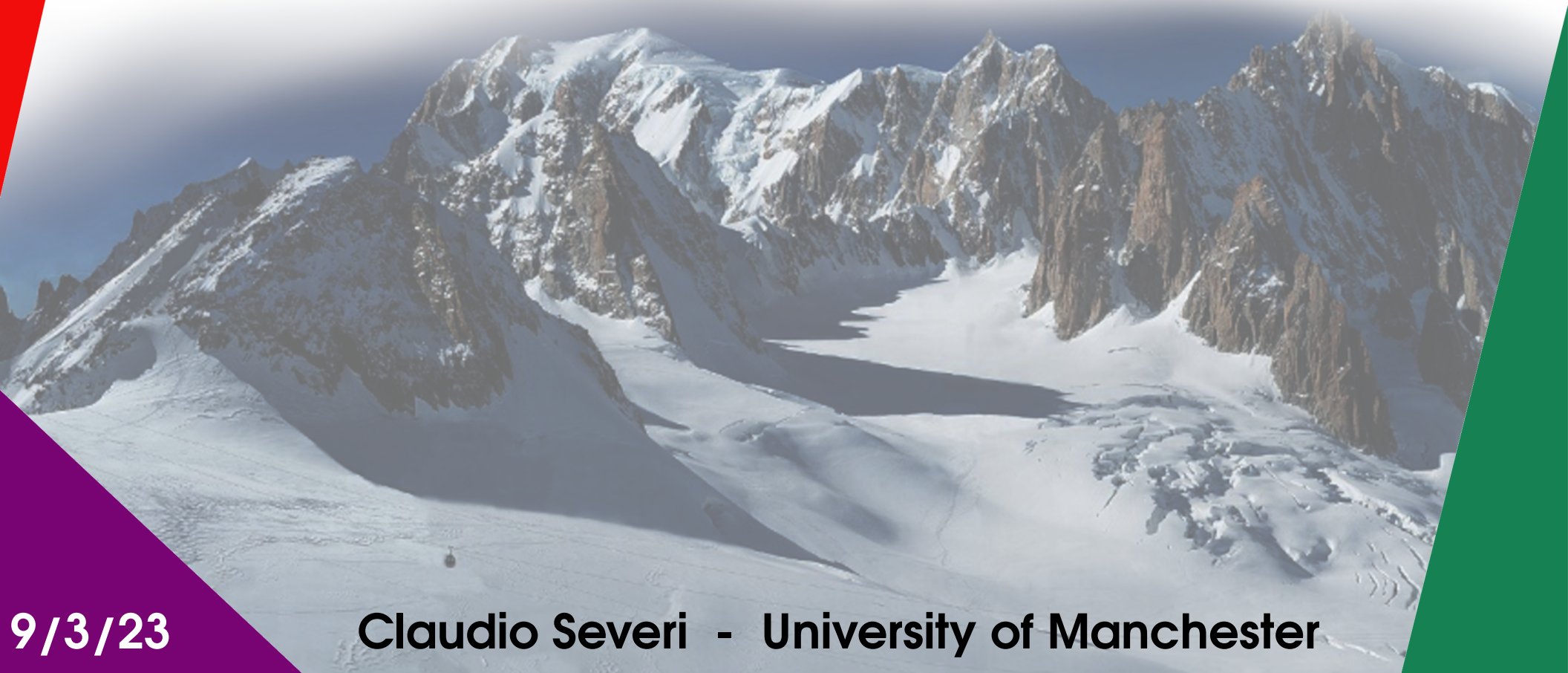
Renormalization group effects on SMEFT interpretations of LHC data

with R.Aoude, F.Maltoni, O.Mattelaer, and E.Vryonidou
2212.05067



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9/3/23

The LHC: where do we stand?

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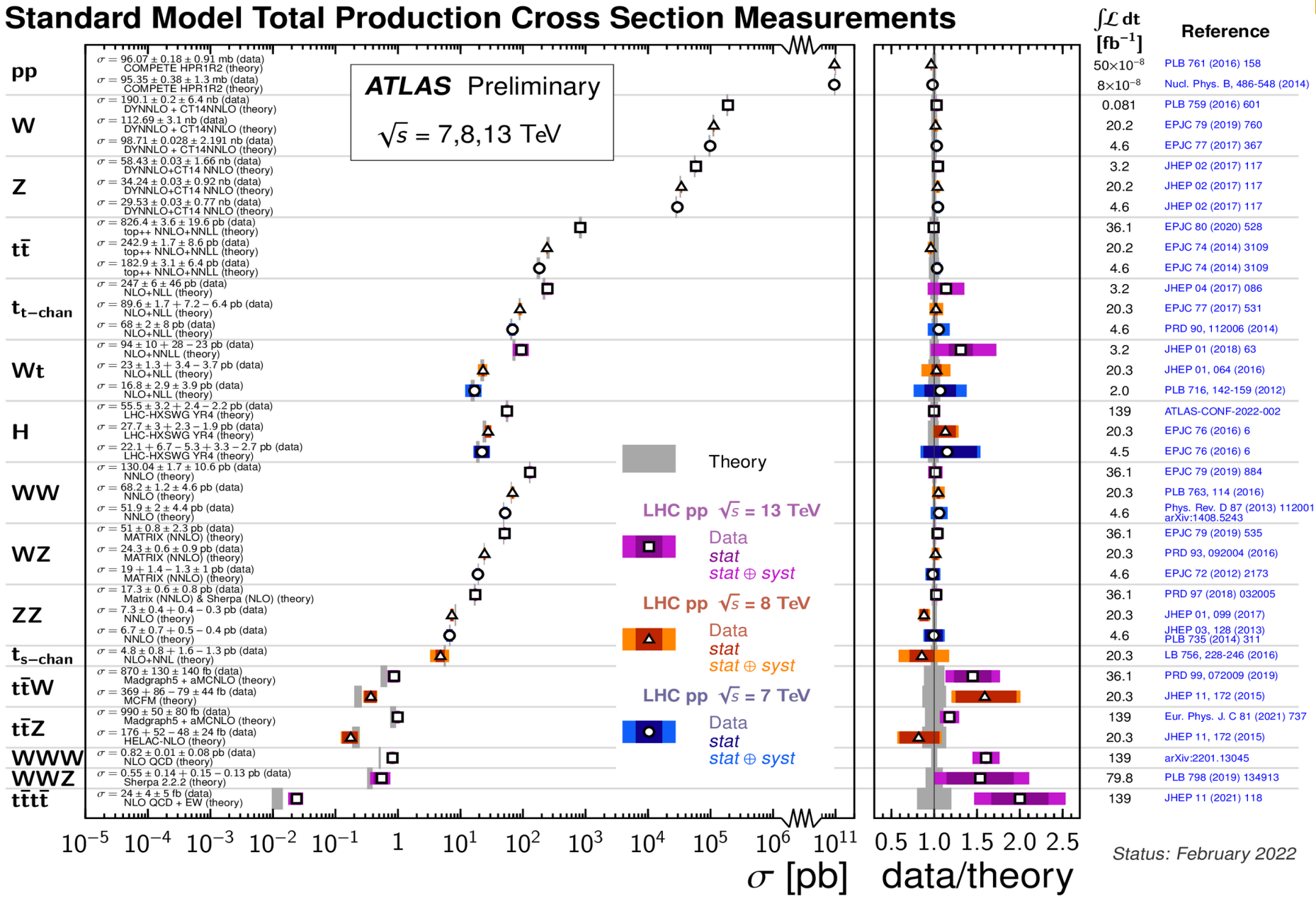

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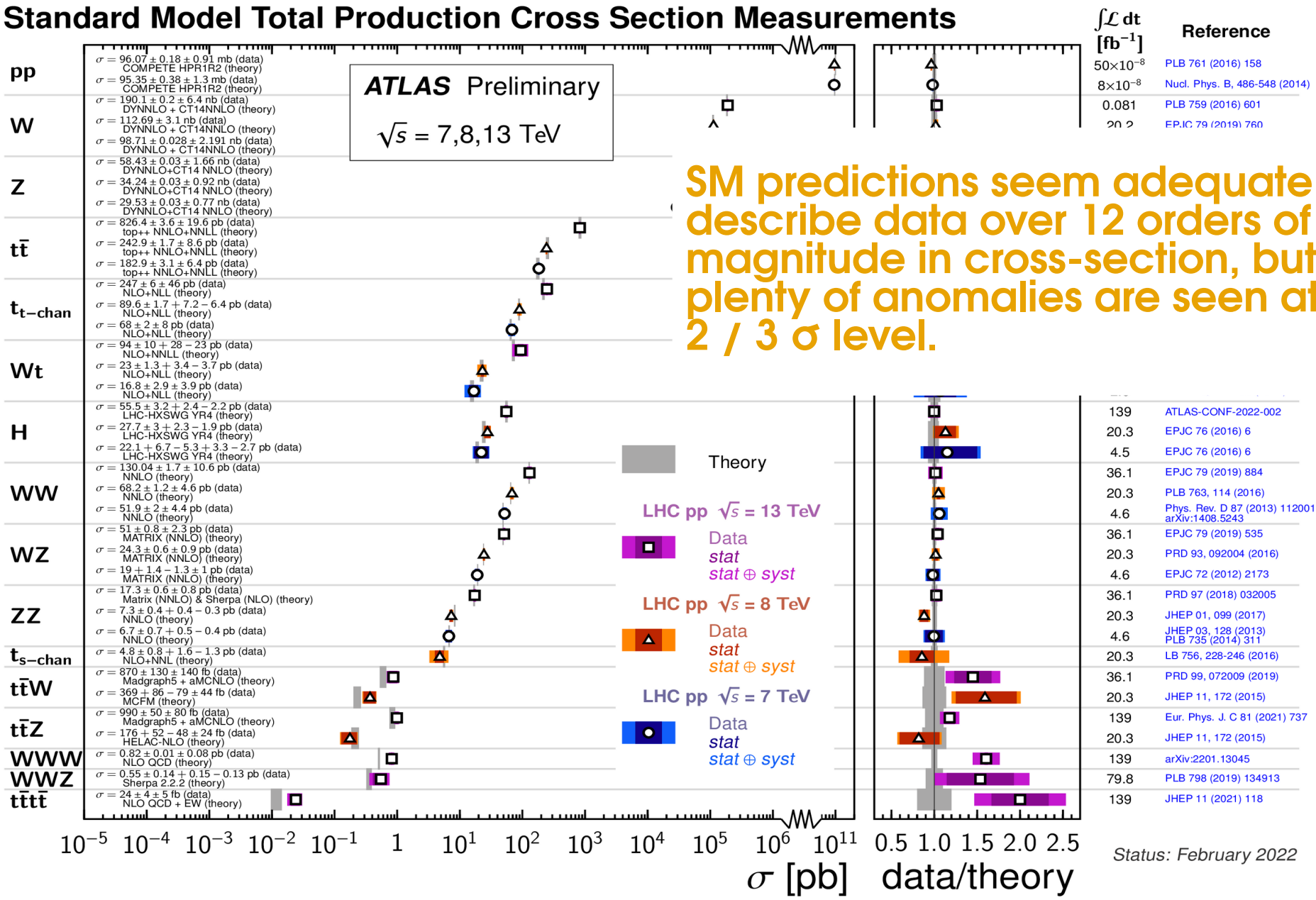

SM predictions seem adequate to describe data over 12 orders of magnitude in cross-section, but plenty of anomalies are seen at the 2 / 3 σ level.

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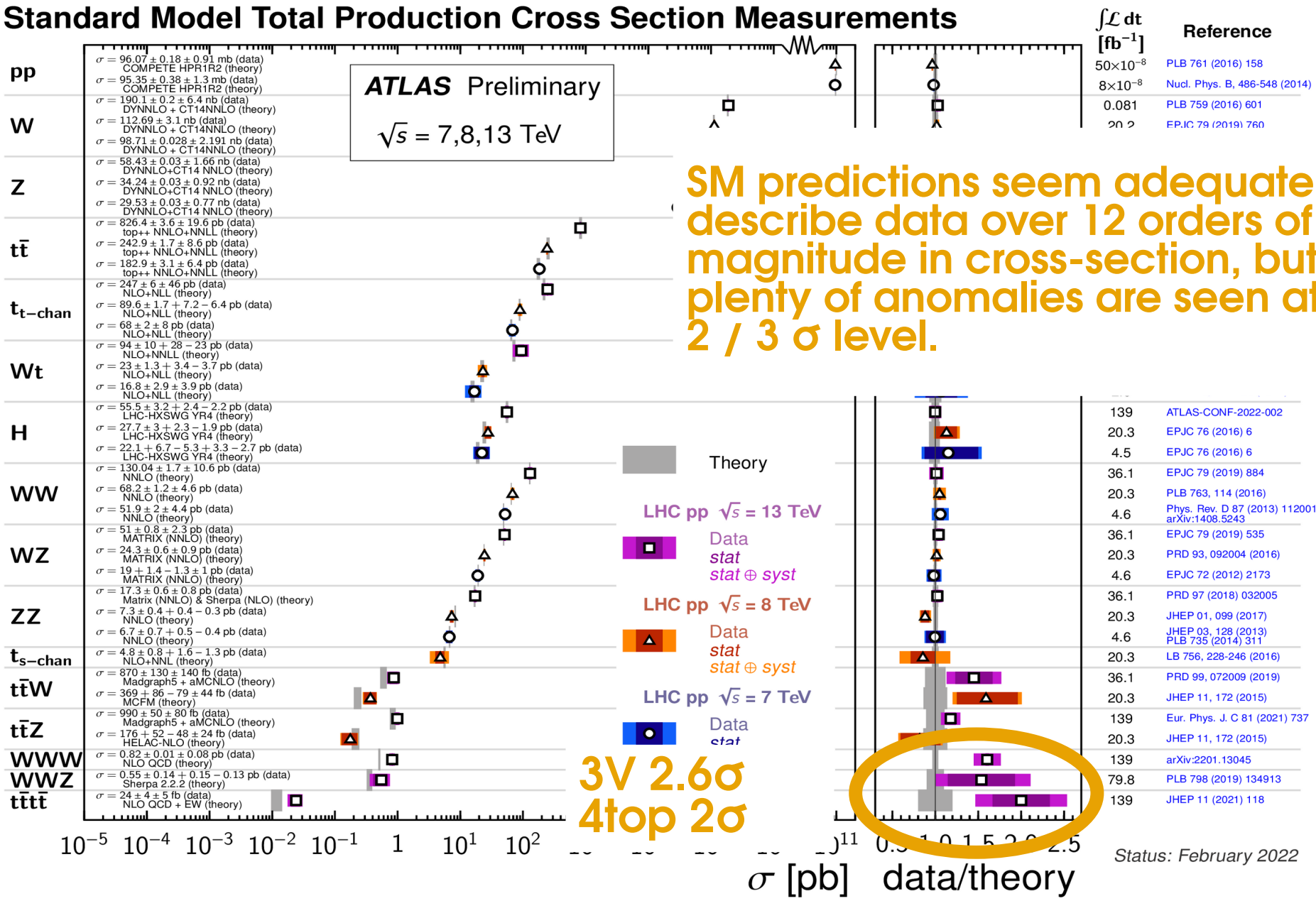

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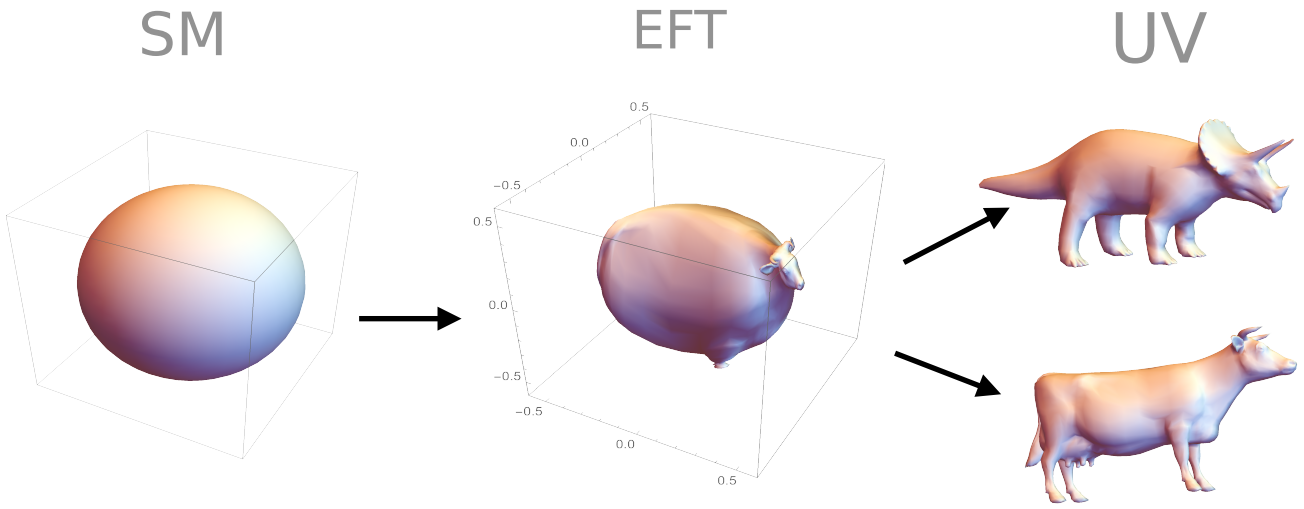
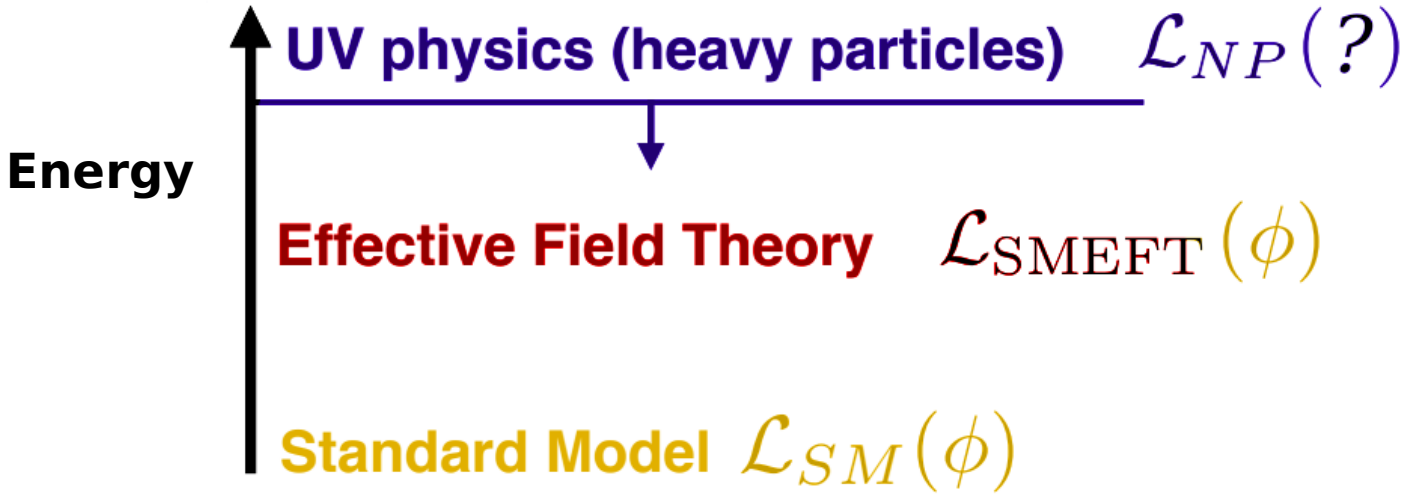
3V 2.6σ
4top 2σ

How about new physics?

How about new physics? The SM Effective Field Theory





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Global SMEFT fits

The latest SMEFiT global fit has been published in May 2021: [2105.00006 and *lhcfitnikhef.github.io/smefit_release/*]

SMEFiT

OUTP-20-05P
Nikhef-2020-020
CP3-21-12
MCNET-21-07
MAN/HEP/2021/004

Combined SMEFT interpretation of Higgs, diboson, and top quark data from the LHC

The fit includes Higgs, top, and diboson data from Run 1 & 2. Work is underway to include new LHC data and precision EW measurements from LEP.

Other groups also produce global fits, [Ellis et al 2012.02779], results are generally consistent.

Global SMEFT fits: the need for RG flow

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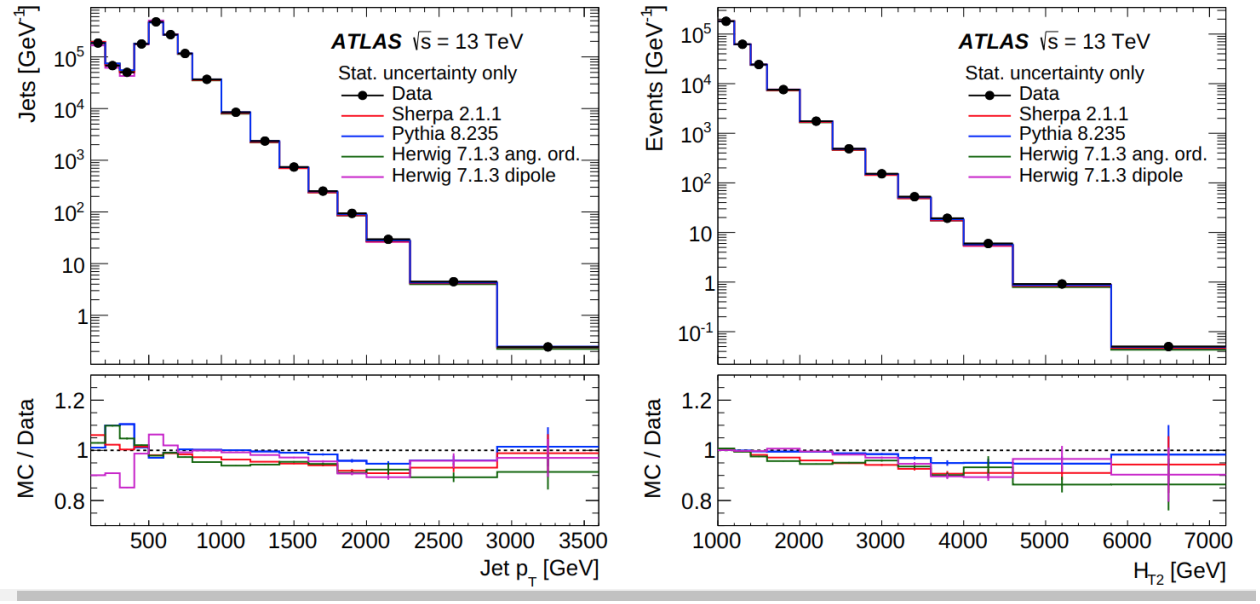
The same SMEFT operators are probed at different scales from different measurement, and even within the same measurement.

Example:
ATLAS analysis of multijet events



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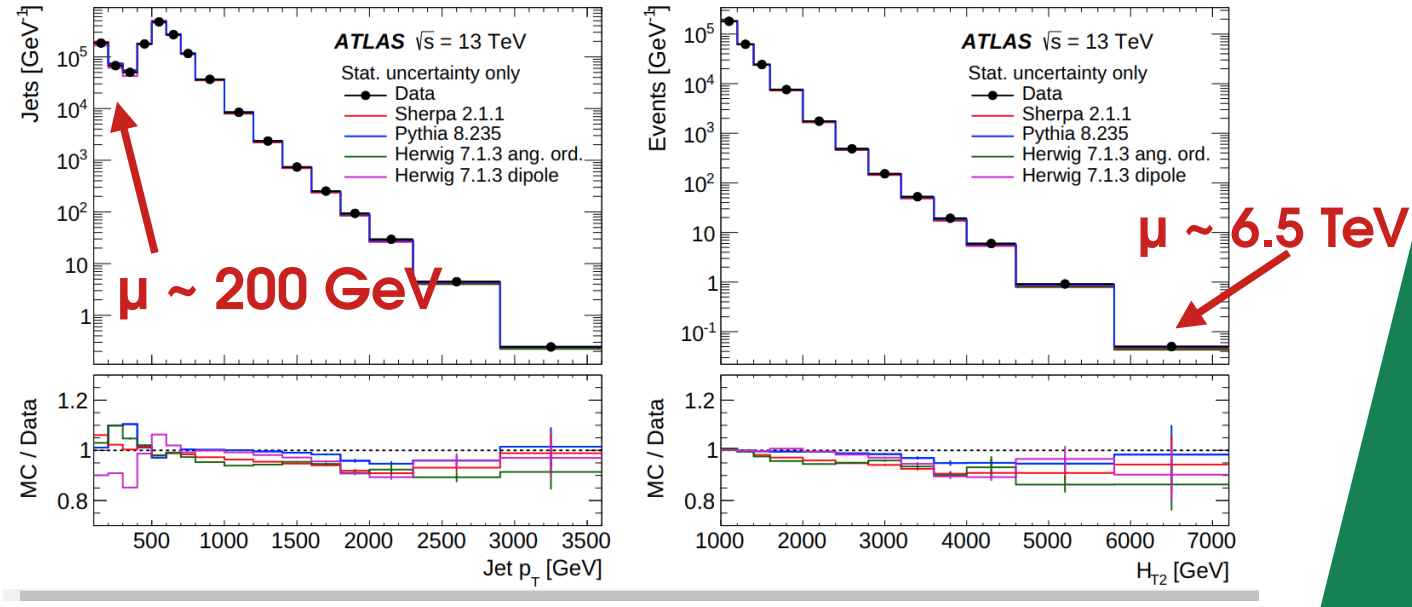

RG flow of the SMEFT

To realistically account for RG effects, running and mixing, one needs to include them in a Monte Carlo tool.

We extracted the RGE from the UV poles of the SMEFT@NLO UFO model [2008.11743]. The extraction is almost entirely automatic.

The RGE of SMEFT@NLO agree with those of [Alonso, Jenkins, Manohar, Trott 1308.2627 1310.4838 1312.2014].

Our code is public and included in MadGraph5 version 3.5+. The implementation is general and works for any model with running couplings.

RG flow of the SMEFT

$$\gamma_{\mathbf{4F}}^{\mathrm{QCD},1} = \frac{1}{3}\left(\begin{array}{c|ccccccccc|ccccccccc}
44/3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 4/3 & 2 & 0 & 0 & 8/3 & 0 & 4/3 \\ \hline
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 8 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 8 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 8 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 8 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -8 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -8 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -8 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 8 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -8 \\ \hline
0 & 36 & 0 & 0 & 0 & 0 & 0 & 0 & 4 & 0 & 0 & 0 & 0 & 0 & 4 & 6 & 2 & 10/3 & 2 \\
0 & 0 & 36 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -12 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
8 & 0 & 0 & 36 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -6 & 6 & 4 & 0 & 8 & 0 & 4 \\
8 & 0 & 0 & 0 & 36 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 4 & -4 & 0 & 4 & 8 & 0 & 4 \\
0 & 0 & 0 & 0 & 0 & -36 & 0 & 0 & 4 & 0 & 8 & 0 & 2 & 0 & -34 & 6 & 0 & 10/3 & 2 \\
0 & 0 & 0 & 0 & 0 & 0 & -36 & 0 & 4 & 0 & 8 & 0 & 0 & 2 & 4 & -32 & 0 & 10/3 & 2 \\
8 & 0 & 0 & 0 & 0 & 0 & 0 & -36 & 0 & 0 & 4 & 0 & 4 & 6 & 0 & 0 & -32 & 0 & 4 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 44 & 0 & 16 & 0 & 0 & 0 & 8 & 12 & 0 & -16/3 & 4 \\
8 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 4 & -36 & 8 & 0 & 4 & 6 & 4 & 6 & 8 & 10/3 & -36
\end{array}\right)$$

Sectors of the SMEFT anomalous dimension matrix we extracted

$$\gamma_{0/2\mathrm{F}}^{\mathrm{QCD},1} = \frac{1}{3}\begin{pmatrix}
-24 & 96y_t & 96y_t^2 & 0 & 0 \\
0 & -6\beta_0 & 12y_t & 0 & 0 \\
0 & 0 & 4 & 0 & 0 \\
0 & 0 & 8g_2 & 8 & 0 \\
0 & 0 & 8g_2\cos\theta_W - 40/3\, g_1 \sin\theta_W & 0 & 8
\end{pmatrix}$$

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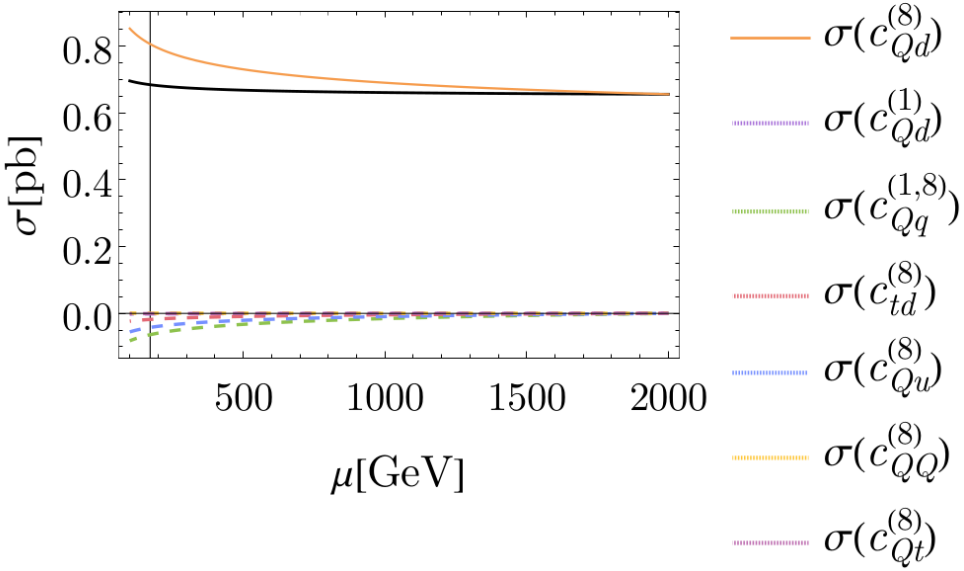
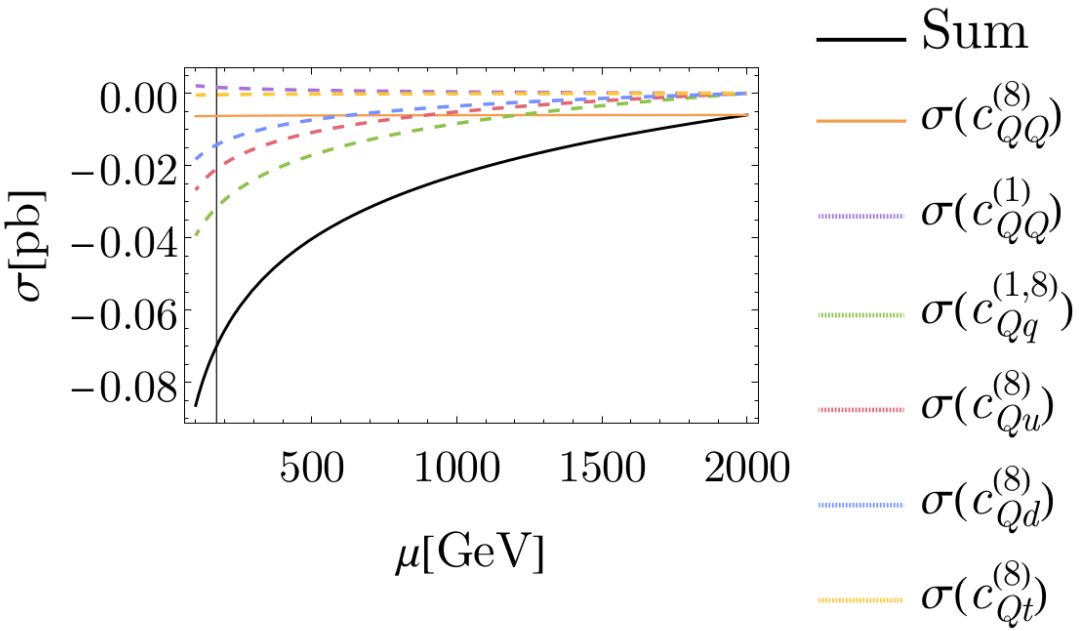
Global SMEFT fits: the need for RGE flow

We have implemented the one-loop QCD RGE of the SMEFT in MadGraph.

The SM and SMEFT couplings are evolved according to a user-specified function, point by point in phase space, as the events are generated.





But does it really matter?

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We assessed the effect of the RGE on bounds on Wilson coefficients obtained from real data.

While we update the global fit to include RGE effects, as a starter we considered a set of recent LHC measurements in the top sector:

Experiment	$\sqrt{s}$ [TeV]	$\mathcal{L}$ [fb^{-1}]	Channel	Observable	SM Th. Ref.
ATLAS	8	20.3	Dilepton	$\sigma_{t\bar{t}}$	NNLO+NNLL QCD, NLO EW
CMS	8	19.7	Lepton+jets	$dA_C/dy_{t\bar{t}}$ [3 bins]	NNLO QCD, NLO EW
ATLAS	8	20.3	Lepton+jets	$dA_C/d\beta_{t\bar{t}}$ [3 bins]	NNLO QCD, NLO EW
CMS	8	19.6	Lepton+jets	$\sigma_{t\bar{t}}$	NNLO+NNLL QCD, NLO EW
CMS	8	19.7	$e\mu$	$\sigma_{t\bar{t}}$	NNLO+NNLL QCD, NLO EW
ATLAS	8	20.2	Lepton+jets	$\sigma_{t\bar{t}}$	NNLO+NNLL QCD, NLO EW
CMS	13	35.9	Dilepton	$d\sigma_{t\bar{t}}/dm_{t\bar{t}}$ [7 bins]	NNLO+NNLL QCD, NLO EW
ATLAS	13	36	Lepton+jets	$d\sigma_{t\bar{t}}/dm_{t\bar{t}}$ [7 bins]	NNLO+NNLL QCD, NLO EW
ATLAS	13	139	Lepton+jets	$\sigma_{t\bar{t}}$	NNLO+NNLL QCD, NLO EW
CMS	13	137	Lepton+jets	$\sigma_{t\bar{t}}$	NNLO+NNLL QCD, NLO EW

The effect on global fits

The SMEFT contribution is evaluated under three RGE scenarios:

1. “No Running”

2. “Fixed scale”: The SMEFT is defined at 2 TeV, and RGE-evolved down to μ = mtop.

3. “Dynamical scale”: The SMEFT is defined at 2 TeV, and evolved point by point to μ = HT/2.

Results

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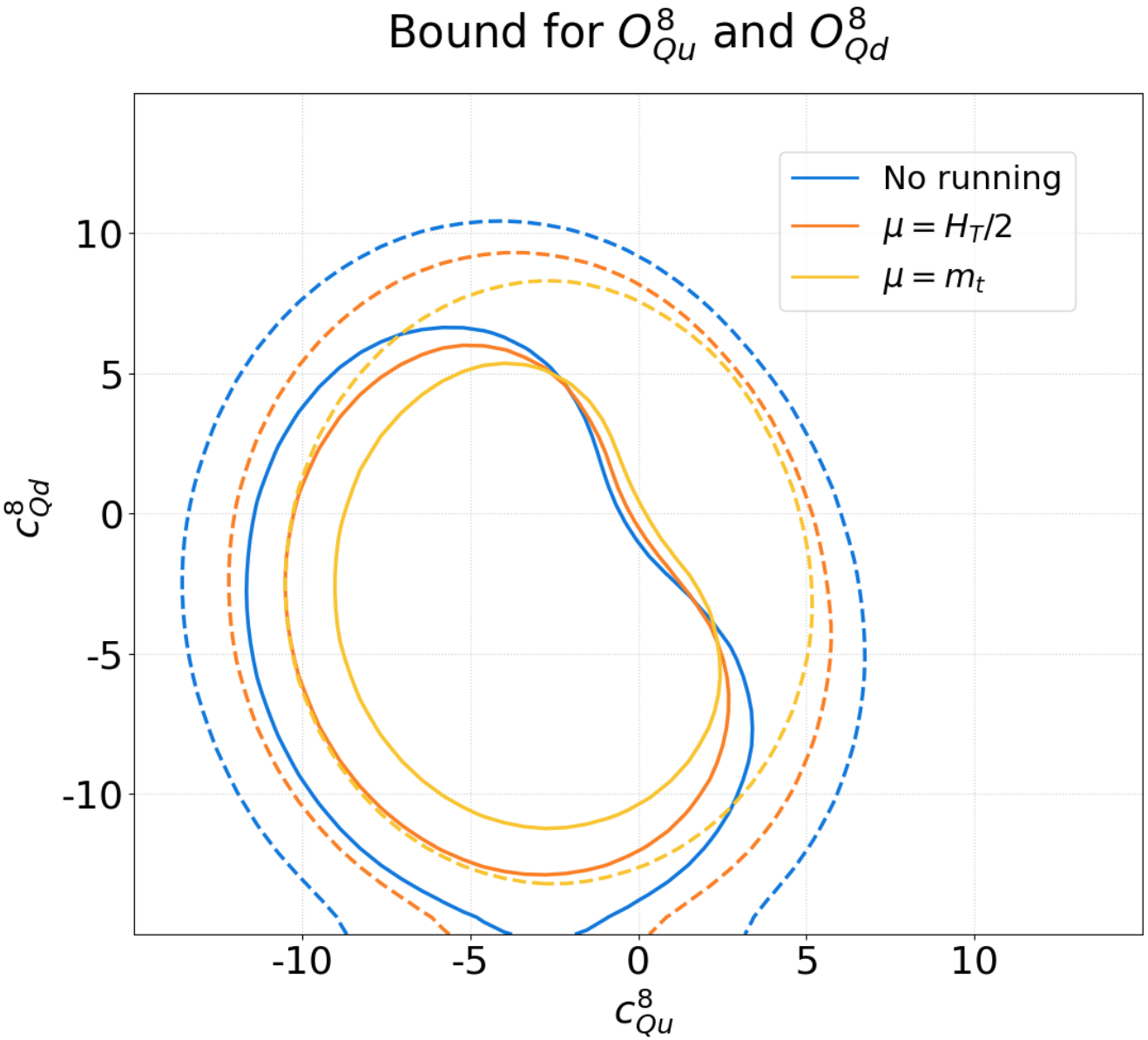
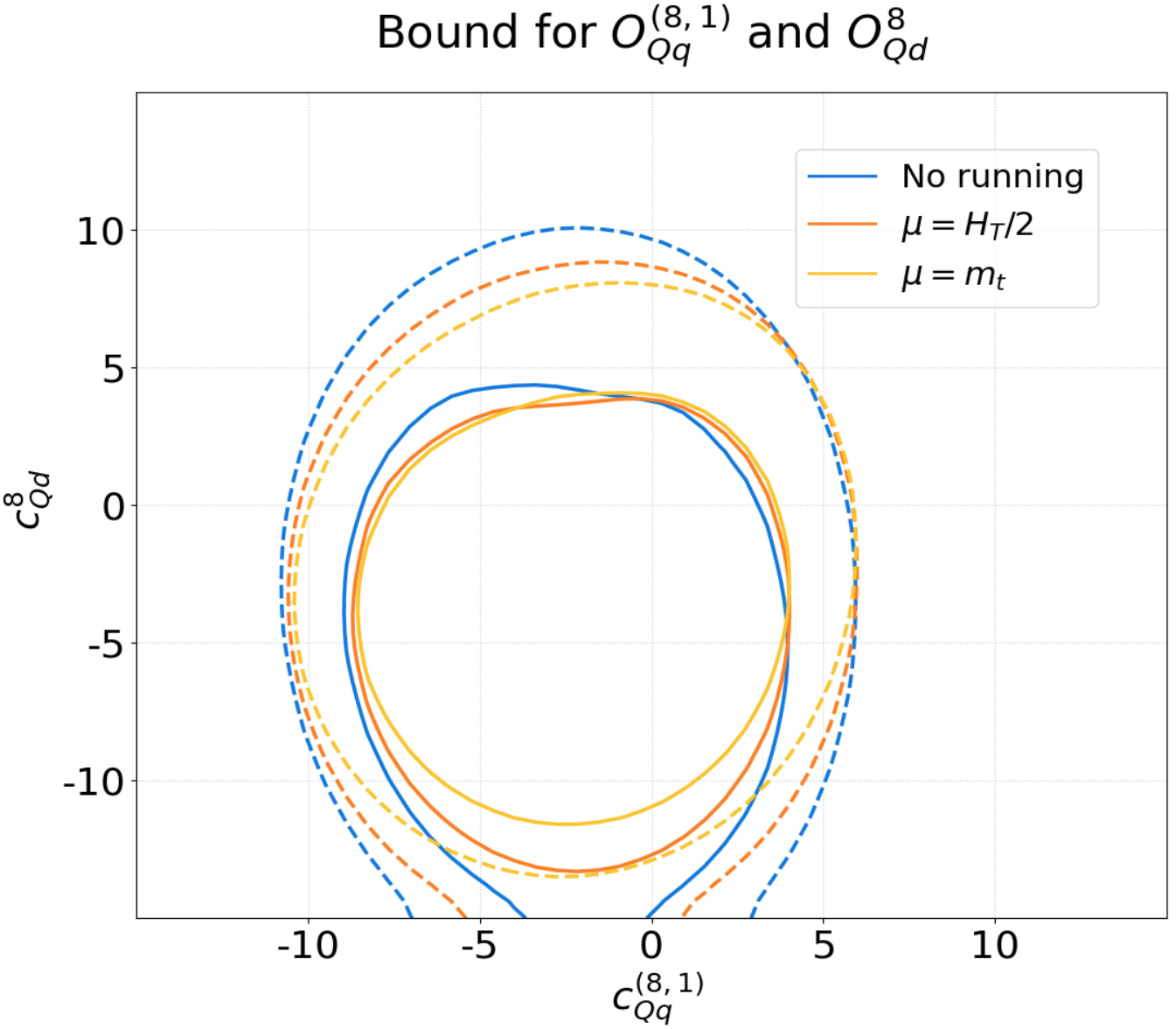
RG effects amount to a shift similar to the spread between 68% and 95% contours.



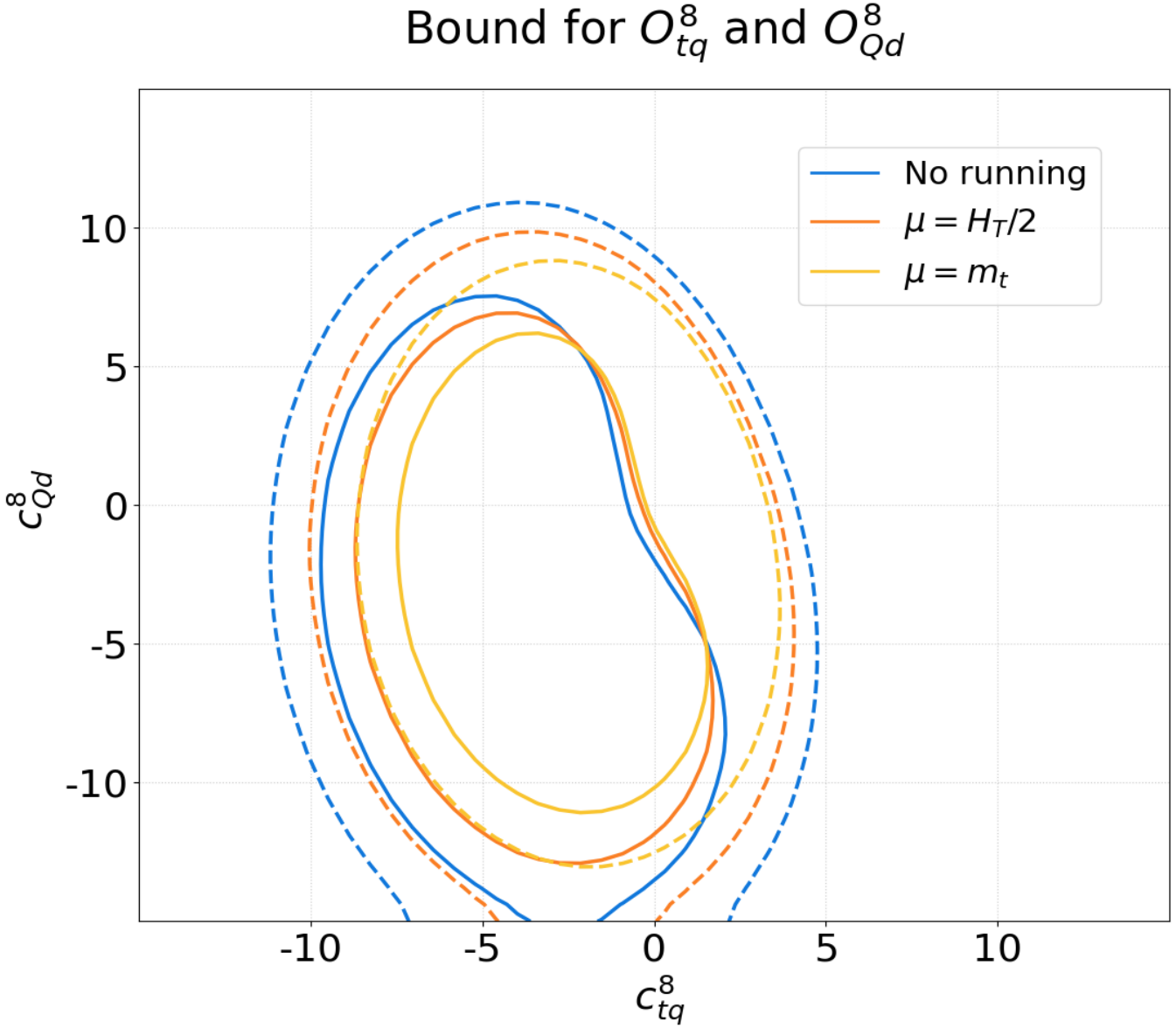
Results

The RG flow consistently improves the bound with respect to no running!



Results

RG-improved bounds also seem smoother than the old ones.



Conclusions

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We have implemented the RG flow of the SMEFT at LO+LL in MadGraph.

A full NLO+NLL simulation now only requires the 2-loop anomalous dimension, everything else is ready.

The inclusion of RGE effects in SMEFT fit highlights previously hidden features of the data.

A fit in the top sector shows that RGE effects amount to deviations of ~ 1 sigma and to better and smoother bounds.

The updated global fit is coming, stay tuned!