The LHC Run II top quark legacy on global PDF and SMEFT analyses

for QCD@LHC2022, in Orsay, France

QCD@LHC2022

28 November 2022 to 2 December 2022

IJCLab Orsay, France

James Moore, University of Cambridge

PBSP

erc

European Research Council

Established by the European Commission

PBSP: Physics Beyond the Standard Proton

- The **PBSP group** is based at the **University of Cambridge**, and is headed by **Maria Ubiali**; the project is **ERC-funded.**
- The aim is to **investigate interplay between BSM physics and proton structure** - the subject of the rest of this talk!
- The team members are:
  - *Postdocs:* Zahari Kassabov, Maeve Madigan, Luca Mantani
  - *PhD students:* Mark Costantini, Shayan Iranipour (*former*), Elie Hammou, **James Moore**, Manuel Morales Alvarado, Cameron Voisey (*former*)

Talk overview

1. The need for joint PDF-SMEFT determinations

2. The SIMUnet methodology for joint PDF-SMEFT fits

3. The impact of Run II top data on joint PDF-SMEFT fits

1. - The need for joint PDF-SMEFT determinations

PDF-SMEFT interplay

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- Optimal PDF parameters θ^* then have an **implicit dependence** on initial SMEFT parameter choice: $\text{PDF}(\theta^*) \equiv \text{PDF}(\theta^*(\bar{c}))$.

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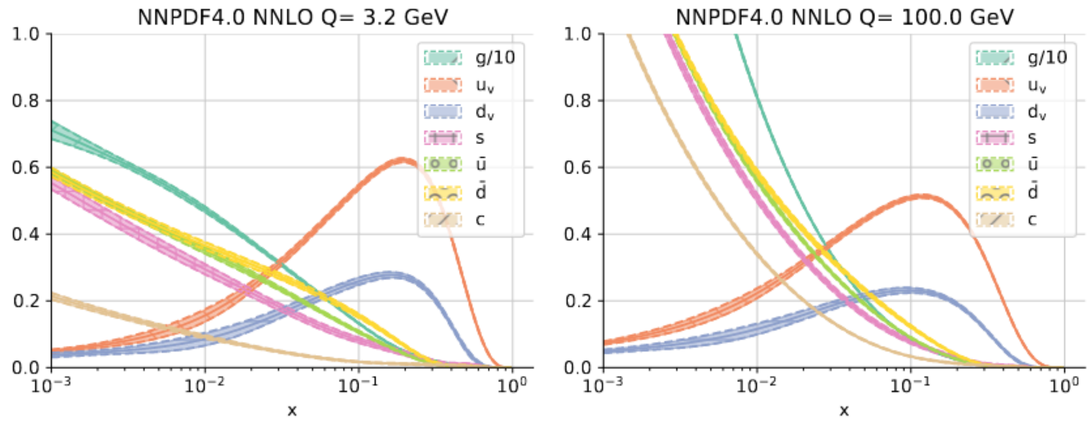

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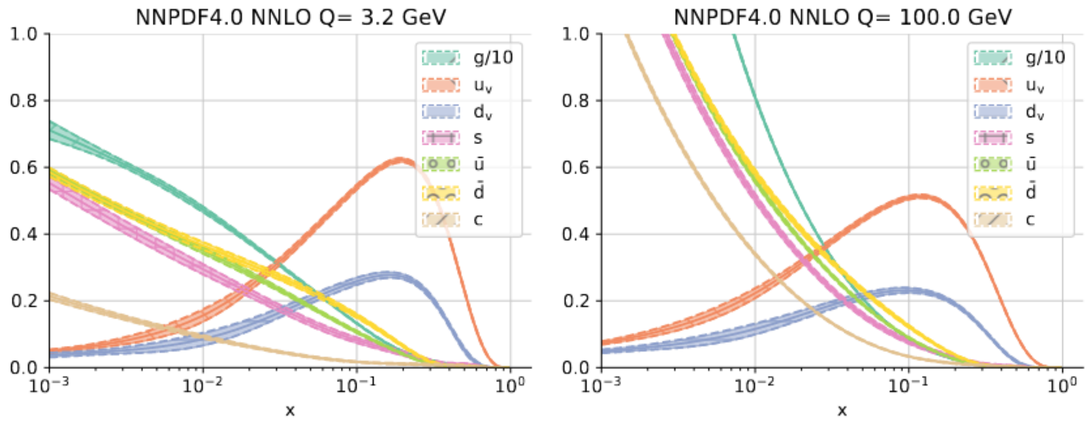

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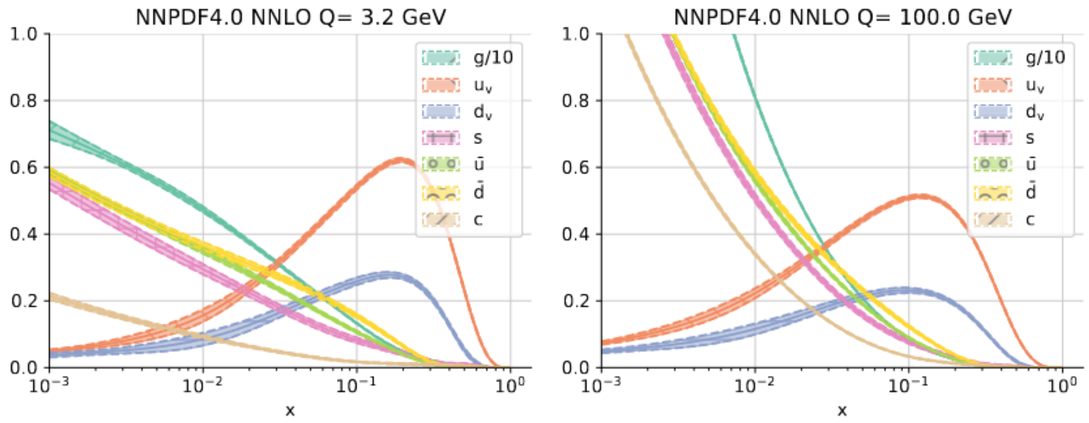

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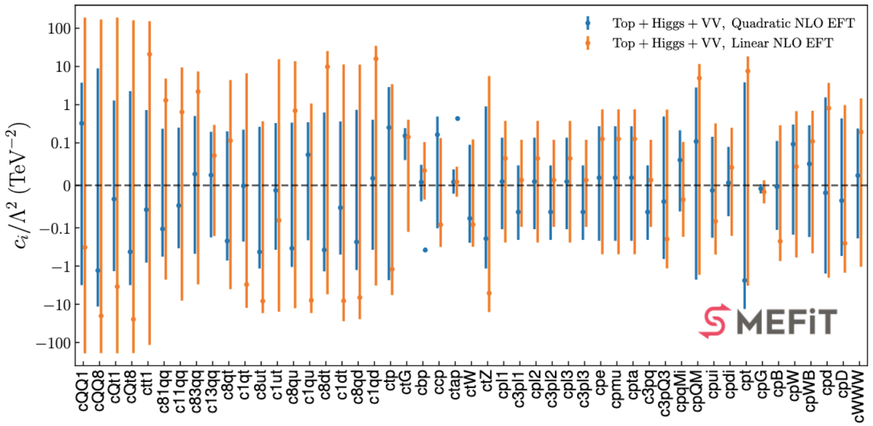

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- In particular, if we fit PDFs **assuming all SMEFT couplings are zero**, but then **use those PDFs in a fit of SMEFT couplings**, our resulting bounds **could be misleading** (the same applies to SM parameters).
- We could even **miss New Physics**, or **see New Physics that isn't really there**!

PDF-SMEFT interplay: natural questions

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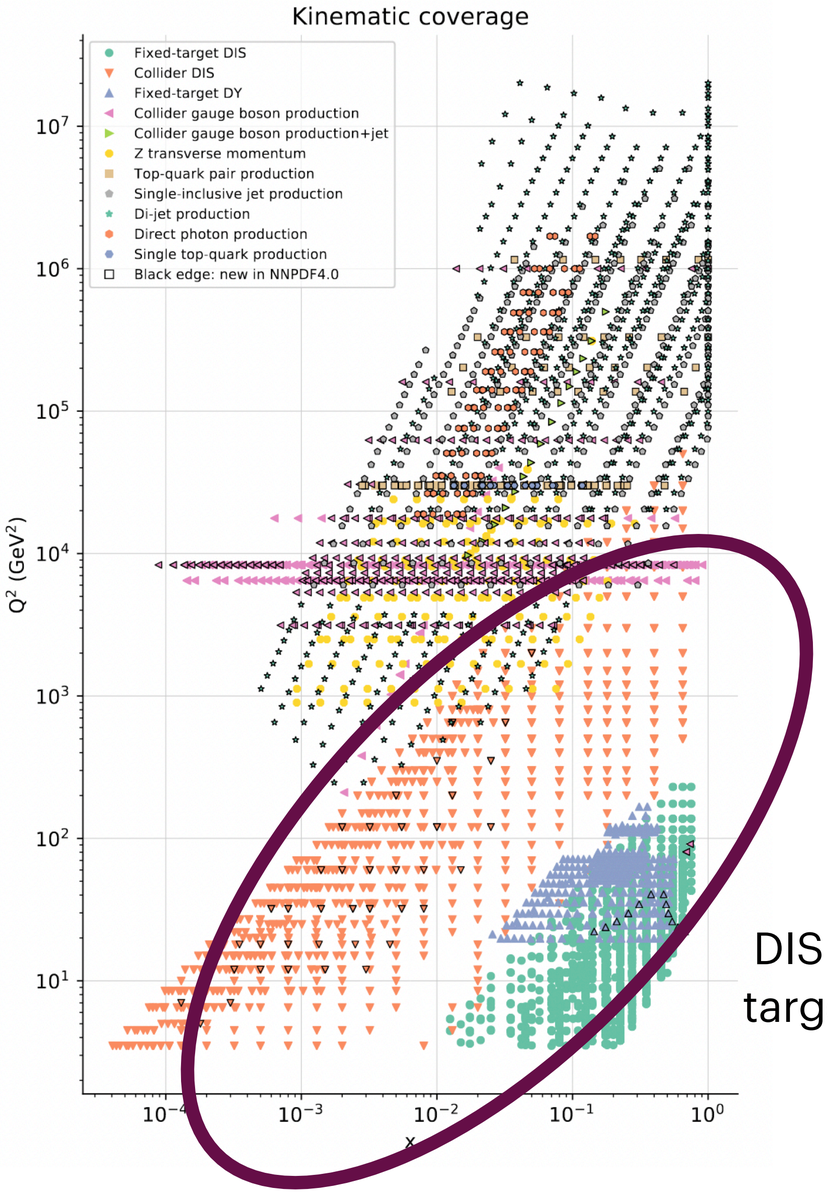
  - It depends on the SMEFT operators. Some operators (e.g. four-fermion operators) will **contaminate DIS and DY data**, which comprise the majority of the data going into PDF fits. So often '*uncontaminated PDFs' don't exist*!
  - Right: kinematic coverage of NNPDF4.0 by dataset.

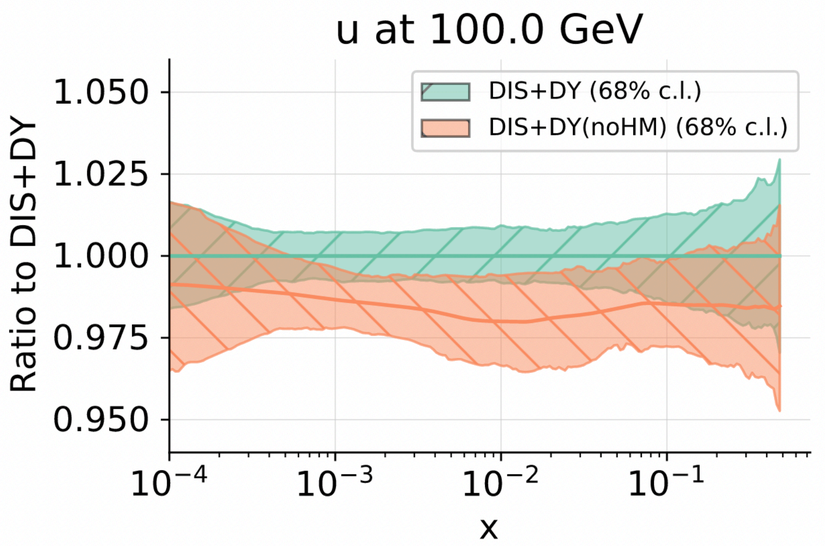


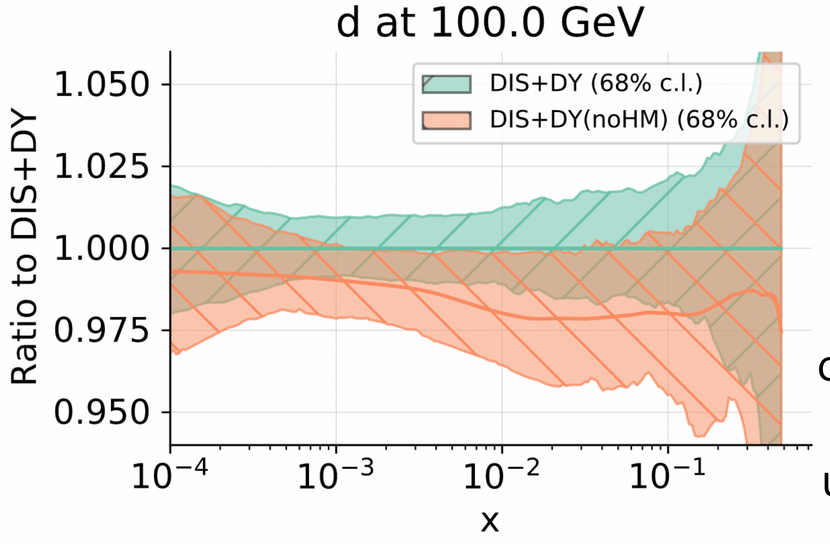
DIS and fixed target DY data

PDF-SMEFT interplay: natural questions

- *Question 1:* **Can't I just use PDF sets which are fitted using data that is not affected by SMEFT operators?**

  - Furthermore, if we include more data in a PDF fit, we obtain **better quality fits**. Therefore, we expect that using 'uncontaminated PDFs' will result in **poorer quality SMEFT fits**; we won't be using the 'best quality' PDFs that are available - this is shown explicitly in *Greljo et al., 2104.02723*, where PDF sets including and excluding high-mass DY data are compared.





without certain DY data points, high-x uncertainty increases

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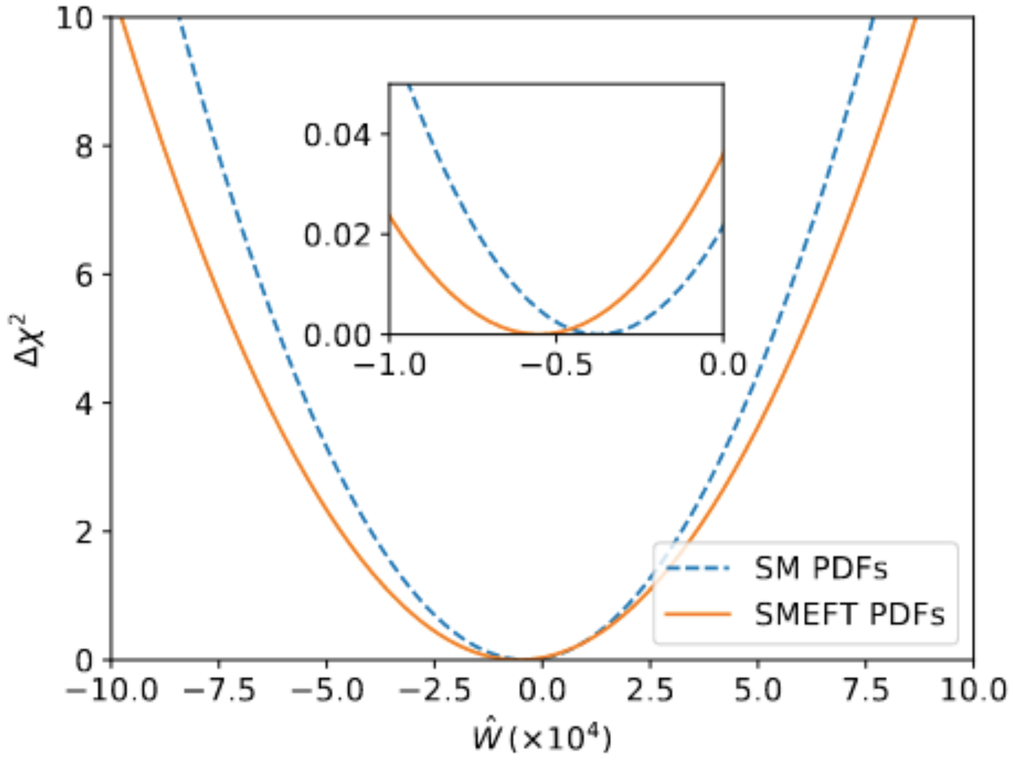
  - It was shown in *Carrazza et al., 1905.05215*, that interplay is very mild in the case of simultaneous extractions of four-fermion operators and PDFs using DIS-only data.
  - Similarly, it was shown in the PBSP team's earlier study, *Greljo et al., 2104.02723*, that interplay is mild between the $\hat{W}$, $\hat{Y}$ operators and PDFs using current DIS and DY data.



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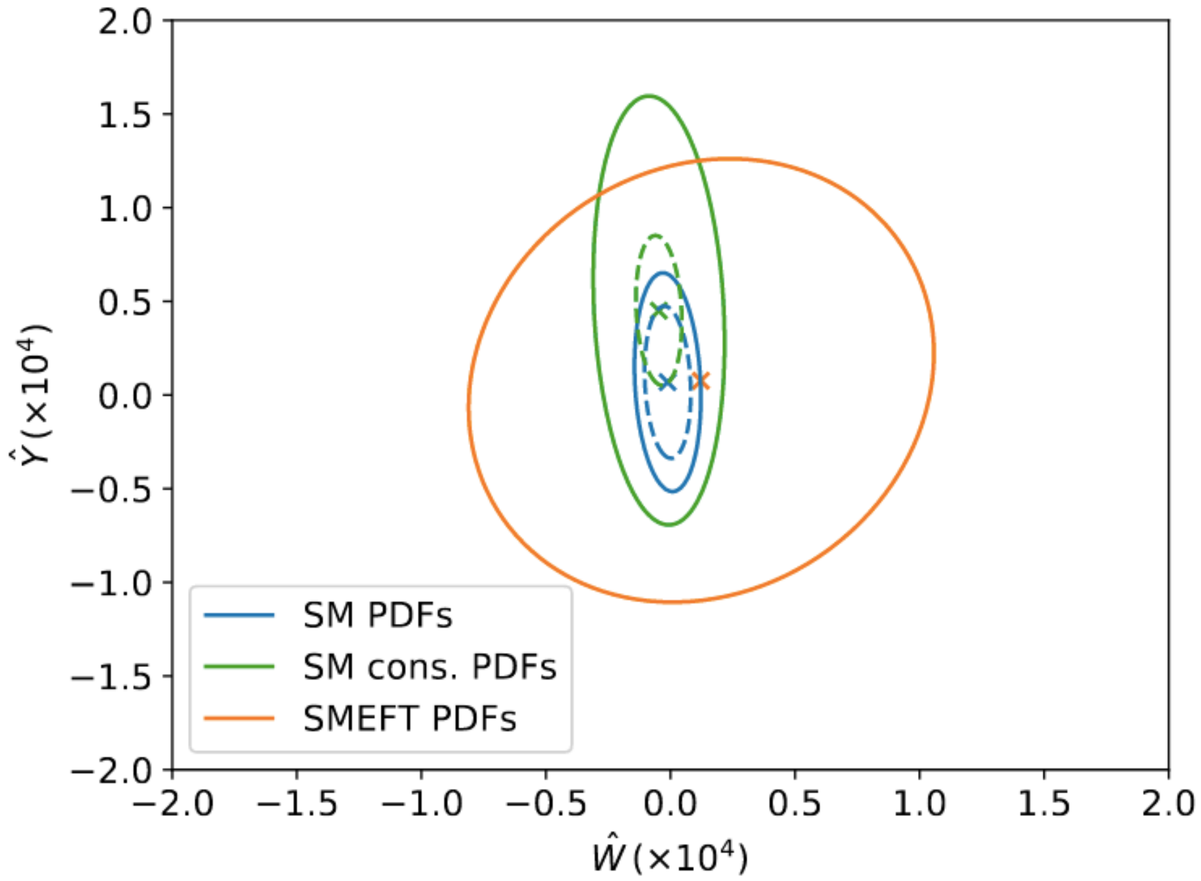
- *Question 2*: **Won't the PDF-SMEFT interplay be negligible?**
  - *However,* it was also shown in *Greljo et al., 2104.02723*, that interplay is **very significant** between the $\hat{W}$, $\hat{Y}$ operators and PDFs using **projected high-luminosity DY data**.



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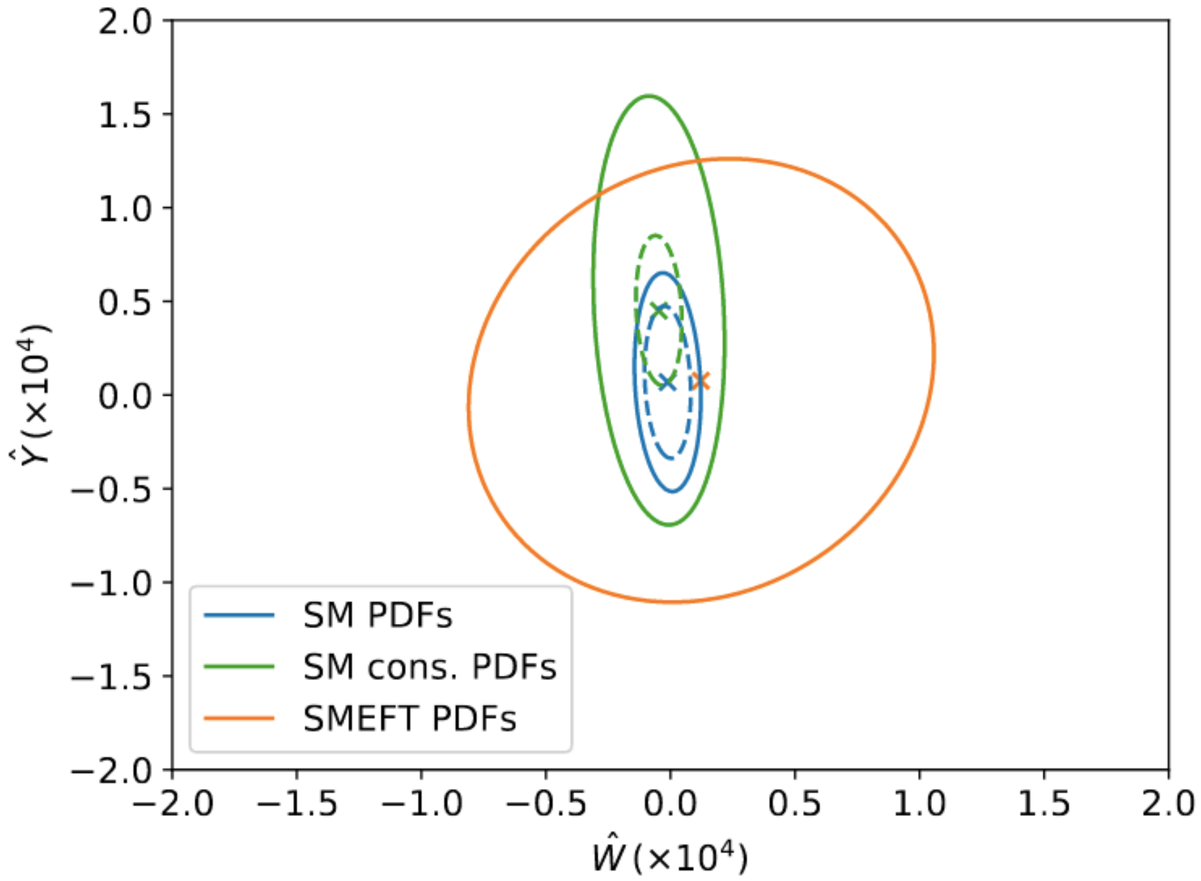
  - *However,* it was also shown in *Greljo et al., 2104.02723*, that interplay is **very significant** between the $\hat{W}$, $\hat{Y}$ operators and PDFs using **projected high-luminosity DY data**.
  - We see that using fixed PDFs results in a **significant underestimation** of uncertainties on the WCs - we might wrongly conclude **New Physics**!



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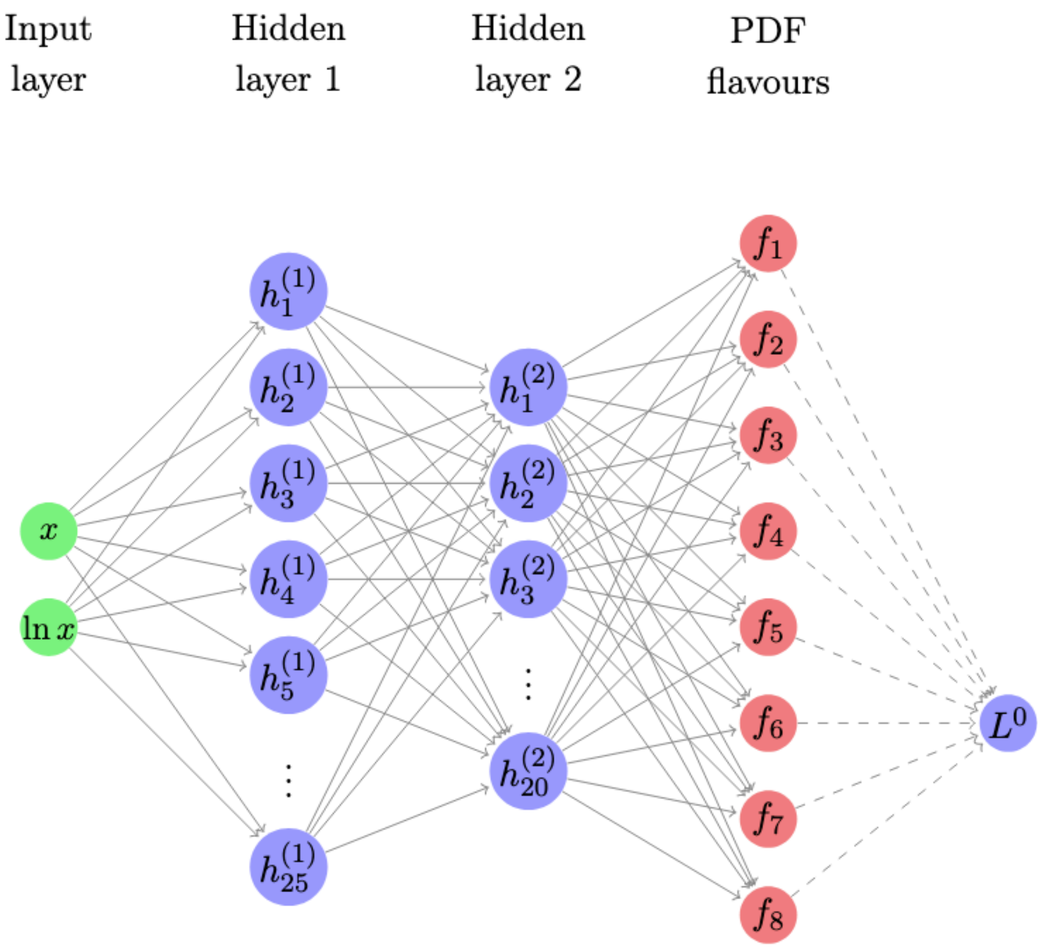
3. SIMUnet methodology

- Extend the NNPDF replica networks with a new layer with edges corresponding to the WCs.
- Train the network as per an NNPDF fit, but also learning the WCs.

See 2201.07240

The SIMUnet methodology: details

- The SIMUnet methodology **extends the existing NNPDF neural network** with an additional **convolution layer**.



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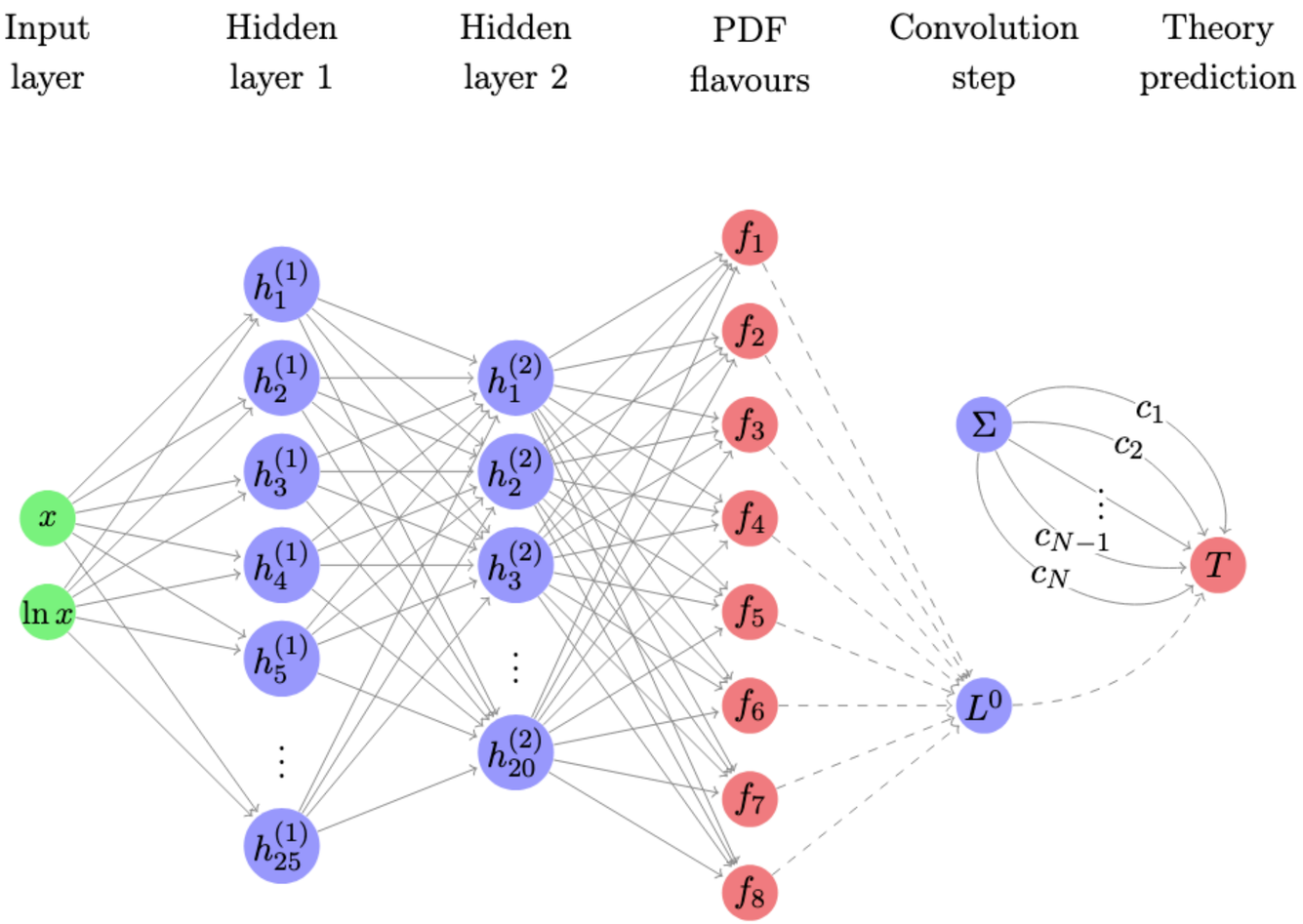
- The SIMUnet methodology **extends the existing NNPDF neural network** with an additional **convolution layer**.
- The SMEFT couplings are added as **weights of neural network edges**, and are **trained alongside the PDFs**.



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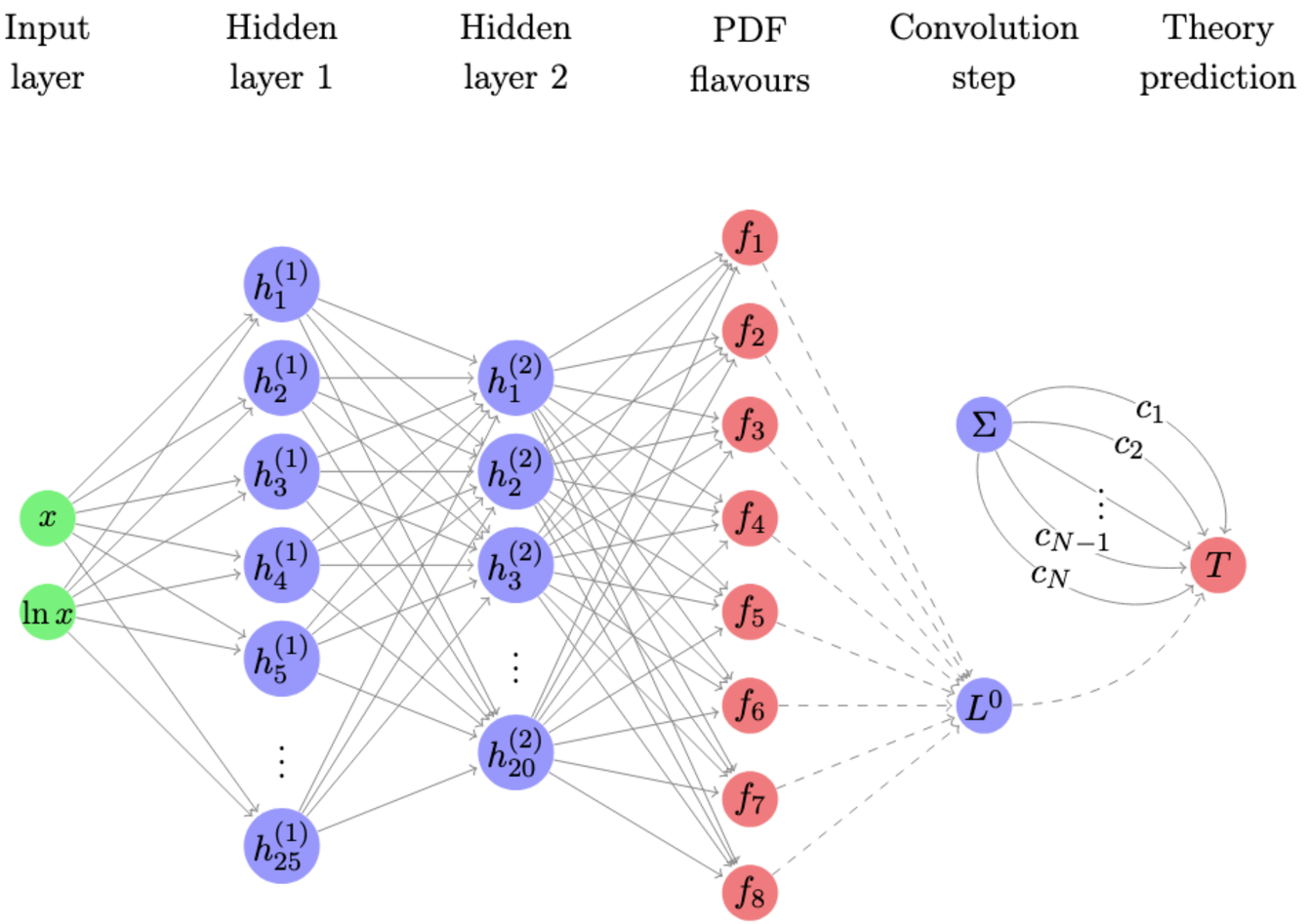

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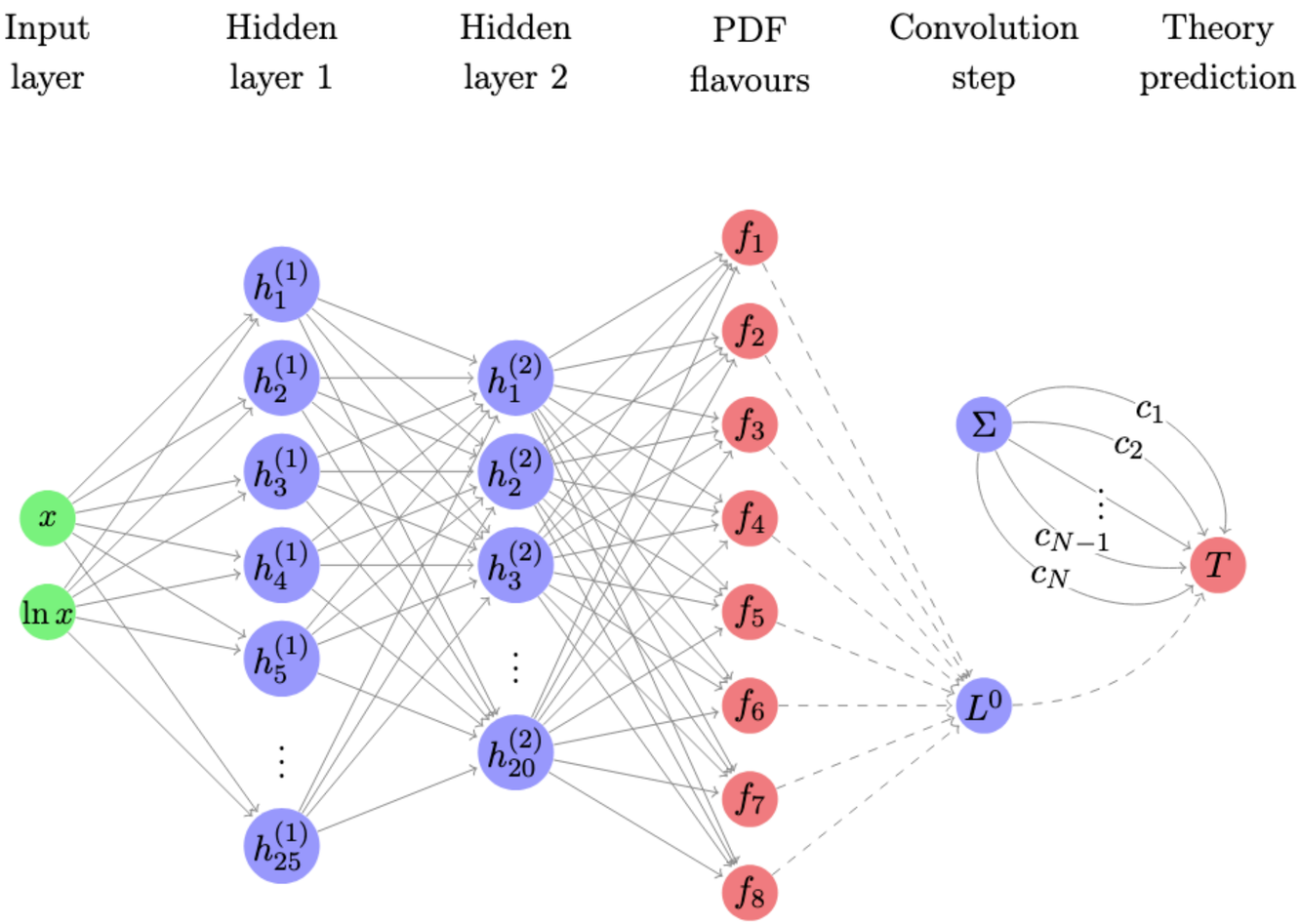

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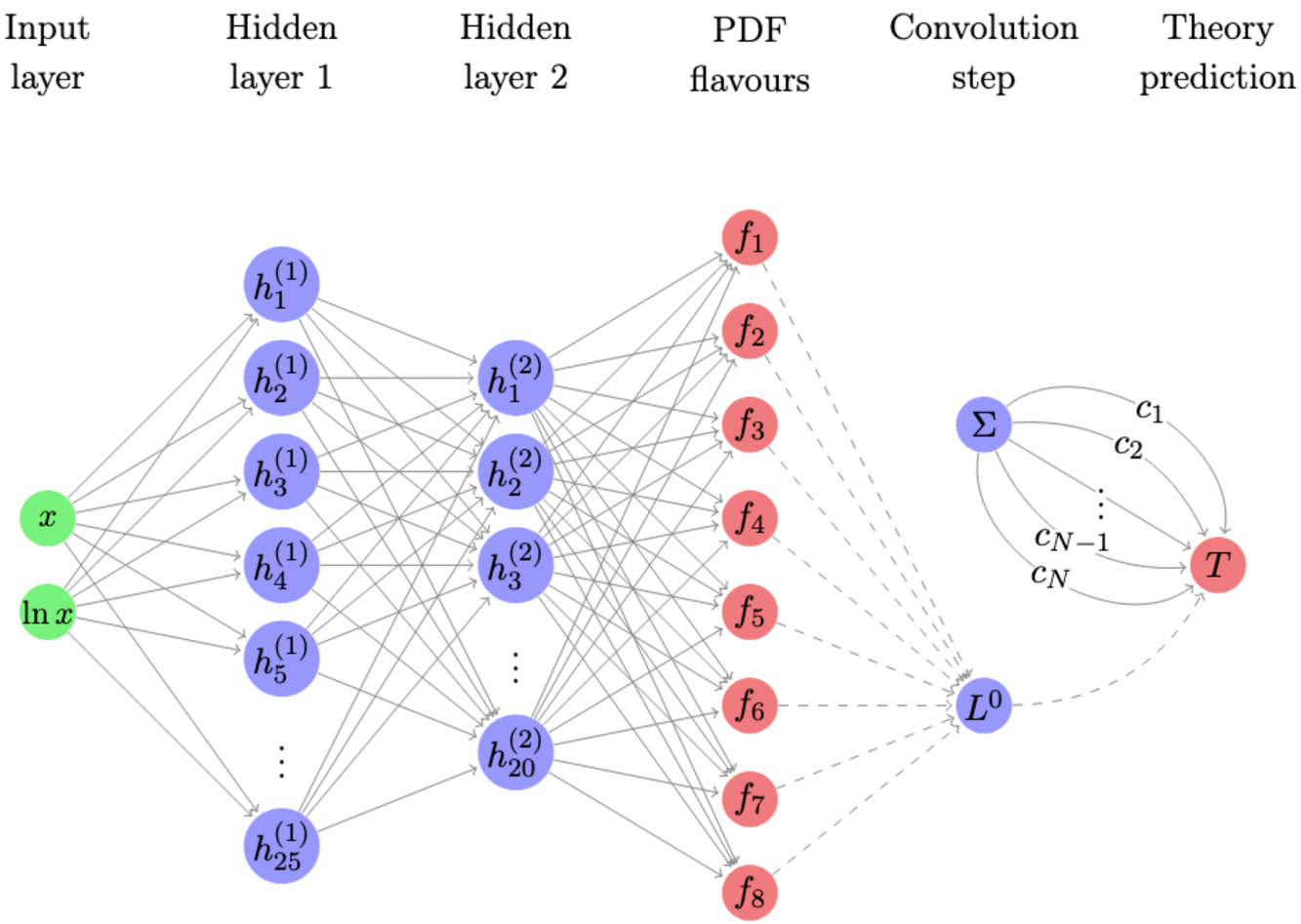

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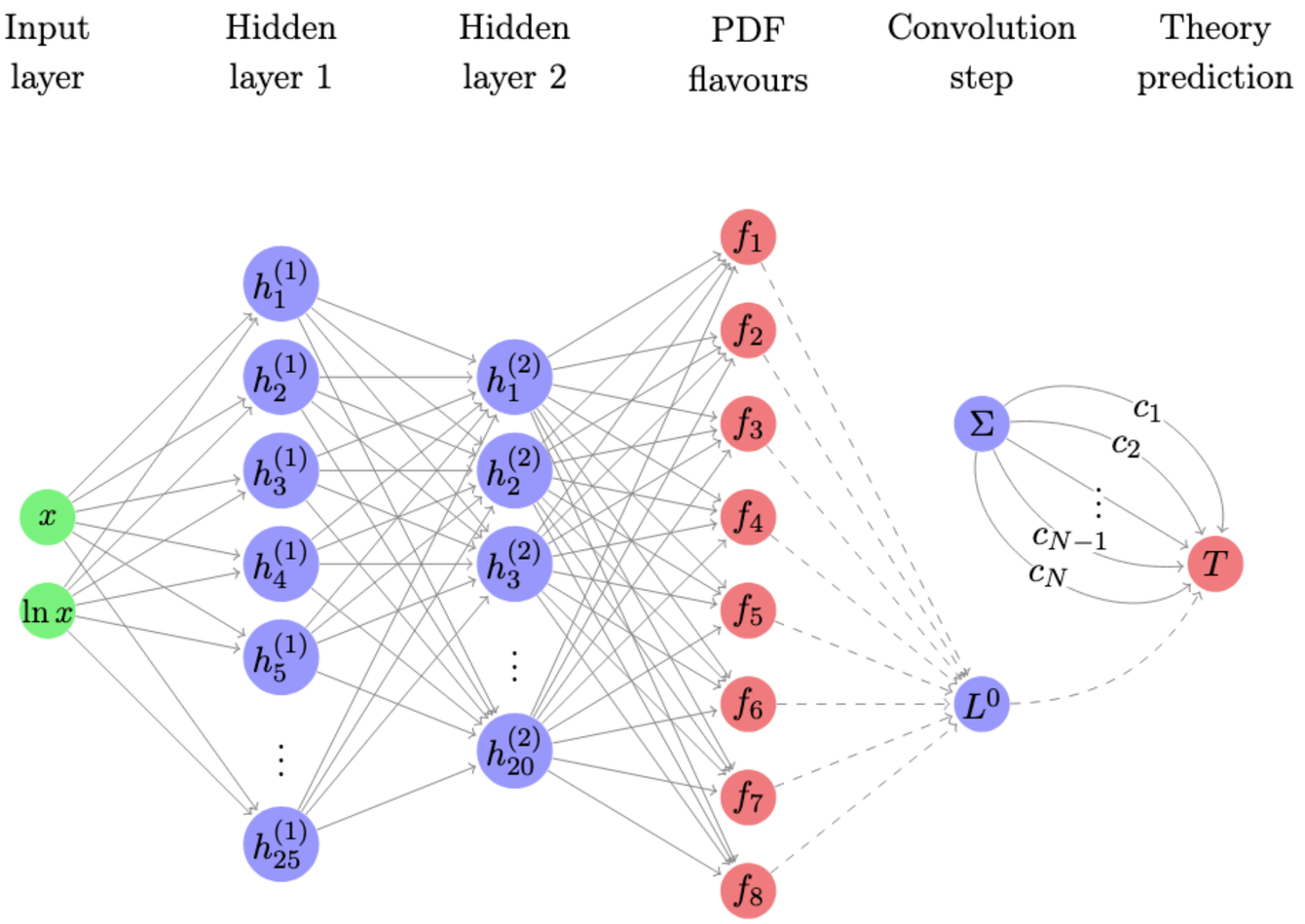
  - Can perform **fixed PDF fits** by **freezing the PDF part of the network**.

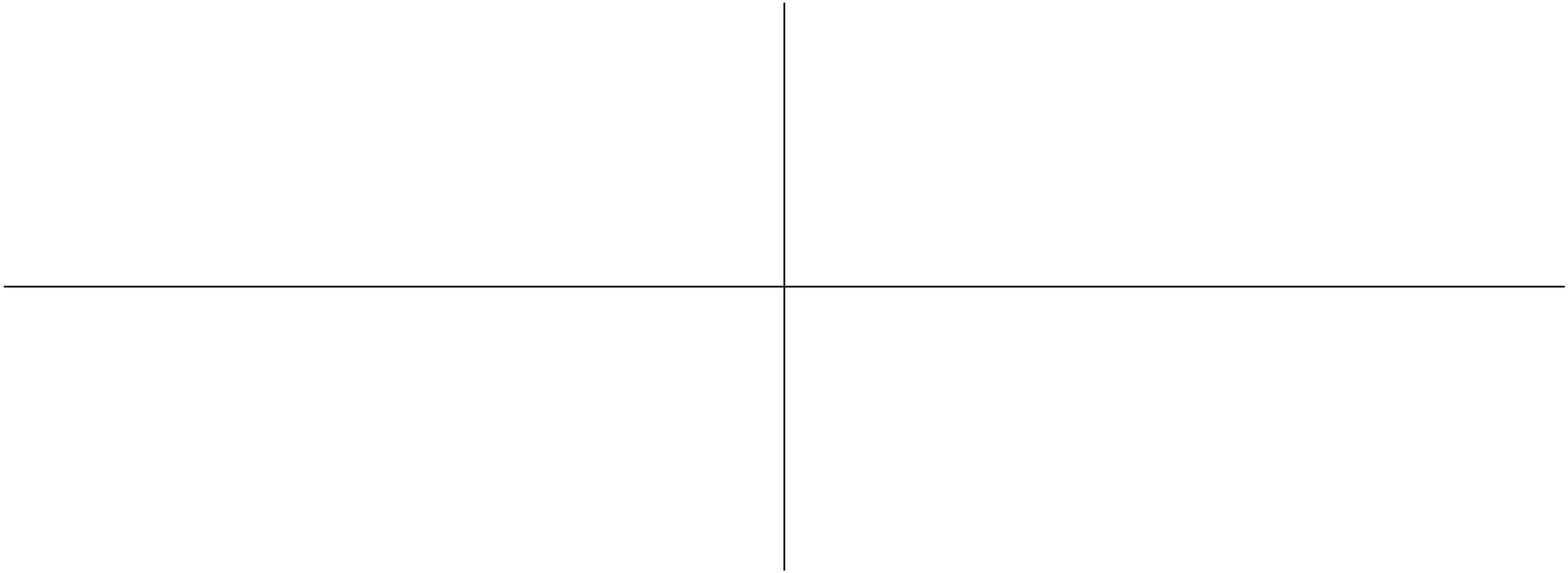


3. - The impact of Run II top data on joint PDF-SMEFT fits

Based on an upcoming publication
by the PBSP team + Juan Rojo

Run II top quark data

- **Huge amount of Run II top quark data** from ATLAS and CMS. Four basic processes:



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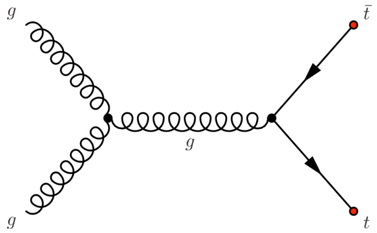

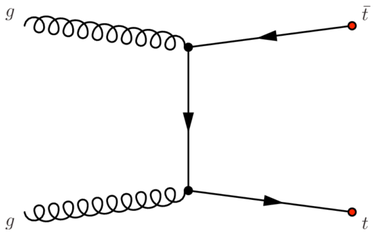

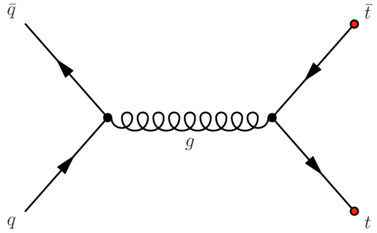

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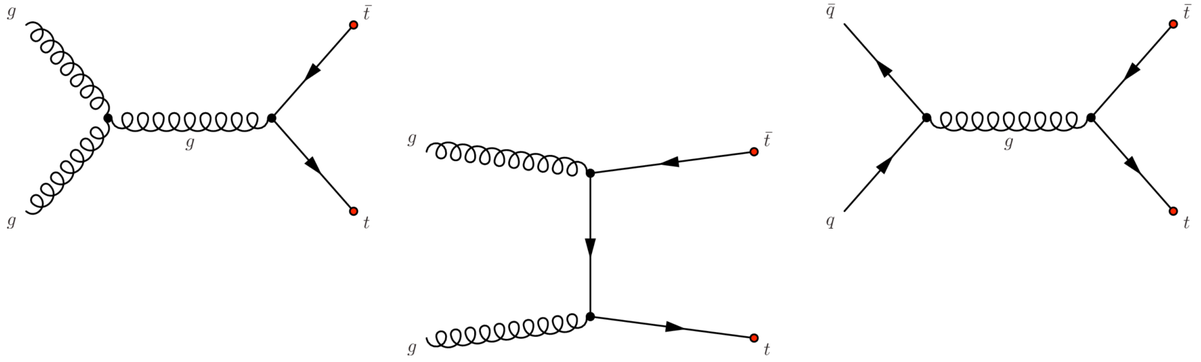

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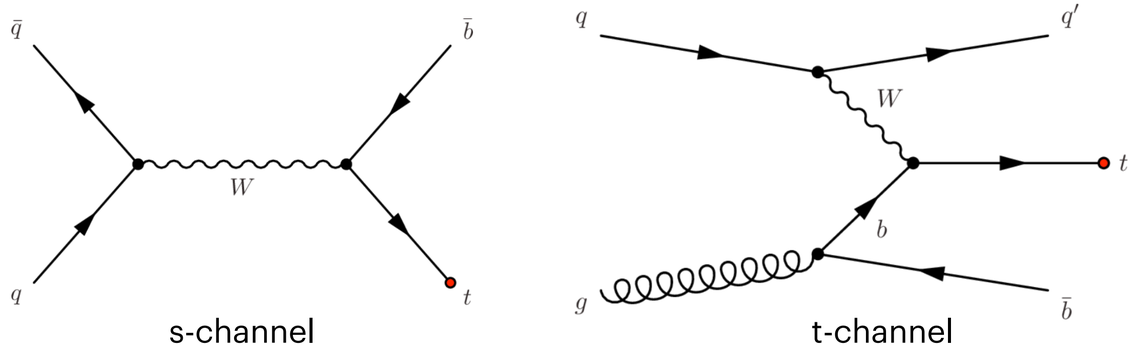

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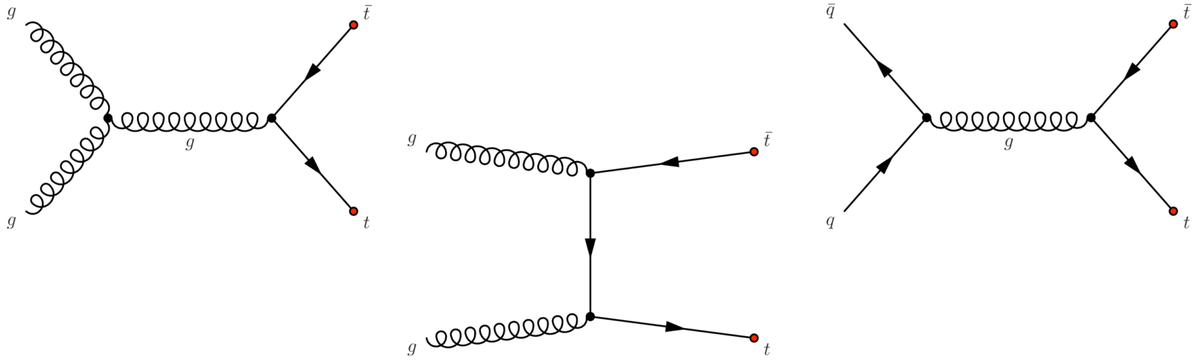

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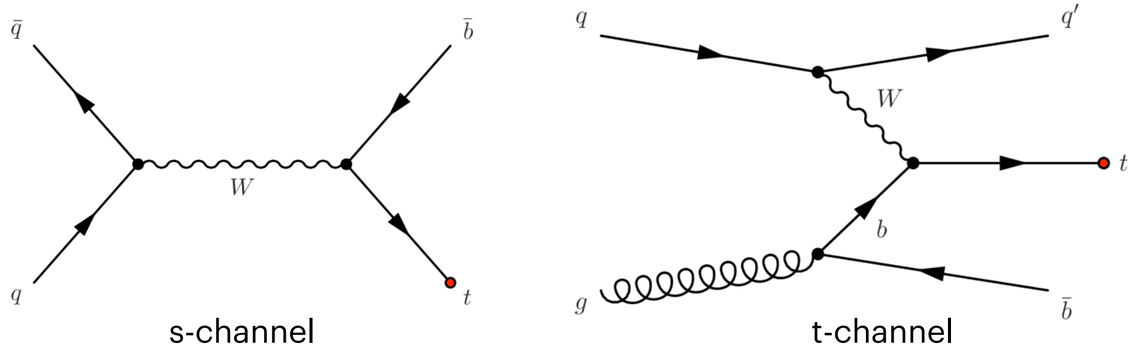

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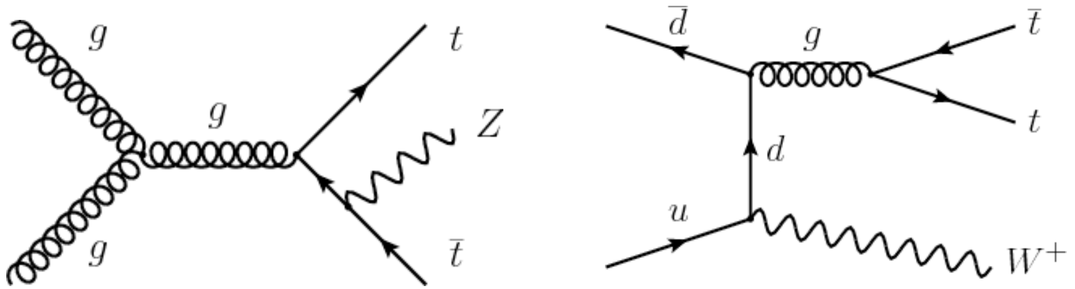

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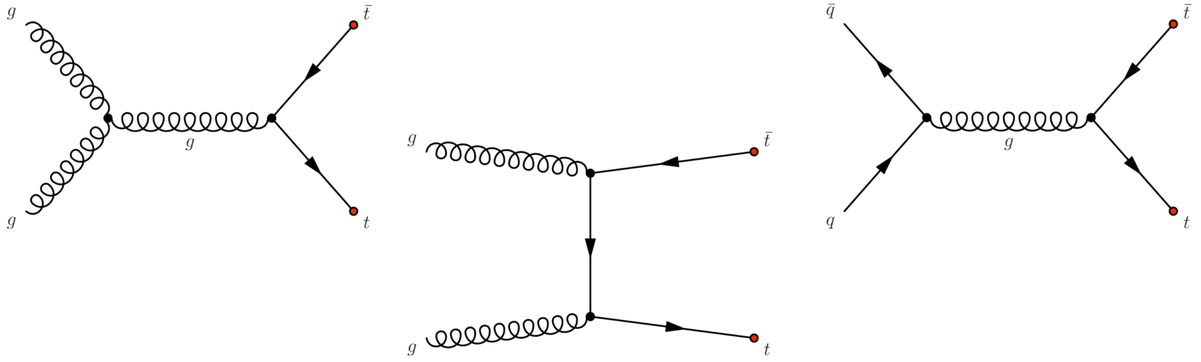

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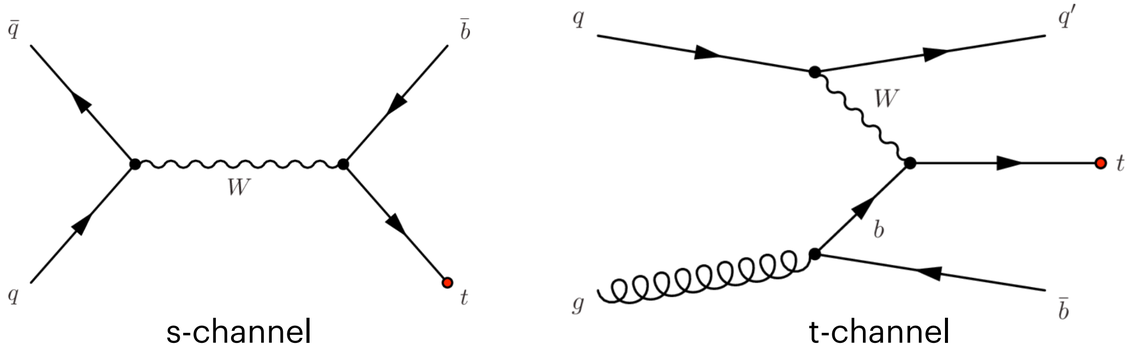

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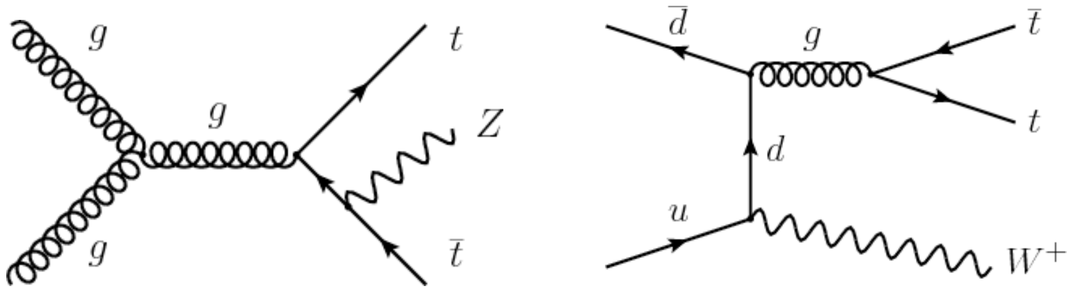

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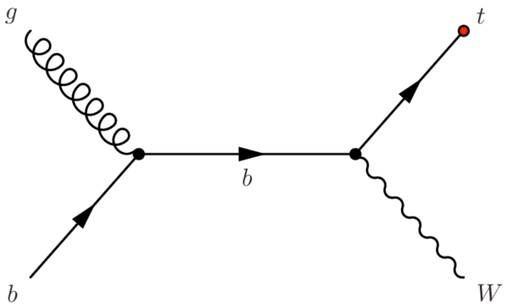

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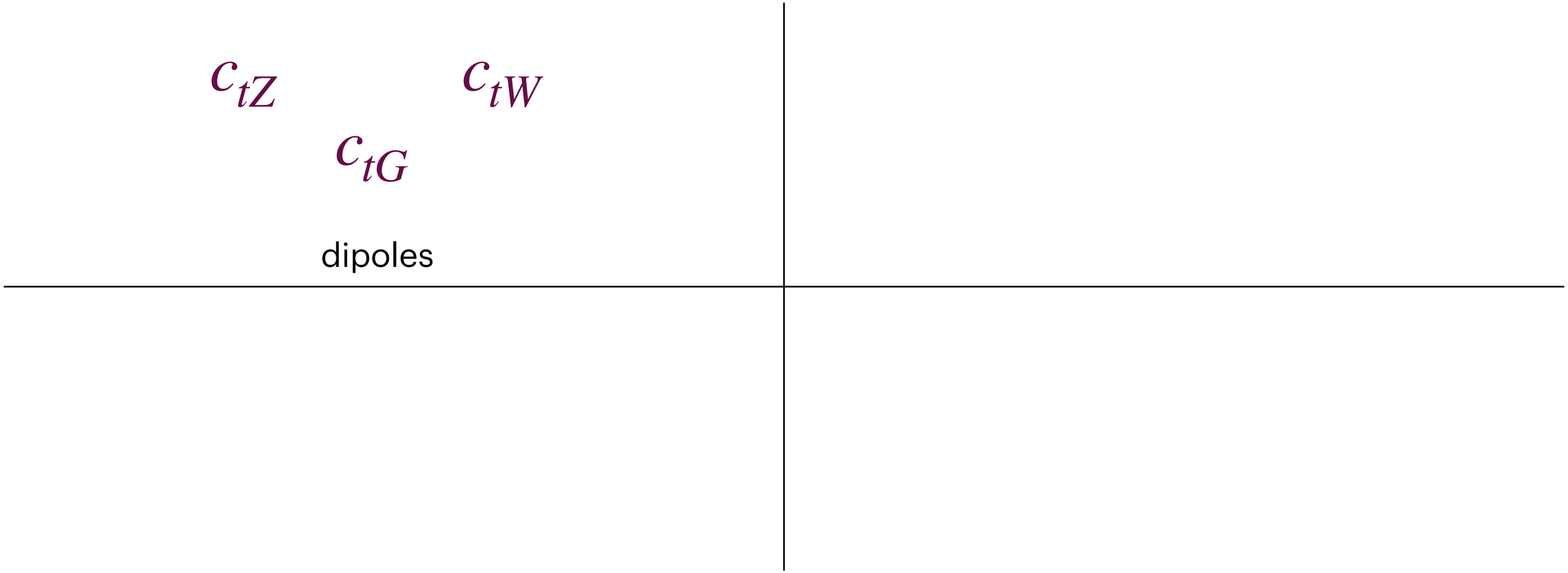

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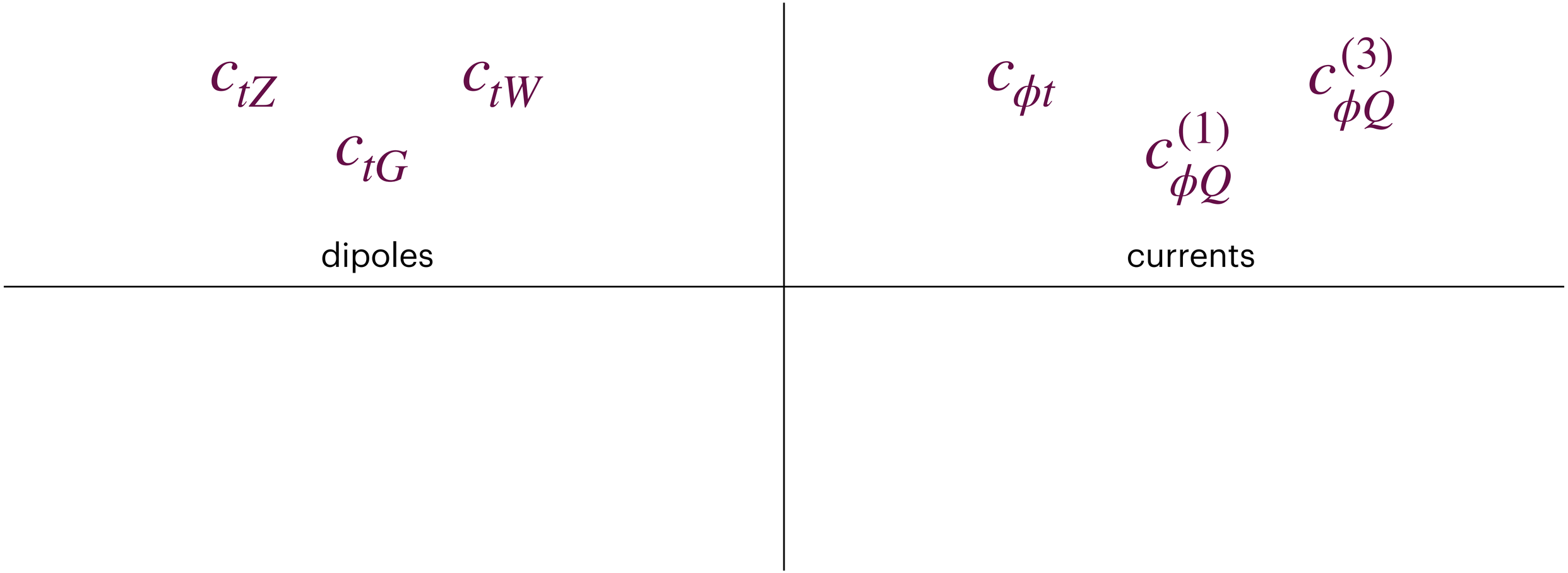

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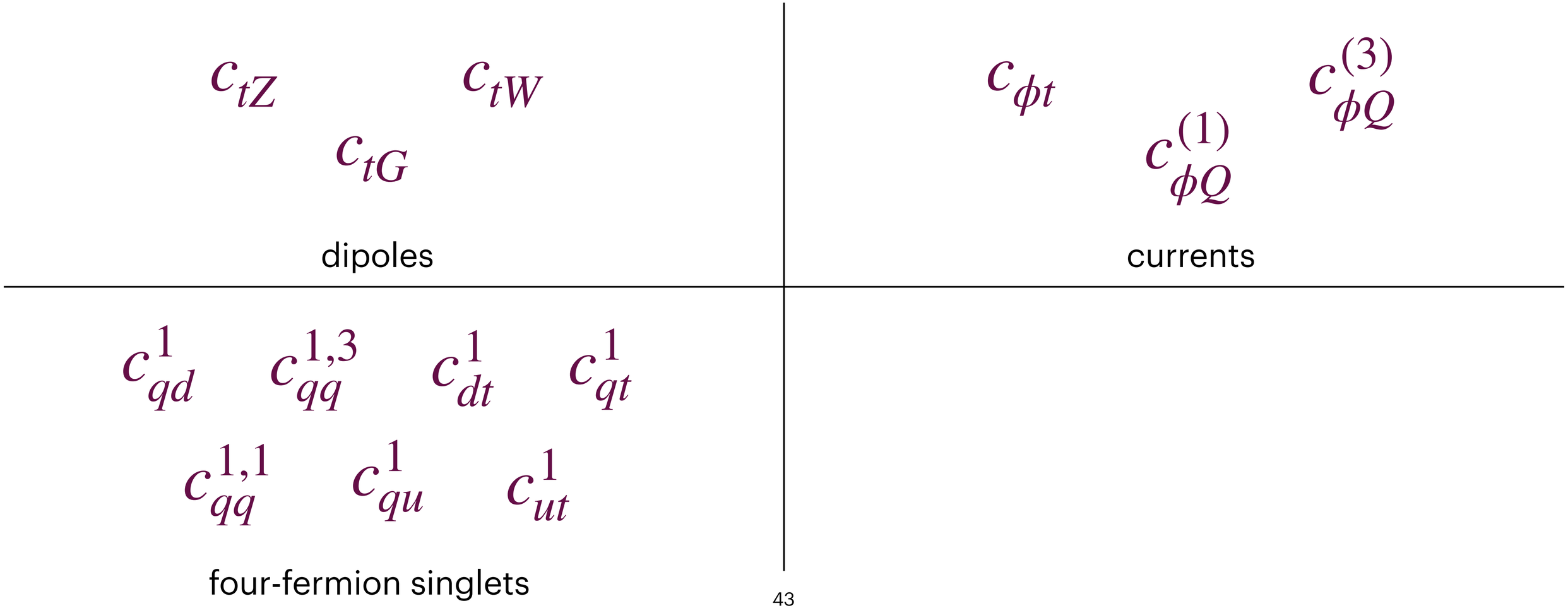

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c_{tZ} c_{tW} c_{tG}

dipoles

$c_{\phi t}$ $c_{\phi Q}^{(3)}$ $c_{\phi Q}^{(1)}$

currents

c_{qd}^{1} $c_{qq}^{1,3}$ c_{dt}^{1} c_{qt}^{1} $c_{qq}^{1,1}$ c_{qu}^{1} c_{ut}^{1}

four-fermion singlets

c_{qd}^{8} $c_{qq}^{8,3}$ c_{dt}^{8} c_{qt}^{8} $c_{qq}^{8,1}$ c_{qu}^{8} c_{ut}^{8}

four-fermion octets

Key questions for the rest of the talk:

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2. How do PDFs compare between SM PDF fits and simultaneous PDF-EFT fits?

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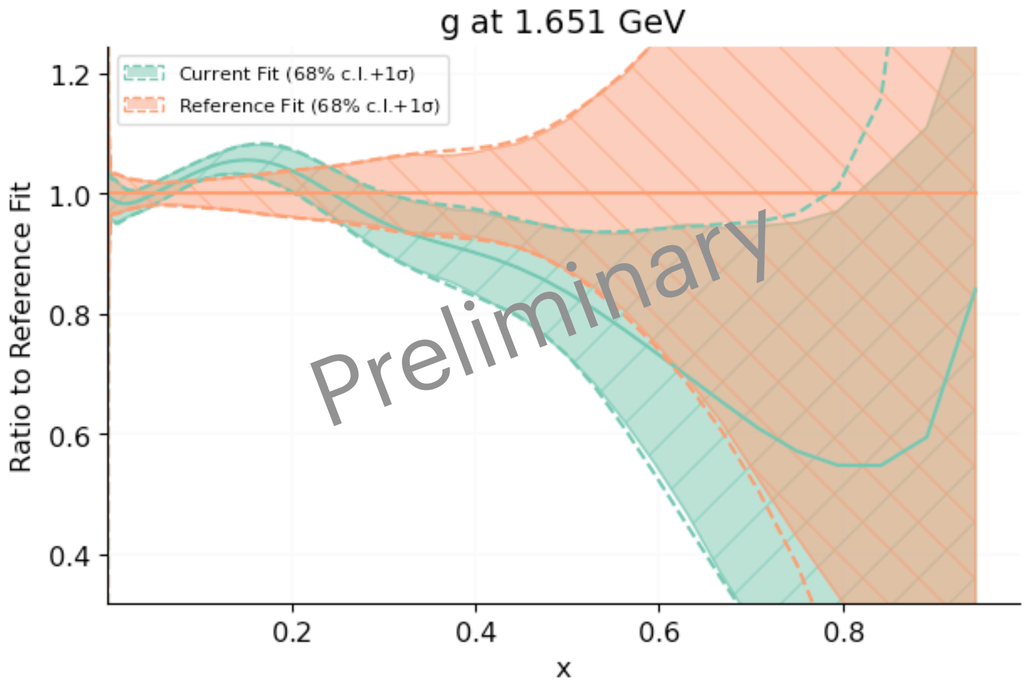
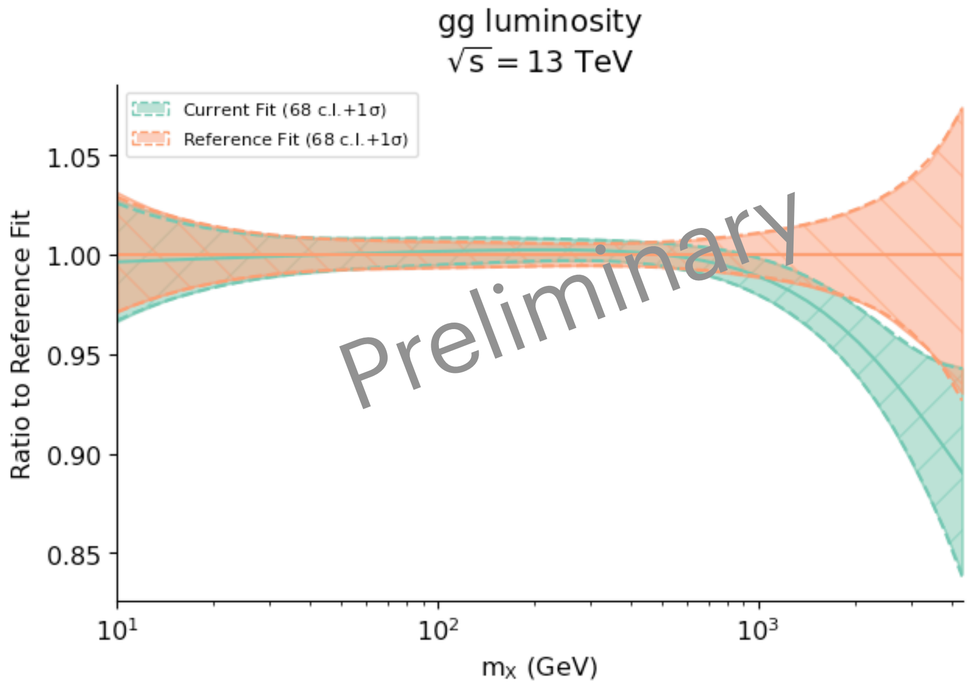
  - Fitmaker (137 top data points)
- We work with theory predictions accurate to **NNLO in QCD in the SM**, and include **NLO QCD and quadratic corrections in the SMEFT**.

Preliminary results: PDFs and luminosities

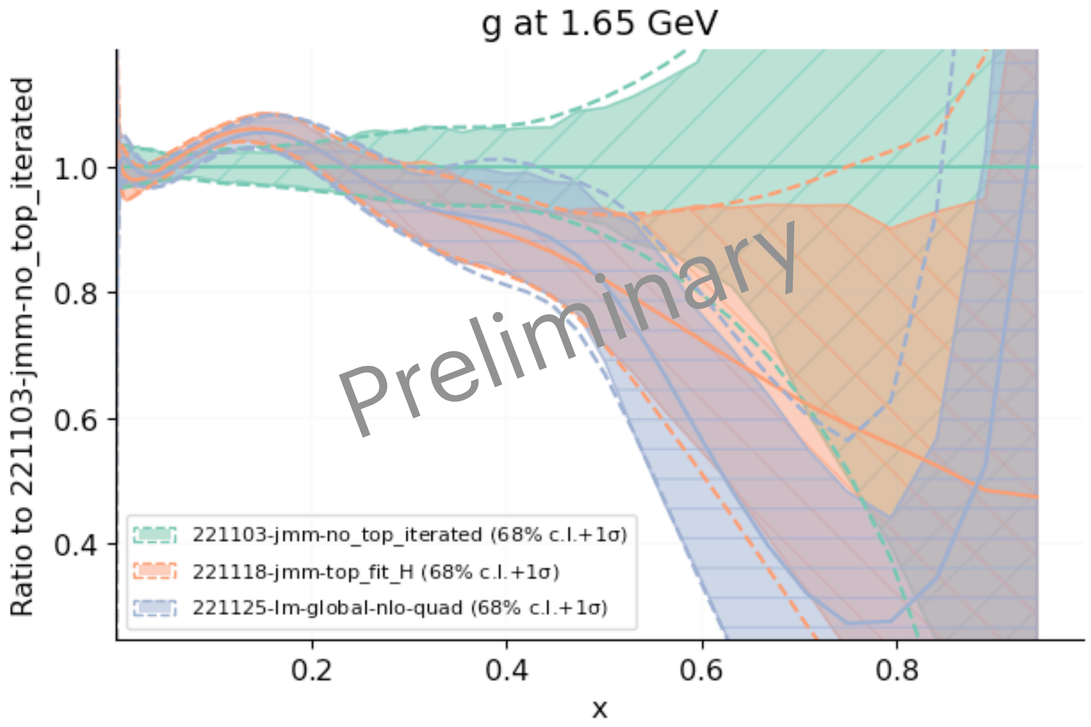
- First, we consider the impact of our dataset on PDFs **in the SM**. As expected from previous PDF studies, the contribution of the top data results in a **significant shift in the gluon PDF** in the **high-x region**.
- Orange: no-top PDF, green: SM PDF including top data:

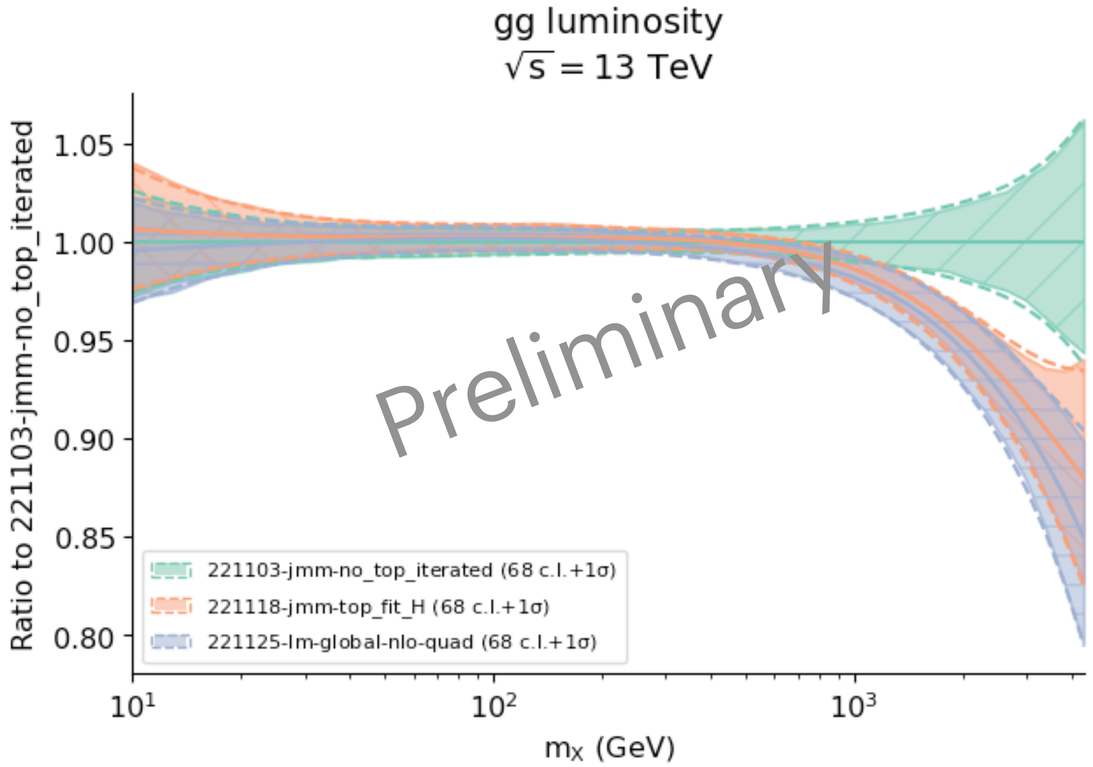




Preliminary results: PDFs and luminosities

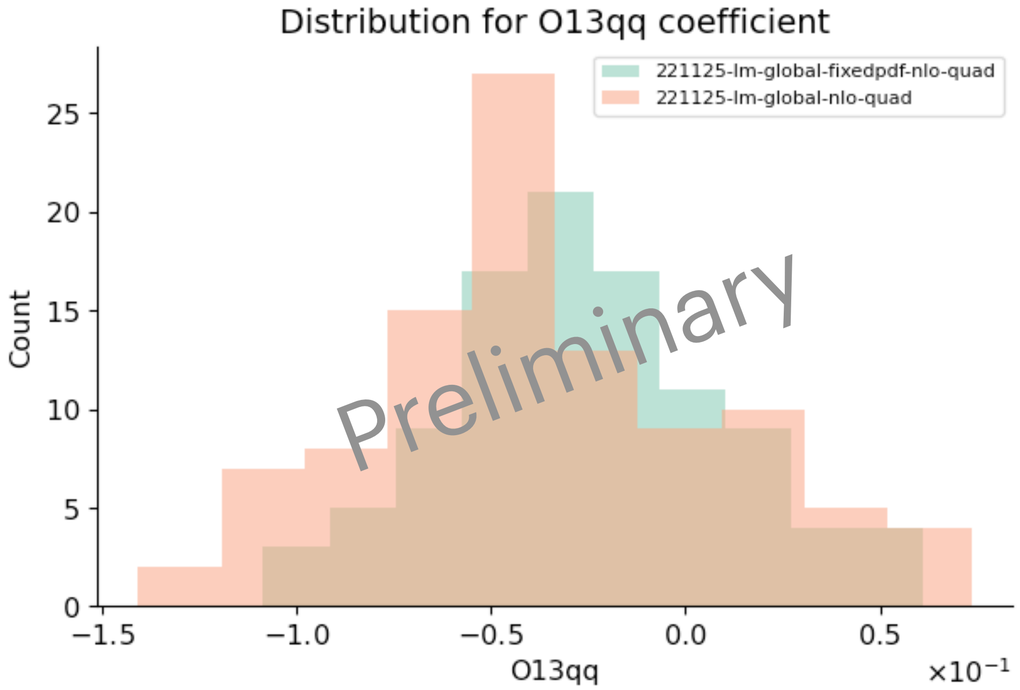
- When we perform a simultaneous fit of PDFs and WCs, the shift in the high-x gluon is **slightly enhanced**.
- Green: no-top PDF, orange: SM fit, blue: simultaneous fit:

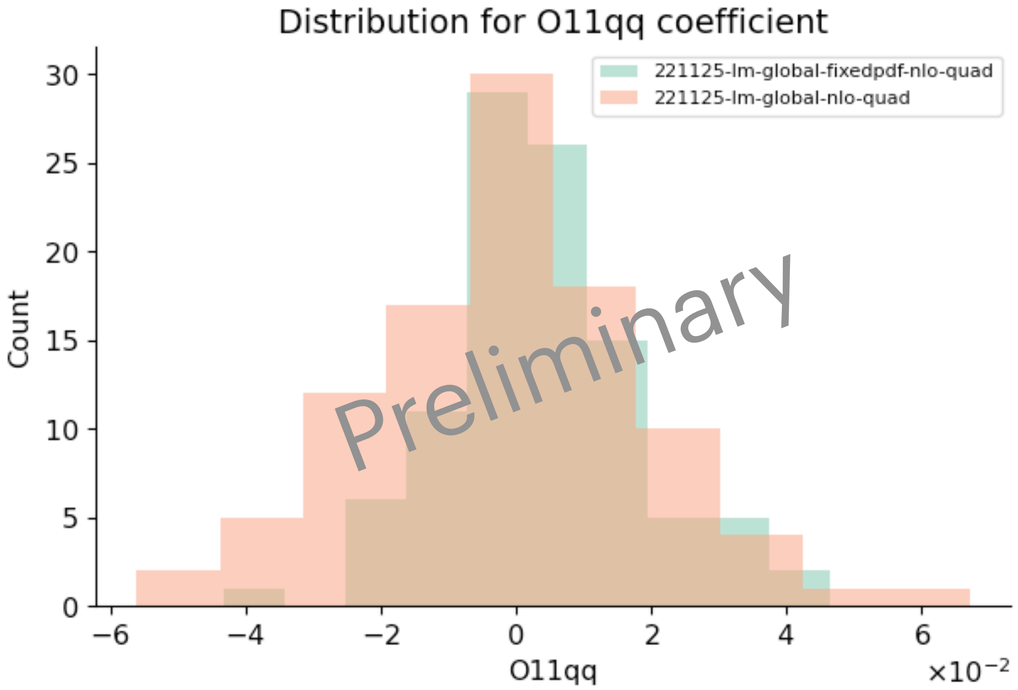




Preliminary results: Wilson coefficients

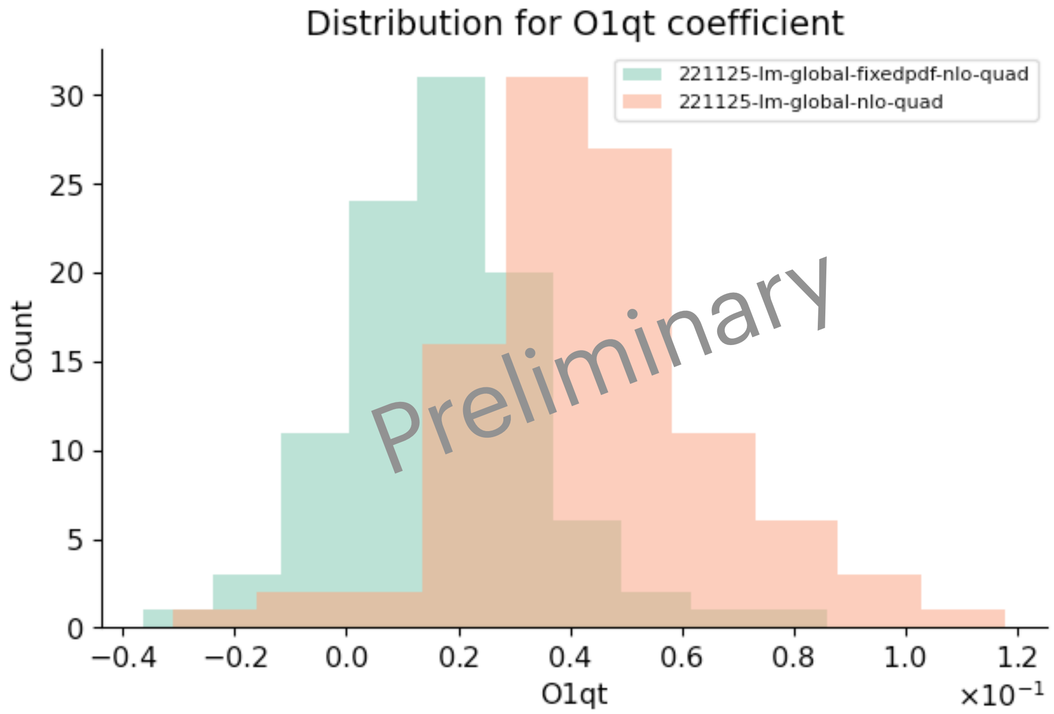
- Using the SIMUnet methodology, we find that bounds on the WCs are **slightly broader** (on average ~20%) compared to using fixed PDFs.
- Example distributions (orange: simultaneous, green: no-top fixed PDF):

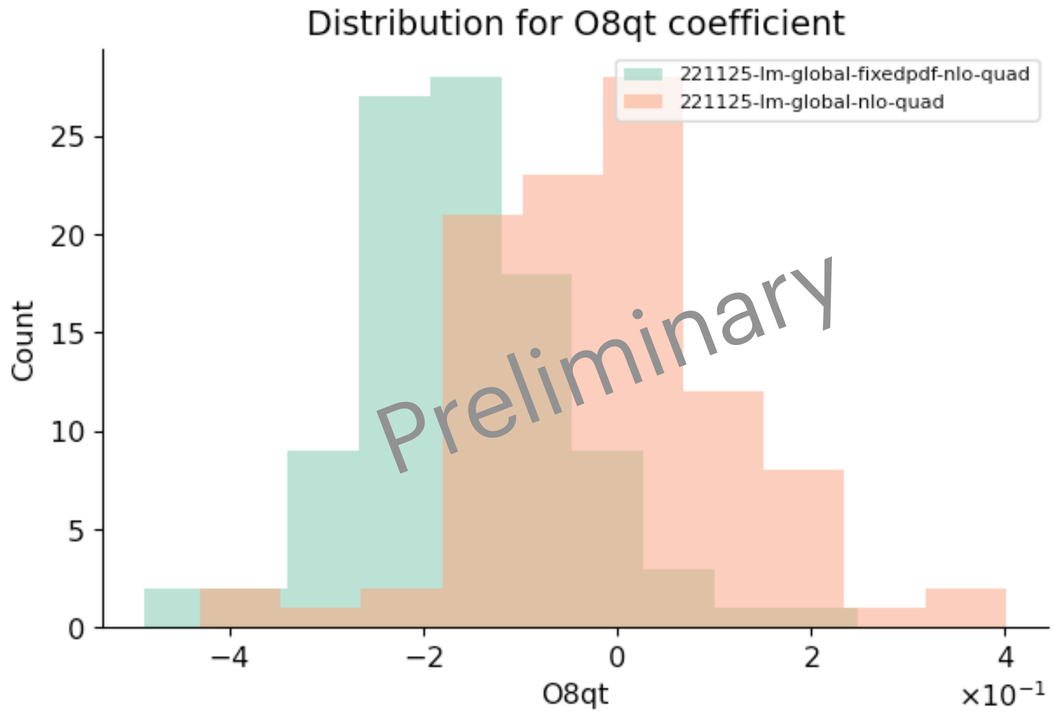




Preliminary results: Wilson coefficients

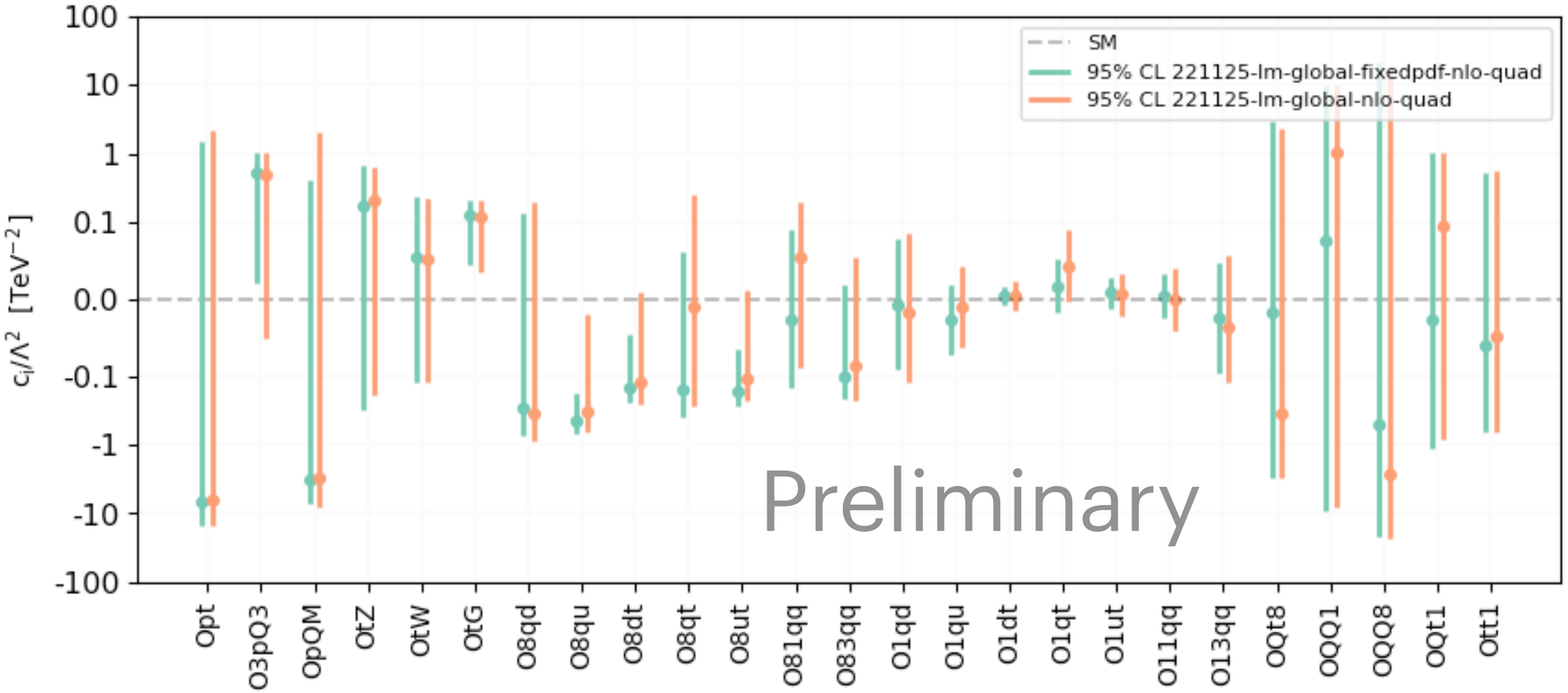
- For some operators, there is additionally a **small shift** in the central value of the distributions.
- Example distributions (orange: simultaneous, green: no-top fixed PDF):





Preliminary results: Wilson coefficients

- Summary of preliminary bounds (note logarithmic scale):
- Orange: simultaneous, green: no-top fixed PDF.



Preliminary results: fit quality

- Finally, using the SIMUnet methodology, we achieve a **significantly better** χ^2 statistics than using a fixed no-top baseline PDF in a SMEFT-only fit:

	SMEFT-only fit, using fixed no-top PDF set	**Simultaneous fit of PDFs and SMEFT**
χ^2 to top-sector data	1.287	1.034
Total χ^2	1.164	1.150

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mainly driven by **better PDF fit**

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- A **flexible, fast methodology, SIMUnet,** is available for simultaneous determination of PDFs and WCs.

- The PBSP team, and Juan Rojo, have applied this new methodology to PDF-SMEFT fits in the **top-sector**.

Thanks for listening!
Questions?