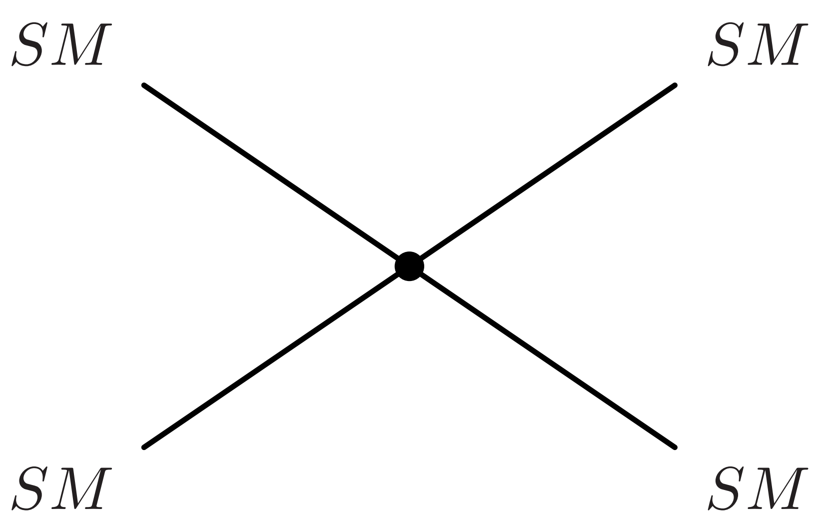

Interaction can be described without explicit presence of new states!

New framework → **Effective Field Theory**

SMEFT fits are highly dependent on several input assumptions

Flavour assumptions

EW input scheme

EFT truncation

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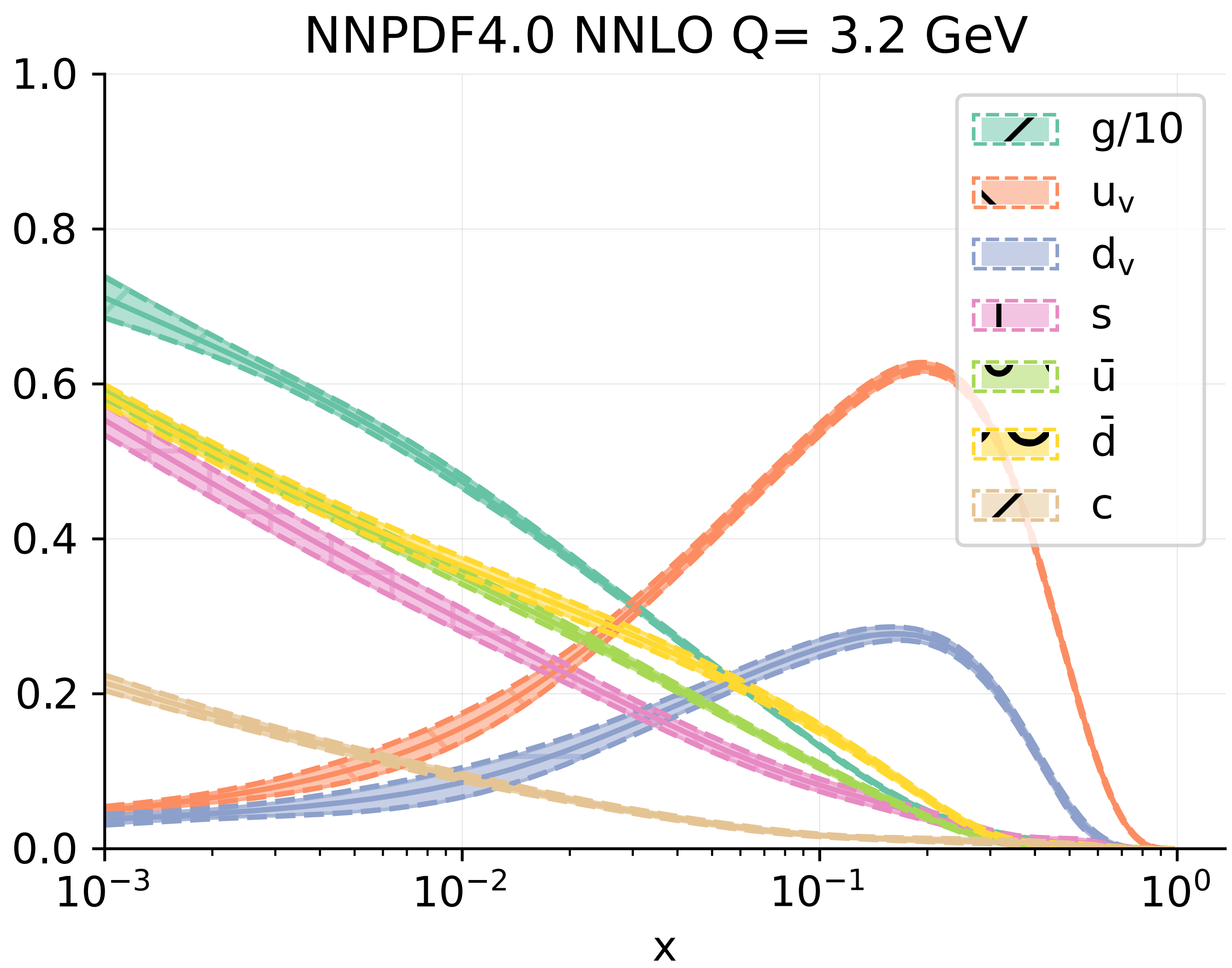
Parton distribution functions



Ball et. al, NNPDF4.0, 2109.02653

	c_{tG}	$c_{\varphi t}$	c_{tZ}	c_{tW}	$c_{\varphi Q}^{(3)}$	$c_{\varphi Q}^{(-)}$	c_{Qd}^{1}	c_{Qu}^{1}	c_{dt}^{1}	c_{qt}^{1}	c_{ut}^{1}	$c_{Qq}^{1,1}$	$c_{Qq}^{1,3}$	c_{Qd}^{8}	c_{Qu}^{8}	c_{dt}^{8}	c_{qt}^{8}	c_{ut}^{8}	$c_{Qq}^{8,1}$	$c_{Qq}^{8,3}$	c_{Qt}^{8}	c_{QQ}^{1}	c_{QQ}^{8}	c_{Qt}^{1}	c_{tt}^{1}
$t\bar{t}$ total xsec	88.0													7.0	3.0	2.0	4.0	1.0	1.0						
$t\bar{t}$ differential xsec	3.0						51.0	37.0	53.0	41.0	37.0	43.0		35.0	14.0	45.0	13.0	22.0	25.0	12.0					
$t\bar{t}$ A_c							49.0	63.0	47.0	59.0	63.0	57.0	1.0	53.0	68.0	50.0	62.0	76.0	66.0	80.0					
$t\bar{t}Z$	2.0	99.0				97.0								3.0	1.0	1.0	4.0		2.0	1.0					
$t\bar{t}W$																	10.0		4.0	3.0					
single t				6.0	64.0								86.0							2.0					
tW				1.0	15.0																				
W helicities				90.0																					
$t\bar{t}\gamma$	5.0		100.0	3.0										1.0	13.0	2.0	8.0	2.0	2.0	1.0					
$t\bar{t}t\bar{t}$																					95.0	100.0	65.0	21.0	100.0
$t\bar{t}b\bar{b}$	1.0																				5.0		35.0	79.0	
tZj		1.0			21.0	3.0							13.0												

$$F_{ii}(D) \Big/ \sum_{\text{sectors } D'} F_{ii}(D')$$

fixed-PDF EFT fit

Luca Mantani

	c_{tG}	$c_{\varphi t}$	c_{tZ}	c_{tW}	$c_{\varphi Q}^{(3)}$	$c_{\varphi Q}^{(-)}$	c_{Qd}^{1}	c_{Qu}^{1}	c_{dt}^{1}	c_{qt}^{1}	c_{ut}^{1}	$c_{Qq}^{1,1}$	$c_{Qq}^{1,3}$	c_{Qd}^{8}	c_{Qu}^{8}	c_{dt}^{8}	c_{qt}^{8}	c_{ut}^{8}	$c_{Qq}^{8,1}$	$c_{Qq}^{8,3}$	c_{Qt}^{8}	c_{QQ}^{1}	c_{QQ}^{8}	c_{Qt}^{1}	c_{tt}^{1}
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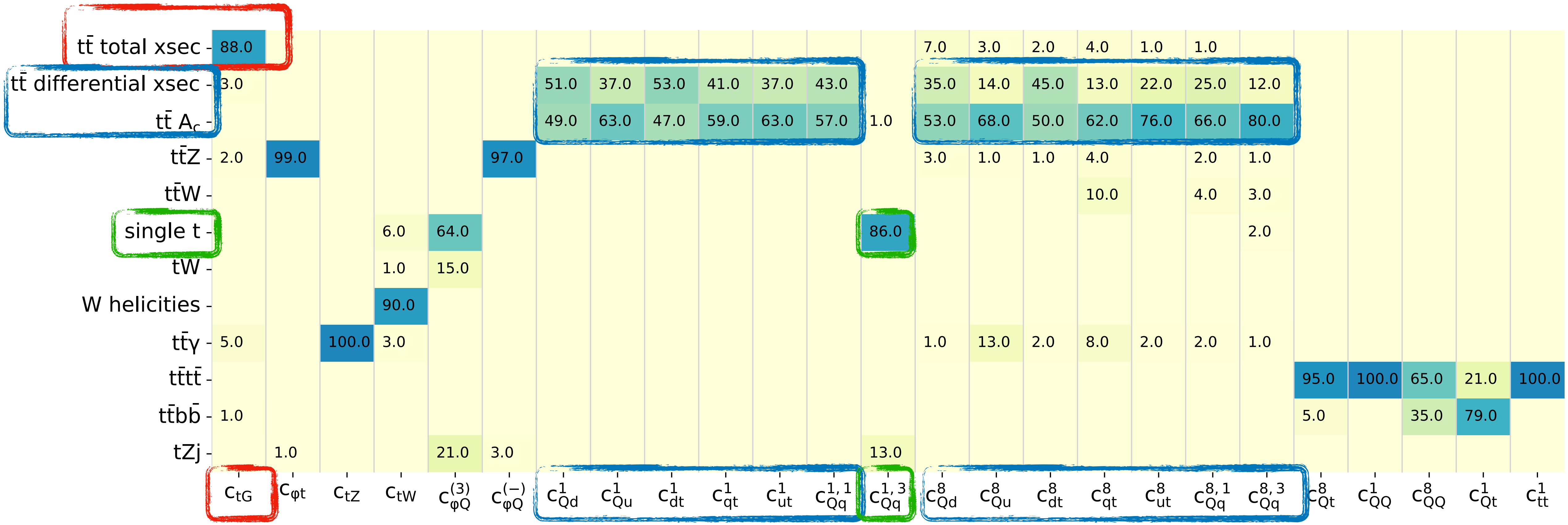

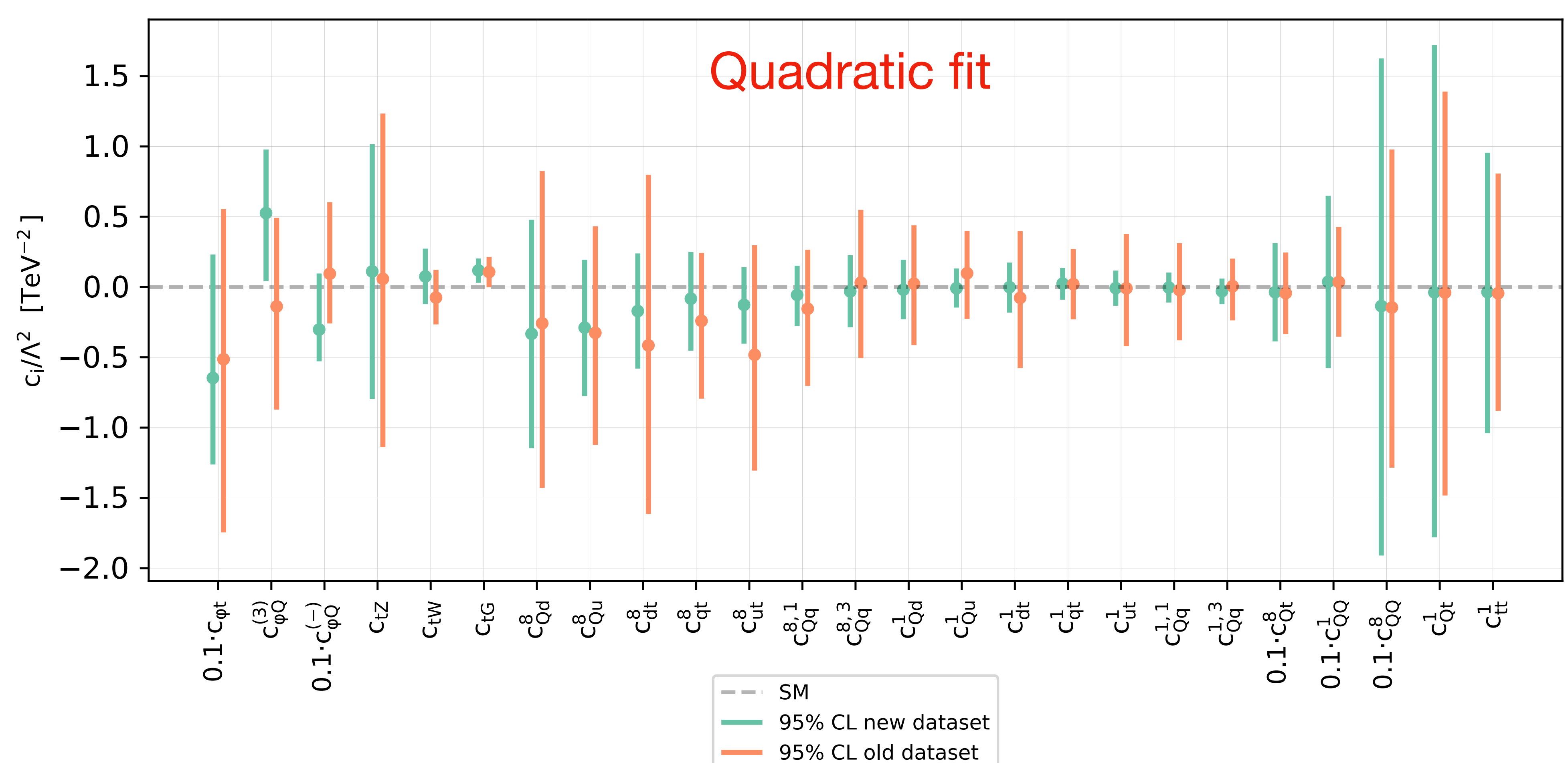

Performed with NS in SMEFiT

Particularly interesting sector: **Drell-Yan**

- Used in PDFs to extract information on high-x valence quarks
- Used in SMEFT interpretations to constrain 4F operators

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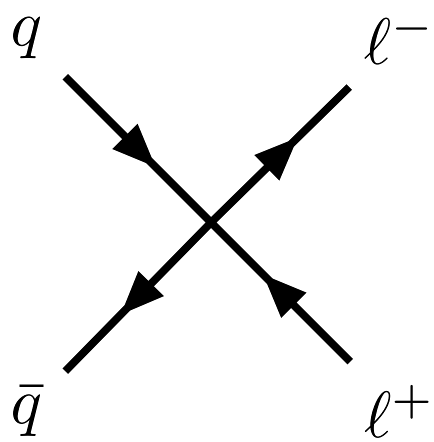
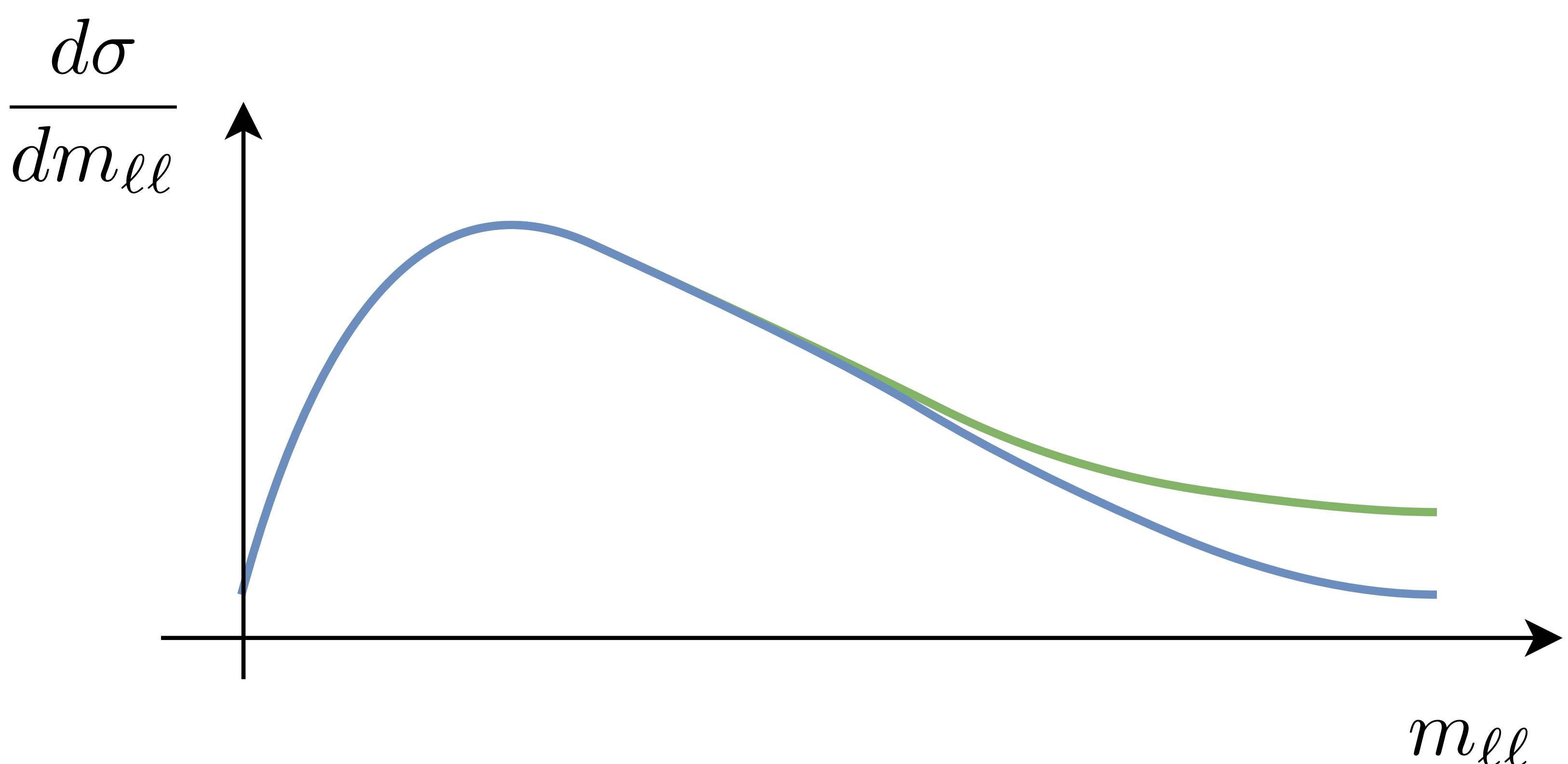


$$\mathcal{A} \sim \mathcal{A}_{\text{SM}} + C\,\frac{E^2}{\Lambda^2}$$



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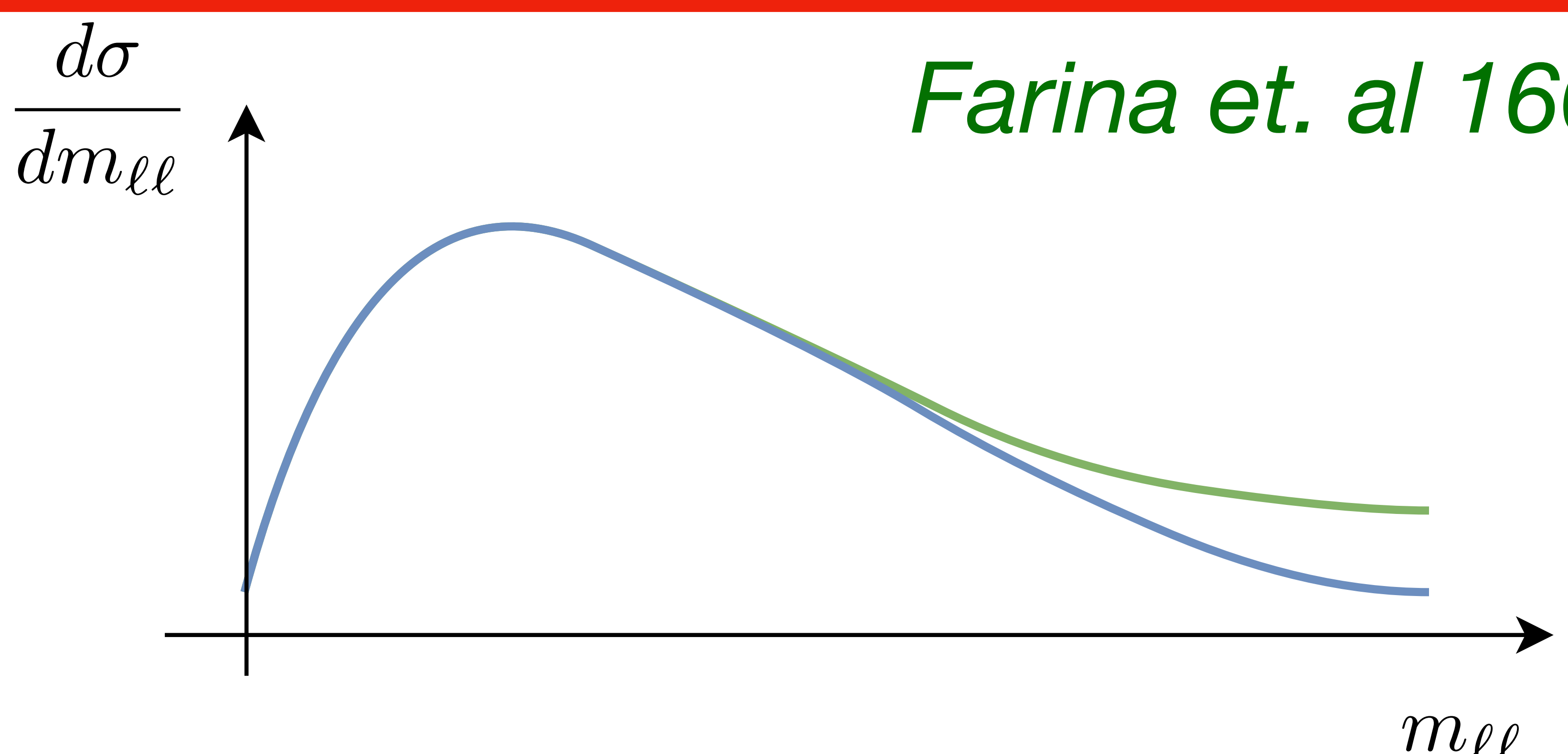
Energy helps accuracy

Farina et. al 1609.08157



Future directions

Let's consider a simple scenario: 1 operator, 1 datapoint

$$\chi^2 = \frac{(\sigma(c) - \sigma_{exp})^2}{\delta\sigma^2} \qquad \Delta\chi^2 = \chi^2 - \chi_{min} = 1$$

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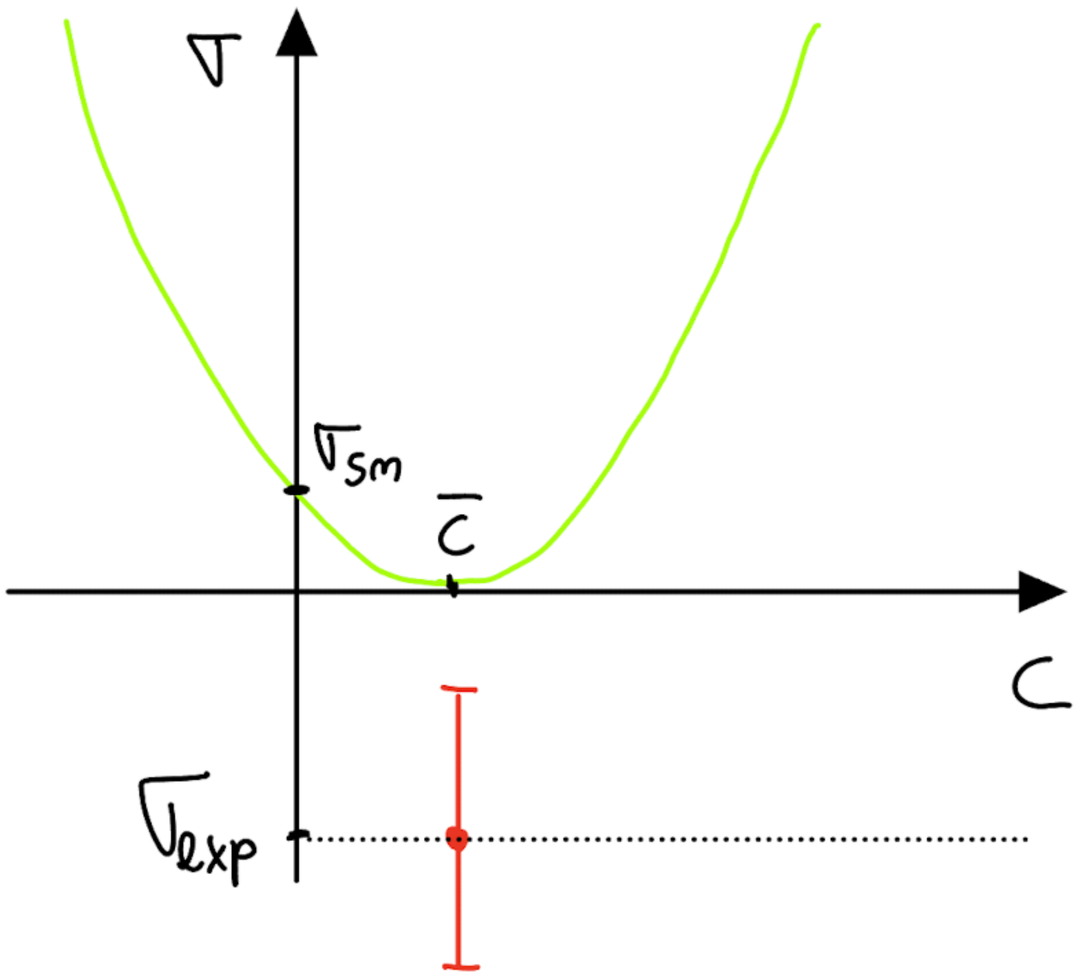
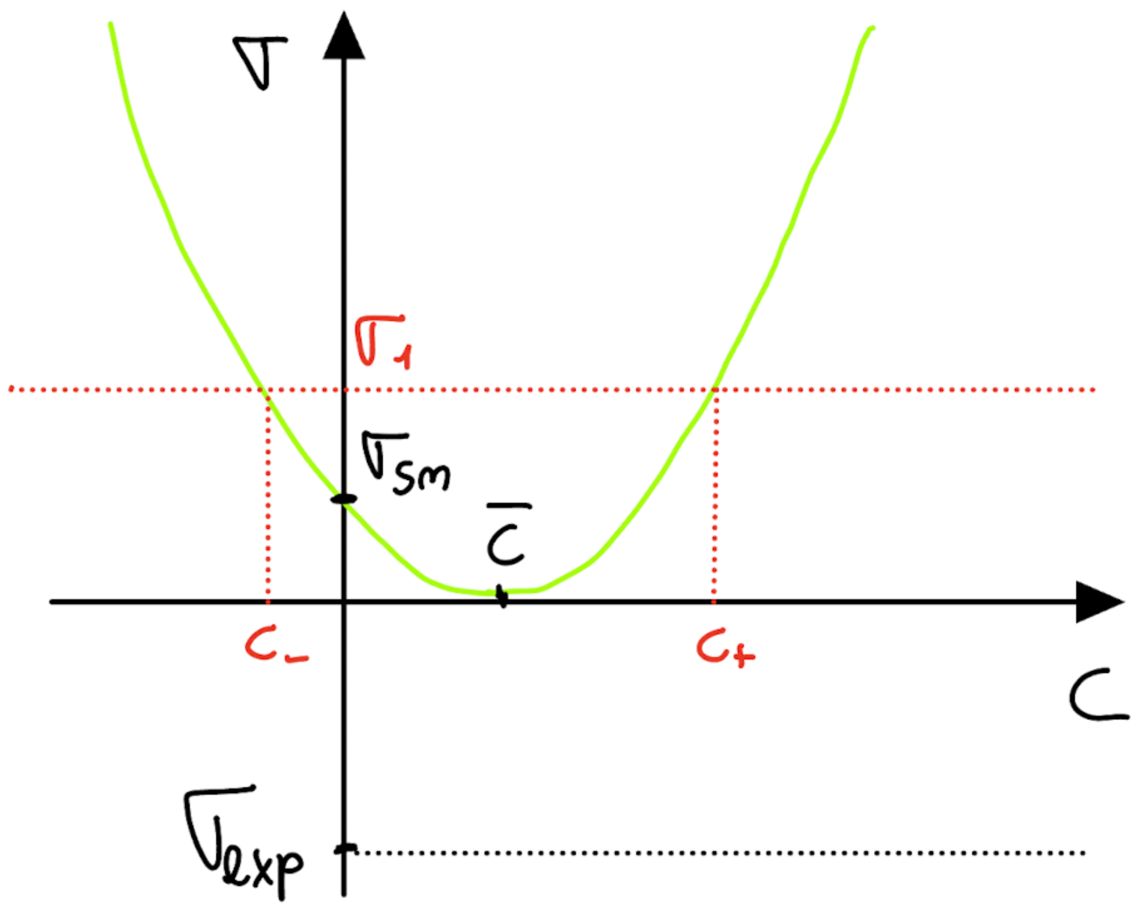


Let's consider a simple scenario: 1 operator, 1 datapoint

Monte Carlo replica 1



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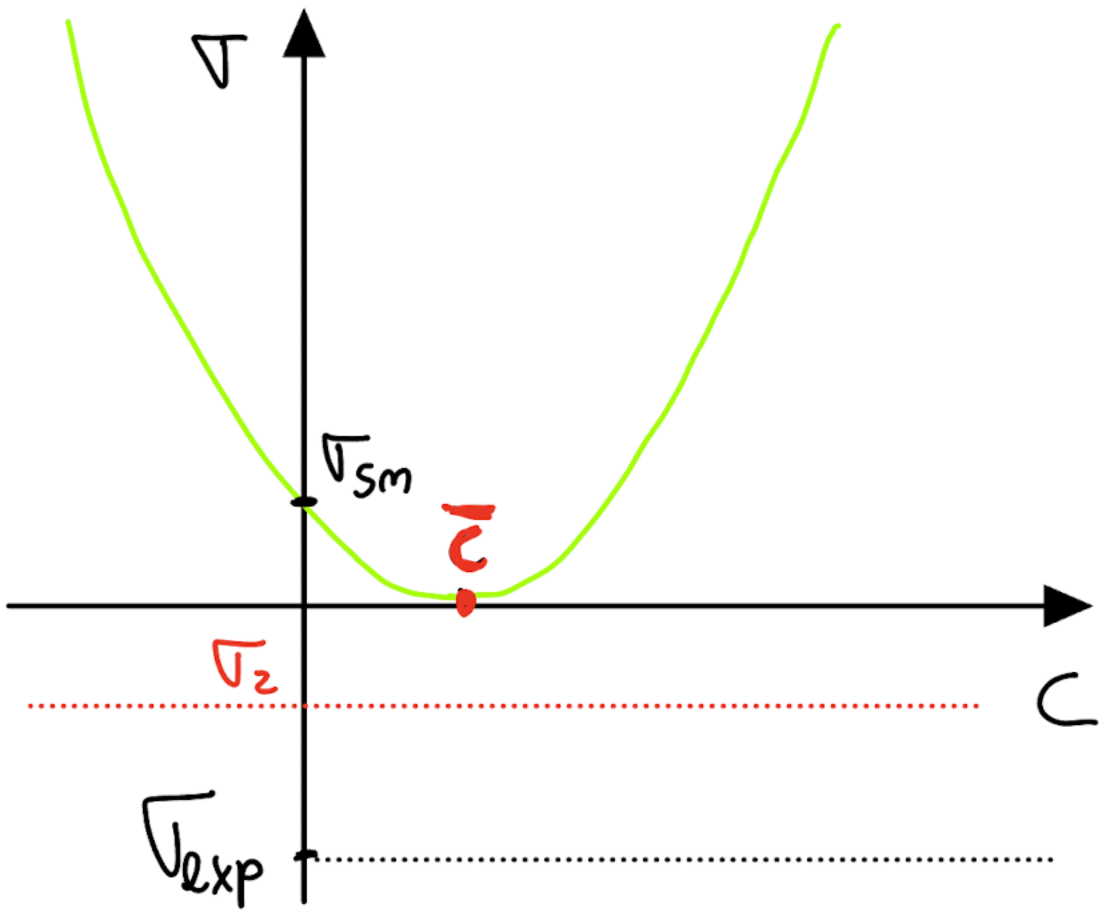
Monte Carlo replica 2



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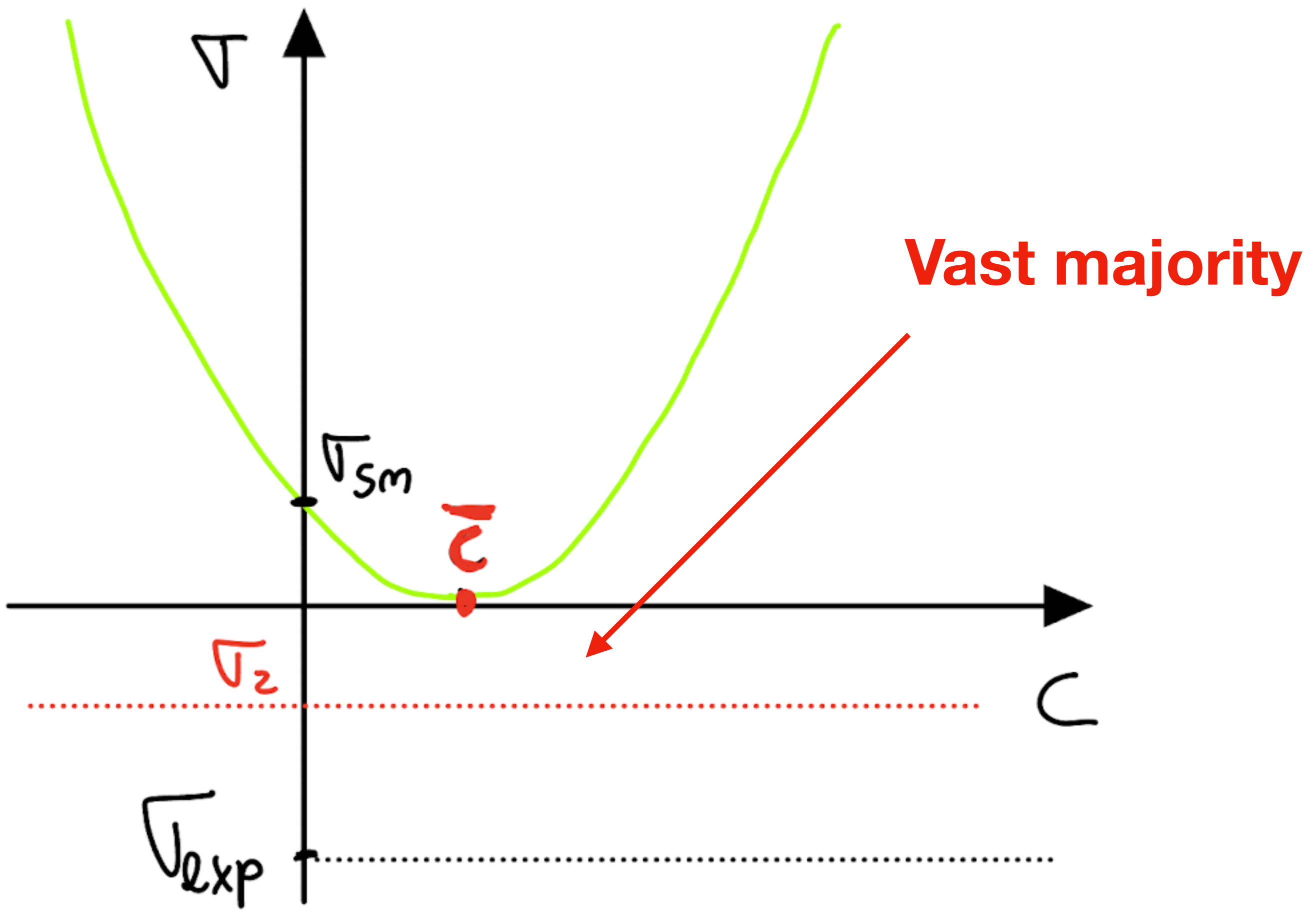

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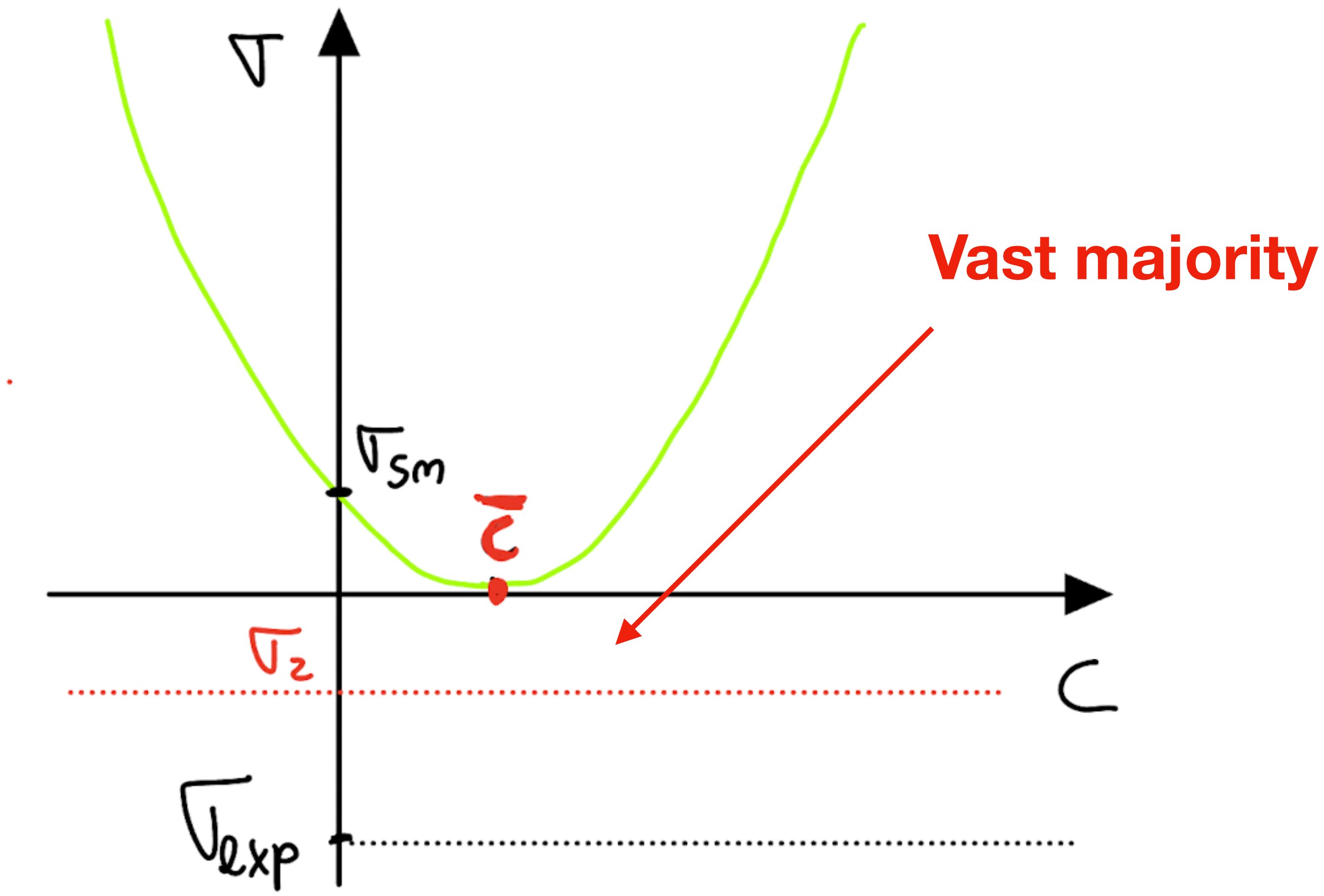
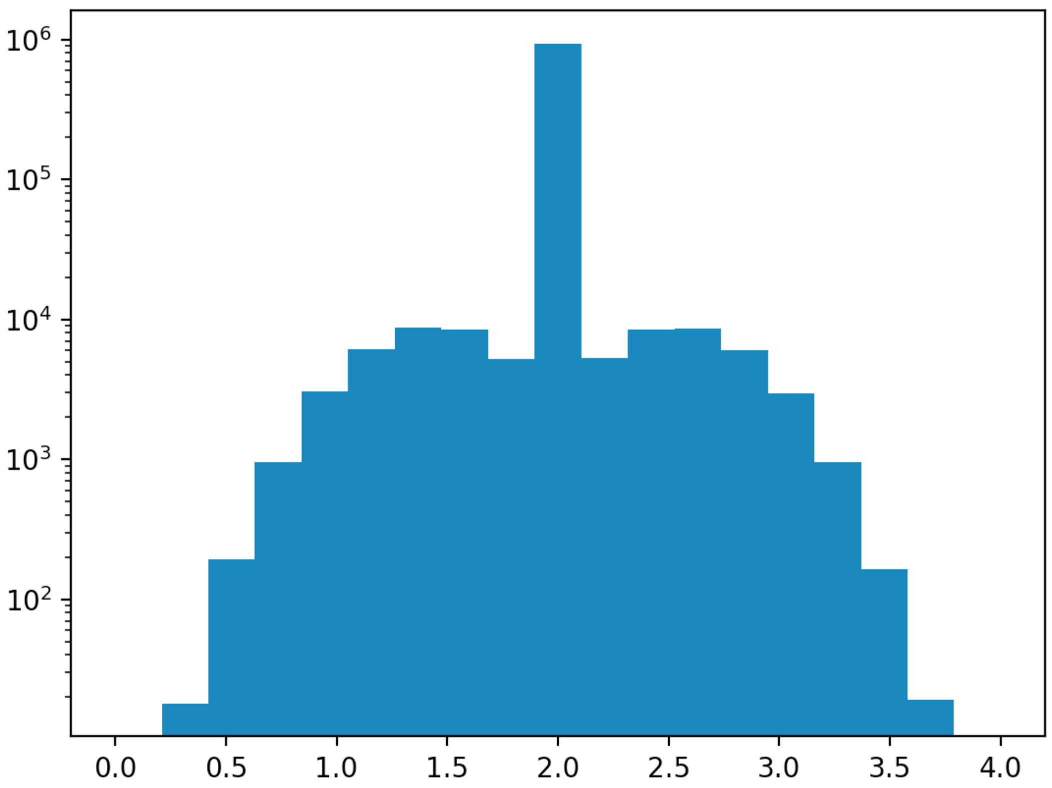


Computed bounds completely wrong:
the spike dominates



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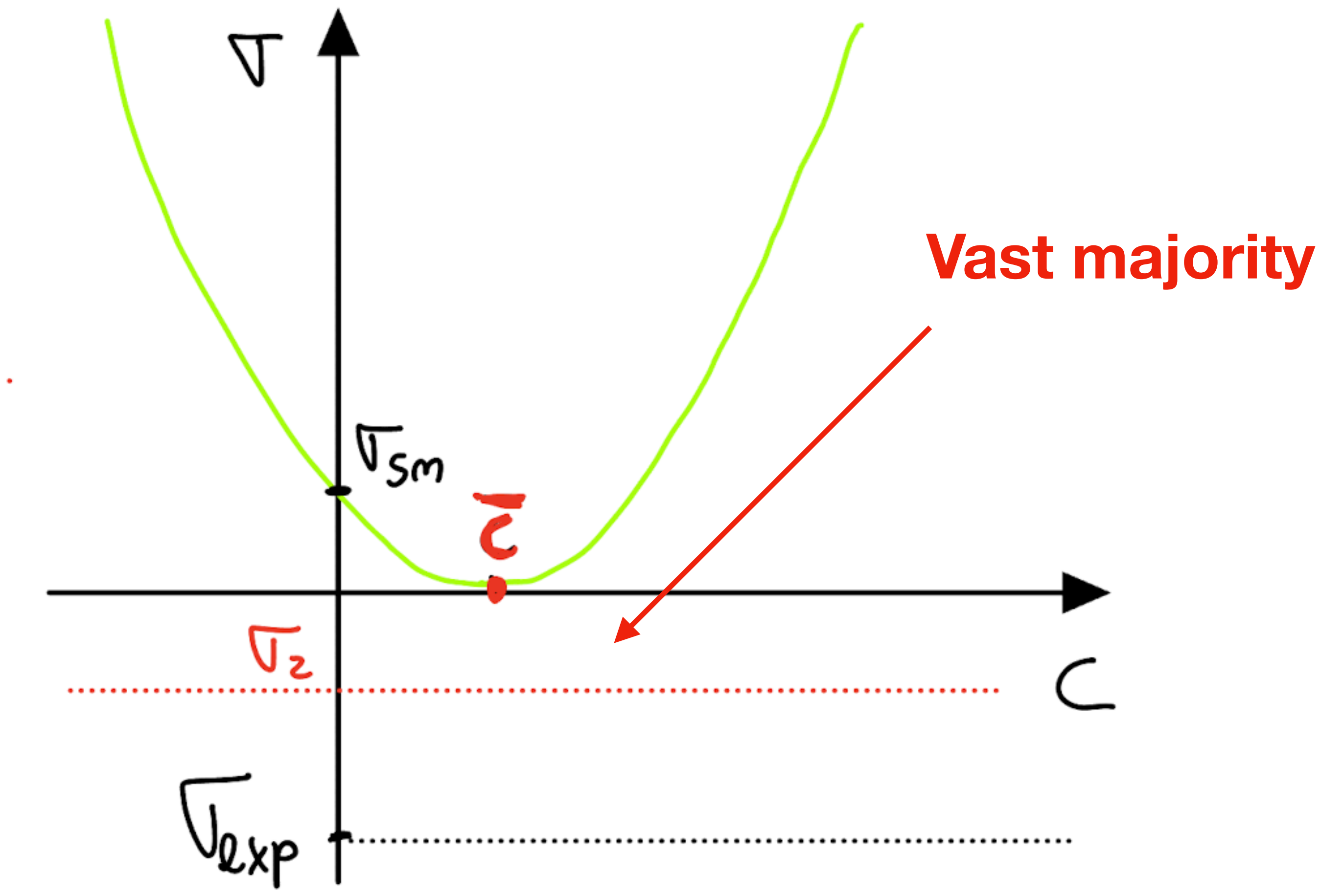

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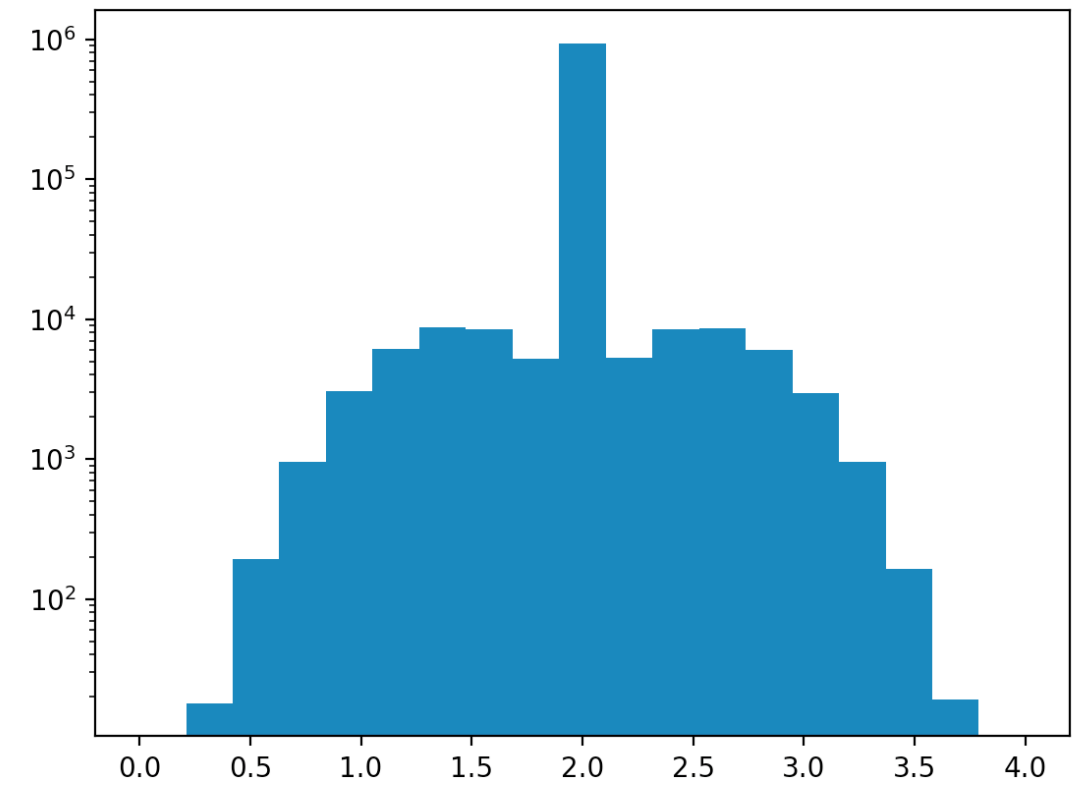
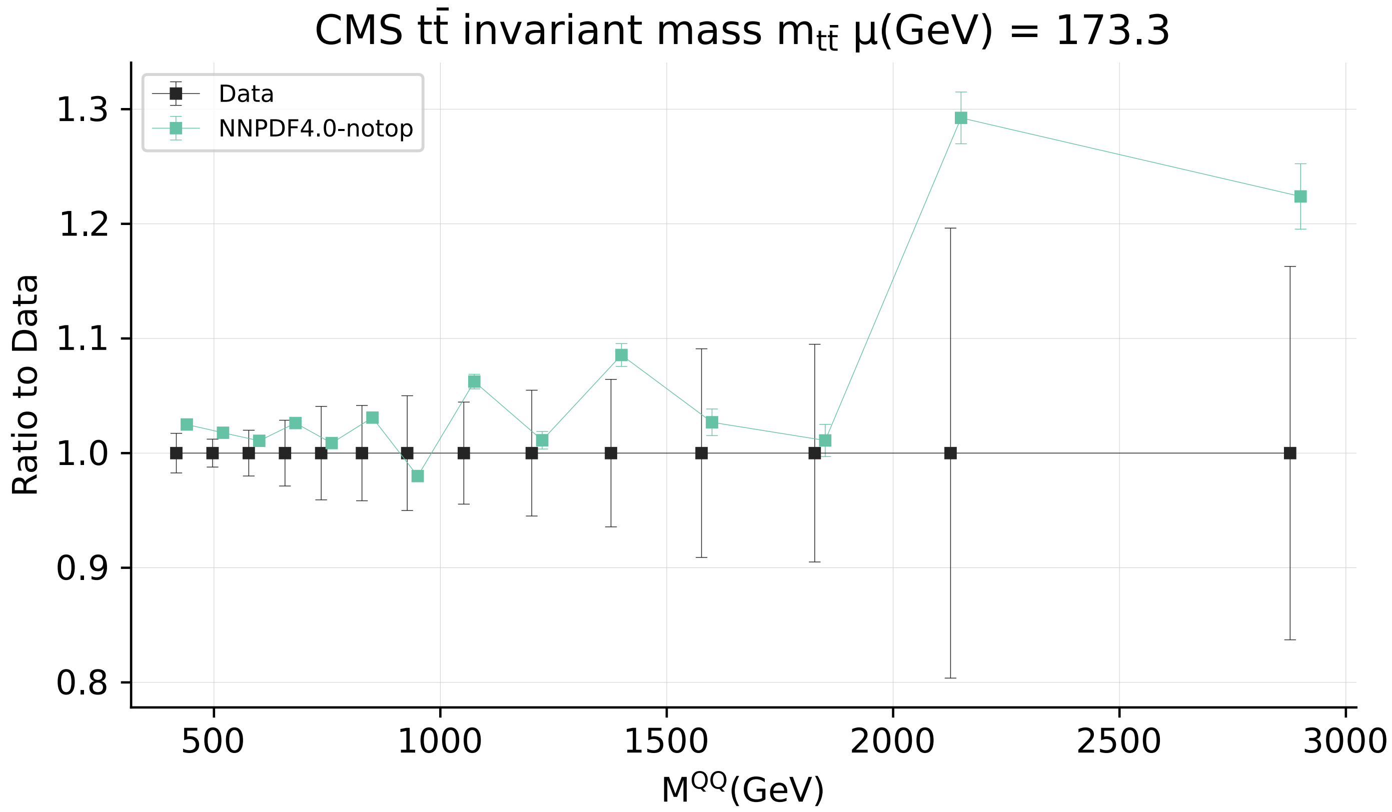
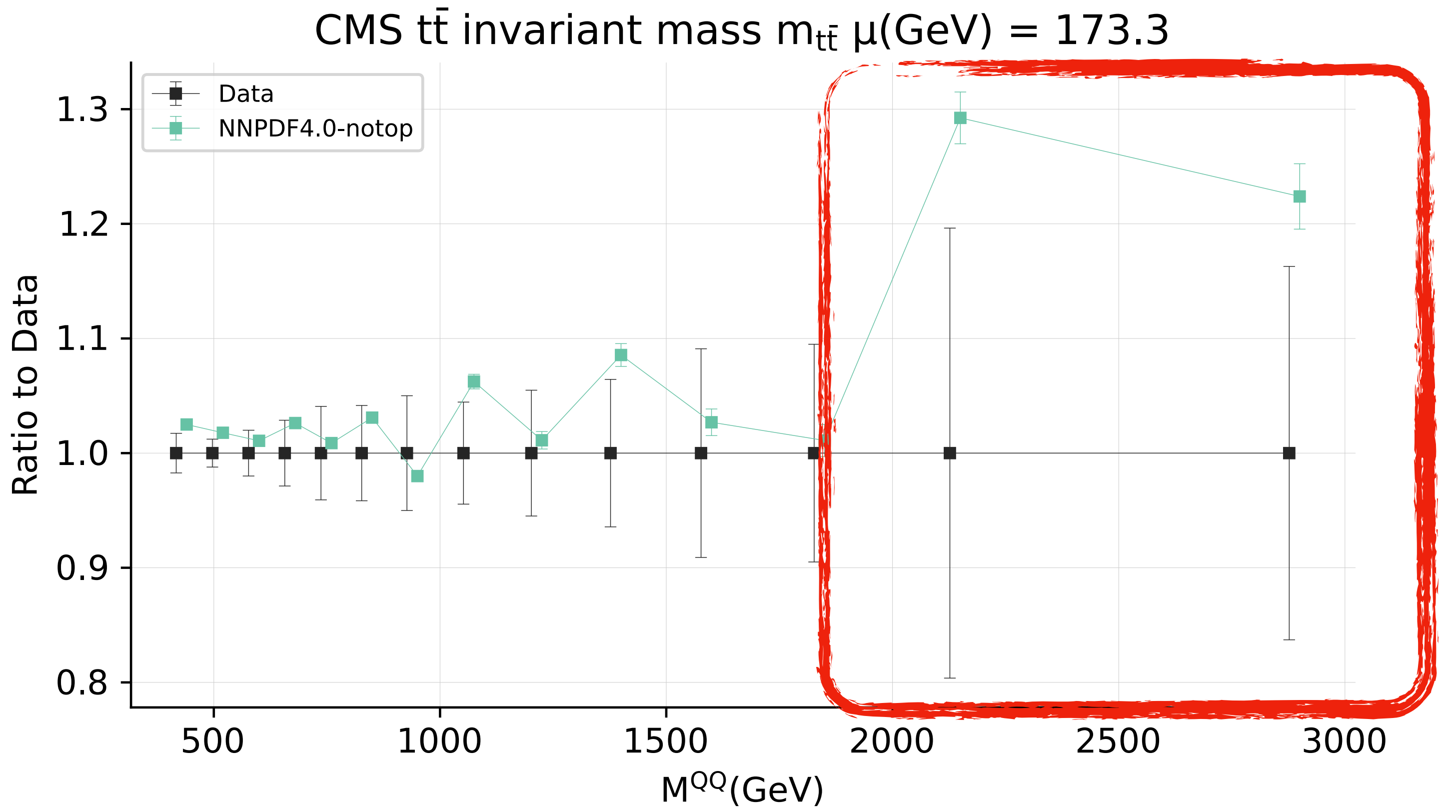
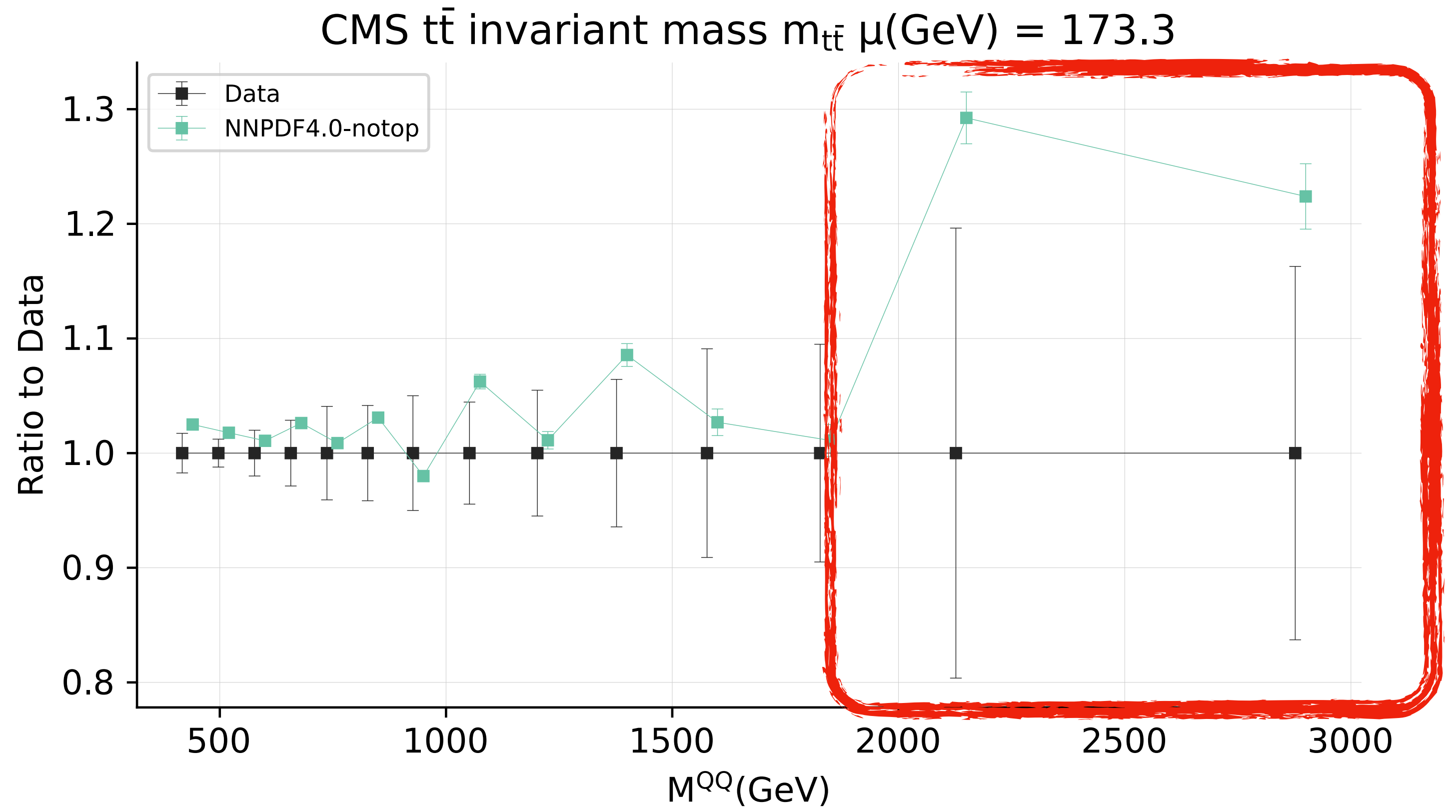


$$P_{c^{(i)}}(c) \propto \delta\left(c + \frac{t^{\text{lin}}}{2t^{\text{quad}}}\right) \int_{-\infty}^{t_{\min}} dx \ \exp\left(-\frac{1}{2\sigma^2}(x-d)^2\right) + \frac{2}{|2ct^{\text{quad}} + t^{\text{lin}}|} \exp\left(-\frac{1}{2\sigma^2}(d - t(c))^2\right) .$$


CMS tt̄ invariant mass m_tt̄ μ(GeV) = 173.3
Data
NNPDF4.0-notop
Ratio to Data
1.3
1.2
1.1
1.0
0.9
0.8
500
1000
1500
2000
2500
3000
M^QQ(GeV)



SM overshoots

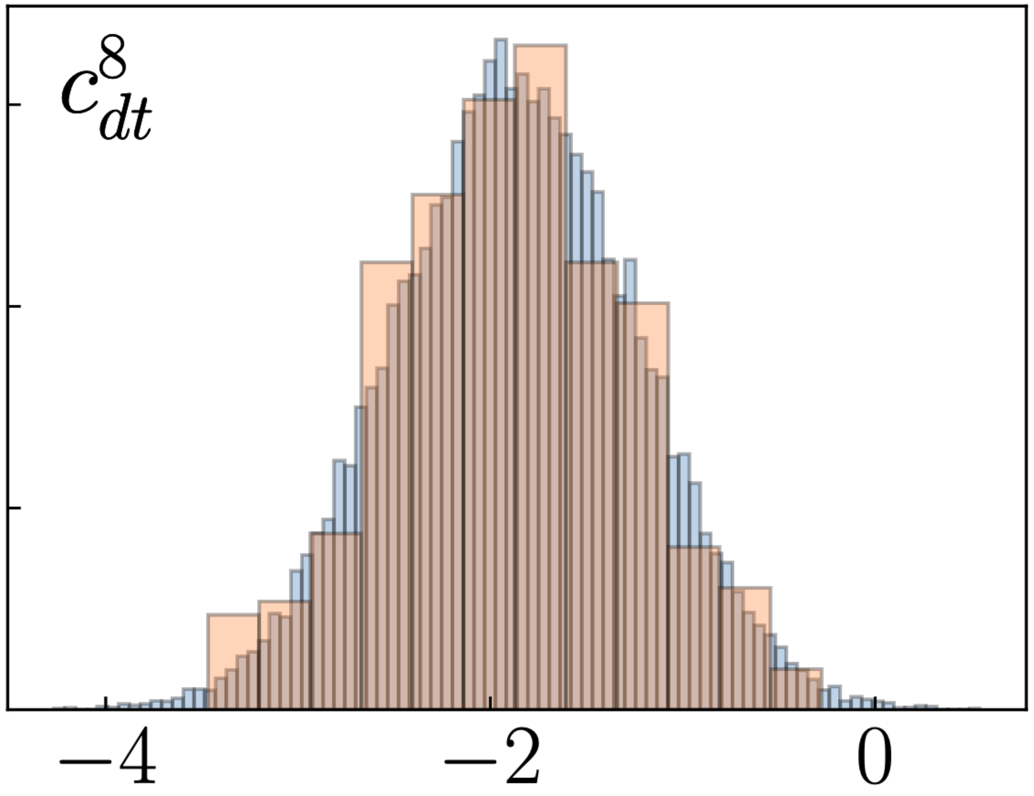


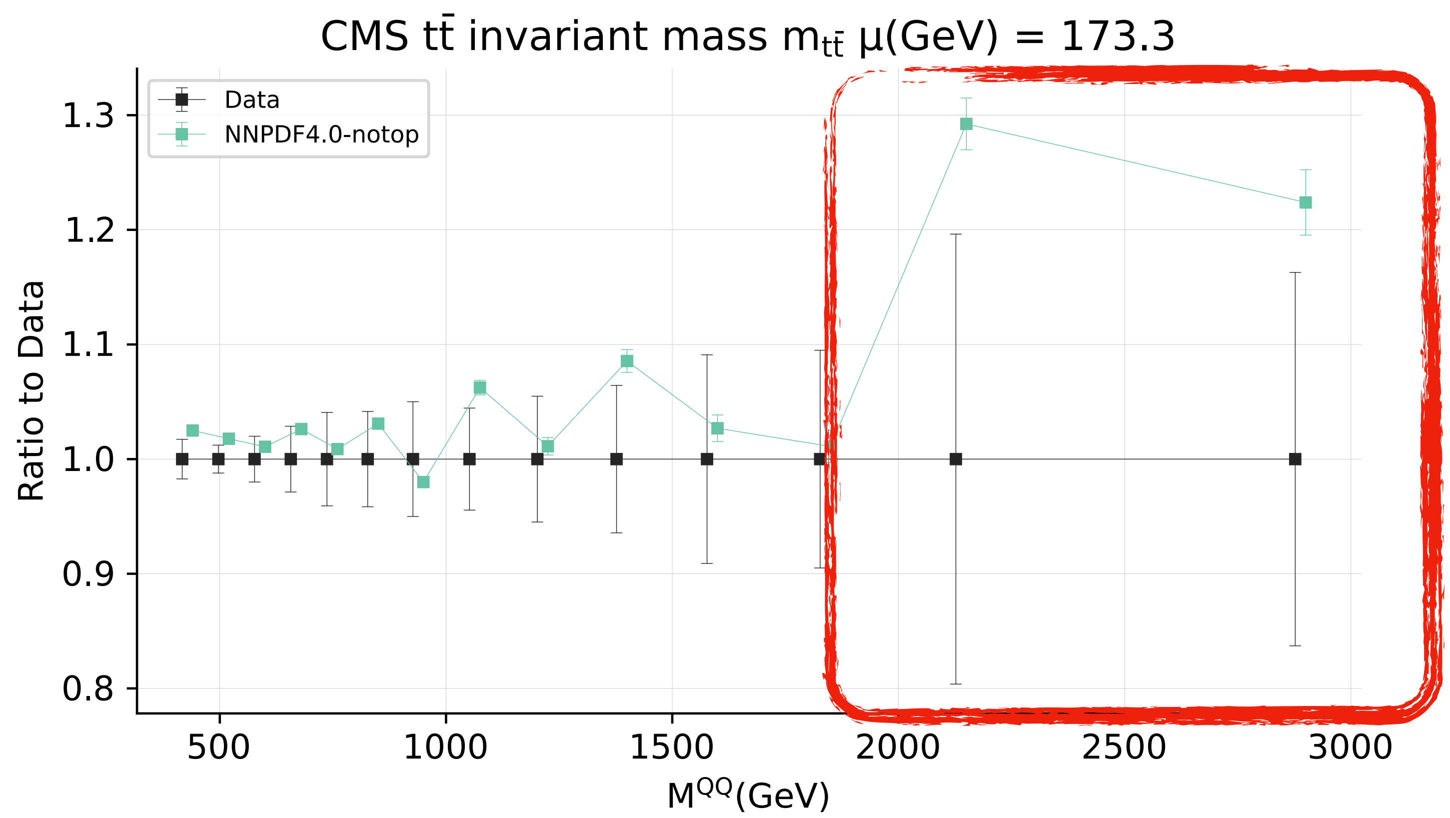
SM overshoots

MC fit

NS fit

Linear fit





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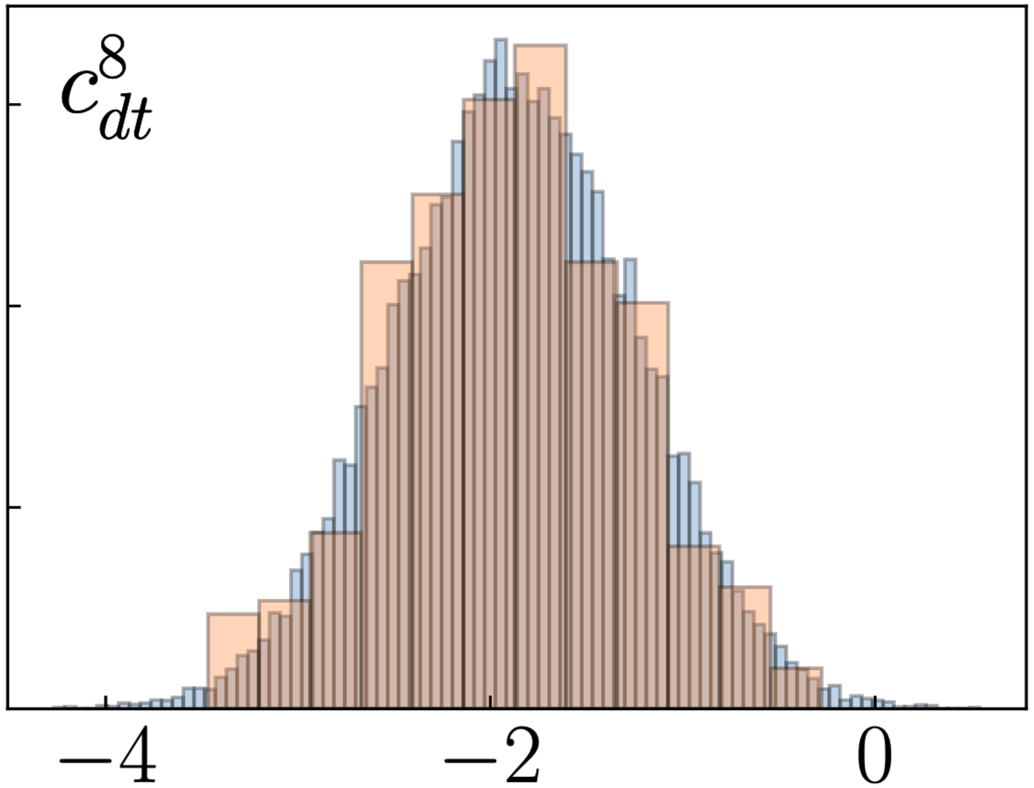

Quadratic fit