Workshop on Standard Model Effective Theory

Single Top in the SMEFT

Rhea Moutafis

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OVERVIEW

Introduction

SMEFT Basics

Relevant Operators

Correlated Uncertainties

Results

Conclusion

INTRODUCTION

INTRODUCTION

- at LHC: production of new particles or imprints via interferences & virtual effects
- single top especially sensitive to electroweak interactions
- subset of top sector
  → possibility to focus on the technical side
- goal: constrain 7 main dim-6 operators concerning single top with *SFitter*

SMEFT BASICS

SMEFT BASICS

- effects of new heavy BSM particles:

$$\mathscr{L}_{SMEFT} = \mathscr{L}_{SM} + \sum_{i}^{N_{d6}} \frac{c_i}{\Lambda^2} \mathcal{O}_i^{(6)} + \ldots,$$

- cross sections:

$$\sigma_{SMEFT} = \sigma_{SM} + \sum_{i}^{N_{d6}} \frac{c_i}{\Lambda^2} \sigma_i + \sum_{i,j}^{N_{d6}} \frac{c_i c_j}{\Lambda^4} \tilde{\sigma}_{ij} + \ldots,$$

SMEFT BASICS

$$\sigma_{u\bar{d}\to t\bar{b}} = \left(1 + \frac{2c^{3}_{\varphi q} v^2}{\Lambda^2}\right) \frac{g^4 (s - m_t^2)^2 (2s + m_t^2)}{384 \pi s^2 (s - m_W^2)^2}$$

$$+ \; c_{tW} \; \frac{g^2 m_t m_W (s - m_t^2)^2}{8\sqrt{2}\pi \Lambda^2 s (s - m_W^2)^2}$$

$$+ \; c^{3,1}_{Qq} \; \frac{g^2 (s - m_t^2)^2 (2s + m_t^2)}{48 \pi \Lambda^2 s^2 (s - m_W^2)}$$

RELEVANT OPERATORS

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CHANNELS
s-channel
t-channel
W-assoc.
Z-assoc.
t decay

RELEVANT OPERATORS

CHANNELS	OPERATORS
s-channel	$^{\ddagger}\mathcal{O}_{uG}^{(ij)} = (\bar{q}_i\sigma^{\mu\nu}T^A u_j)\tilde{\varphi}G^A_{\mu\nu}$
t-channel	$^{\ddagger}\mathcal{O}_{uW}^{(ij)} = (\bar{q}_i\sigma^{\mu\nu}\tau_I u_j)\tilde{\varphi}W^I_{\mu\nu}$
	$\mathcal{O}_{\varphi q}^{3(ij)} = (\varphi^{\dagger} i\overleftrightarrow{D}^I_{\mu}\varphi)(\bar{q}_i\gamma^{\mu}\tau^I q_j)$
W-assoc.	$^{\ddagger}\mathcal{O}_{dW}^{(ij)} = (\bar{q}_i\sigma^{\mu\nu}\tau_I d_j)\varphi W^I_{\mu\nu}$
Z-assoc.	$^{\ddagger}\mathcal{O}_{\varphi ud}^{1(ij)} = (\tilde{\varphi}^{\dagger} i\overleftrightarrow{D}_{\mu}\varphi)(\bar{u}_i\gamma^{\mu}d_j)$
t decay	$\mathcal{O}_{qq}^{1(ijkl)} = (\bar{q}_i\gamma^{\mu}q_j)(\bar{q}_k\gamma_{\mu}q_l)$
	$\mathcal{O}_{qq}^{3(ijkl)} = (\bar{q}_i\gamma^{\mu}\tau^I q_j)(\bar{q}_k\gamma_{\mu}\tau^I q_l)$

RELEVANT OPERATORS

CHANNELS	OPERATORS	WILSON COEFFICIENTS	
s-channel	$^{\ddagger}\mathcal{O}_{uG}^{(ij)} = (\bar{q}_i\sigma^{\mu\nu}T^A u_j)\tilde{\varphi}G^A_{\mu\nu}$	Re$\{\mathcal{O}_{uG}^{(33)}\}$	c_{tG}
t-channel	$^{\ddagger}\mathcal{O}_{uW}^{(ij)} = (\bar{q}_i\sigma^{\mu\nu}\tau_I u_j)\tilde{\varphi}W^I_{\mu\nu}$	Re$\{\mathcal{O}_{uW}^{(33)}\}$	c_{tW}
	$\mathcal{O}_{\varphi q}^{3(ij)} = (\varphi^\dagger i\overleftrightarrow{D}^I_\mu\varphi)(\bar{q}_i\gamma^\mu\tau^I q_j)$	$\mathcal{O}_{\varphi q}^{3(33)}$	$c^3_{\varphi q}$
W-assoc.	$^{\ddagger}\mathcal{O}_{dW}^{(ij)} = (\bar{q}_i\sigma^{\mu\nu}\tau_I d_j)\varphi W^I_{\mu\nu}$	Re$\{\mathcal{O}_{dW}^{(33)}\}$	c_{bW}
Z-assoc.	$^{\ddagger}\mathcal{O}_{\varphi ud}^{1(ij)} = (\tilde{\varphi}^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{u}_i\gamma^\mu d_j)$	Re$\{\mathcal{O}_{\varphi ud}^{(33)}\}$	$c_{\varphi tb}$
t decay	$\mathcal{O}_{qq}^{1(ijkl)} = (\bar{q}_i\gamma^\mu q_j)(\bar{q}_k\gamma_\mu q_l)$	$\mathcal{O}_{qq}^{3(ii33)} + \frac{1}{6}(\mathcal{O}_{qq}^{1(i33i)} - \mathcal{O}_{qq}^{3(i33i)})$	$c^{3,1}_{Qq}$
	$\mathcal{O}_{qq}^{3(ijkl)} = (\bar{q}_i\gamma^\mu\tau^I q_j)(\bar{q}_k\gamma_\mu\tau^I q_l)$	$\mathcal{O}_{qq}^{1(i33i)} - \mathcal{O}_{qq}^{3(i33i)}$	$c^{3,8}_{Qq}$

RELEVANT OPERATORS

VERTEX	CHANNELS	OPERATORS	WILSON COEFFICIENTS	
	s-channel	$^{\ddagger}\mathcal{O}_{uG}^{(ij)} = (\bar{q}_i \sigma^{\mu\nu} T^A u_j)\tilde{\varphi} G^A_{\mu\nu}$	$\text{Re}\{\mathcal{O}_{uG}^{(33)}\}$	c_{tG}
	t-channel	$^{\ddagger}\mathcal{O}_{uW}^{(ij)} = (\bar{q}_i \sigma^{\mu\nu} \tau_I u_j)\tilde{\varphi} W^I_{\mu\nu}$	$\text{Re}\{\mathcal{O}_{uW}^{(33)}\}$	c_{tW}
		$\mathcal{O}_{\varphi q}^{3(ij)} = (\varphi^\dagger i\overleftrightarrow{D}^I_\mu \varphi)(\bar{q}_i \gamma^\mu \tau^I q_j)$	$\mathcal{O}_{\varphi q}^{3(33)}$	$c^3_{\varphi q}$
Wtb	W-assoc.	$^{\ddagger}\mathcal{O}_{dW}^{(ij)} = (\bar{q}_i \sigma^{\mu\nu} \tau_I d_j)\varphi W^I_{\mu\nu}$	$\text{Re}\{\mathcal{O}_{dW}^{(33)}\}$	c_{bW}
	Z-assoc.	$^{\ddagger}\mathcal{O}_{\varphi ud}^{1(ij)} = (\tilde{\varphi}^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar{u}_i \gamma^\mu d_j)$	$\text{Re}\{\mathcal{O}_{\varphi ud}^{(33)}\}$	$c_{\varphi tb}$
	t decay	$\mathcal{O}_{qq}^{1(ijkl)} = (\bar{q}_i \gamma^\mu q_j)(\bar{q}_k \gamma_\mu q_l)$	$\mathcal{O}_{qq}^{3(ii33)} + \frac{1}{6}(\mathcal{O}_{qq}^{1(i33i)} - \mathcal{O}_{qq}^{3(i33i)})$	$c^{3,1}_{Qq}$
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VERTEX	CHANNELS	OPERATORS	WILSON COEFFICIENTS	
	s-channel	$^{\ddagger}\mathcal{O}_{uG}^{(ij)} = (\bar{q}_i \sigma^{\mu\nu} T^A u_j)\tilde{\varphi} G_{\mu\nu}^A$	$\text{Re}\{\mathcal{O}_{uG}^{(33)}\}$	c_{tG}
	t-channel	$^{\ddagger}\mathcal{O}_{uW}^{(ij)} = (\bar{q}_i \sigma^{\mu\nu} \tau_I u_j)\tilde{\varphi} W_{\mu\nu}^I$	$\text{Re}\{\mathcal{O}_{uW}^{(33)}\}$	c_{tW}
		$\mathcal{O}_{\varphi q}^{3(ij)} = (\varphi^\dagger i\overleftrightarrow{D}_\mu^I \varphi)(\bar{q}_i \gamma^\mu \tau^I q_j)$	$\mathcal{O}_{\varphi q}^{3(33)}$	$c_{\varphi q}^{3}$
qq'q''t	W-assoc.	$^{\ddagger}\mathcal{O}_{dW}^{(ij)} = (\bar{q}_i \sigma^{\mu\nu} \tau_I d_j)\varphi W_{\mu\nu}^I$	$\text{Re}\{\mathcal{O}_{dW}^{(33)}\}$	c_{bW}
	Z-assoc.	$^{\ddagger}\mathcal{O}_{\varphi ud}^{1(ij)} = (\tilde{\varphi}^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar{u}_i \gamma^\mu d_j)$	$\text{Re}\{\mathcal{O}_{\varphi ud}^{(33)}\}$	$c_{\varphi tb}$
	t decay	$\mathcal{O}_{qq}^{1(ijkl)} = (\bar{q}_i \gamma^\mu q_j)(\bar{q}_k \gamma_\mu q_l)$	$\mathcal{O}_{qq}^{3(ii33)} + \frac{1}{6}(\mathcal{O}_{qq}^{1(i33i)} - \mathcal{O}_{qq}^{3(i33i)})$	$c_{Qq}^{3,1}$
		$\mathcal{O}_{qq}^{3(ijkl)} = (\bar{q}_i \gamma^\mu \tau^I q_j)(\bar{q}_k \gamma_\mu \tau^I q_l)$	$\mathcal{O}_{qq}^{1(i33i)} - \mathcal{O}_{qq}^{3(i33i)}$	$c_{Qq}^{3,8}$

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VERTEX	CHANNELS	OPERATORS	WILSON COEFFICIENTS	
ttg	s-channel	$^{\ddagger}\mathcal{O}_{uG}^{(ij)} = (\bar{q}_i \sigma^{\mu\nu} T^A u_j)\tilde{\varphi} G^A_{\mu\nu}$	$\mathrm{Re}\{\mathcal{O}_{uG}^{(33)}\}$	c_{tG}
	t-channel	$^{\ddagger}\mathcal{O}_{uW}^{(ij)} = (\bar{q}_i \sigma^{\mu\nu} \tau_I u_j)\tilde{\varphi} W^I_{\mu\nu}$	$\mathrm{Re}\{\mathcal{O}_{uW}^{(33)}\}$	c_{tW}
		$\mathcal{O}_{\varphi q}^{3(ij)} = (\varphi^\dagger i\overleftrightarrow{D}^I_\mu \varphi)(\bar{q}_i \gamma^\mu \tau^I q_j)$	$\mathcal{O}_{\varphi q}^{3(33)}$	$c^3_{\varphi q}$
	W-assoc.	$^{\ddagger}\mathcal{O}_{dW}^{(ij)} = (\bar{q}_i \sigma^{\mu\nu} \tau_I d_j)\varphi W^I_{\mu\nu}$	$\mathrm{Re}\{\mathcal{O}_{dW}^{(33)}\}$	c_{bW}
	Z-assoc.	$^{\ddagger}\mathcal{O}_{\varphi ud}^{1(ij)} = (\tilde{\varphi}^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar{u}_i \gamma^\mu d_j)$	$\mathrm{Re}\{\mathcal{O}_{\varphi ud}^{(33)}\}$	$c_{\varphi tb}$
	t decay	$\mathcal{O}_{qq}^{1(ijkl)} = (\bar{q}_i \gamma^\mu q_j)(\bar{q}_k \gamma_\mu q_l)$	$\mathcal{O}_{qq}^{3(ii33)} + \frac{1}{6}(\mathcal{O}_{qq}^{1(i33i)} - \mathcal{O}_{qq}^{3(i33i)})$	$c^{3,1}_{Qq}$
		$\mathcal{O}_{qq}^{3(ijkl)} = (\bar{q}_i \gamma^\mu \tau^I q_j)(\bar{q}_k \gamma_\mu \tau^I q_l)$	$\mathcal{O}_{qq}^{1(i33i)} - \mathcal{O}_{qq}^{3(i33i)}$	$c^{3,8}_{Qq}$

RELEVANT OPERATORS

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		$\mathcal{O}_{\varphi q}^{3(ij)} = (\varphi^\dagger i\overleftrightarrow{D}^I_\mu \varphi)(\bar{q}_i \gamma^\mu \tau^I q_j)$	$\mathcal{O}_{\varphi q}^{3(33)}$	$c^3_{\varphi q}$
ttZ, ttγ	W-assoc.	$^{\ddagger}\mathcal{O}_{dW}^{(ij)} = (\bar{q}_i \sigma^{\mu\nu} \tau_I d_j)\varphi W^I_{\mu\nu}$	Re$\{\mathcal{O}_{dW}^{(33)}\}$	c_{bW}
	Z-assoc.	$^{\ddagger}\mathcal{O}_{\varphi ud}^{1(ij)} = (\tilde{\varphi}^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar{u}_i \gamma^\mu d_j)$	Re$\{\mathcal{O}_{\varphi ud}^{(33)}\}$	$c_{\varphi tb}$
	t decay	$\mathcal{O}_{qq}^{1(ijkl)} = (\bar{q}_i \gamma^\mu q_j)(\bar{q}_k \gamma_\mu q_l)$	$\mathcal{O}_{qq}^{3(ii33)} + \frac{1}{6}(\mathcal{O}_{qq}^{1(i33i)} - \mathcal{O}_{qq}^{3(i33i)})$	$c^{3,1}_{Qq}$
		$\mathcal{O}_{qq}^{3(ijkl)} = (\bar{q}_i \gamma^\mu \tau^I q_j)(\bar{q}_k \gamma_\mu \tau^I q_l)$	$\mathcal{O}_{qq}^{1(i33i)} - \mathcal{O}_{qq}^{3(i33i)}$	$c^{3,8}_{Qq}$

CORRELATED UNCERTAINTIES

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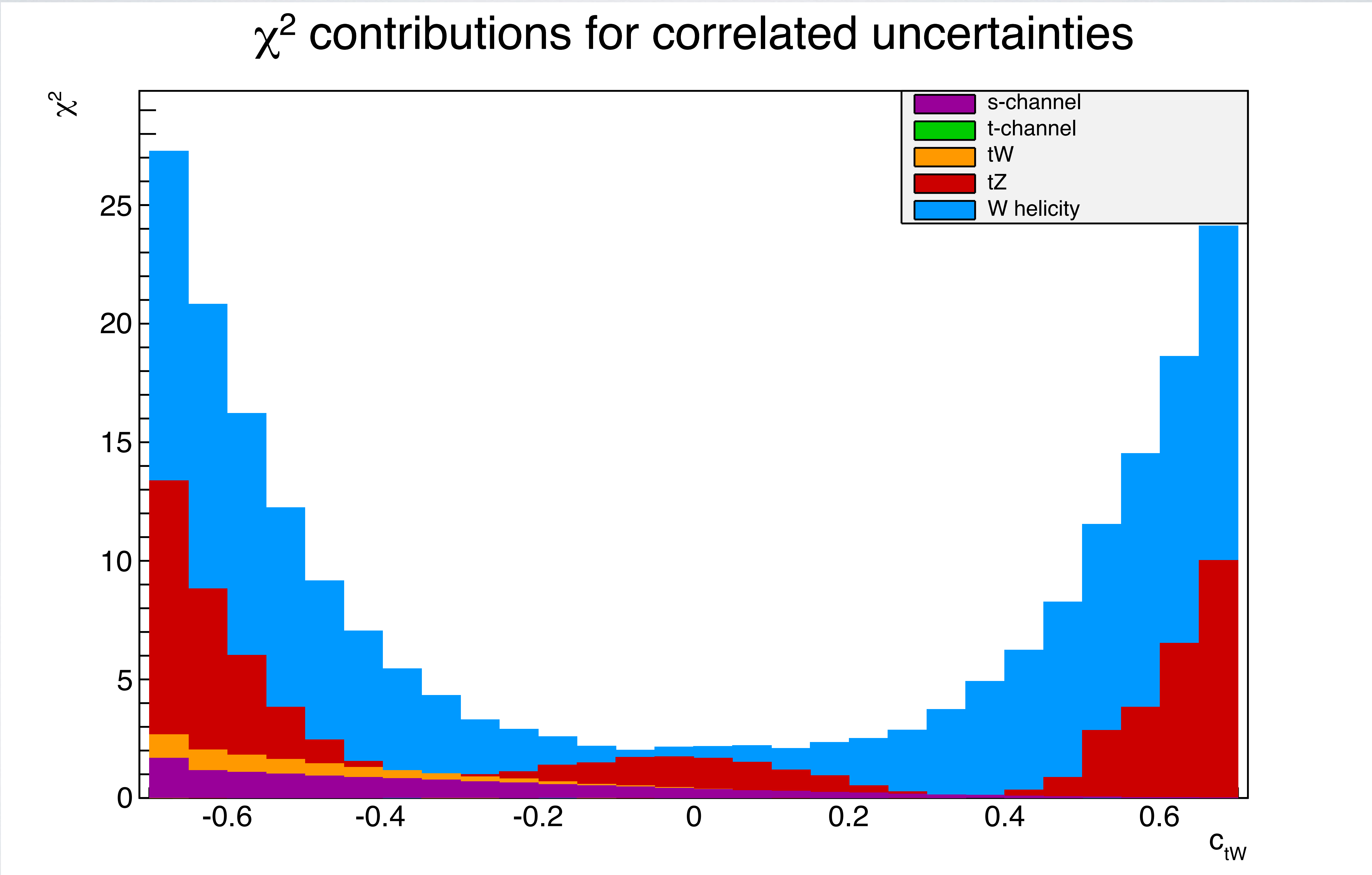
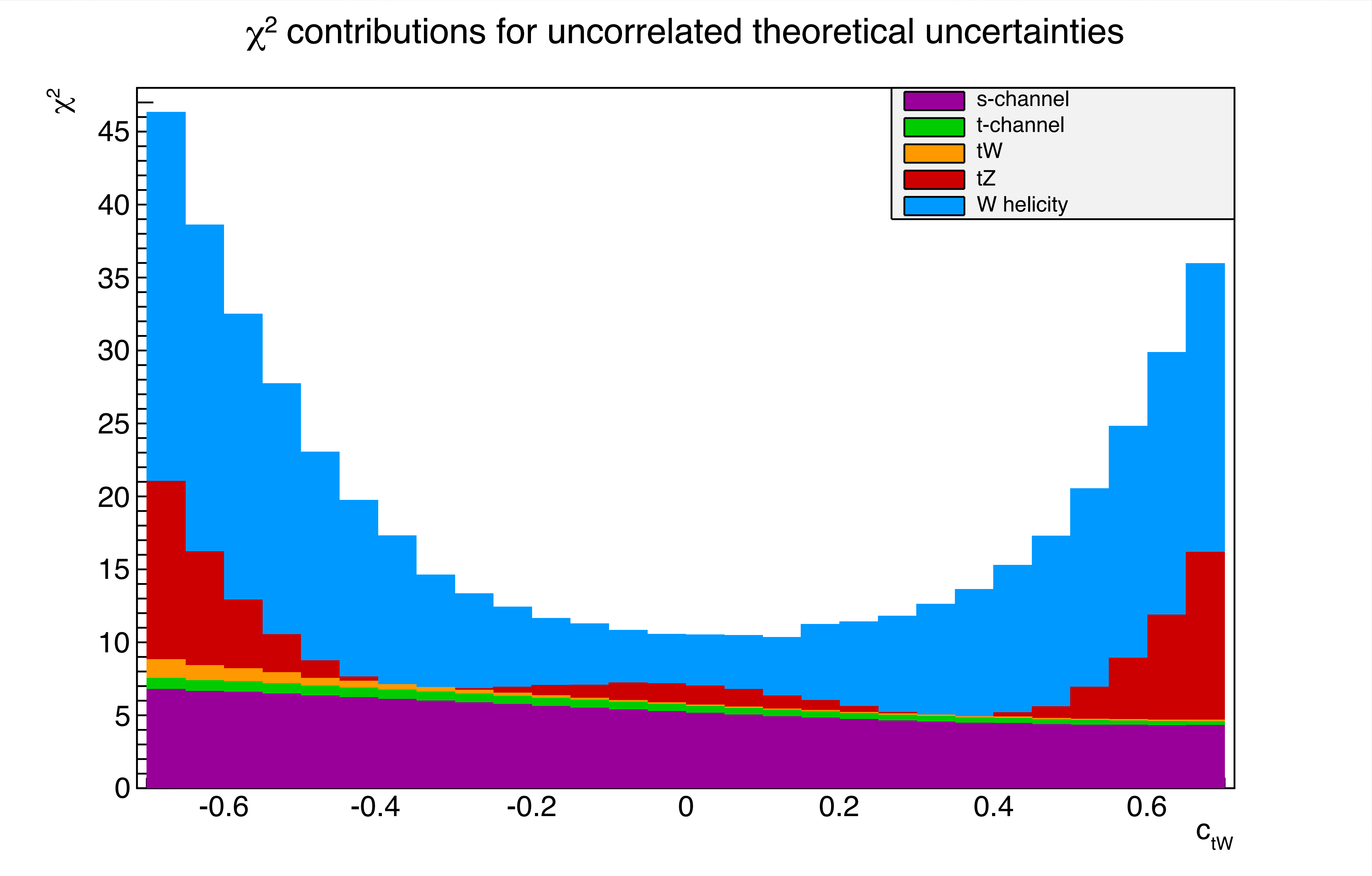
- theoretical: identical predictions
  → averaging (alternative nuisance parameters, but we get too many)
- systematic: build matrix of uncertainties, write correlated ones in same column
- all handled with *DataPrep*

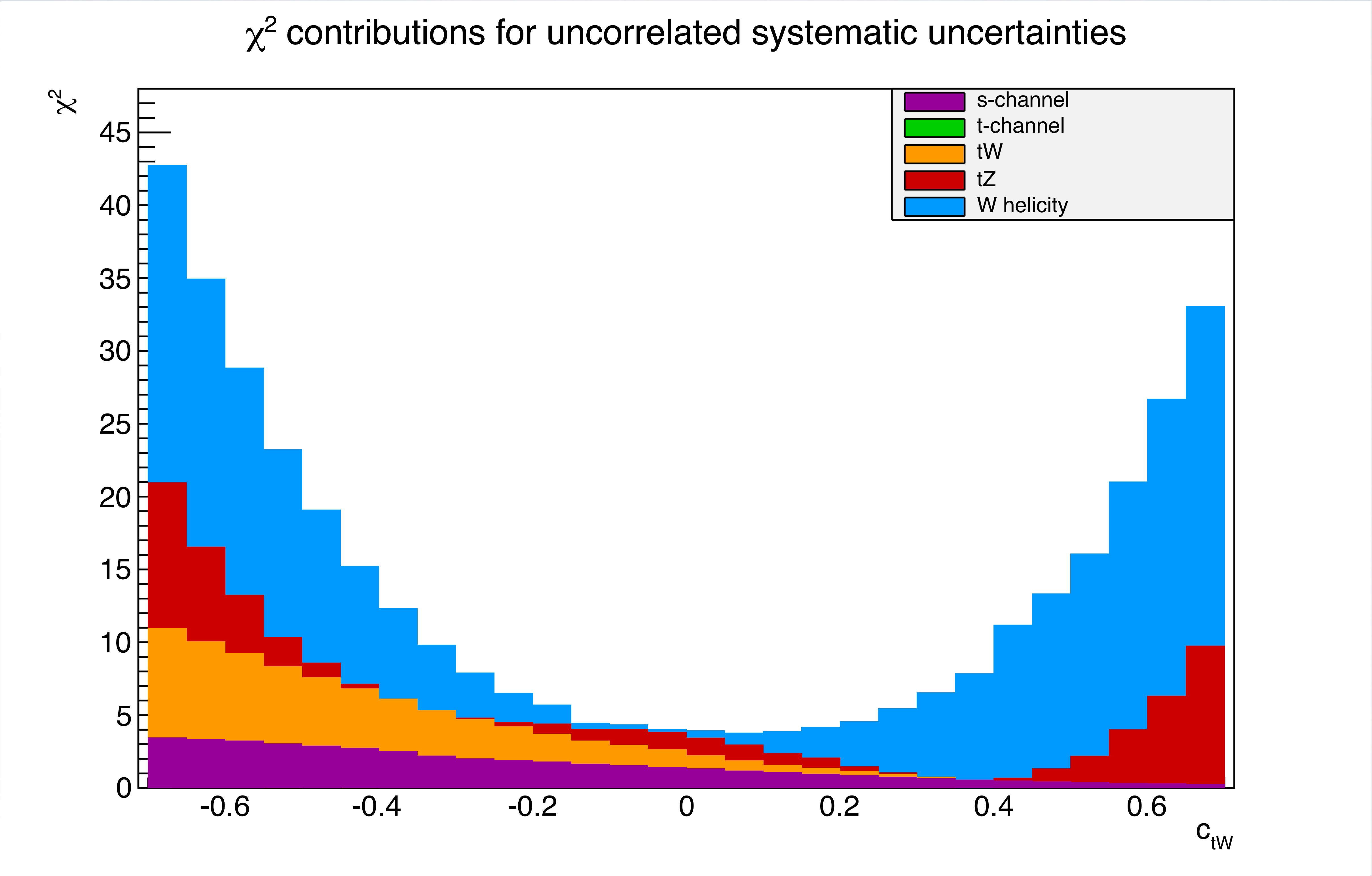
CORRELATED UNCERTAINTIES



CORRELATED UNCERTAINTIES

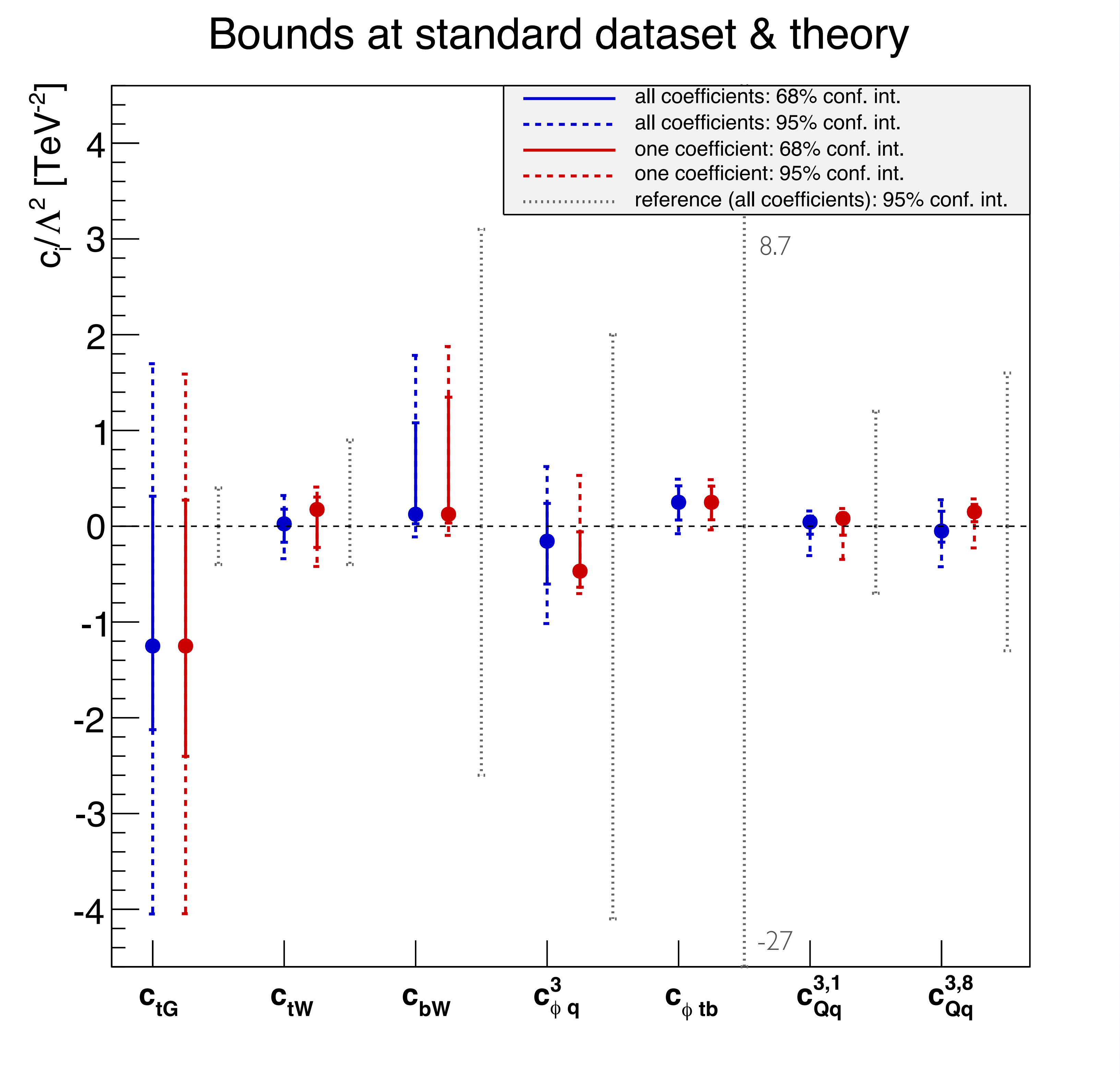


CORRELATED UNCERTAINTIES



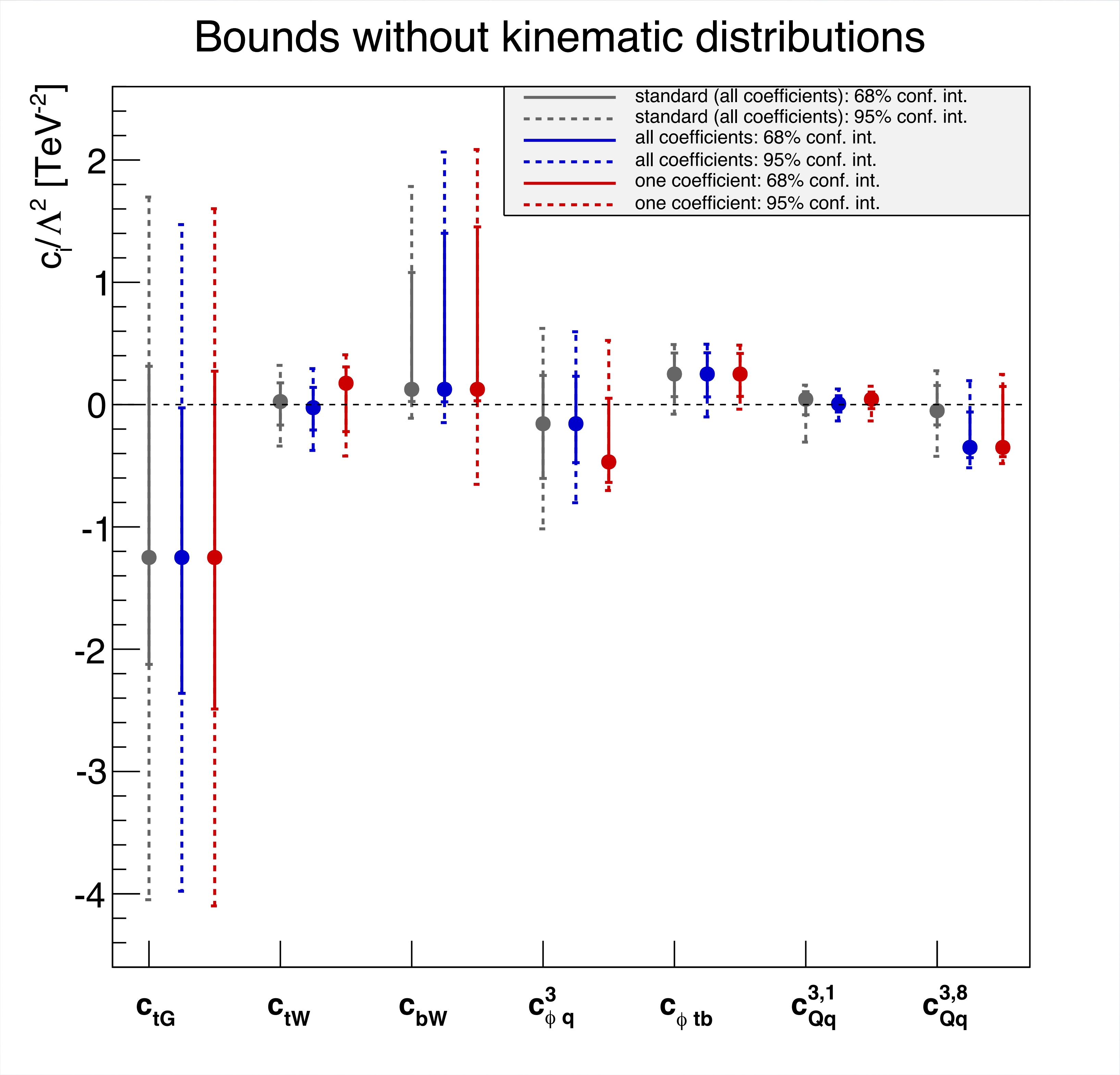
RESULTS

RESULTS



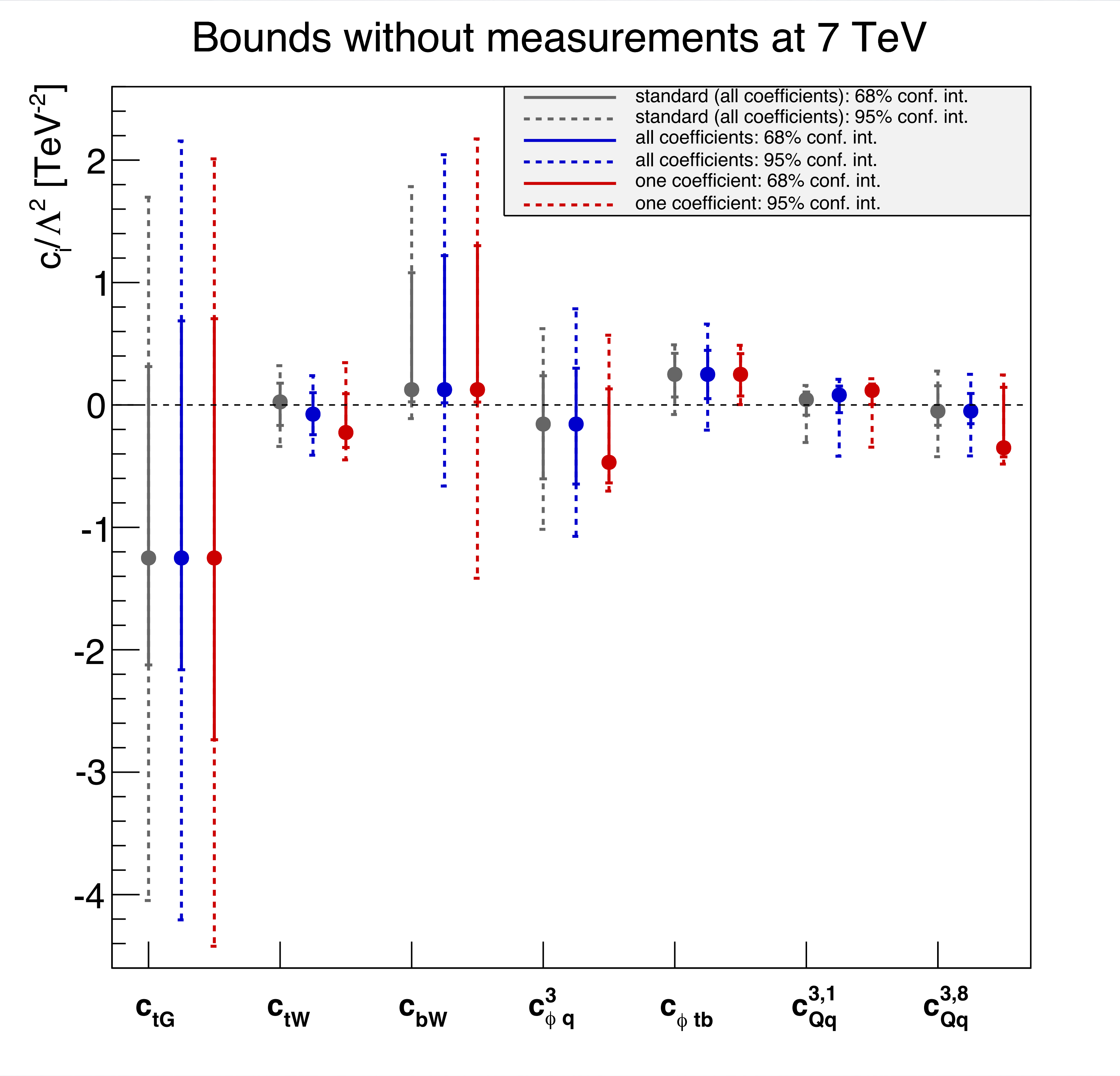
Bounds at standard dataset & theory
c_i/Λ^2 [TeV^{-2}]
4
3
2
1
0
-1
-2
-3
-4
all coefficients: 68% conf. int.
all coefficients: 95% conf. int.
one coefficient: 68% conf. int.
one coefficient: 95% conf. int.
reference (all coefficients): 95% conf. int.
8.7
-27
c_{tG}
c_{tW}
c_{bW}
$c^3_{\phi q}$
$c_{\phi tb}$
$c^{3,1}_{Qq}$
$c^{3,8}_{Qq}$

RESULTS



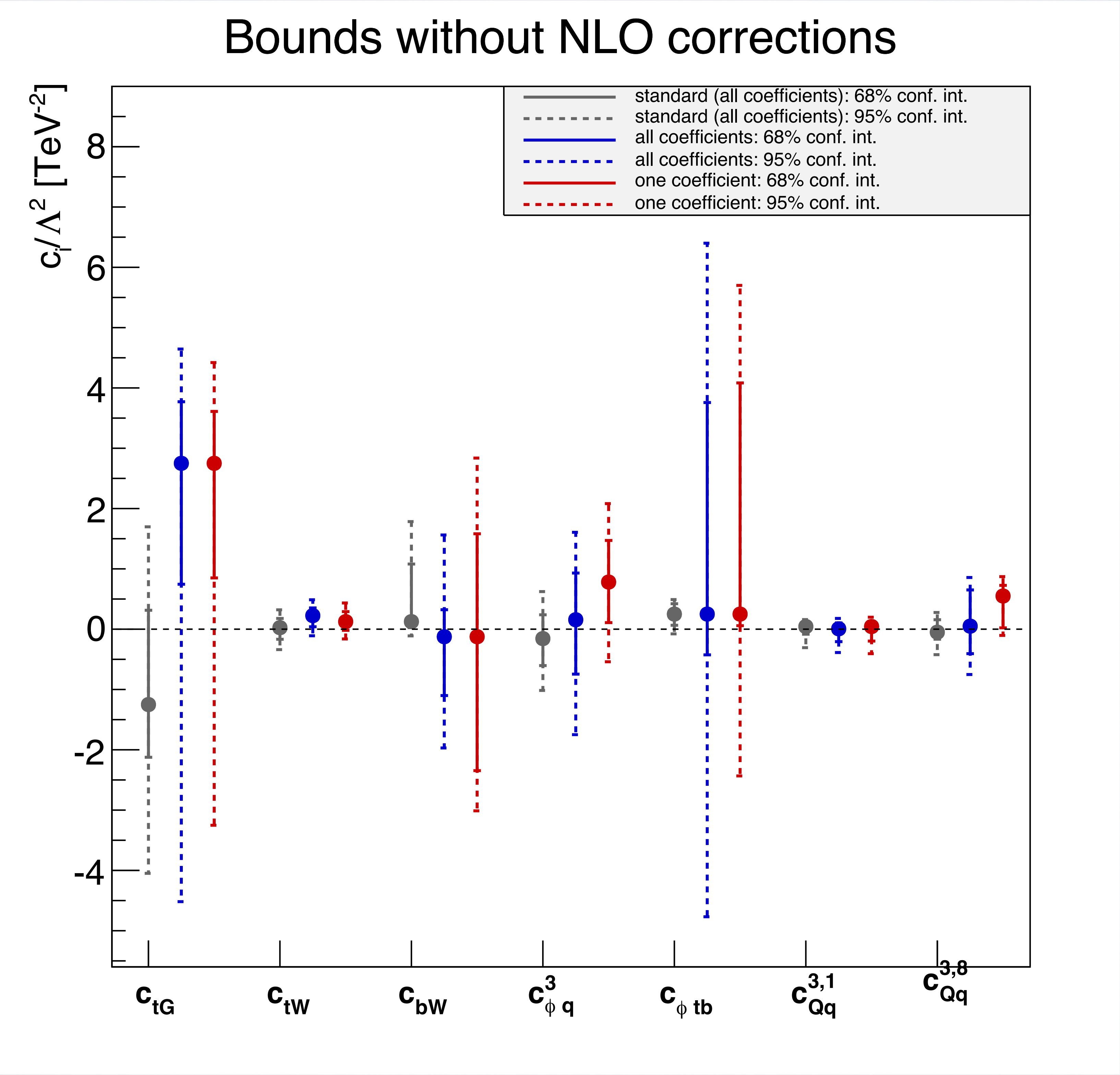
Bounds without kinematic distributions
c_i/Λ^2 [TeV^{-2}]
2
1
0
-1
-2
-3
-4
standard (all coefficients): 68% conf. int.
standard (all coefficients): 95% conf. int.
all coefficients: 68% conf. int.
all coefficients: 95% conf. int.
one coefficient: 68% conf. int.
one coefficient: 95% conf. int.
c_{tG}
c_{tW}
c_{bW}
$c^3_{\phi q}$
$c_{\phi tb}$
$c^{3,1}_{Qq}$
$c^{3,8}_{Qq}$

RESULTS



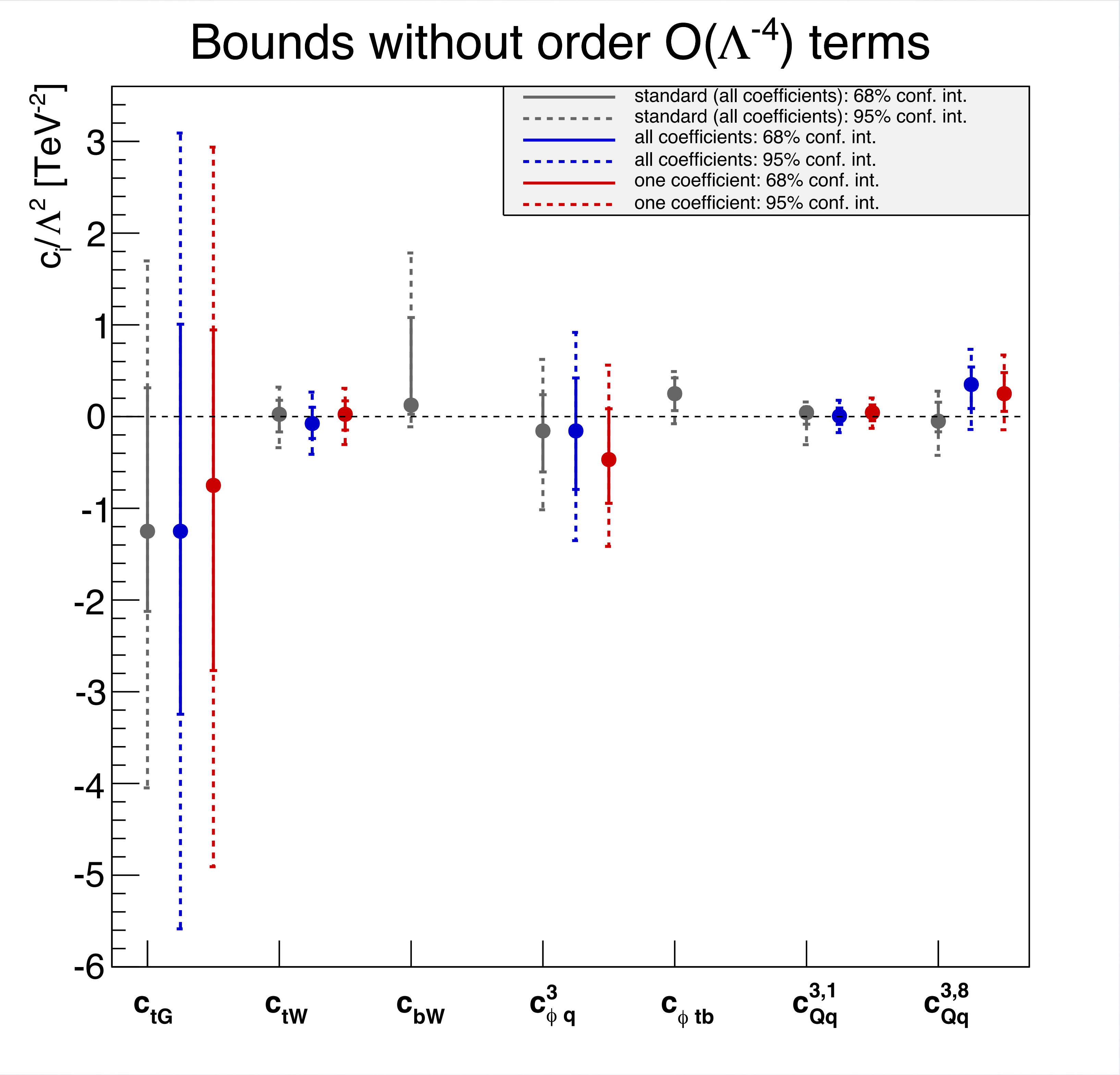
Bounds without measurements at 7 TeV
c_i/Λ^2 [TeV^{-2}]
2
1
0
-1
-2
-3
-4
standard (all coefficients): 68% conf. int.
standard (all coefficients): 95% conf. int.
all coefficients: 68% conf. int.
all coefficients: 95% conf. int.
one coefficient: 68% conf. int.
one coefficient: 95% conf. int.
c_{tG}
c_{tW}
c_{bW}
$c^3_{\phi q}$
$c_{\phi tb}$
$c^{3,1}_{Qq}$
$c^{3,8}_{Qq}$

RESULTS



Bounds without NLO corrections
c_i/Λ^2 [TeV^{-2}]
standard (all coefficients): 68% conf. int.
standard (all coefficients): 95% conf. int.
all coefficients: 68% conf. int.
all coefficients: 95% conf. int.
one coefficient: 68% conf. int.
one coefficient: 95% conf. int.
8
6
4
2
0
-2
-4
c_{tG}
c_{tW}
c_{bW}
$c^3_{\phi q}$
$c_{\phi tb}$
$c^{3,1}_{Qq}$
$c^{3,8}_{Qq}$

RESULTS



Bounds without order O(Λ-4) terms
ci/Λ2 [TeV-2]
standard (all coefficients): 68% conf. int.
standard (all coefficients): 95% conf. int.
all coefficients: 68% conf. int.
all coefficients: 95% conf. int.
one coefficient: 68% conf. int.
one coefficient: 95% conf. int.
3
2
1
0
-1
-2
-3
-4
-5
-6
ctG
ctW
cbW
c3ϕ q
cϕ tb
c3,1Qq
c3,8Qq

CONCLUSION

CONCLUSION

- new: correlated uncertainties
- s-channel important!
- distributions do not seem to change anything, 7 TeV-data has small impact
- NLO corrections very important, O(Λ^-4) not so much
- results in perfect agreement with SM & 5 times more accurate than literature!
- looking forward to merging datasets :)

Thank you!

BONUS SLIDES

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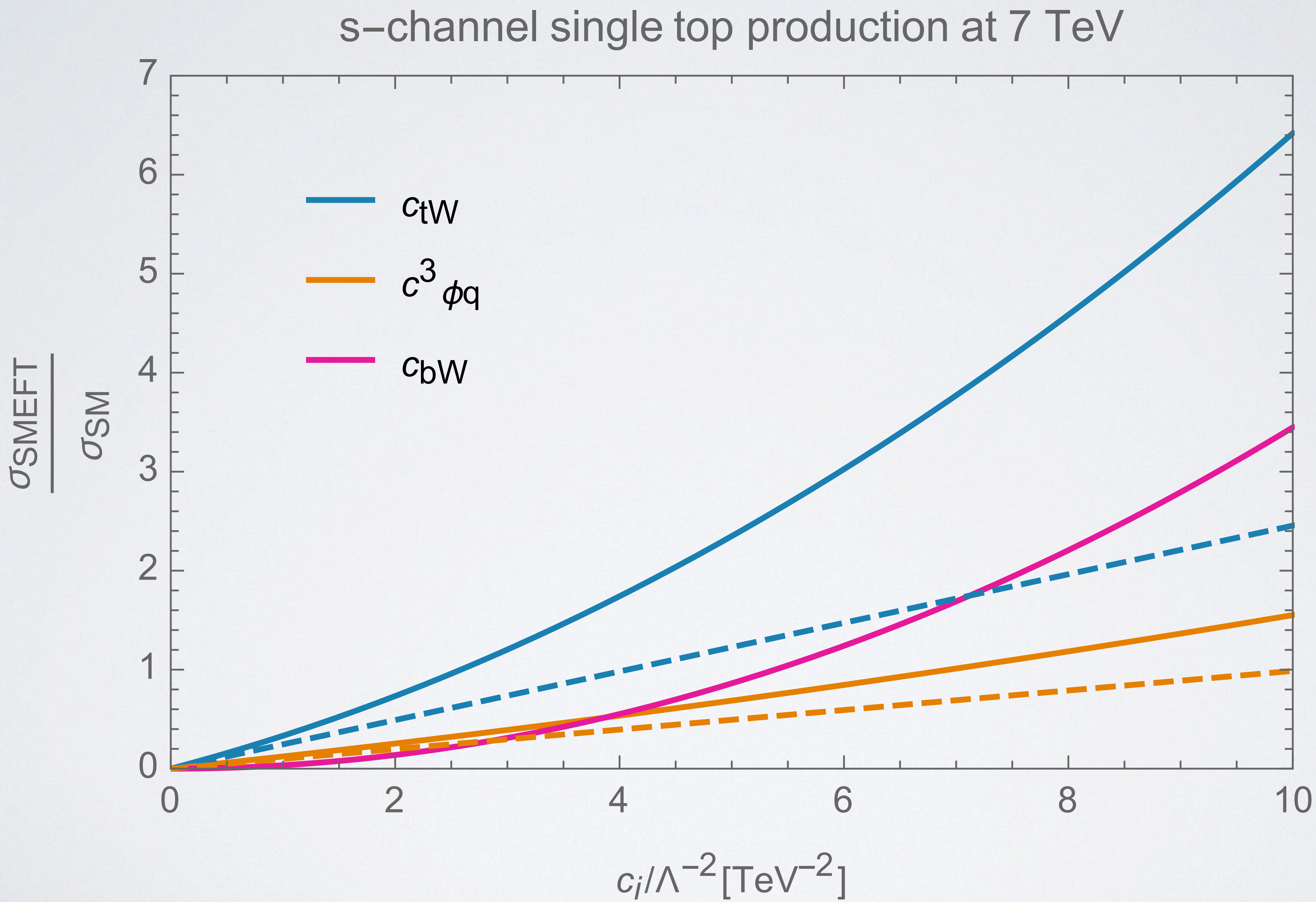

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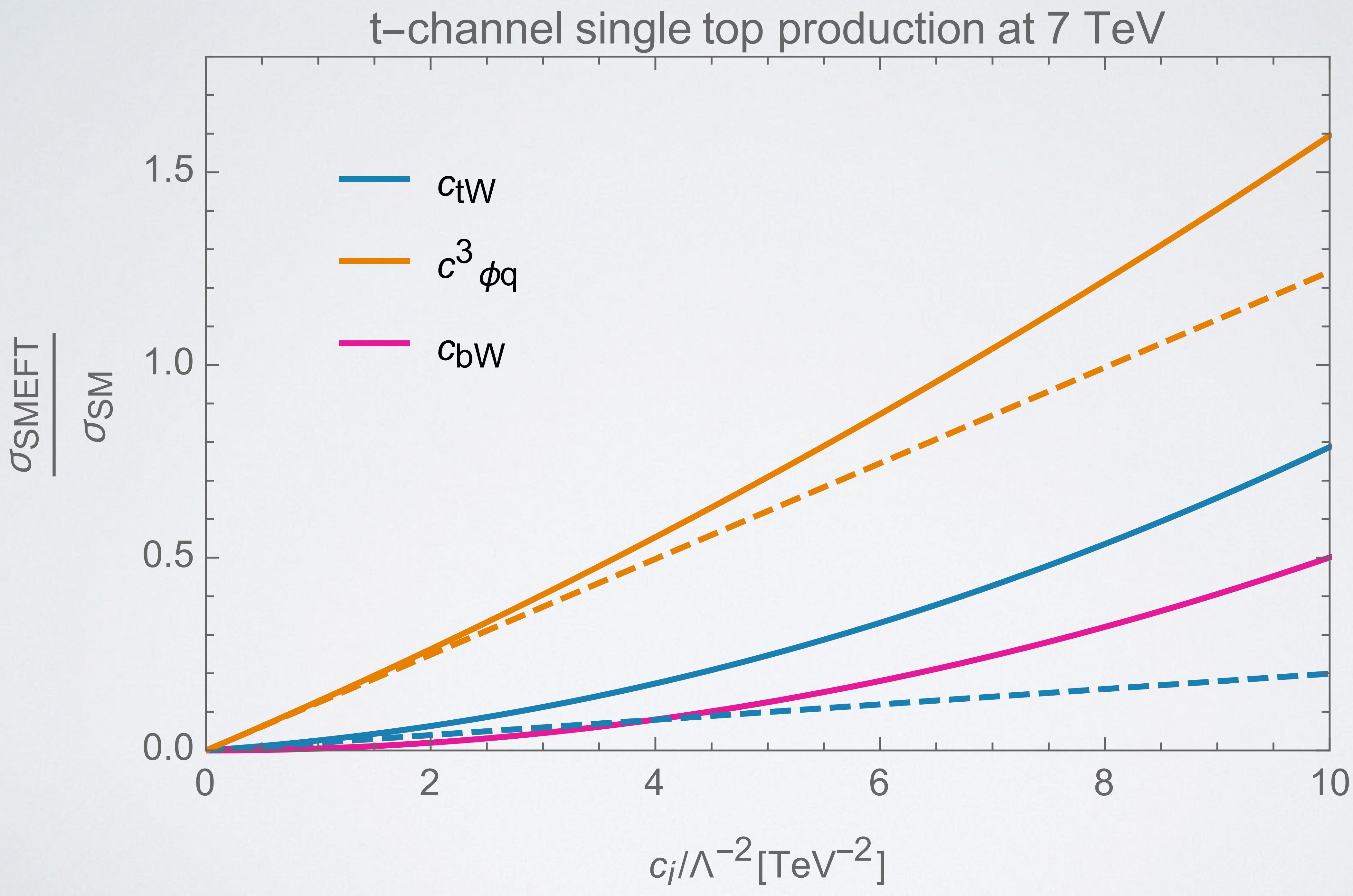

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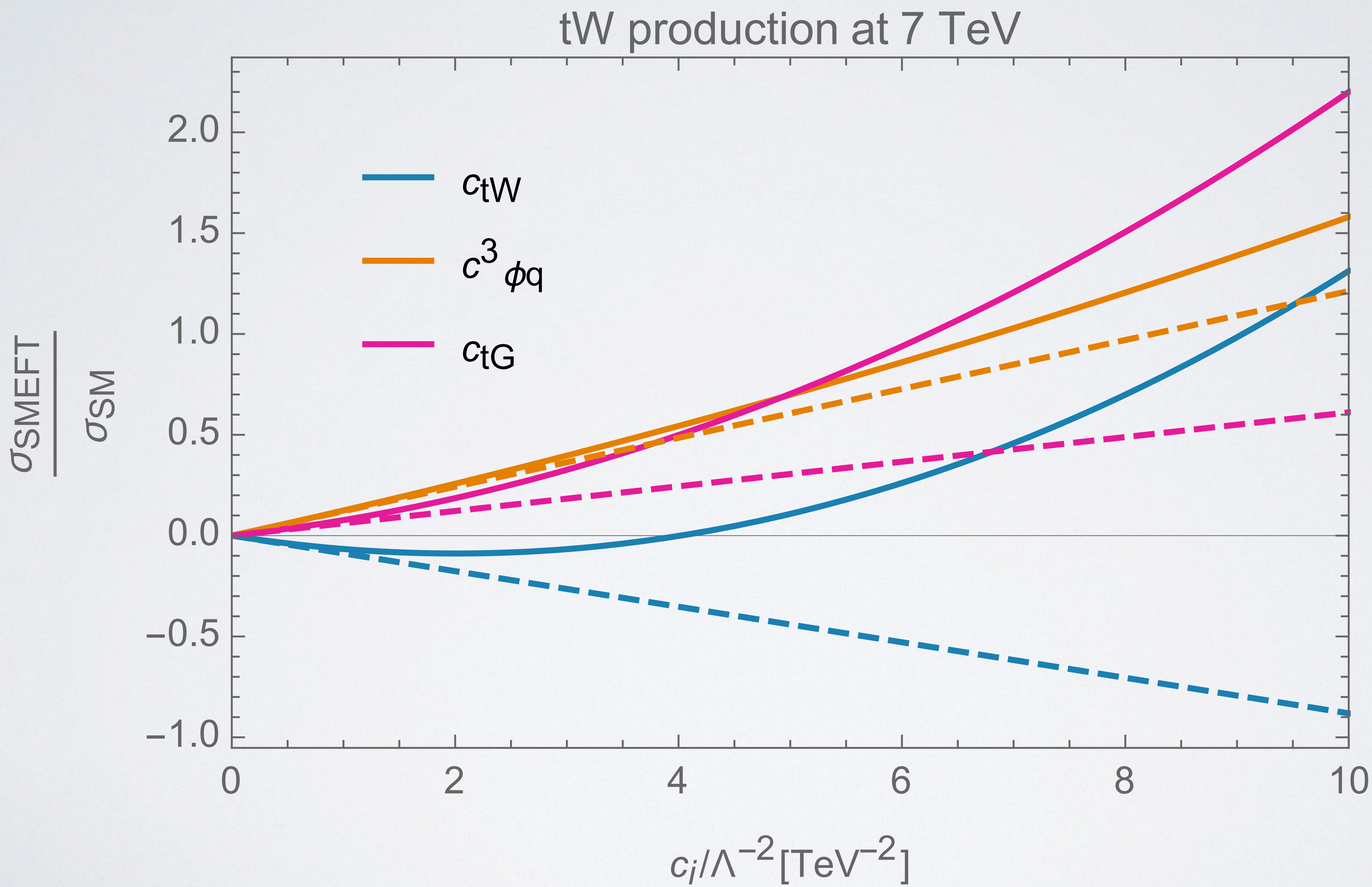

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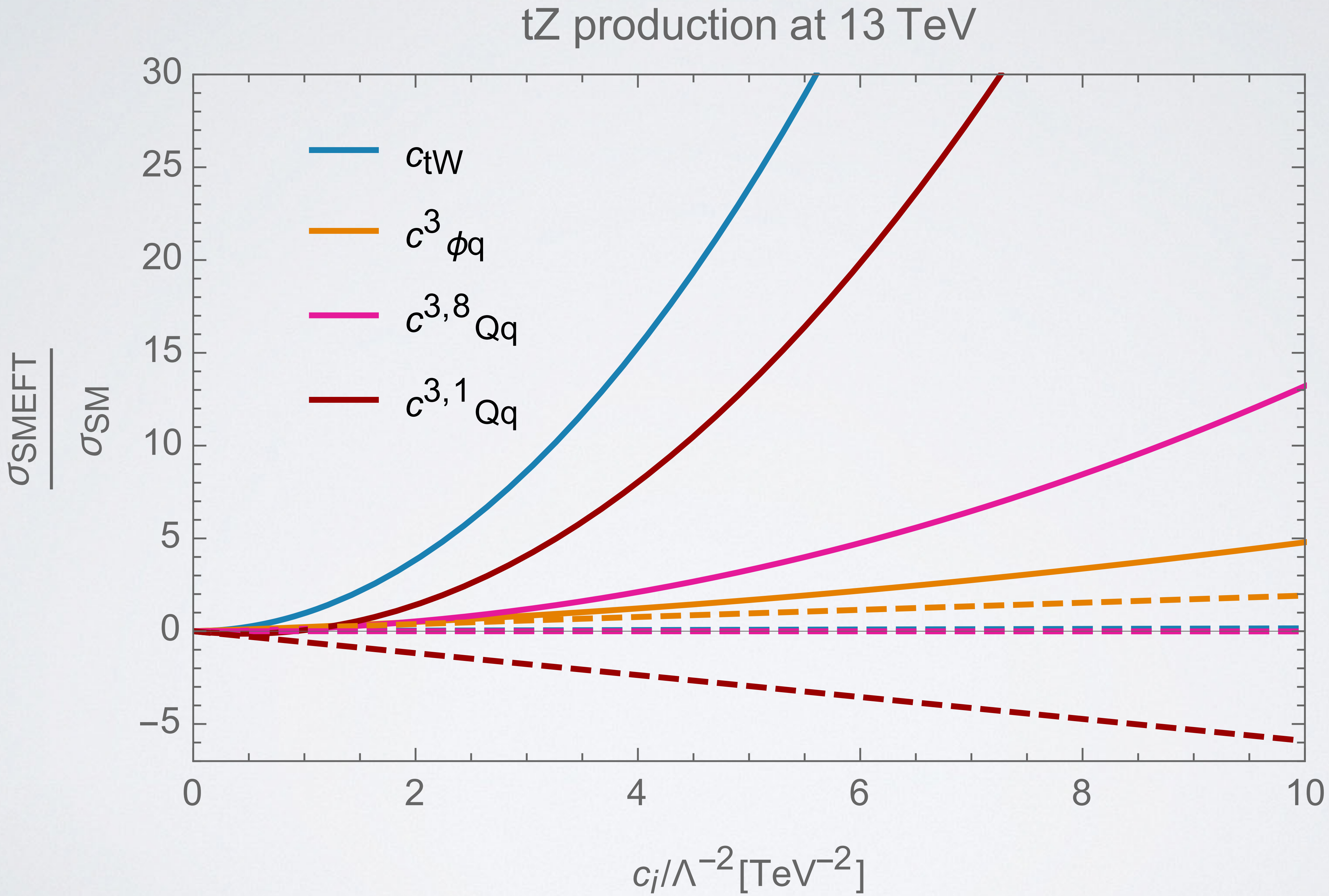

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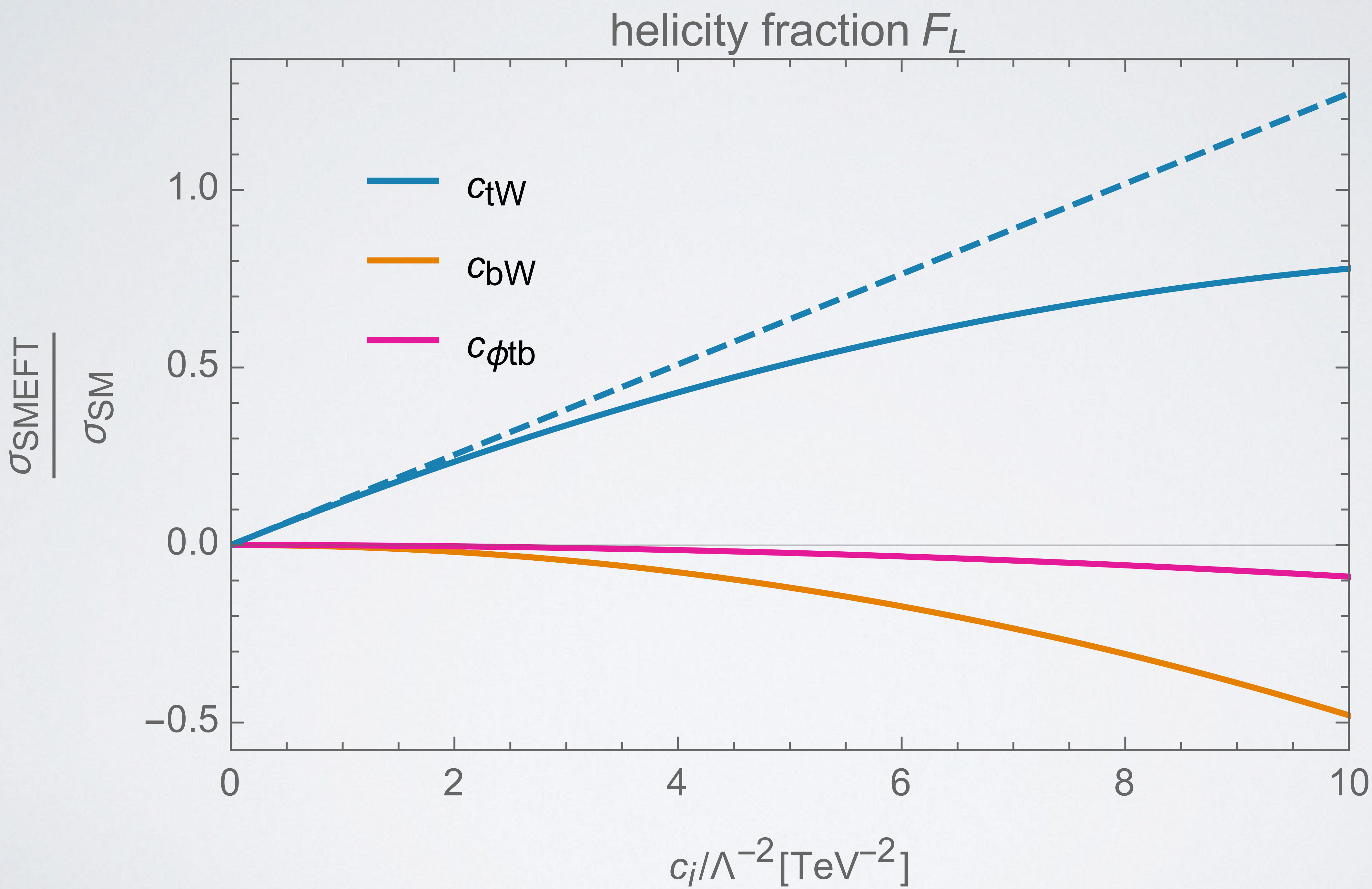

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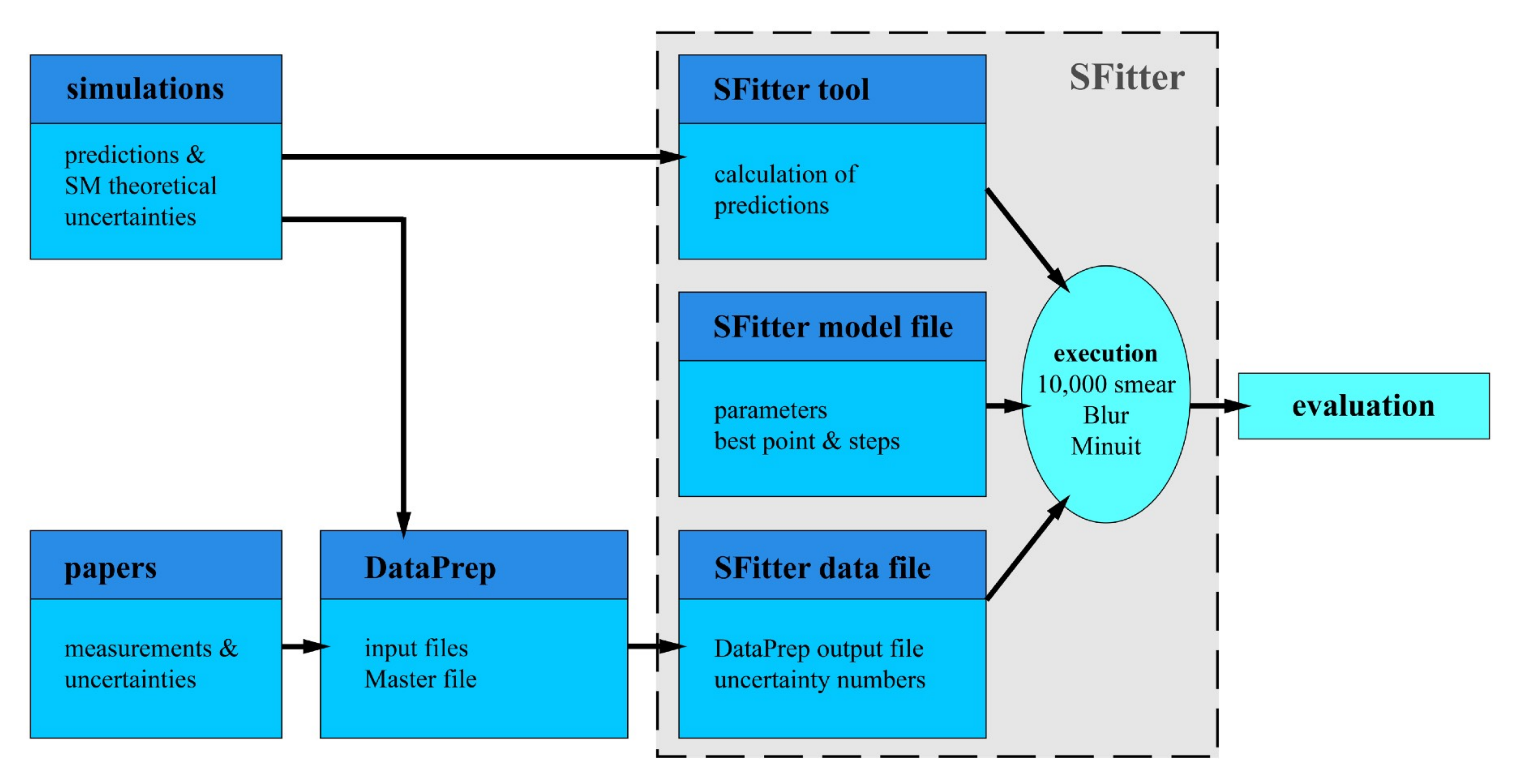

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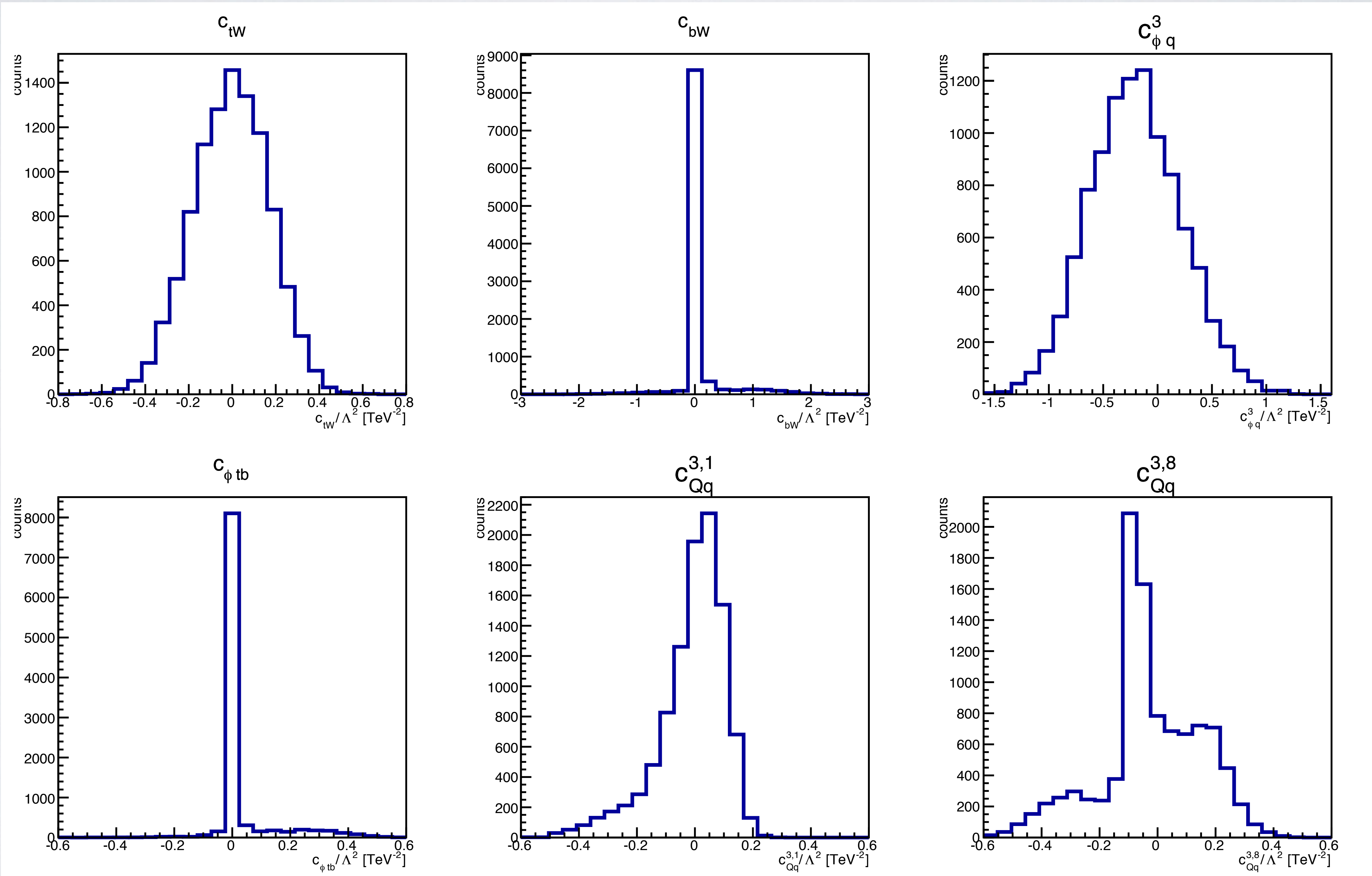

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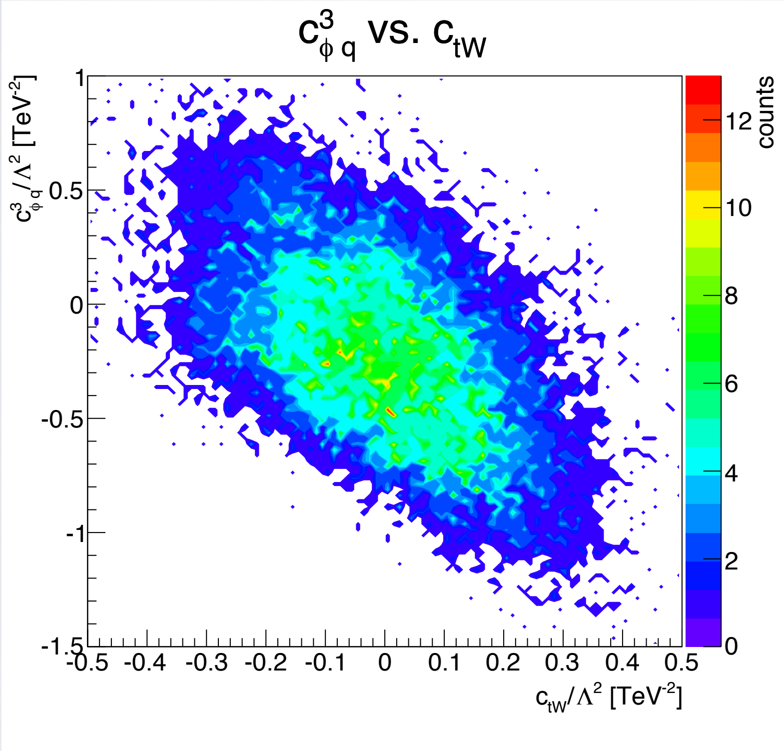

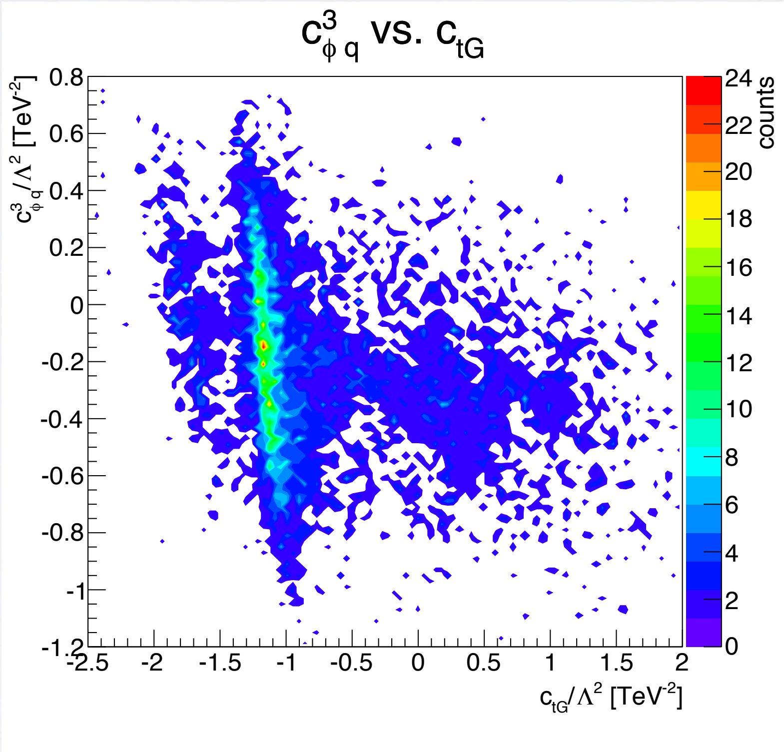

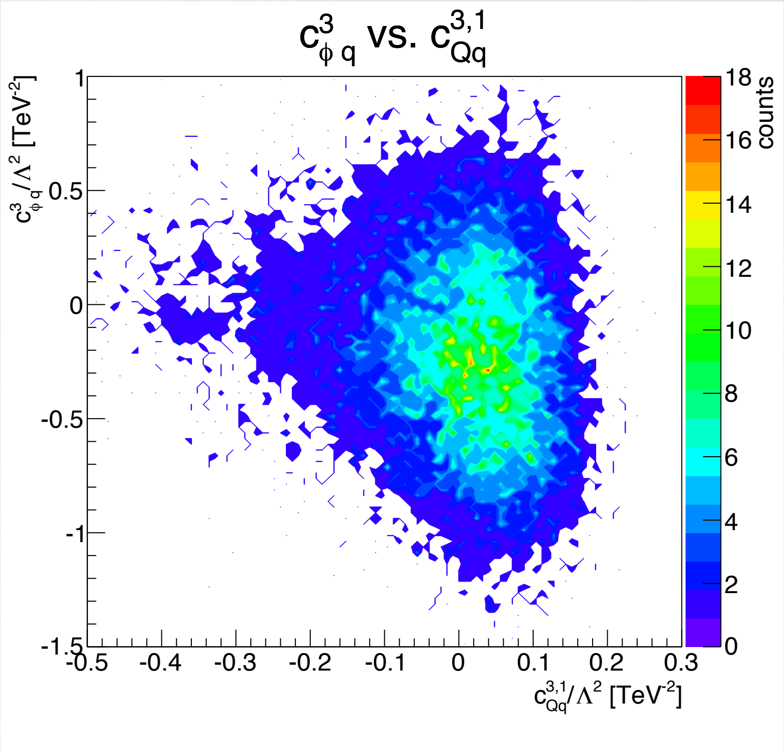

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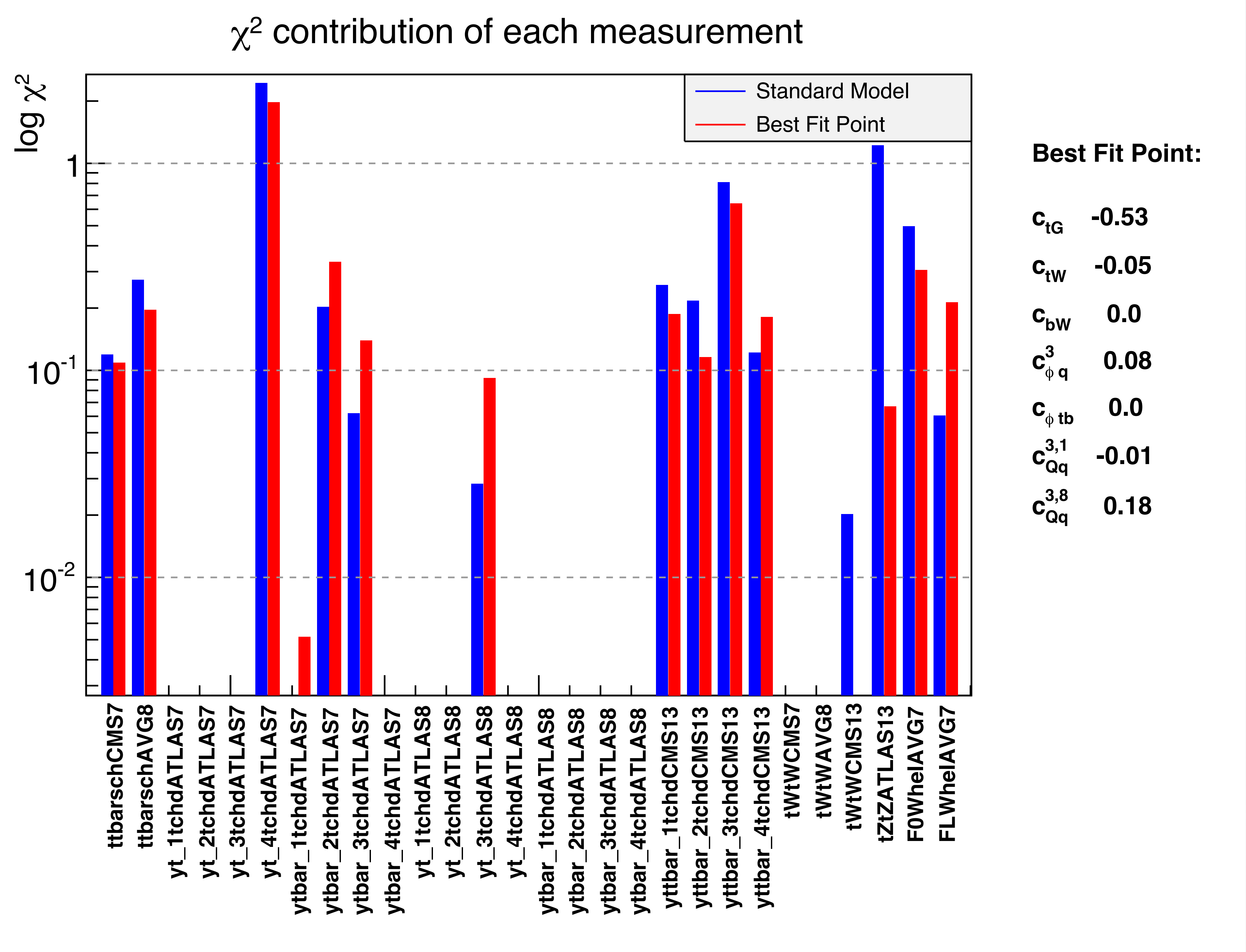

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