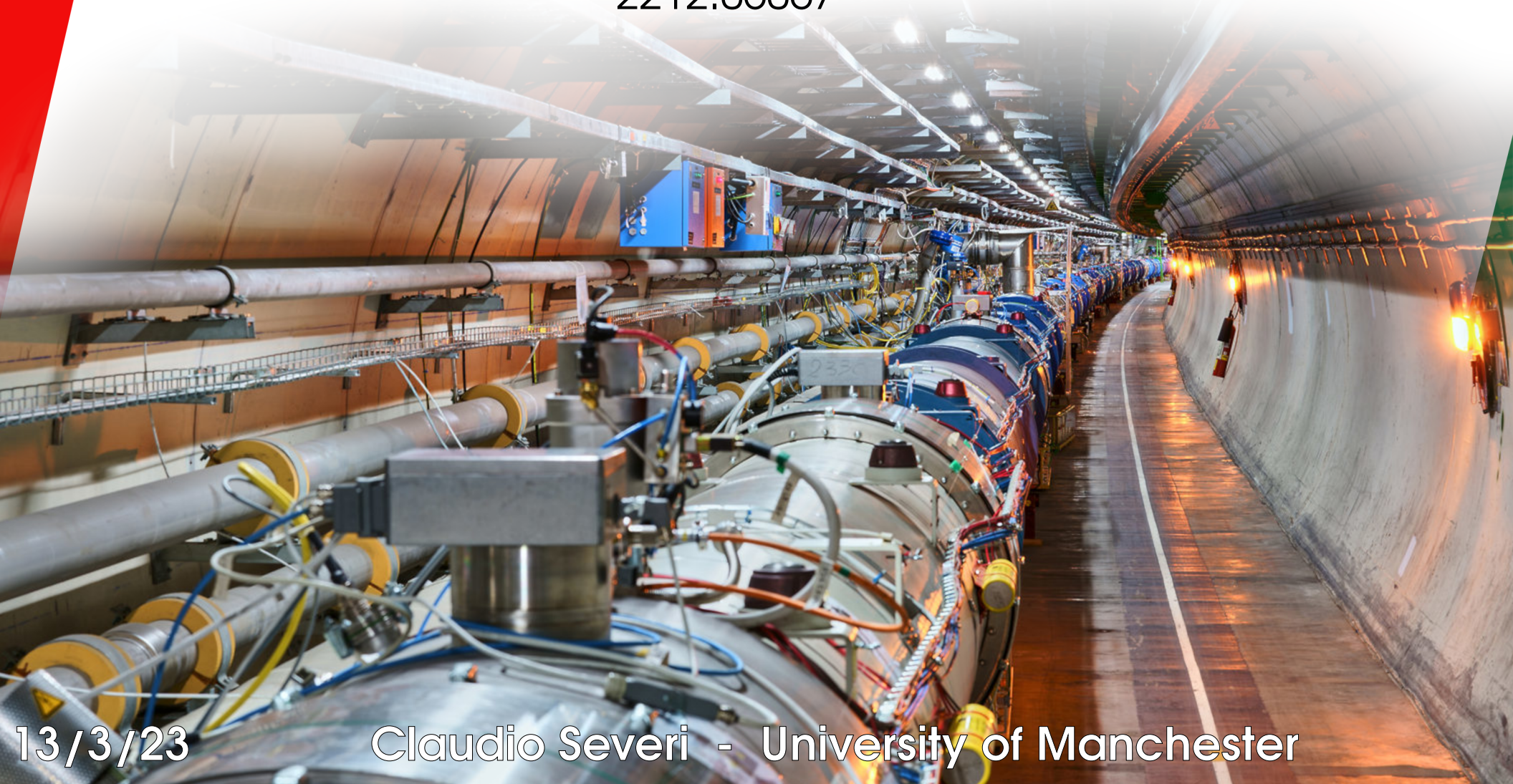
Renormalization group effects on SMEFT interpretations of LHC data

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

2212.05067



The LHC: where do we stand?

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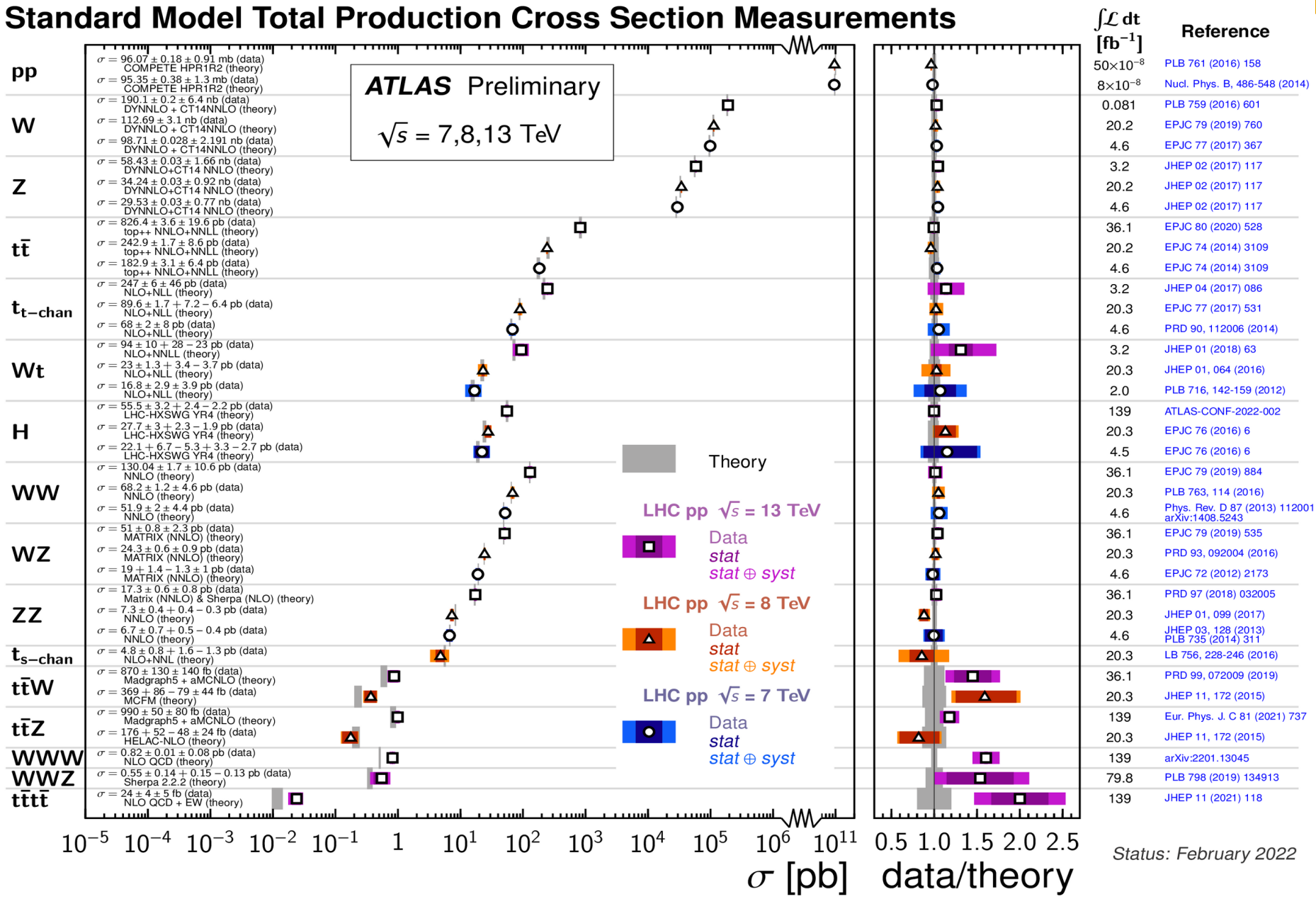

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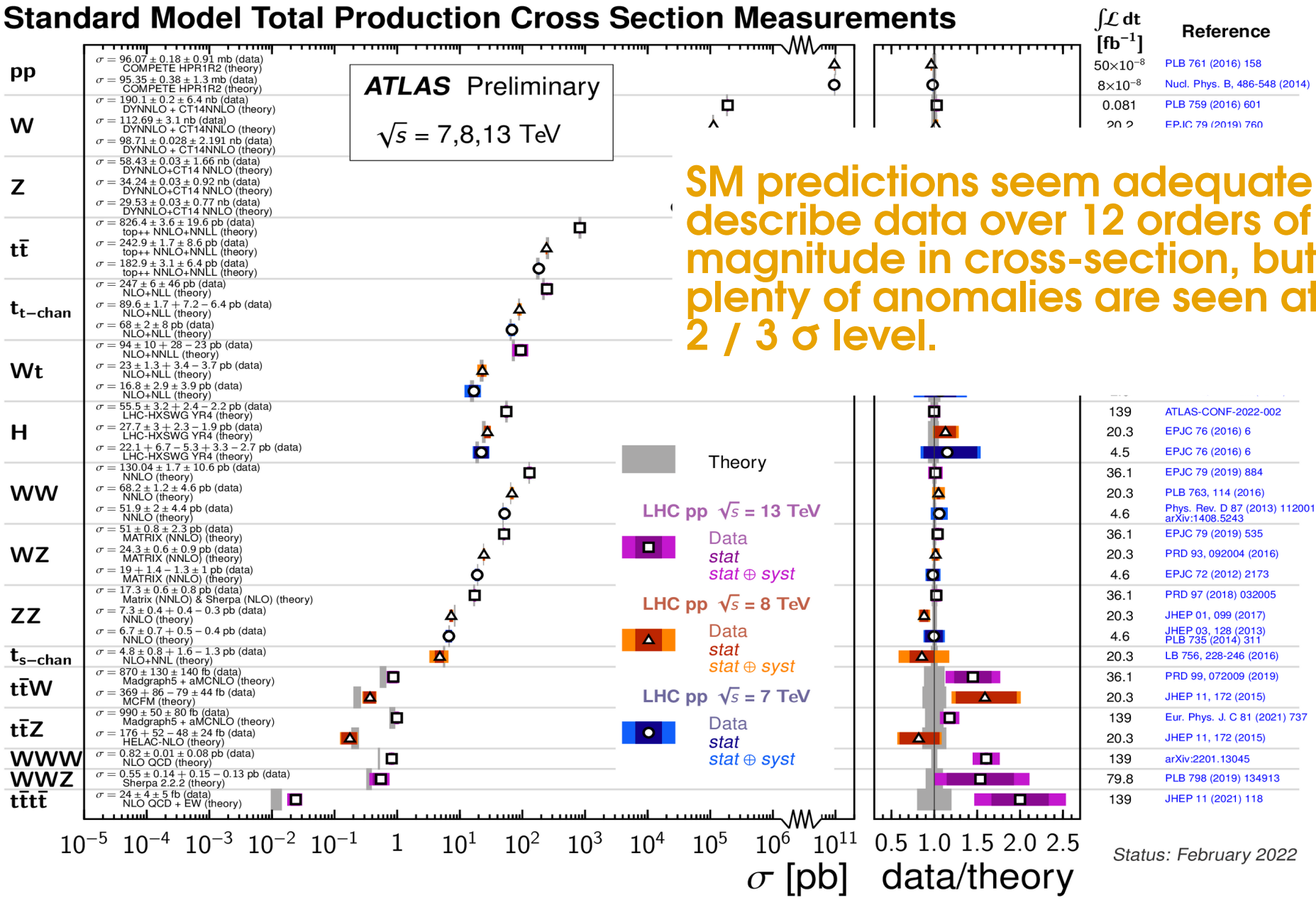

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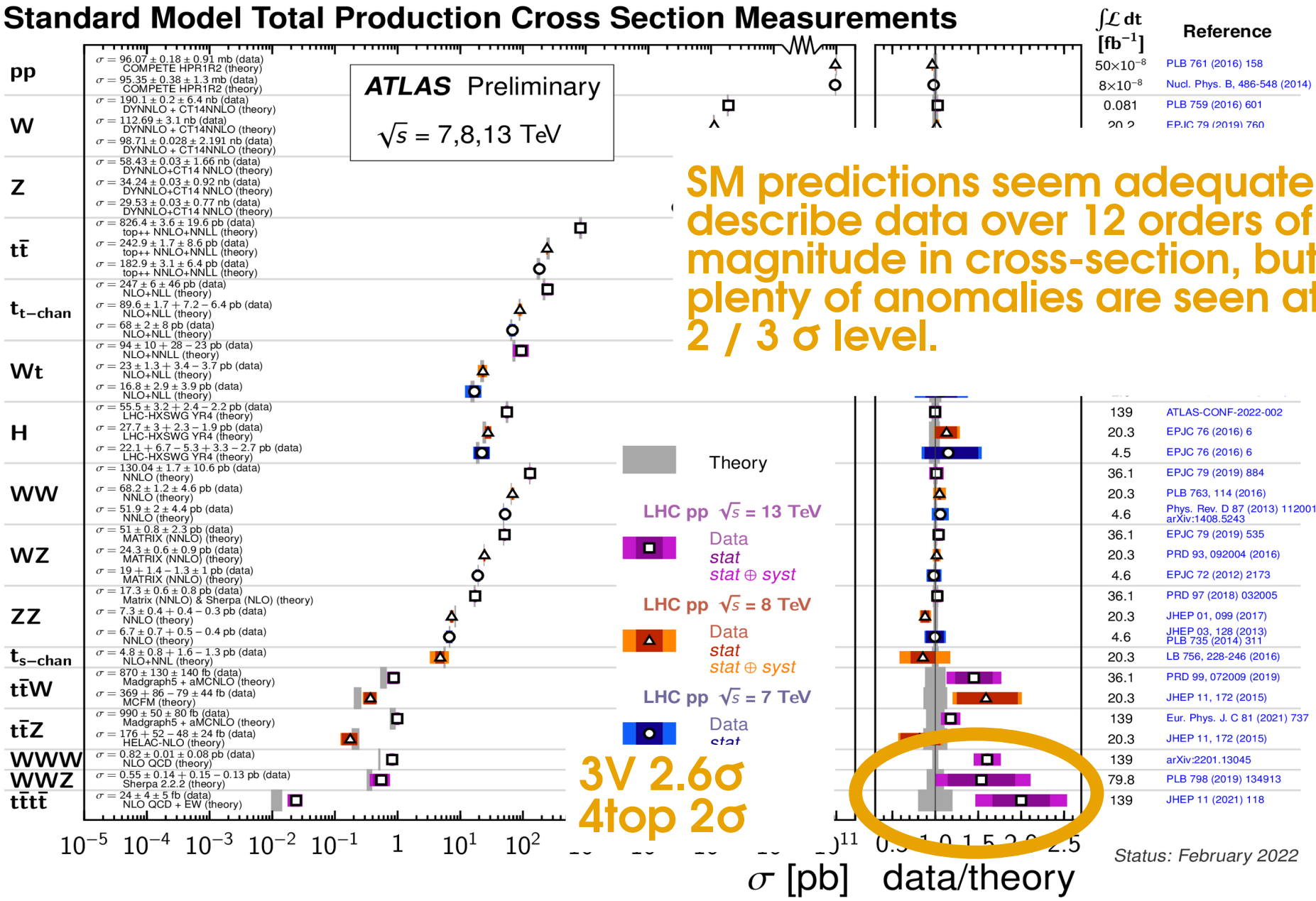

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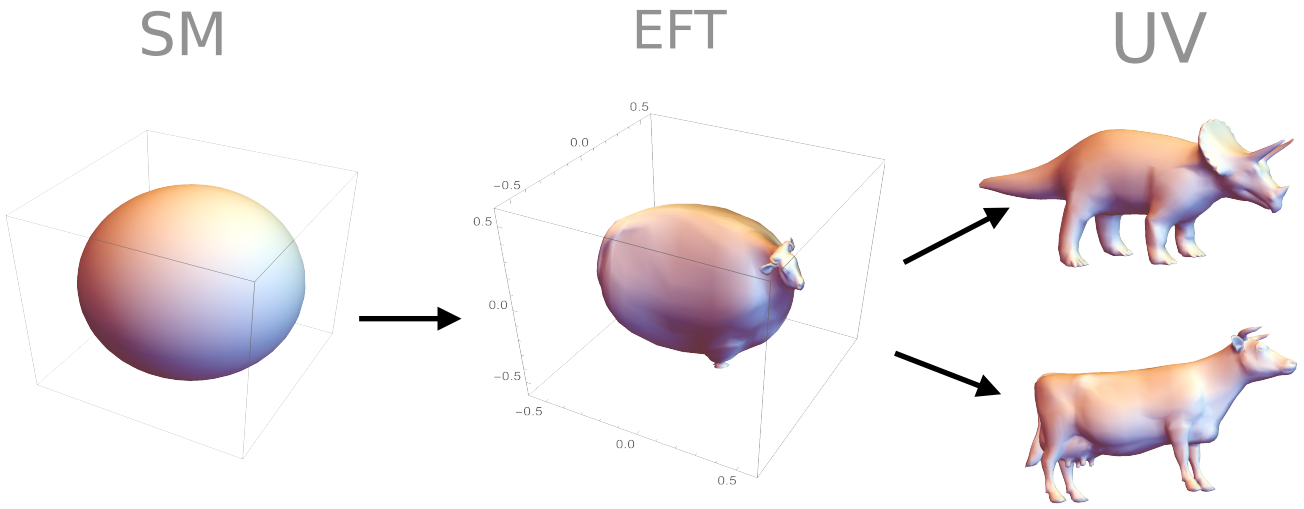
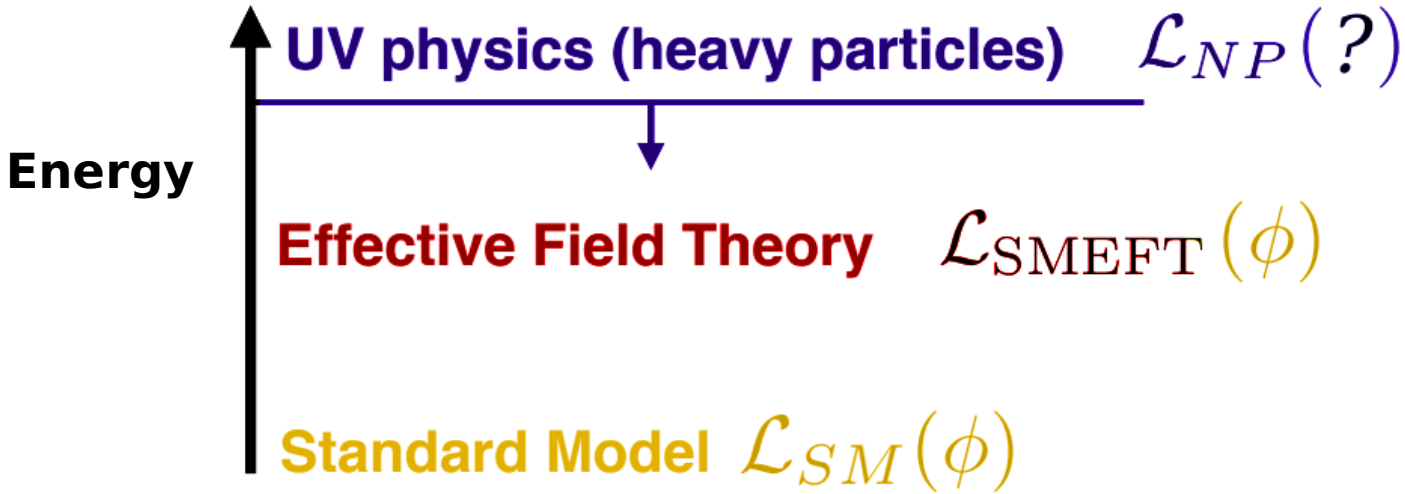
How about new physics?

How about new physics? The SM Effective Field Theory





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 with each other.

Global SMEFT fits: the need for RG flow

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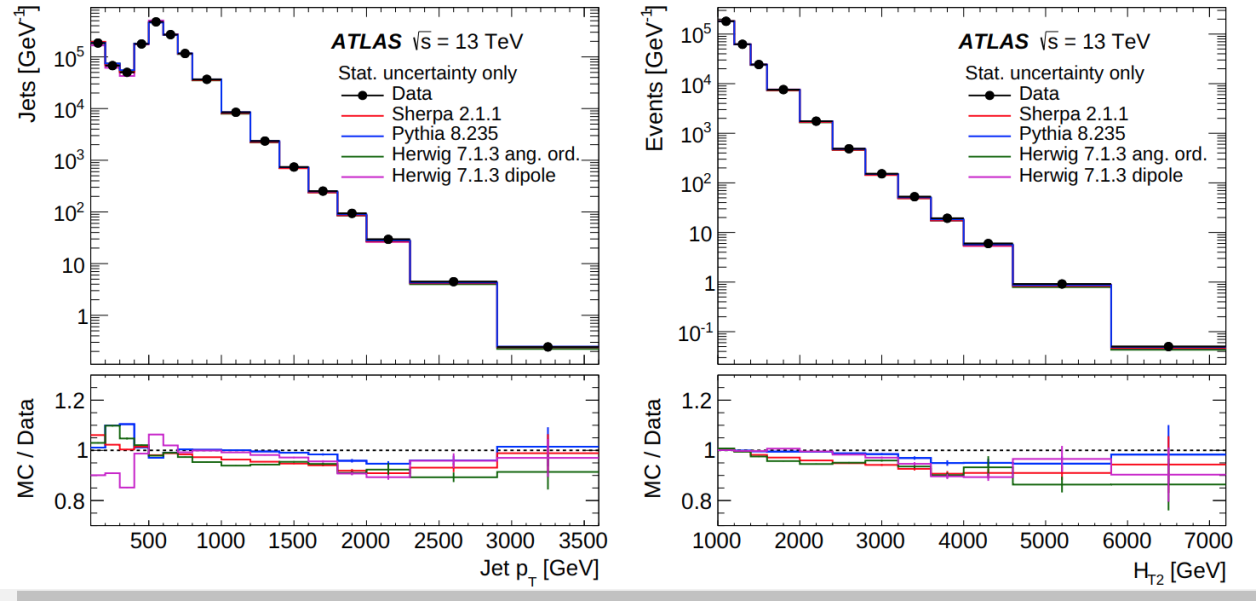
The same SMEFT operators are probed at different scales from different measurement, and even within the same measurement.

Example:
ATLAS analysis of multijet events



Claudio Severi - University of Manchester

Global SMEFT fits: the need for RG flow

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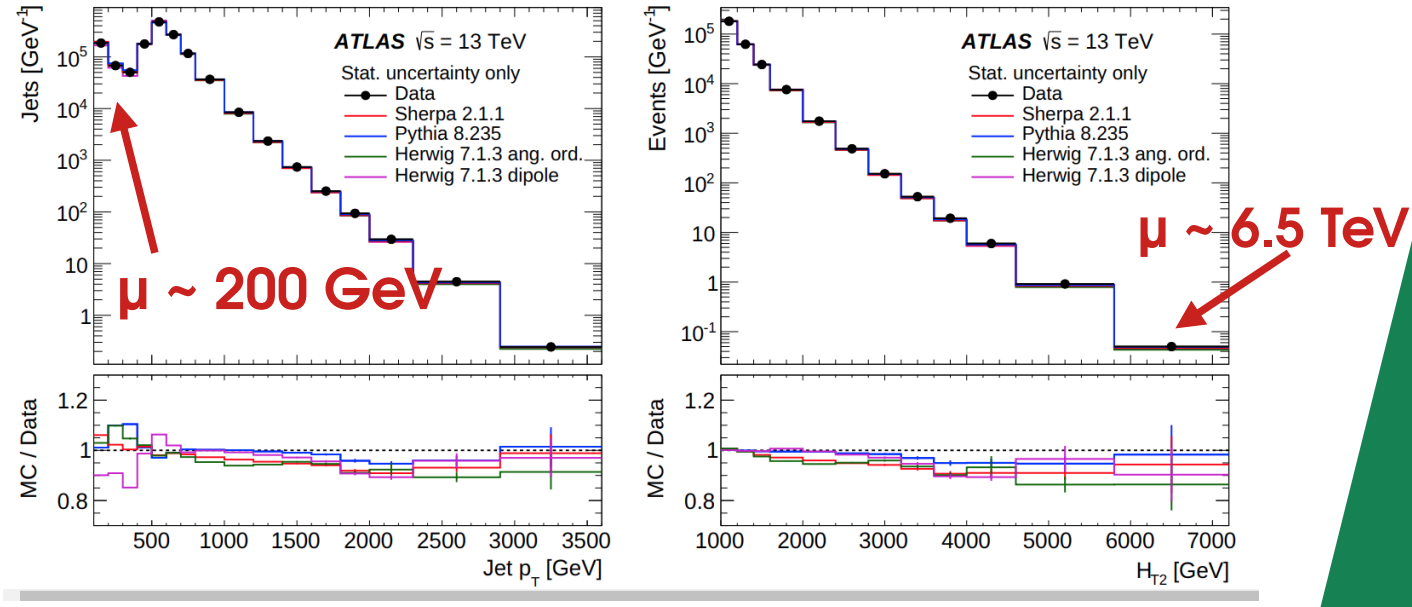


RG flow of the SMEFT

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

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

Sectors of the SMEFT anomalous dimension matrix we extracted

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

MadGraph implementation of the RGE flow

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

A new section has been added to the run card:

```
#*********************************************************************
# CONTROL The extra running scale (not QCD)                          *
#    Such running is NOT include in systematics computation          *
#*********************************************************************
True = fixed_extra_scale ! False means dynamical scale
172.5 = mue_ref_fixed ! scale to use if fixed scale mode
1.0 = mue_over_ref ! ratio to mur if dynamical scale
```

The SMEFT couplings are evolved independently of the SM ones, either to a fixed scale or point by point in phase space, as the events are generated.

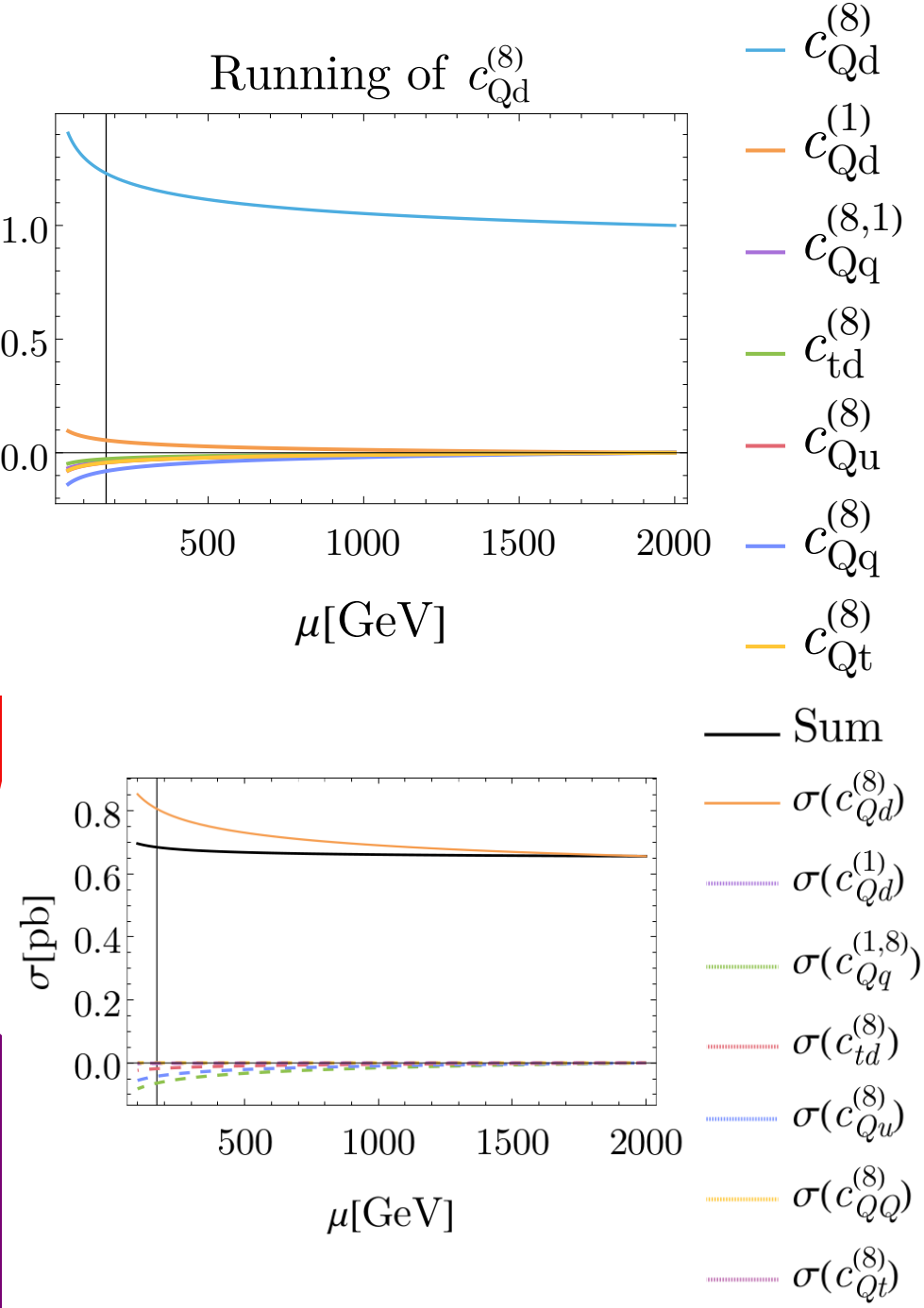
MadGraph implementation of the RGE flow

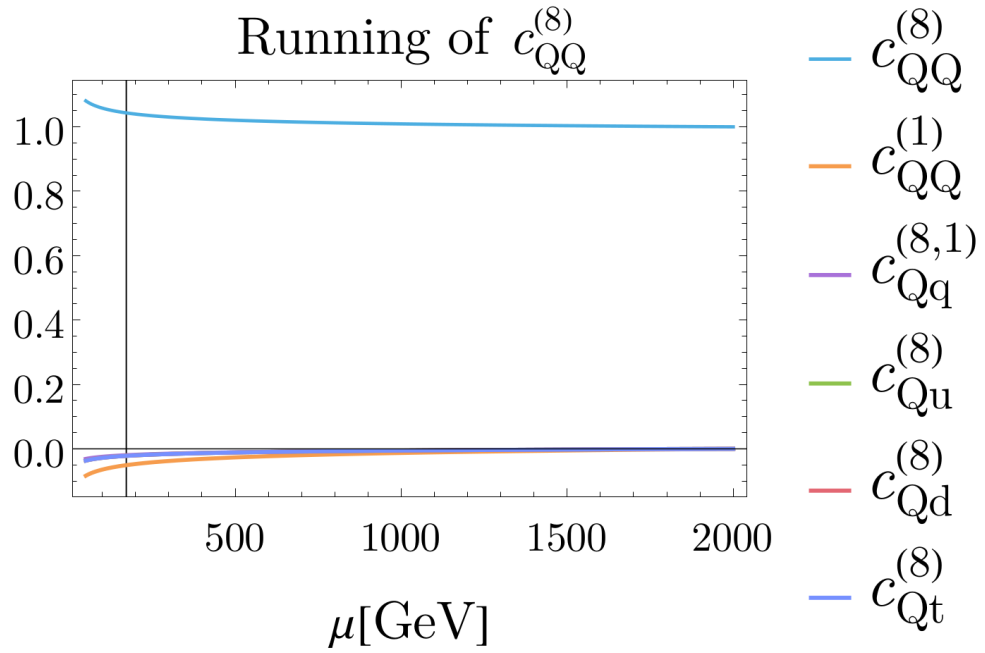
The parameter card can specify, block by block, the initial scale Q at which the couplings are defined:

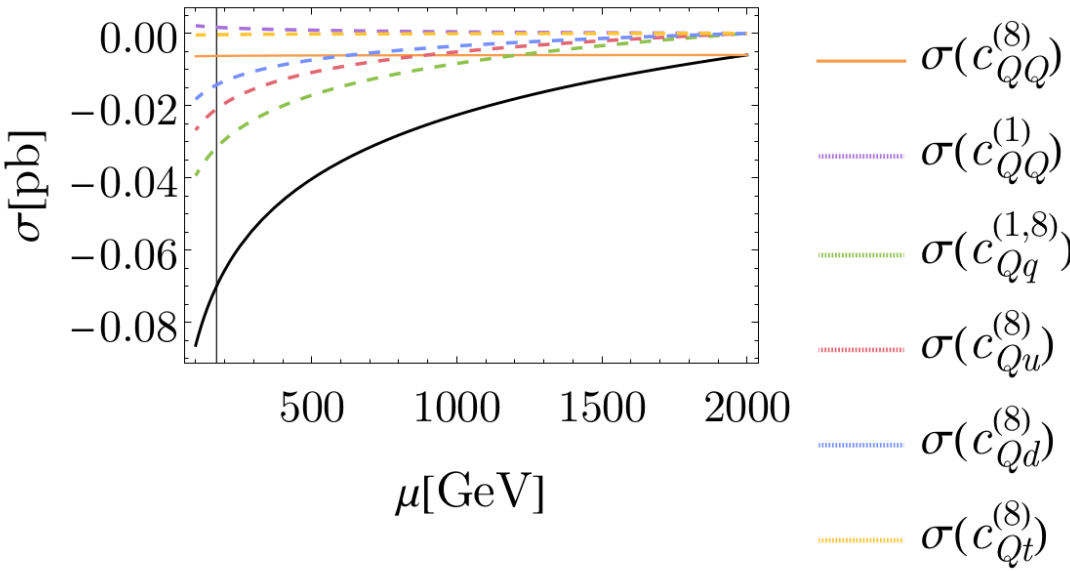
```
#####################################
## INFORMATION FOR DIM62F
#####################################
Block dim62f Q= 2000
     1 1.000000e+00 # cpl1
     2 0.000000e+00 # cpl2
     3 0.000000e+00 # cpl3
```

The RGEs are solved at run time with the boundary condition above, and according to the user selection in the run card.

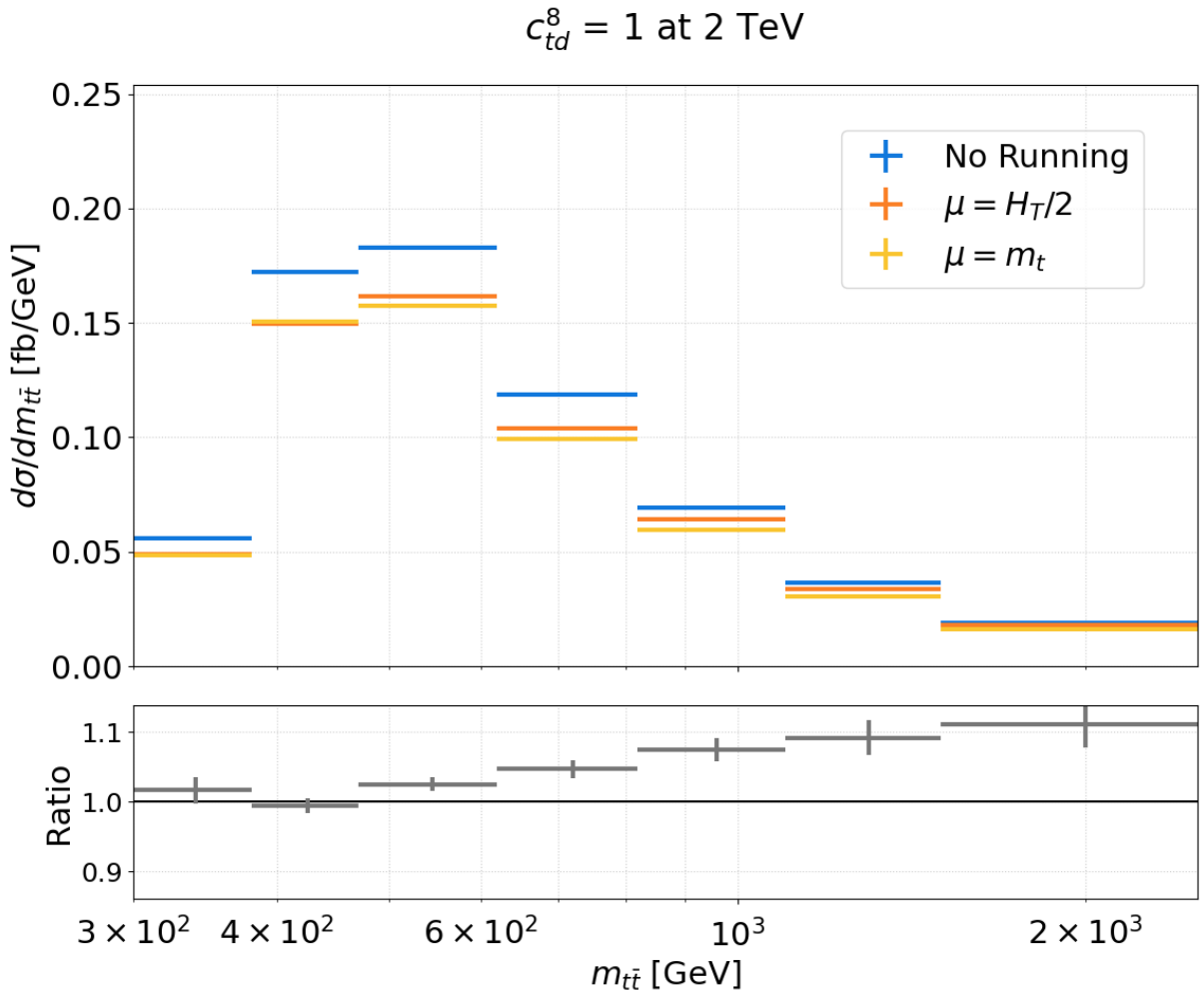
RG flow of Wilson coefficients







RG flow of differential distributoins



~20% shift between no running and running

Ratio between Ht/2 and mt, estimate of SMEFT scale variation

But does it really matter?

But does it really matter?

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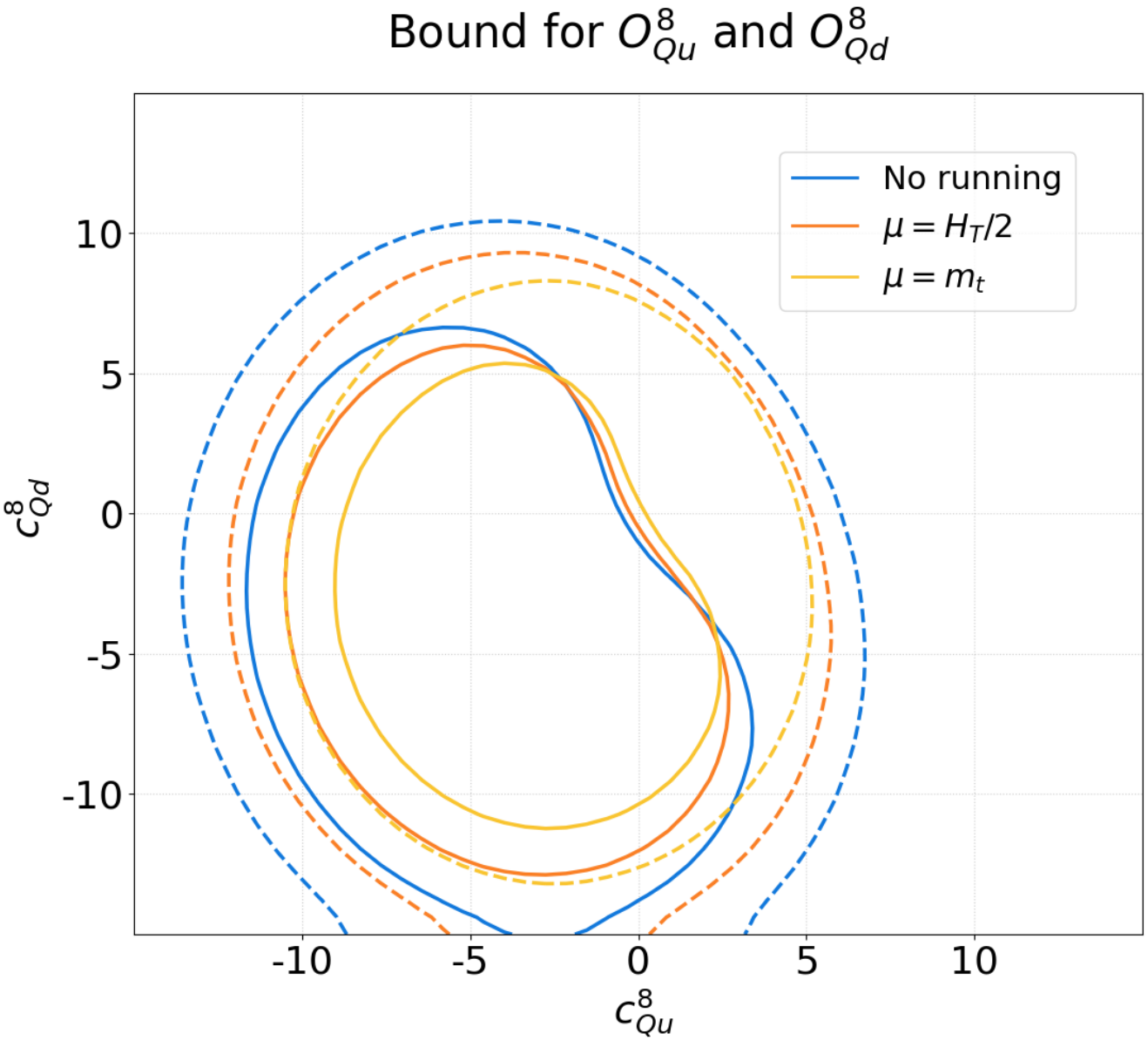
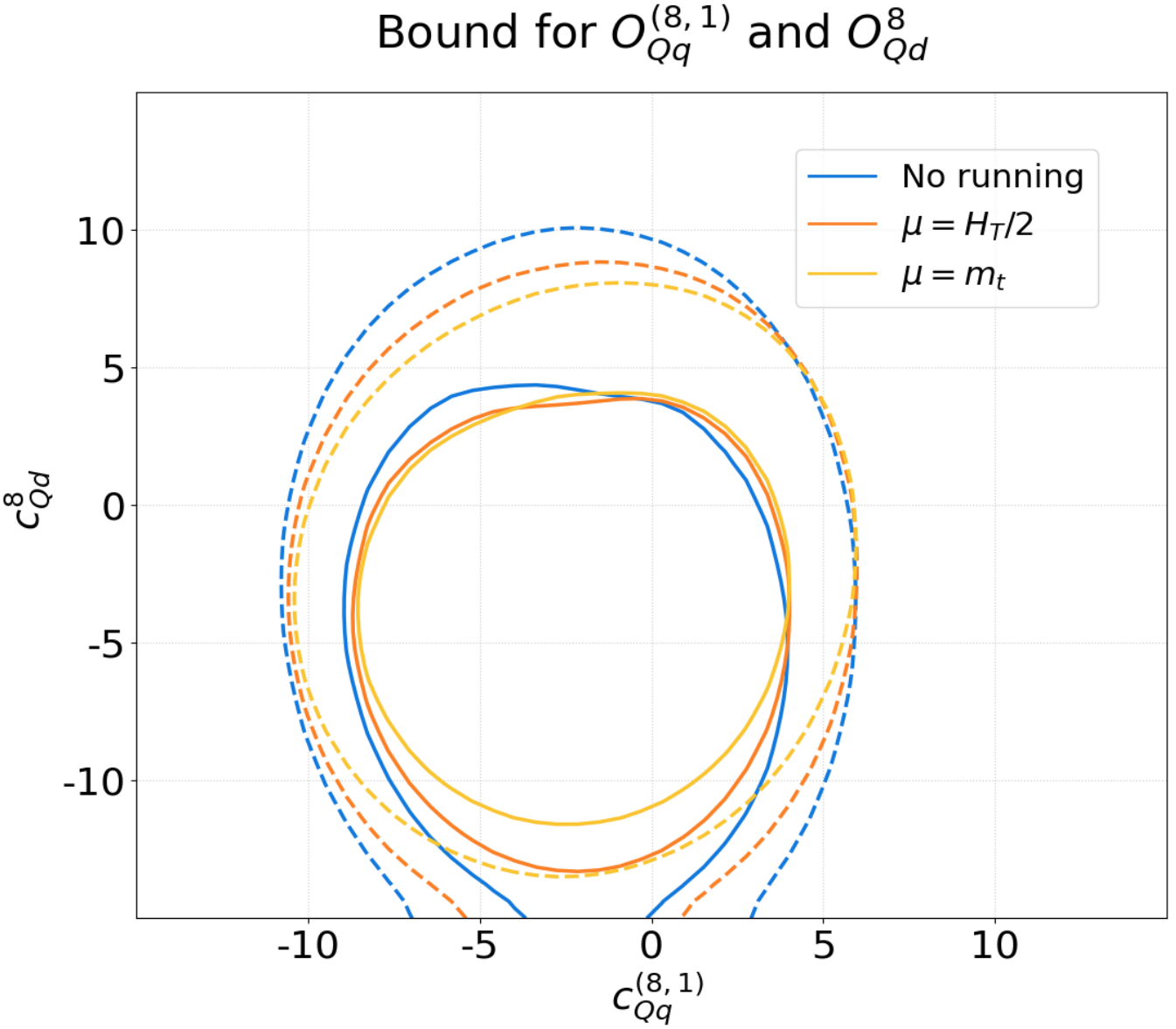
RG effects amount to a shift similar to the spread between 68% and 95% contours.



Results

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



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!