University of Glasgow

Christoph Englert

sort of an EFT summary

Probing Physics Beyond the SM with precision

MITP Mainz

02.03.2018

Questions raised during the week

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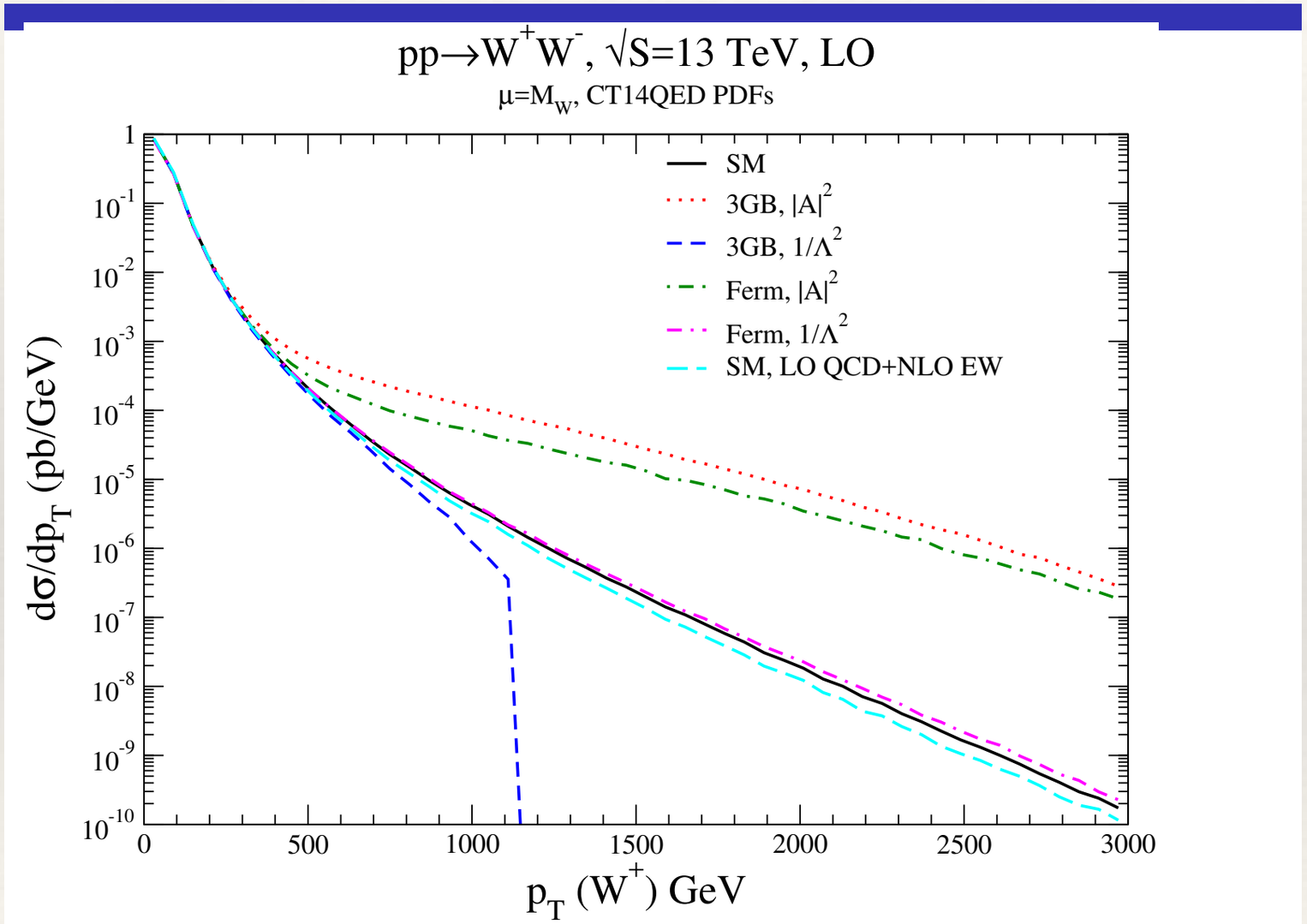
- *"Large effects from dim6^n EFT tails - what do they mean?"*



Baglio, Dawson, **IL** PRD96 (2017) 073003

Ian's talk

Questions raised during the week

- *"Large effects from dim6^n EFT tails - what do they mean?"*
- *"Should EFT be the new gold standard?"*
- *"What about dimension 8?"*
- *"Is EFT-precision a worthwhile exercise?"*

The SMEFT – where we are

Ilaria's talk

B cons. $N_f = 1 \rightarrow$	2	76	22	895

$$\mathcal{L}_{\rm SMEFT} = \mathcal{L}_{\rm SM} + \frac{1}{\Lambda}\mathcal{L}_5 + \frac{1}{\Lambda^2}\mathcal{L}_6 + \frac{1}{\Lambda^3}\mathcal{L}_7 + \frac{1}{\Lambda^4}\mathcal{L}_8 + \ldots$$

$N_f = 3 \rightarrow$	12	2499	948	36971

- # of parameters known for all orders
- complete bases available for $\mathcal{L}_5$, $\mathcal{L}_6$, $\mathcal{L}_7$

$\mathcal{L}_5$: Majorana ν masses

$\mathcal{L}_6$: leading deviations from SM $\rightarrow$ our focus

- complete RGE available
- many tree-level calculations of Higgs / EW / flavor observables
- 1-loop results available for selected processes
- formulation in R_ξ gauge
- various tools available for numerical analysis

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technicalities are getting ironed out

EFT framework

- EFT dim6 calculations

Mike's talk

e.g. [Grzadkowski, Iskrzynski, Misiak, Rosiek `10]

Lagrangian

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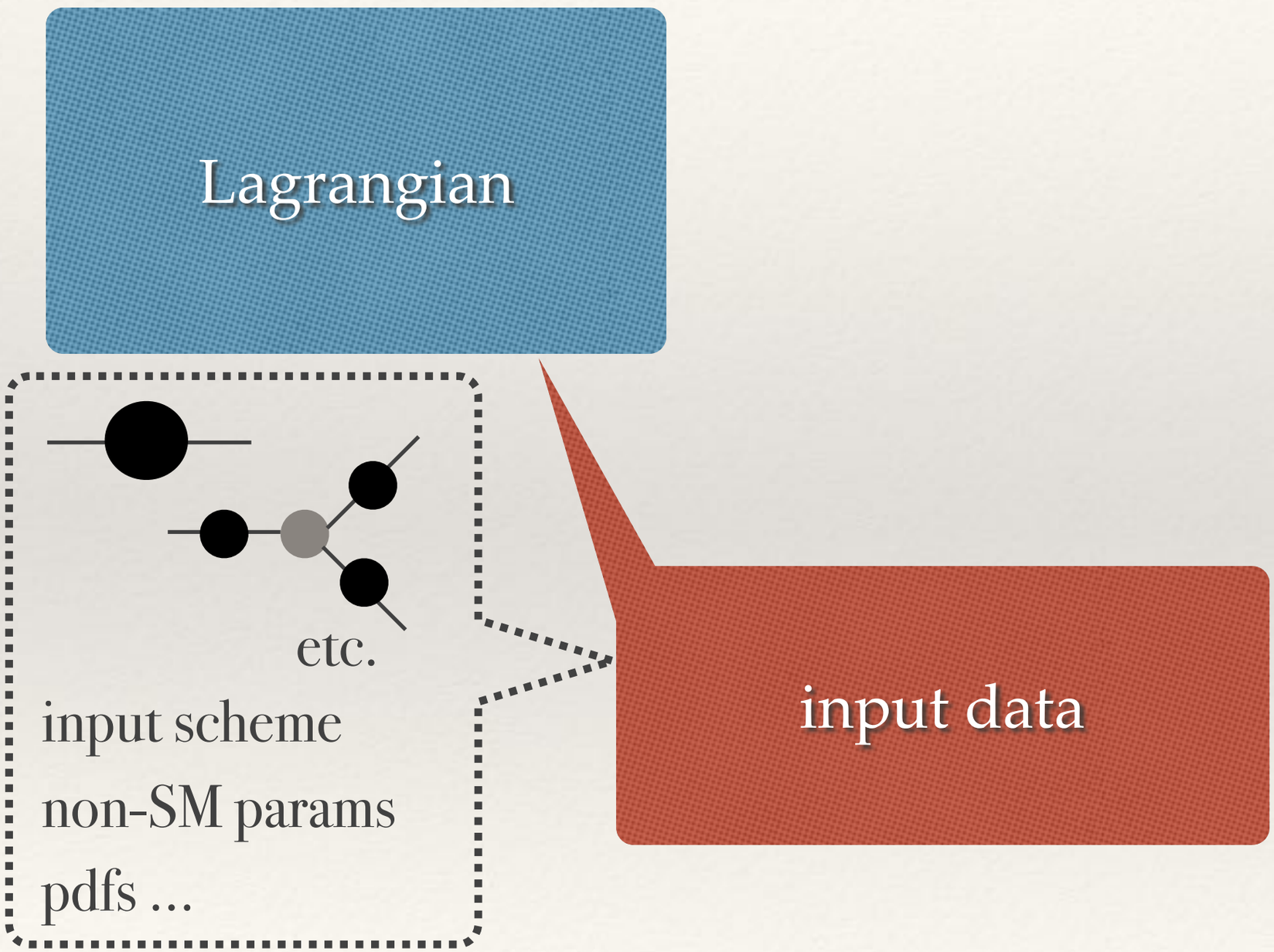

[Ghezzi et al. `15] [Hartmann et al. `15,`16] [Gauld et al. `16] ...

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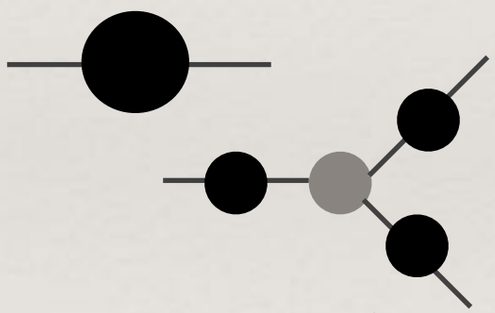
Lagrangian

mostly LO

predictions



etc.

input scheme

non-SM params

pdfs ...

input data

measurement

$\neq$

input data

[Ghezzi et al. `15] [Hartmann et al. `15,`16] [Gauld et al. `16] ...

NLO EFT - Final tree result

- The final tree result is of the form

1505.02646 Hartmann, Trott

$$
\begin{aligned}
\frac{i\,\mathcal{A}^{NP}_{total}}{i\,v\,e^2\,A^{h\gamma\gamma}_{\alpha\beta}} &= C_{\gamma\gamma}\left(1+\frac{\delta R_h}{2}+\frac{\delta\,v}{v}\right),\\
&+\left(\frac{C_{\gamma\gamma}}{16\,\pi^2}\left(\frac{g_1^2}{4}+\frac{3\,g_2^2}{4}+6\,\lambda\right)+\frac{C_{HWB}}{16\,\pi^2}\left(-3\,g_2^2+4\,\lambda\right)\right)\log\left(\frac{m_h^2}{\Lambda^2}\right),\\
&+\frac{C_{\gamma\gamma}}{16\,\pi^2}\left(\left(\frac{g_1^2}{4}+\frac{g_2^2}{4}+\lambda\right)\mathcal{I}[m_Z^2]+\left(\frac{g_2^2}{2}+2\lambda\right)\mathcal{I}[m_W^2]+(\sqrt{3}\,\pi-6)\,\lambda\right),\\
&+\frac{C_{HWB}}{16\,\pi^2}\left(2e^2\left(1+6\frac{m_W^2}{m_h^2}\right)-2\,g_2^2\left(1+\log\left(\frac{m_W^2}{m_h^2}\right)\right)+(4\,\lambda-g_2^2)\,\mathcal{I}[m_W^2],\right.\\
&\qquad\left.+4\left(3e^2-g_2^2-6e^2\frac{m_W^2}{m_h^2}\right)\mathcal{I}_y[m_W^2]\right),\\
&-\frac{g_2^2\,C_{HW}}{4\,\pi^2}\left(3\,\frac{m_W^2}{m_h^2}+\left(4-\frac{m_h^2}{m_W^2}-6\frac{m_W^2}{m_h^2}\right)\mathcal{I}_y[m_W^2]\right).
\end{aligned}
\tag{3.6}
$$

Mike's talk

Where $C^{NP}_{\gamma\gamma} = C_{HB} + C_{HW} - C_{HWB}$

$$
\mathcal{I}[m^2] \equiv \int_0^1 dx\,\log\left(\frac{m^2-m_h^2\,x\,(1-x)}{m_h^2}\right),\quad \mathcal{I}_y[m^2] \equiv \int_0^{1-x} dy\int_0^1 dx\,\frac{m^2}{m^2-m_h^2\,x\,(1-x-y)},
$$

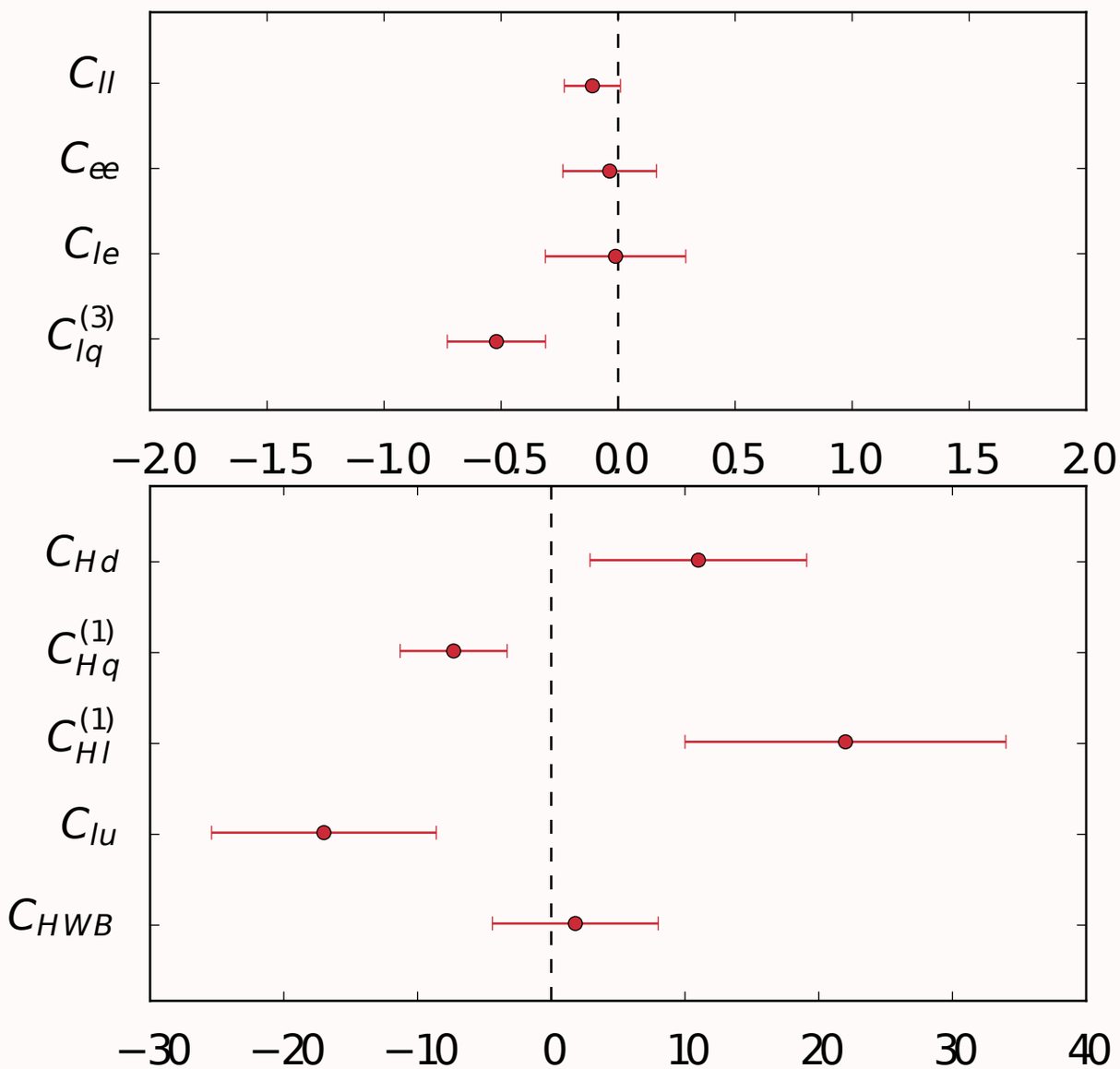
Adding $\bar{\psi}\psi \to \bar{\psi}\psi\bar{\psi}\psi$ production from LEP2

Ilaria's talk

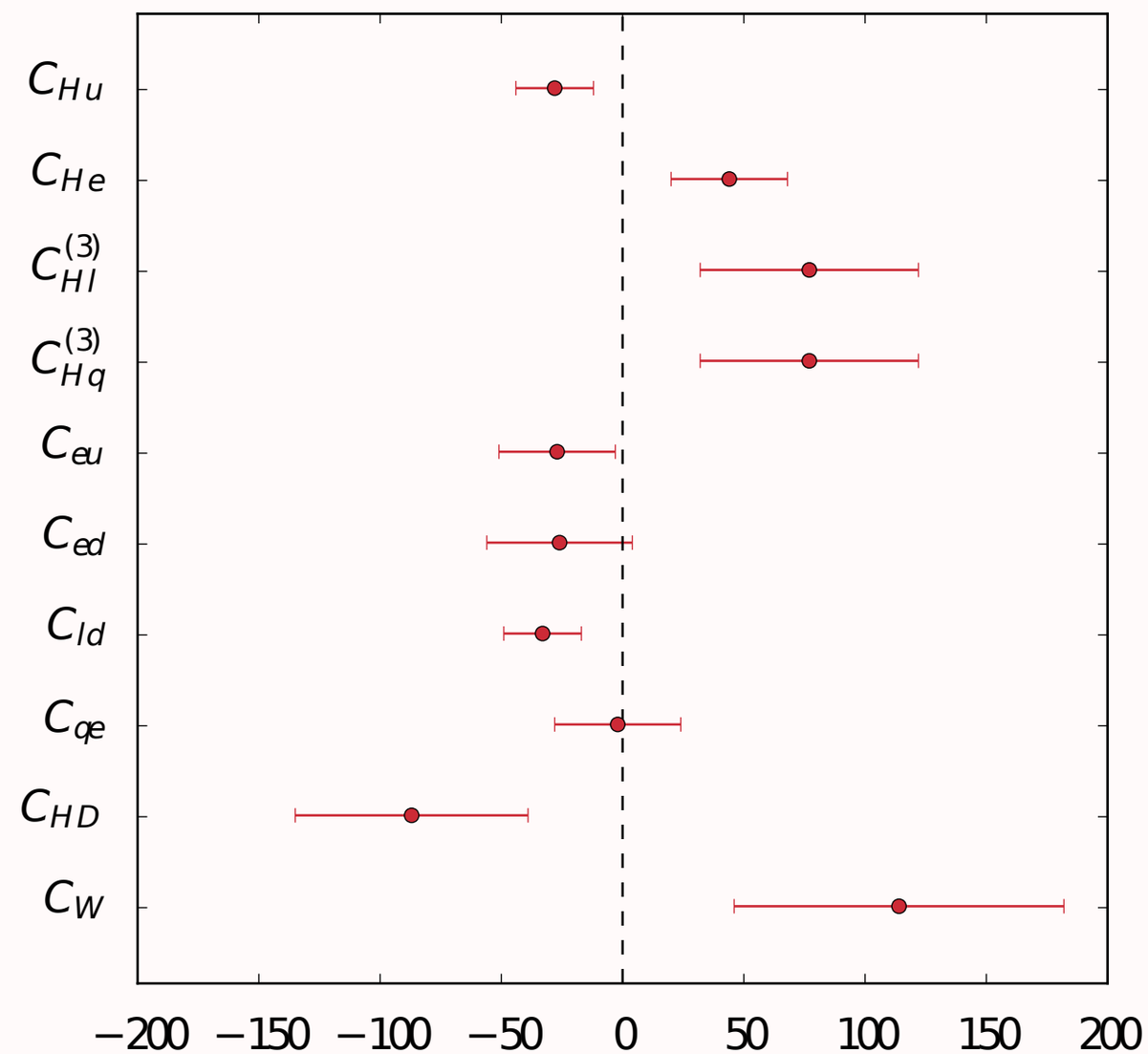
Berthier, Bjørn, Trott 1606.06693

177 observables

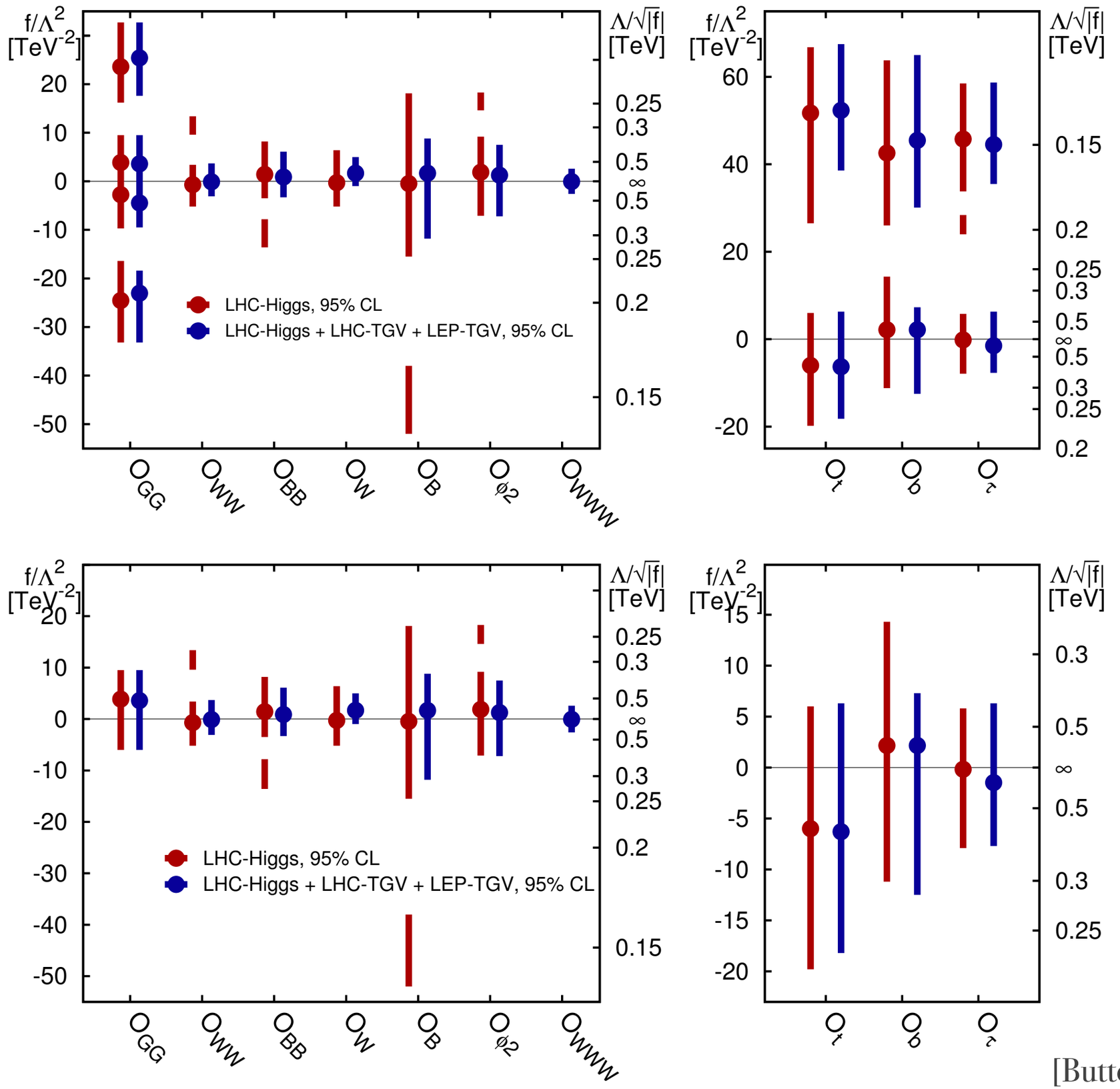
20 Wilson coefficients, assuming CP + $U(3)^5$



1σ regions $C_i\, v^2/\Lambda^2\,(\times 100)$

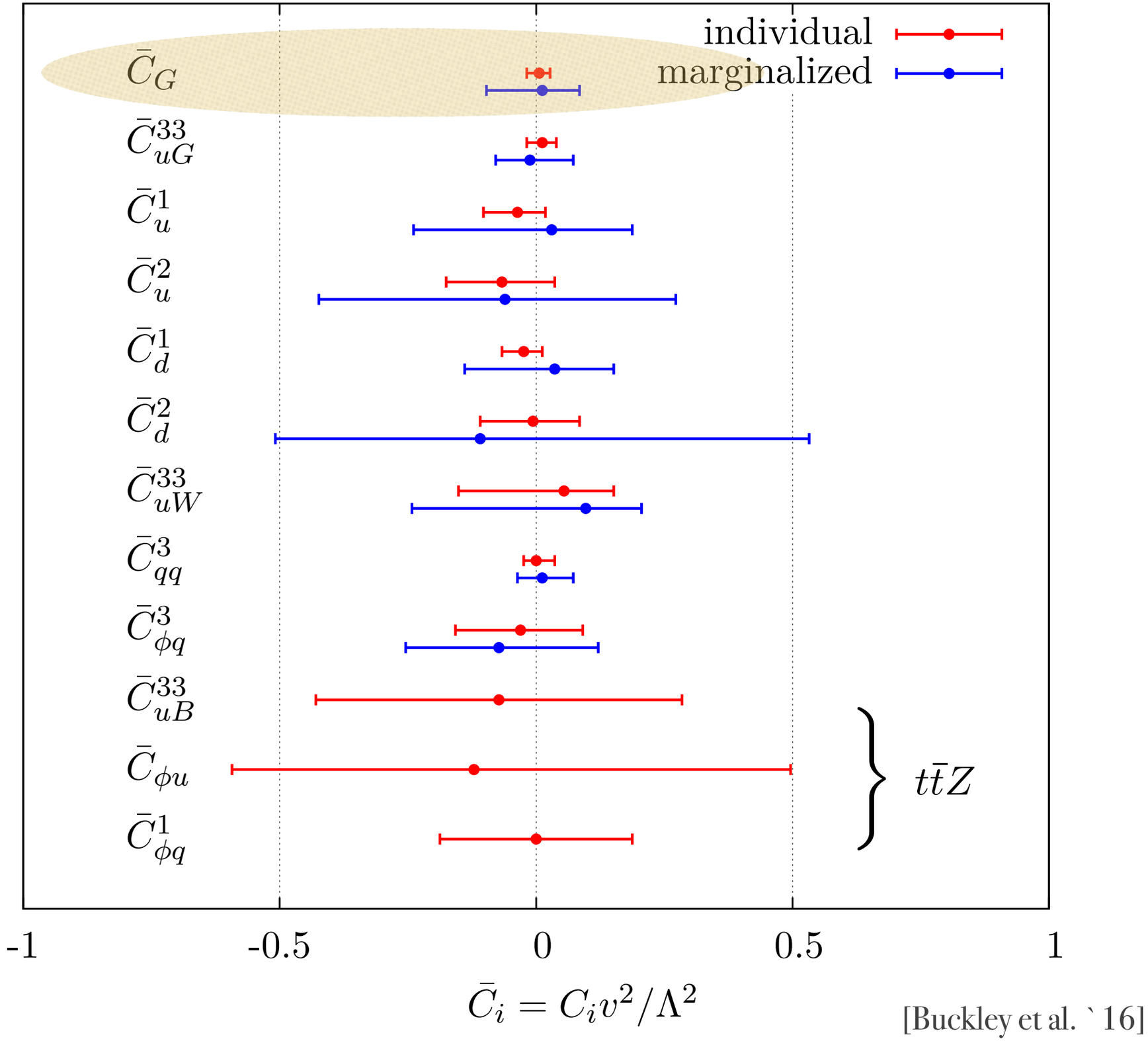


LHC EFT fits: gauge-Higgs sector



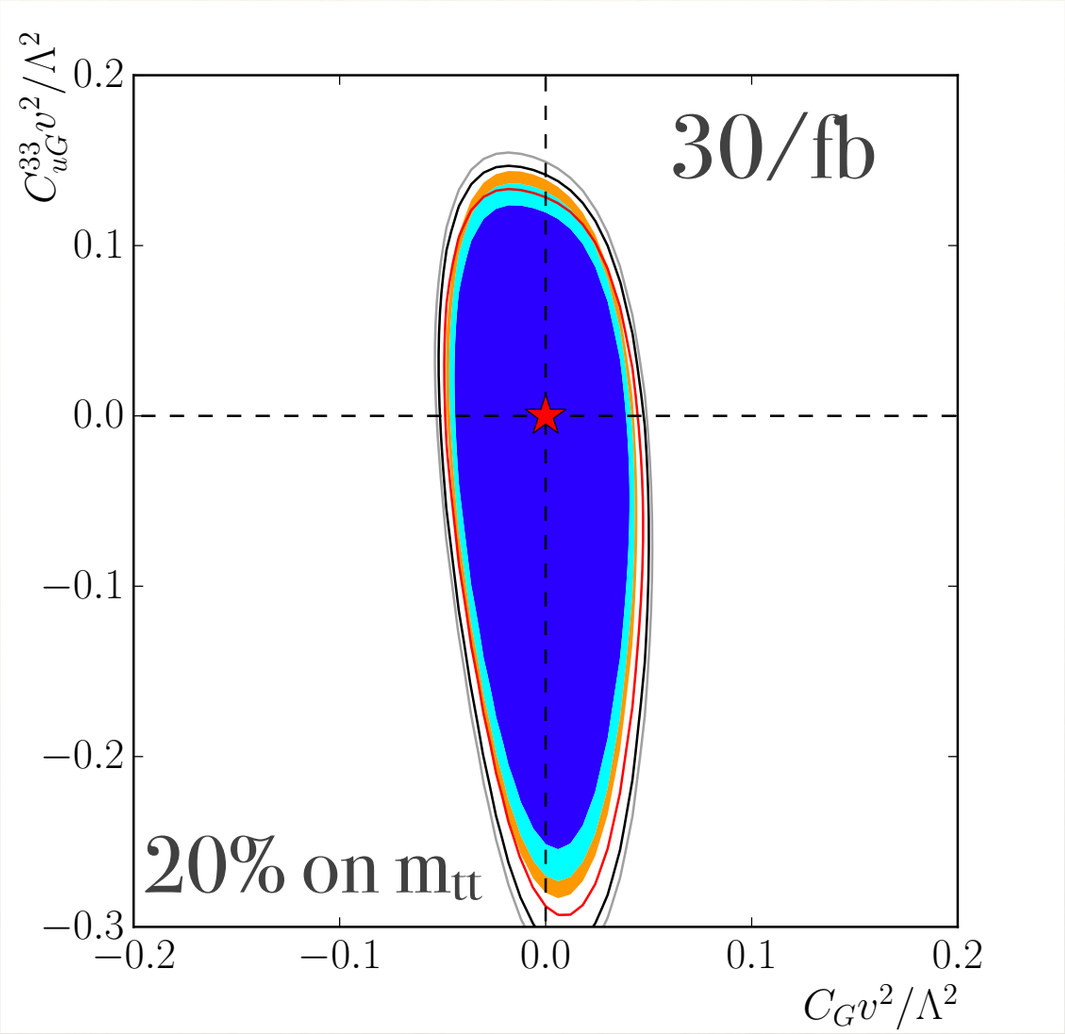
[Butter et al. `16]

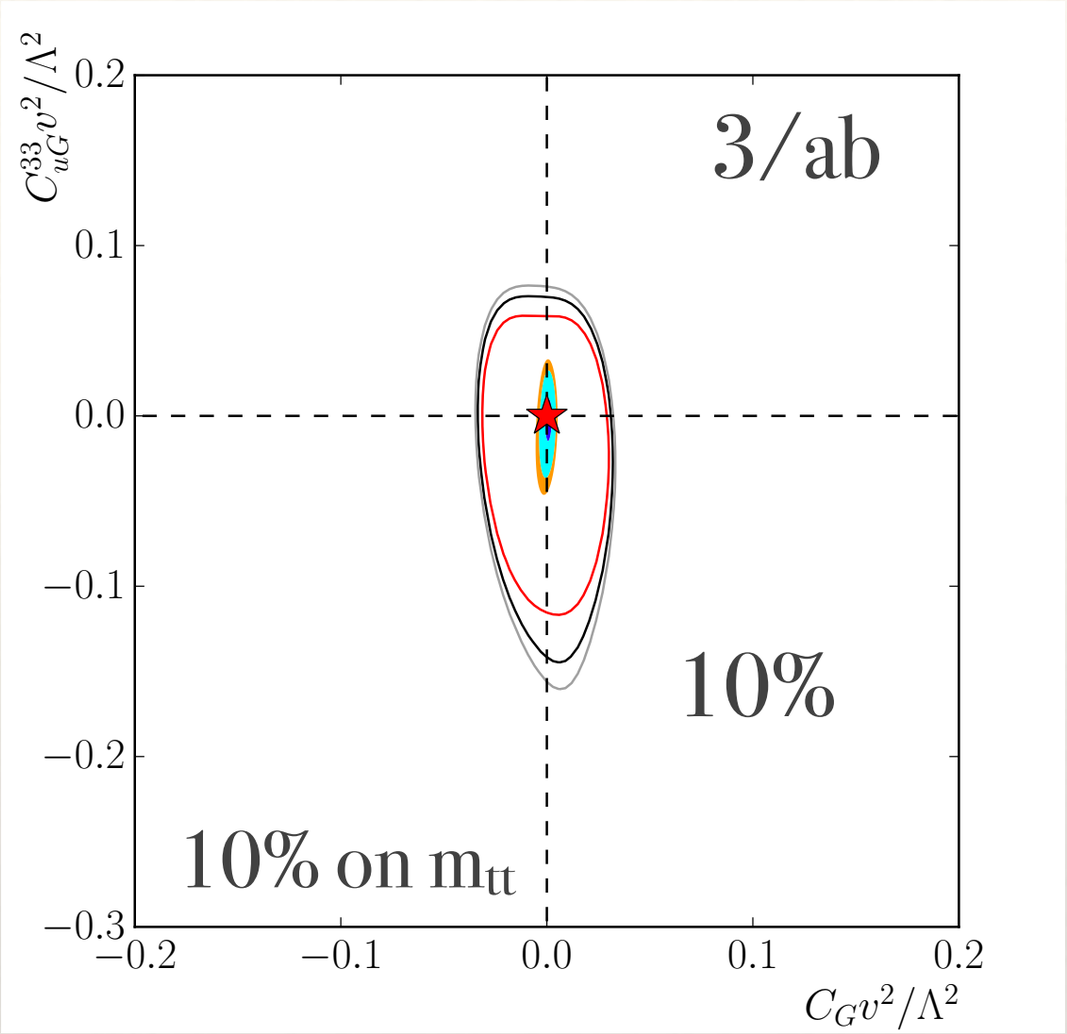
LHC EFT fits: top sector



[Buckley et al. `16]

EFT extrapolations





[CE, Moore, Nordström, Russell `17]

- lines: exp. and theor. uncertainties
- filled: experimental systematics only

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- Every signal with, e.g., a ttbar background receives correction from ~10 operators. Is signal/background modelling still workable?
- <u>data-driven techniques</u>: correlations between control and signal regions will be obscured by construction
    - *W* mass measurement relies on a p_T and m_T fit
    - neutrino momentum is reconstructed though hadronic recoil that is calibrated through in-situ *Z* events

Matthias’ talk

EFT vs full models

full models vs EFT

"maximum optimism"

EFT vs full models

full models vs EFT

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- SM extension addresses a problem deemed "serious"
  - tuning
  - dark matter
  - baryogenesis
  - ...

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  - only SM fields are light
  - SM symmetries
  - maybe extra simplifications to make things manageable

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Perturbativity, validity and all that

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D6 ~ SM

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1. NDA or matching calculations can give an idea

[Manohar, Georgi `02]
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[Freitas, Lopez-Val, Plehn `16]
e.g. [Anastasiou et al. "Match Maker" tba]

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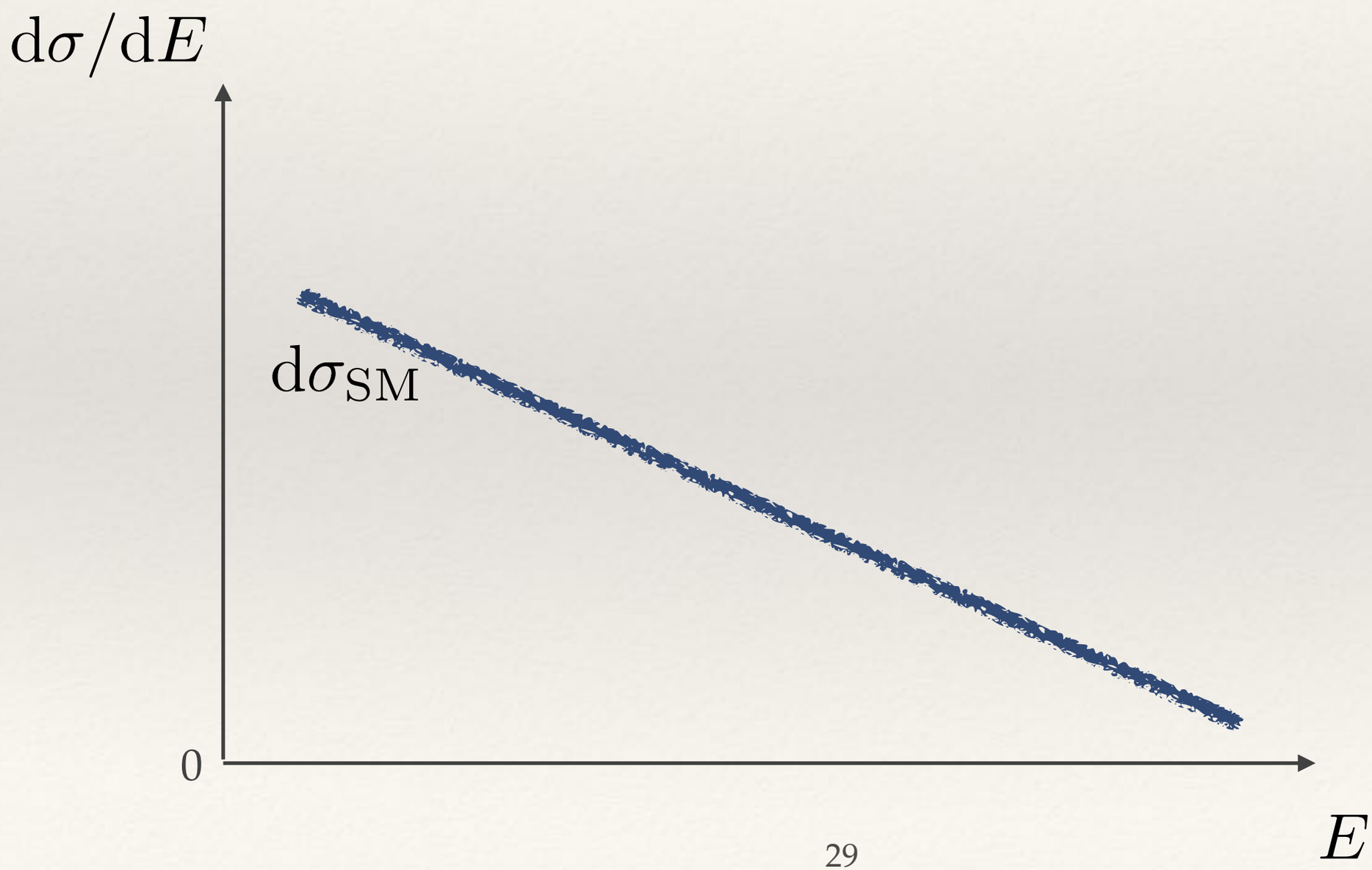
2. negative weights are not unknown in pQFT. E.g. they do not signalise the breakdown of QCD, but a loss of reliability, i.e. **they are a blessing**.

Validity and fits

2. negative weights = **baseline of reliability of** $c_i O_i / \Lambda^2$



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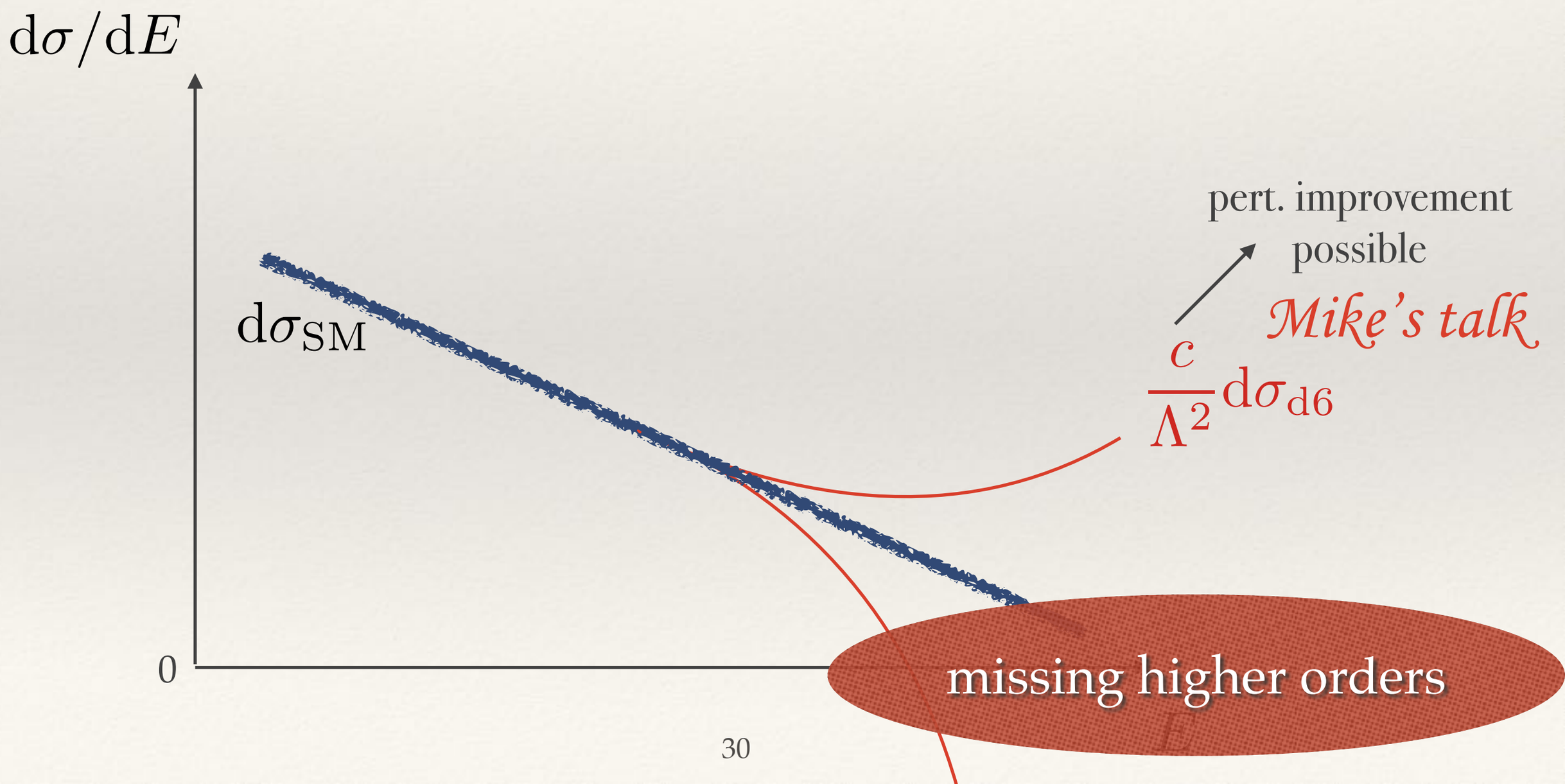

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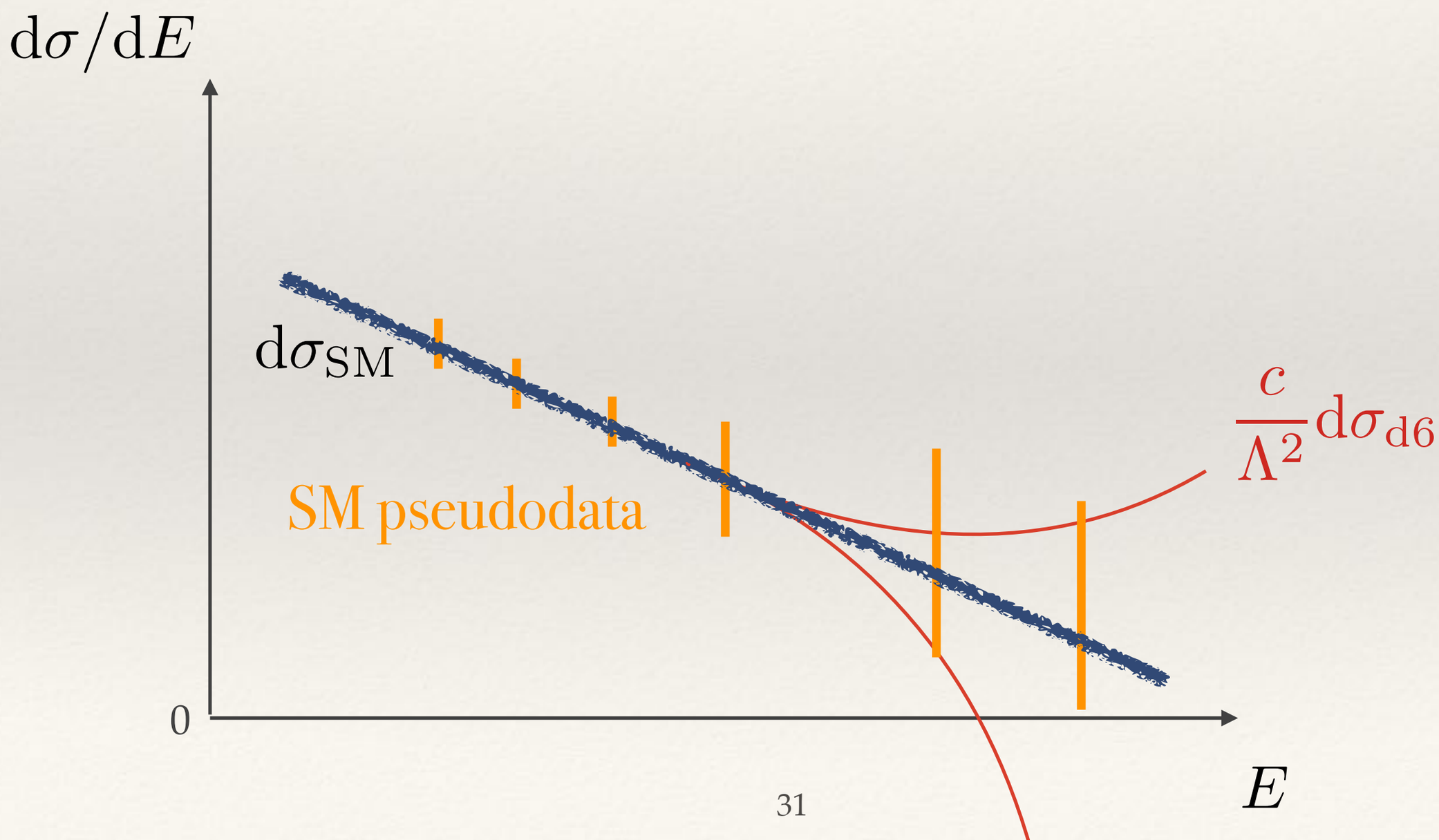

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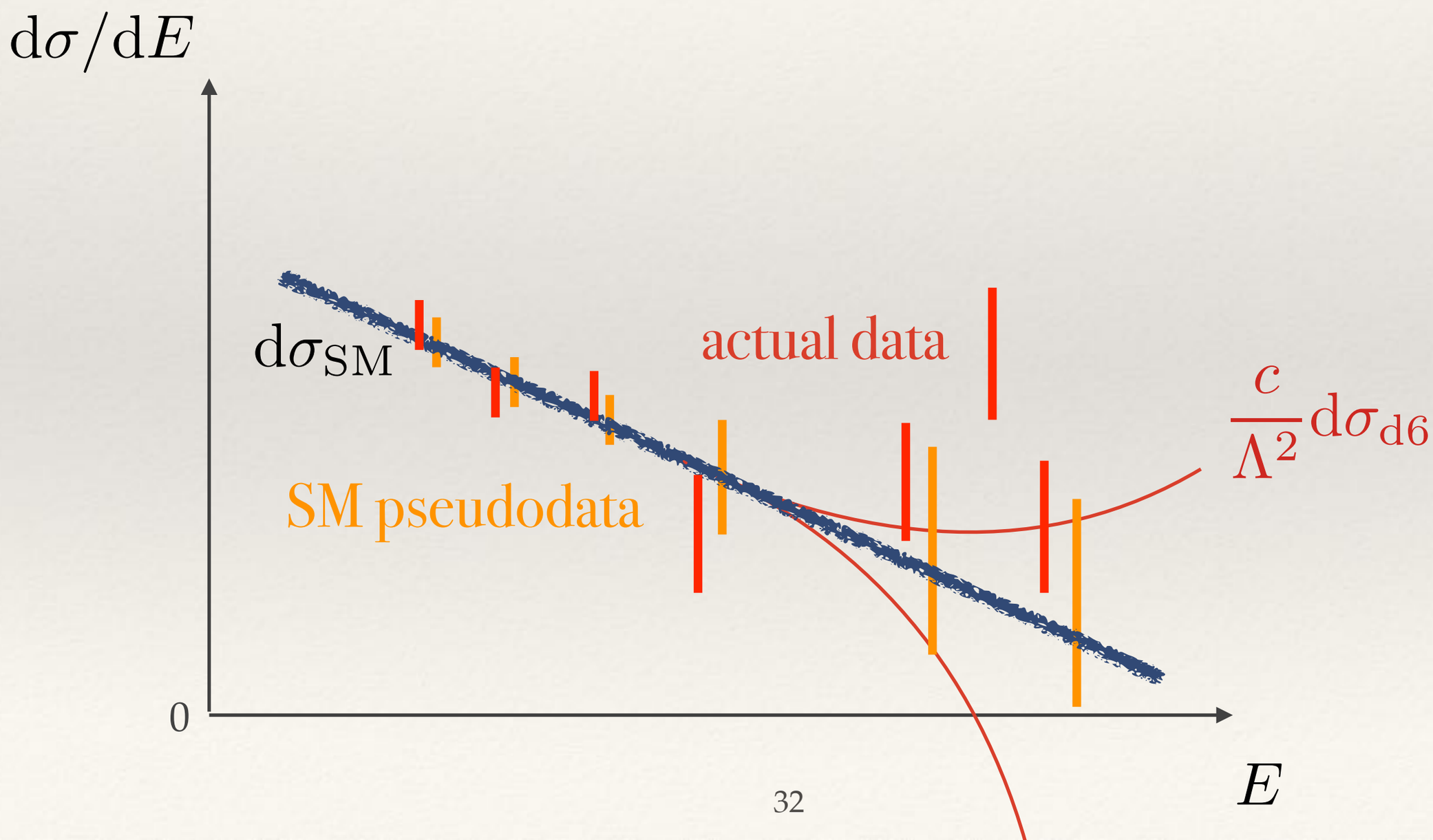

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(i) $\frac{c}{\Lambda^2} \mathrm{d}\sigma_{\mathrm{d6}} \lesssim \mathrm{d}\sigma_{\mathrm{SM}}$ for range sampled by SM pseudodata

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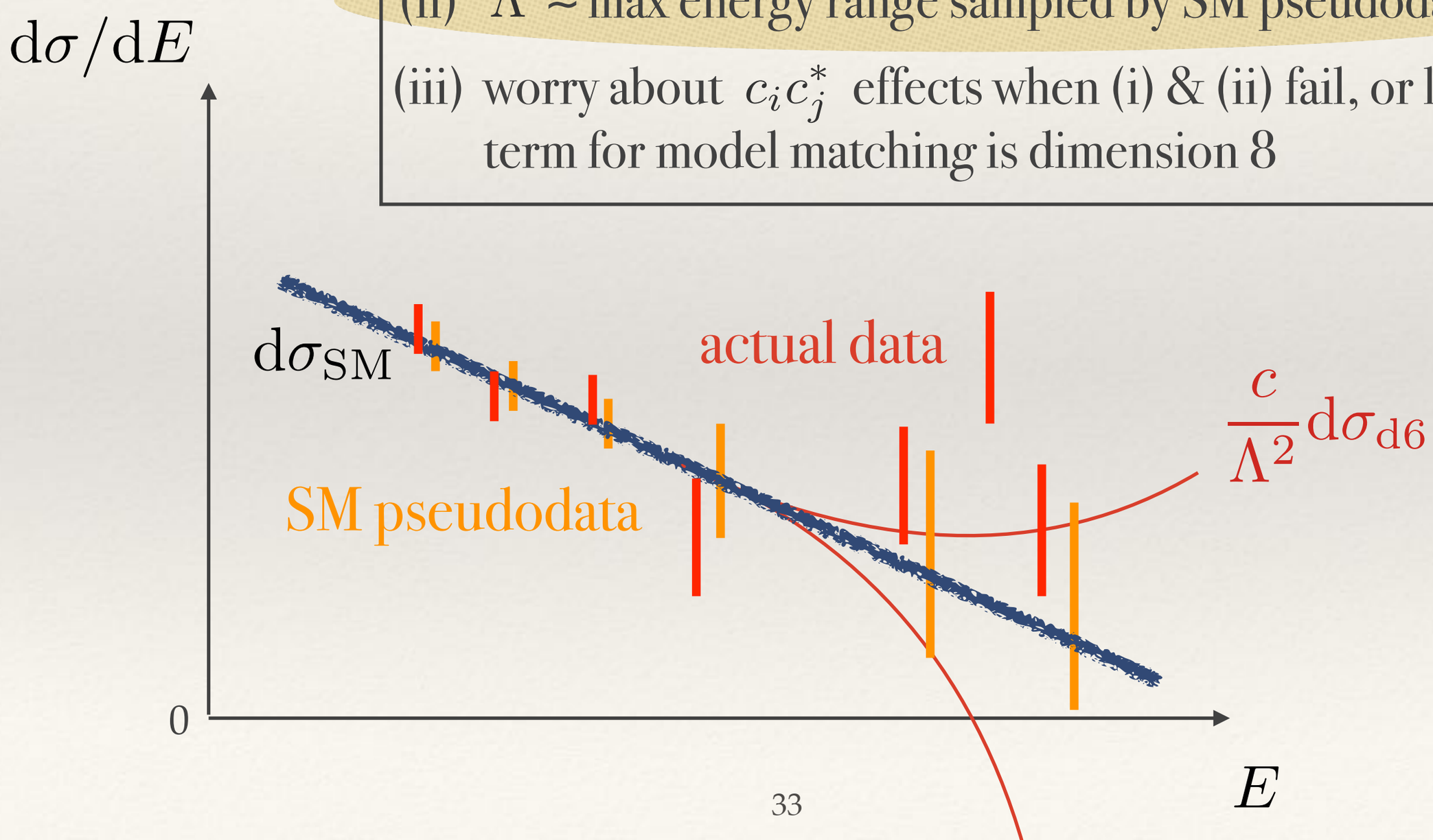
(iii) worry about $c_i c_j^*$ effects when (i) & (ii) fail, or leading term for model matching is dimension 8



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[Azatov et al. `16]

accidental cancellations

- include dim6^2 ?
- use gauge-invariance to go off-shell

[Duff, Zeppenfeld `09]
[Dixon, Shadmi `94]
[Krauss, Kuttimalai, Plehn `16]

BSM model has no $1/m^2$

- in general constraint will depend on the model

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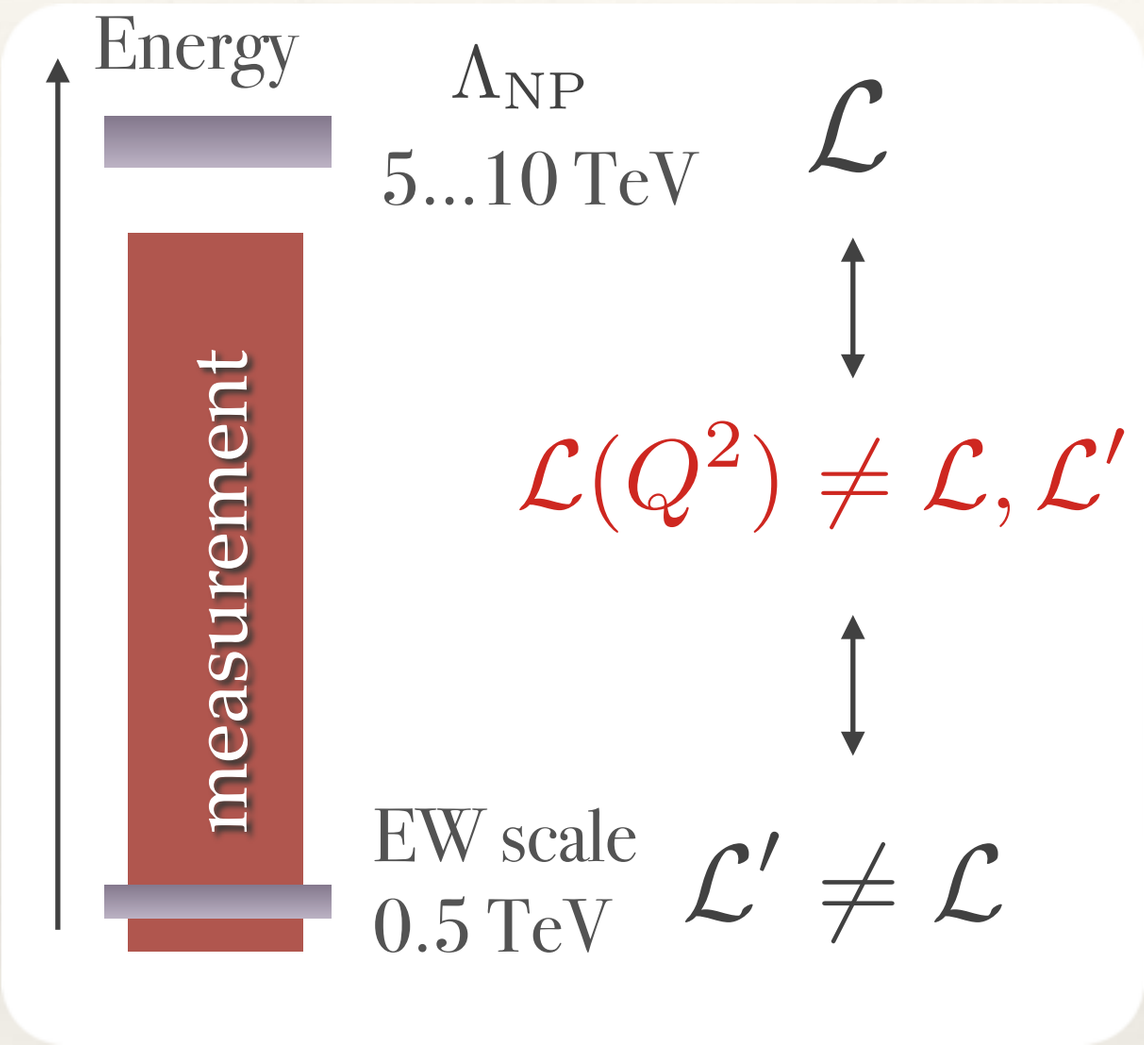
experimental input?

- if agreement with the SM extends over a large region in energy, the Wilson coefs can be pushed to non-perturbative values

Is this problematic?

non-perturbative constraints?

[Hagiwara, Ishihara, Szalapski, Zeppenfeld `92, `93]
[Alam, Dawson, Szalapski `97]
[Grojean, Jenkins, Manohar, Trott `13]
[Jenkins, Manohar, Trott `13]
[Alonso et al. `13]



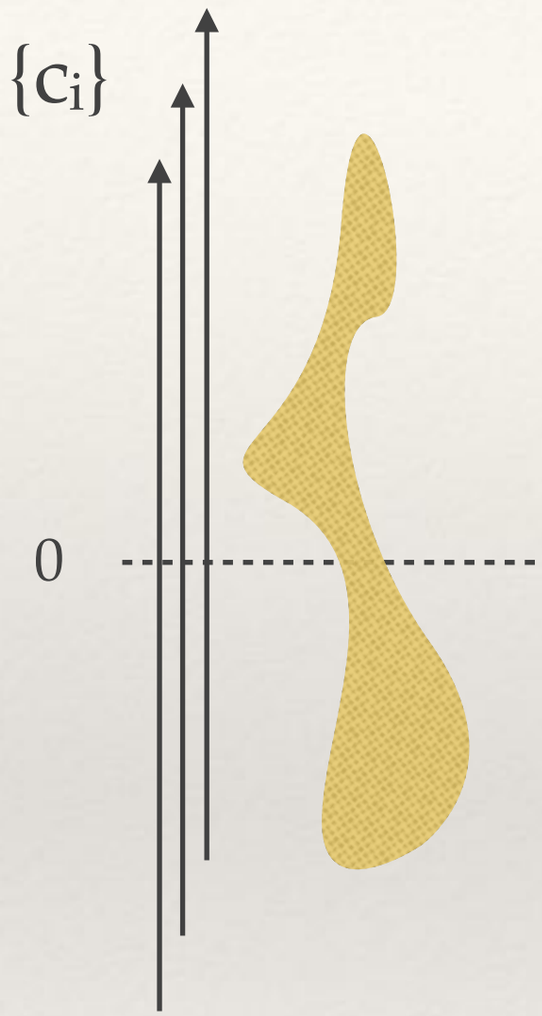
- typically relevant for strong mixing or evolution over enormous scale differences
- perturbative UV theories could flow to non-perturbative EFTs?

I do not know of any realistic first principle scenario

- constraints should be matched to concrete UV predictions

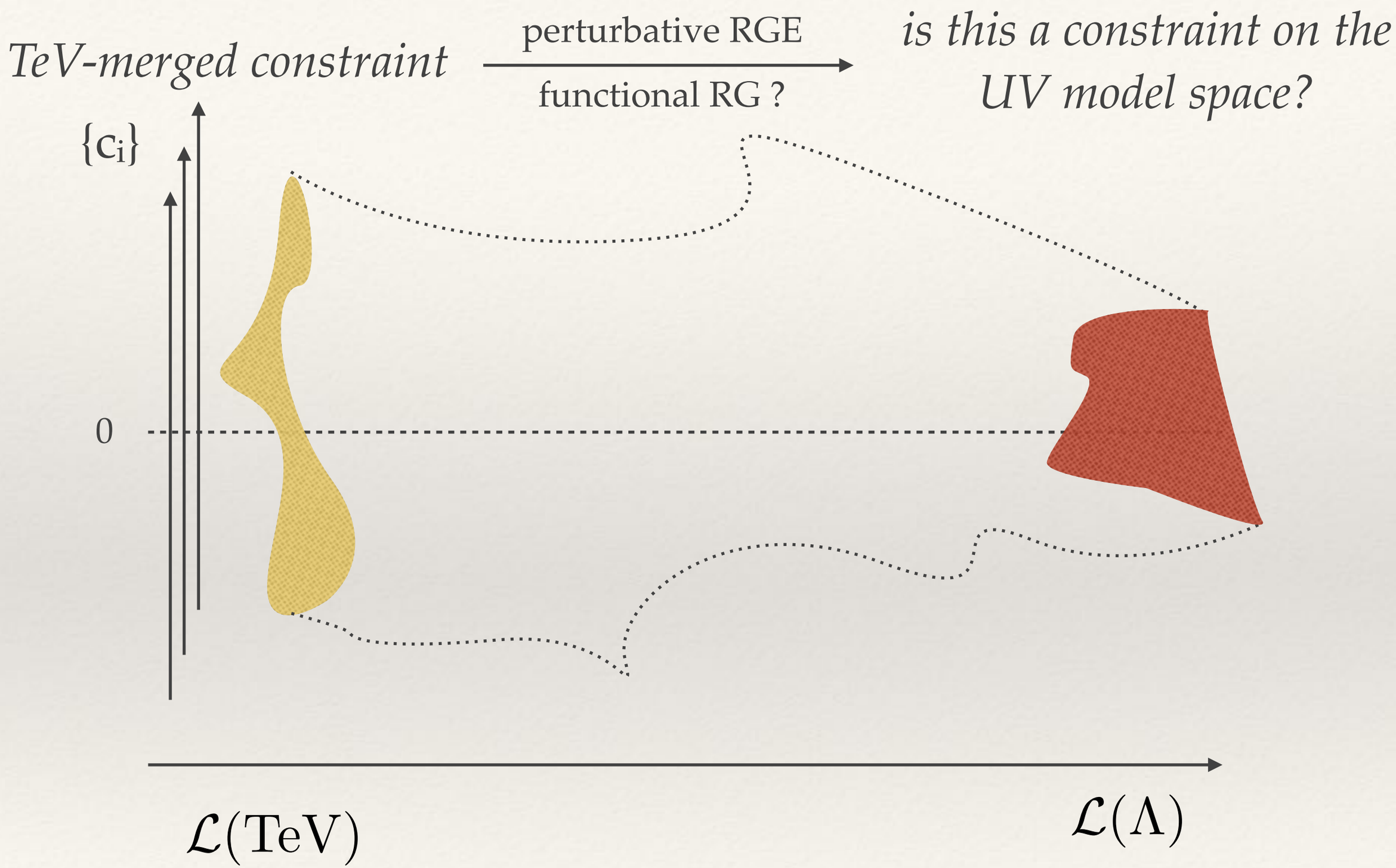
[Drozd, Ellis, Quevillon, You `15]
[Ellis, Quevillon, You, Zhang `17]
[Anastasiou et al. "Match Maker" tba]

Perturbativity, Validity and all that



$\mathcal{L}(\mathrm{TeV})$

Perturbativity, Validity and all that



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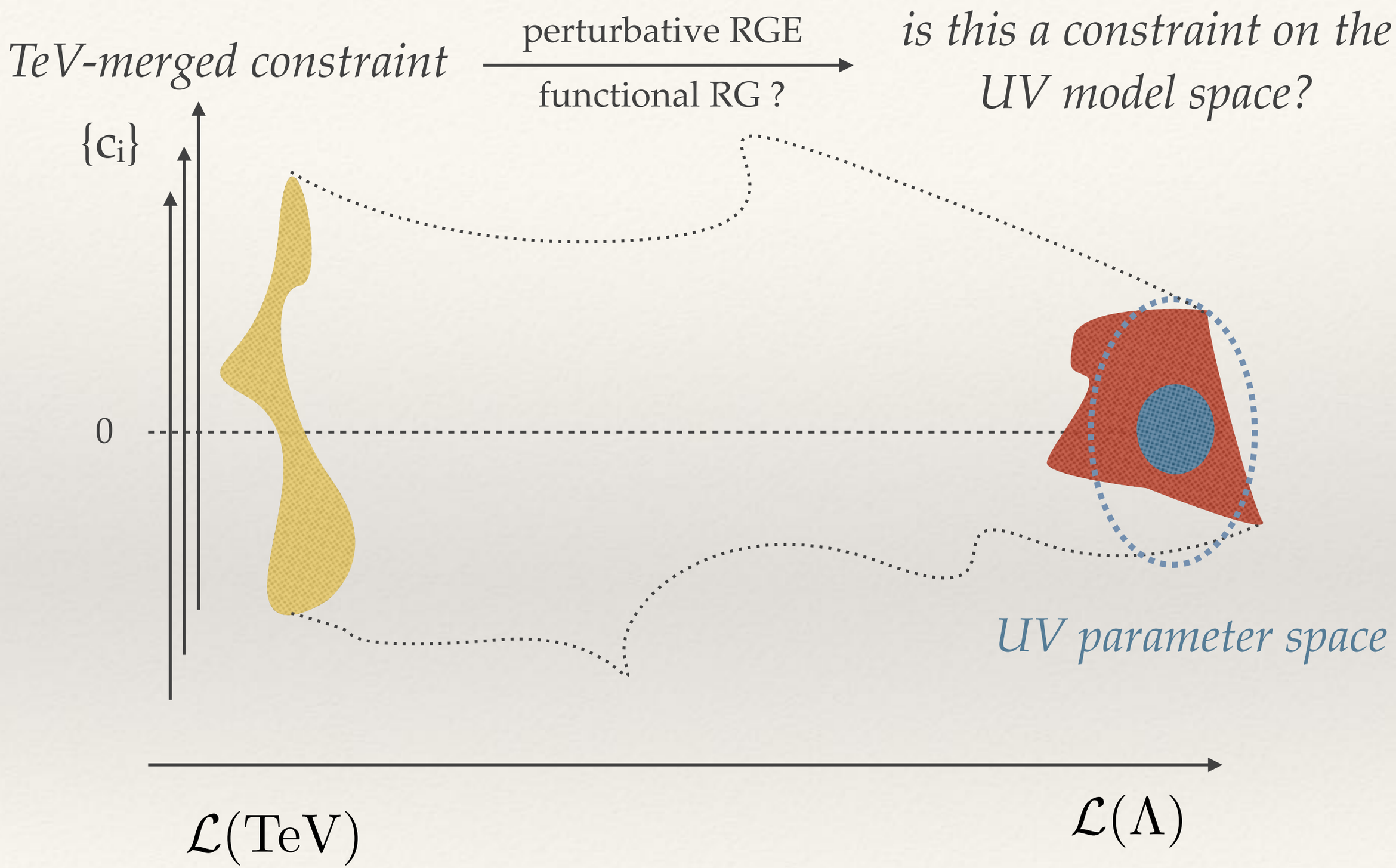

Summary?

- EFT is a way to inform specific UV completions
- EFT techniques should be used to perform coupling analyses with large statistics
  - extend coupling analyses to off-shell states and include tails consistently
  - possibility of perturbative improvement
- proof-of-principle fits in selected sectors using different techniques
  - experiments have the chance to pick up the momentum