SMEFT:
The *new* Standard Model

Veronica Sanz (Sussex & Valencia)-> Sebastian->Anke

KITP Precision21

University of Sussex

Universitat de València

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why do we do it, where are we going with it

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BTW, I suggest you inflict this pain yourself:
read some nice reviews & do some chi2 fit
Masso ('17), Brivio&Trott ('19)

Setting up the scene

Why do we need a *new* SM?

Particle Physics: today's pulse

Super-excited about new experimental probes

new LHC upgrades, *new* gravitational wave signals, *new* direct detection experiments, *new* experiments looking for XYZ new physics, *new* astrophysical probes

new Opportunities

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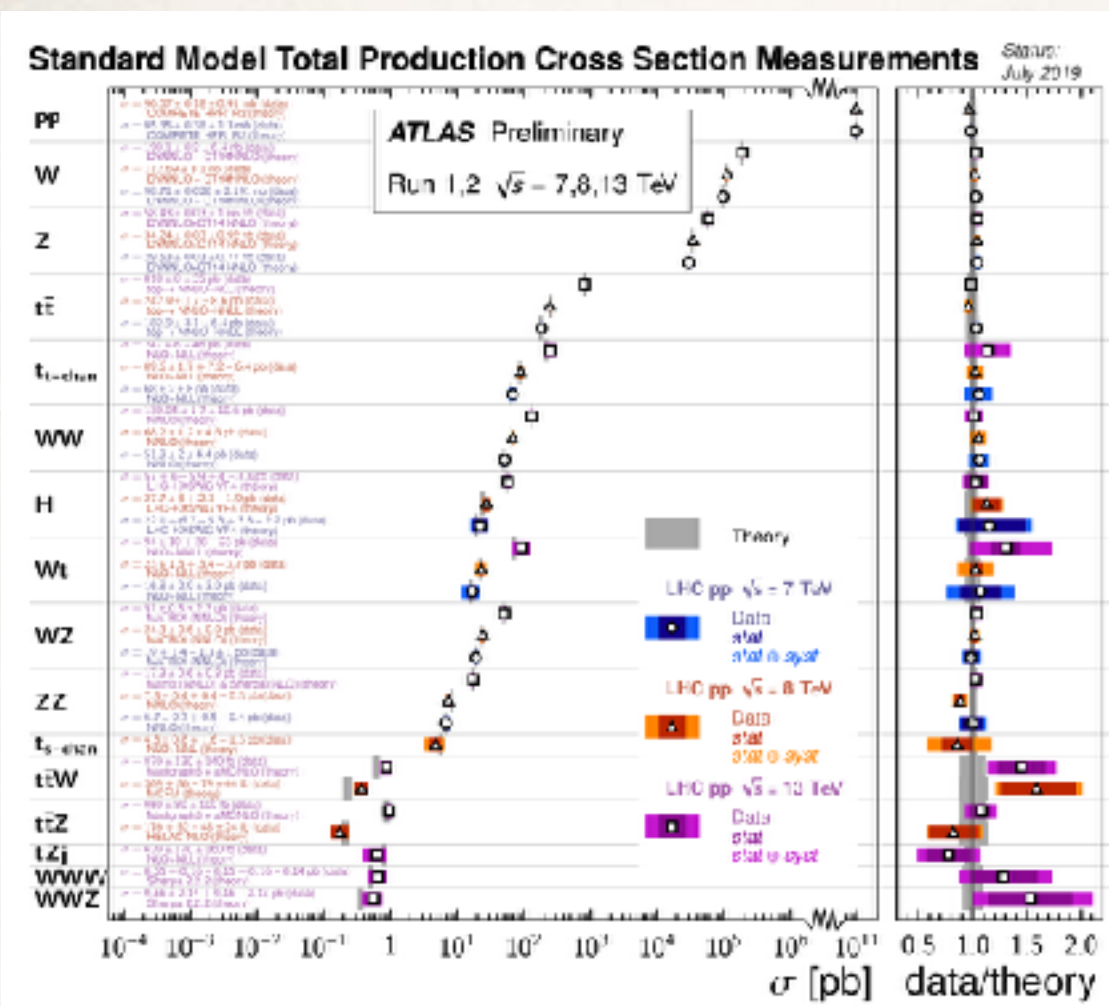
Utterly baffled by the lack of discoveries
'et tu, Naturalness?'
and with a deep theory-fatigue
'A new theory? Bah, humbug! surely a rehash of one of Georgi's old ideas, or a Frankenstein model with complex structure > problems '

(Personal) Statements x10
for illustration purposes

Lack of discoveries…

The LHC is our best probe to microscopic physics:
controlled and well-understood environment
programme already at the precision stage
yet what we have seen so far is (from a BSM perspective)
nothing to write home about



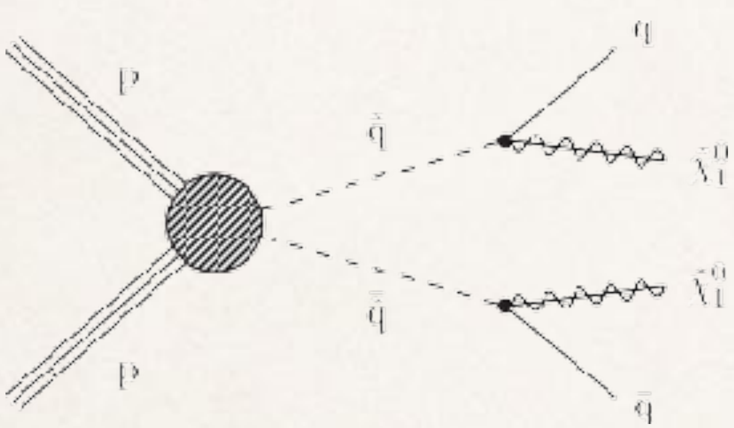
This statement doesn't make justice to the
exciting LHC physics programme,
and to the legacy of the Higgs discovery

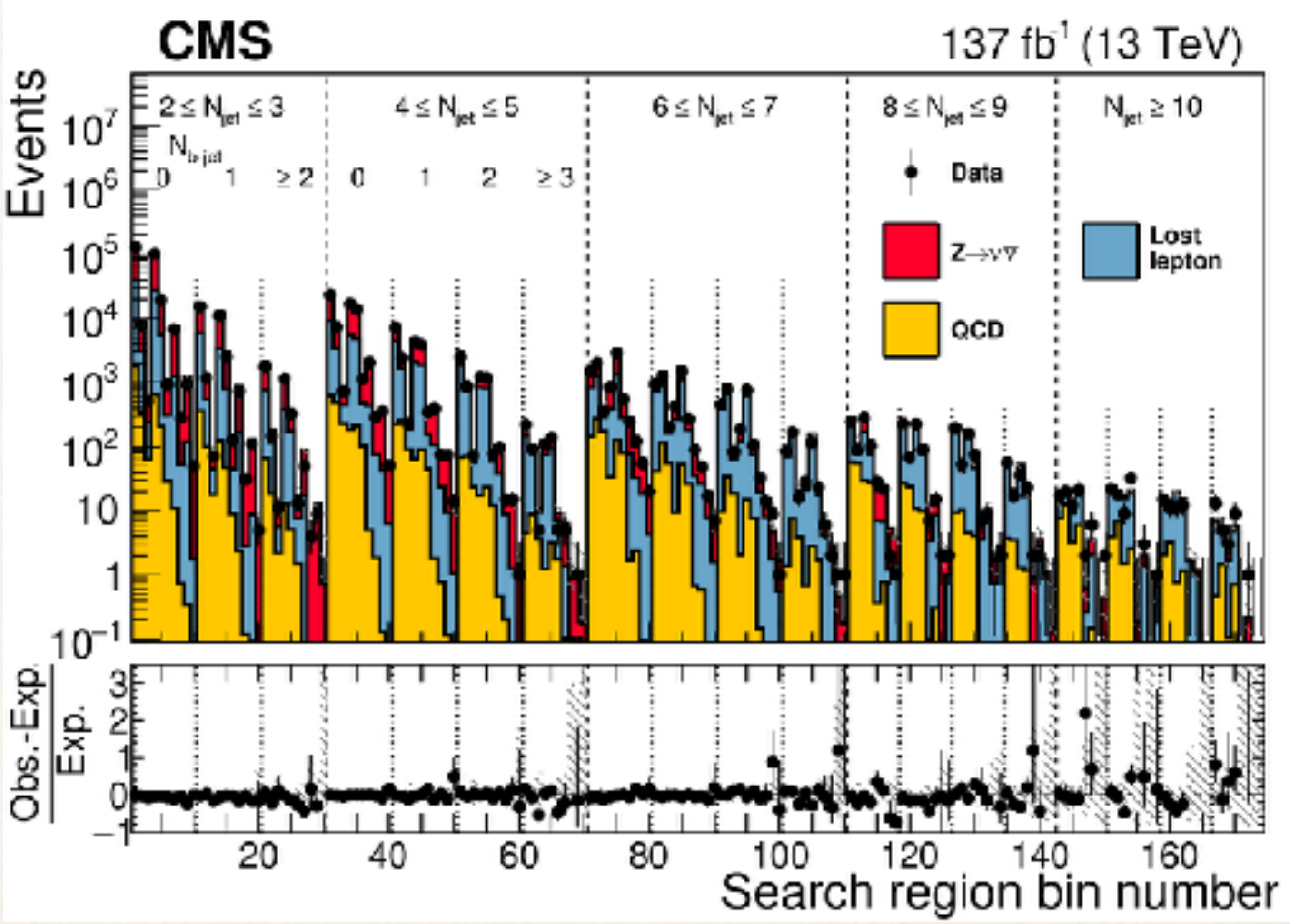
Lots of very precise measurements
spanning a good range in energy
with Run3&beyond: more to come

Lack of discoveries…

We haven't seen indications of producing BSM particles: resonances, excesses in MET distributions…

Example: SUSY analysis searching for Dark Matter with jets





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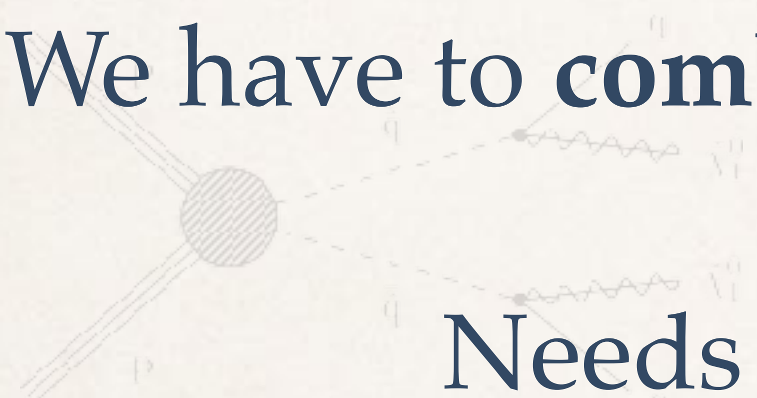

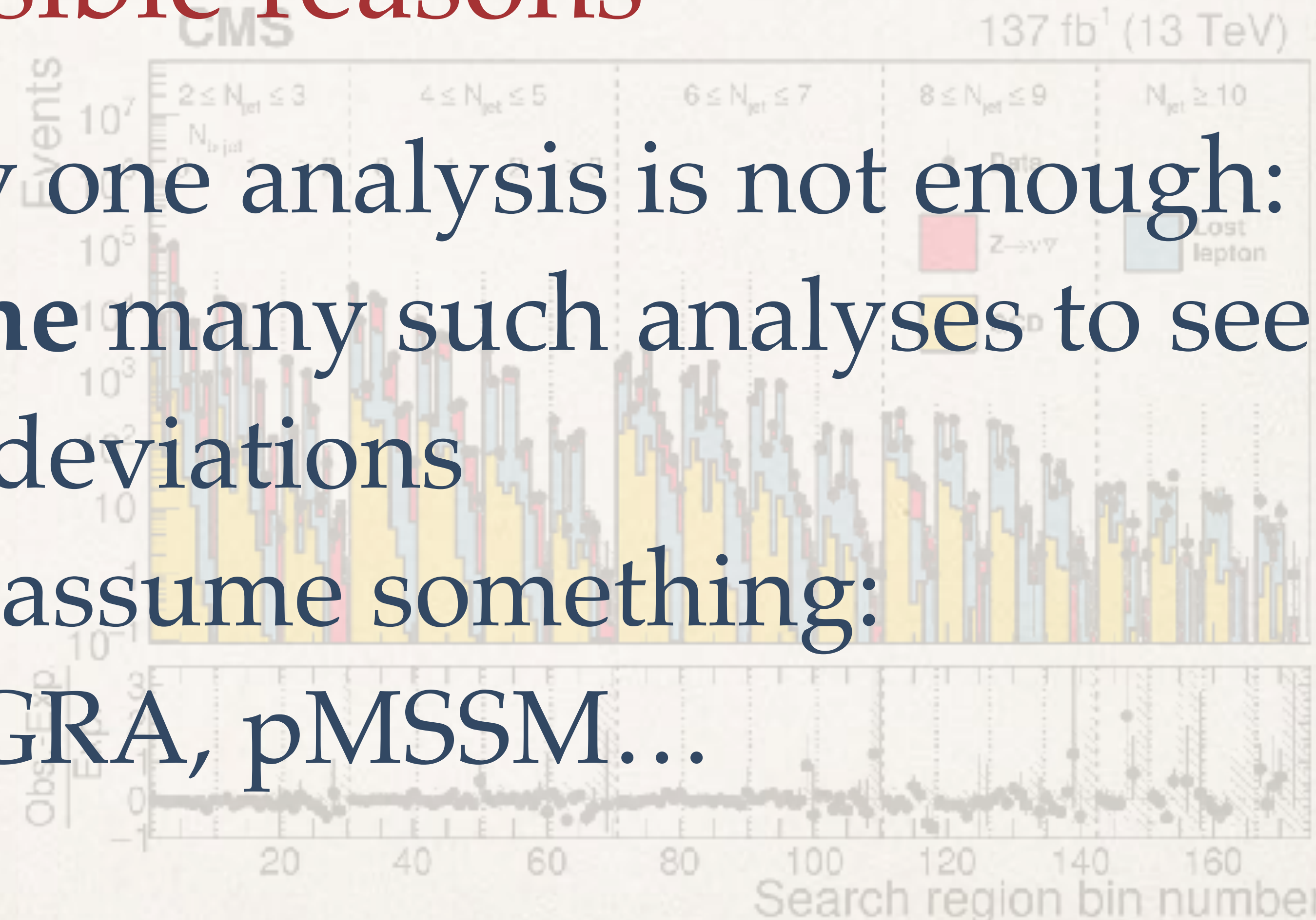

To reach discovery one analysis is not enough:
We have to **combine** many such analyses to see deviations

Needs to assume something:
mSUGRA, pMSSM…

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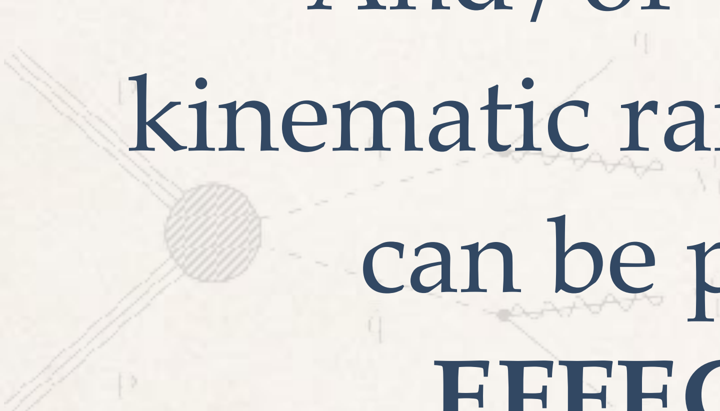


And/or we haven't reached yet the kinematic range where these BSM particles can be produced in the final state

EFFECTIVE FIELD THEORY

Casting a wide net: the *new* SM

EFT approach

Well-defined theoretical approach
Assumes New Physics states are heavy
Write Effective Lagrangian with only light (SM) particles
BSM effects can be incorporated as a momentum expansion

dimension-6 dimension-8

$$\mathcal{L} = \mathcal{L}_{SM} + \sum \frac{c_i}{\Lambda^2} \mathcal{O}_i^{d=6} + \sum \frac{c_i}{\Lambda^4} \mathcal{O}_i^{d=8} + \dots$$

BSM effects SM particles

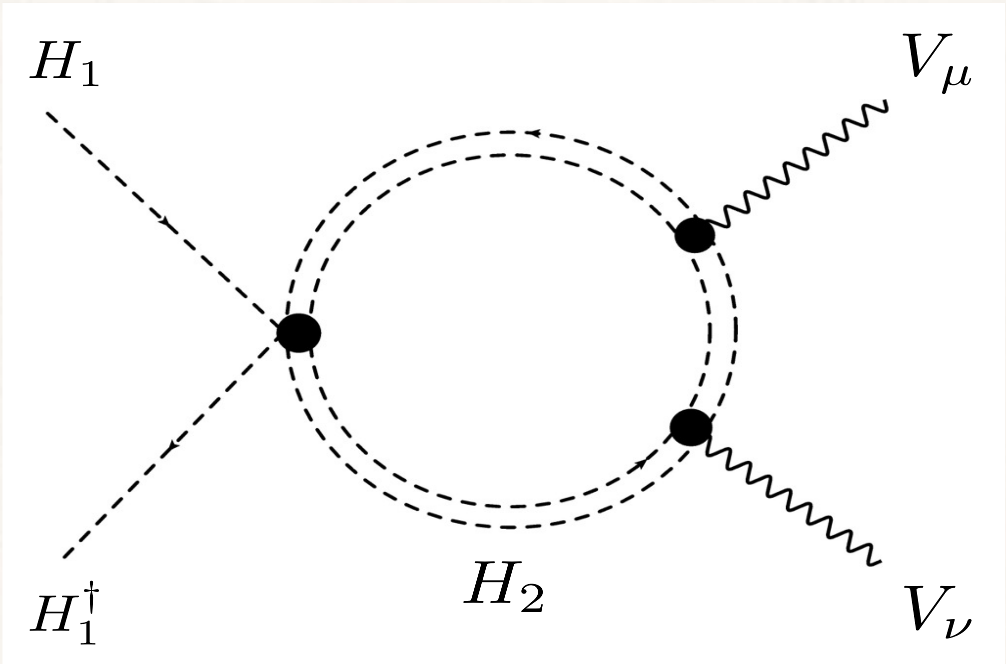
BSM is a **perturbation** around the SM
Each operator can be improved at higher orders in QCD and EW corrections

EFT from UV models

As long as the new states are heavy, one can **integrate them out**

example:

2HDM



compute the integral
expand of external momenta
below the mass

GORBAHN, NO, VS. 1502.07352

first terms on the expansion are a number of dimension-six operators e.g.

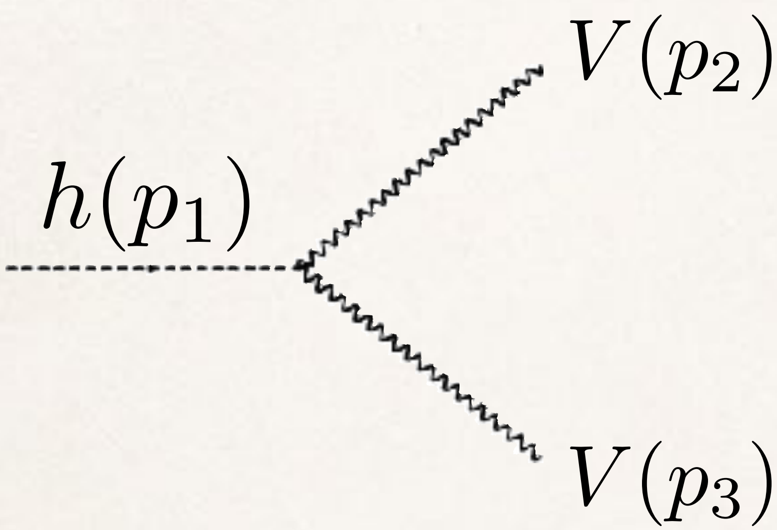
$$\frac{ig}{2m_W^2}\bar{c}_W\left[\Phi^\dagger T_{2k}\overleftrightarrow{D}_\mu\Phi\right]D_\nu W^{k,\mu\nu} \qquad \text{where } \bar{c}_W = \frac{m_W^2\,(2\,\tilde{\lambda}_3+\tilde{\lambda}_4)}{192\,\pi^2\,\tilde{\mu}_2^2}$$

next term in the expansion: dimension-eight

Differential information is key

Models offer richer kinematics than the kappa-formalism
and the EFT approach captures them

$$-\frac{1}{4} h\, g^{(1)}_{hVV} V_{\mu\nu} V^{\mu\nu} \quad -h\, g^{(2)}_{hVV} V_{\nu} \partial_{\mu} V^{\mu\nu} \quad -\frac{1}{4} h\, \tilde{g}_{hVV} V_{\mu\nu} \tilde{V}^{\mu\nu}$$

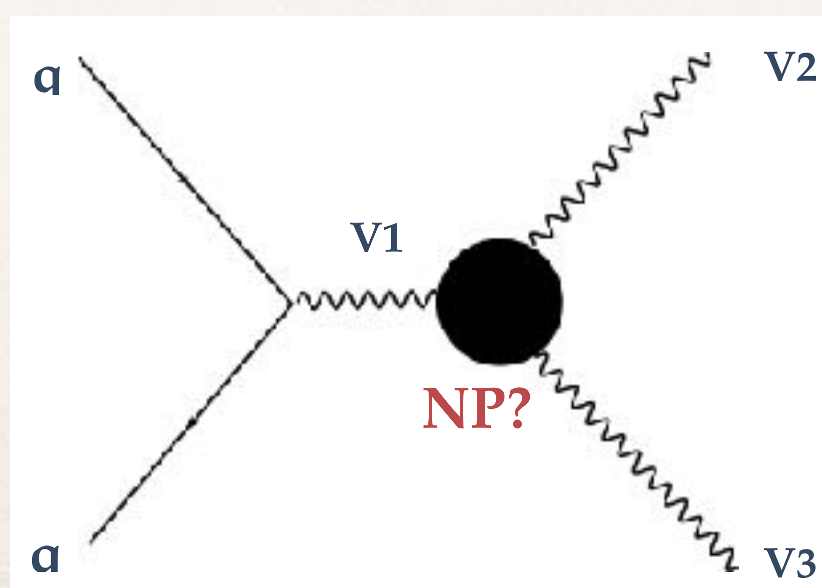


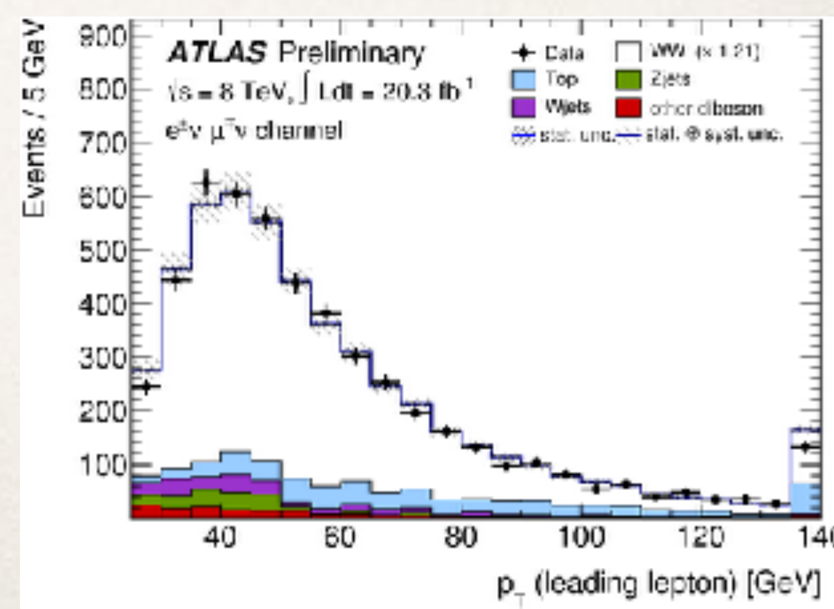
$$i\eta_{\mu\nu} \left(g^{(1)}_{hVV} \left(\frac{\hat{s}}{2} - m_V^2 \right) + 2 g^{(2)}_{hVV} m_V^2 \right)$$

$$-i g^{(1)}_{hVV} p_3^{\mu} p_2^{\nu} \quad -i \tilde{g}_{hVV} \epsilon^{\mu\nu\alpha\beta} p_{2,\alpha} p_{3,\beta}$$

+ off-shell pieces

exploited in searches for anomalous **TGCs**





Matching to UV theories

Within the EFT, connection to models is *straightforward*

EFT

$$\bar{c}_H = -\left[-4\tilde{\lambda}_3\tilde{\lambda}_4 + \tilde{\lambda}_4^2 + \tilde{\lambda}_5^2 - 4\tilde{\lambda}_3^2\right]\frac{v^2}{192\,\pi^2\,\tilde{\mu}_2^2}$$

$$\bar{c}_6 = -\left(\tilde{\lambda}_4^2 + \tilde{\lambda}_5^2\right)\frac{v^2}{192\,\pi^2\,\tilde{\mu}_2^2}$$

$$\bar{c}_T = (\tilde{\lambda}_4^2 - \tilde{\lambda}_5^2)\,\frac{v^2}{192\,\pi^2\,\tilde{\mu}_2^2}$$

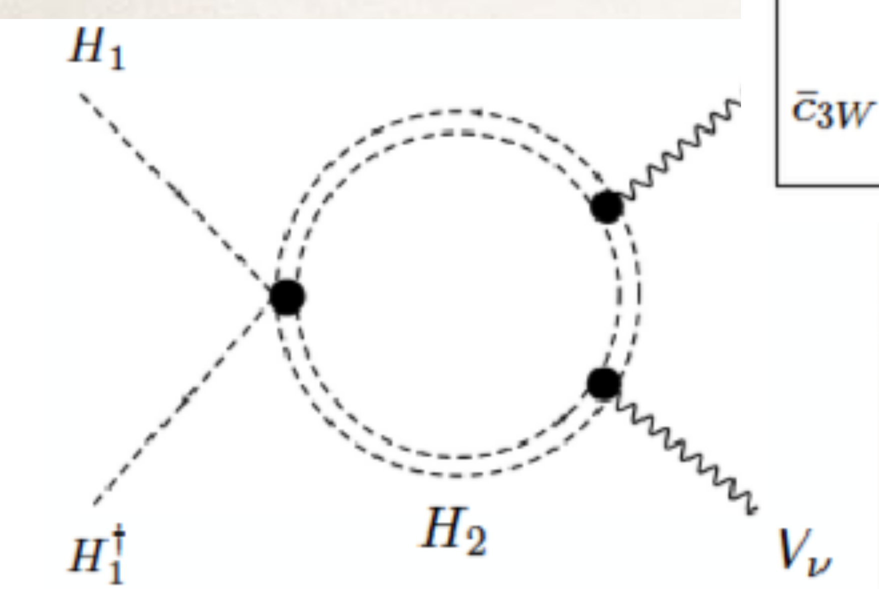
$$c_\gamma = \frac{m_W^2\,\tilde{\lambda}_3}{256\,\pi^2\,\tilde{\mu}_2^2}$$

$$\bar{c}_W = -\bar{c}_{HW} = \frac{m_W^2\,(2\,\tilde{\lambda}_3 + \tilde{\lambda}_4)}{192\,\pi^2\,\tilde{\mu}_2^2} = \frac{8}{3}\,\bar{c}_\gamma + \frac{m_W^2\,\tilde{\lambda}_4}{192\,\pi^2\,\tilde{\mu}_2^2}$$

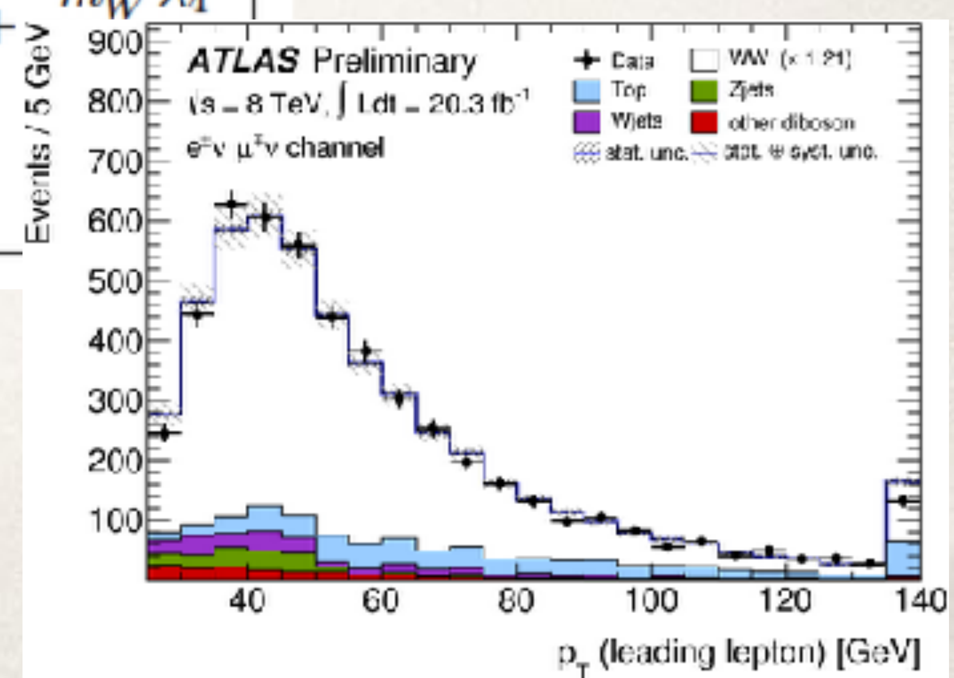
$$\bar{c}_B = -\bar{c}_{HB} = \frac{m_W^2\,(-2\,\tilde{\lambda}_3 + \tilde{\lambda}_4)}{192\,\pi^2\,\tilde{\mu}_2^2} = -\frac{8}{3}\,\bar{c}_\gamma + m_W^2\,\tilde{\lambda}_4$$

$$\bar{c}_{3W} = \frac{\bar{c}_{2W}}{3} = \frac{m_W^2}{1440\,\pi^2\,\tilde{\mu}_2^2}$$

MODELS



DATA

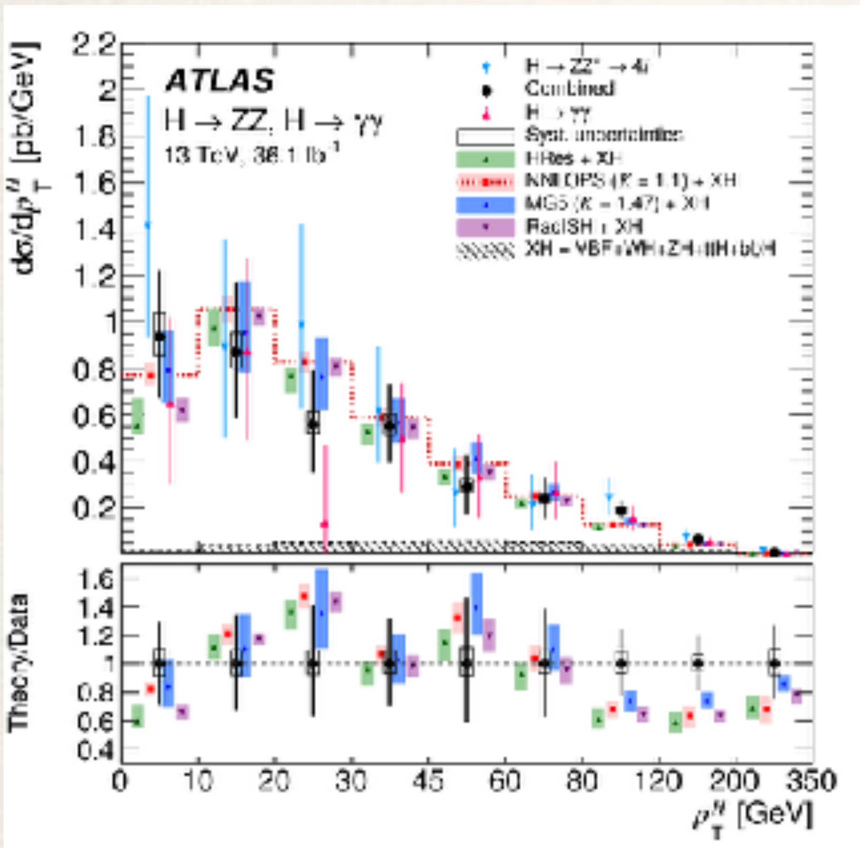


Advantages

- **Combination**: LHC Higgs and EW production, low energy, EWPTs
- **Precision:** higher-order EW and QCD, dimension-eight, chiral logs
- **Consistency:** Backgrounds and signal
- **Reduces model biases:** explore theories beyond known paradigms
- **Matching:** Direct connection to models

Disadvantages

EFTs in PP are an old friend



Maybe you have been working on
low-E flavour/CPV/BLV physics
precision calculations or simply using bounds
What's different for the EFT@EW scale?

We're testing it using a *hadron* collider
flavour physics: heavy means heavy
EW EFT: we are in this border between kinematic reach and precision
& parameter space is very large

Disadvantages

- **Assumptions**: Only SM light states
- **Complexity:** Large number of parameters
- **Validity:** EFT cannot be used in regions of energies ~ scale of new resonances

Challenges

1. Theory biases

Is the EFT framework really *model-independent?*

Not completely

e.g. In non-linear realisations of EWSB

the Higgs could be a **SINGLET**

as opposed to the doublet case

Higgs = (vev + higgs particle + W/Z dofs)

CONSEQUENCES

*de-correlation of Higgs and VV

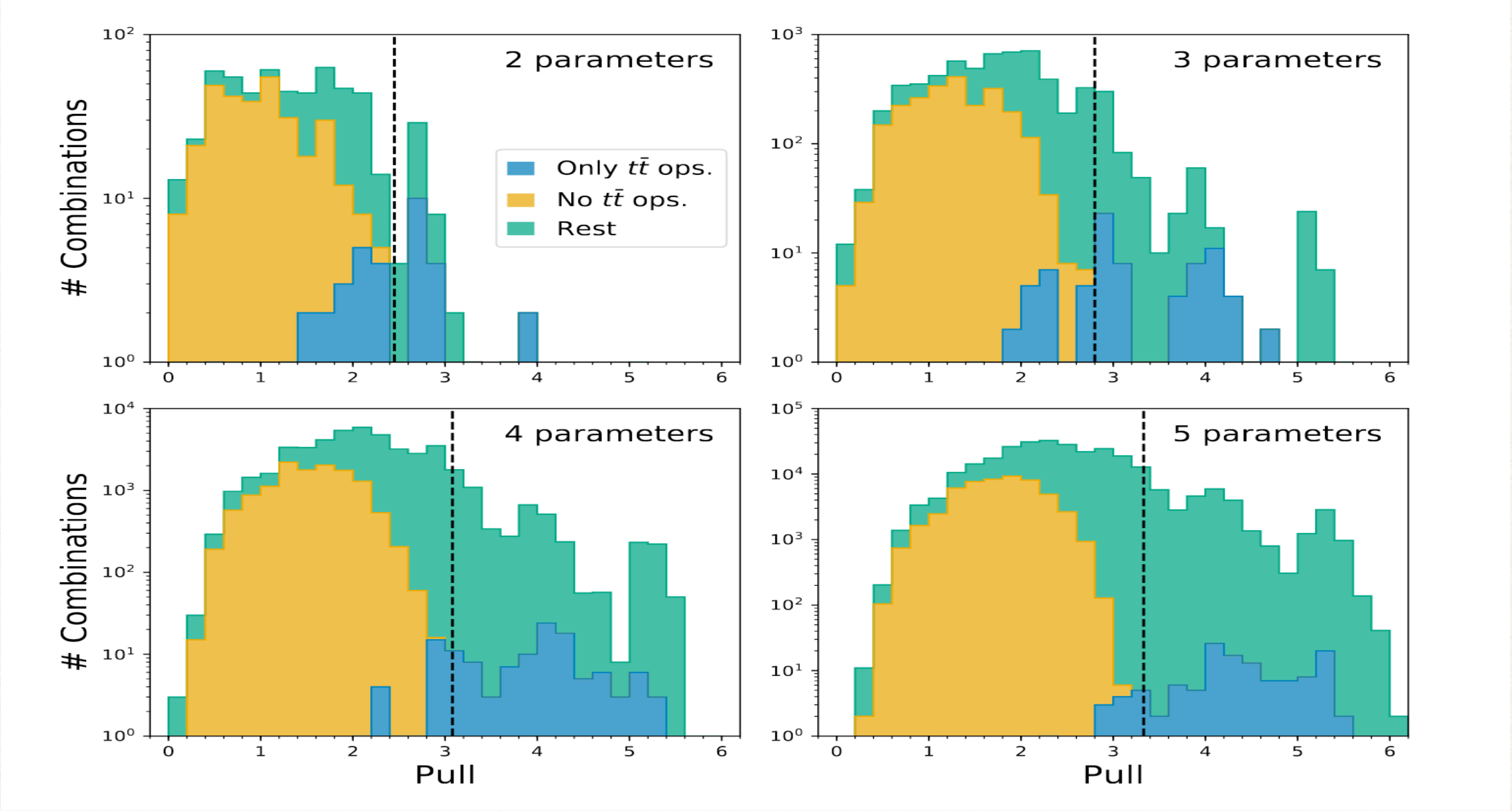
*EFT expansion changes

EFT provides a *large enough* set of deformations from the SM serves the purpose of guiding searches and interpretation in terms of UV models

2. Parameter complexity

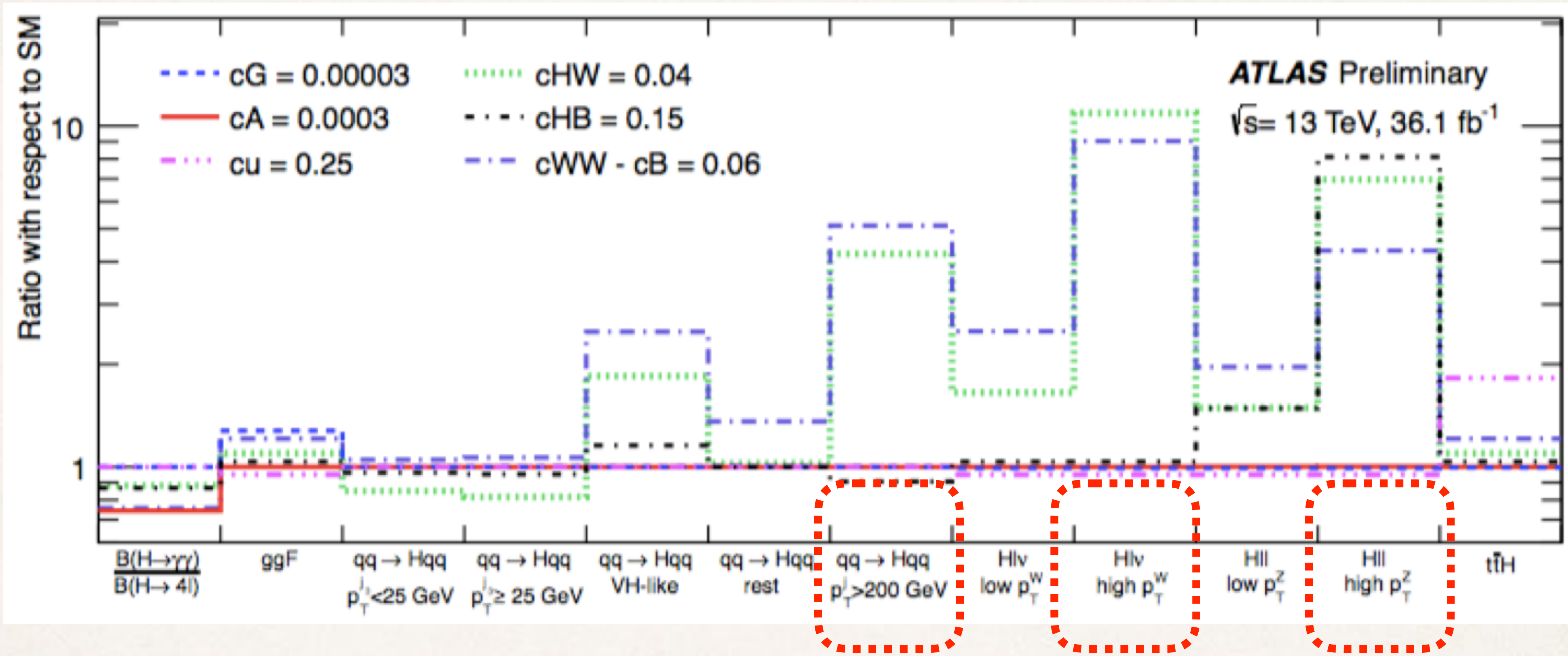
BUT EFT's extra parameters constrained by current measurements
Data can't favour SM yet

Theory	χ^2	χ^2/n_d	p-value
SM	157	0.987	0.532
SMEFT	137	0.987	0.528
SMEFT*	143	0.977	0.564



Combination of many channels is key—> GLOBAL FITS

3. *Extreme* kinematics



In these regions our theoretical/experimental understanding is weaker

e.g. WW at high-pT (large EW corrections)

e.g. Higgs+jet at high-pTH

and the **EFT validity** needs to be taken into account

This problem can be addressed by working harder

Many of us developing MC tools EFT@NLO and dim-8 effects

To tackle the SMEFT complexity
and reach the level of discovery
we need better, more precise measurements
and tools to compare with them

Now, to Sebastian!
Global Fits

SMEFT - the new Standard Model

Part II: Global Fits, an Introduction

UNIVERSITÄT
HEIDELBERG
ZUKUNFT
SEIT 1386

KITP - Precision21
23.03.2021

SFitter

Sebastian
Bruggisser

Why Global Fits?

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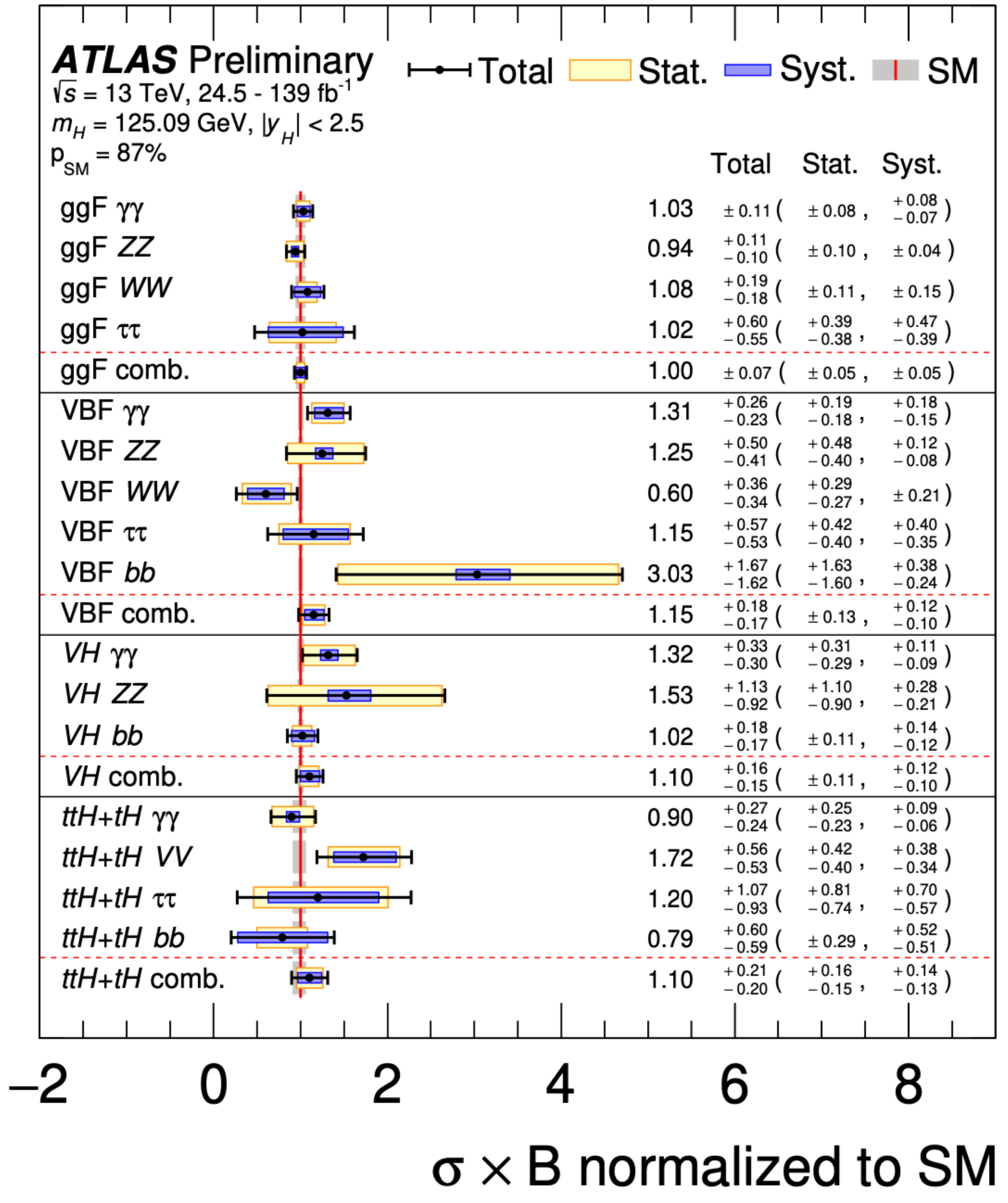
ATLAS-CONF-2020-027



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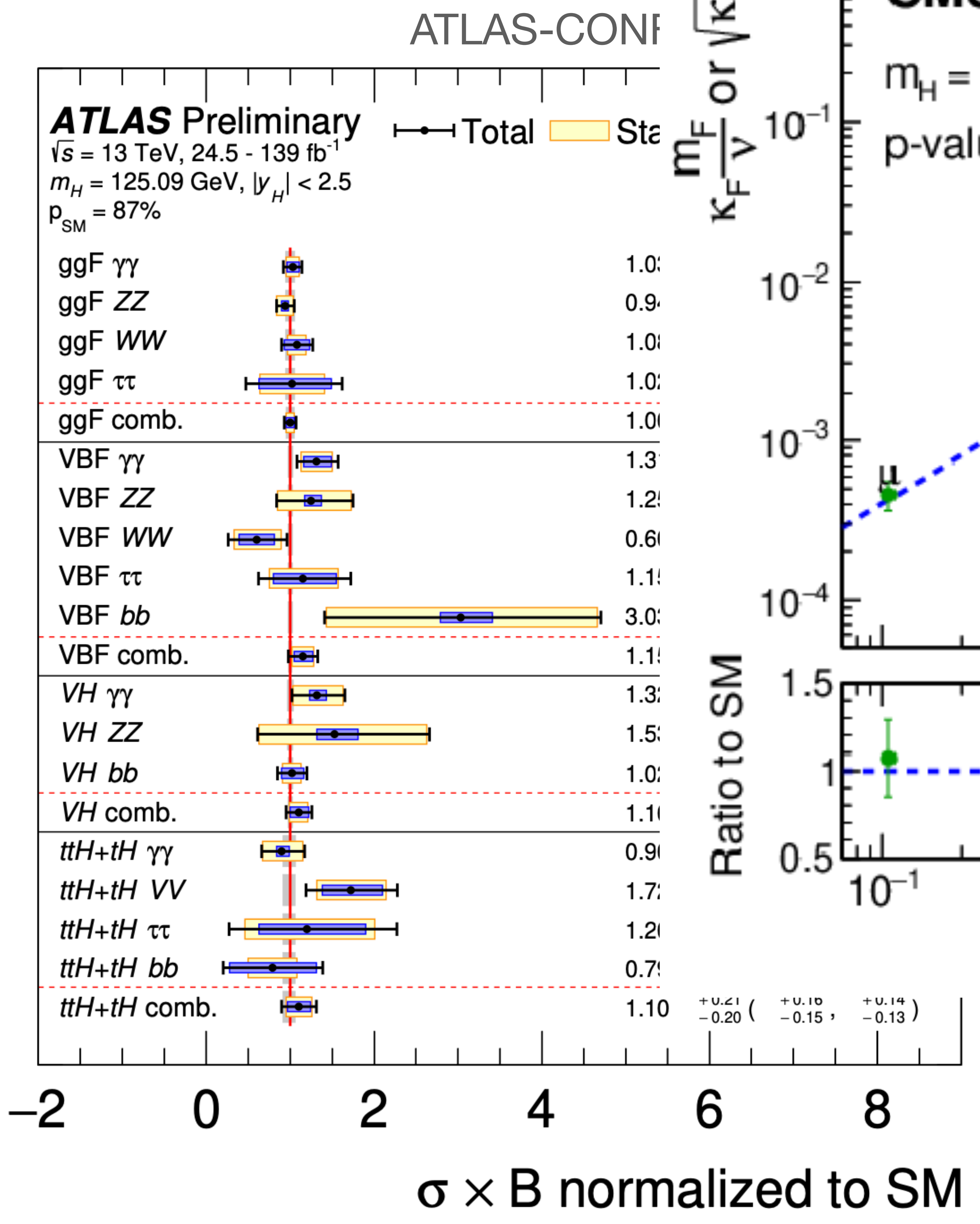

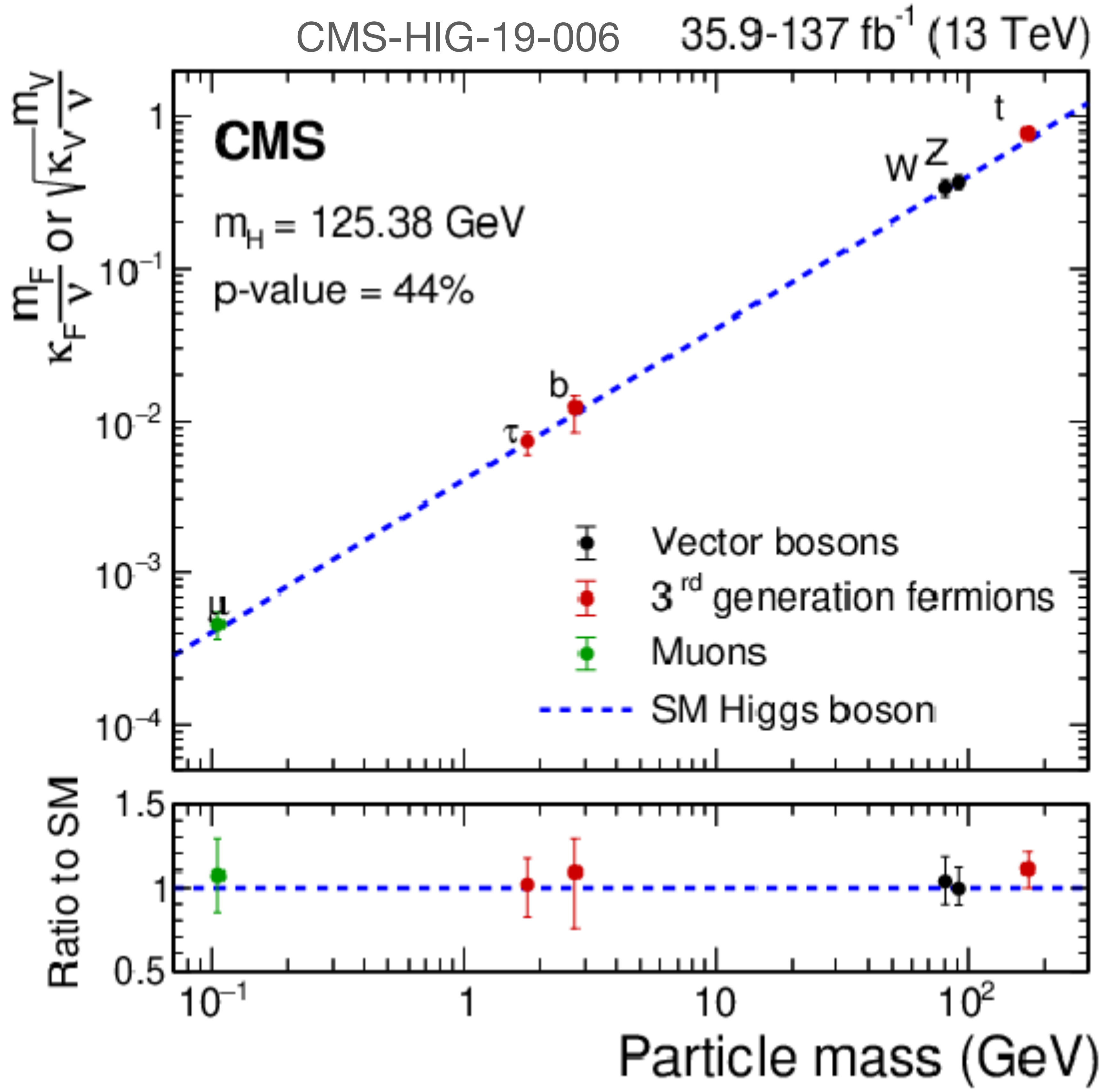

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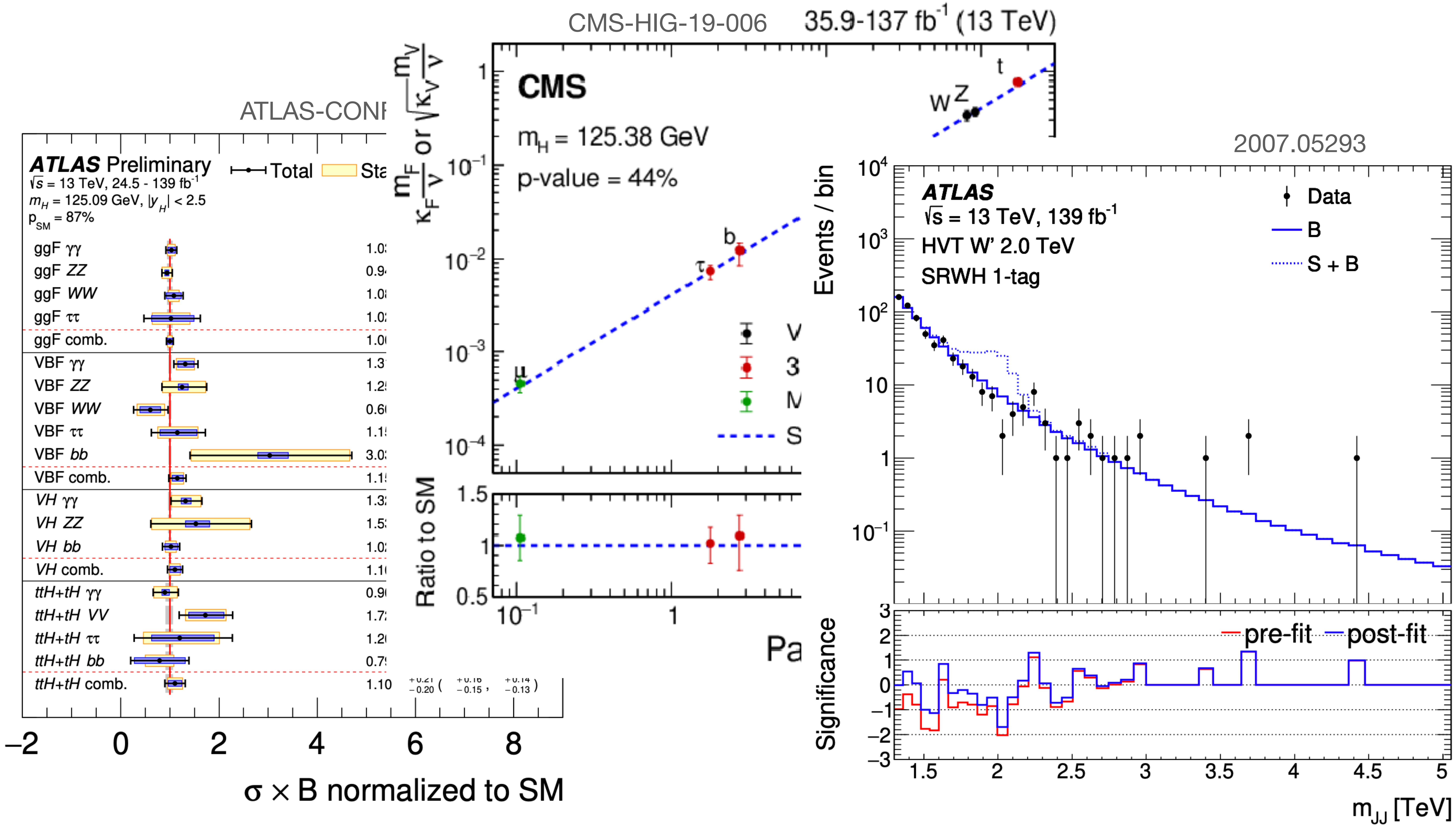

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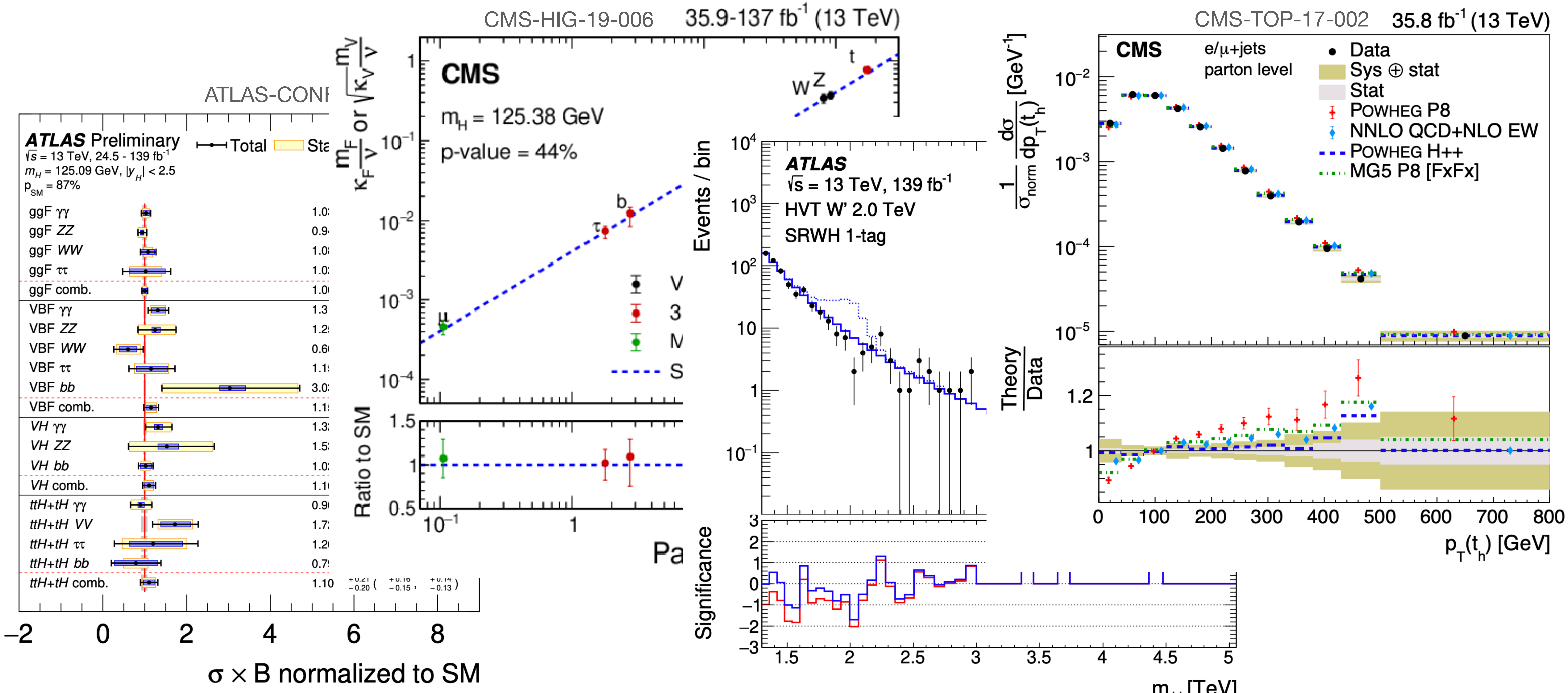

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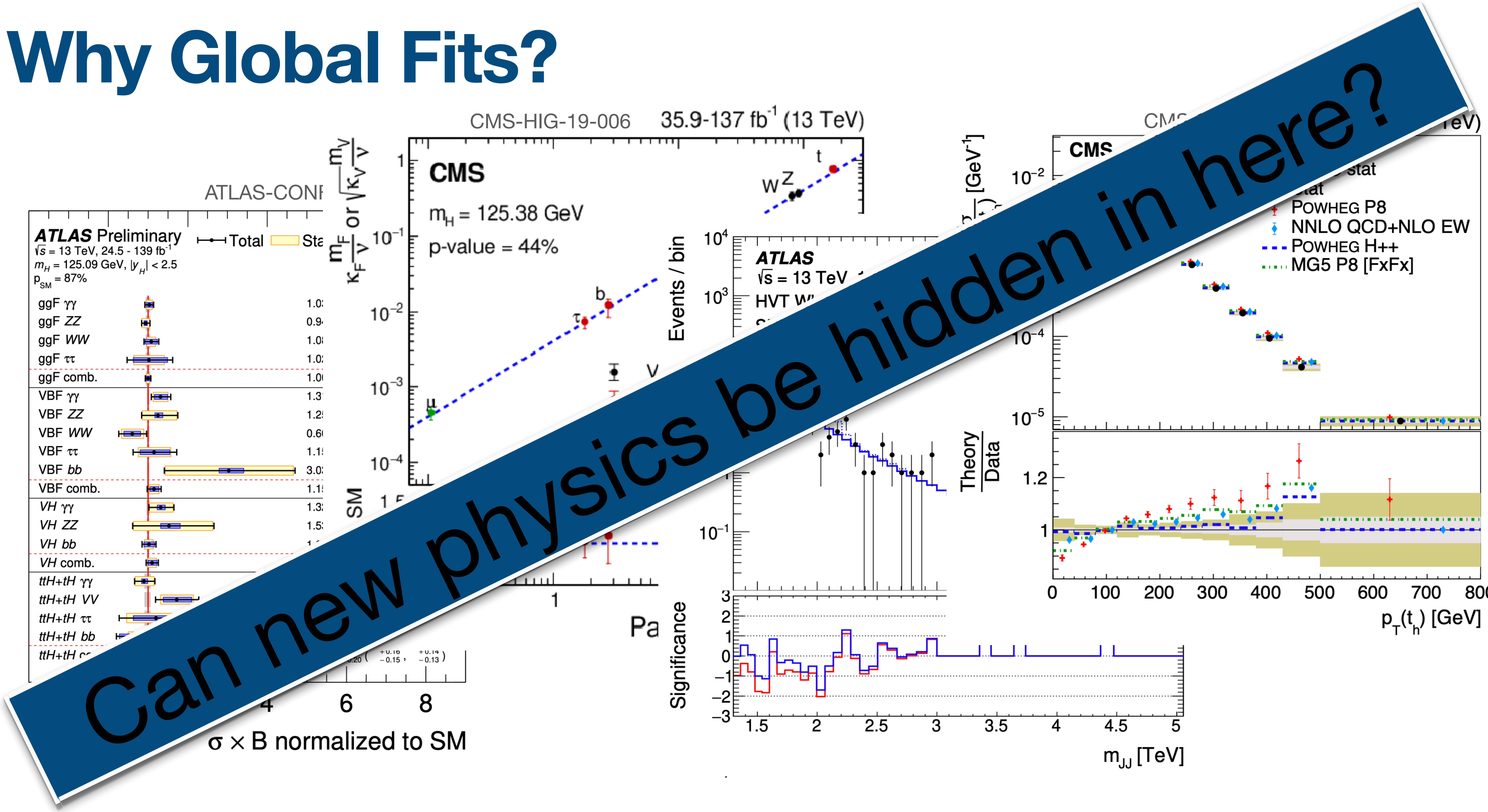

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  - SMEFT
    - Basis
    - Flavour
    - Order
    - etc.

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Construct Likelihood

- Toy Monte Carlo
- Markov Chains
- Analytical
- ...

Extract limits

Toy MC

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$$\mu_2 = 93 + 3(c_1 - c_2)$$

Predictions

$$\mu_{1/2}^{exp} = 100 \pm 10$$

Measurements

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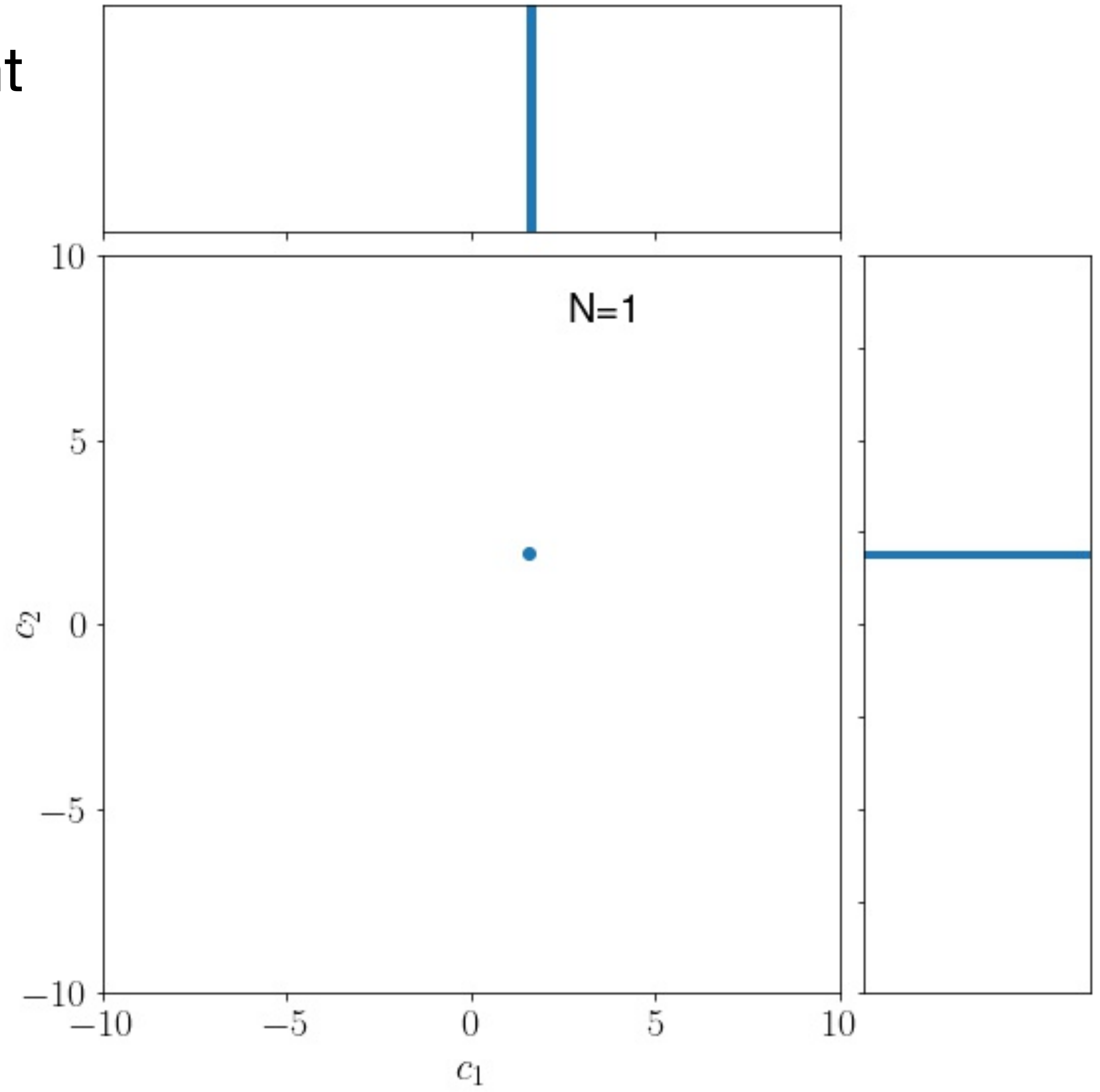

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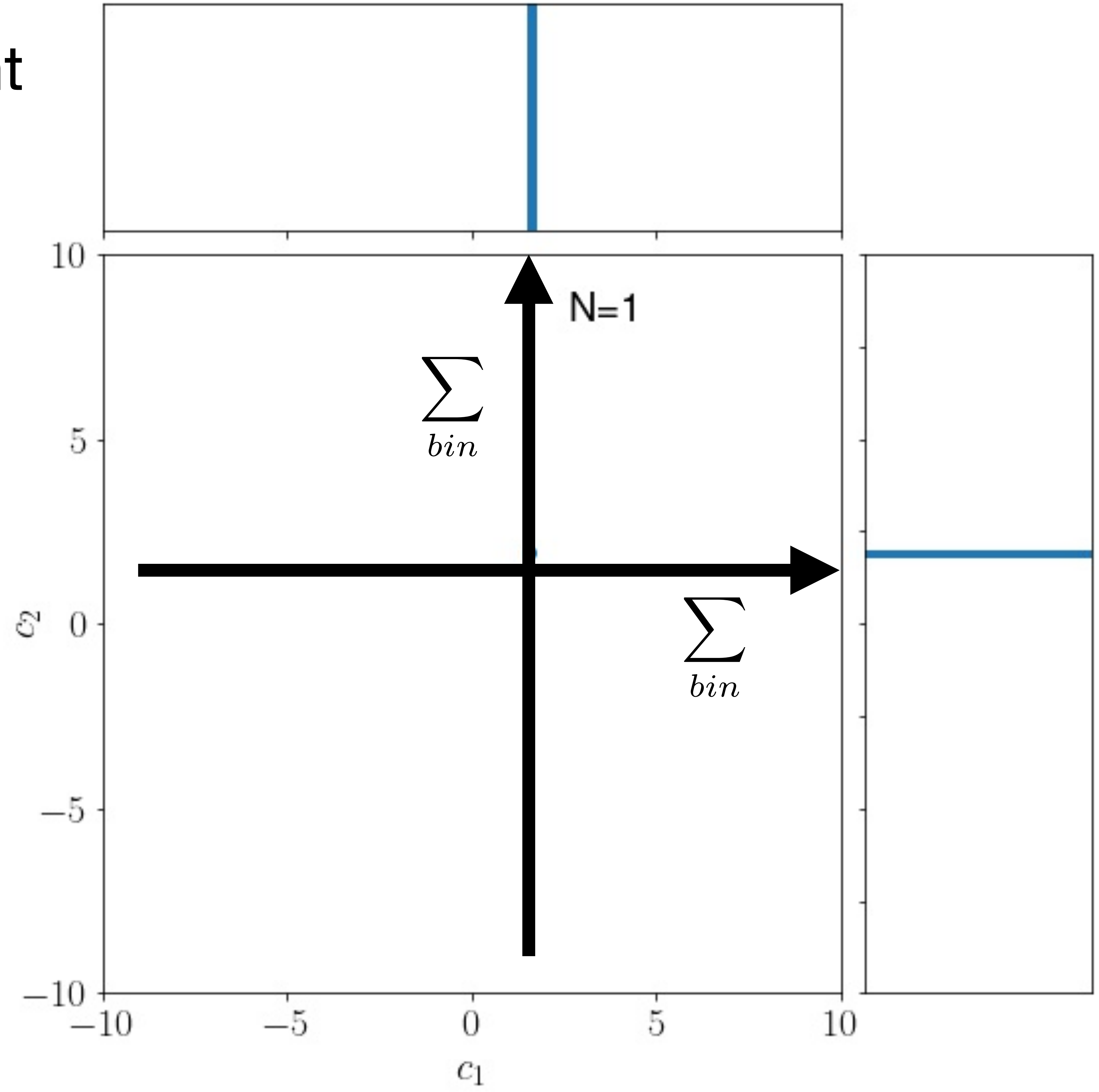

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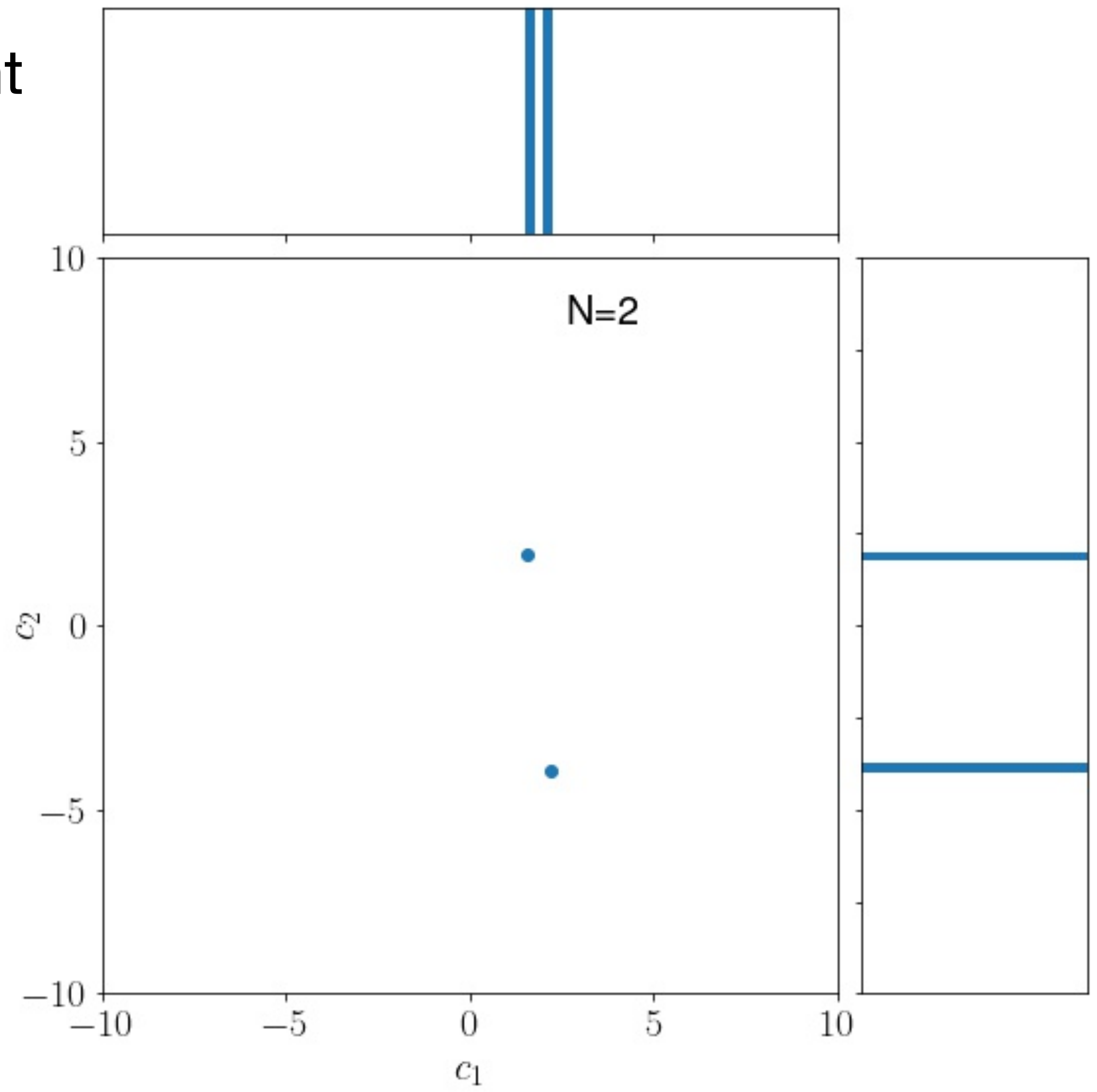

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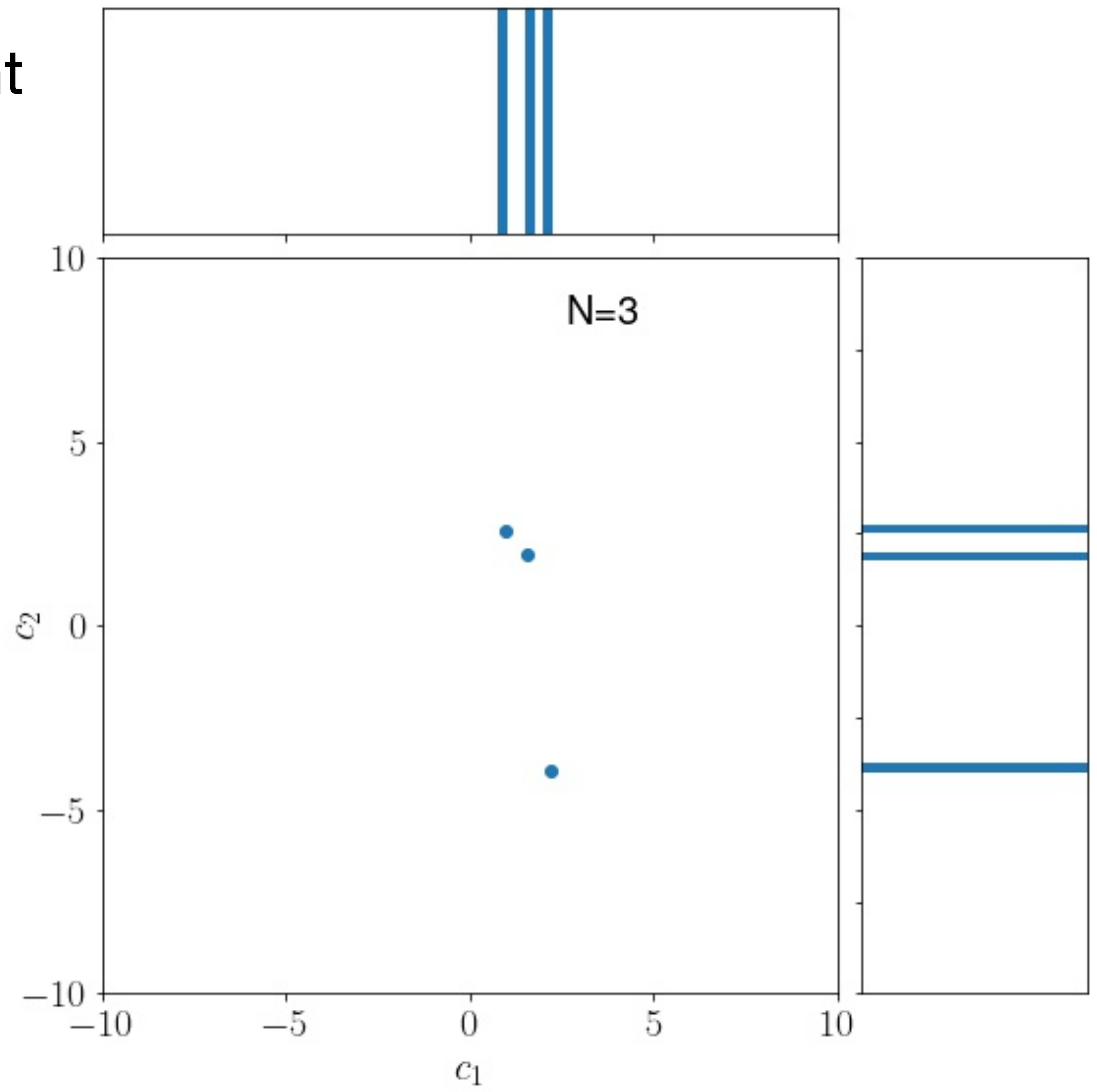

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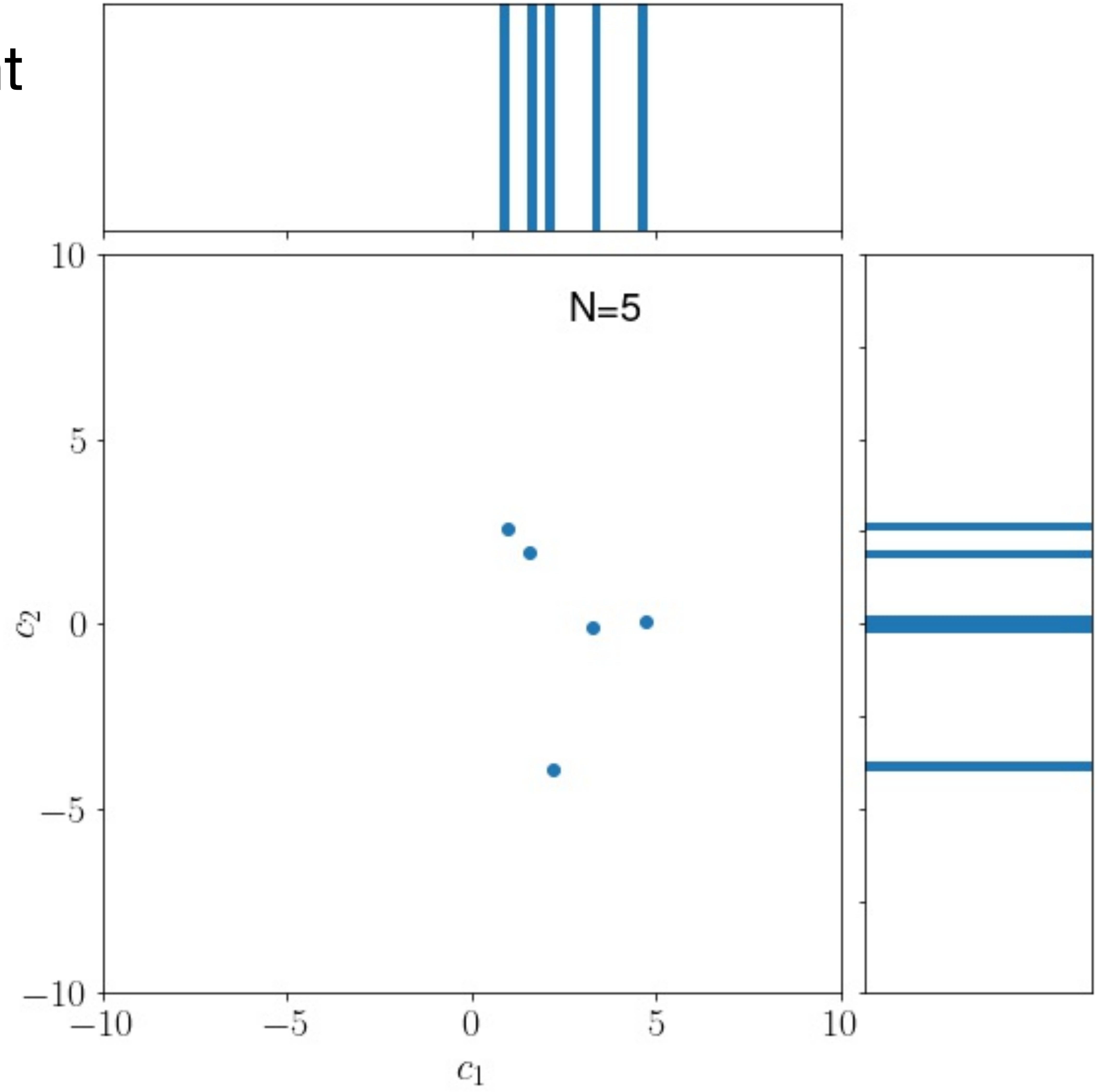

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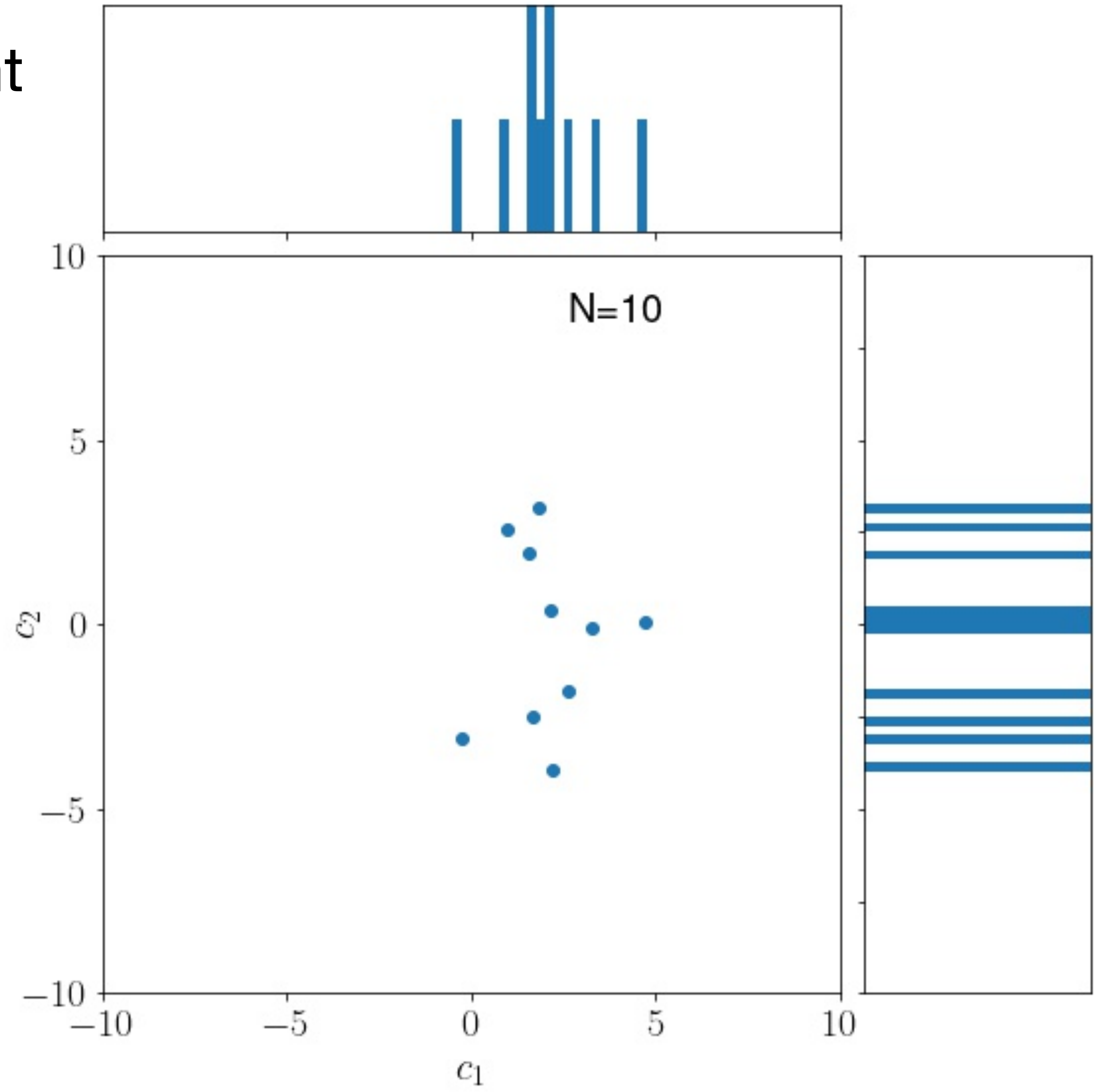

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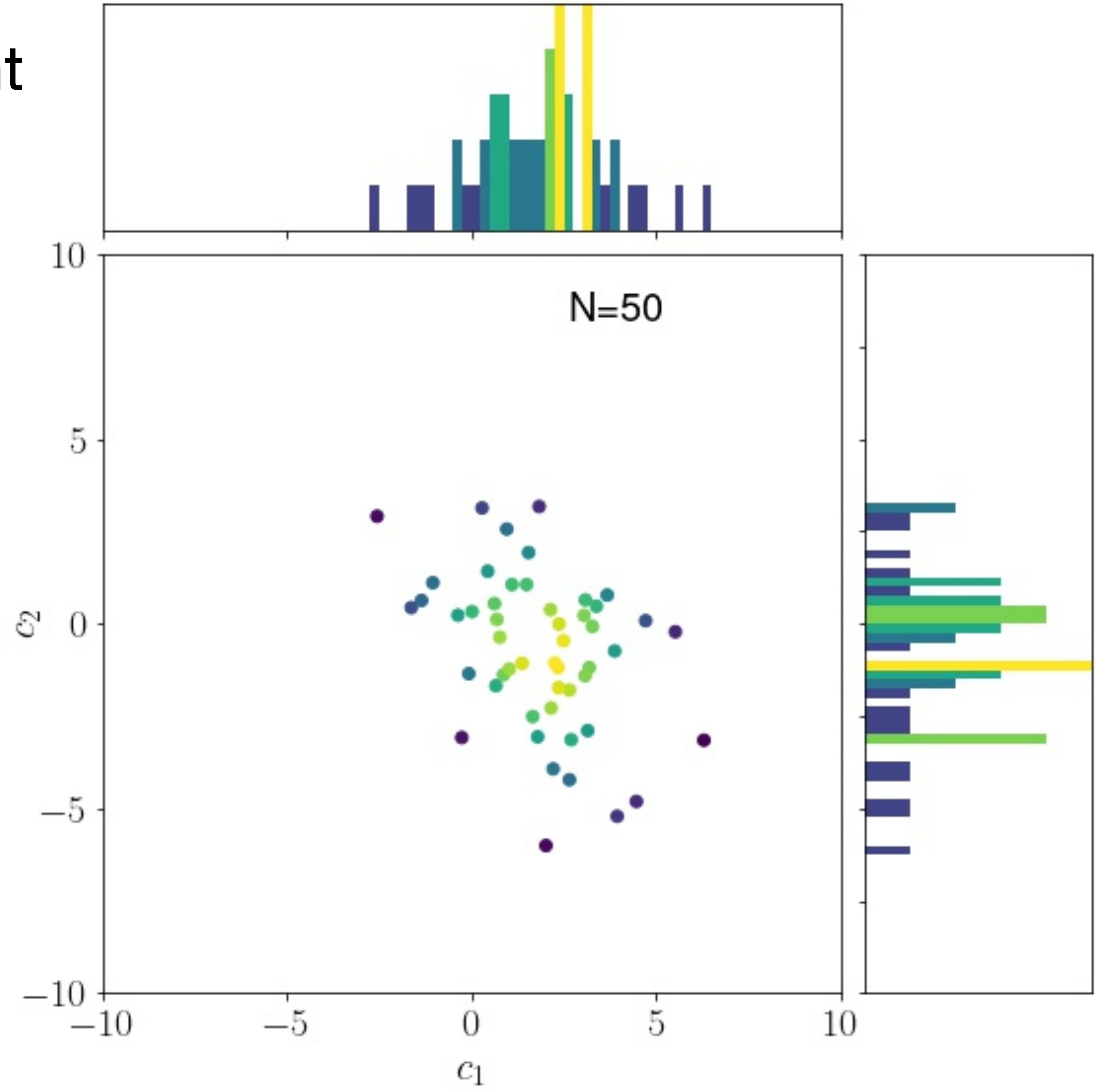

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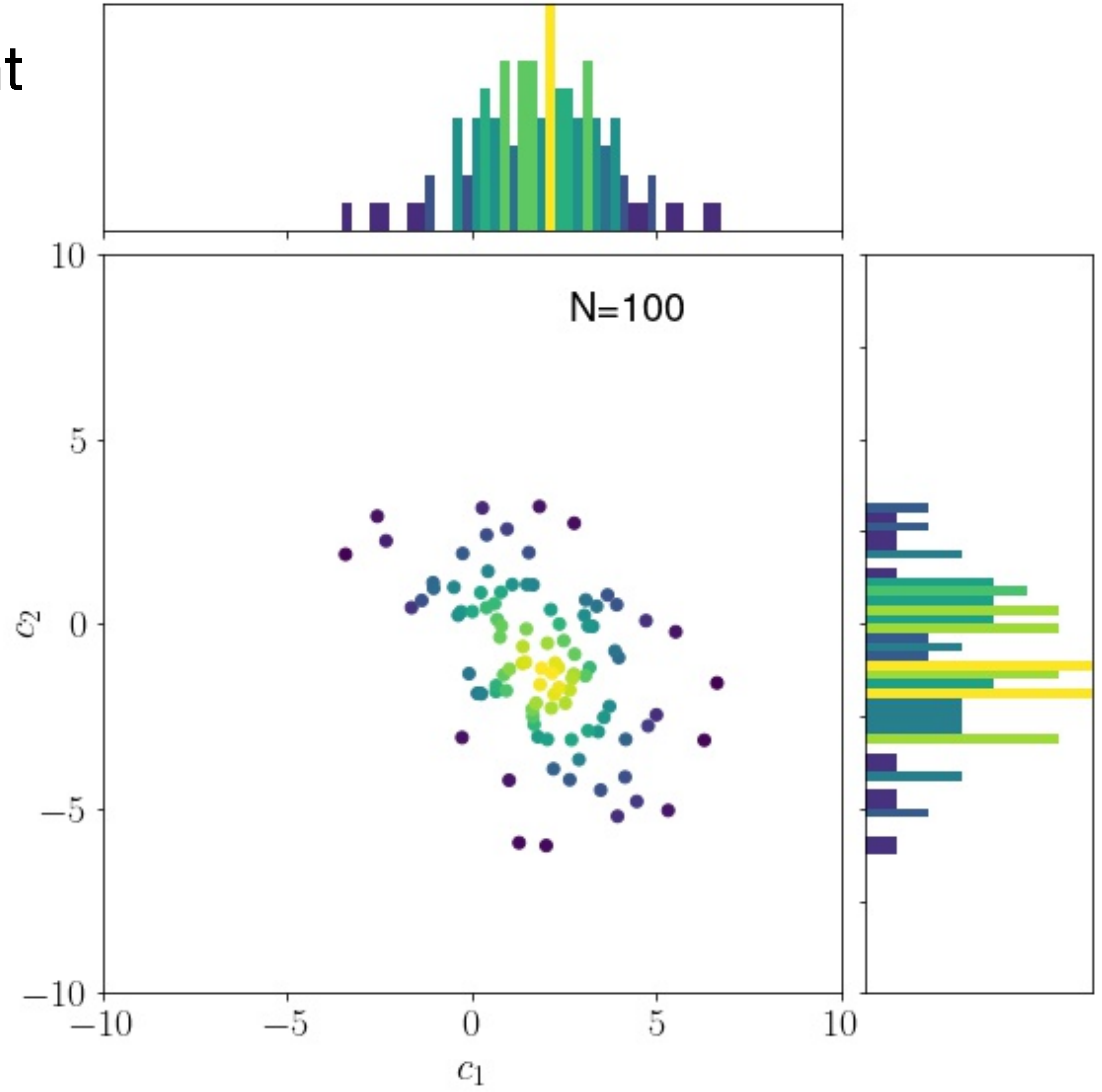

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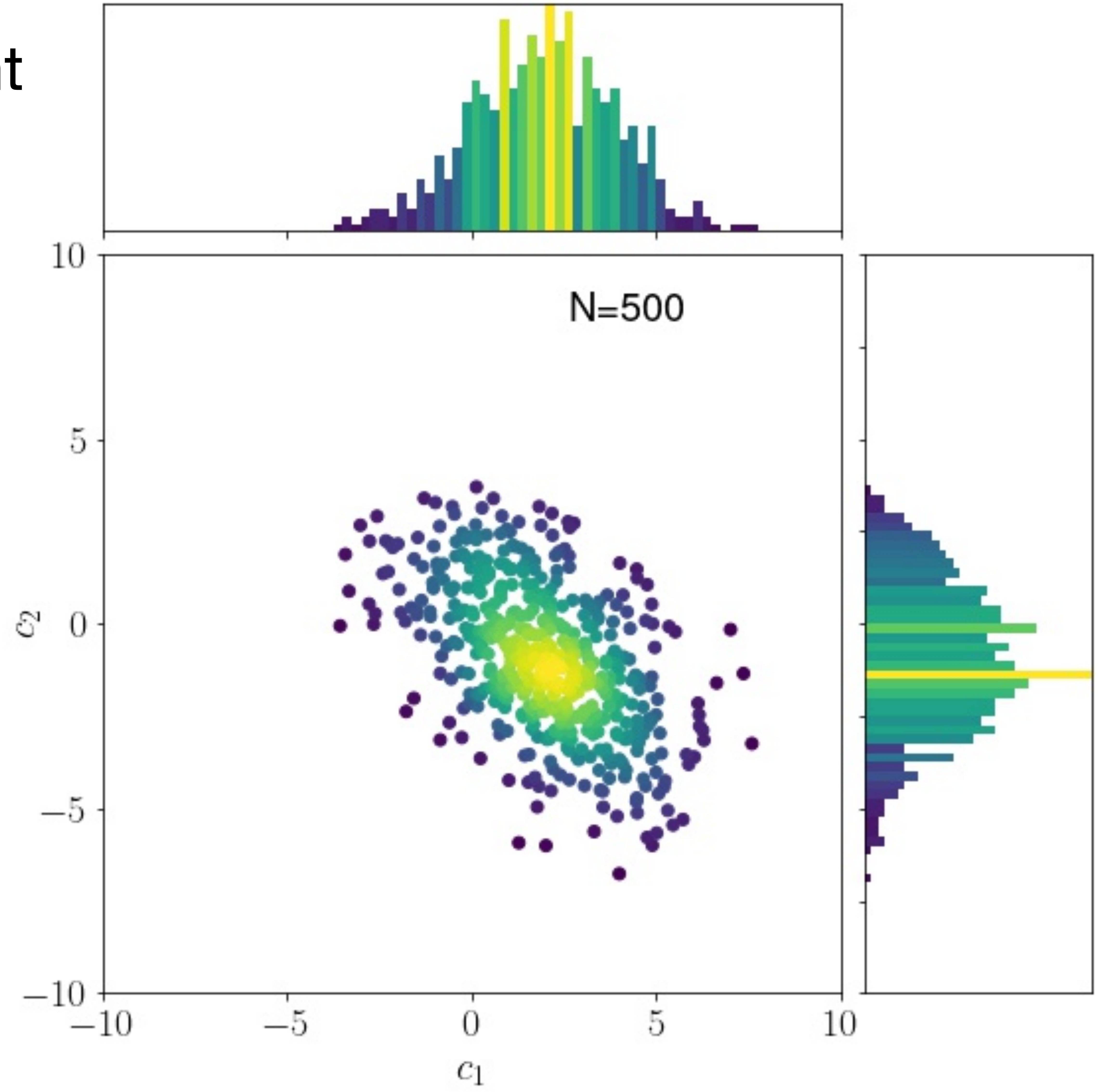

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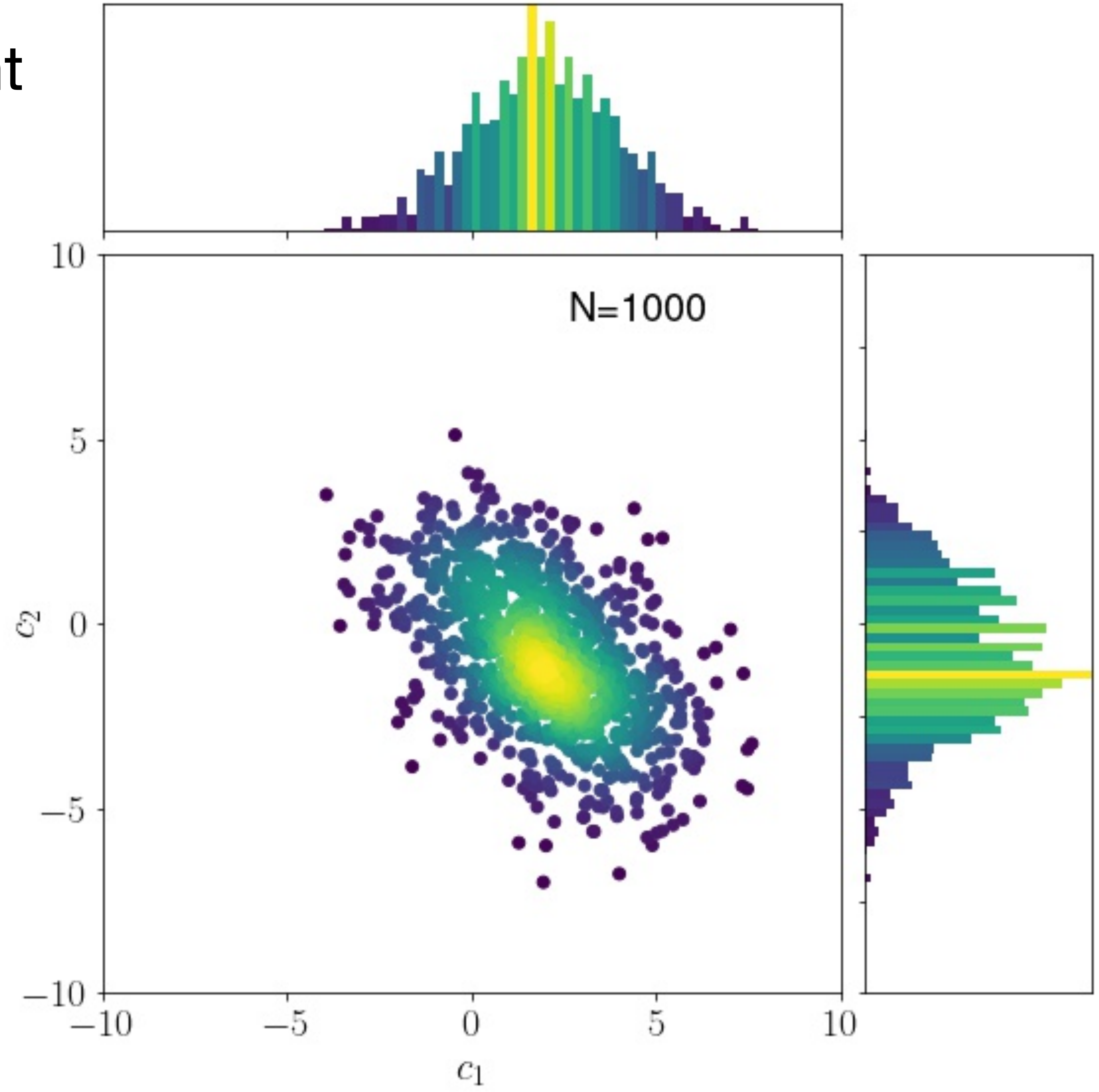

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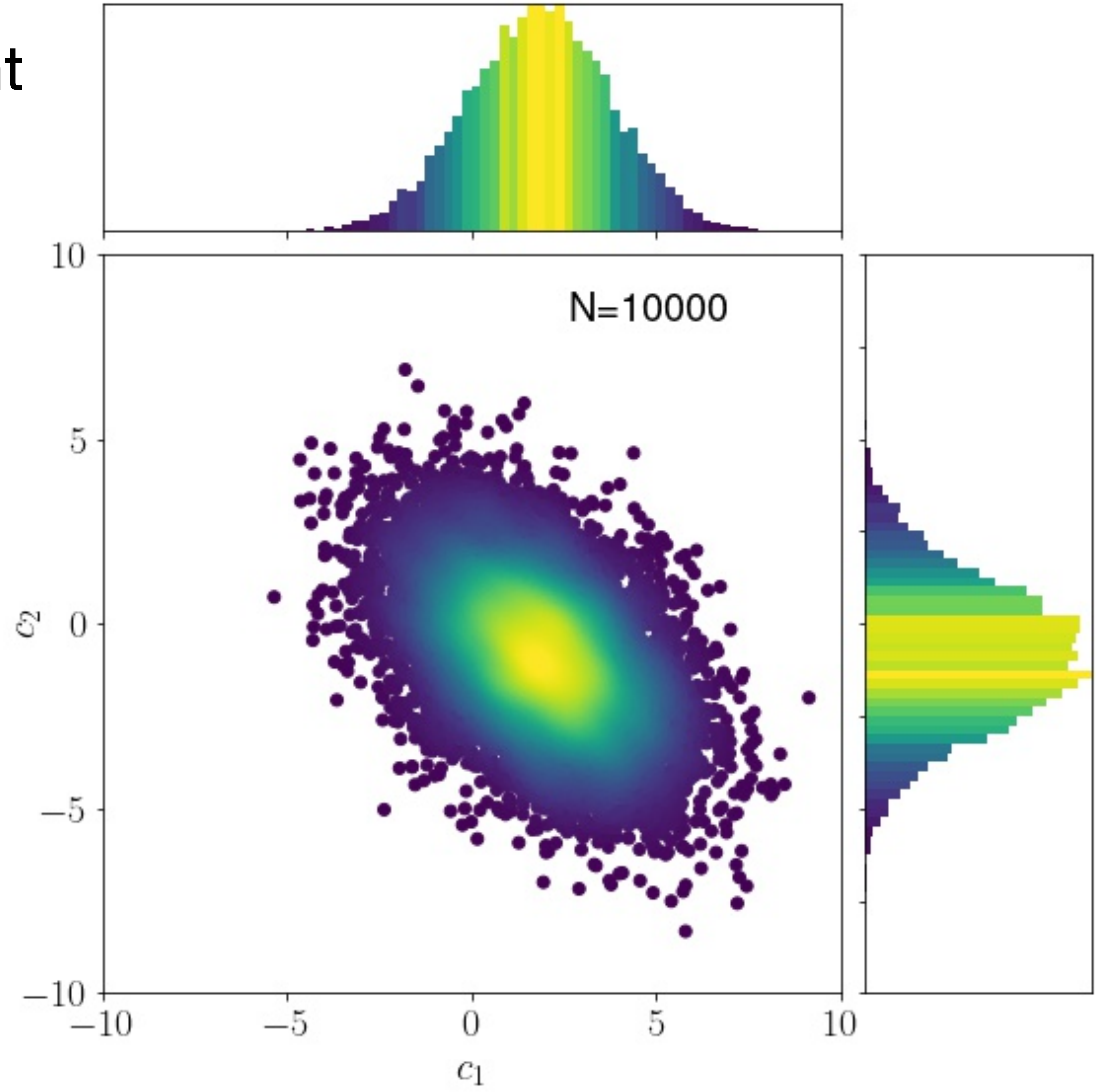

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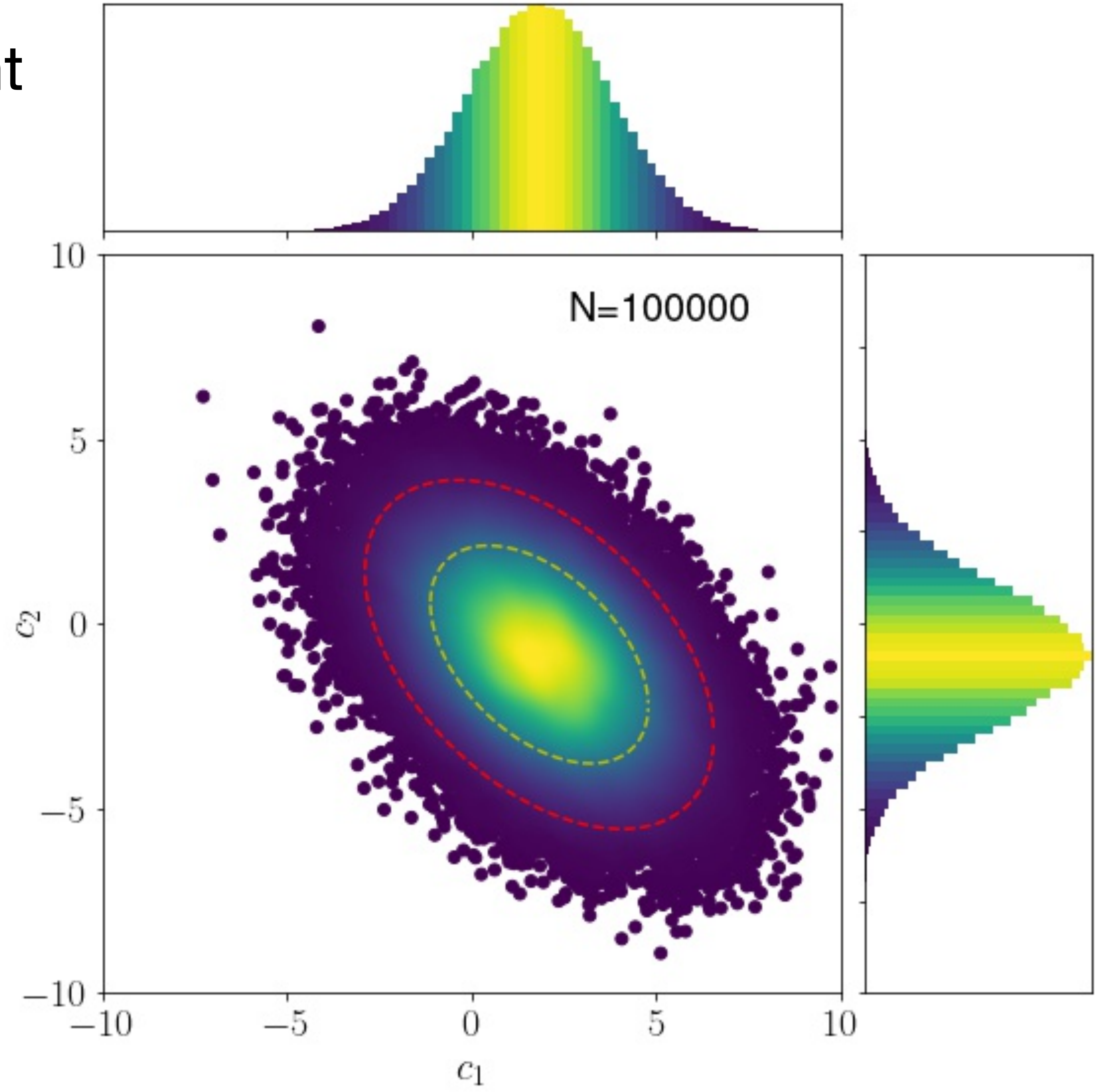
$$\mu_1 = 105 - 5(c_1 + c_2)$$

$$\mu_2 = 93 + 3(c_1 - c_2)$$

Predictions

$$\mu_{1/2}^{exp} = 100 \pm 10$$

Measurements



Markov Chains

Metropolis-Hastings

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- Start at random point x_i

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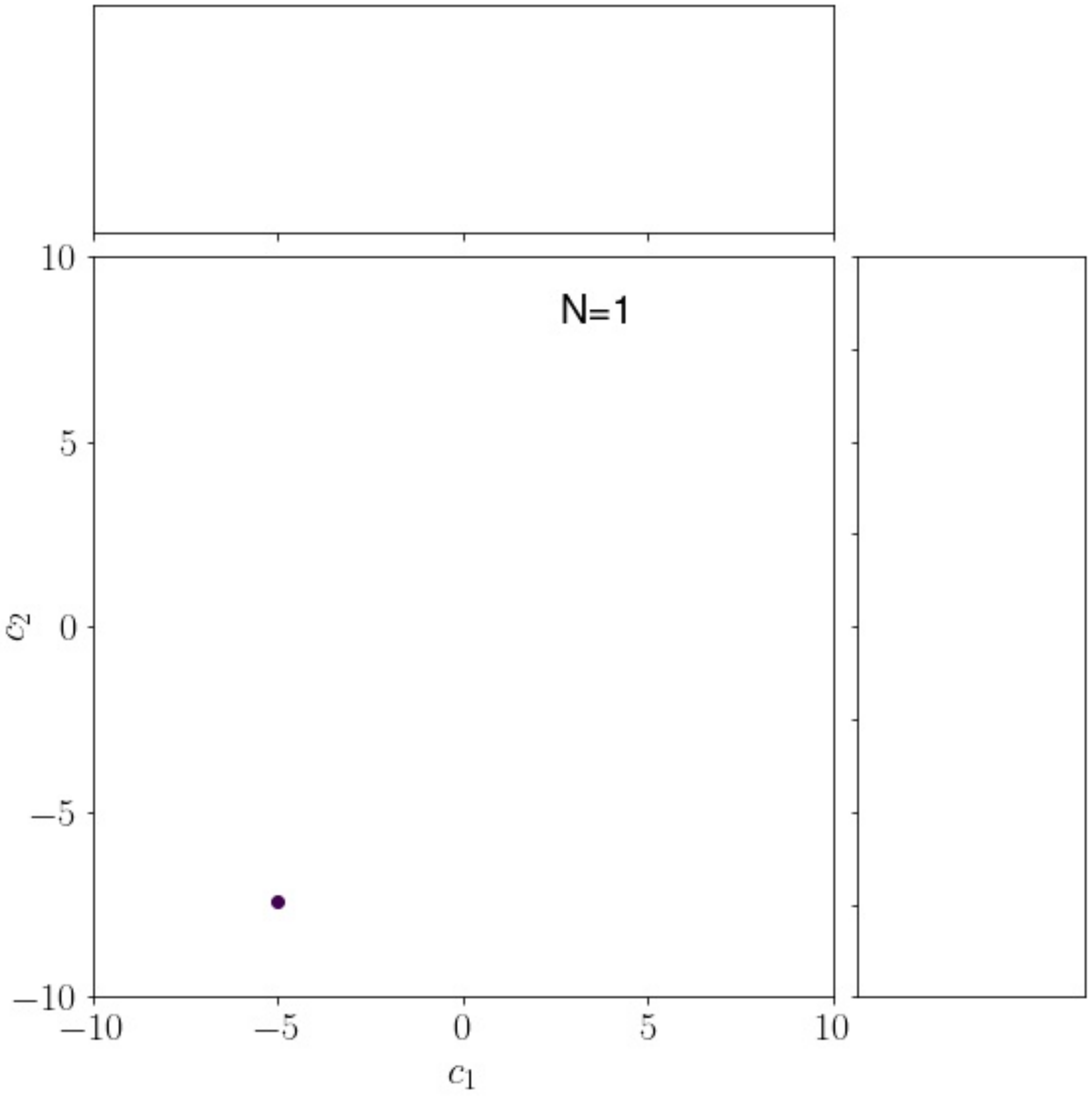

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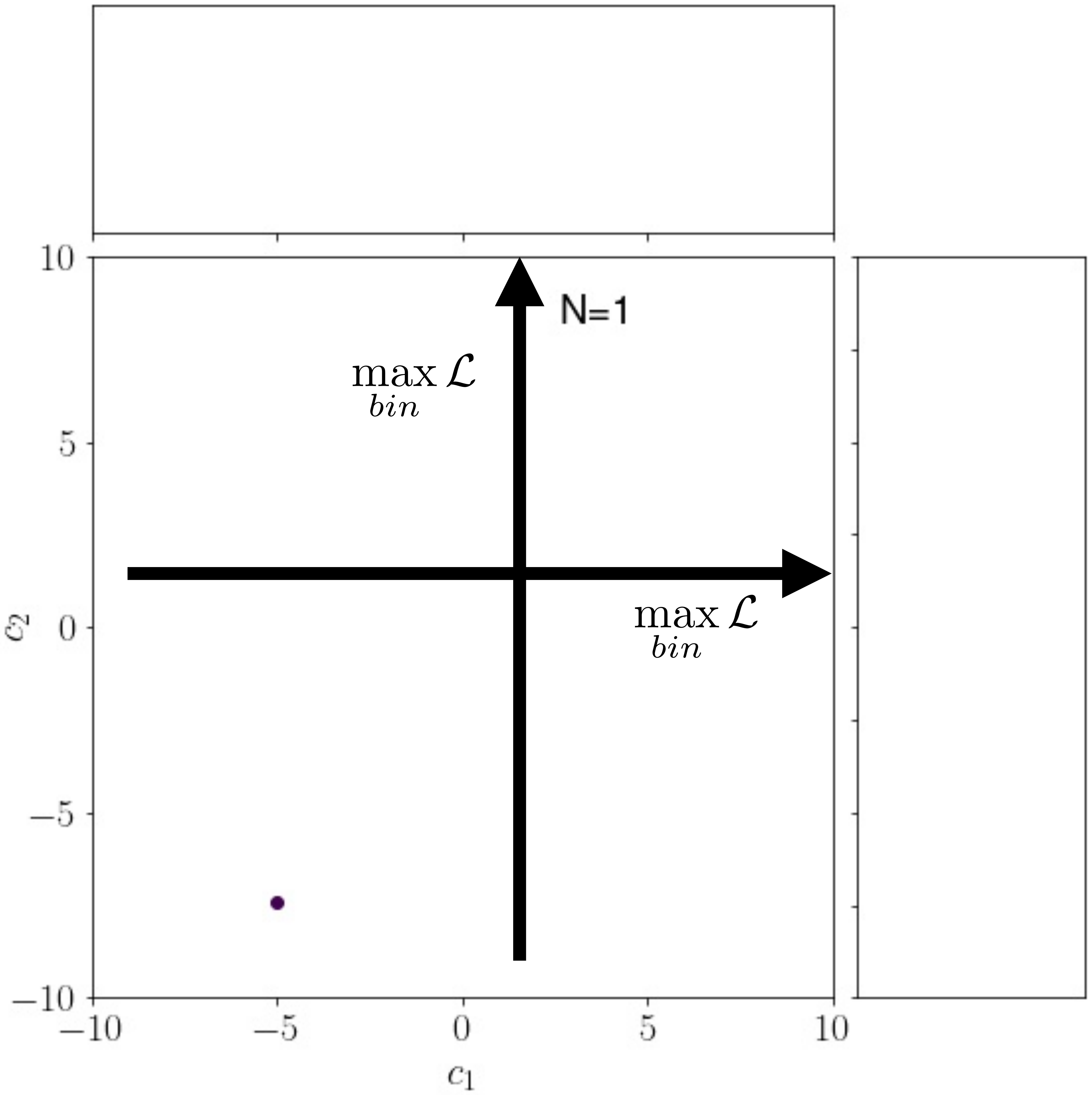

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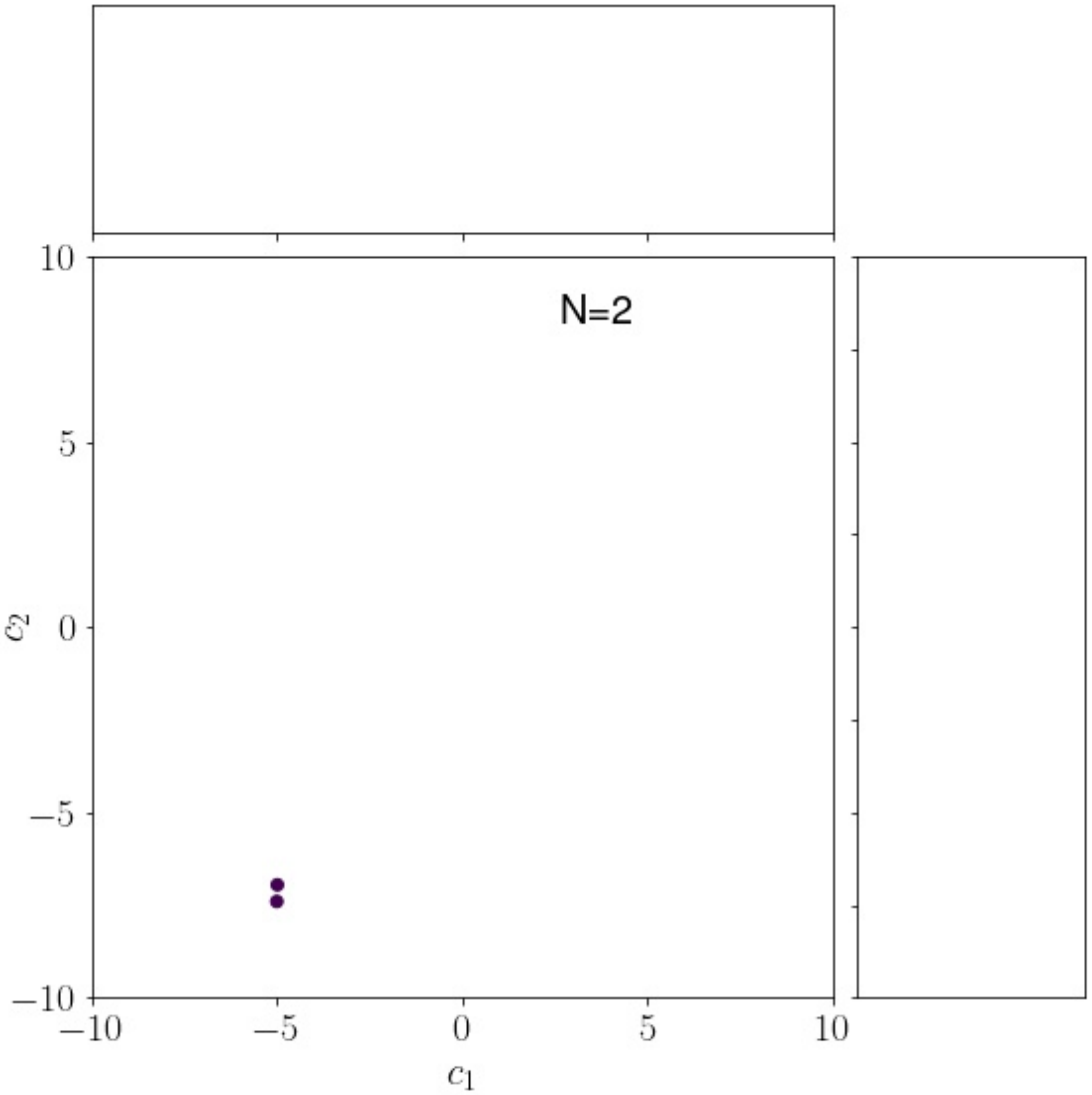

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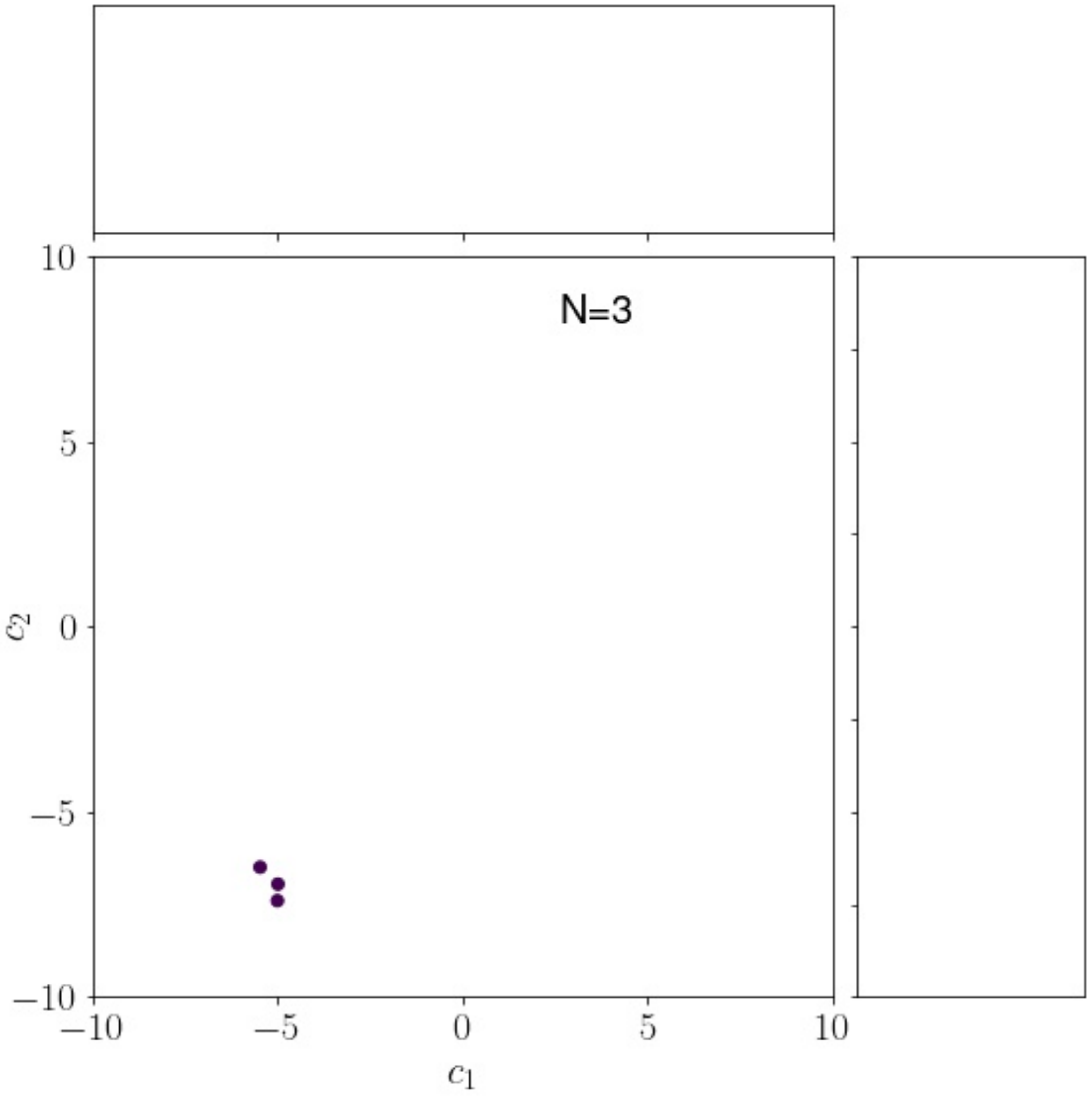

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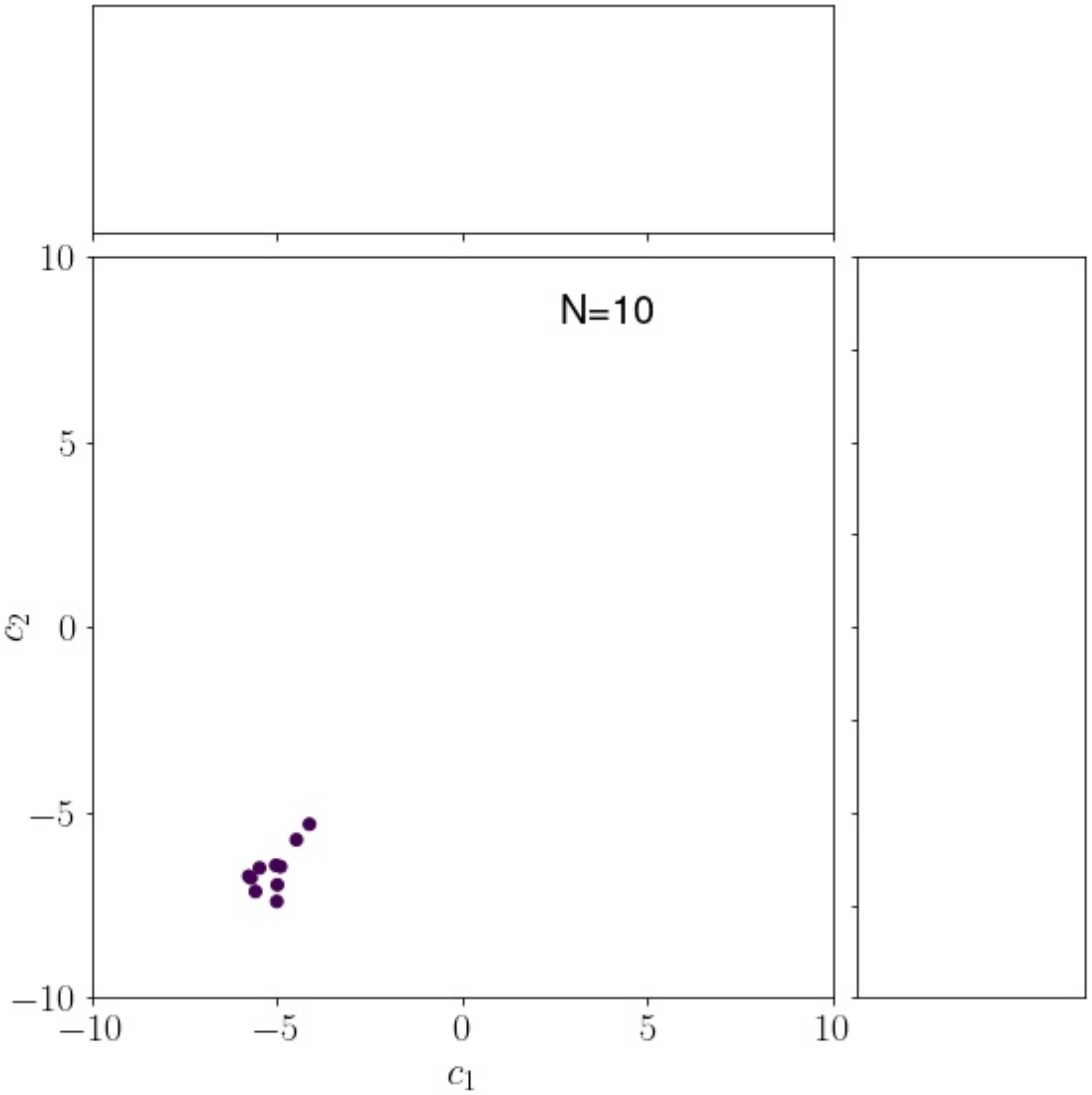

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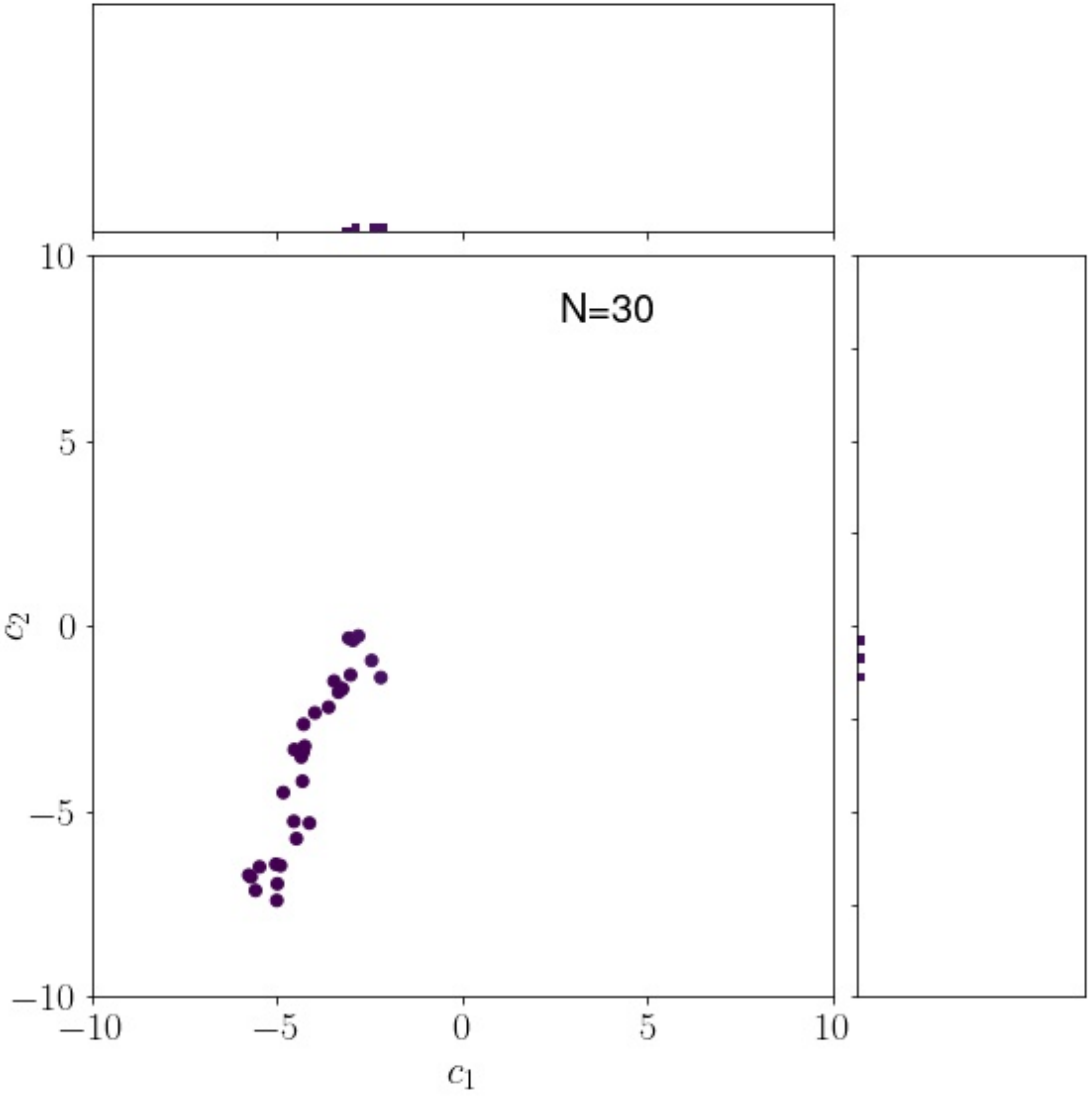

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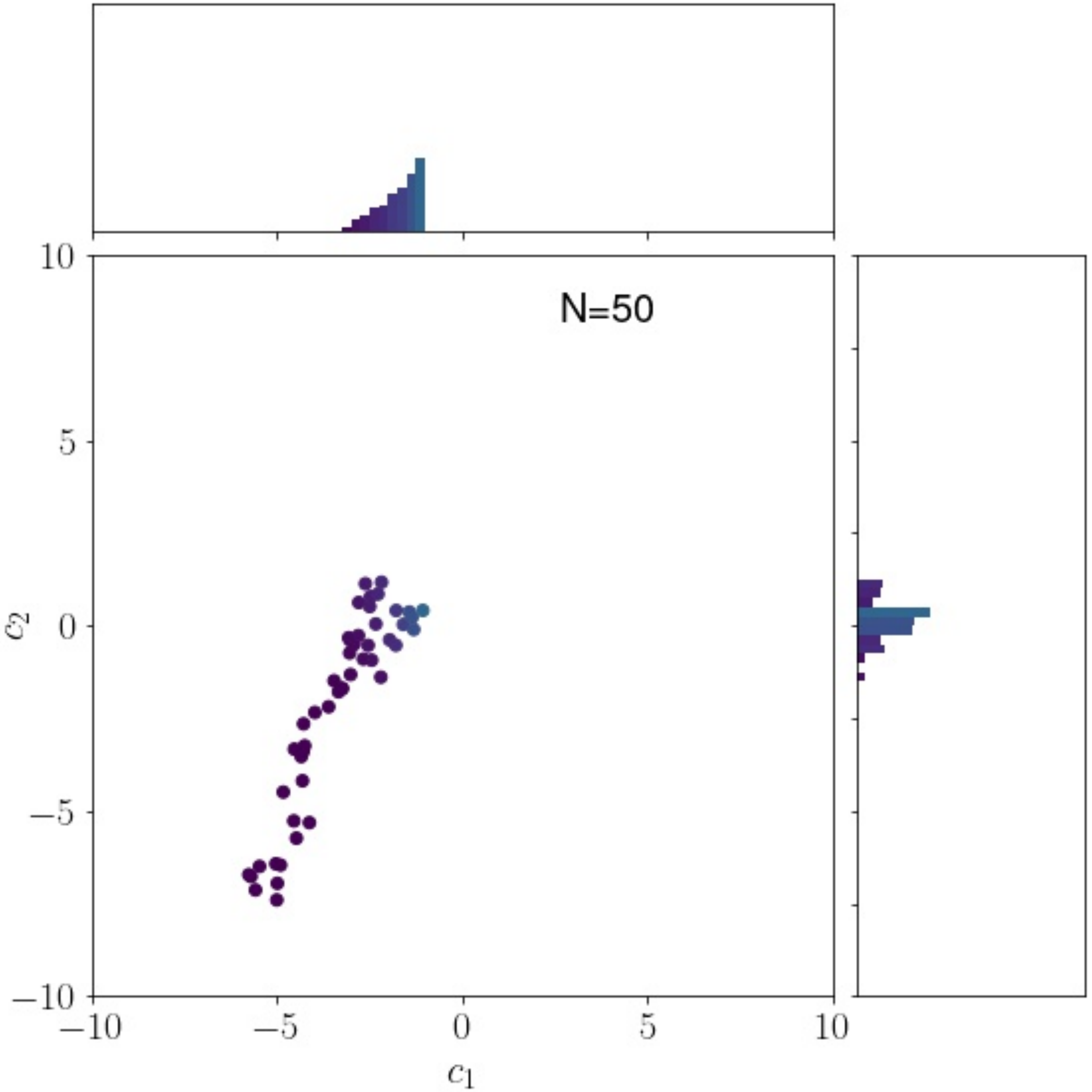

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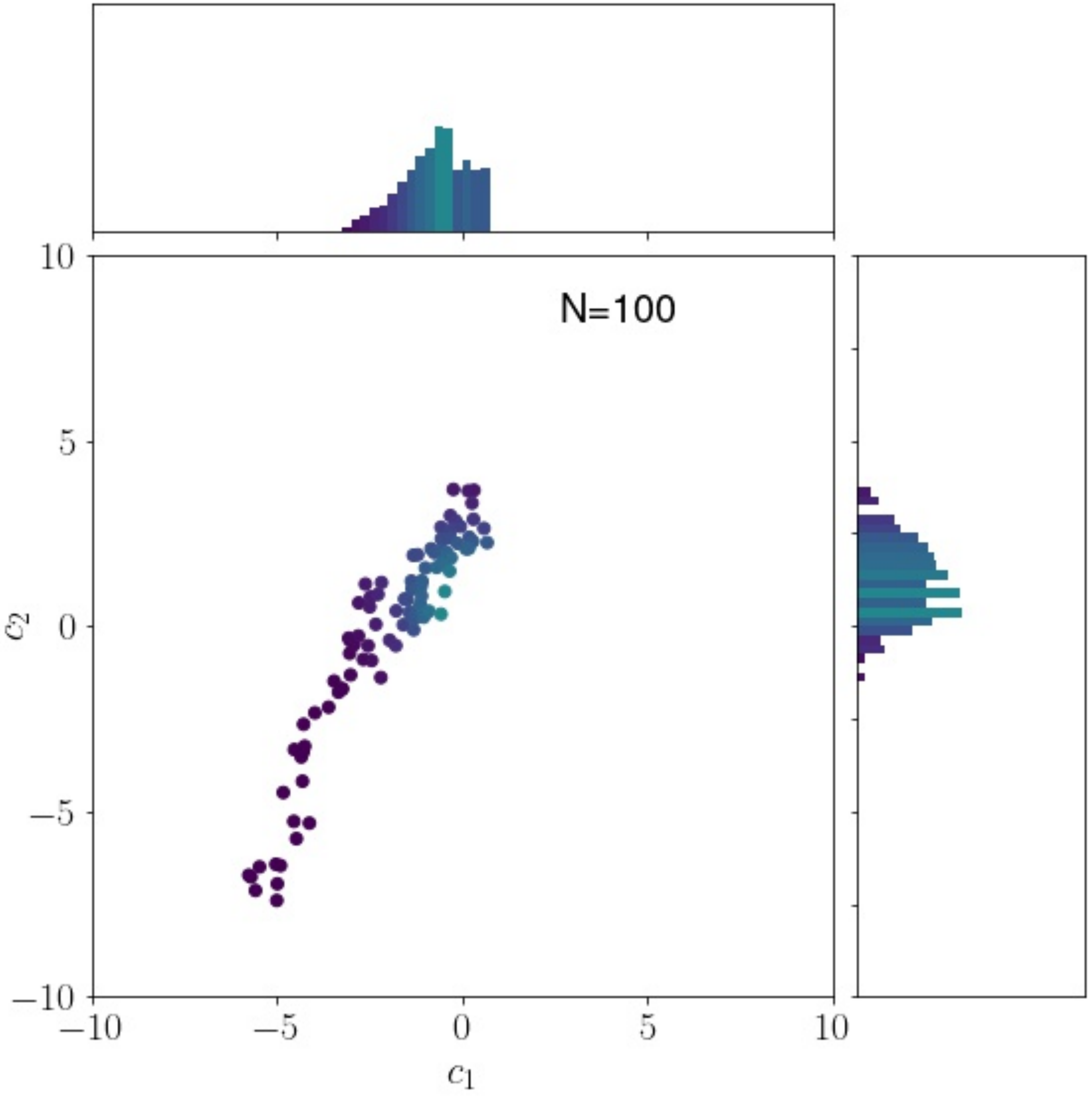

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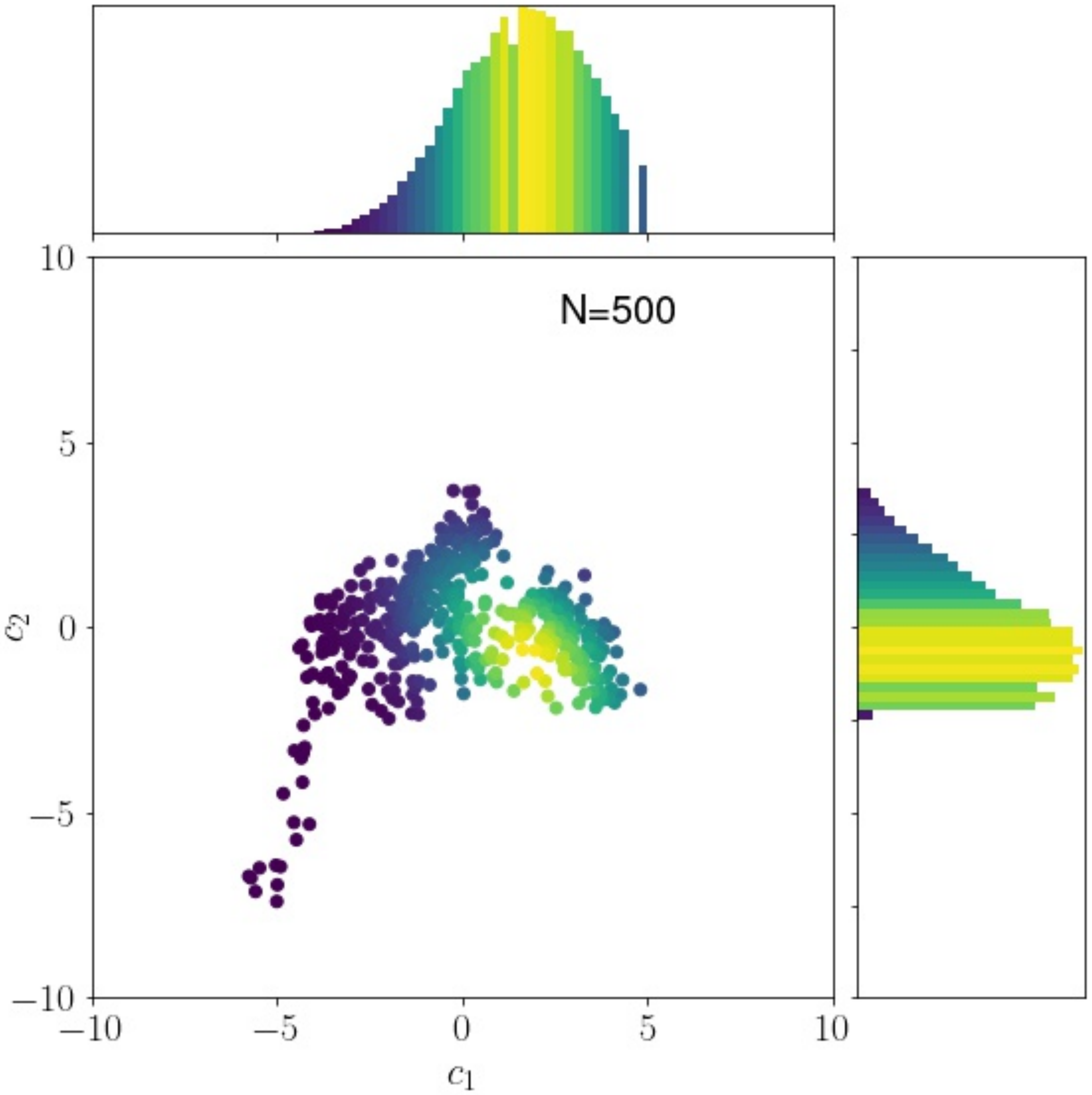

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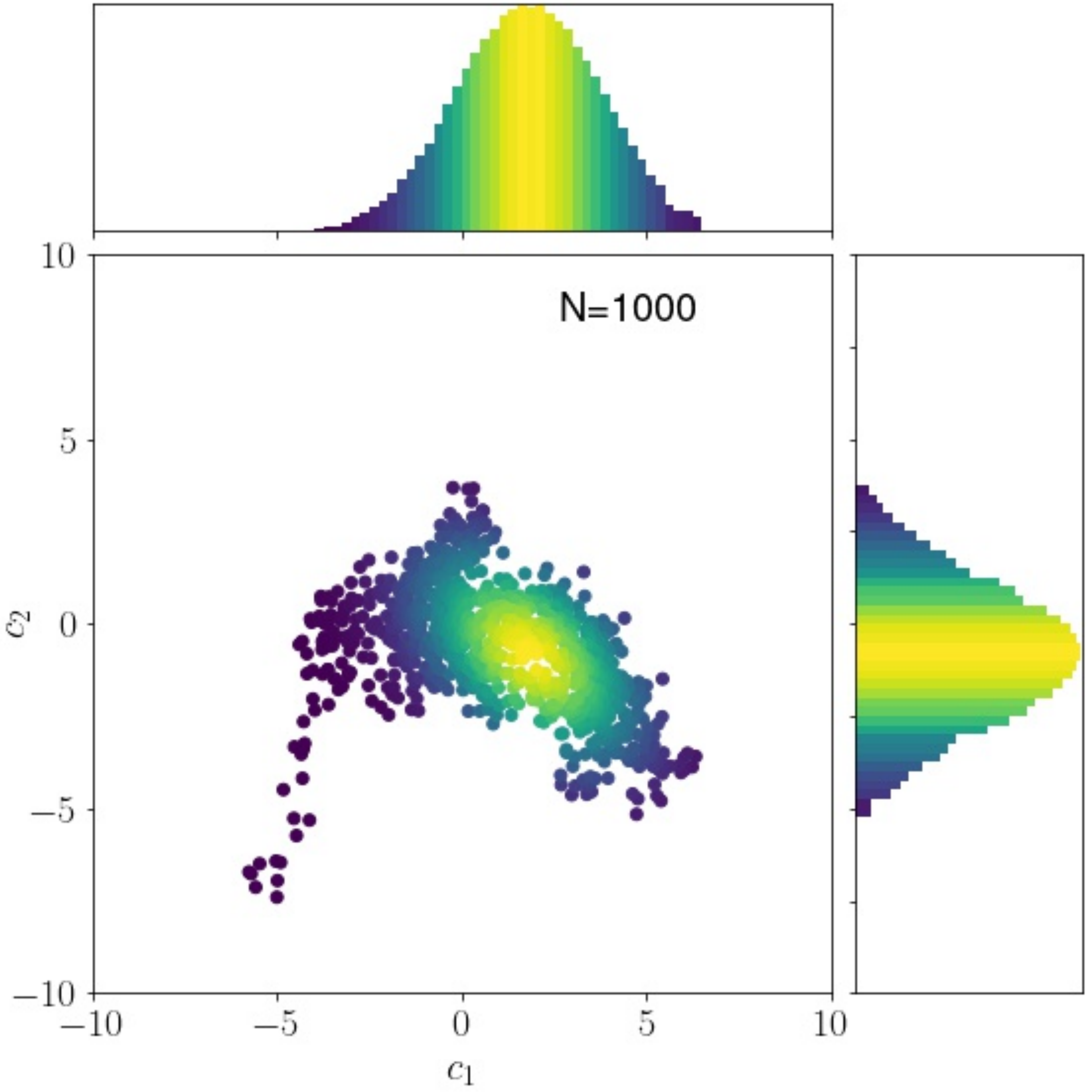

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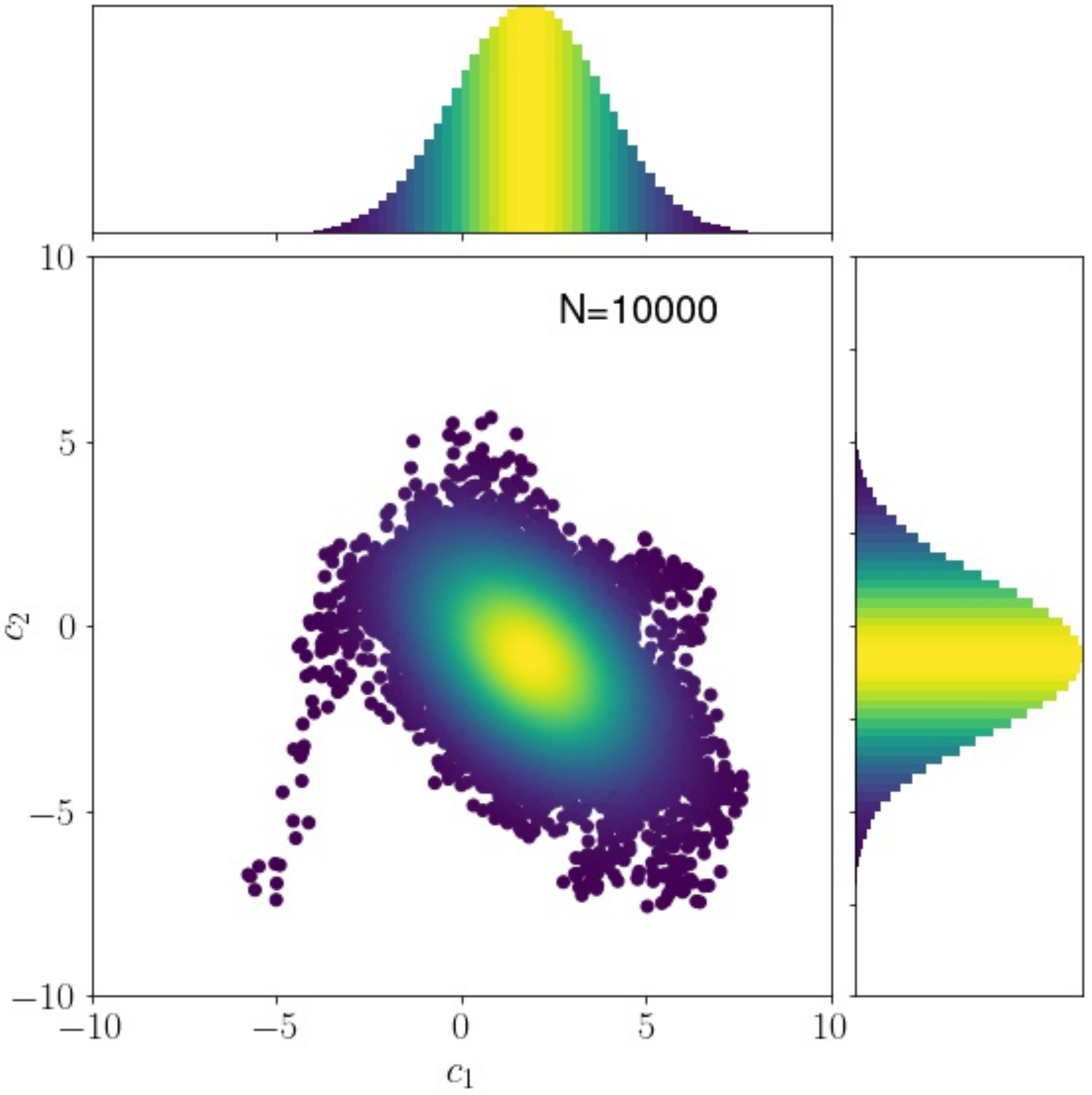

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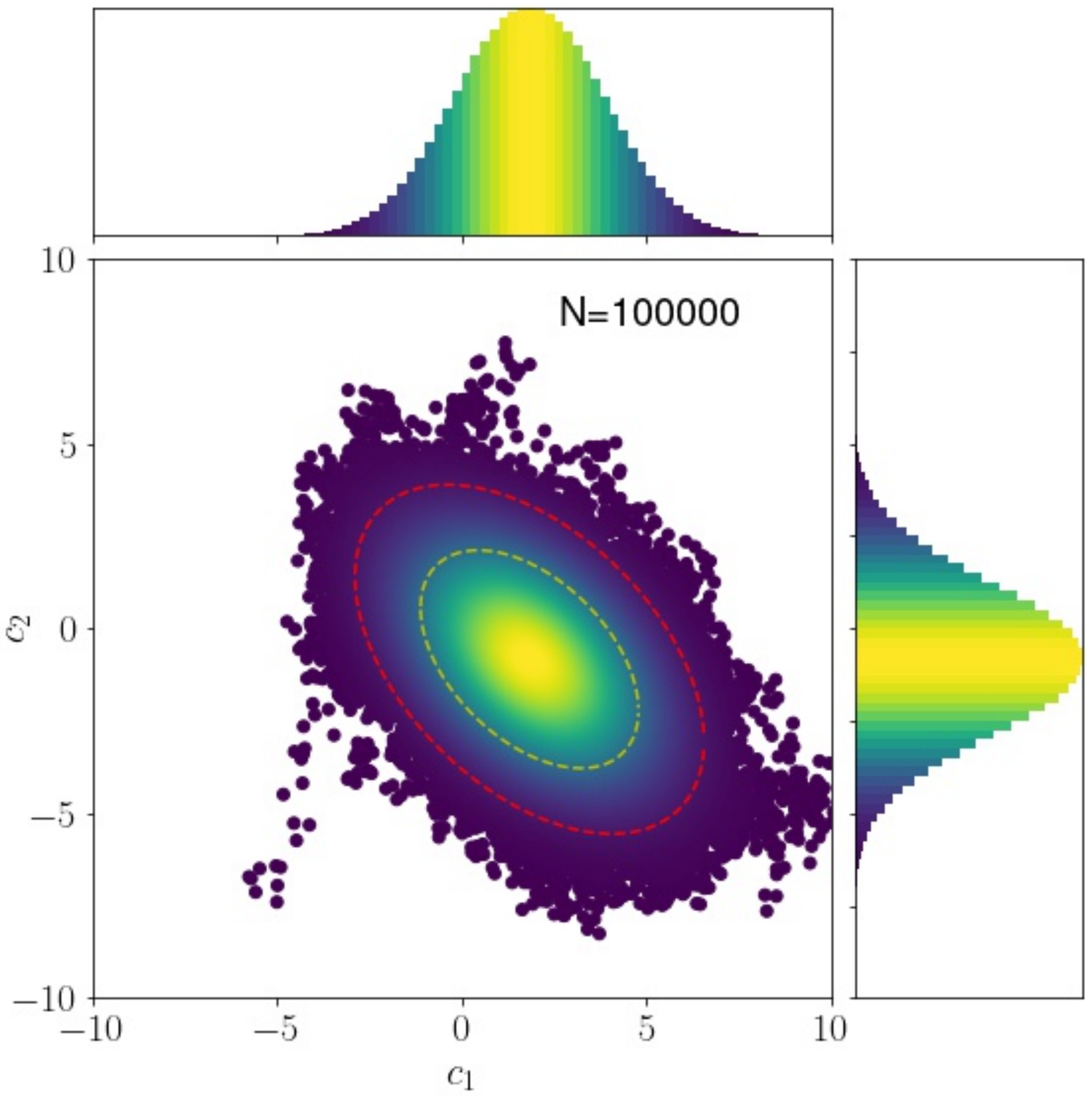
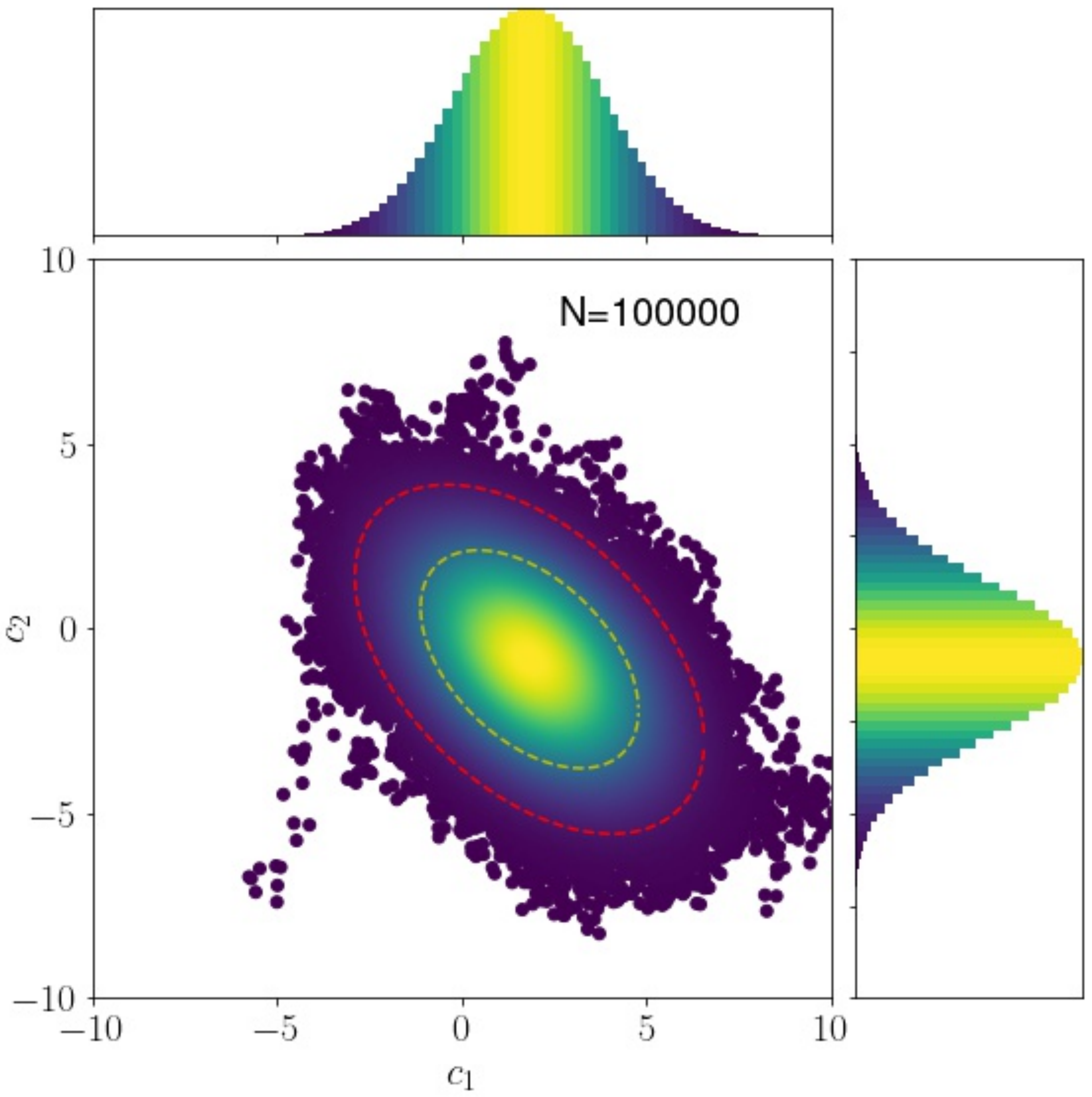


MC vs. Toys

Markov Chain

Toy Monte Carlo



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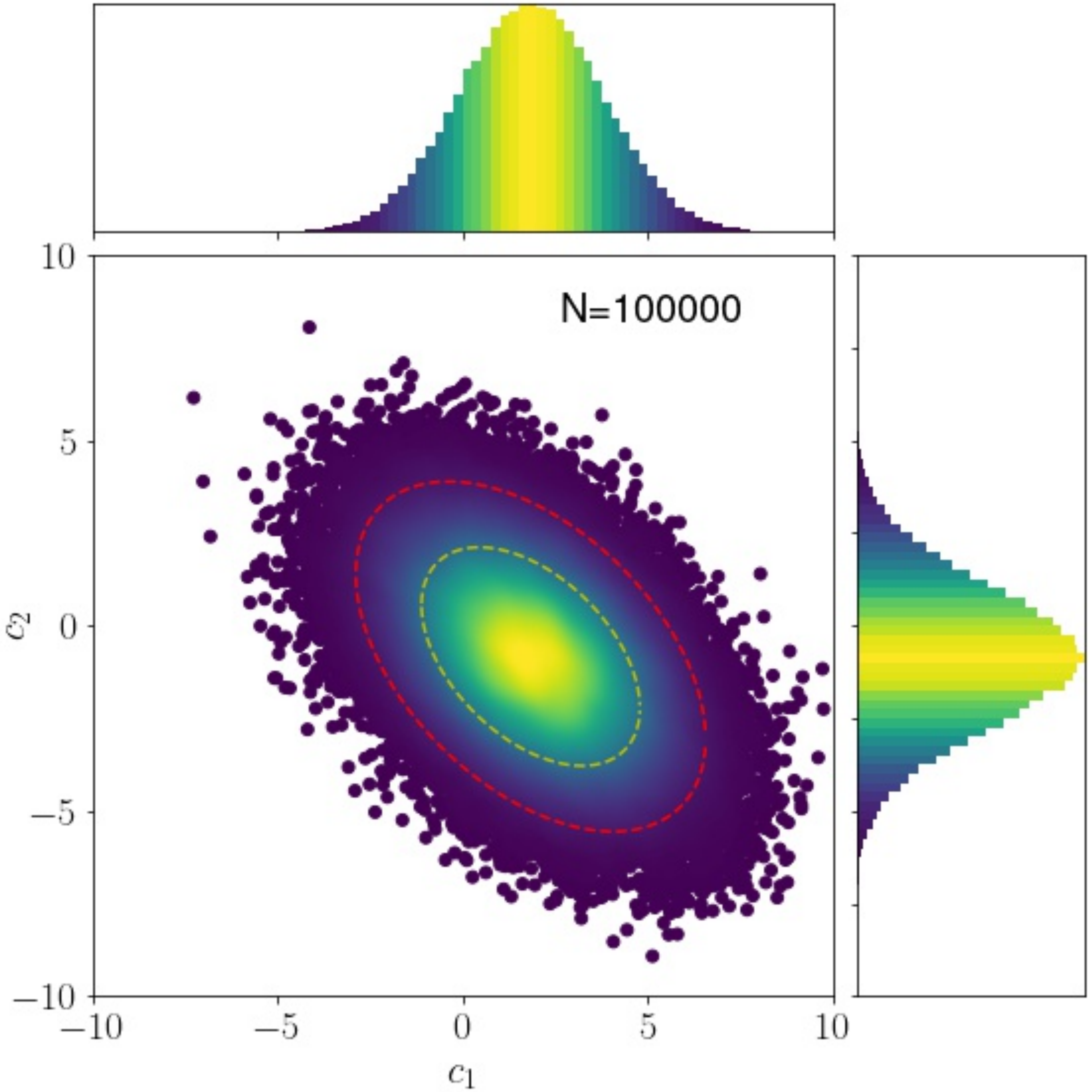

The Data

Where the sensitivity comes from

The Data

$$O_{tG} = C_{tG}(\bar{q}_3\sigma^{\mu\nu}T^A u_3)\tilde{\phi}G^A_{\mu\nu}$$

$$O^8_{tu} = C^8_{tu}(\bar{u}_3\gamma^\mu T^A u_3)(\bar{u}_i\gamma_\mu T^A u_i)$$

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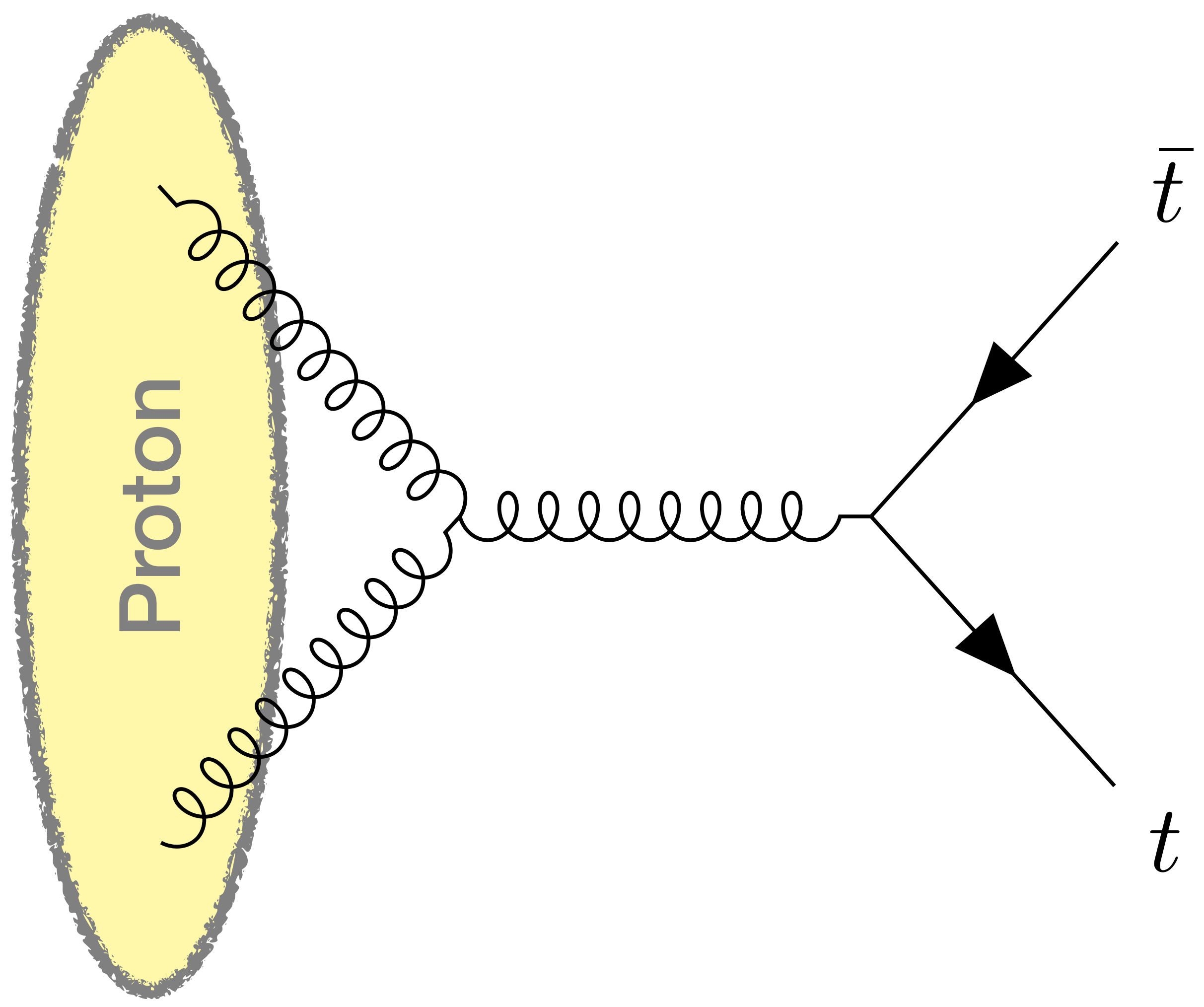

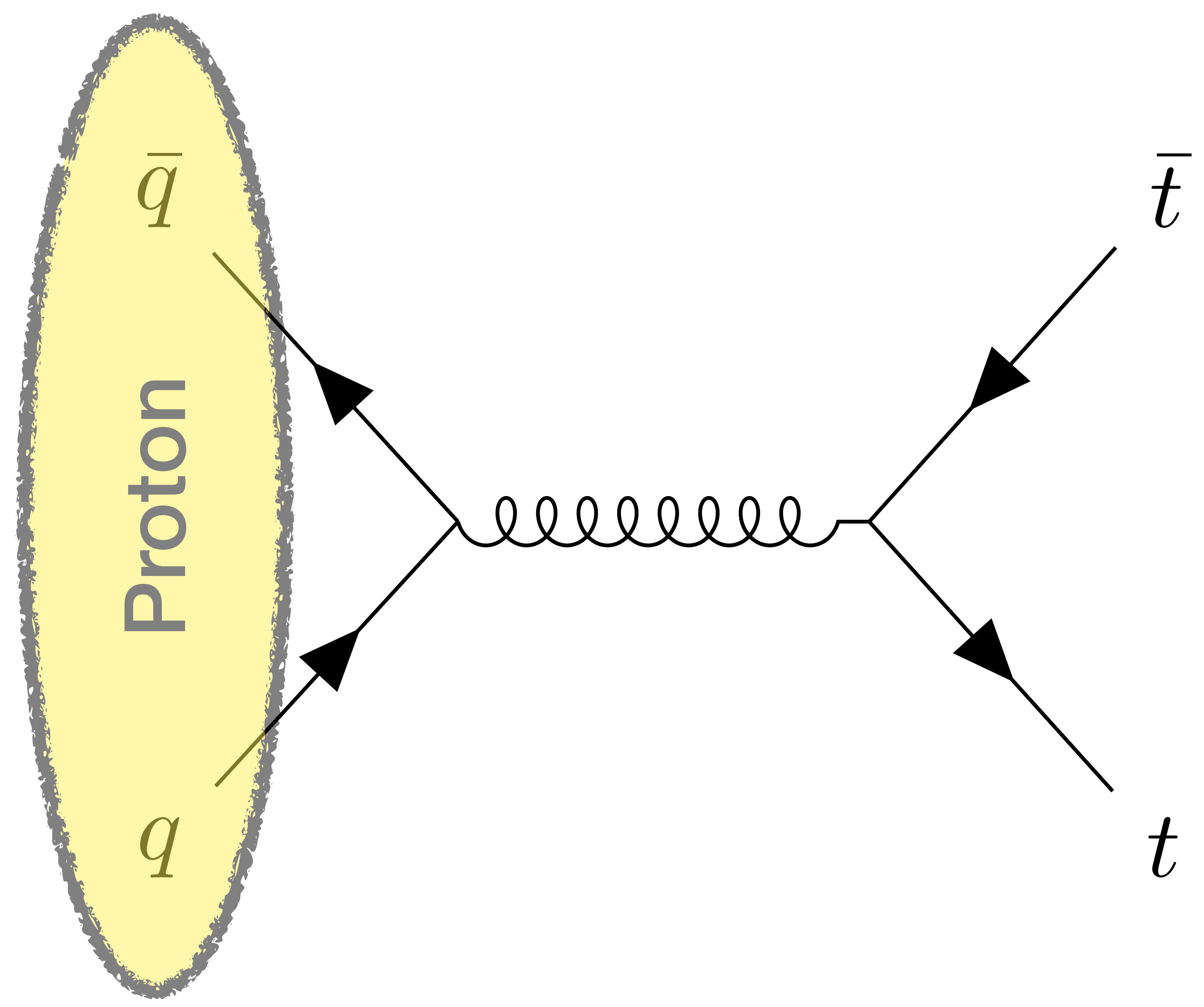

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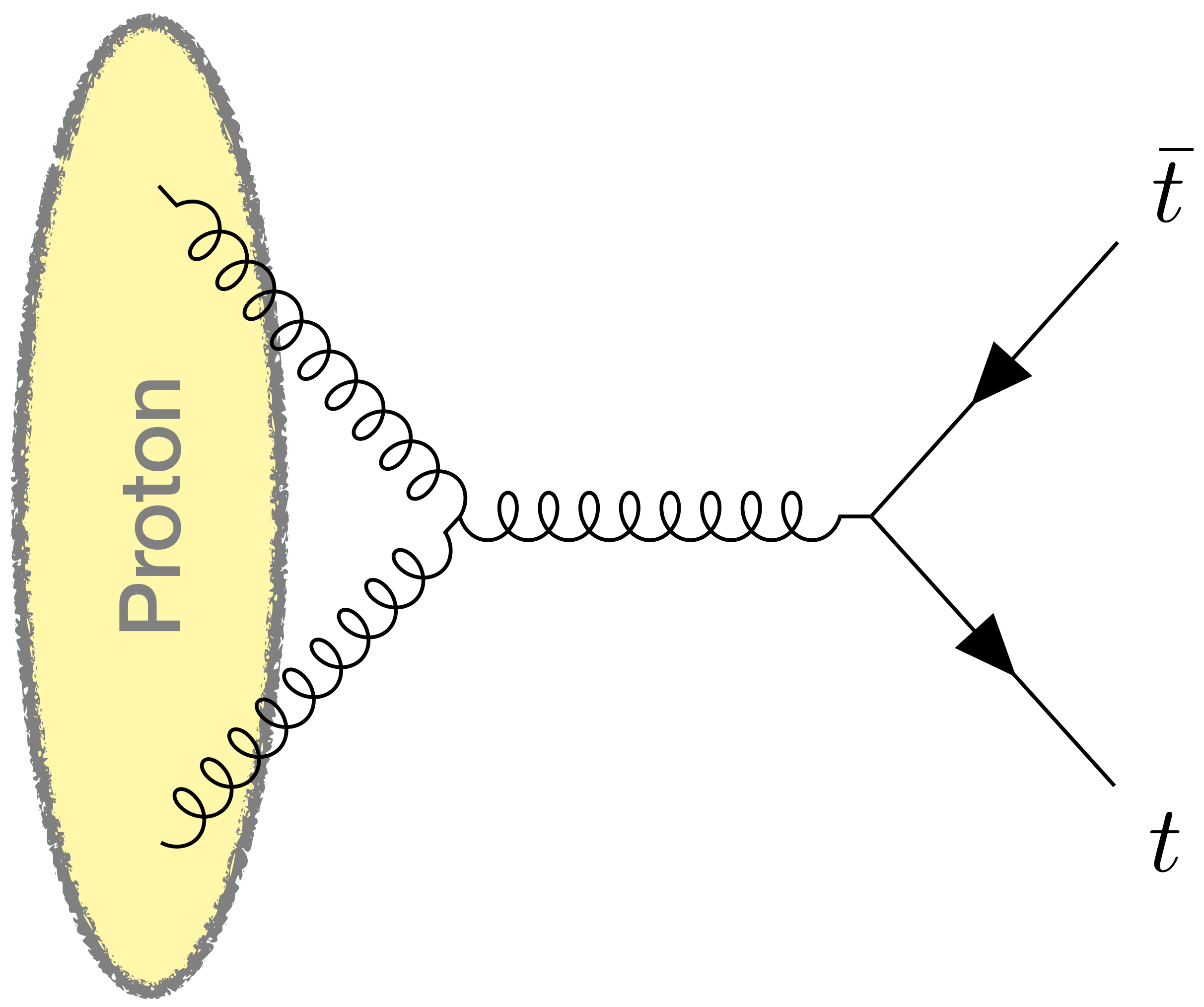

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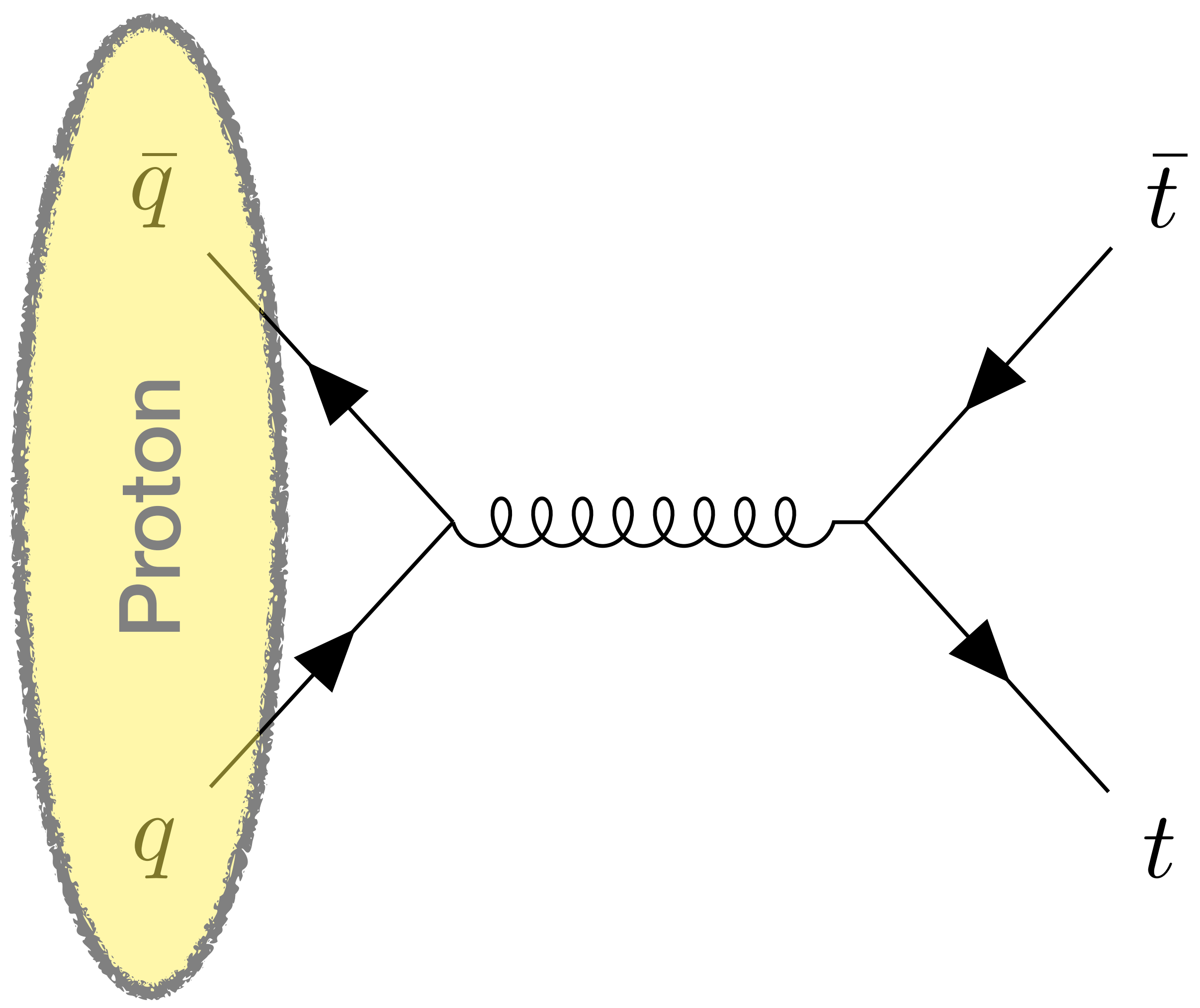

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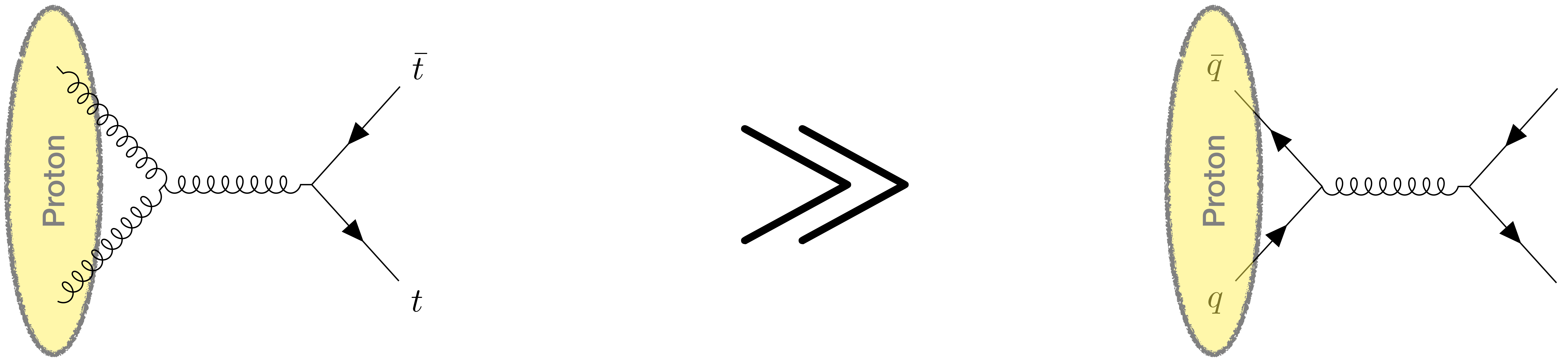
Where the sensitivity comes from

$$\frac{1}{\sigma}\frac{d\sigma}{dm_{t\bar{t}}} \approx \frac{\sigma_{SM}(m_{t\bar{t}})}{\sigma_{SM}(2m_t} \left(1 + \mathcal{O}(1)\frac{C_{tG}}{\Lambda^2} + \mathcal{O}(m^2_{t\bar{t}})\frac{C^8_{tu}}{\Lambda^2}\right)$$



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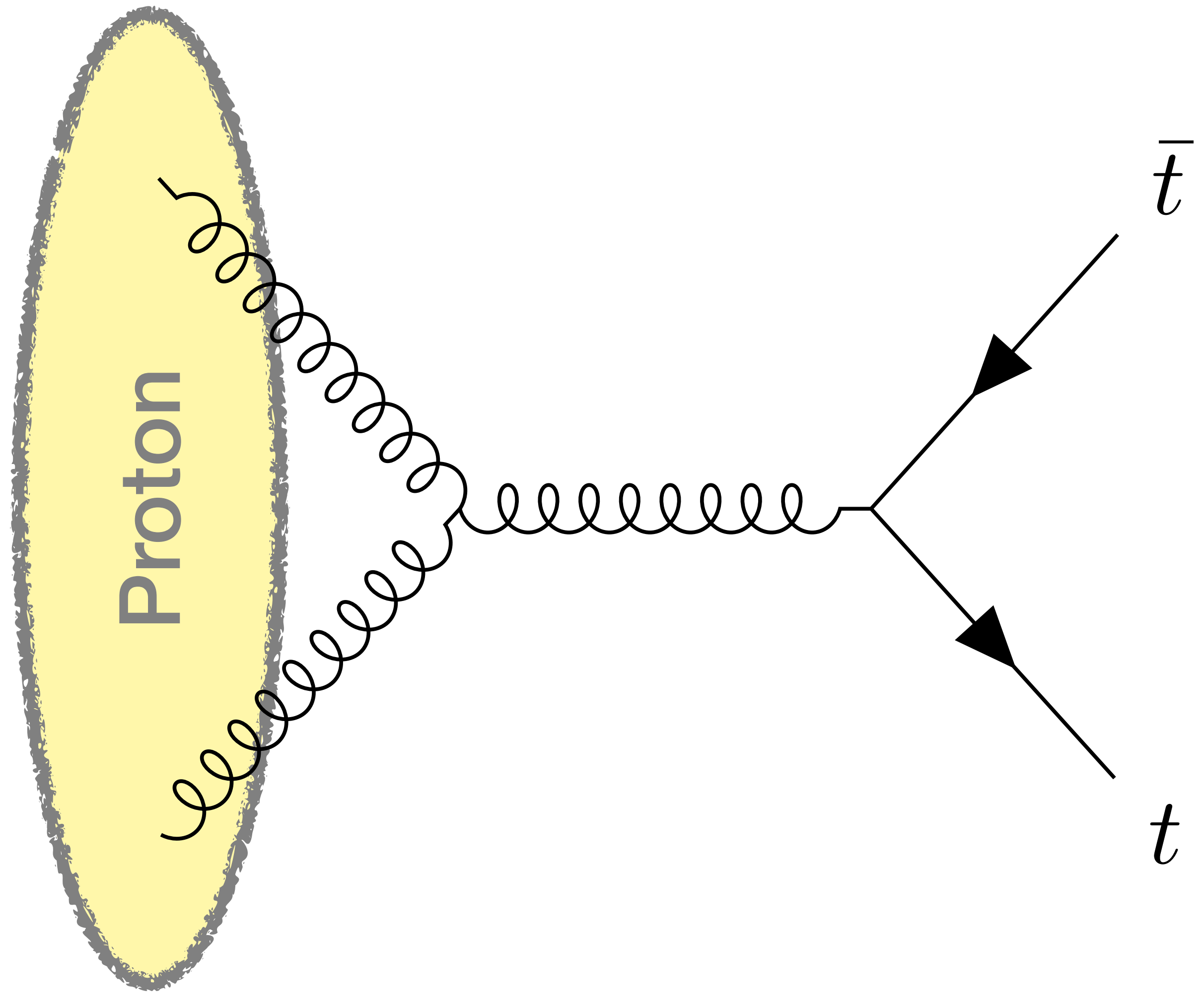
Stays small



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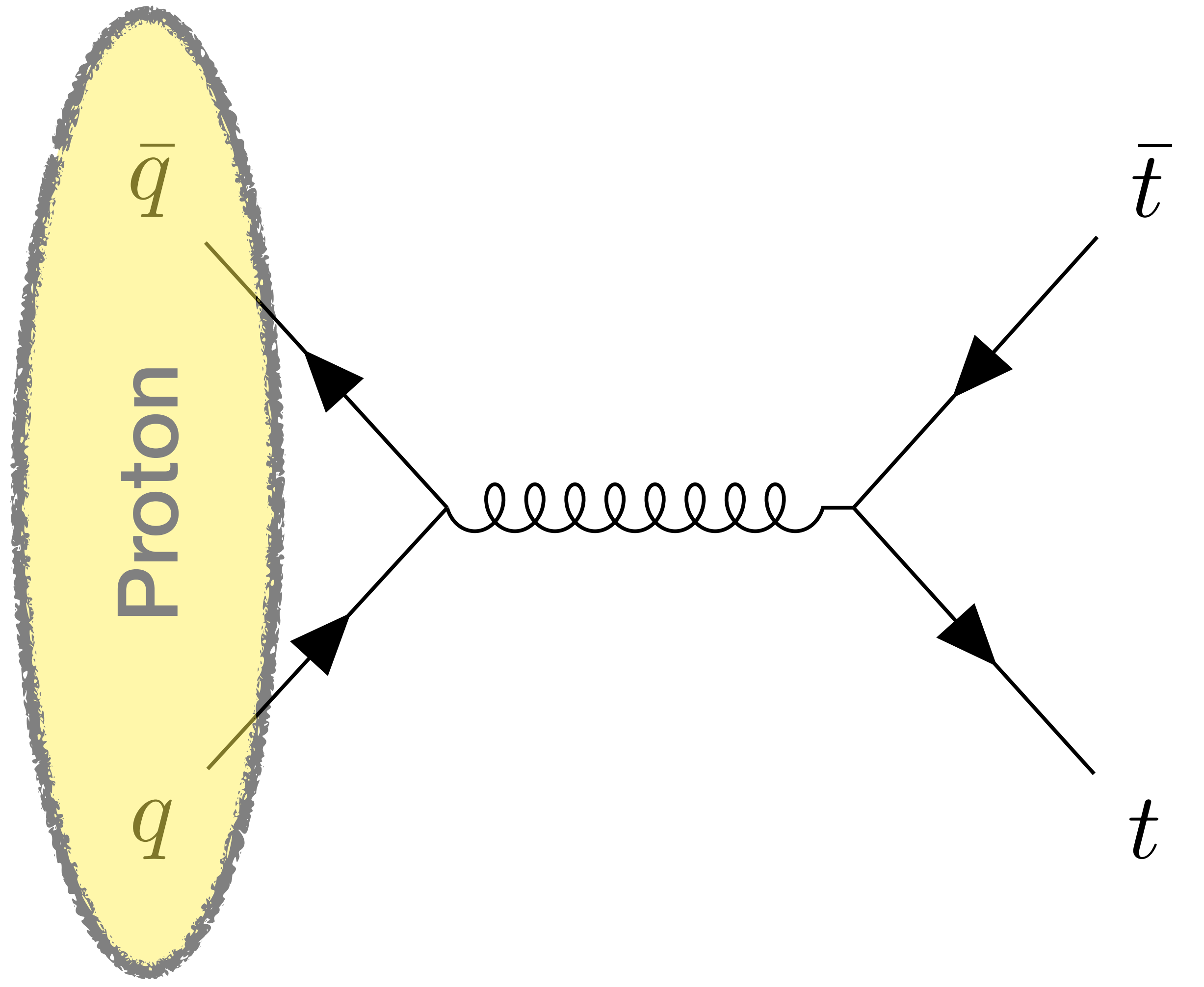

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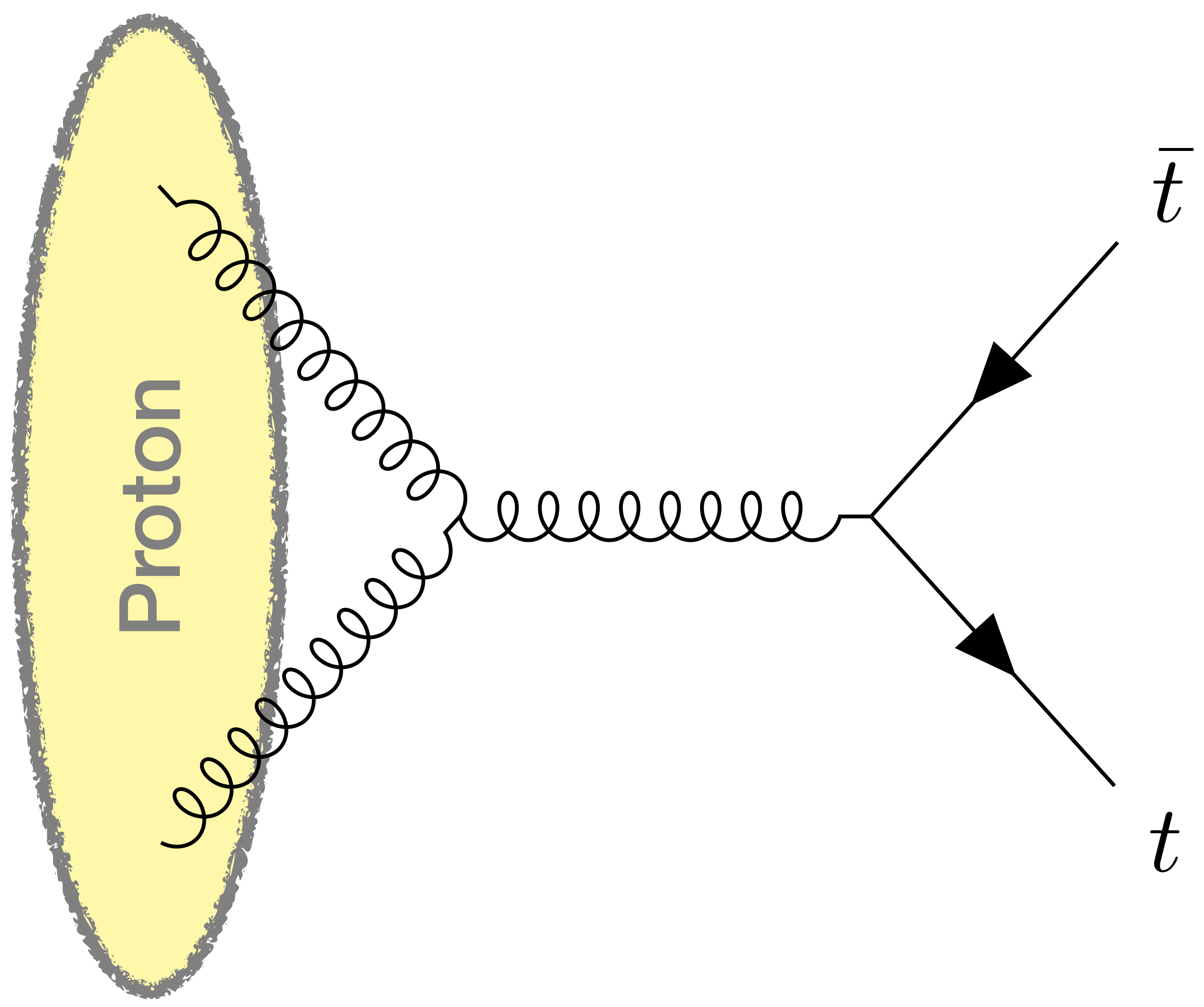
Stays small

Grows very large for high bins



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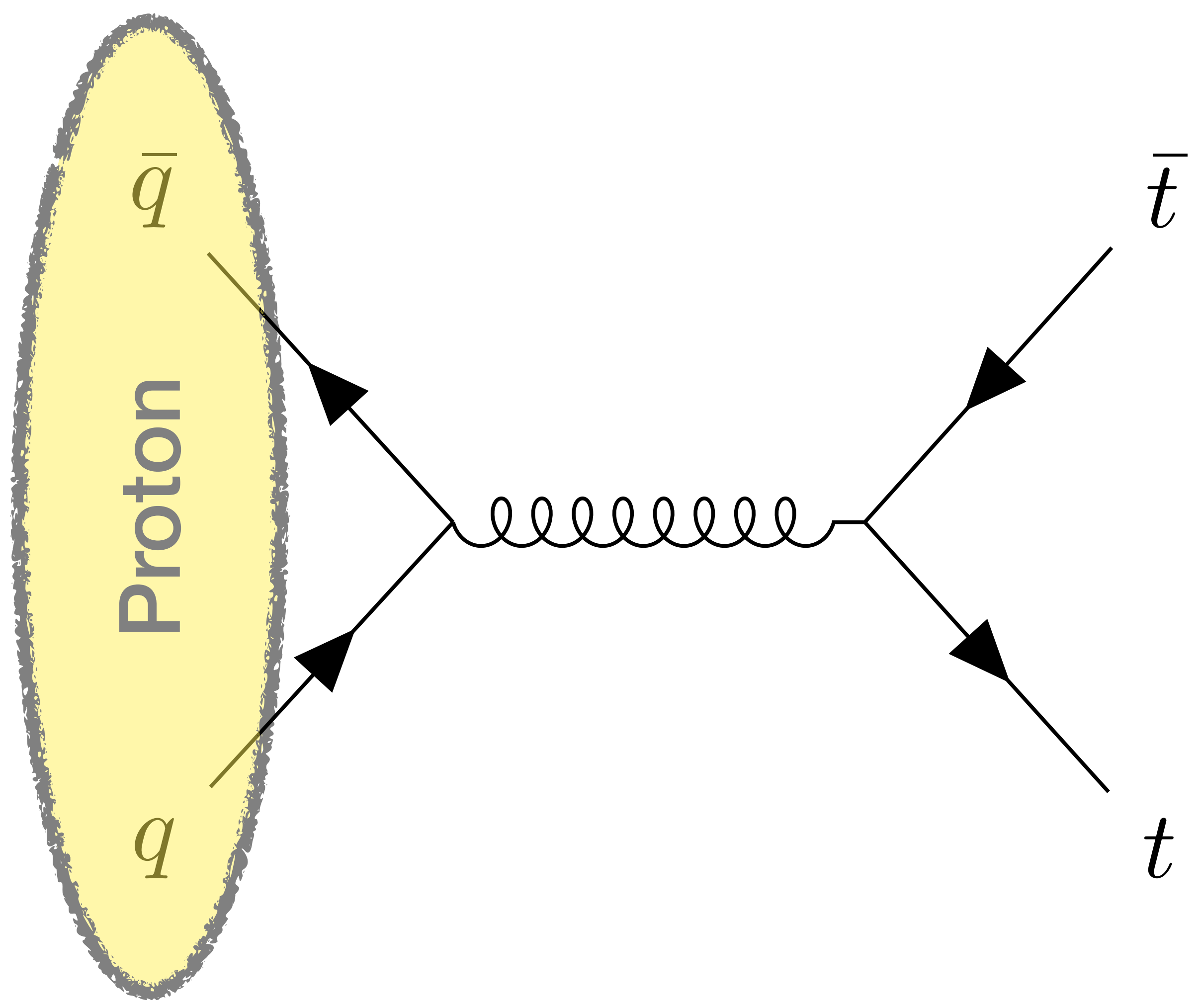

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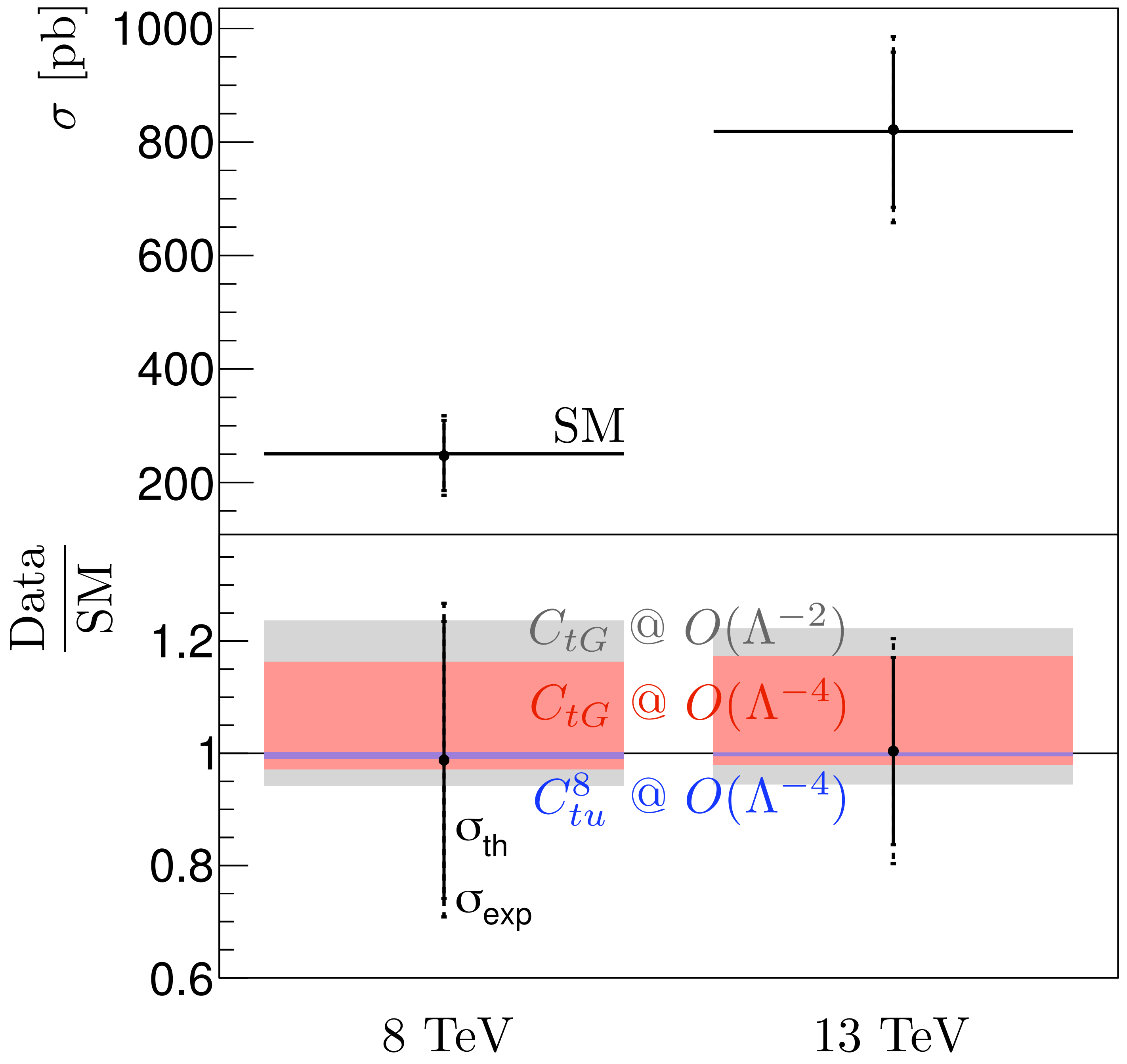

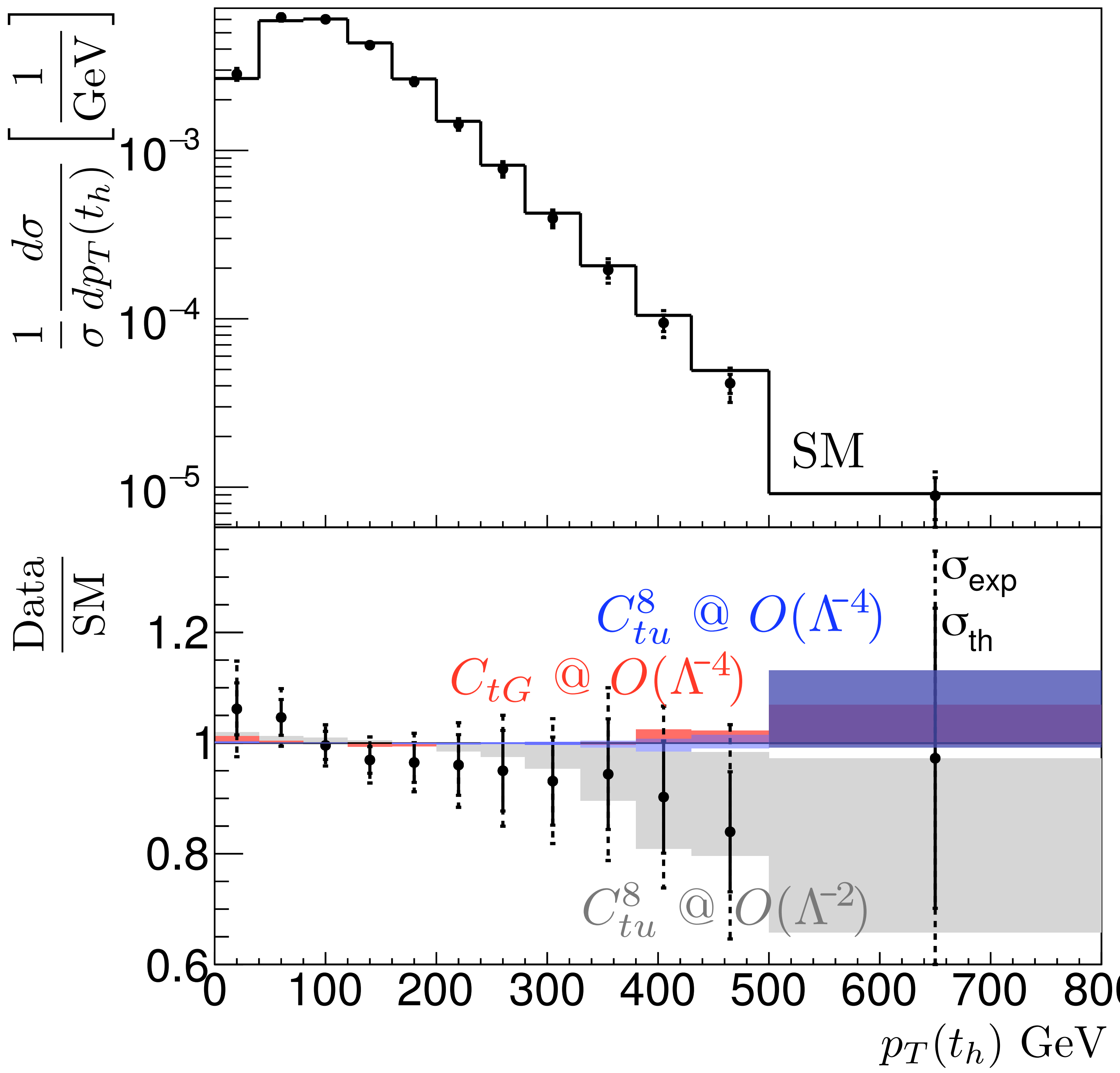

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Resolving blind directions

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SU(2) Singlet
Sensitive to u+d initial state

The Data

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SU(2) Tripplet
Sensitive to u-d initial state

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$$r(x) = \frac{f_u(x)f_{\bar{u}}(s/xS)}{f_d(x)f_{\bar{d}}(s/xS)}$$

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Valence quark maximum

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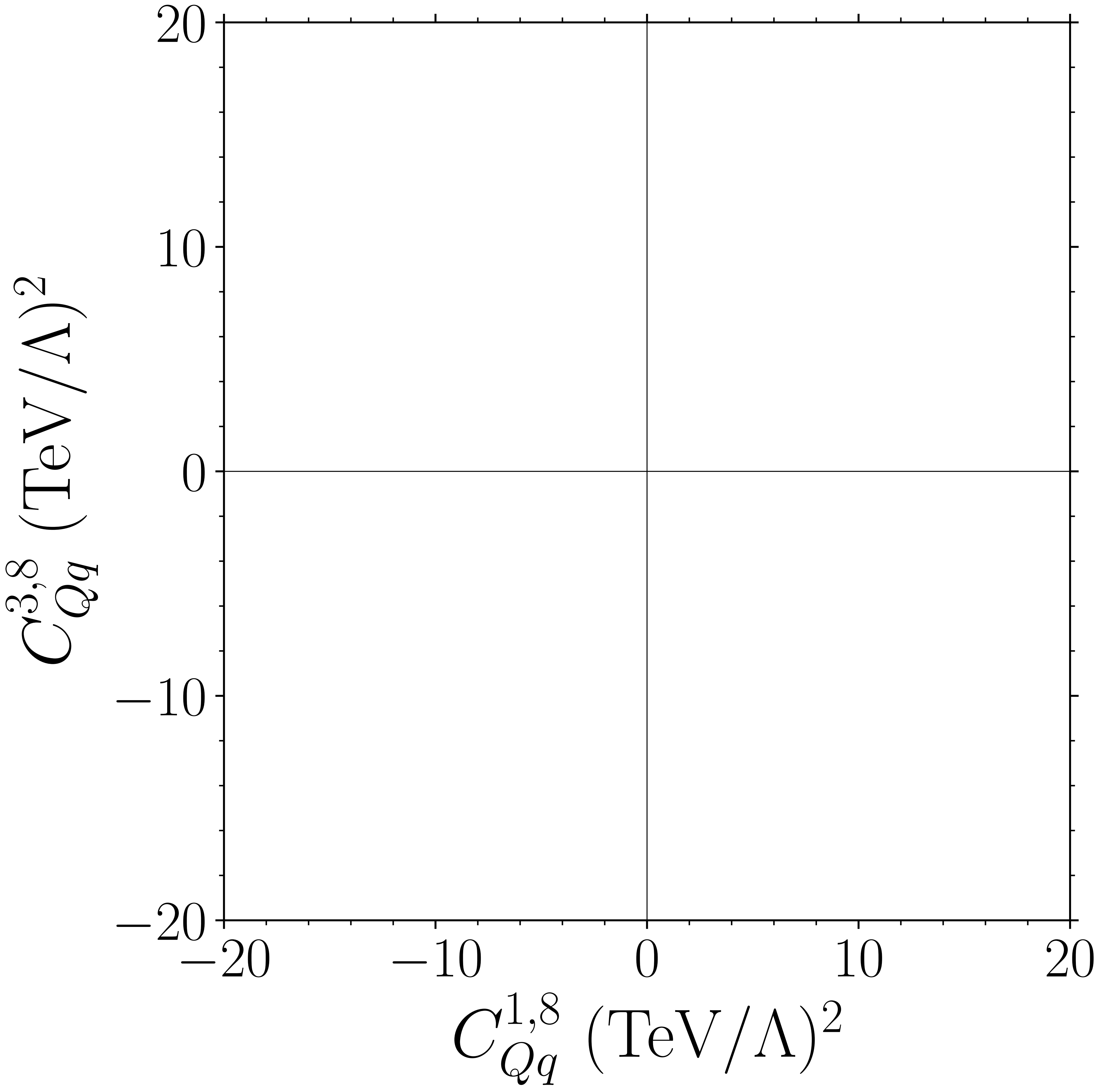

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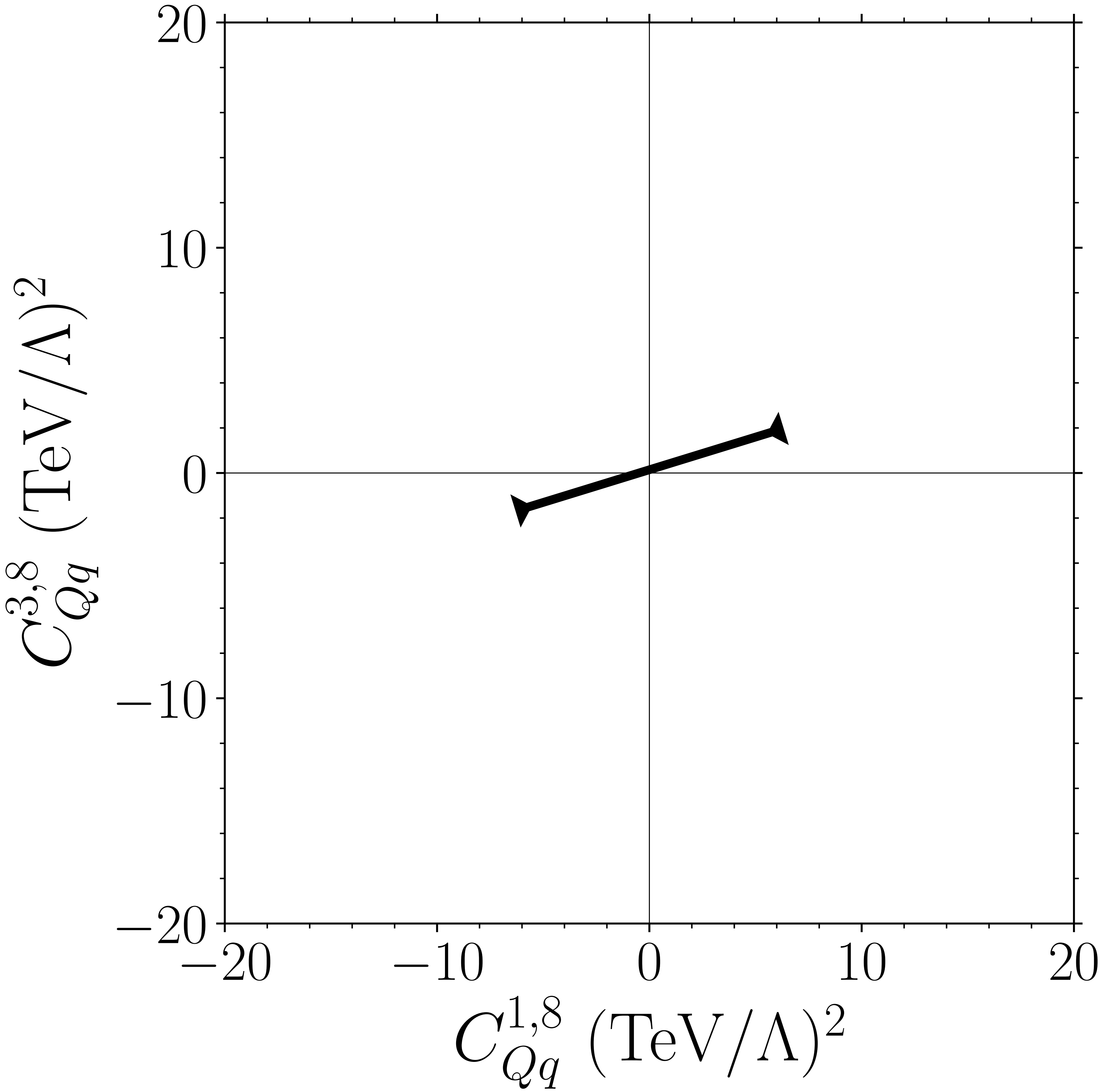

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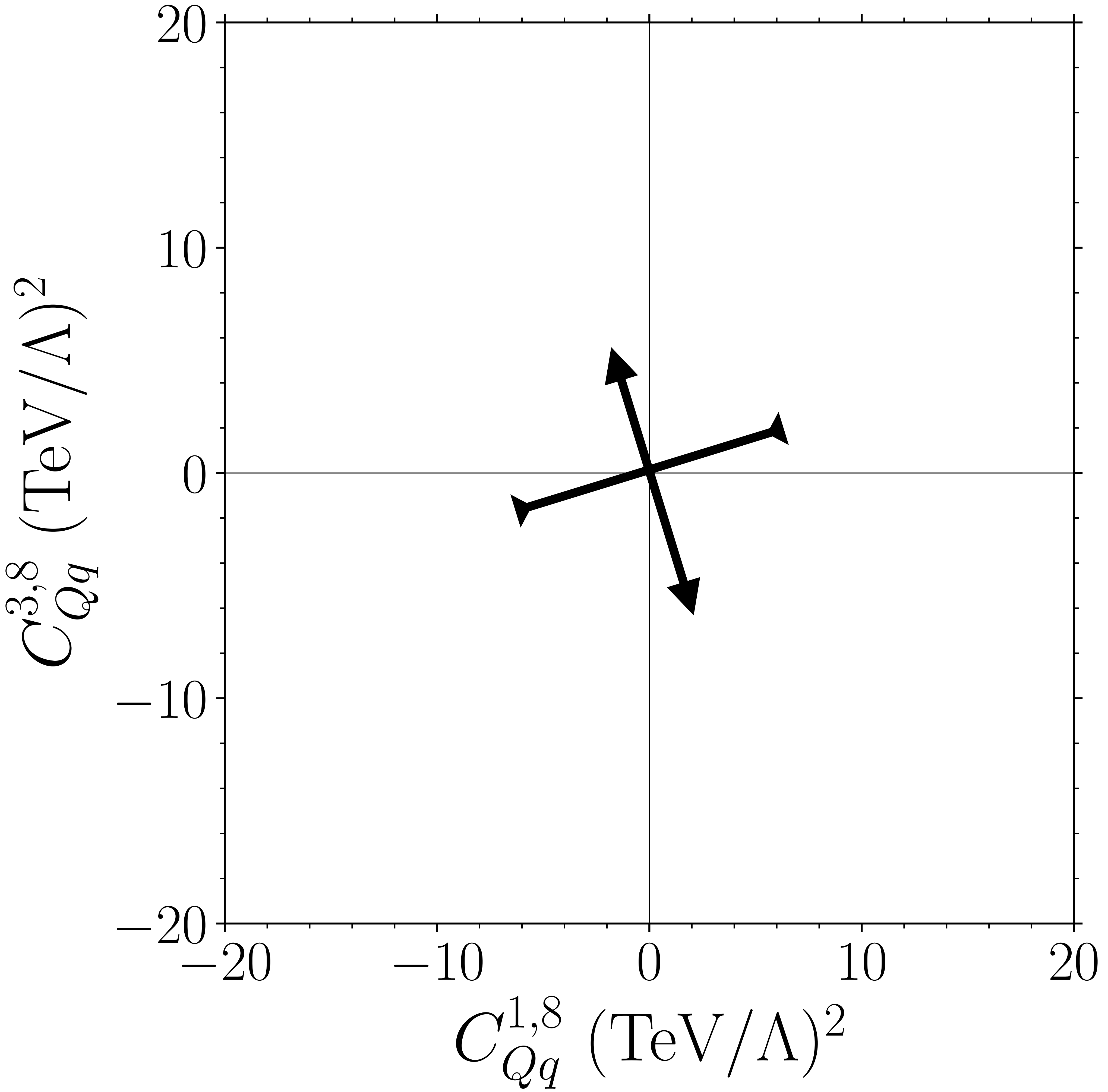
Valence quark maximum

$$\sigma_{t\bar{t}} = \sigma_{t\bar{t}}^{SM} + \sigma_{t\bar{t}}^{NP}\left[\quad 3\, C_{Qq}^{1,8} + \quad 1\, C_{Qq}^{3,8} \right]$$



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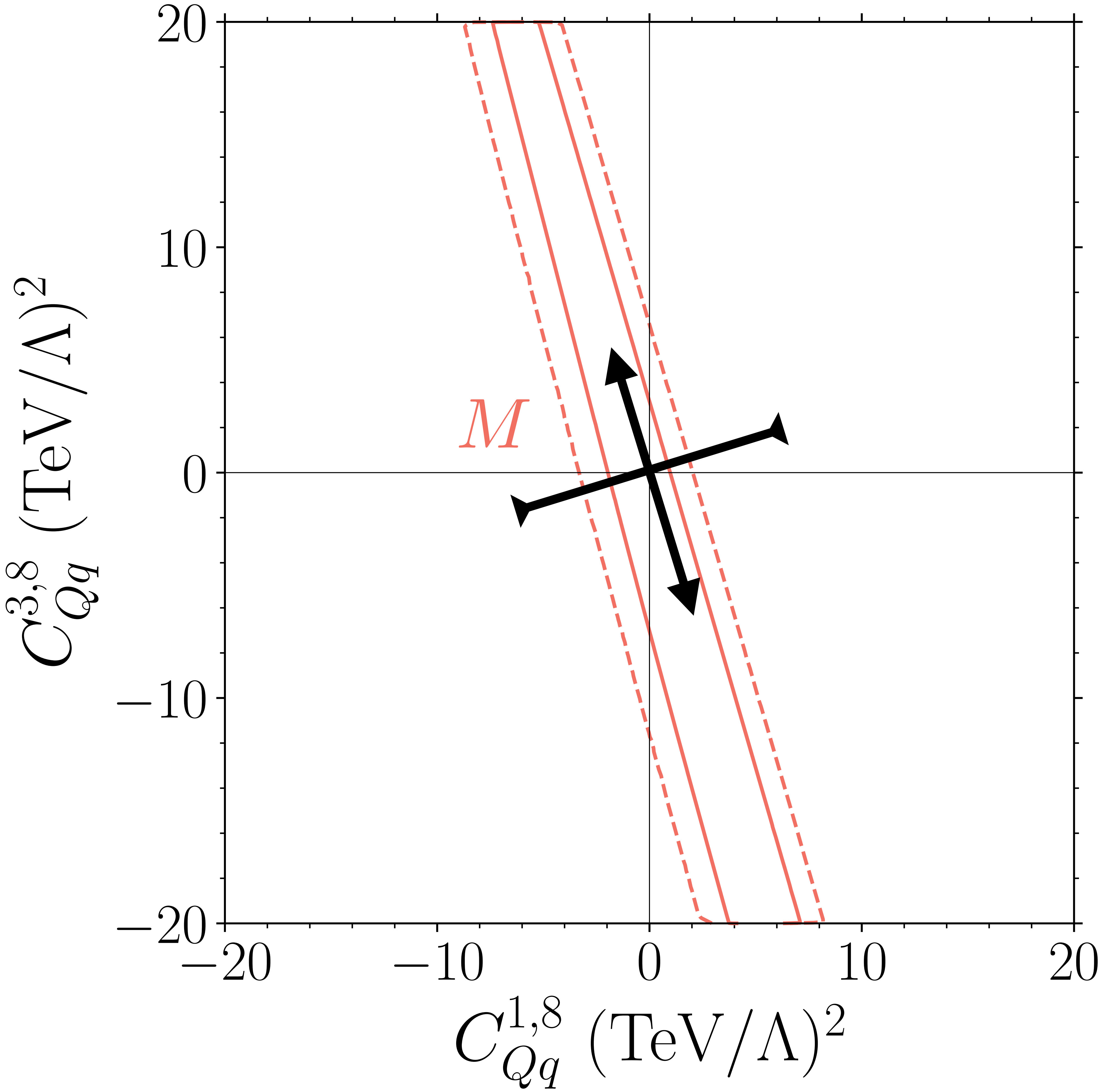
Valence quark maximum

$$\sigma_{t\bar{t}} = \sigma_{t\bar{t}}^{SM} + \sigma_{t\bar{t}}^{NP}\left[\quad 3\,C_{Qq}^{1,8} + \quad 1\,C_{Qq}^{3,8}\right]$$



The Data

Resolving blind directions

$$O_{Qq}^{1,8} = C_{Qq}^{1,8}(\bar{q}_3\gamma^\mu T^A q_3)(\bar{q}_i\gamma_\mu T^A q_i) \qquad O_{Qq}^{3,8} = C_{Qq}^{3,8}(\bar{q}_3\gamma^\mu T^A \tau^I q_3)(\bar{q}_i\gamma_\mu T^A \tau^I q_i)$$

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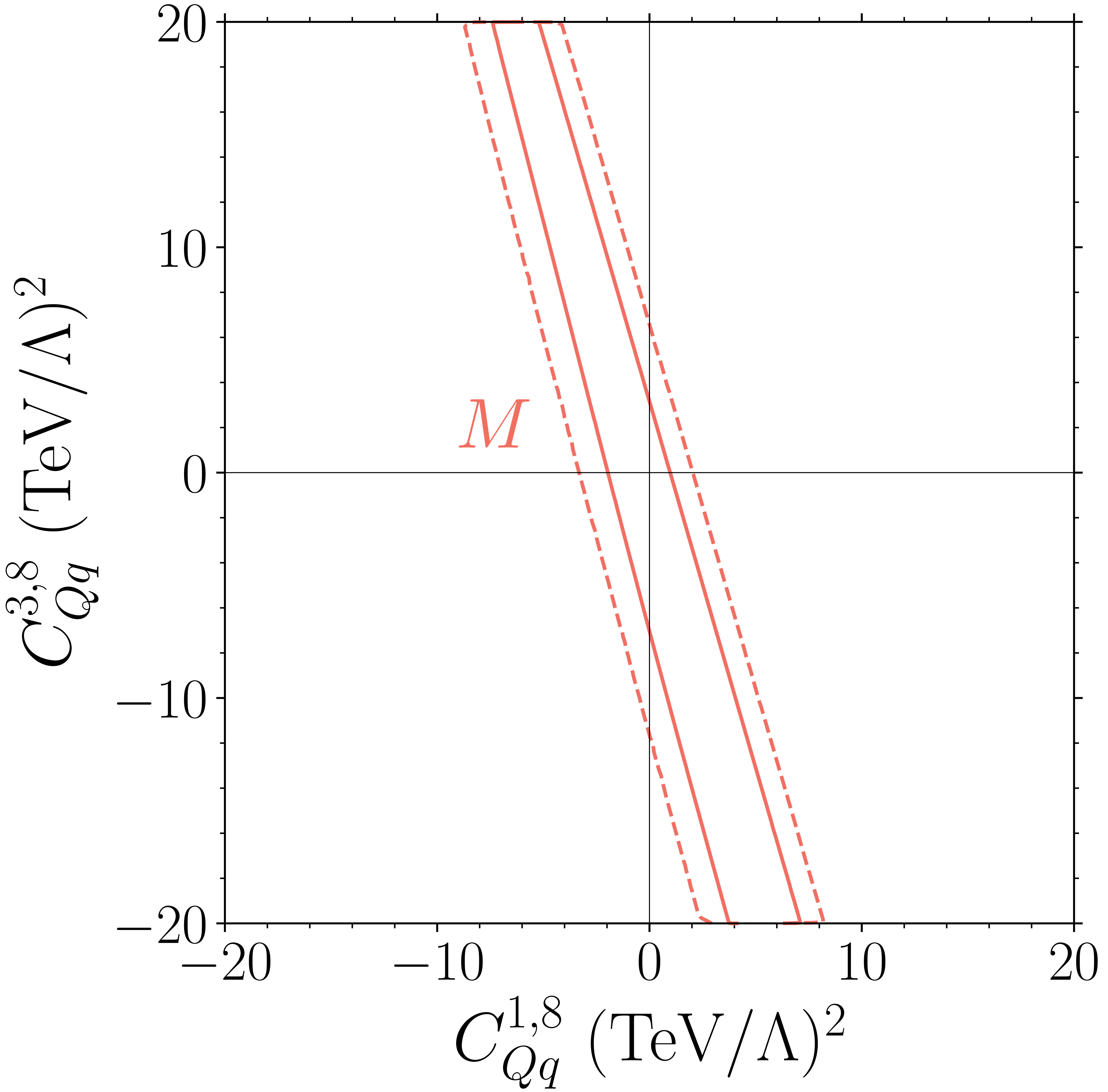
Probe different r(x) in boosted regime



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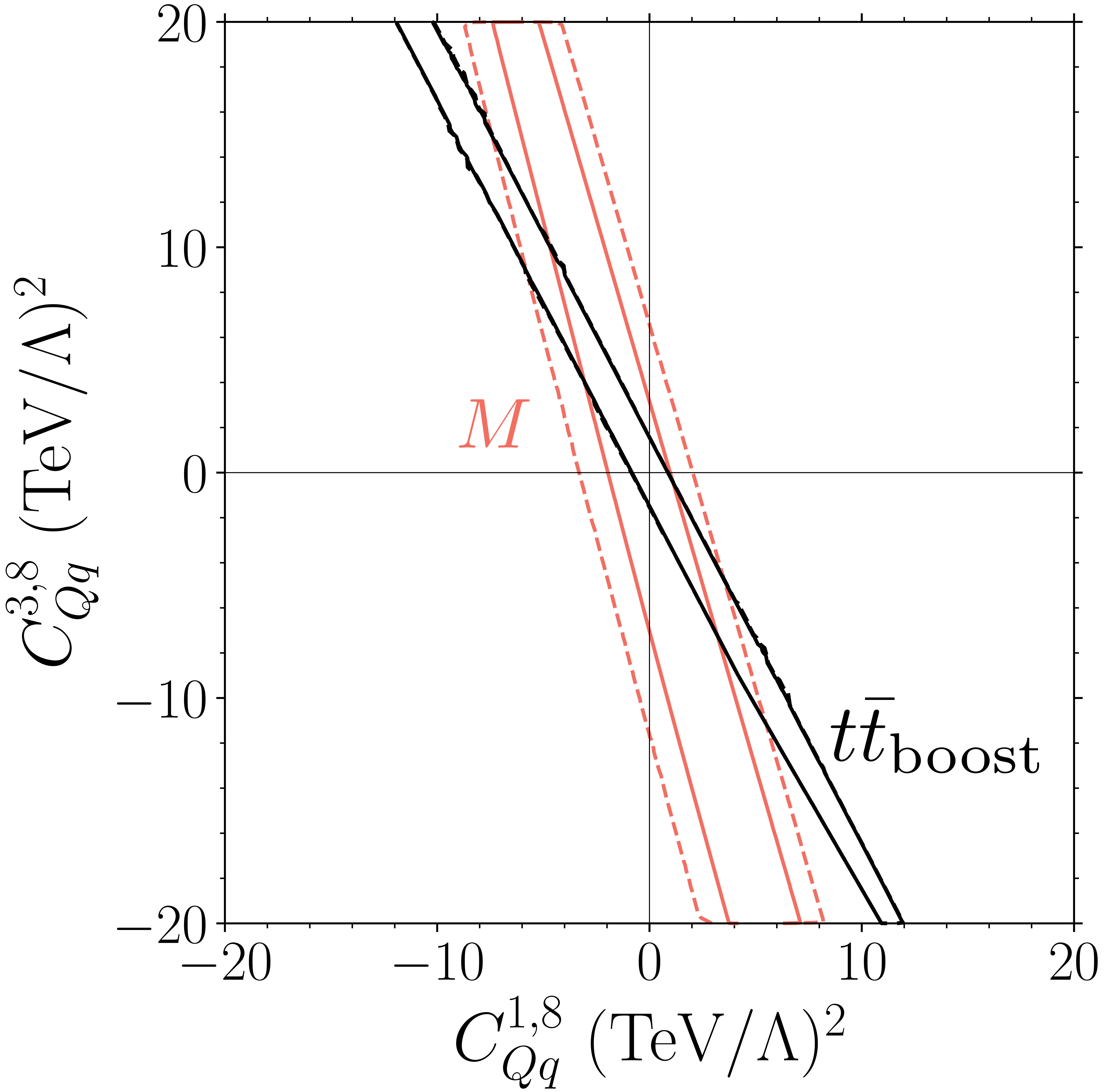

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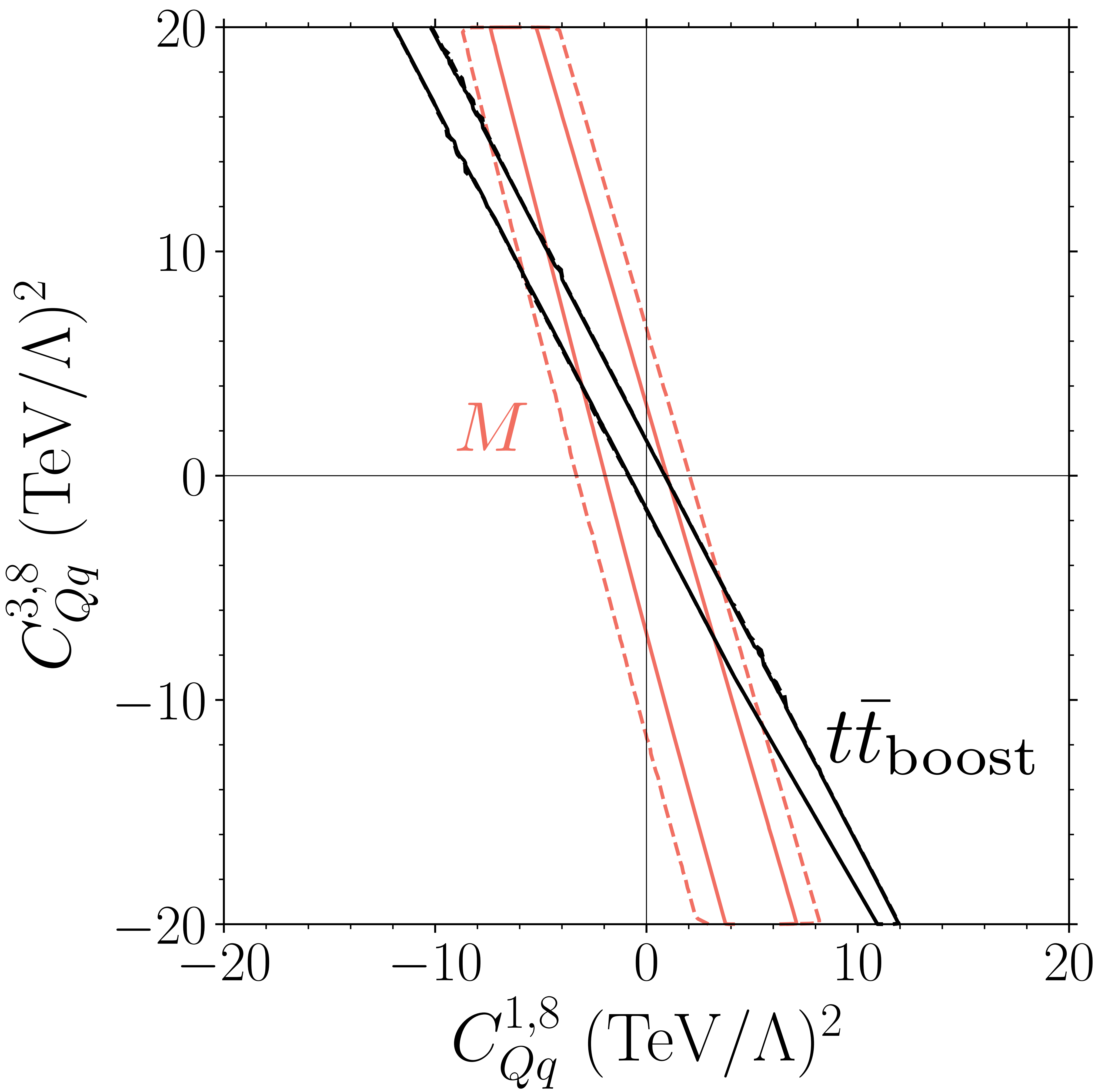

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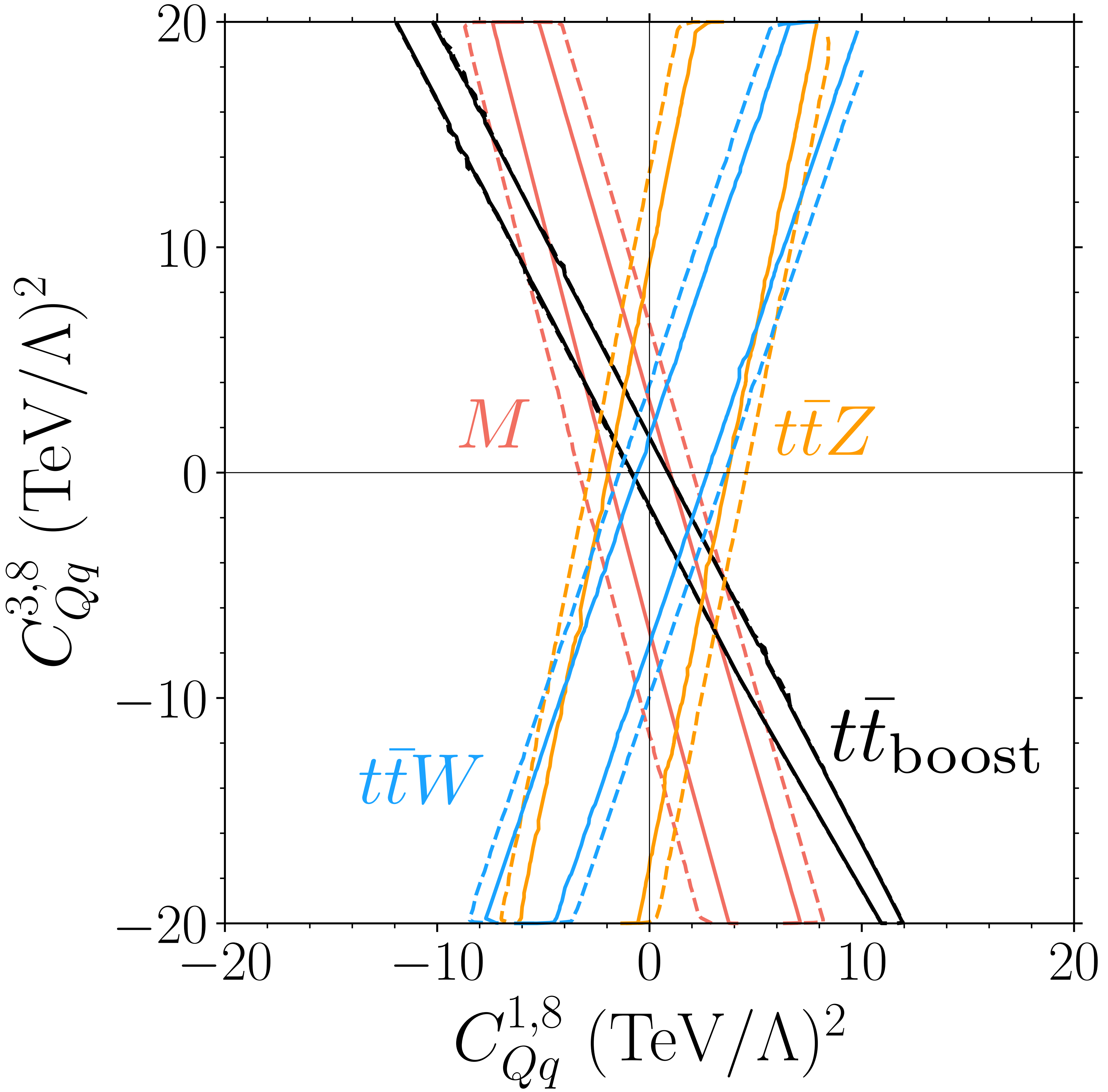

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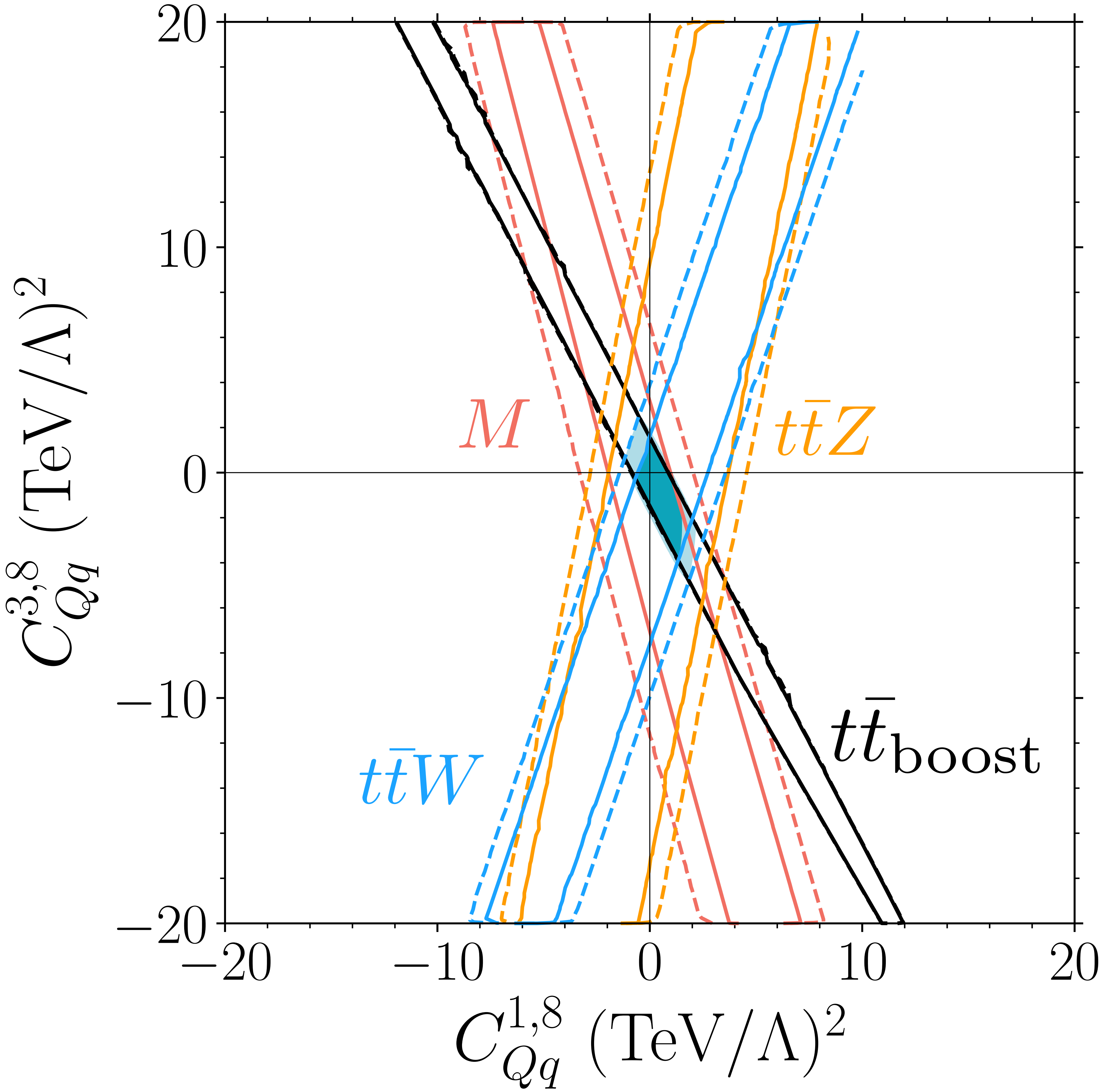

The Model

Linear vs. Quadratic

The Model

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$$\mathcal{A} = \mathcal{A}_{SM} + \frac{c_i}{\Lambda^2}\mathcal{A}_i$$

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$$\sigma \sim |\mathcal{A}|^2 = |\mathcal{A}_{SM}|^2 + \sum_i \frac{c_i}{\Lambda^2}\mathcal{A}_{SM}^*\mathcal{A}_i + h.c. + \sum_{i,j}\frac{c_i^* c_j}{\Lambda^4}\mathcal{A}_i^*\mathcal{A}_j + h.c.$$

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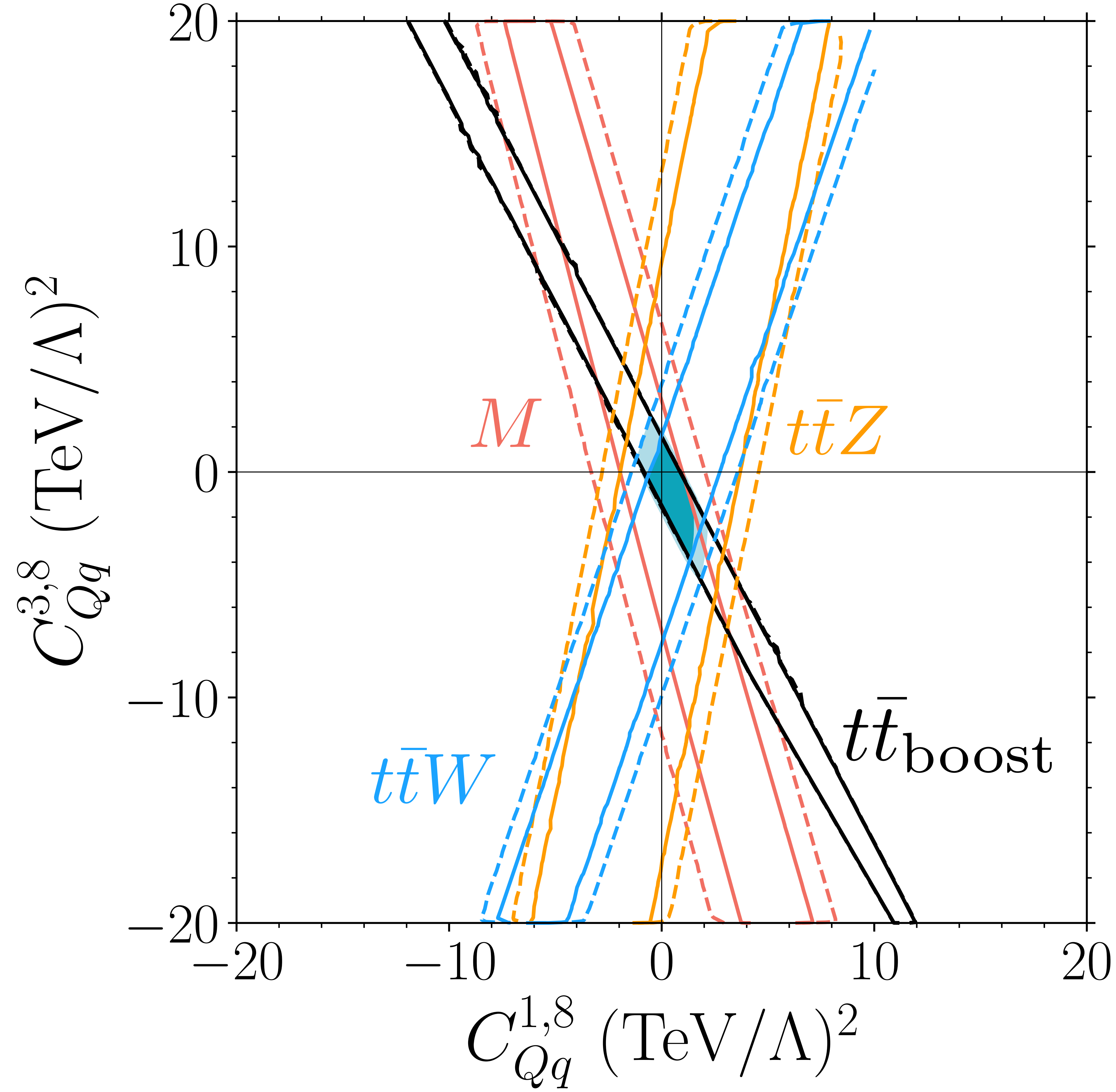

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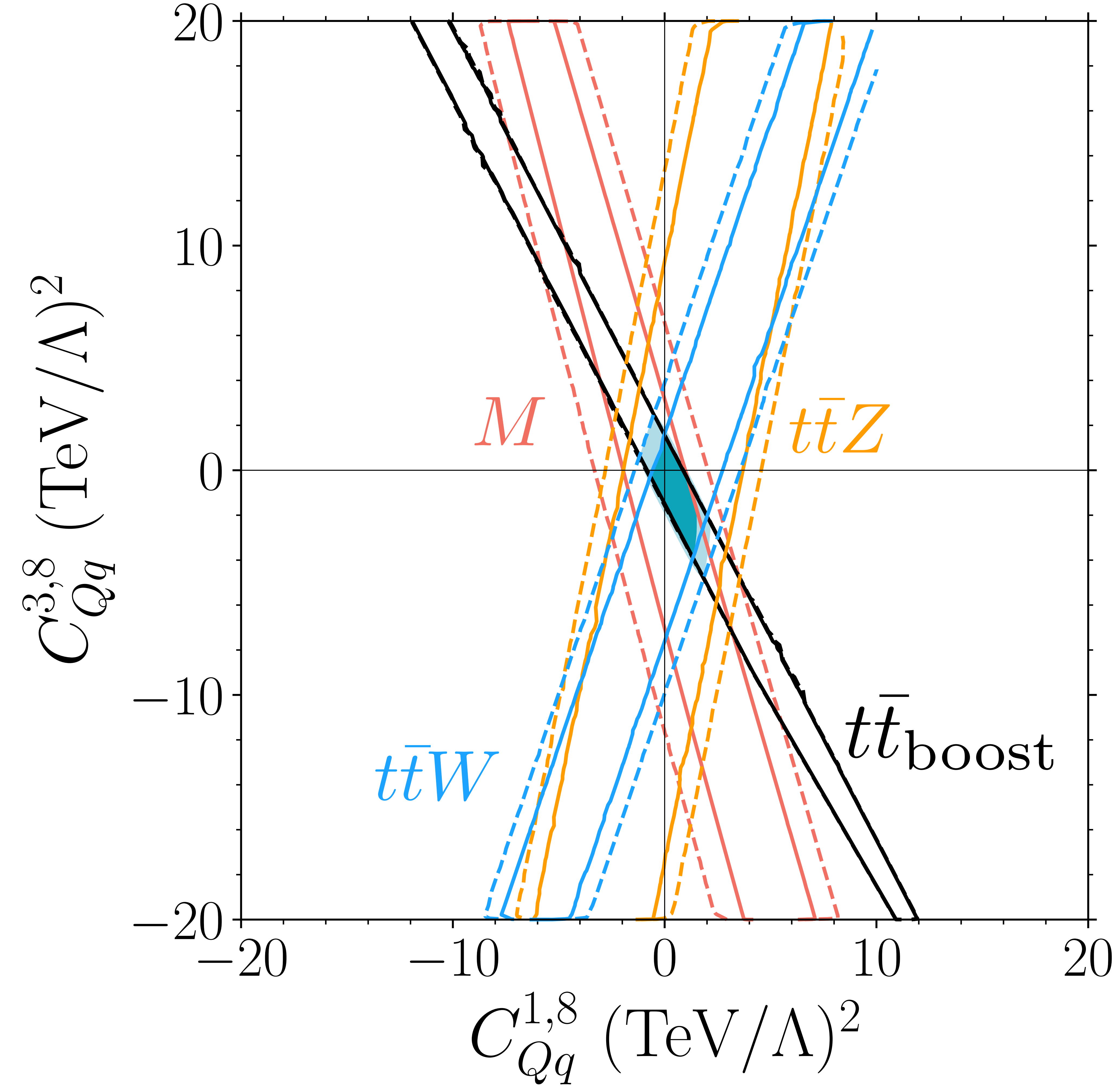

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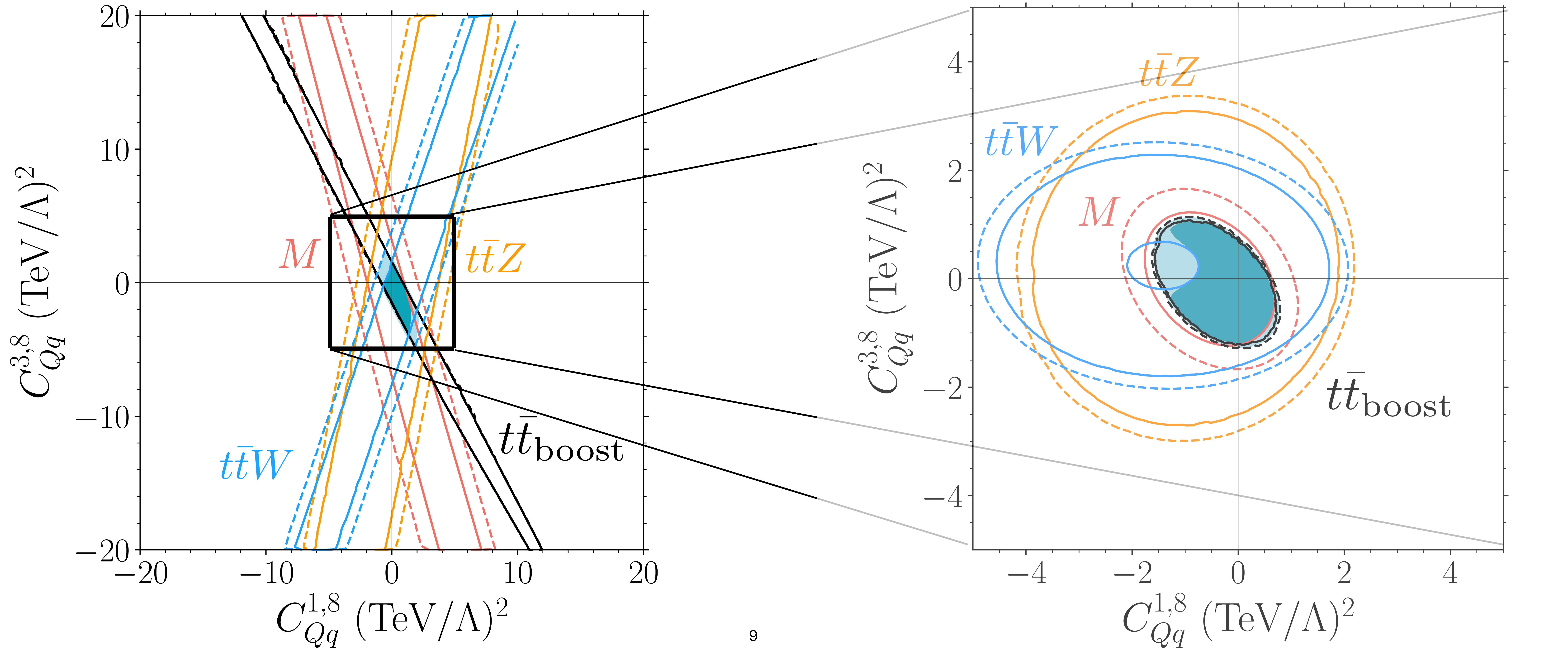

Uncertainties

What matters?

$$\mu_j = \bar{\mu}_j \pm \sigma_{\mathrm{pois},j} \pm \sigma_{\mathrm{gauss},j} \pm \sum_i \sigma_{\mathrm{syst},ij} \pm \sigma_{\mathrm{theo},j}$$

Central Value

Statistical Uncertainty

Uncorrelated systematic Uncertainty

Correlated systematics Uncertainty

Flat Uncertainties

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Central Value — Statistical Uncertainty — Uncorrelated systematic Uncertainty — Correlated systematics Uncertainty — Flat Uncertainties

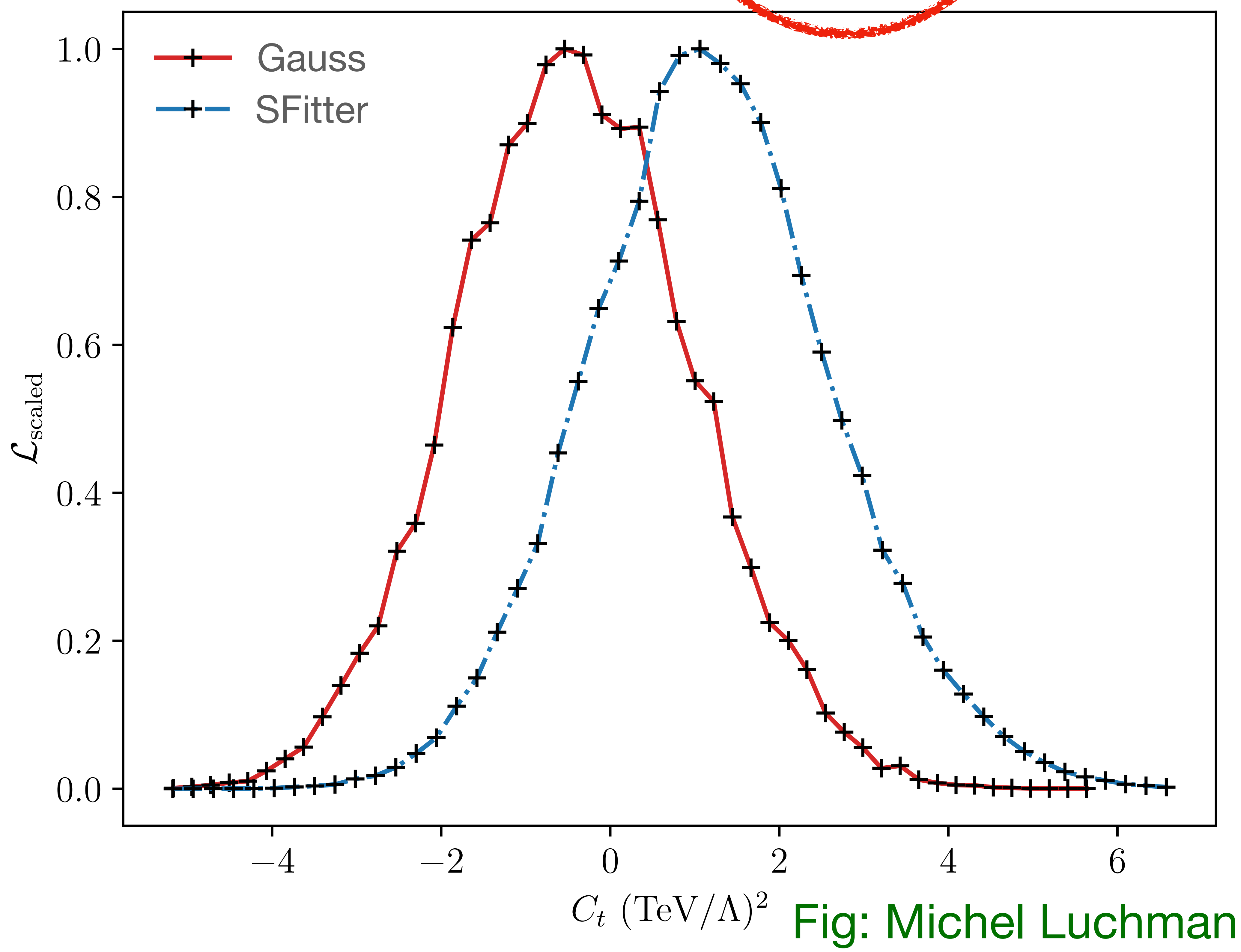

Fig: Michel Luchmann, 8D-Fit

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Full correlations known?

Yes → Full correlation matrix

No → Assume full (1) or no (0) correlation

Uncertainties

What matters?

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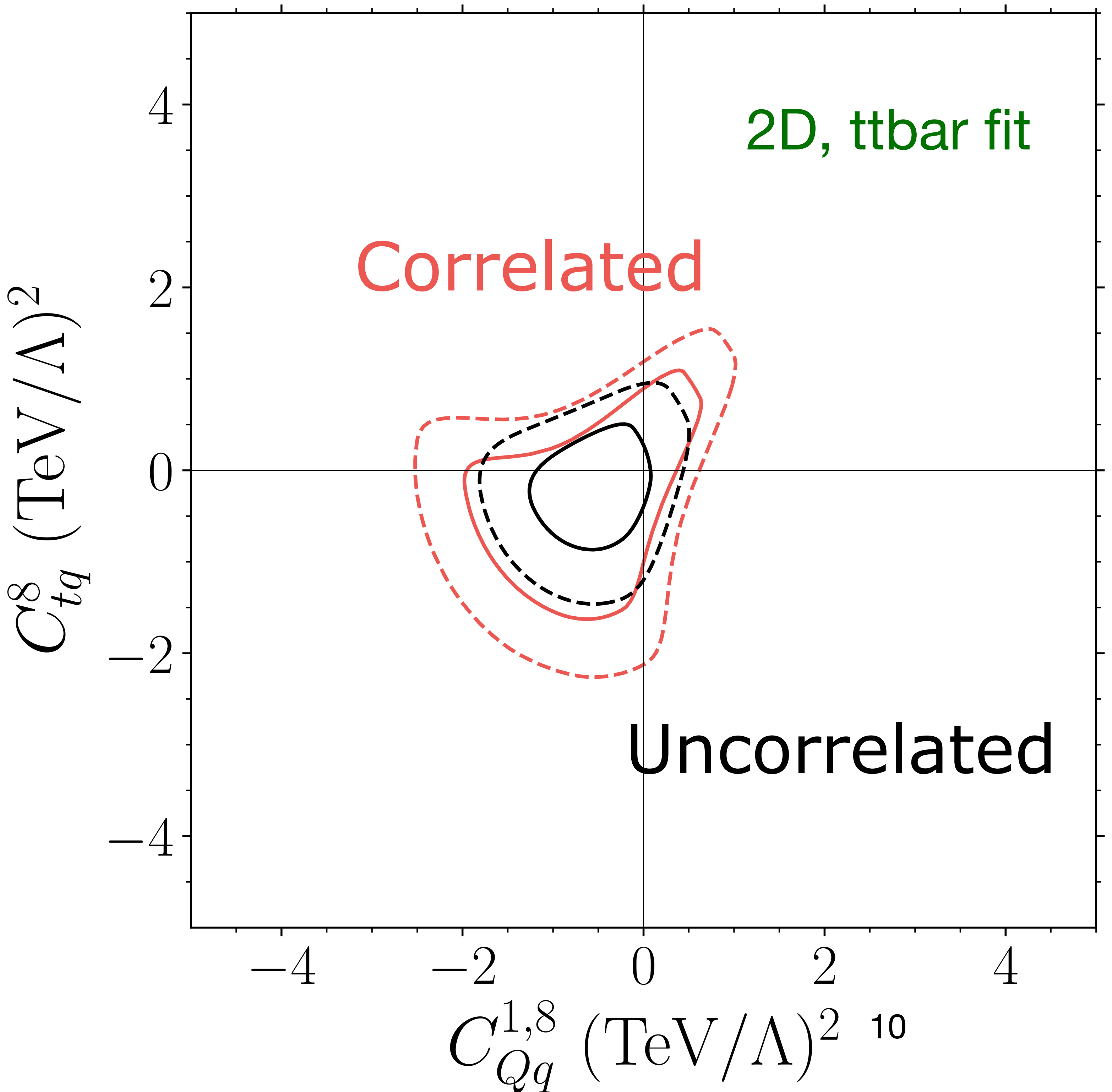

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- Central Value
- Statistical Uncertainty
- Uncorrelated systematic Uncertainty
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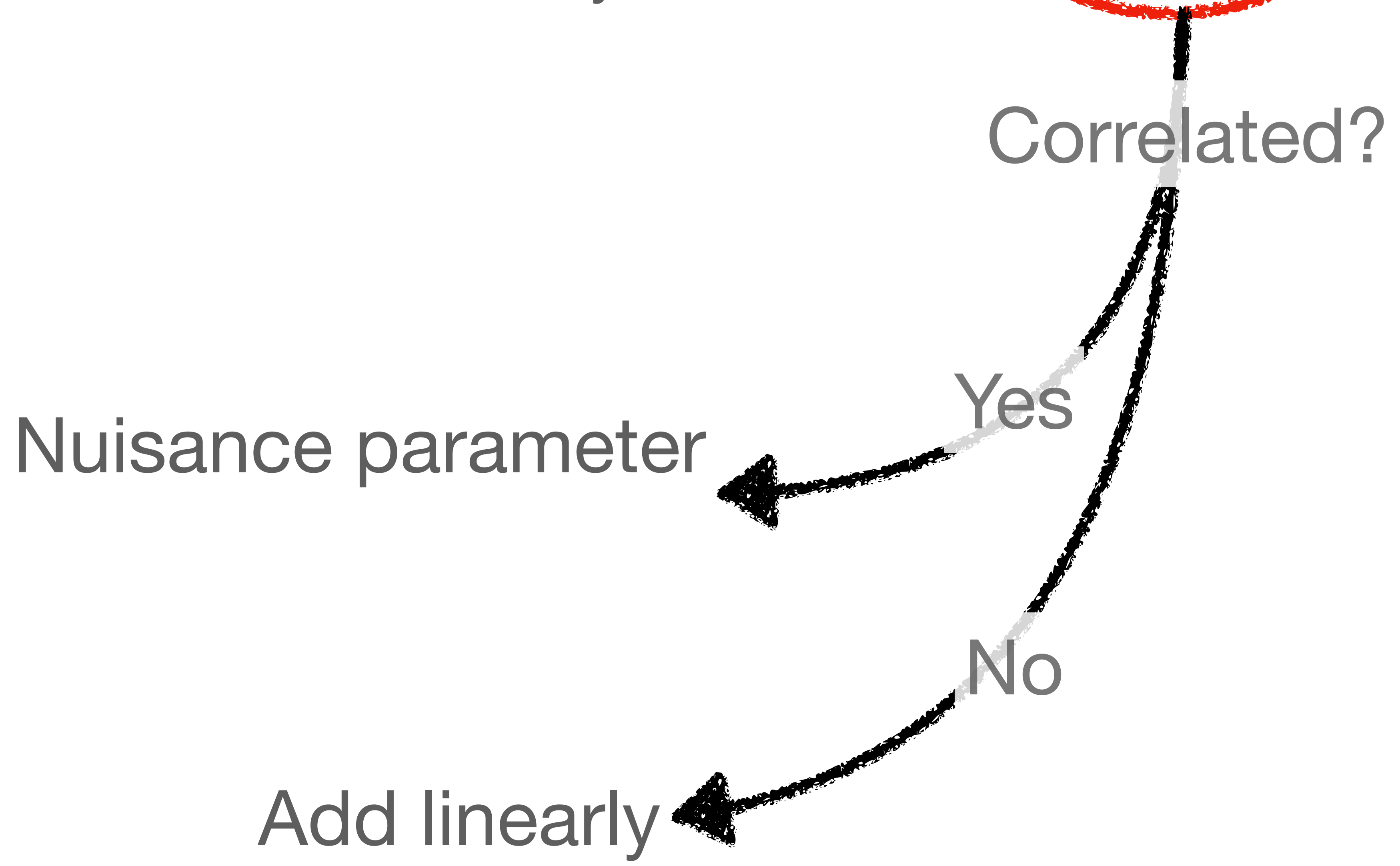
- Flat Uncertainties



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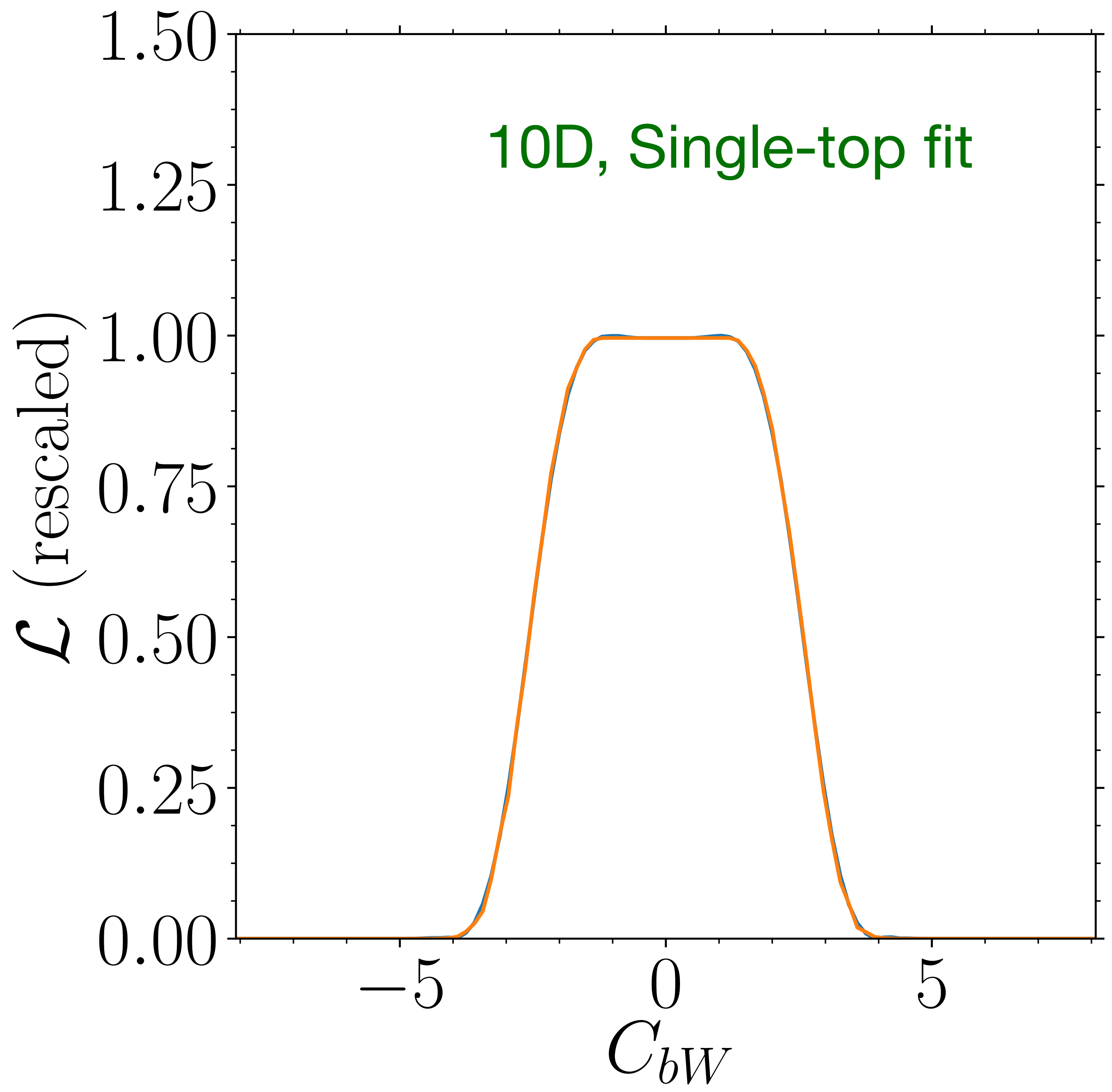


Correlated?

Yes → Nuisance parameter

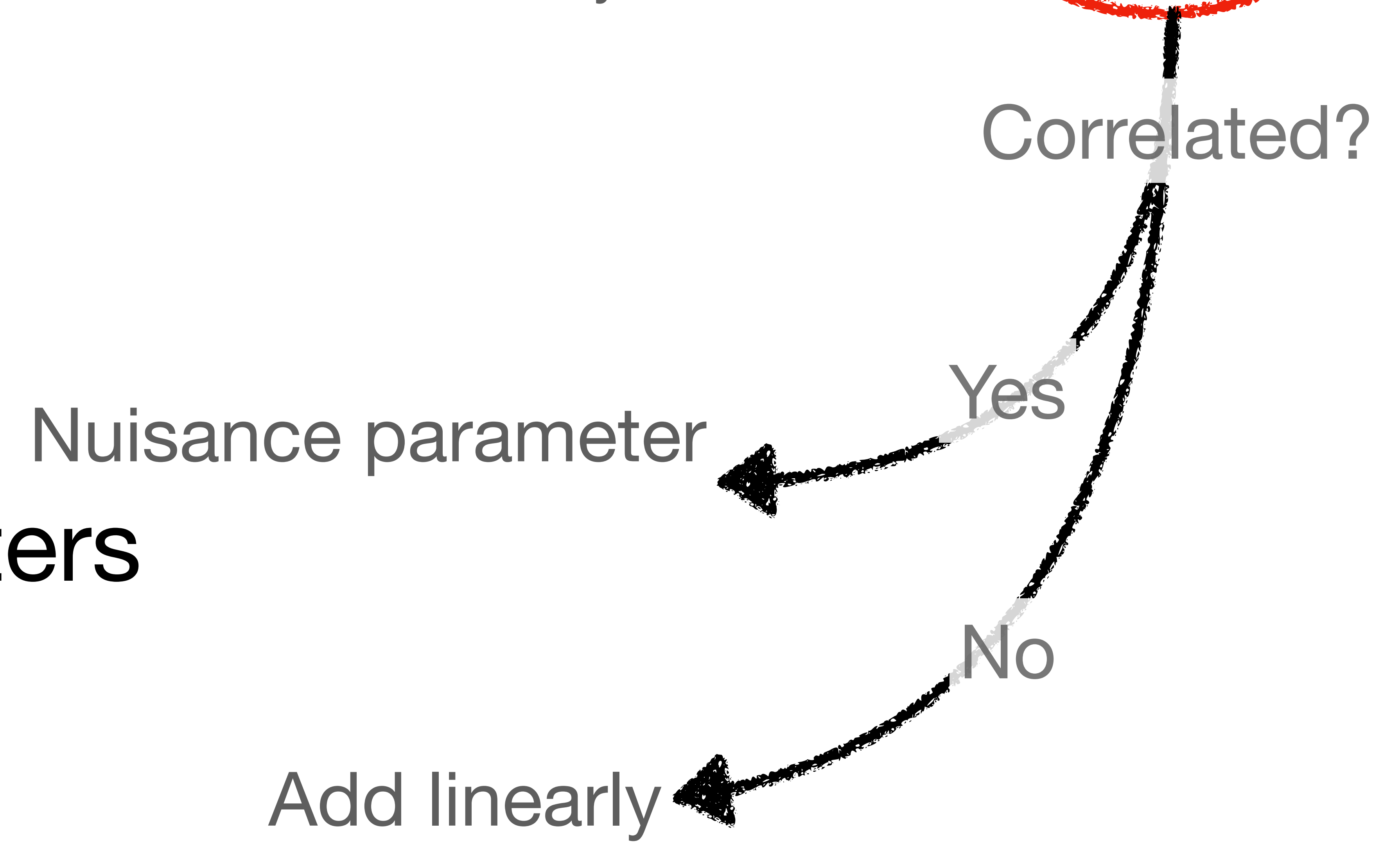
No → Add linearly

Uncertainties

What matters?

$$\mu_j = \bar{\mu}_j \pm \sigma_{\text{pois},j} \pm \sigma_{\text{gauss},j} \pm \sum_i \sigma_{\text{syst},ij} \pm \sigma_{\text{theo},j}$$

Central Value — Statistical Uncertainty — Uncorrelated systematic Uncertainty — Correlated systematics Uncertainty — Flat Uncertainties



- Conservative and ignorant
- Better: e.g. include as nuissance parameters

Summary

What really matters!

- We need Data!
  - at very high momentum
  - unfolded
  - precise
  - varied
- The model matters for the interpretation
- Uncertainties matter → the more information we have the better

SMEFT - the new Standard Model

Part III:
How different sectors interact in a global fit

Anke Biekoetter - IPPP Durham

Unterstützt von / Supported by
Alexander von Humboldt
Stiftung / Foundation

KITP Precision21 - 23 March 2021

SMEFT - the new Standard Model

- Part I: SMEFT basics - Veronica
- Part II: Global fits - Sebastian

- How different sectors interact in a global fit

  Higgs + diboson combined with electroweak precision data

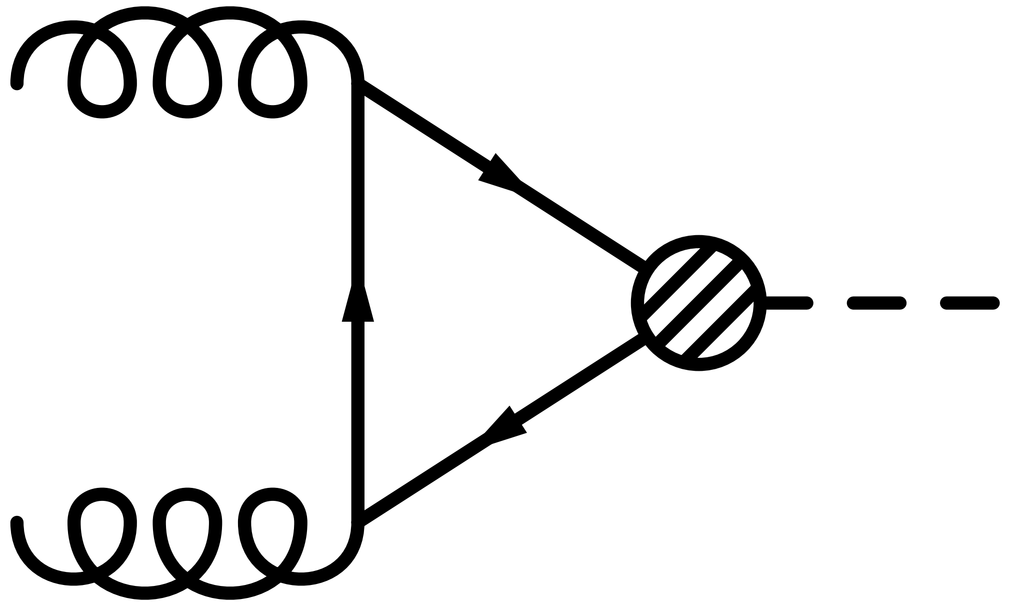
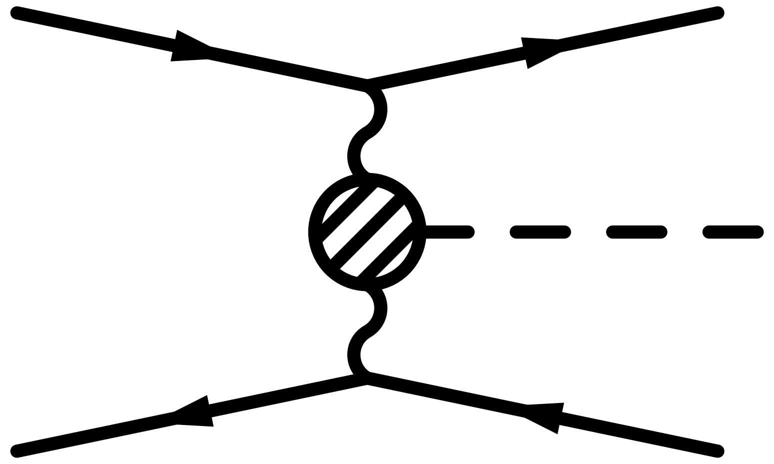
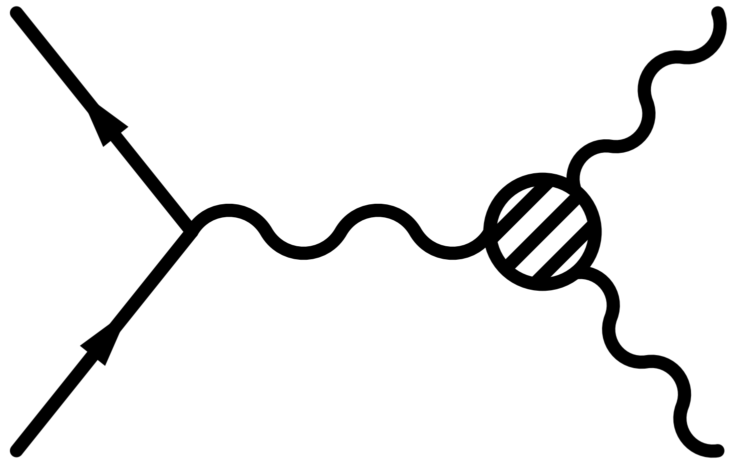
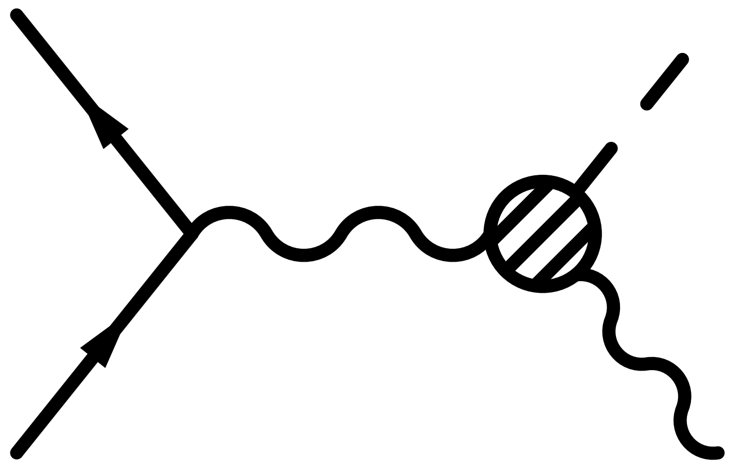
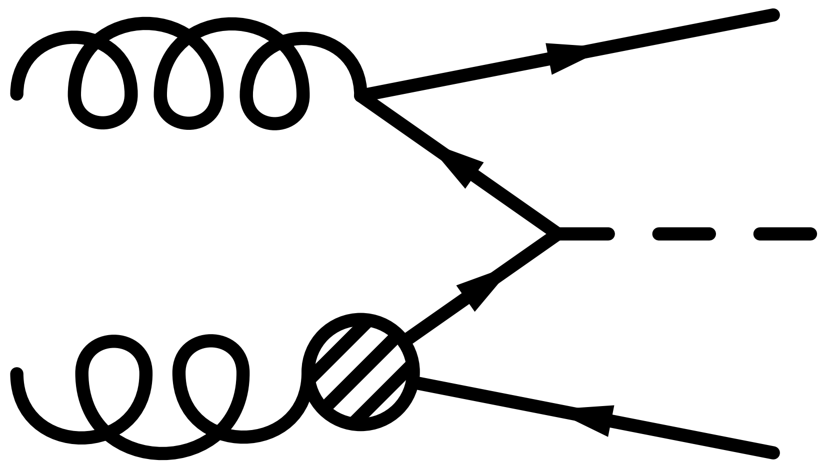
- Outlook: The future of global fits

SMEFT fits - a global effort!

Filled to my best knowledge - apologies for any mistakes

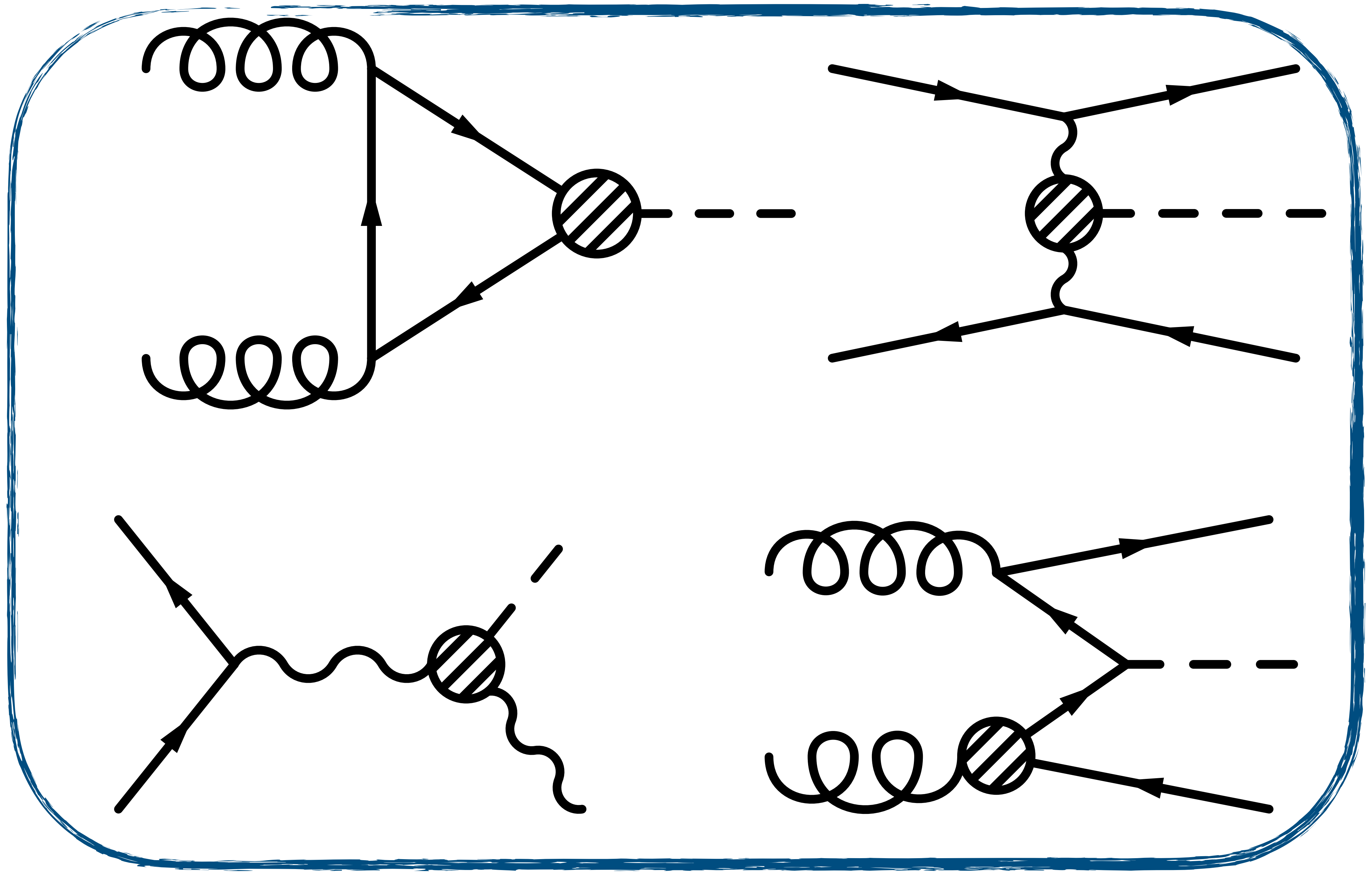
	Eboli, Gonzalez-Garcia et al	Fitmaker	SFitter	TopFitter	HEPfit	SMEFit	Dawson et al.	Chakrabortty et al.
Input	EWPD+Higgs+VV, DY +VV	EWPD+Higgs+VV + top	EWPD+Higgs+VV, top	top	EWPD+Higgs+VV Flavor	EWPD+Higgs+VV, VBS + diboson, top	EWPD+Higgs+VV	EWPD + Higgs
Linear/ quadratic	Both	Linear	Both	Linear	Linear	Both	Linear	Linear
Basis	HISZ	Warsaw	HISZ (Higgs) Warsaw (top)	Warsaw	Warsaw	Warsaw	Warsaw	Warsaw
EW scheme	Alpha	Alpha	Alpha	-	Alpha	mW	mW	Alpha
Flavor assumptions	$SU(3)^5$	$SU(3)^5$ $SU(2)^2 \times SU(3)^3$	$SU(3)^5$ $SU(2)^2 \times SU(3)^3$	$SU(3)^5$	$SU(3)^5$ general	$SU(2)^2 \times SU(3)^3$	$SU(2)^2 \times SU(3)^3$	$SU(3)^5$
NLO QCD included	LO	Top only	Top only	LO	LO	Top only	Vh, diboson, EWPO	EWPO only
Fitting procedure	Chi2	Bayesian	Toy MC, Chi2, Bayesian	Chi2	Bayesian	Toy MC	Chi2	Bayesian
Uncertainties	Gaussian, theory correlated	Gauss	Gauss, Poisson, flat	Gauss	(Asymmetric) Gauss, flat	Gauss	Gauss, uncorrelated	Gauss
UV complete model fits	✗	✓	✓	✓	✓	✗	✓	✓
Specialties	VV + DY	Higgs + EWPO + top + diboson	Correlation of uncertainty classes	Top	Projections	CP odd operators VBS	NLO for VV and Vh	UV complete models
References	1211.4580, 1509.01585, 1805.11108, 1812.01009	1404.3667, 1803.03252, 2012.02779	1308.1979, 1505.05516, 1604.03105, 1812.07587, 1910.03606	1506.08845, 1512.03360, 1901.03164	1710.0540, 1905.03764, 1907.04311, 1910.14012	1901.05965, 1906.05296, 2101.03180	2007.01296	2009.13394, 2010.04088, 2012.03839

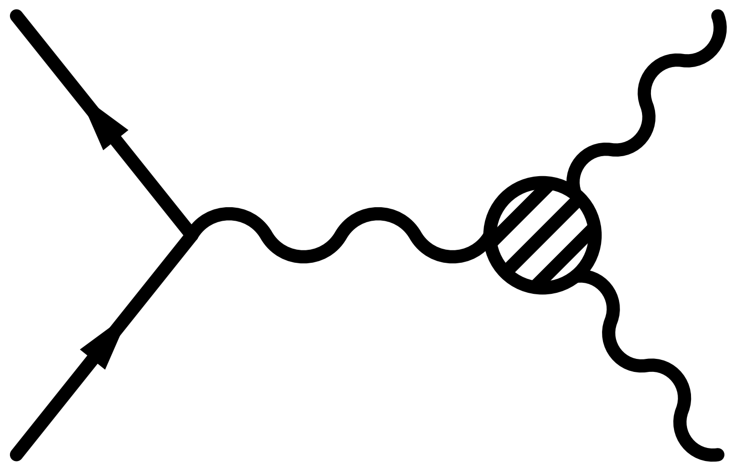
Interplay of two sectors

Interplay of two sectors

Higgs





Interplay of two sectors

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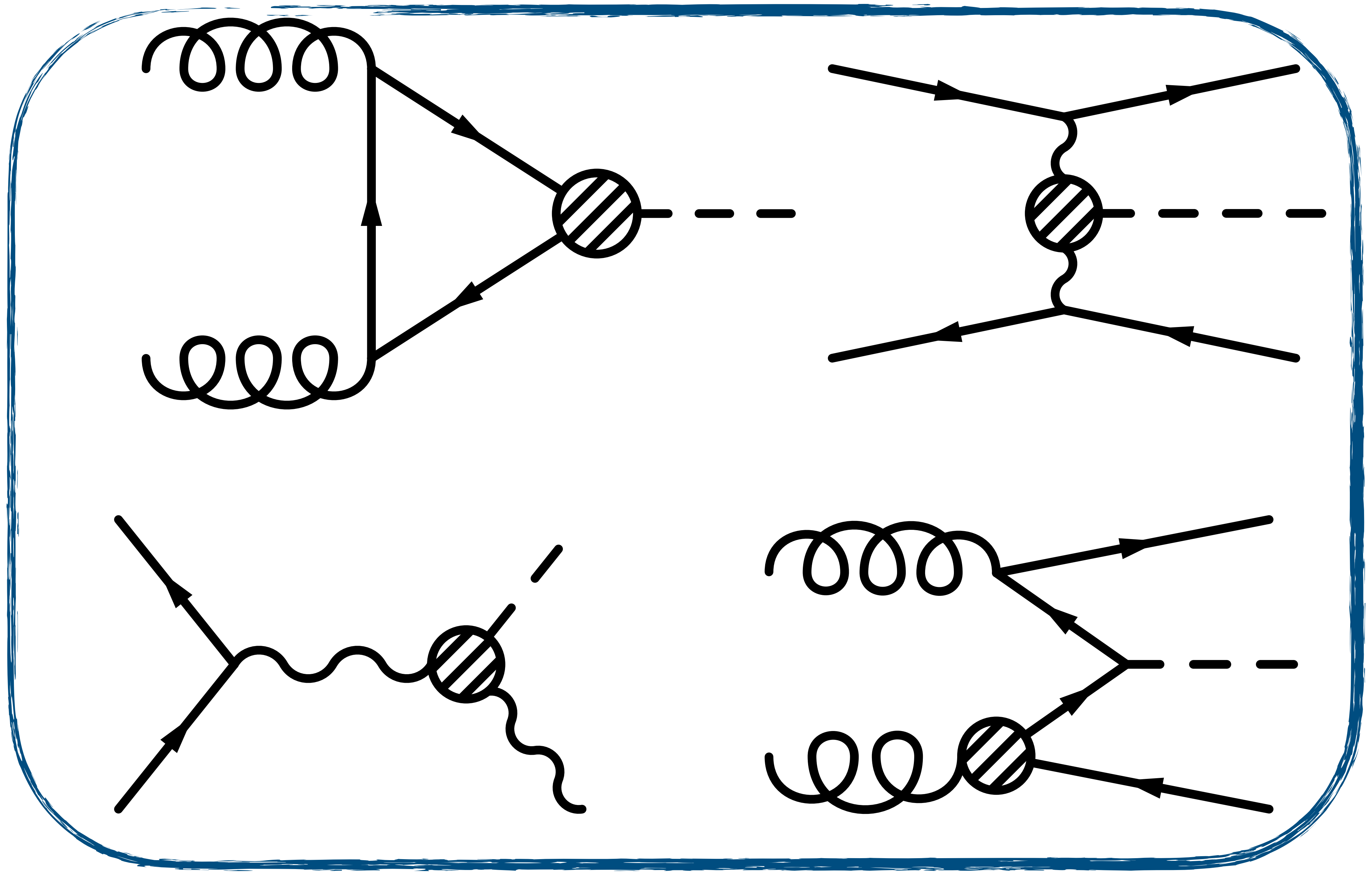
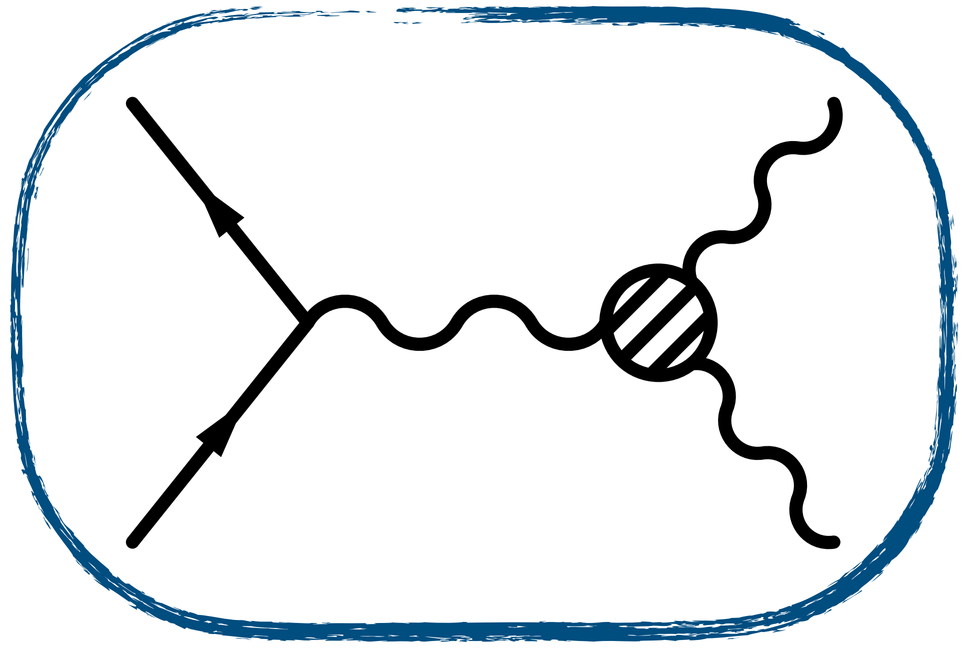
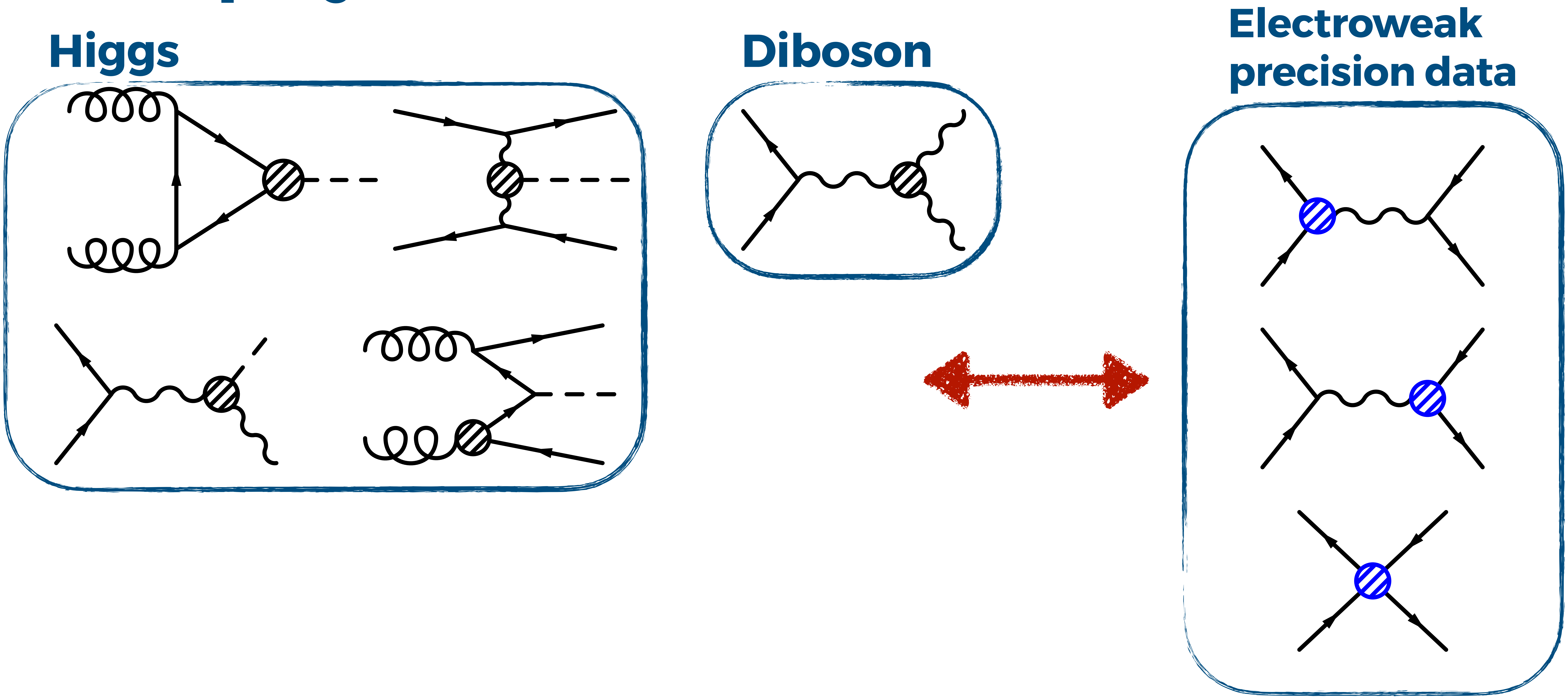


Diboson



Interplay of two sectors



Interplay of two sectors

Higgs

Diboson

Electroweak precision data

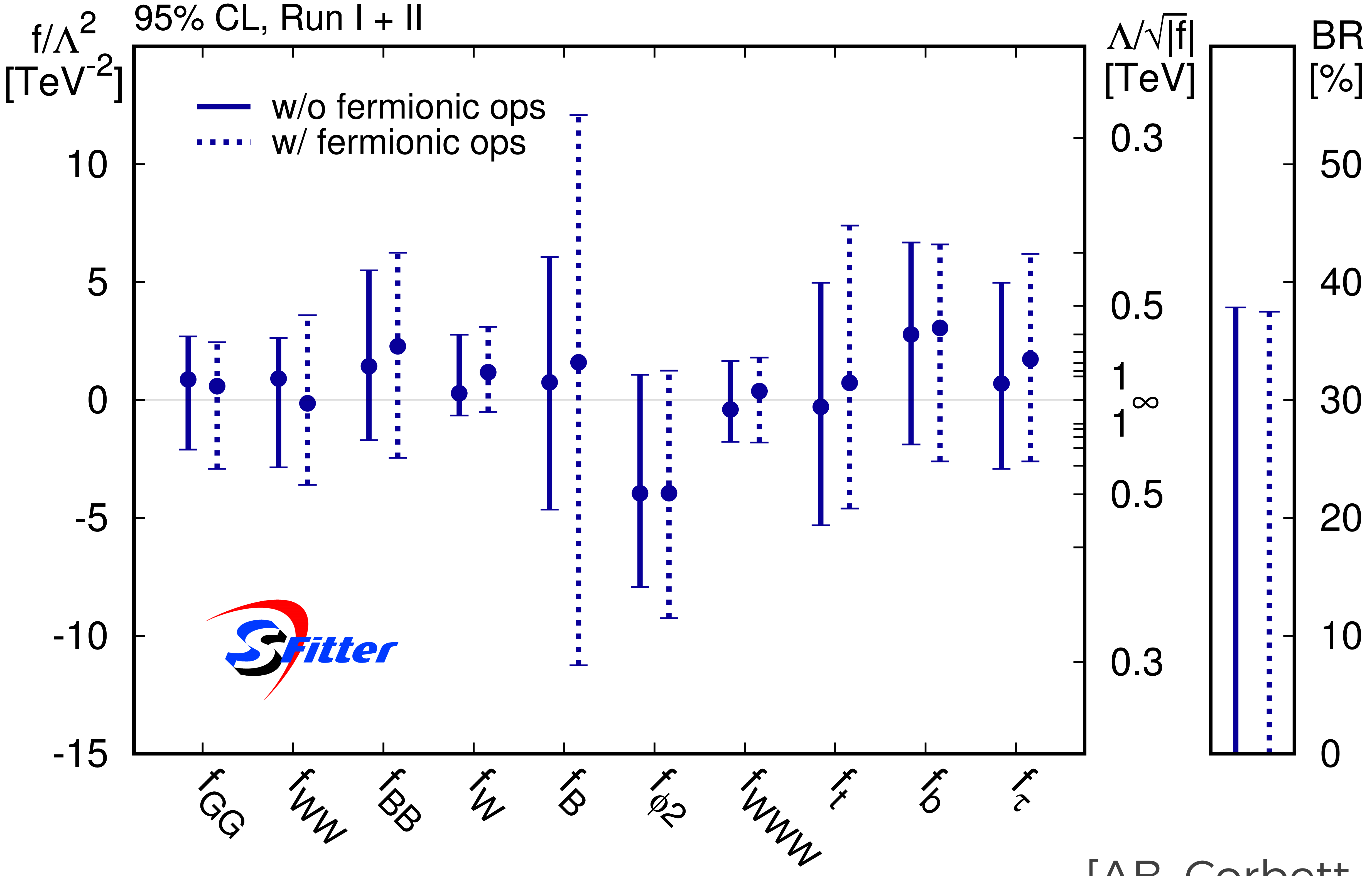
Interplay of two sectors

What is the impact of fermion-gauge couplings on a global fit of Higgs + diboson data?

LHC Run II fit - fermion-gauge operators

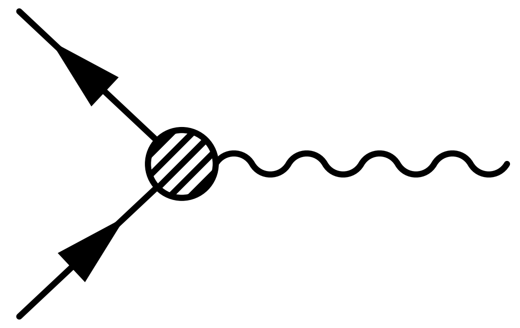
[Hagiwara-Ishihara-Szalapski-Zeppenfeld basis]

$$\mathcal{O}_{GG} = \phi^\dagger\phi\, G^a_{\mu\nu}G^{a\mu\nu}$$
$$\mathcal{O}_{WW} = \phi^\dagger\hat{W}_{\mu\nu}\hat{W}^{\mu\nu}\phi$$
$$\mathcal{O}_{BB} = \phi^\dagger\hat{B}_{\mu\nu}\hat{B}^{\mu\nu}\phi$$
$$\mathcal{O}_{W} = (D_\mu\phi)^\dagger\hat{W}^{\mu\nu}(D_\nu\phi)$$
$$\mathcal{O}_{B} = (D_\mu\phi)^\dagger\hat{B}^{\mu\nu}(D_\nu\phi)$$
$$\mathcal{O}_{\phi 2} = \frac{1}{2}\partial^\mu(\phi^\dagger\phi)\partial_\mu(\phi^\dagger\phi)$$
$$\mathcal{O}_{WWW} = \mathrm{Tr}\left(\hat{W}_{\mu\nu}\hat{W}^{\nu\rho}\hat{W}^\mu_\rho\right)$$
$$\mathcal{O}_{\tau} = \phi^\dagger\phi\, \bar{L}_3\phi e_{R,3}$$
$$\mathcal{O}_{t} = \phi^\dagger\phi\, \bar{Q}_3\tilde{\phi}u_{R,3}$$
$$\mathcal{O}_{b} = \phi^\dagger\phi\, \bar{Q}_3\phi d_{R,3}$$



[AB, Corbett, Plehn (1812.07587)]

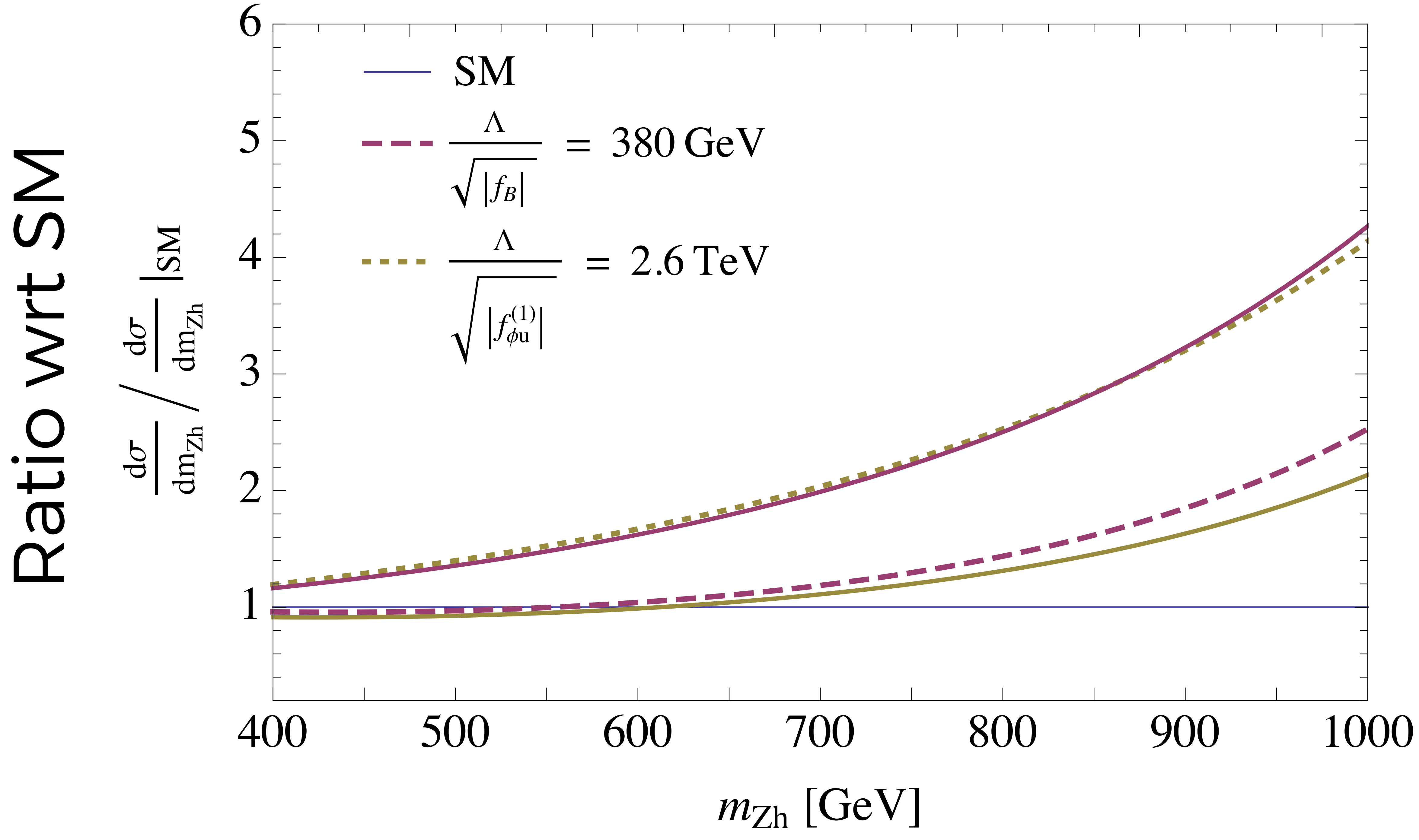
Adding more freedom

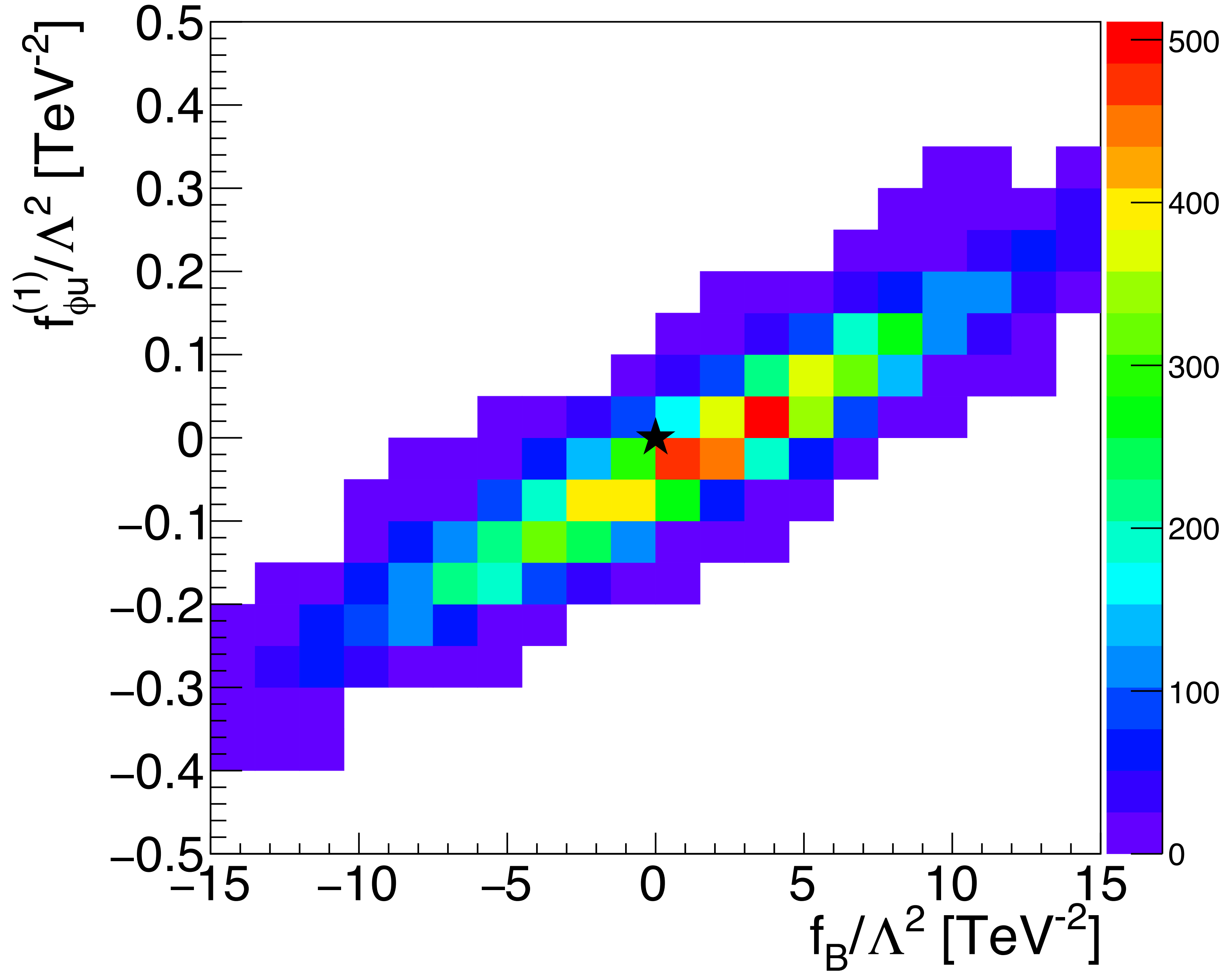


$$\mathcal{O}_{\phi 1} = (D_\mu\phi)^\dagger\,\phi\phi^\dagger\,(D^\mu\phi) \qquad \mathcal{O}_{BW} = \phi^\dagger\hat{B}_{\mu\nu}\hat{W}^{\mu\nu}\phi$$
$$\mathcal{O}^{(1)}_{\phi Q} = \phi^\dagger(i\overleftrightarrow{D}_\mu\phi)(\bar{Q}\gamma^\mu Q) \qquad \mathcal{O}^{(3)}_{\phi Q} = \phi^\dagger(i\overleftrightarrow{D^a}_\mu\phi)(\bar{Q}\gamma^\mu\sigma^a Q) \qquad \mathcal{O}^{(1)}_{\phi u} = \phi^\dagger(i\overleftrightarrow{D}_\mu\phi)(\bar{u}_R\gamma^\mu u_R)$$
$$\mathcal{O}^{(1)}_{\phi d} = \phi^\dagger(i\overleftrightarrow{D}_\mu\phi)(\bar{d}_R\gamma^\mu d_R) \qquad \mathcal{O}^{(1)}_{\phi e} = \phi^\dagger(i\overleftrightarrow{D}_\mu\phi)(\bar{e}_R\gamma^\mu e_R) \qquad \mathcal{O}_{LLLL} = (\bar{L}\gamma_\mu L)(\bar{L}\gamma^\mu L)$$

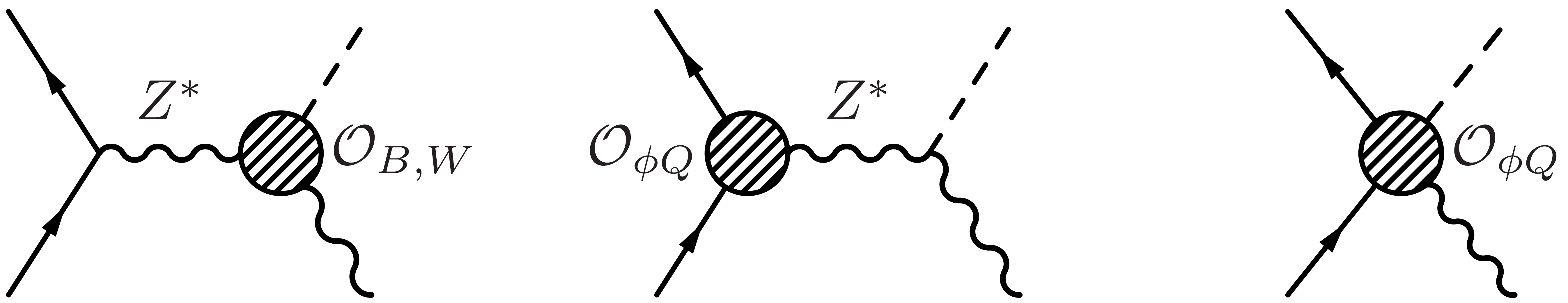
LHC Run II fit - correlations

[Banerjee et al (1807.01796)]
[AB, Corbett, Plehn (1812.07587)]





Contributions to Zh production



$$\mathcal{O}_B = (D_\mu\phi)^\dagger \hat{B}^{\mu\nu}(D_\nu\phi)$$
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$$\mathcal{O}^{(1)}_{\phi Q} = \phi^\dagger(i\overleftrightarrow{D}_\mu\phi)(\bar{Q}\gamma^\mu Q)$$
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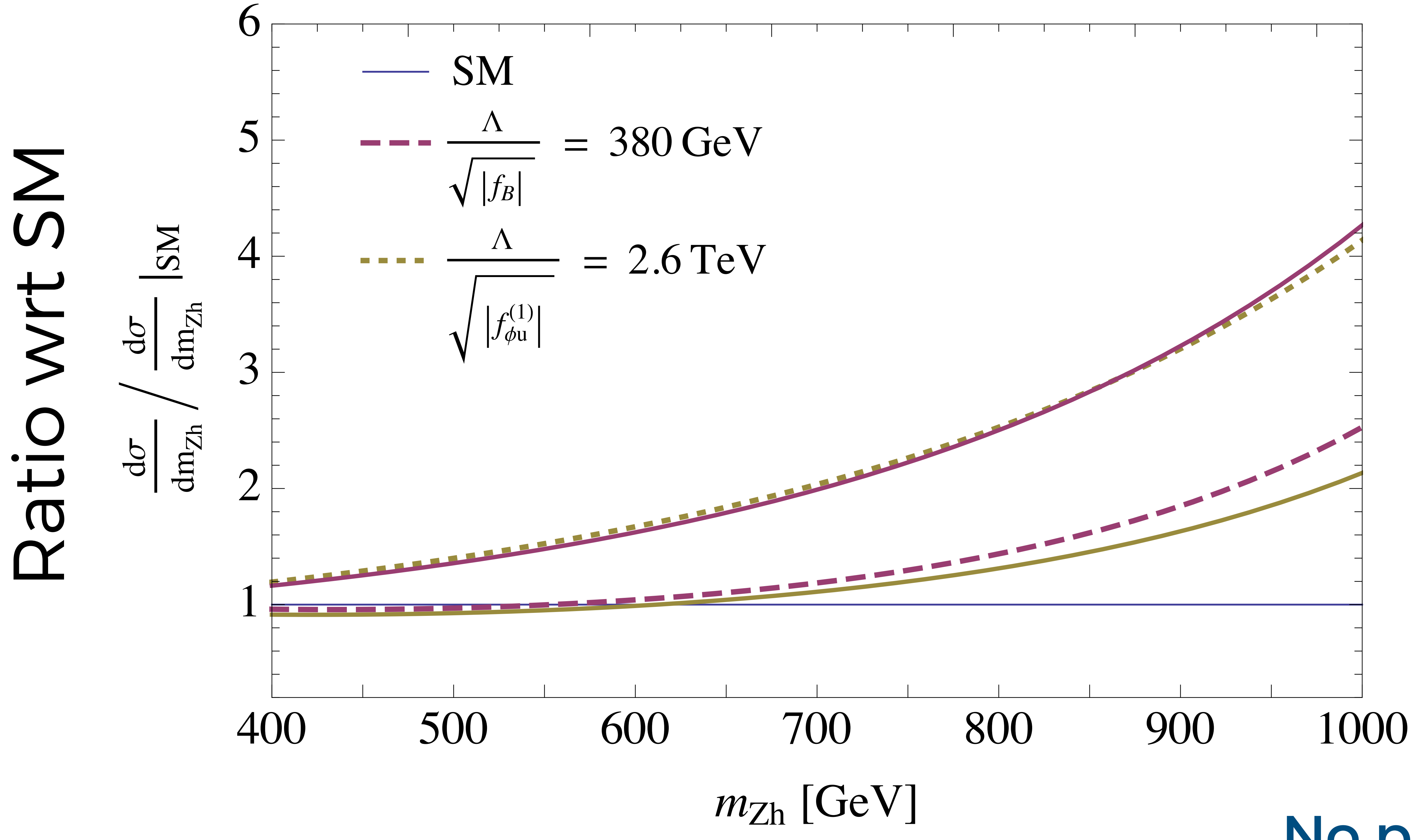
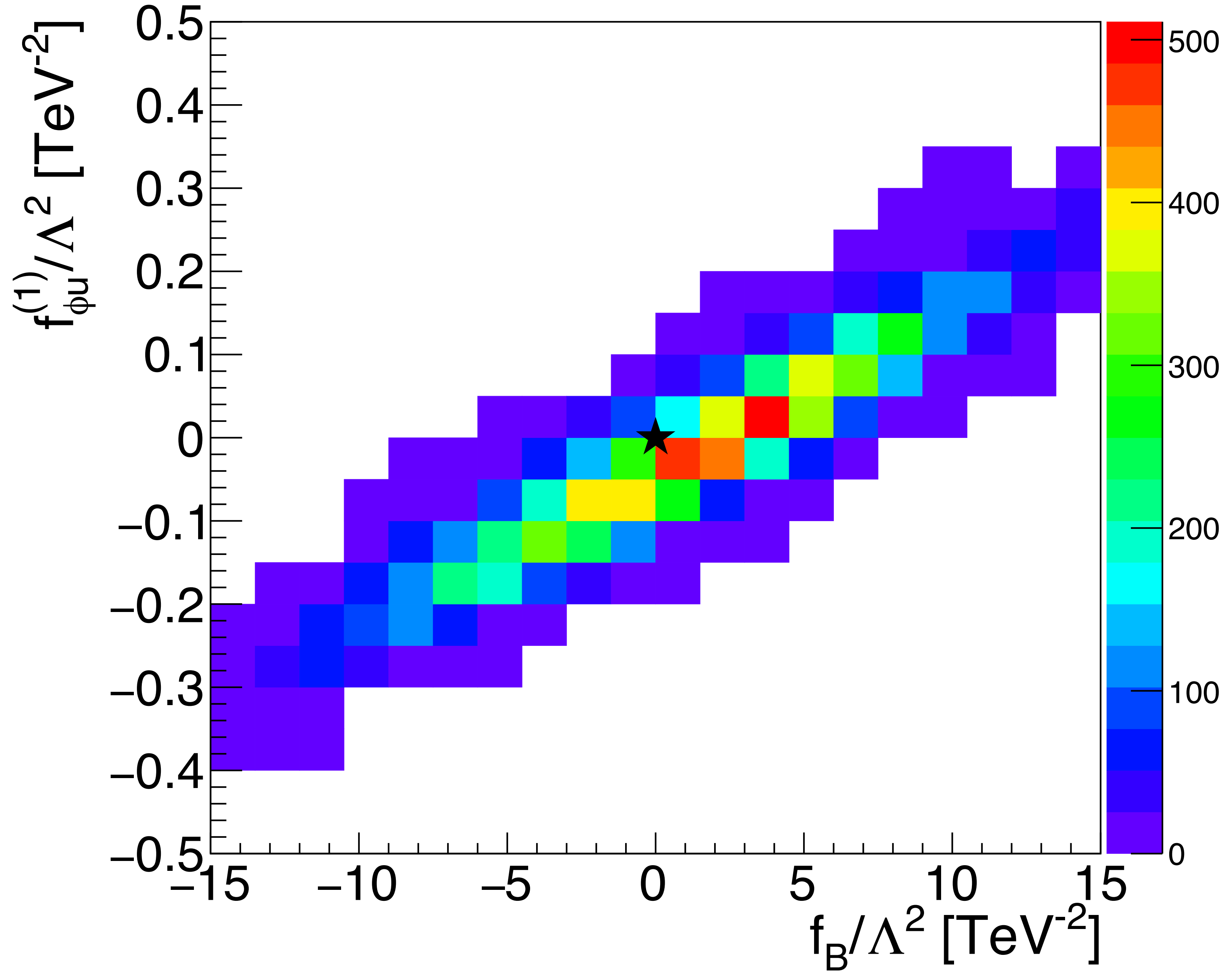
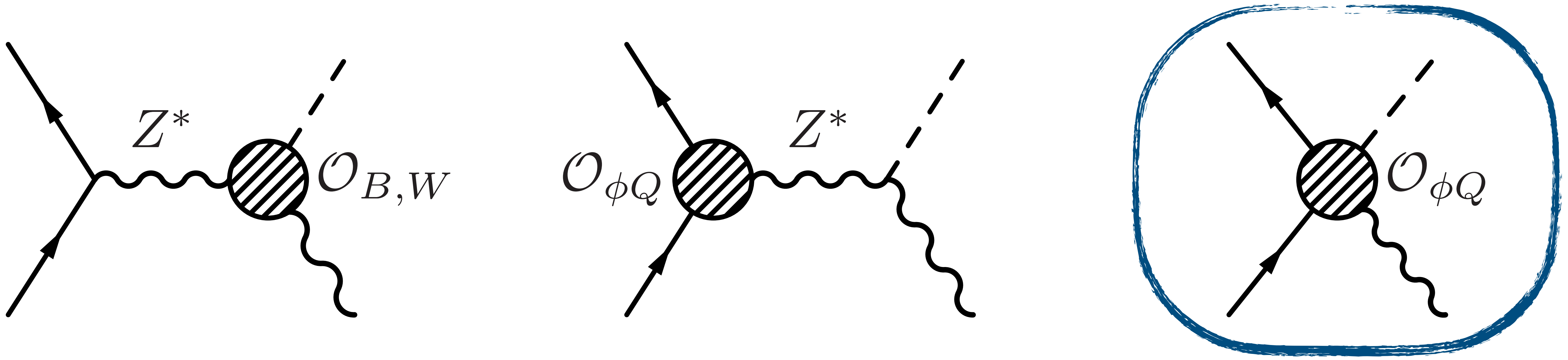
[Banerjee et al (1807.01796)]
[AB, Corbett, Plehn (1812.07587)]





Contributions to Zh production

No propagator suppression



$$\mathcal{O}_B = (D_\mu\phi)^\dagger \hat{B}^{\mu\nu}(D_\nu\phi)$$
$$\mathcal{O}_W = (D_\mu\phi)^\dagger \hat{W}^{\mu\nu}(D_\nu\phi)$$
$$\mathcal{O}_{\phi Q}^{(1)} = \phi^\dagger(i\overleftrightarrow{D}_\mu\phi)(\bar{Q}\gamma^\mu Q)$$
$$\mathcal{O}_{\phi Q}^{(3)} = \phi^\dagger(i\overleftrightarrow{D}^a{}_\mu\phi)(\bar{Q}\gamma^\mu\sigma^a Q)$$

LHC Run II fit - tighter limits on fermion-gauge operators

$$\mathcal{O}_{\phi 1} = (D_\mu \phi)^\dagger \, \phi\phi^\dagger \, (D^\mu \phi)$$

$$\mathcal{O}_{BW} = \phi^\dagger \hat{B}_{\mu\nu} \hat{W}^{\mu\nu} \phi$$

$$\mathcal{O}^{(1)}_{\phi Q} = \phi^\dagger (i \overleftrightarrow{D}_\mu \phi)(\bar{Q}\gamma^\mu Q)$$

$$\mathcal{O}^{(3)}_{\phi Q} = \phi^\dagger (i \overleftrightarrow{D}^a{}_\mu \phi)(\bar{Q}\gamma^\mu \sigma^a Q)$$

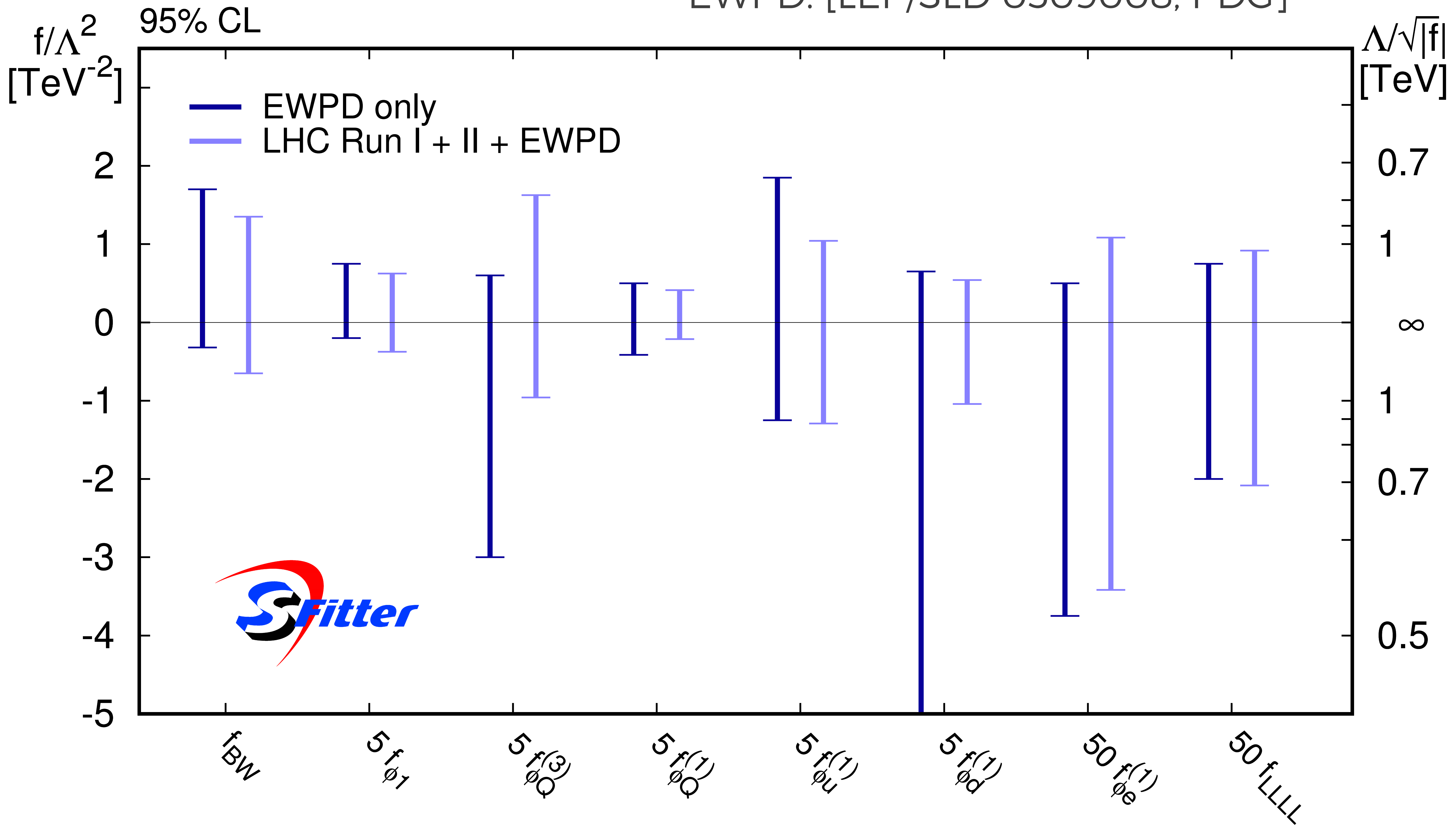
$$\mathcal{O}^{(1)}_{\phi u} = \phi^\dagger (i \overleftrightarrow{D}_\mu \phi)(\bar{u}_R\gamma^\mu u_R)$$

$$\mathcal{O}^{(1)}_{\phi d} = \phi^\dagger (i \overleftrightarrow{D}_\mu \phi)(\bar{d}_R\gamma^\mu d_R)$$

$$\mathcal{O}^{(1)}_{\phi e} = \phi^\dagger (i \overleftrightarrow{D}_\mu \phi)(\bar{e}_R\gamma^\mu e_R)$$

$$\mathcal{O}_{LLLL} = (\bar{L}\gamma_\mu L)(\bar{L}\gamma^\mu L)$$

EWPD: [LEP/SLD 0509008, PDG]



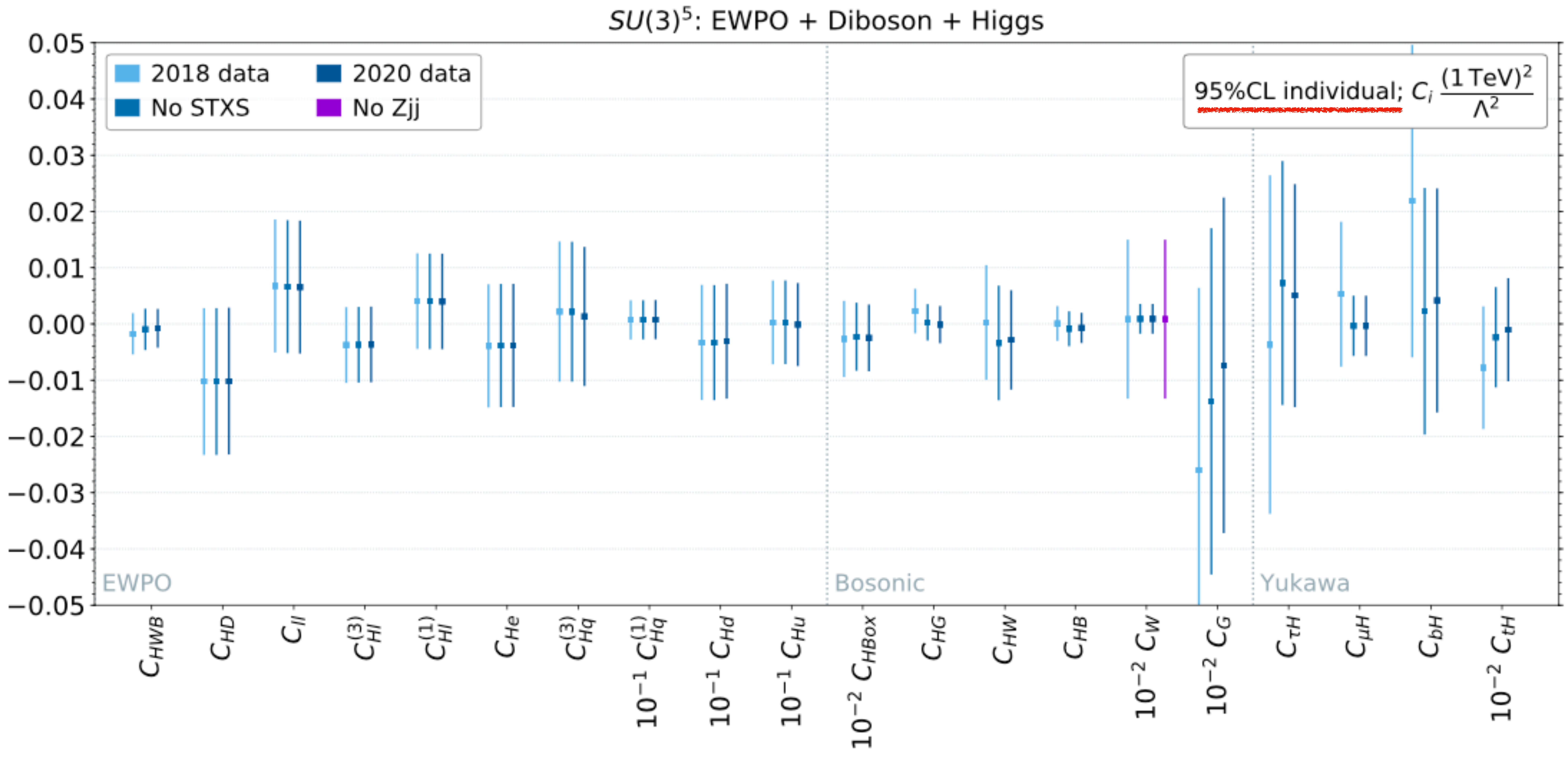
Limits on fermion-gauge operators improved or shifted towards SM values by inclusion of Higgs data

Recent developments in global SMEFT fits

Recent developments I - adding new channels

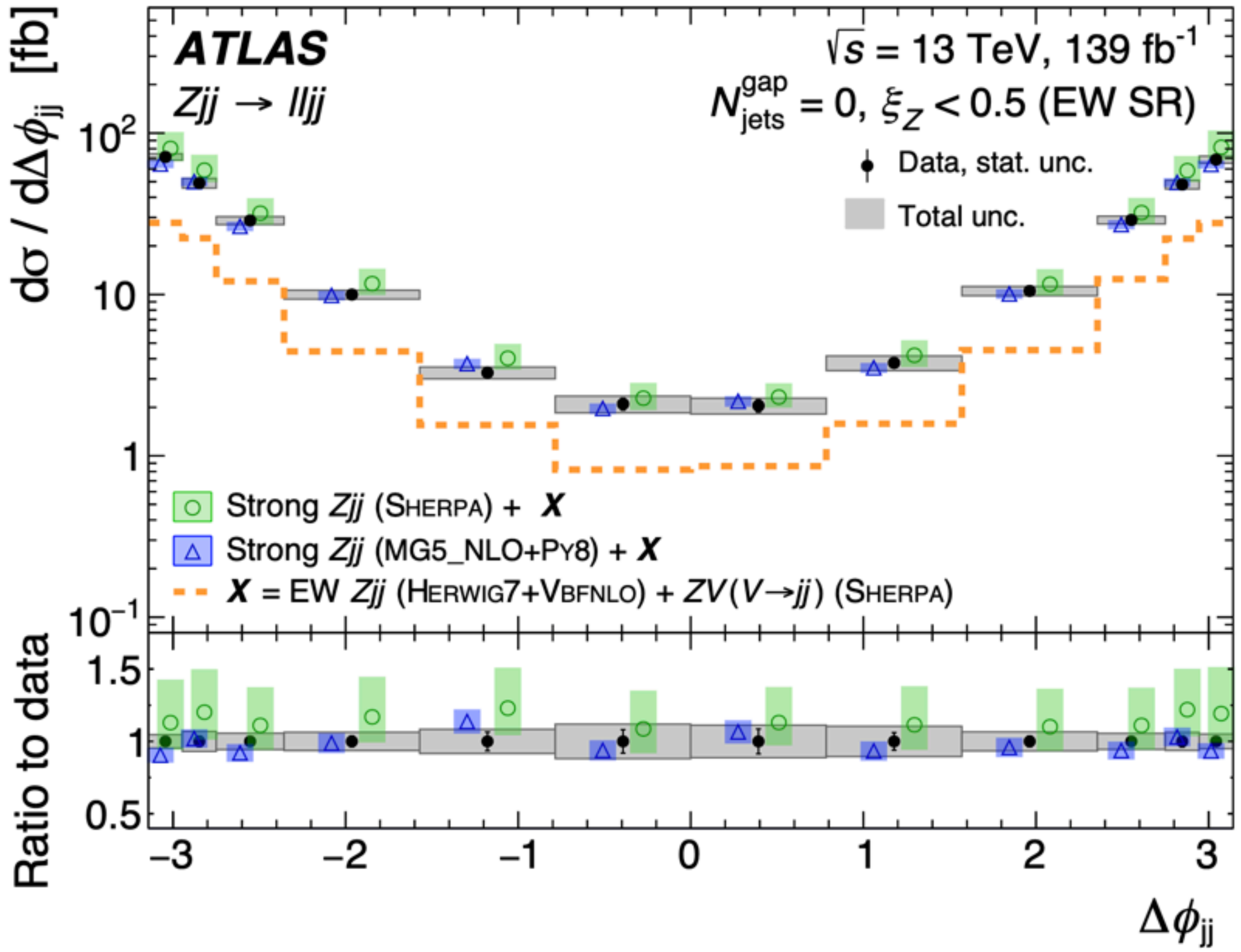
Adding a single new channel can have a sizeable impact for some operators, e.g. $Zjj\,(\Delta\phi_{jj})$

[Ellis, Madigan, Mimasu, Sanz, You (2012.02779)]



Comment: distributions at parton level

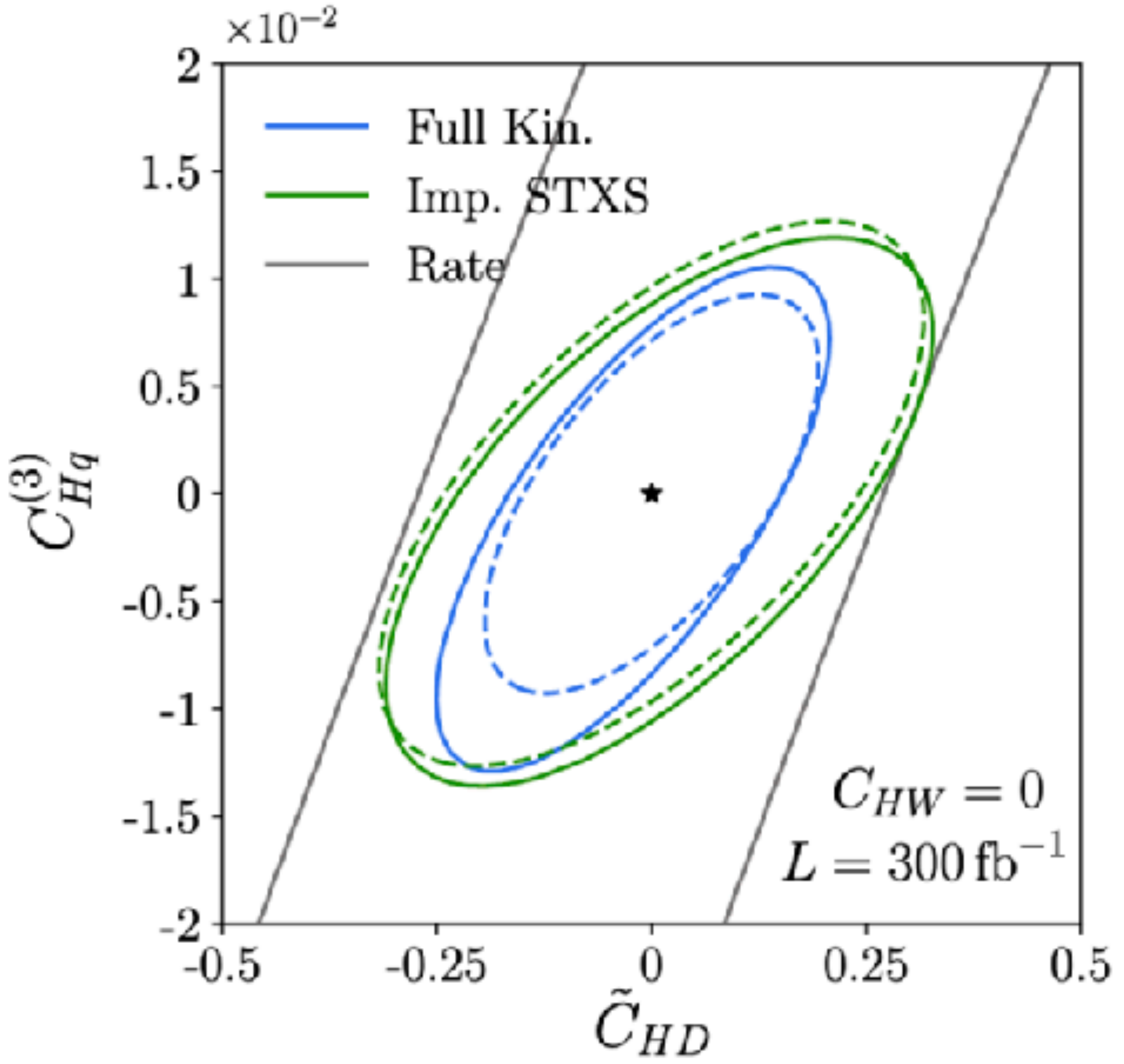
[ATLAS (2006.15458)]



Distributions at parton level are extremely powerful observables for SMEFT fits

Provided for the top sector, but rarely for the Higgs+EW sector (beyond Simplified Template Cross Sections)

[Brehmer et al (1908.06980)]

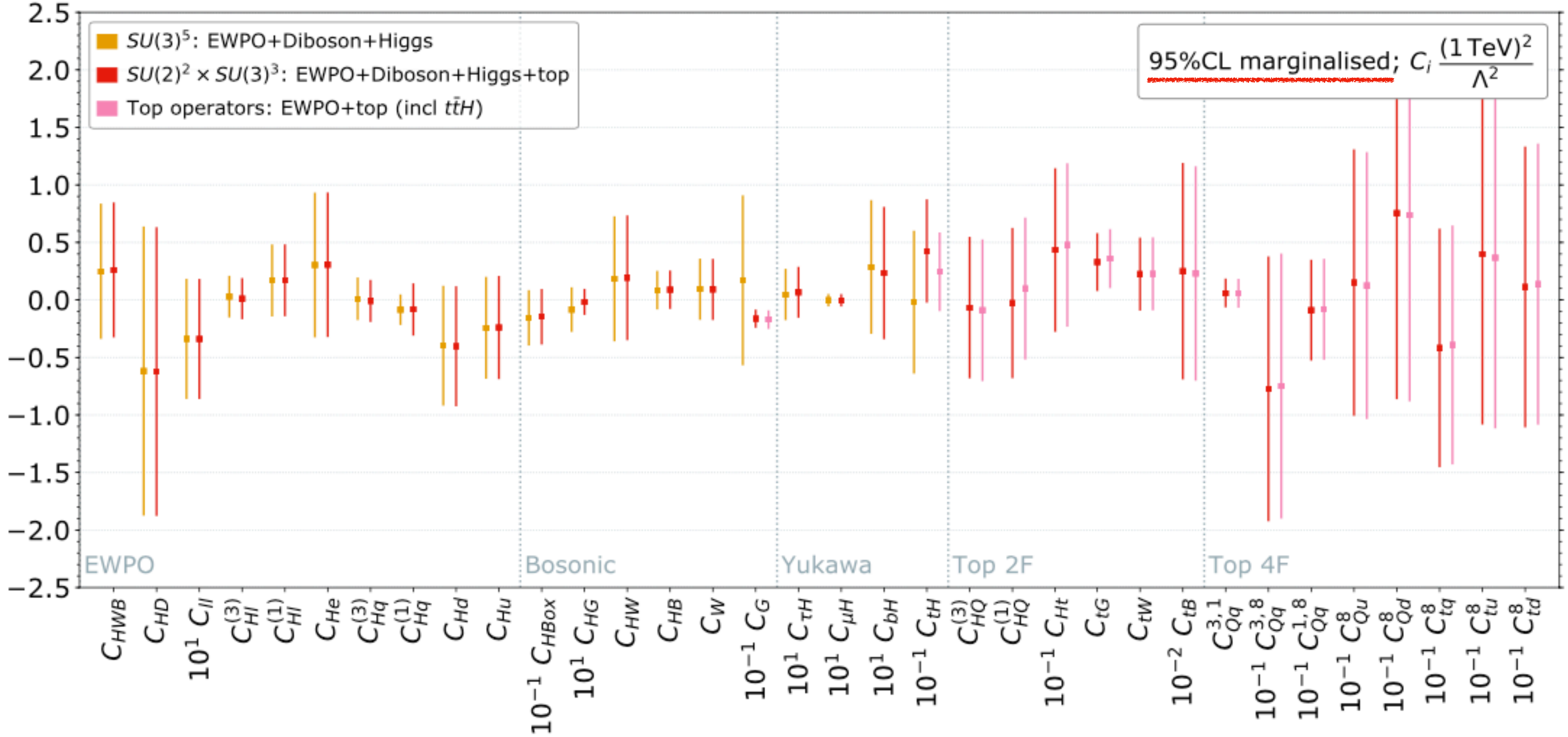


Wh production

Recent developments IIa - combination

Combining different sectors, e.g. top + Higgs

[Ellis, Madigan, Mimasu, Sanz, You (2012.02779)]



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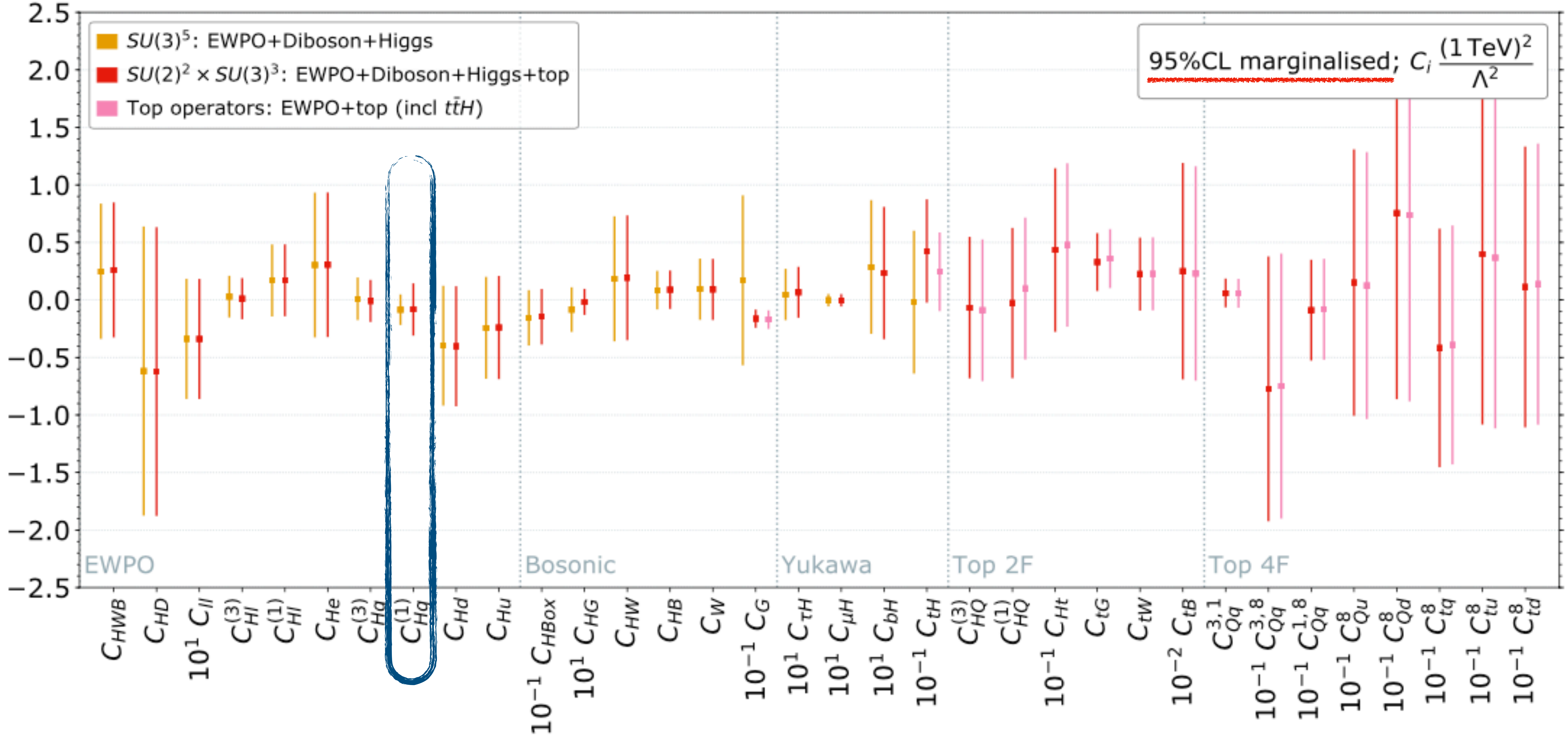
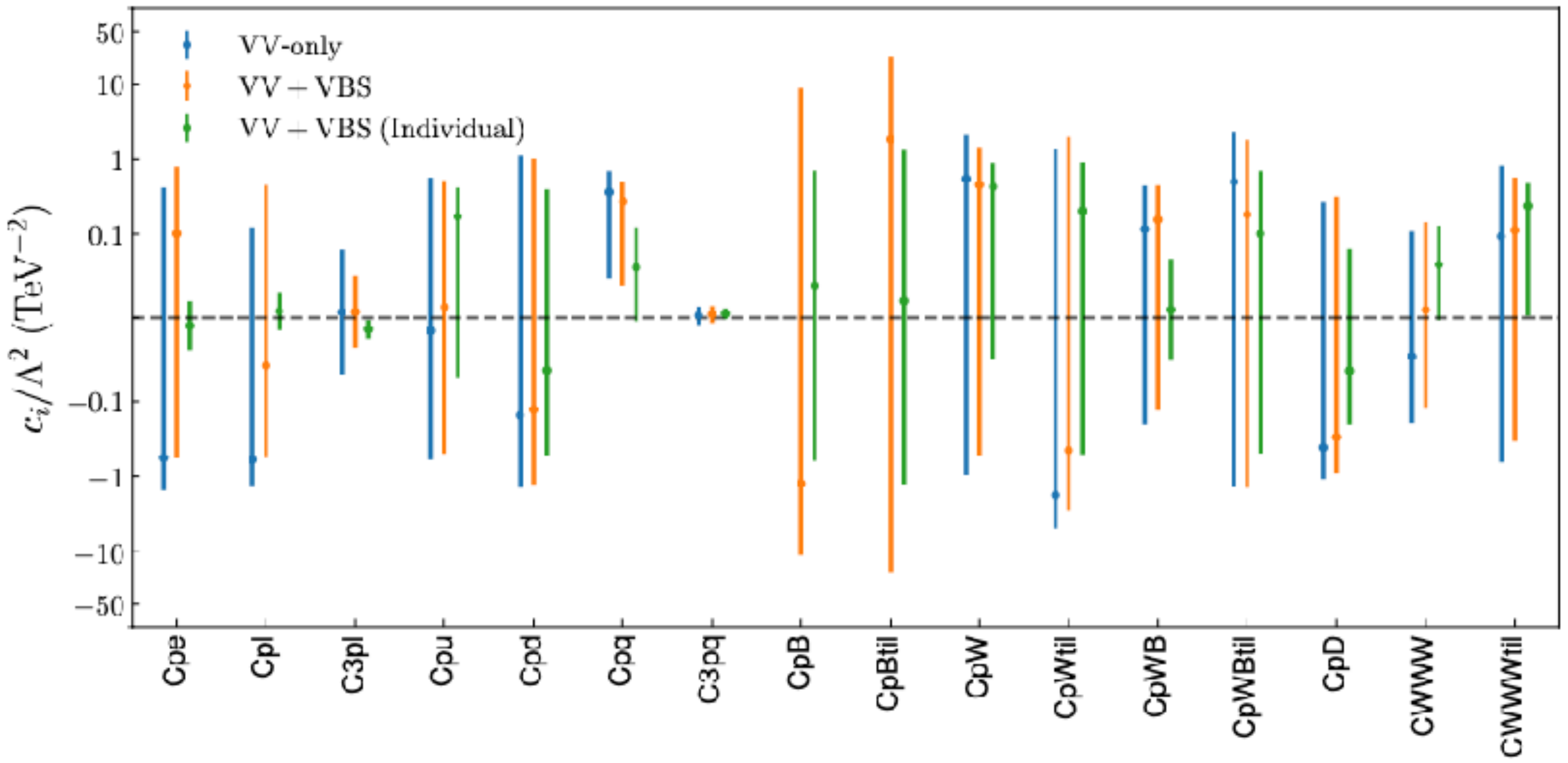
[Ellis, Madigan, Mimasu, Sanz, You (2012.02779)]



Recent developments IIb - combination

diboson (VV) + vector boson scattering (VBS)

[Ethier, Gomez-Ambrosio, Magni, Rojo (2101.03180)]



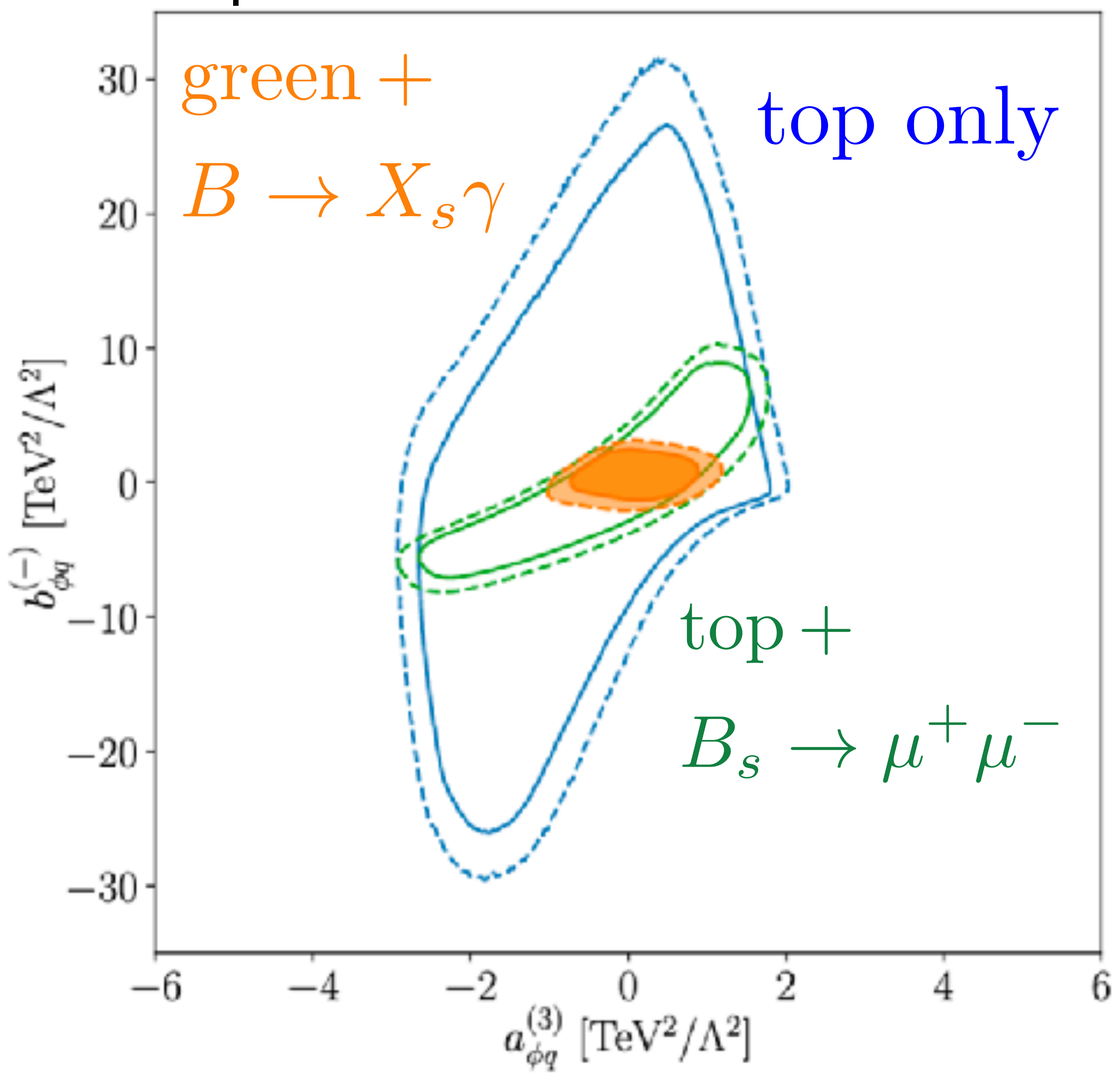
Most of these operators are, however, tightly constrained by Higgs + EWPO

Top + B physics

[Bißmann, (Erdmann), Grunwald, Hiller, Kröninger (1909.13632), (2012.10456)]

[Bruggisser, Schäfer, Westhoff, VanDyk (2101.07273)]

4 parameter fit in MFV



Study more general flavor assumptions

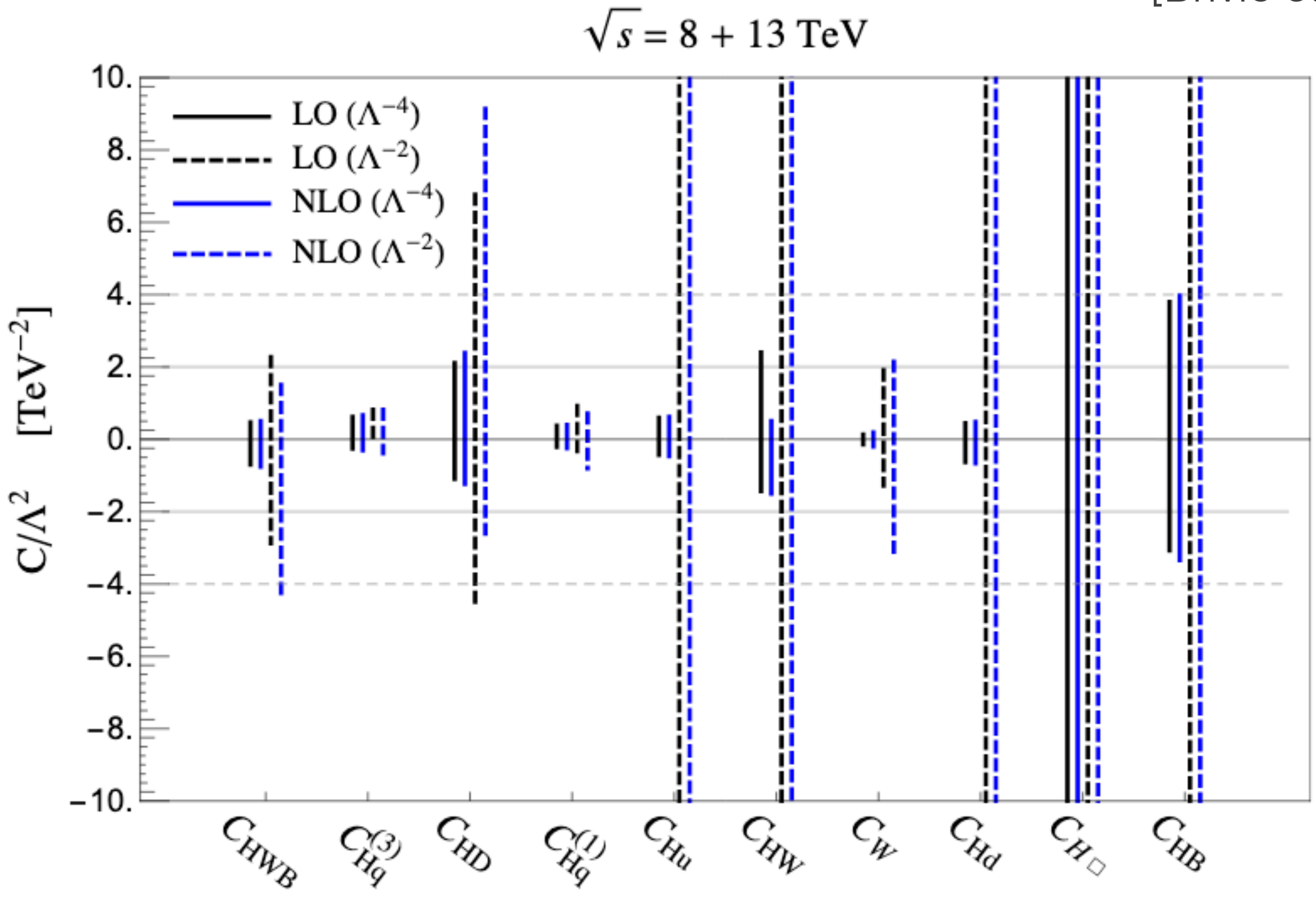
Recent developments III - NLO

[POWHEG: Baglio et al (2003.07862)]
[MG: Degrande et al. (2008.11743)]

[Hartland et al (1901.05965)]
[Ellis et al. (2012.02779)]
[Brivio et al. (1910.03606)]

Top

SMEFT @ NLO, e.g. NLO QCD for diboson + Vh



[Dawson, Homiller, Lane (2007.01296)]

Recent developments III - NLO

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Top

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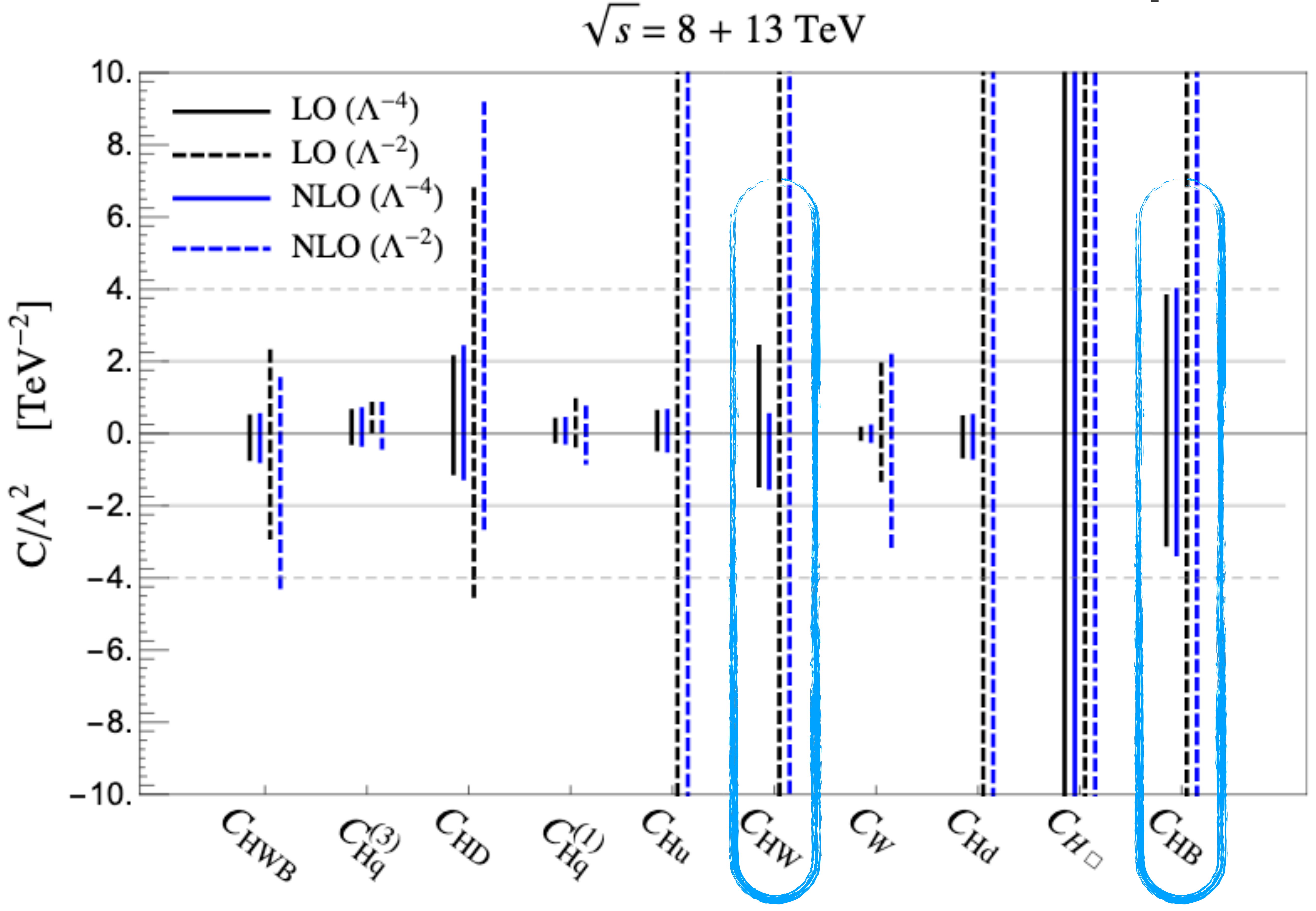


[Dawson, Homiller, Lane (2007.01296)]

UV complete model fits

- Map UV complete models onto EFT
  - Extended scalar sectors
  - Quark bidoublet model
  - Vector-singlet pair model
  - Vector-like quarks
  - …

[Anisha, Bakshi, Chakrabortty, Kumar Patra (2010.04088)]

[Ellis et al. (2012.02779)]

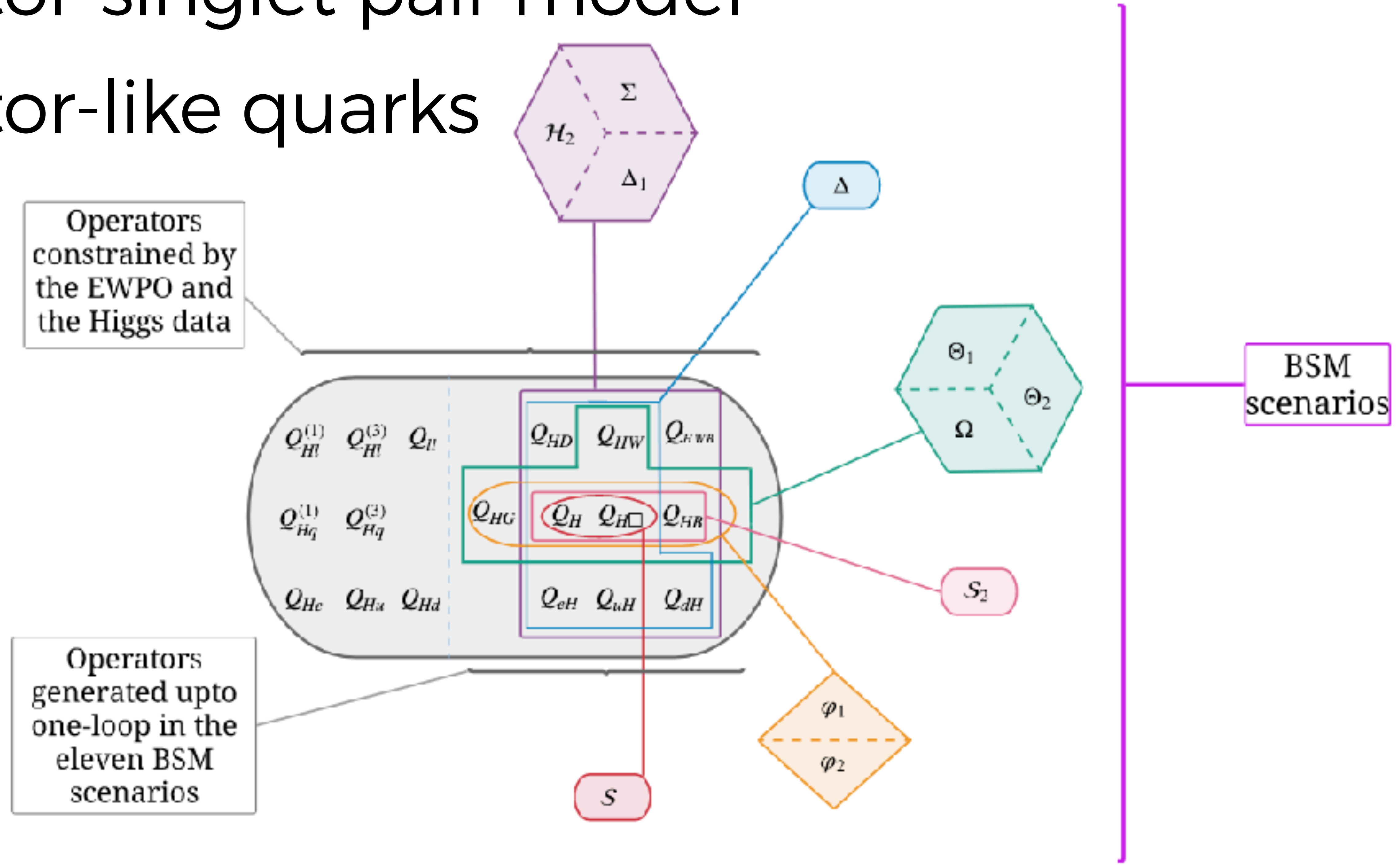
[Gorbahn, No, Sanz (1502.07352)]

[Drozd, Ellis, Quevillon, You (1504.02409)]

[Ellis, (Madigan, Mimasu, Murphy), Sanz, You (1803.03252), (2012.02779)]

[Dawson, Homiller, Lane (2007.01296), (2102.02823)]

[Bakshi, Chakrabortty, (Englert), Spannowsky, (Stylianou) (2009.13394), (2012.03839)]



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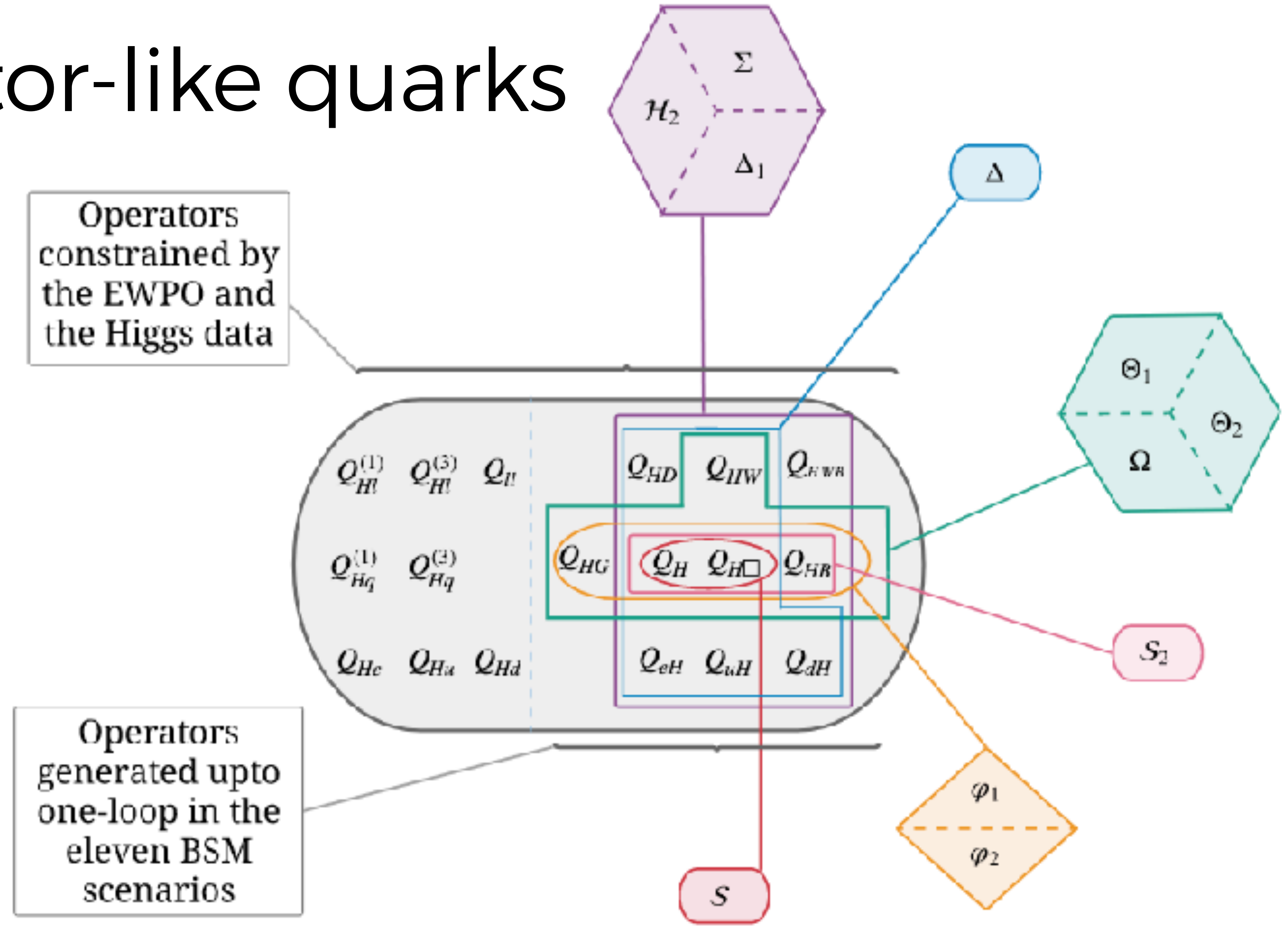


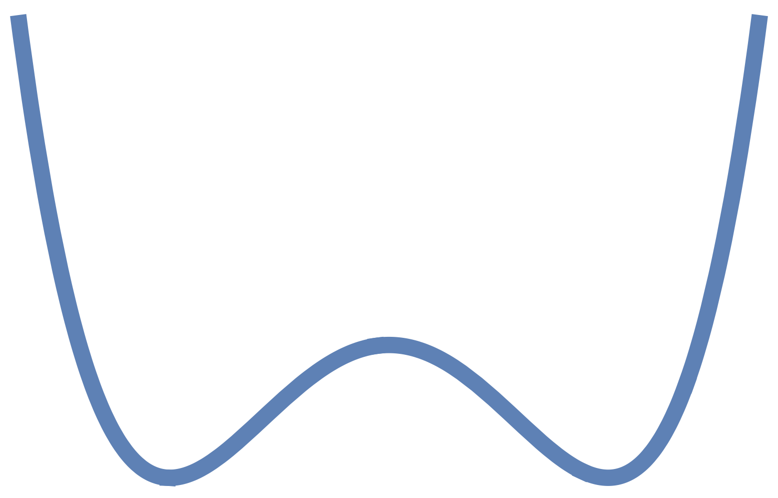
Model	C_{HD}	C_{ll}	C^3_{Hl}	C^1_{Hl}	C_{He}	$C_{H\Box}$	$C_{\tau H}$	C_{tH}	C_{bH}
S						-1			
S_1		1							
Σ			$\frac{5}{8}$	$\frac{3}{16}$			$\frac{y_\tau}{4}$		
Σ_1			$-\frac{5}{8}$	$-\frac{3}{16}$			$\frac{y_\tau}{8}$		
N			$-\frac{1}{4}$	$\frac{1}{4}$					
E			$-\frac{1}{4}$	$-\frac{1}{4}$			$\frac{y_\tau}{2}$		
Δ_1					$\frac{1}{2}$		$\frac{y_\tau}{2}$		
Δ_3					$-\frac{1}{2}$		$\frac{y_\tau}{2}$		
B_1	1					$-\frac{1}{2}$	$-\frac{y_\tau}{2}$	$-\frac{y_t}{2}$	$-\frac{y_b}{2}$
Ξ	-2					$\frac{1}{2}$	y_τ	y_t	y_b
W_1	$-\frac{1}{4}$					$-\frac{1}{8}$	$-\frac{y_\tau}{8}$	$-\frac{y_t}{8}$	$-\frac{y_b}{8}$
φ							$-y_\tau$	$-y_t$	$-y_b$
$\{B, B_1\}$						1	y_τ	y_t	y_b
$\{Q_1, Q_7\}$								y_t	

Summary

We are on the way towards a truly global EFT fit!

The future

- Higgs + diboson + top + VBS + diHiggs + …
- SMEFT@NLO
- More flavor assumptions



What we need

- More distributions at parton level
- More information on correlations

Thank you for your attention!