$t\bar{t}$ Spin Correlations in the di-leptons channel using Run 2 data & EFT interpretation

Tnourji abdellah **Romain Madar**

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Objective

1. Spin Observables
2. Effective field theory interpretation

Why Top quark is so special ?

- Top is an ideal quark for spin measurements :
  - decays before it can form bound states
  - spin information transferred to daughter particles
  - expect top spin observables to be well predicted by perturbative QCD

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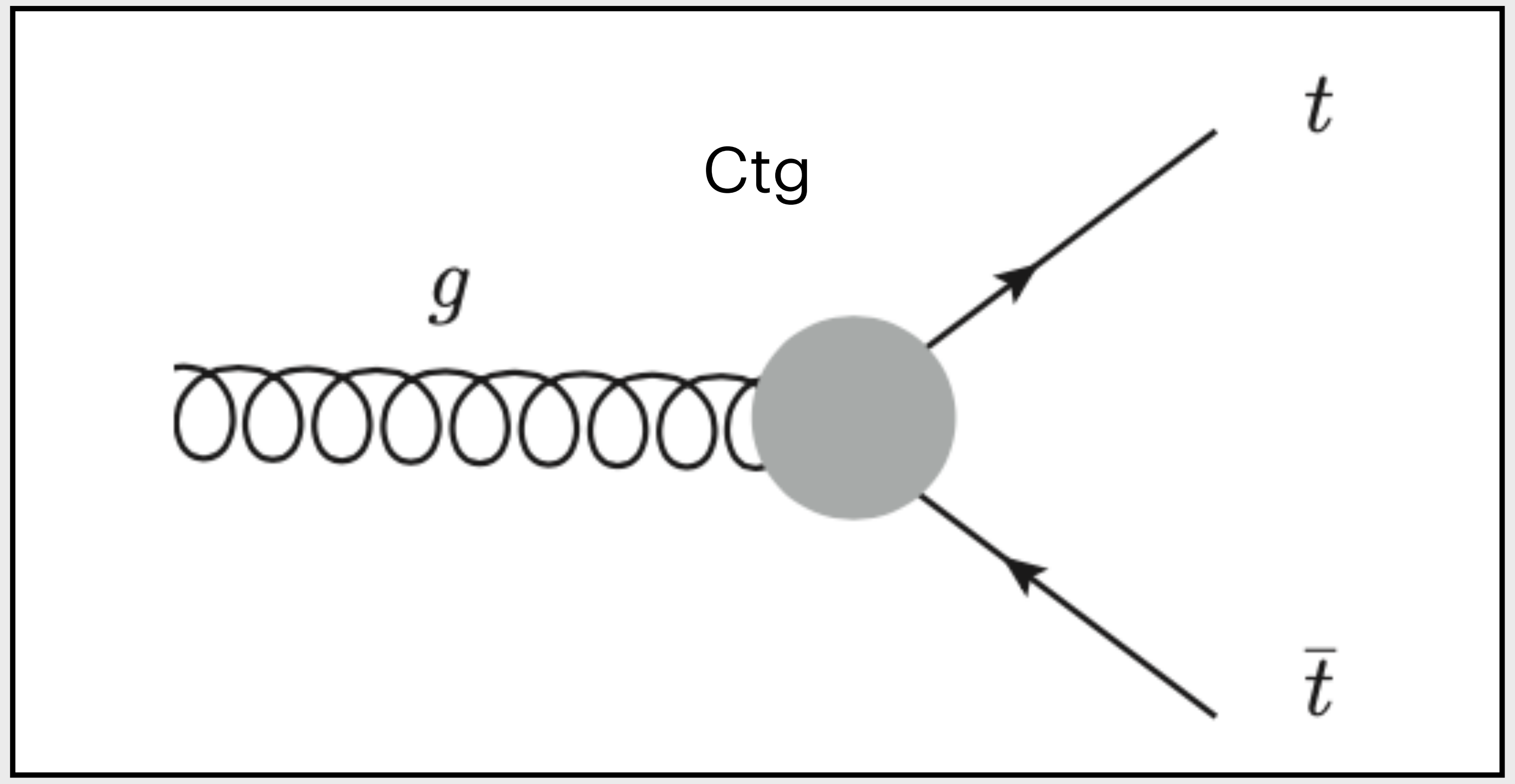
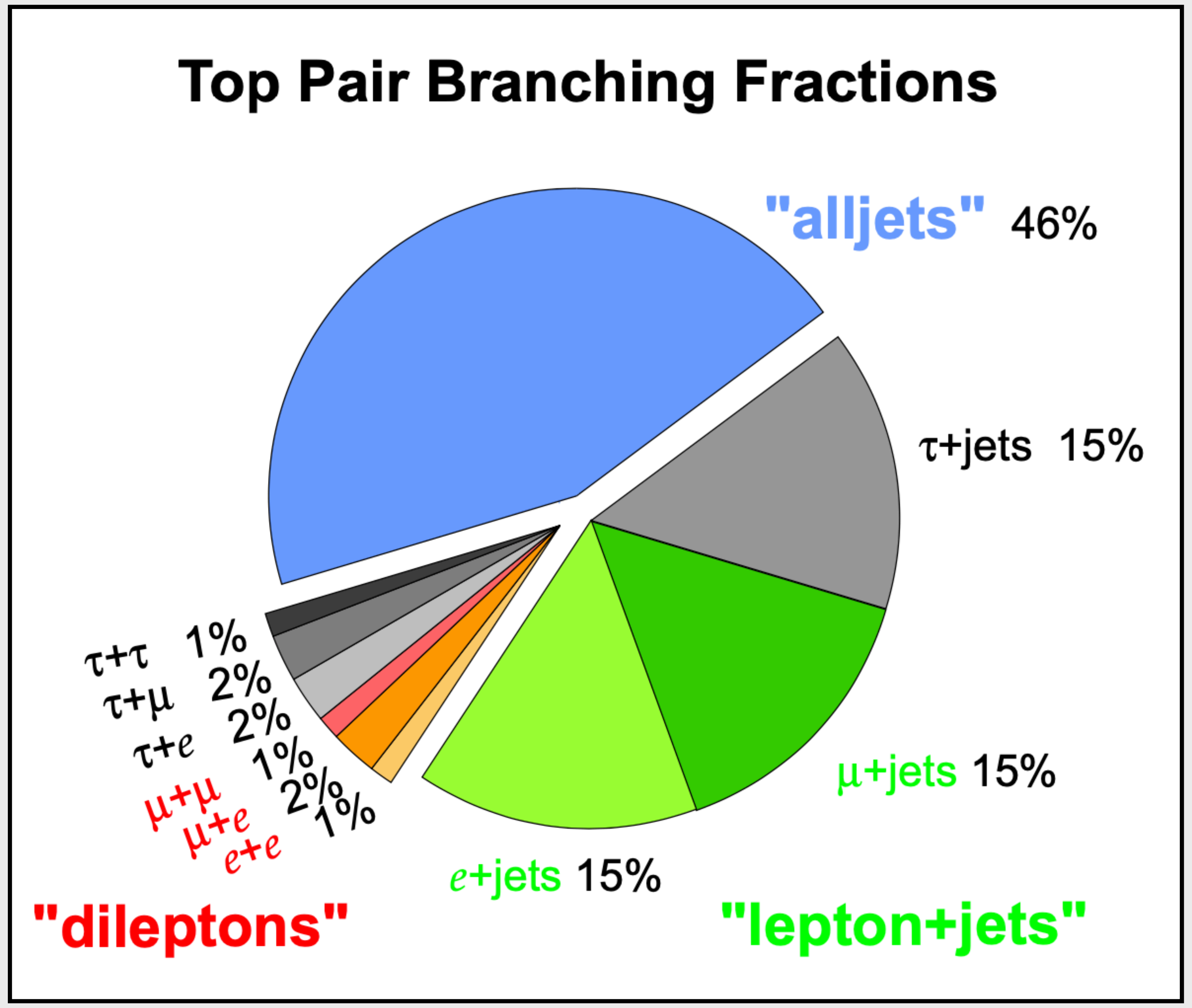
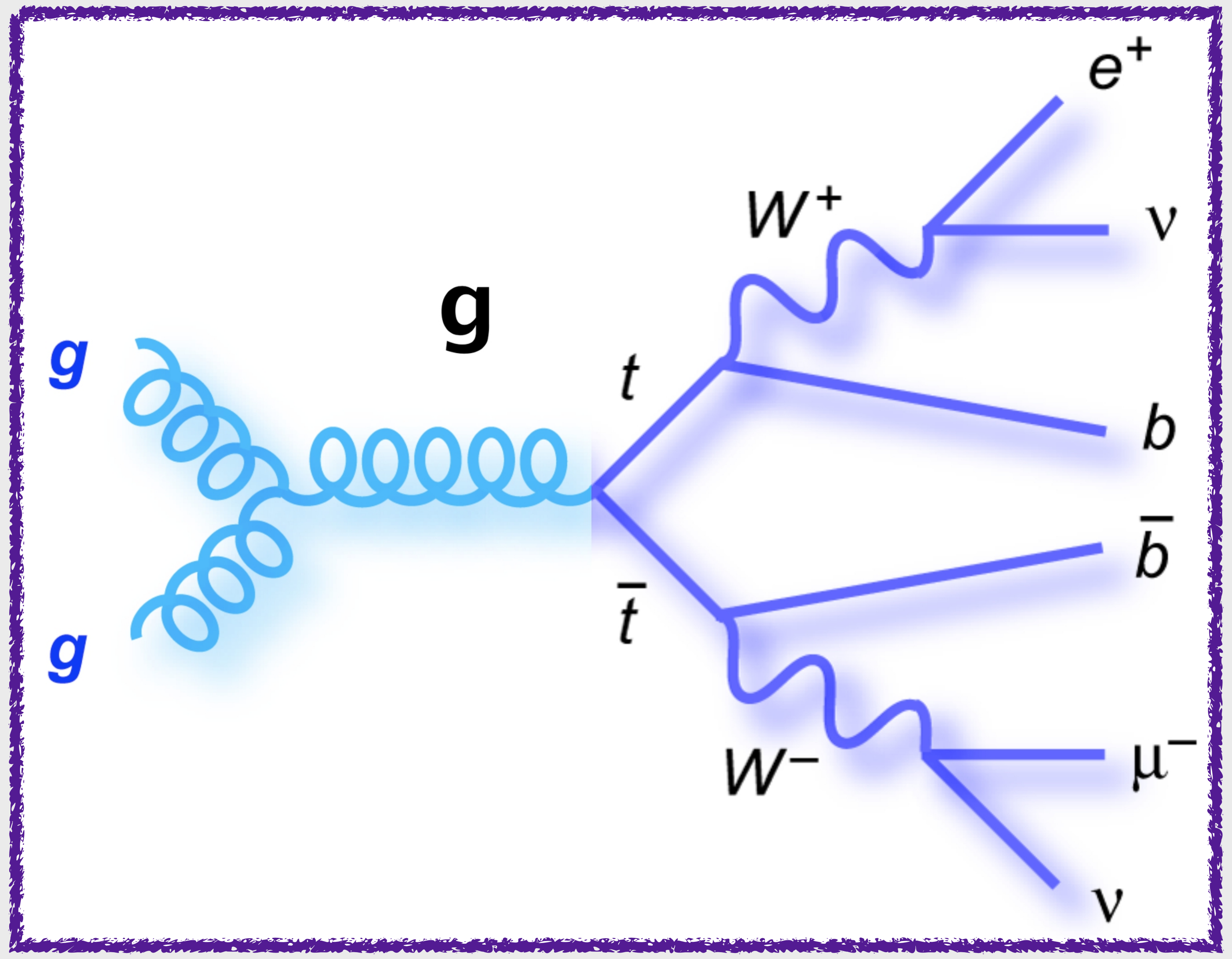
- In the SM, top quarks production is ~ unpolarised
- Top spin measurements are a powerful probe of new physics in $t\bar{t}$ production :
  - new mediator would change spin structure
  - sensitive to many dim-6 EFT operators



Top quarks pair decay mode





- **All - hadronic**
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  - Event fully constrained
- **Semi - leptonic**
  - Hight BR
  - Medium background
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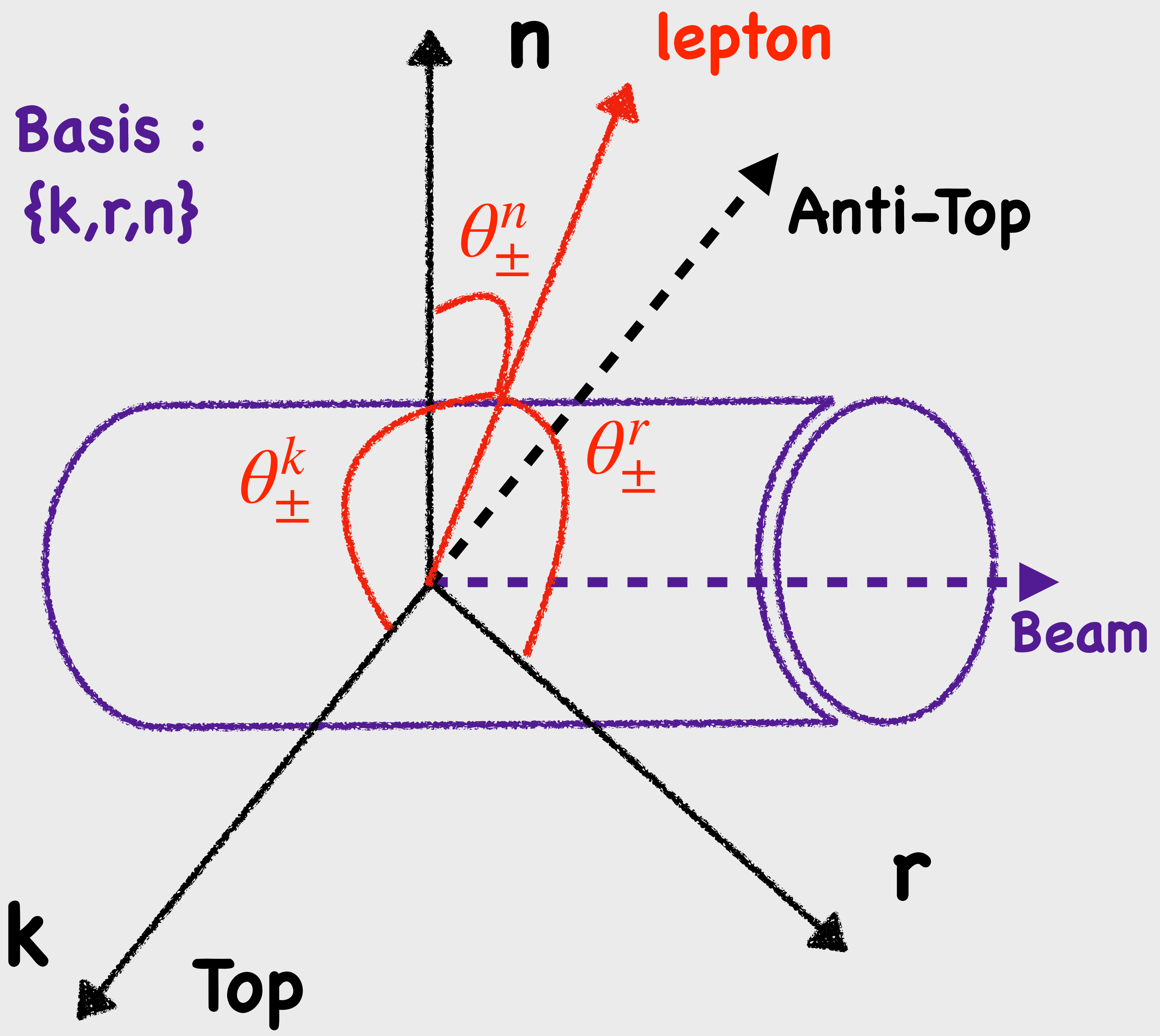
- **Di-leptonic**
  - Small BR
  - S/B Good
  - Event under-constrained

Spin Observables

Probing the spin observables :

- The dominant effect of the spin correlations is to correlate the angles of the decay products between the top quark and anti-top quark :

$$\frac{1}{\sigma}\frac{d^2\sigma}{d\cos(\theta_+^a)d\cos(\theta_-^b)} = \frac{1}{4}(1+B_+^a\cos(\theta_+^a)+B_-^b\cos(\theta_-^b)-C(a,b)\cos(\theta_+^a)\cos(\theta_-^b))$$



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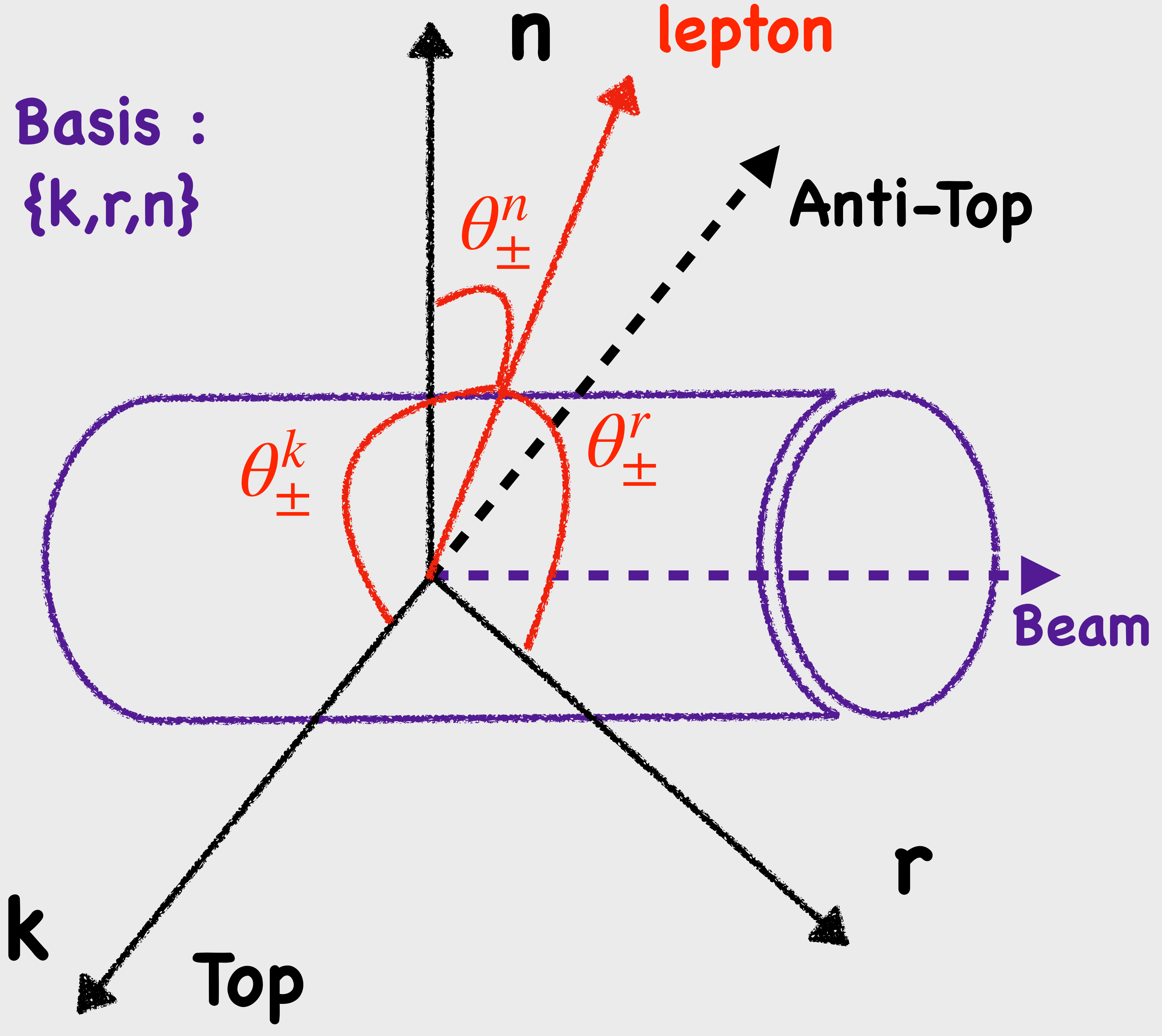
- B_+^a, B_-^b and C(a,b) are the polarisation and spin correction in quantisation axis a and b where a, b = $(\hat{k}, \hat{n}, \hat{r})$.
  - C(a,b) = -9 $< \cos(\theta_a^+)\cos(\theta_b^-) >$ ==> 9 correlations
  - B^a = 3 $< \cos(\theta^a) >$ ==> 6 polarisations



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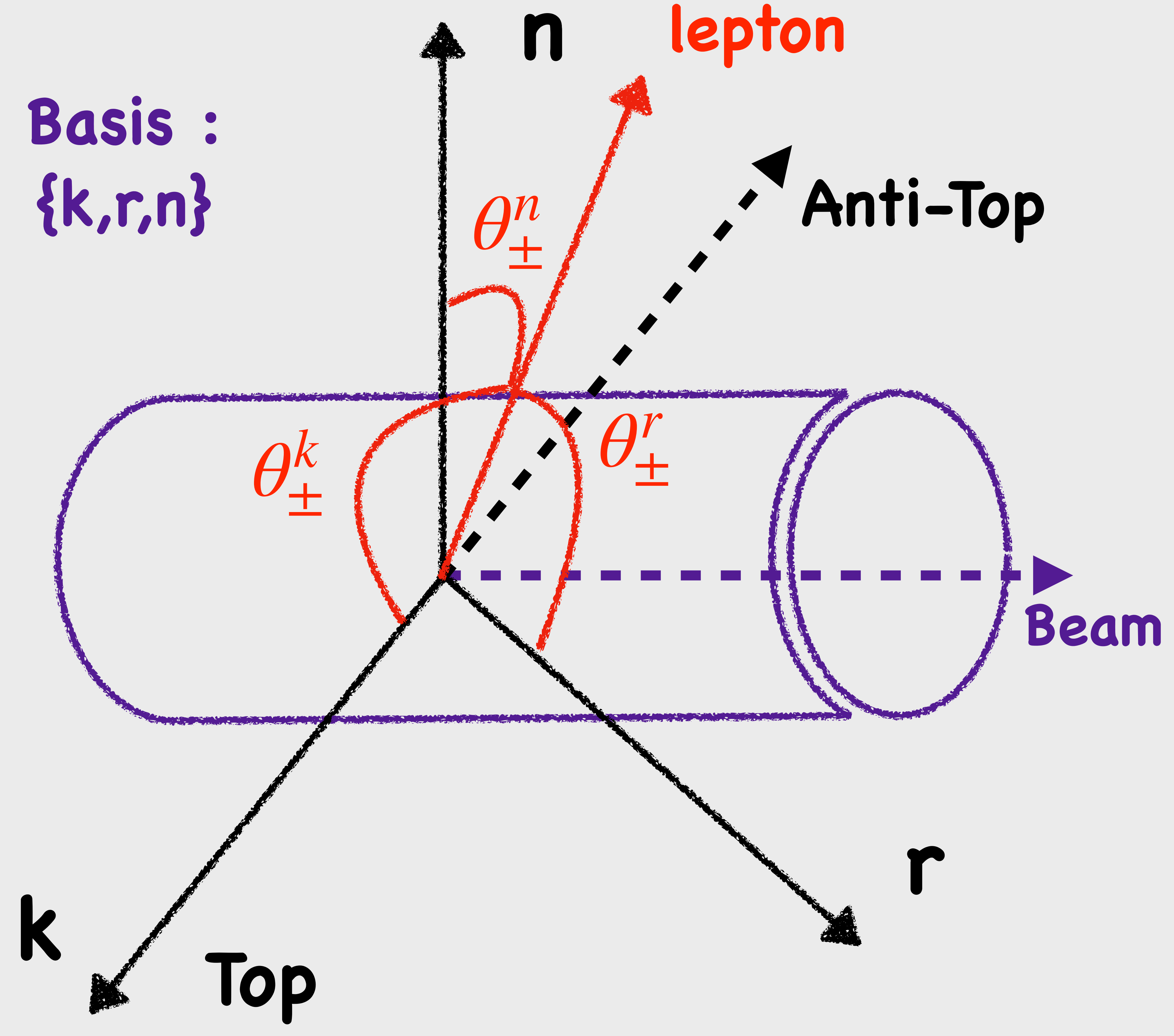
- these 15 coefficients completely characterise spin dependence of $t\bar{t}$ production and can be measured experimentally.



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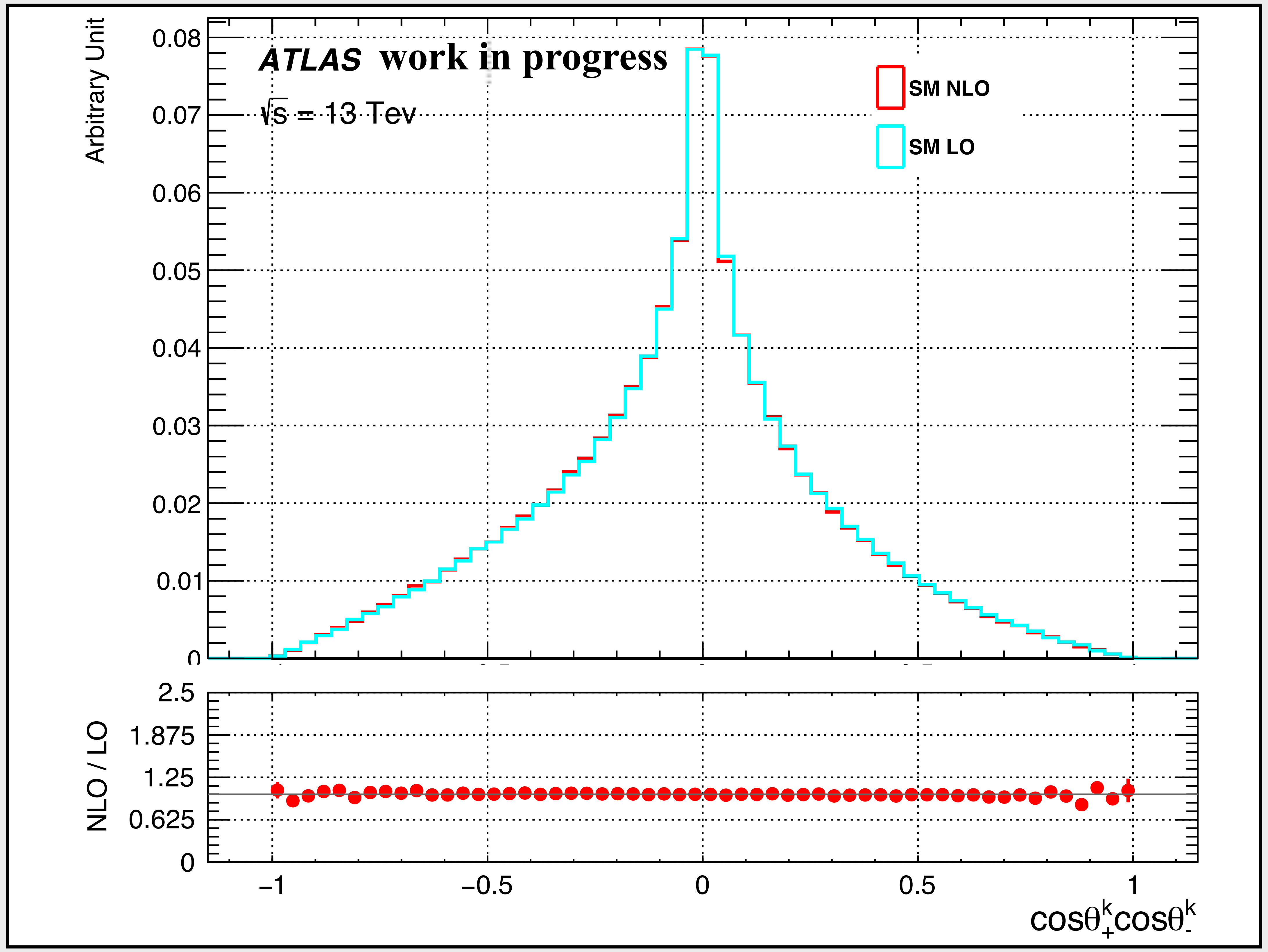
Spin Correlations : C(k,k)

- Distributions for the correlation of top spins along k axis (probing diagonal of **C (a, b)** matrix) : $\mathbf{C\ (k, k) = -\ 9} \ < \cos(\theta_k^+)\cos(\theta_k^-) >$



SM NLO : C(k, k) = 0.366313 +/- 0.0042 (stat)

SM LO : C(k, k) = 0.341856 +/- 0.0042 (stat)

- Spin correlations along each axis consistent with SM expectations (NLO from 1508.05271)

Interpretation

Introduction

- In effective field theory (EFT) language, the Standard Model Lagrangian is the first term in an effective Lagrangian

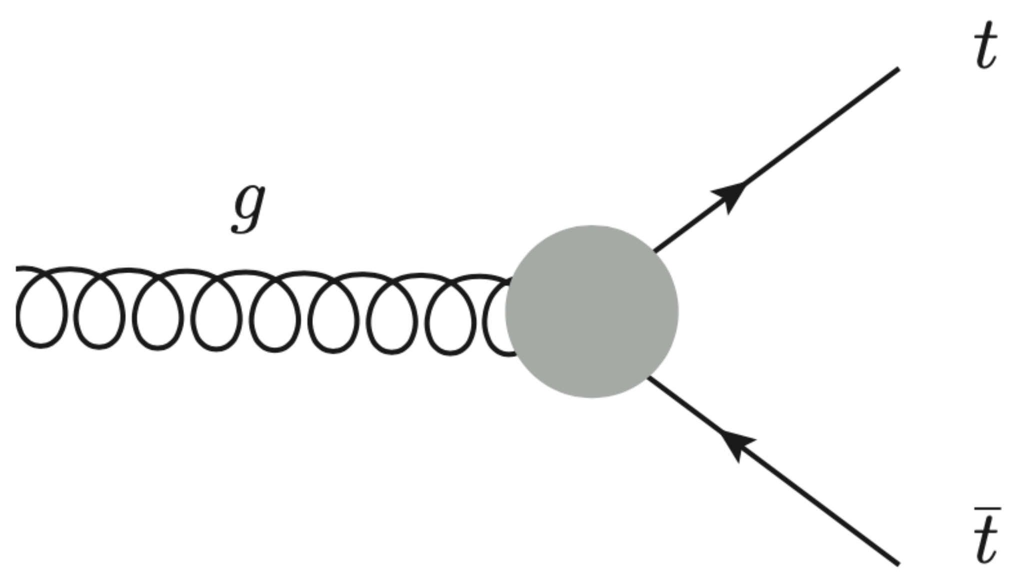
$$\mathcal{L}_{\mathrm{SMEFT}} = \mathcal{L}_{\mathrm{SM}} + \sum_{D>4} \sum_{i} \frac{c_i^{(D)}}{\Lambda^{D-4}} \mathcal{O}_i^{(D)}$$

- Where Λ generically represents the scale of the new physics. C_i are dimensionless Wilson coefficients.
- EFT implemented in dim6top model and SMEFT@NLO model
  - These model are implemented inside MadGraph5_aMC@NLO framework which translate a Lagrangian into a MC sample.

EFT interpretation

- The measured coefficients probe **most of the lowest-order EFT operators** relevant to LHC $t\bar{t}$ production.

$$O_{tG} = y_t g_s (\overline{Q}\sigma^{\mu\nu} T^a t)\tilde{\phi} G^a_{\mu\nu}$$



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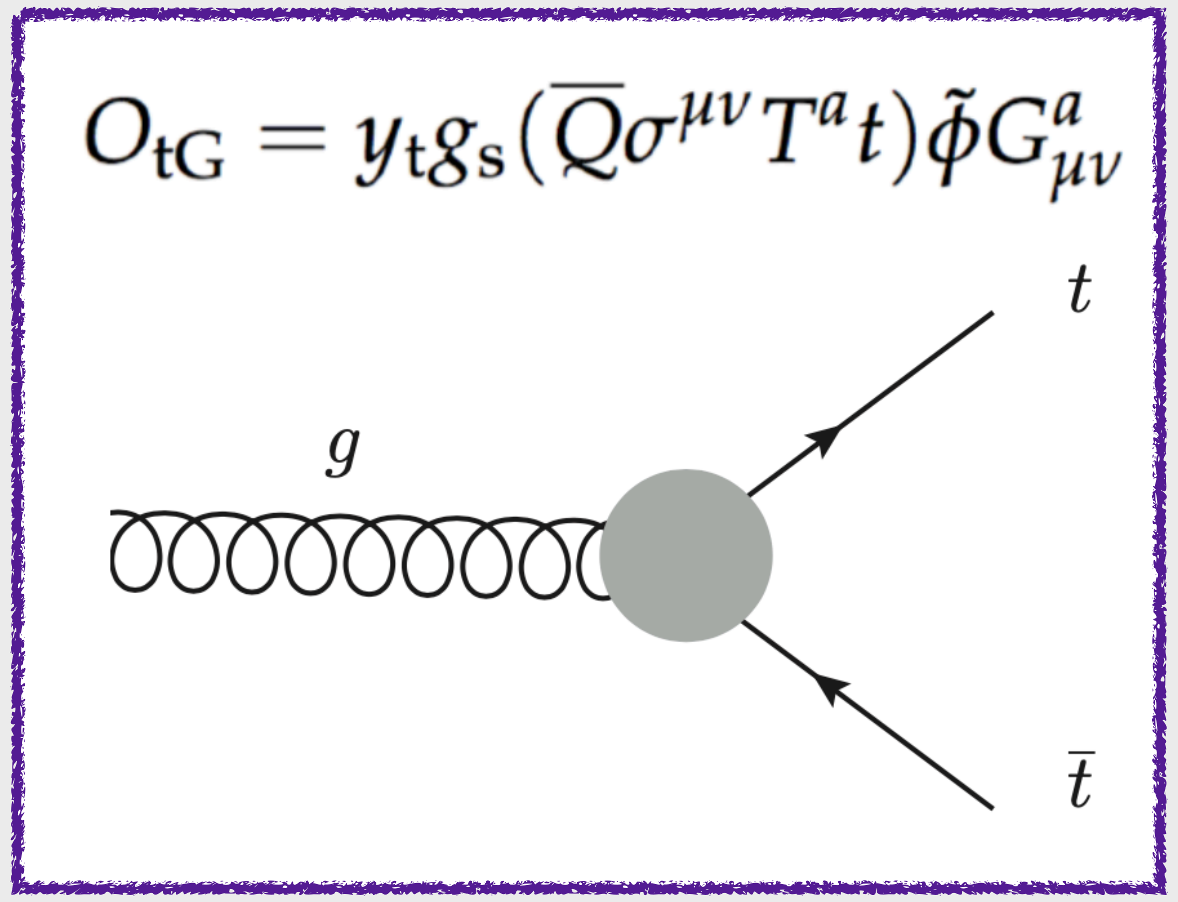

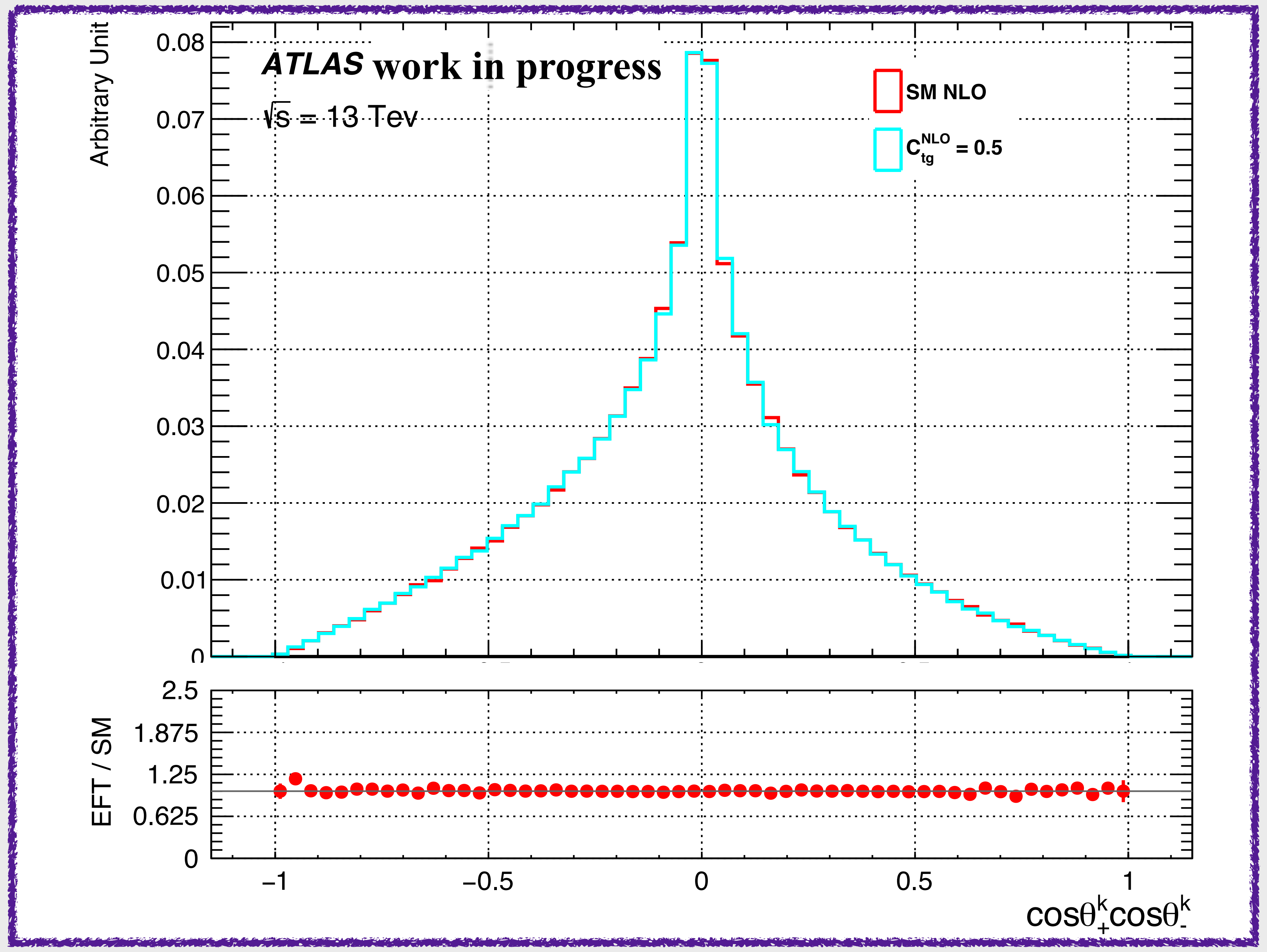

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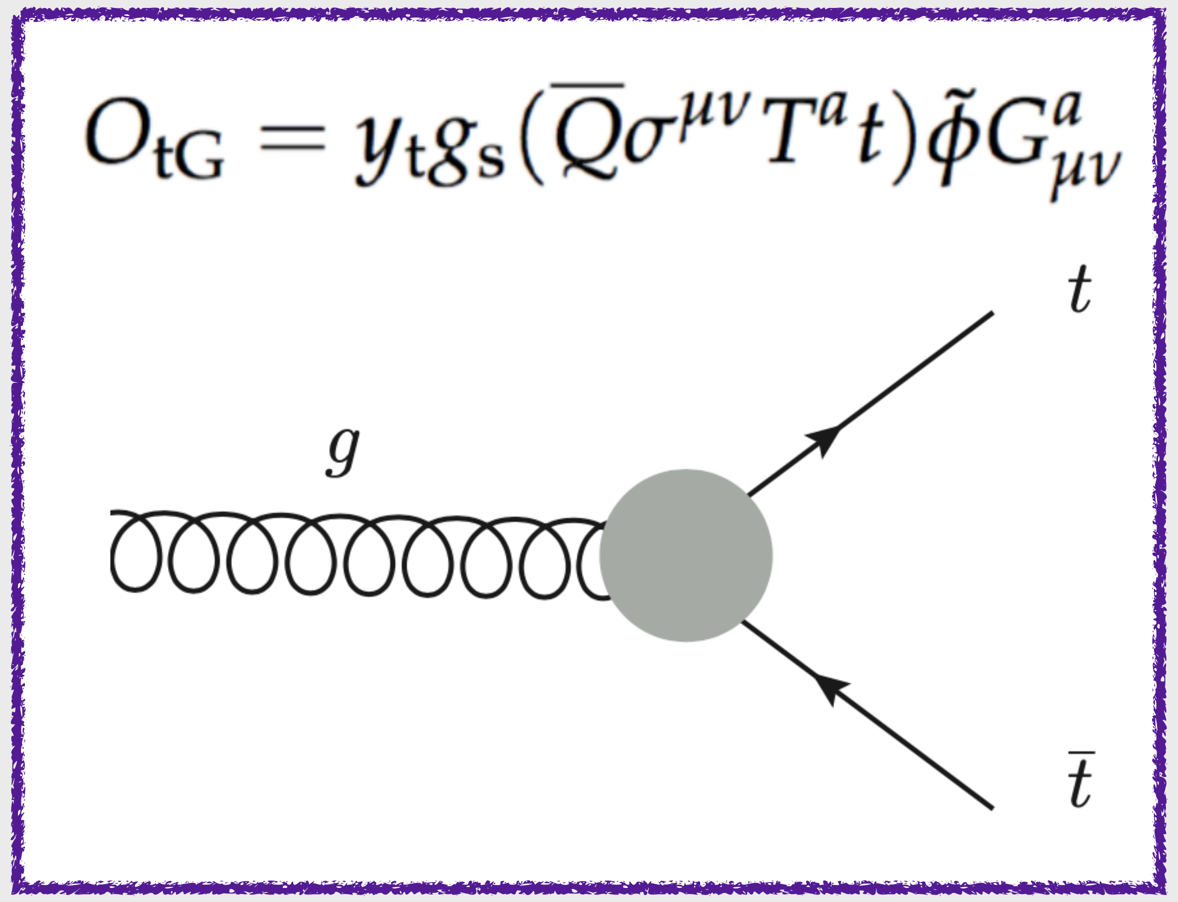

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- **Spin correlation :**
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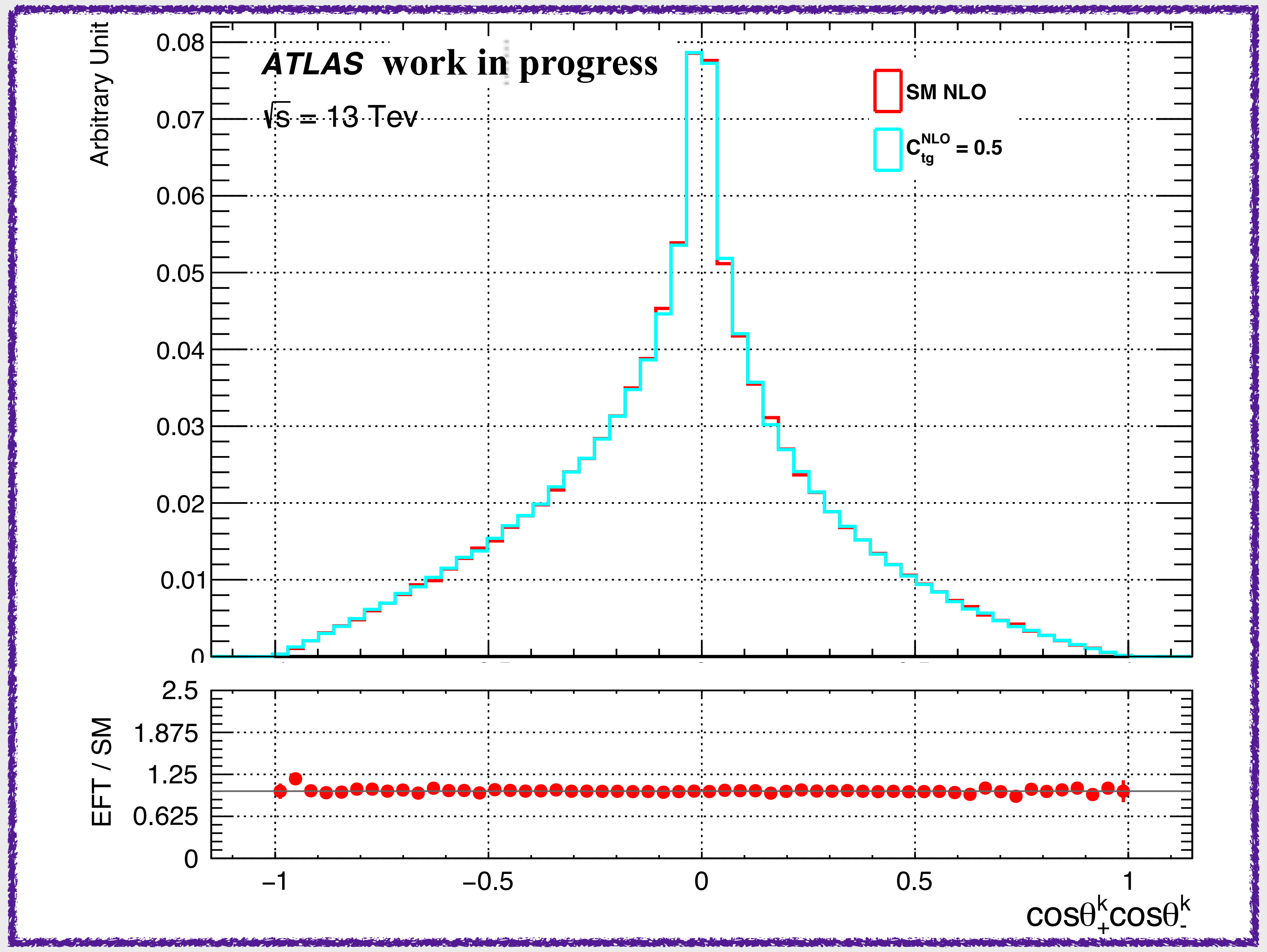
  - **For other spin corrections observables, the effect is very low or not observed.**



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Compute α_i and β_i

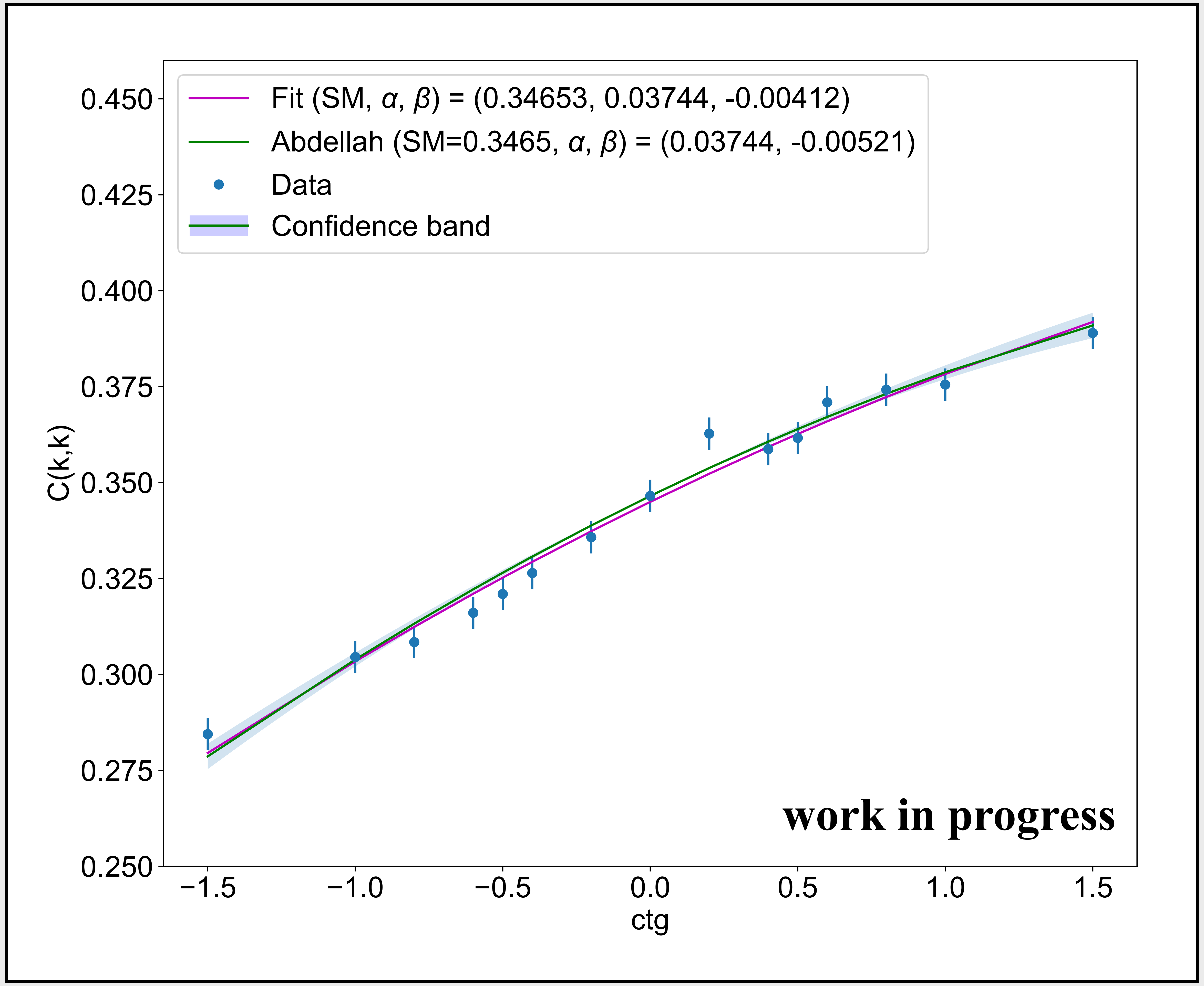
$$C(k,k)_{EFT} \approx C(k,k)_{SM} + \boxed{\alpha_{tg}\frac{c_{tg}}{\Lambda^2}} + \boxed{\beta_{tg}\frac{c_{tg}^2}{\Lambda^4}}$$

Linear Term

quadratic Term

α_i/Λ^2 and β_i/Λ^4 at LO : C(k,k)

SMEFT@NLO model



- SMEFT model is used to generate MC sample
- The value of Ctg affect the spin correlation

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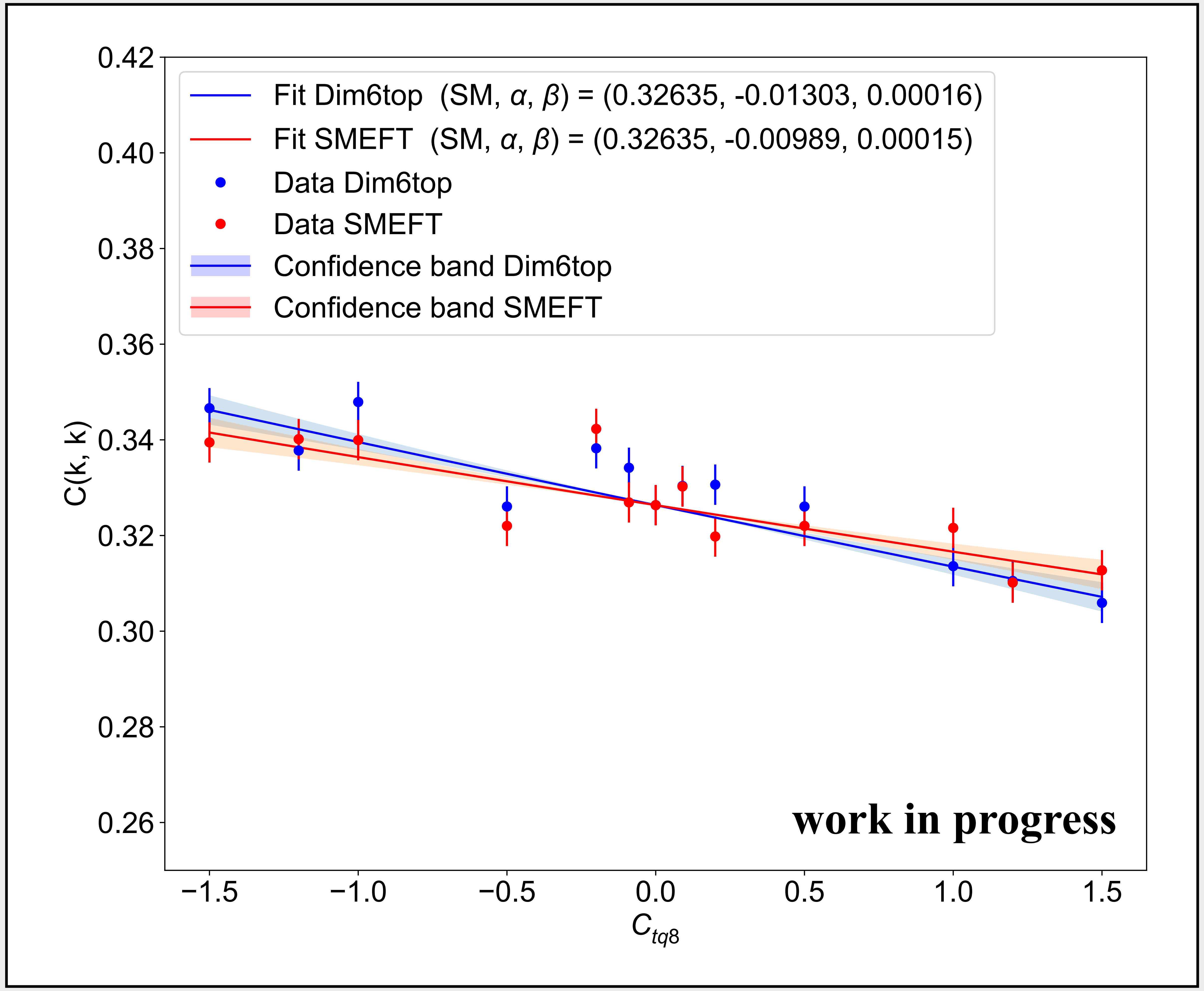
Linear Term quadratic Term

Comparaison between SMEFT and Dim6Top Model



☑ SMEFT model and Dim6top model show appx. same value of α_{ctq8} and β_{ctq8} [within the statistical uncertainties.]

Summary

1. Spin observables is sensitive to a different coefficient of the spin density matrix of $t\bar{t}$ production.

2. Precision top quark spin measurements are a powerful probe of new physics and complementary to other approaches

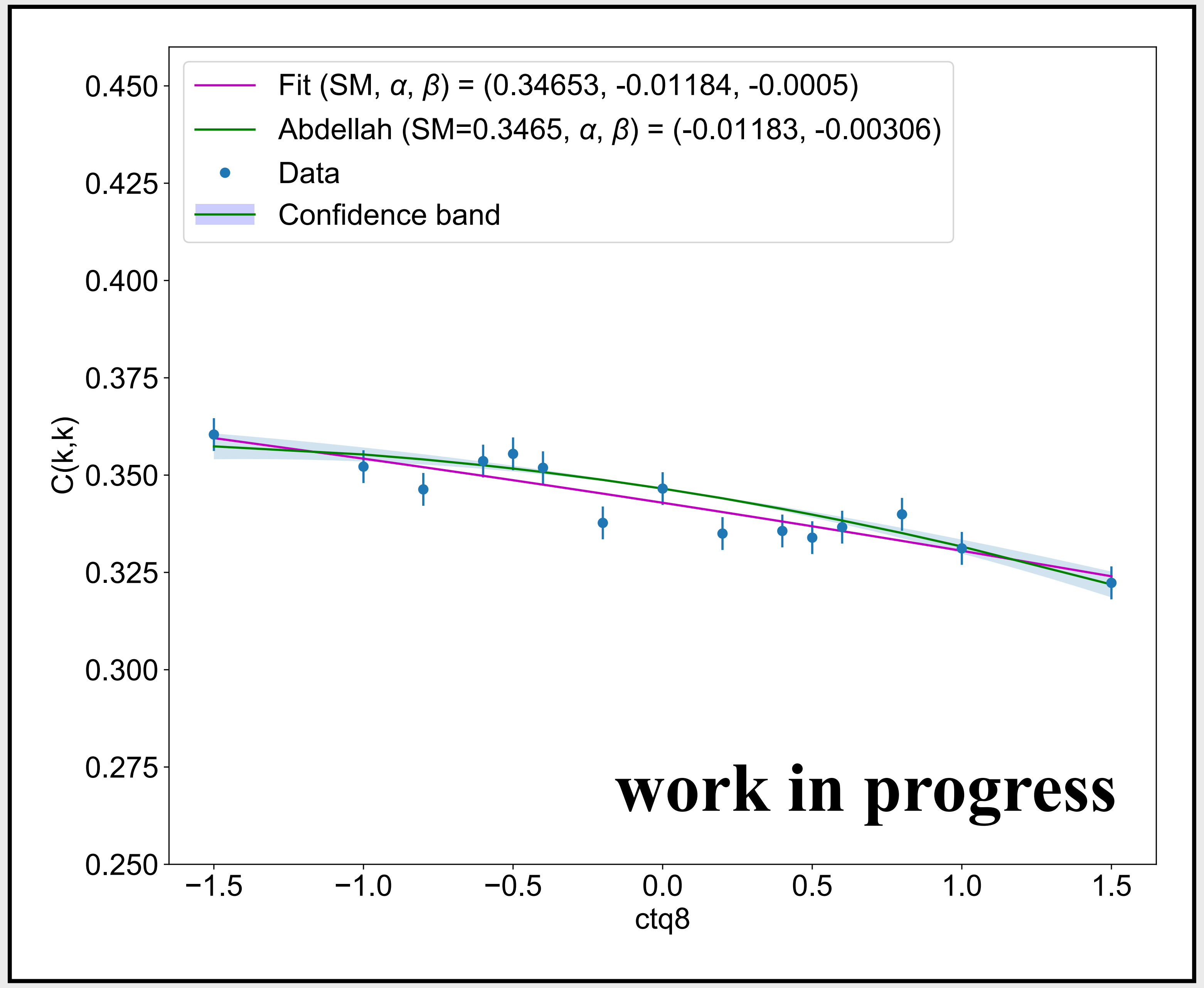
3. Spin observables are sensitive to many BSM operator which can be use to constrain the Wilson coefficients

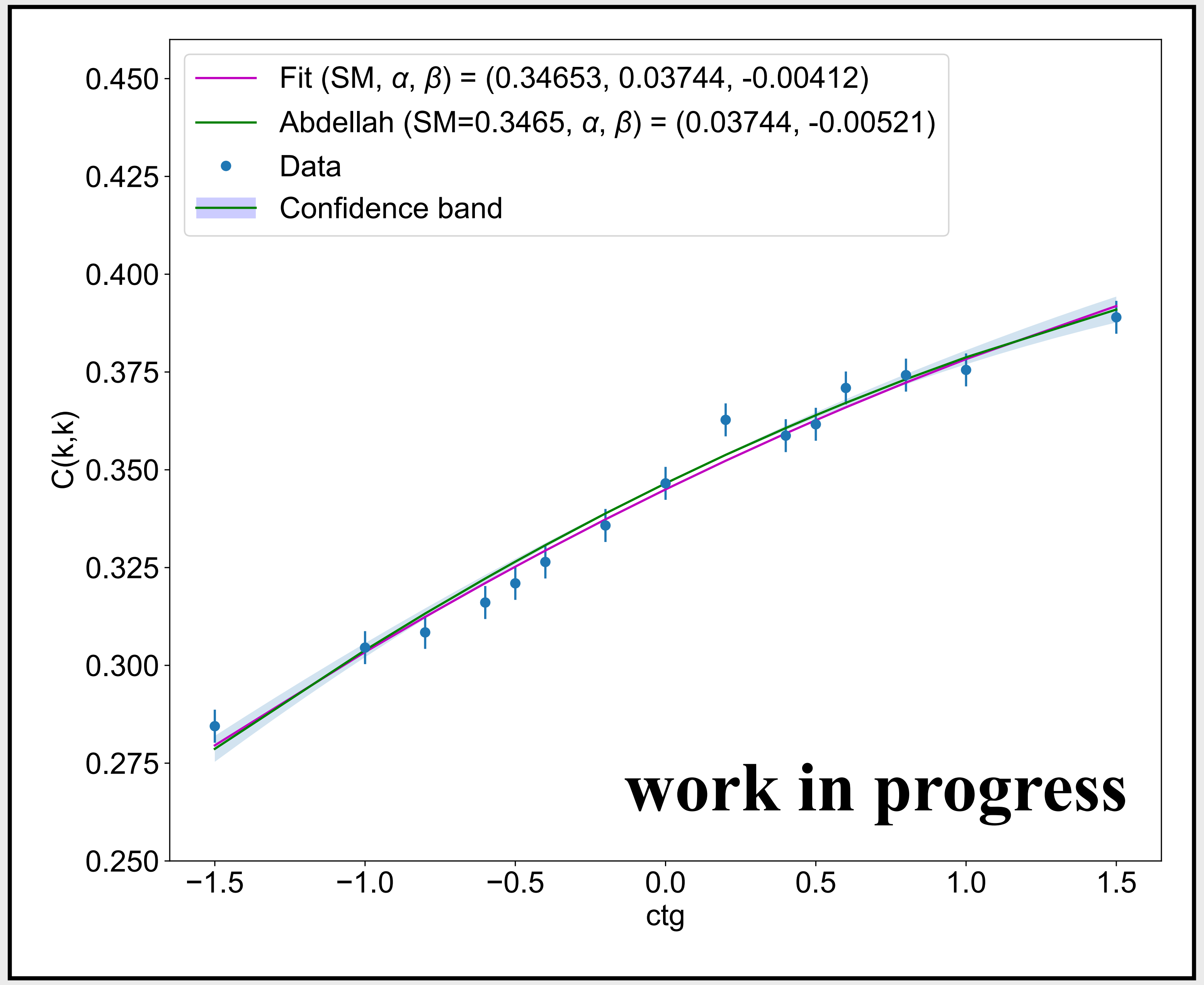
4. A Comparaison between SMEFT and Dim6top is shown

Back up

α_i/Λ^2 and β_i/Λ^4 at LO : C(k,k)

C(r,r) and C(n,n) in back-up





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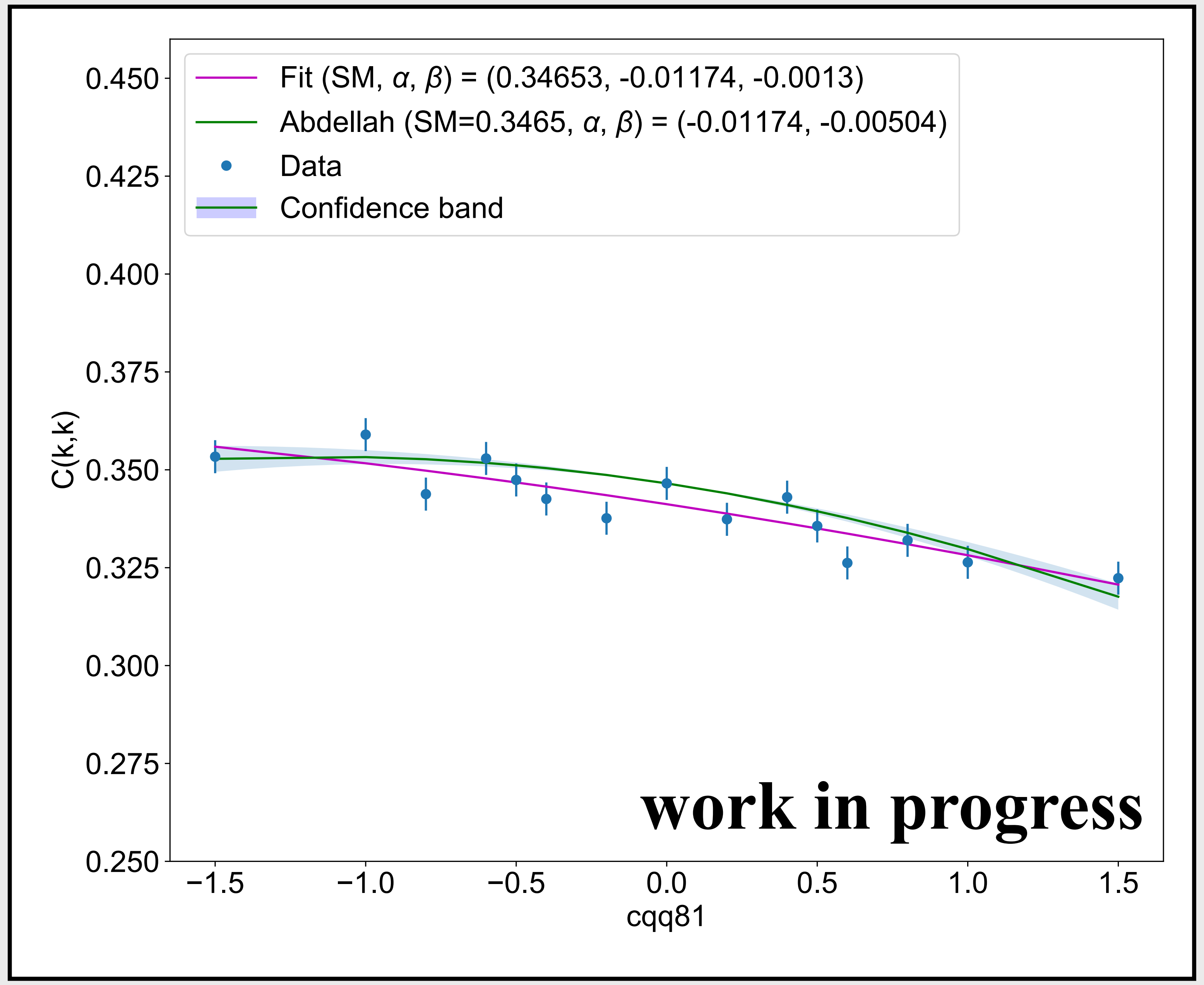

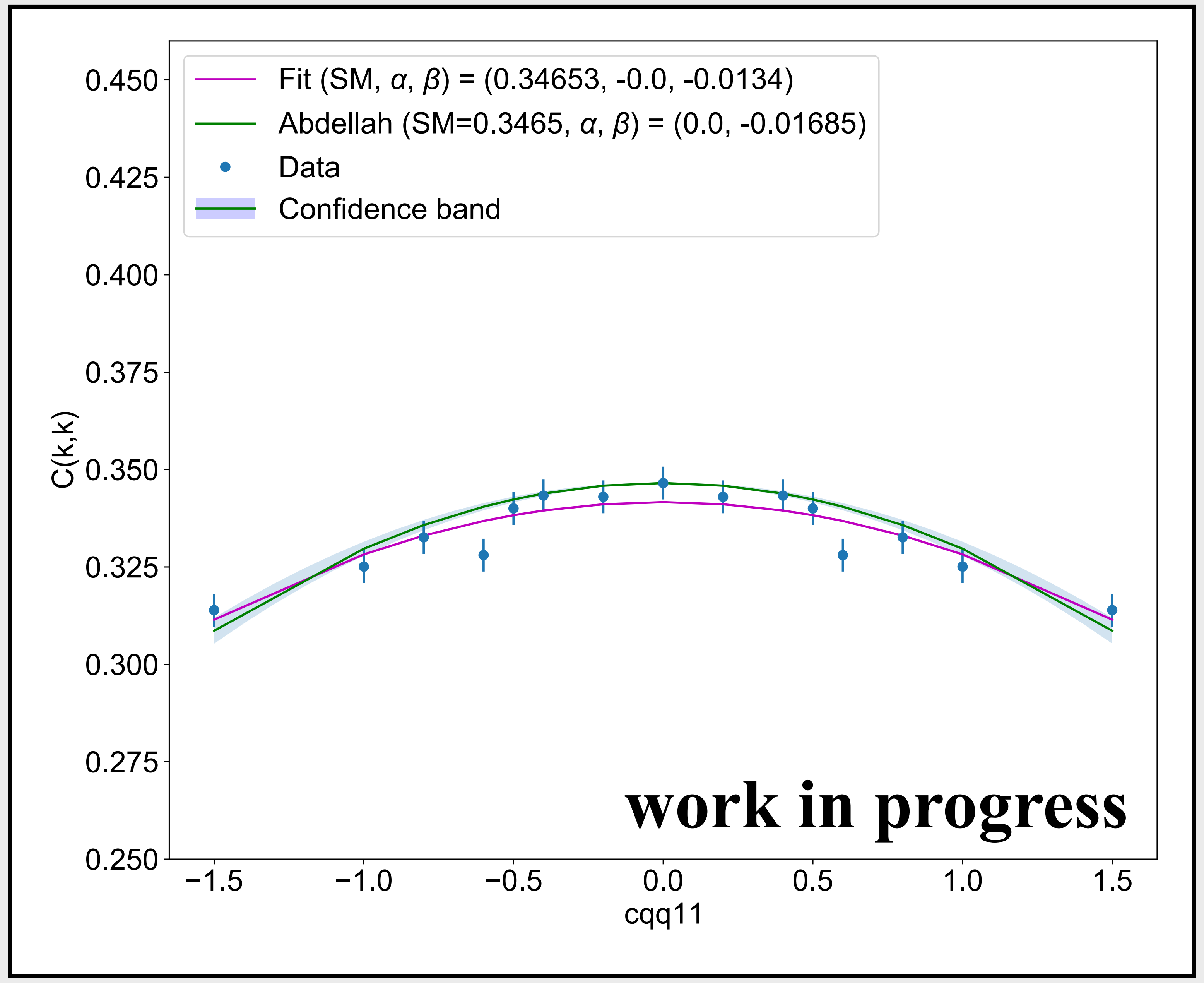

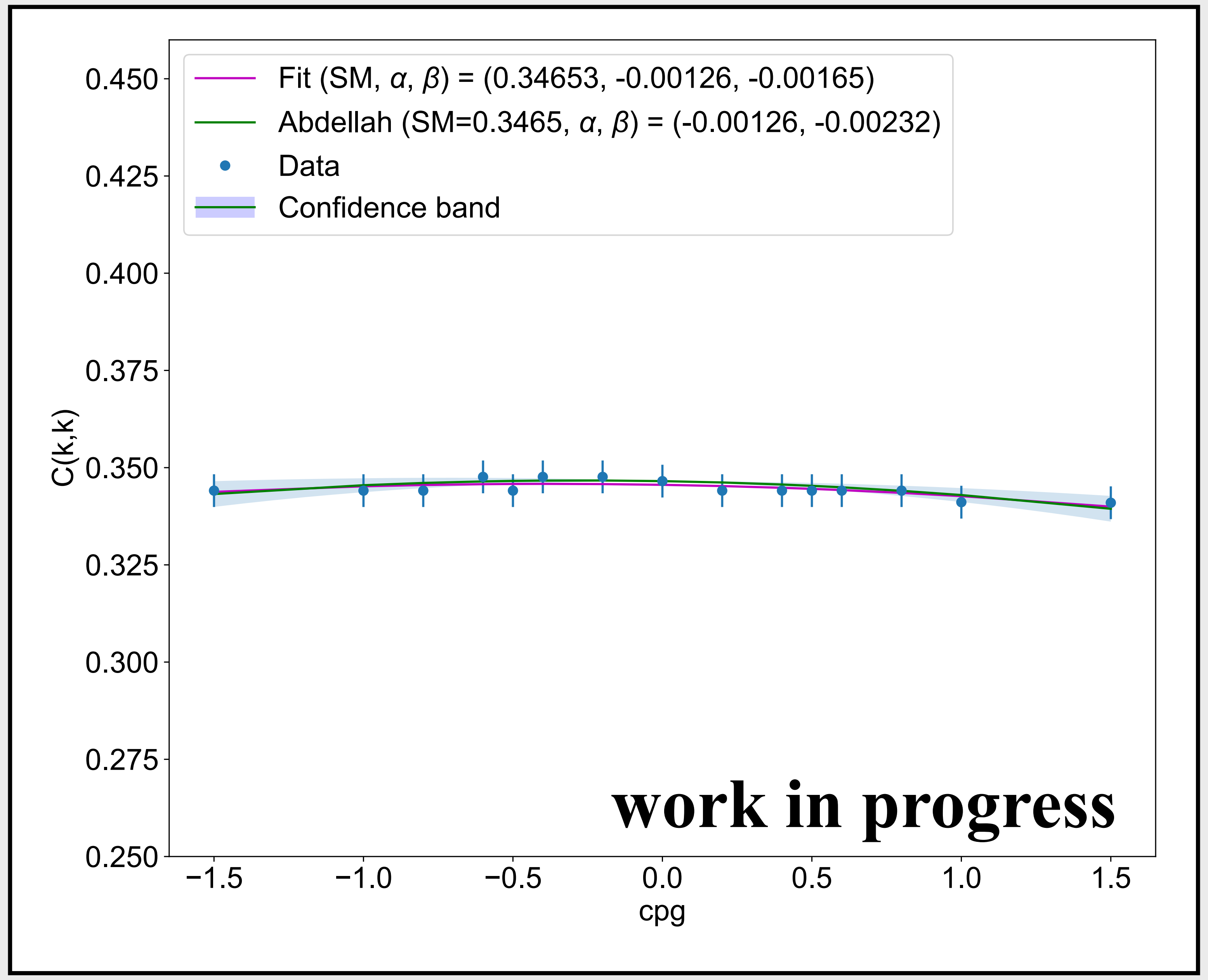

Introduction

- Heaviest fundamental particle (known) :
  - $m_t = 173.34 \pm 0.27(stat) \pm 0.71(syst) GeV$ [link]
- Short life time 10^{-24} , so it decay before hadronization.
- LHC is a Top Factory, large paire production.

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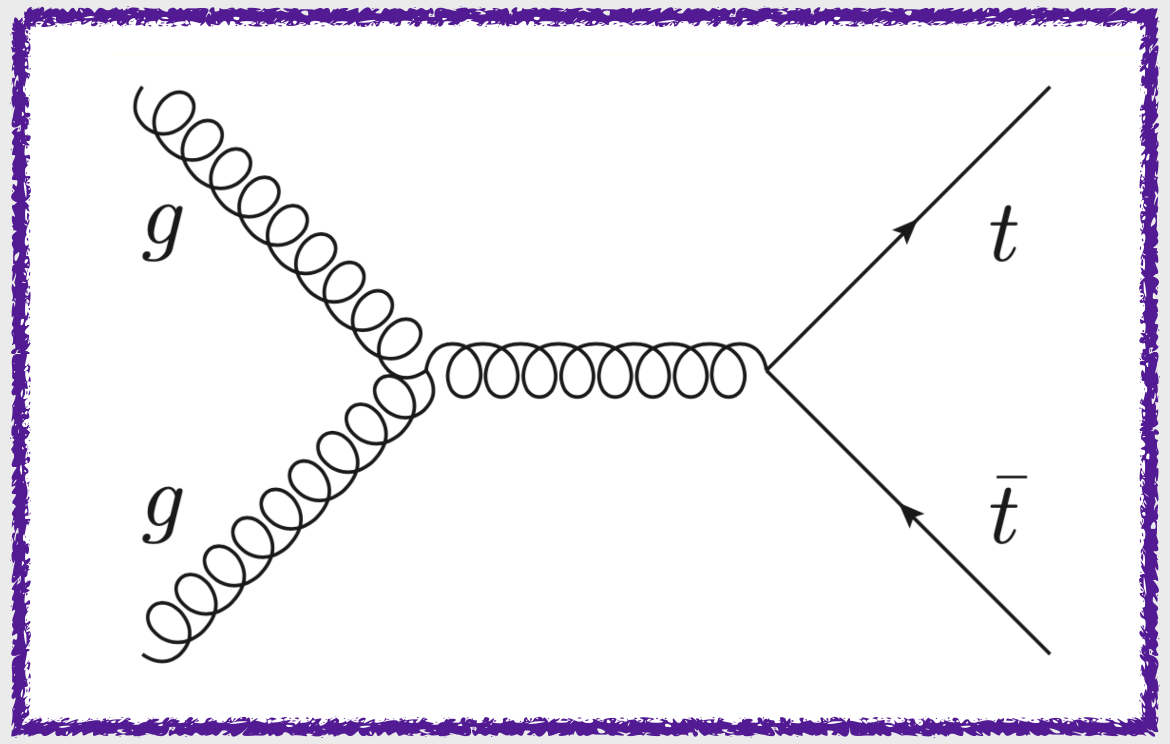

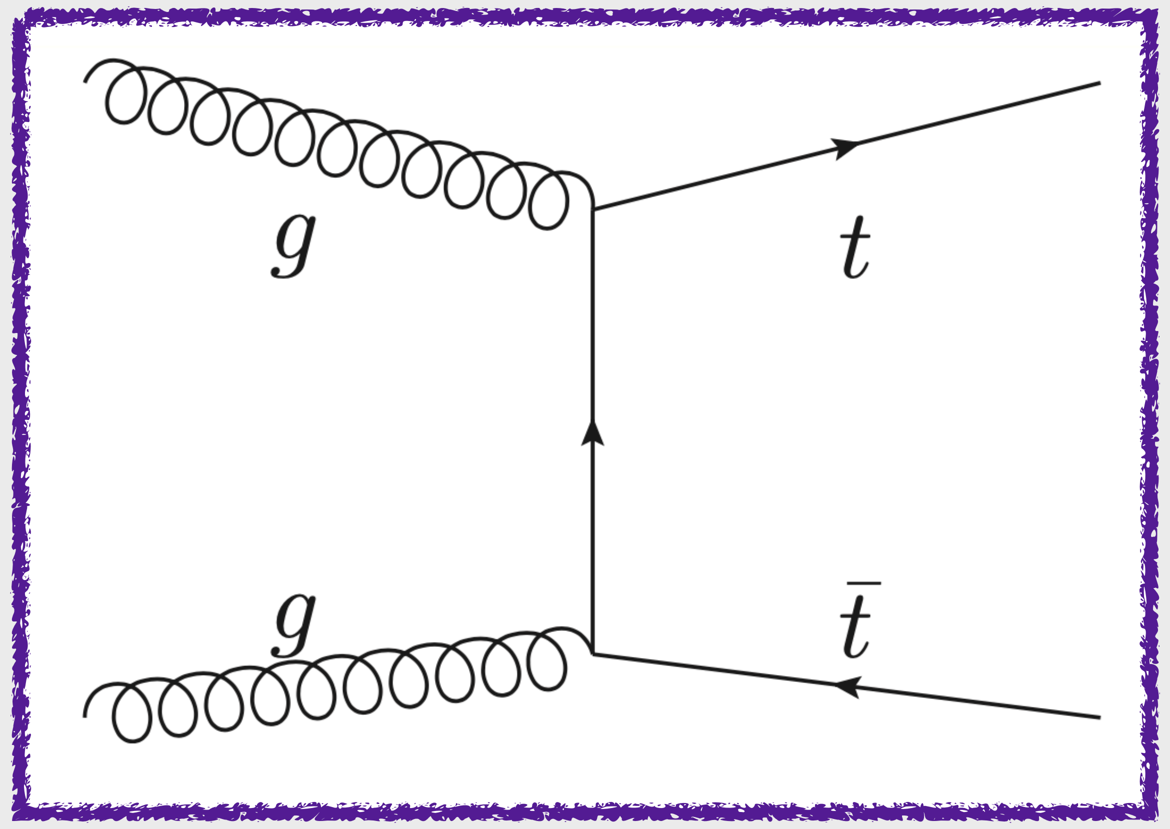

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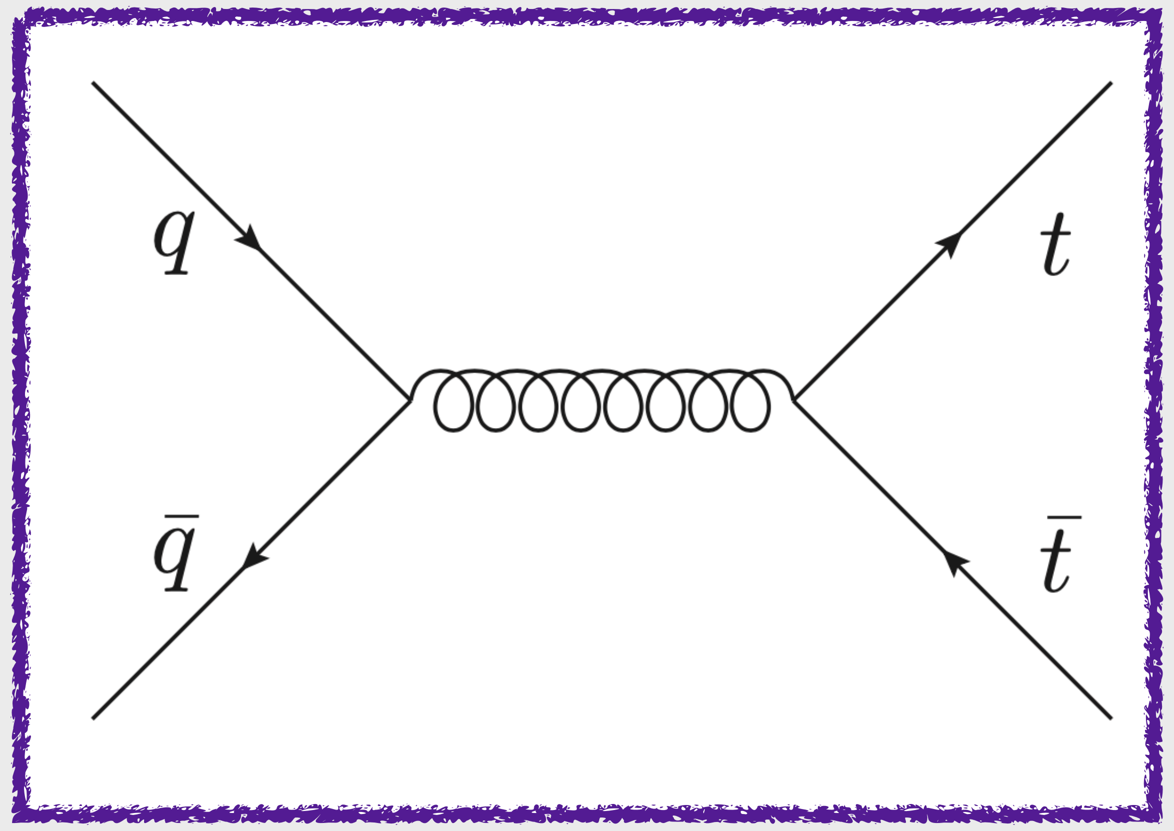

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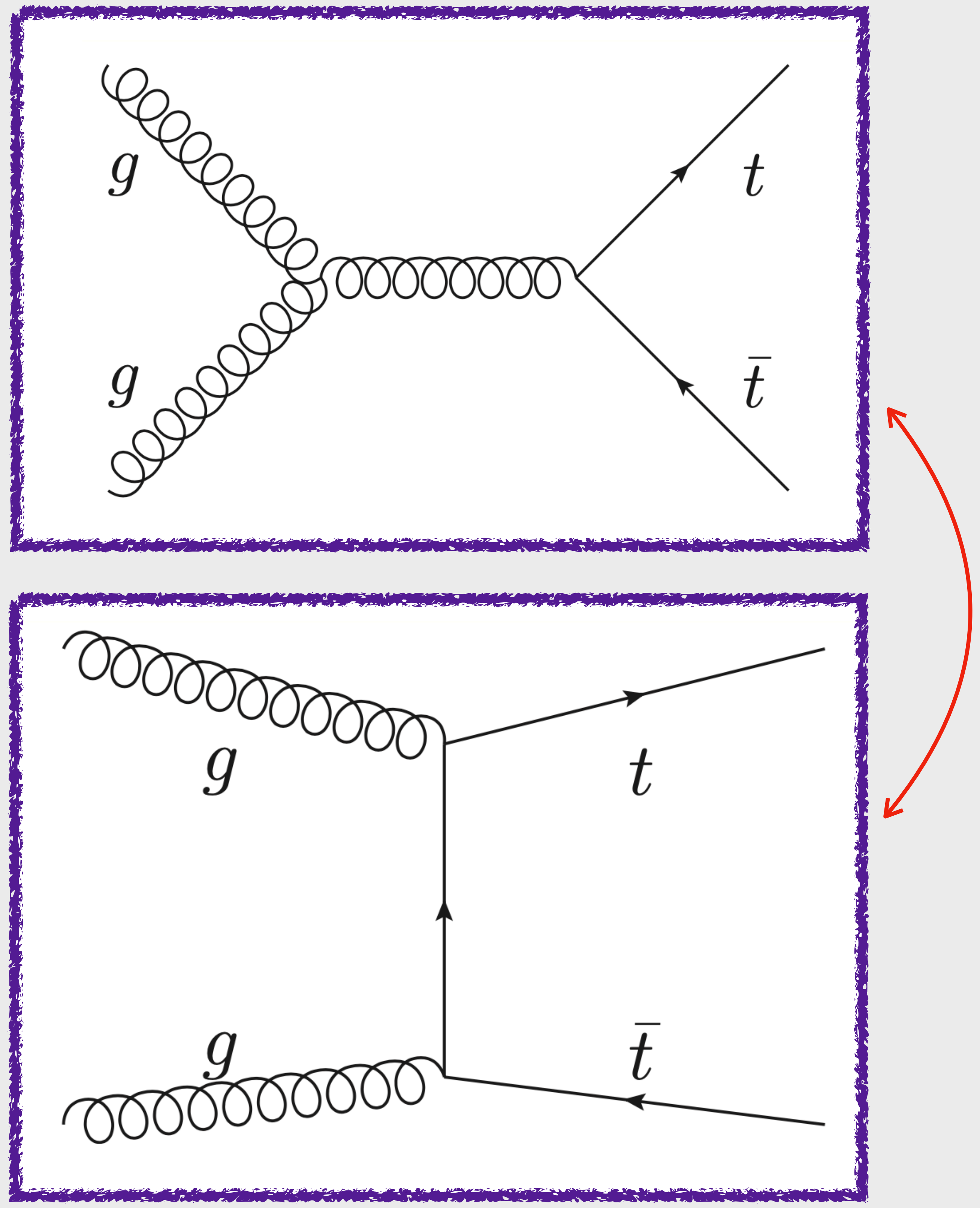
- ☑ **For next-to-leading-order (NLO) : qg initiated subprocess contribute.**



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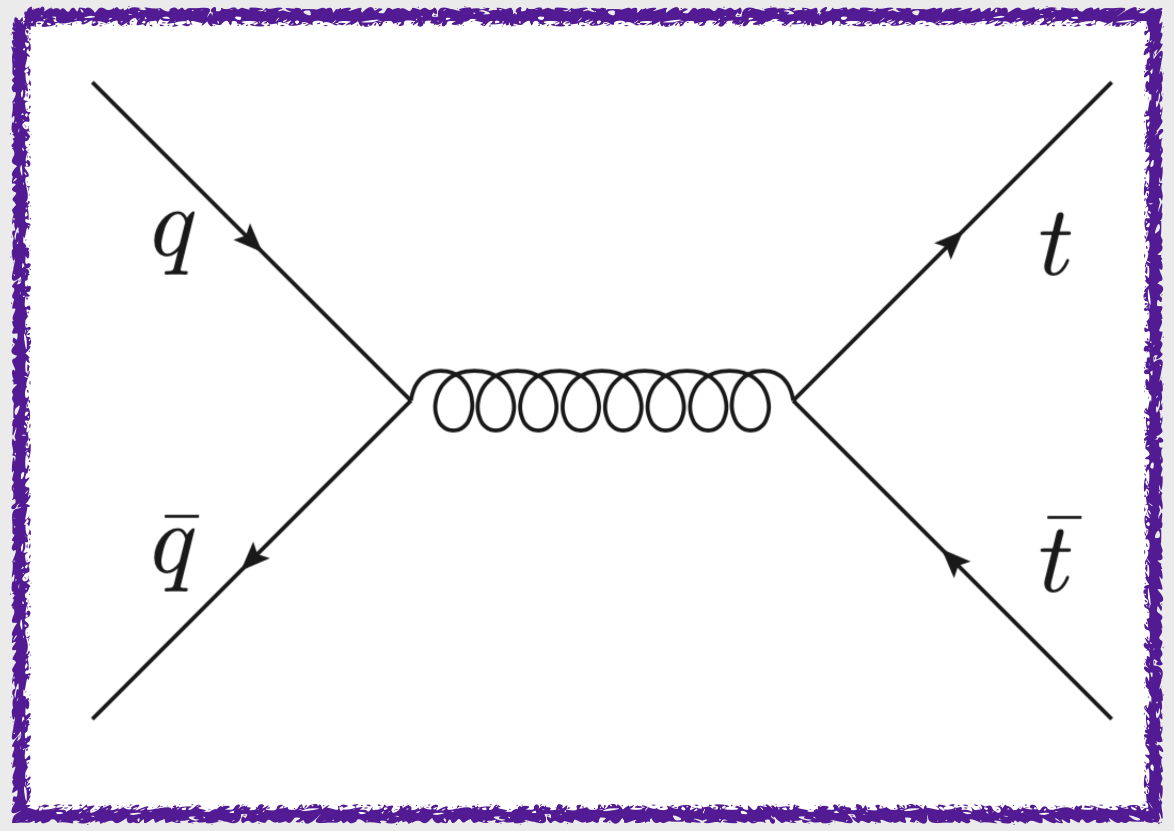

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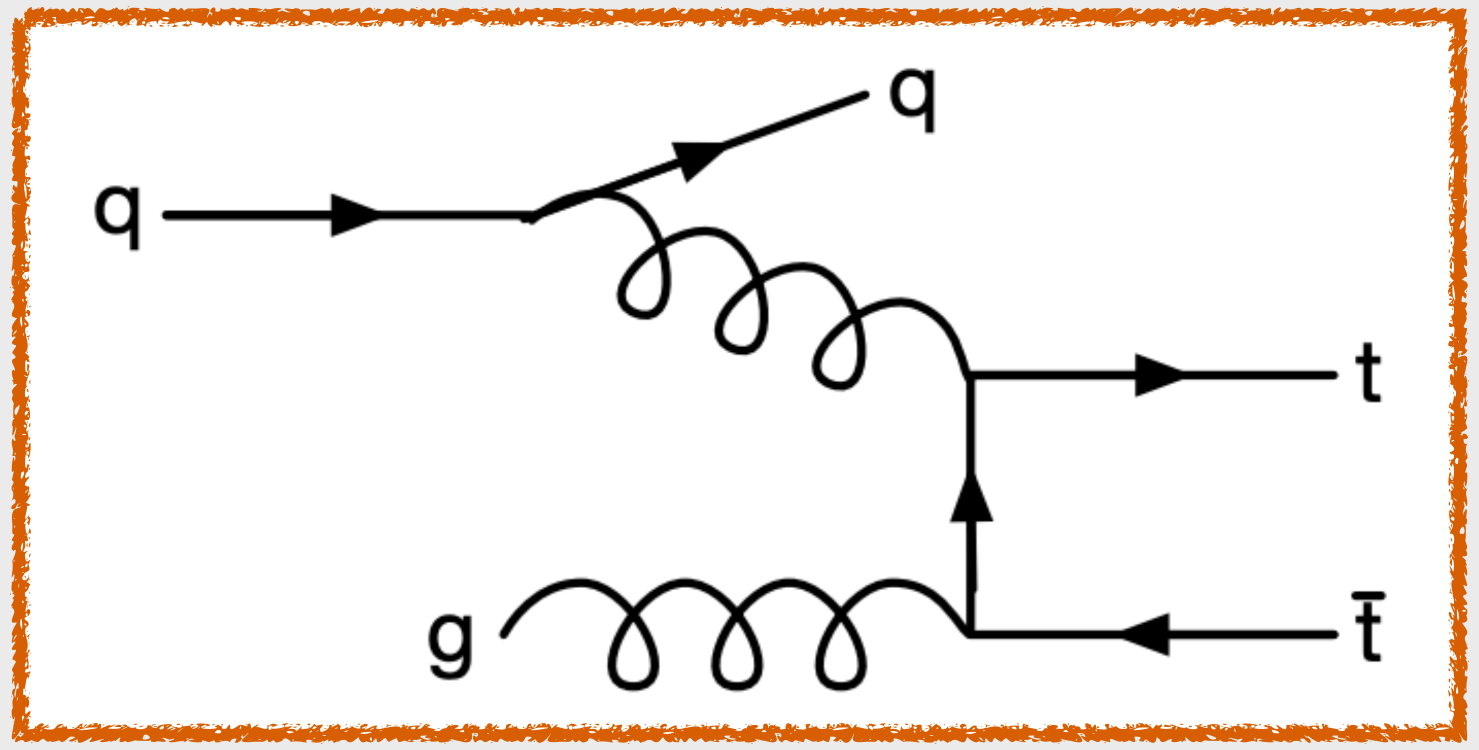

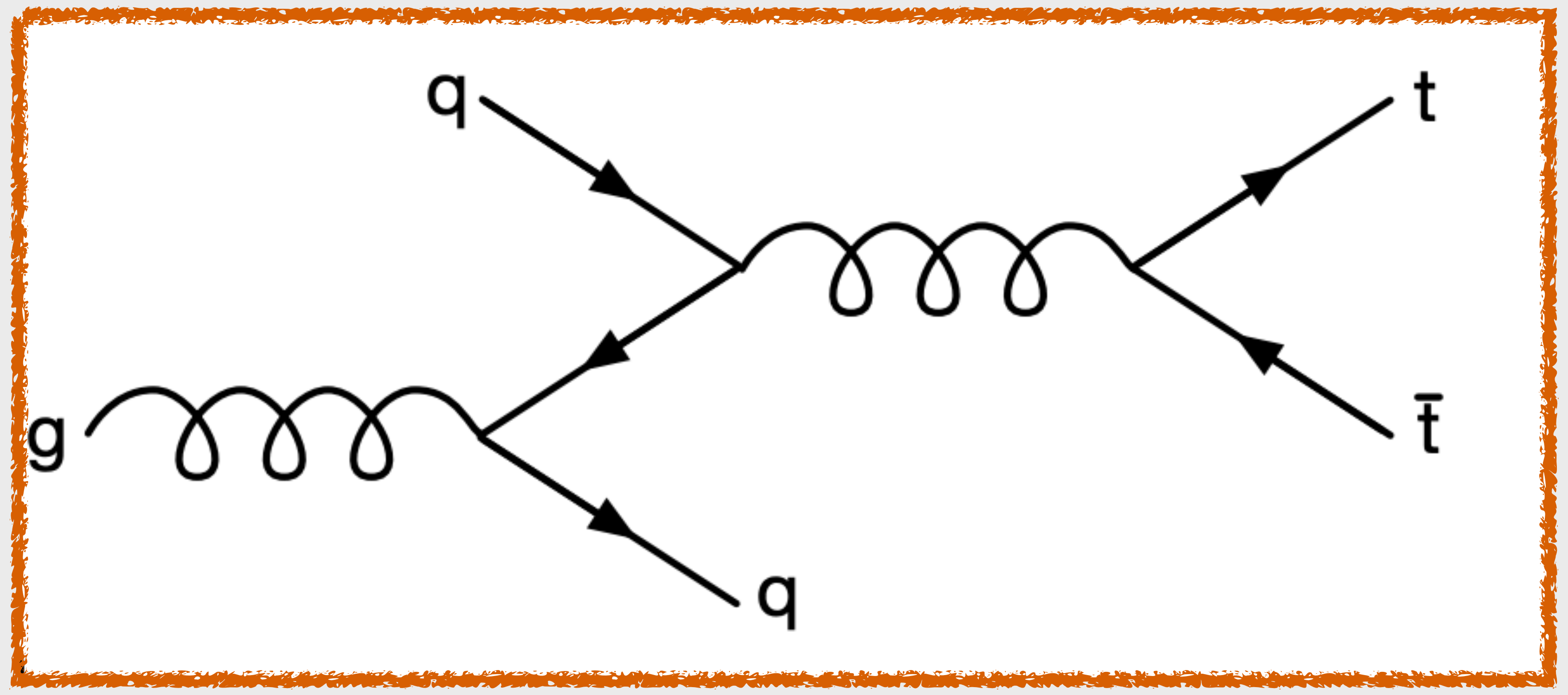

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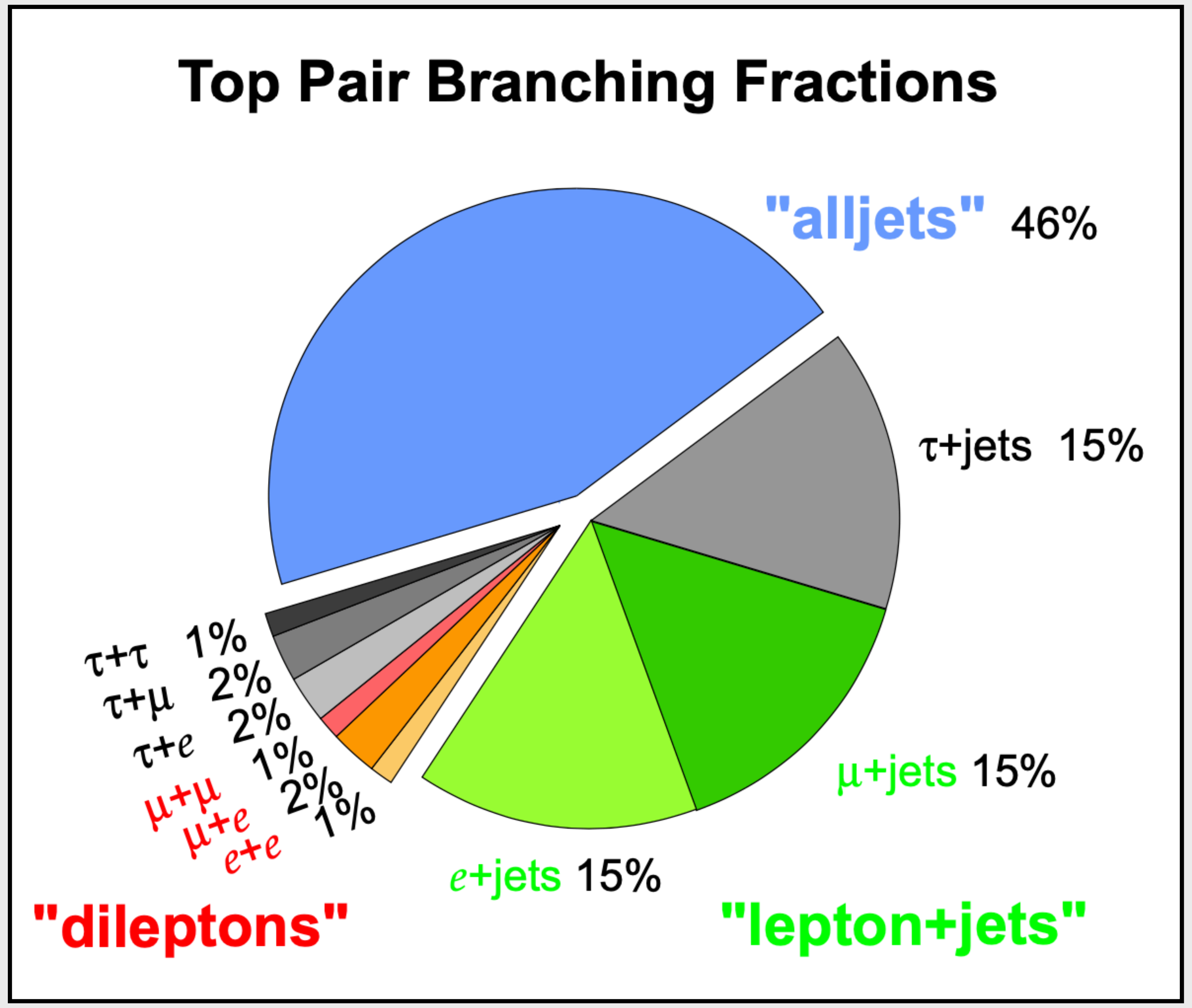
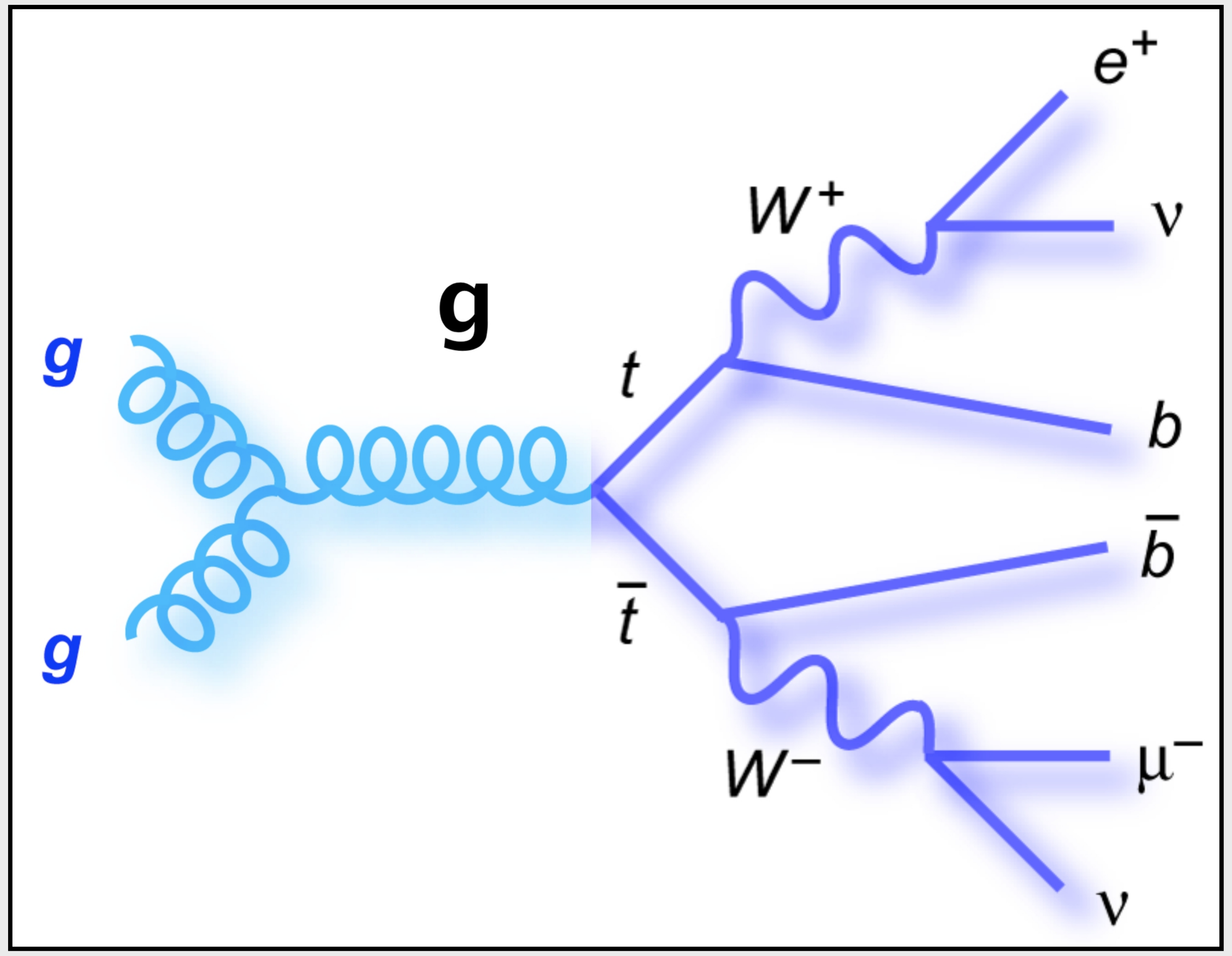
Top quarks pair decay mode





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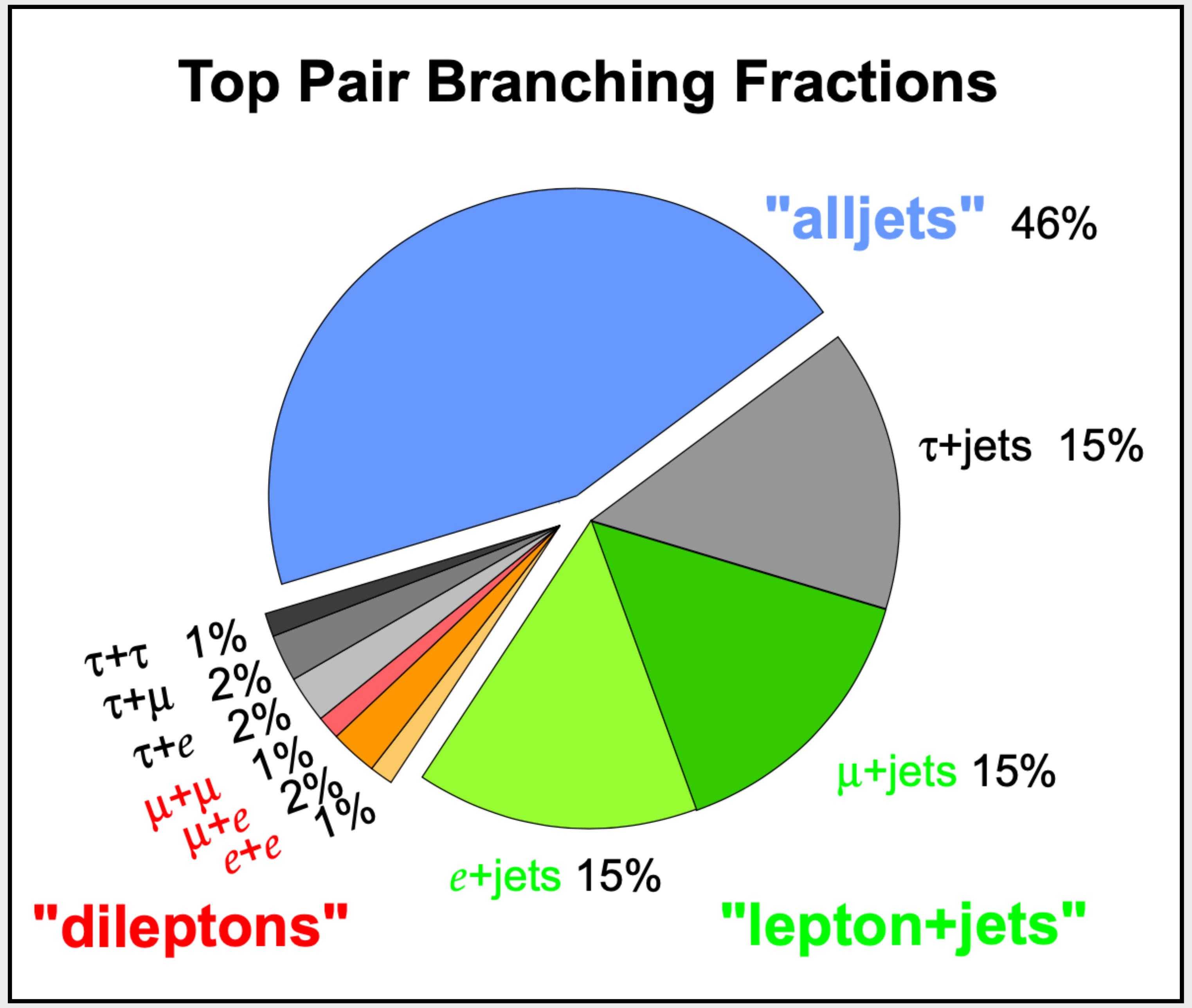

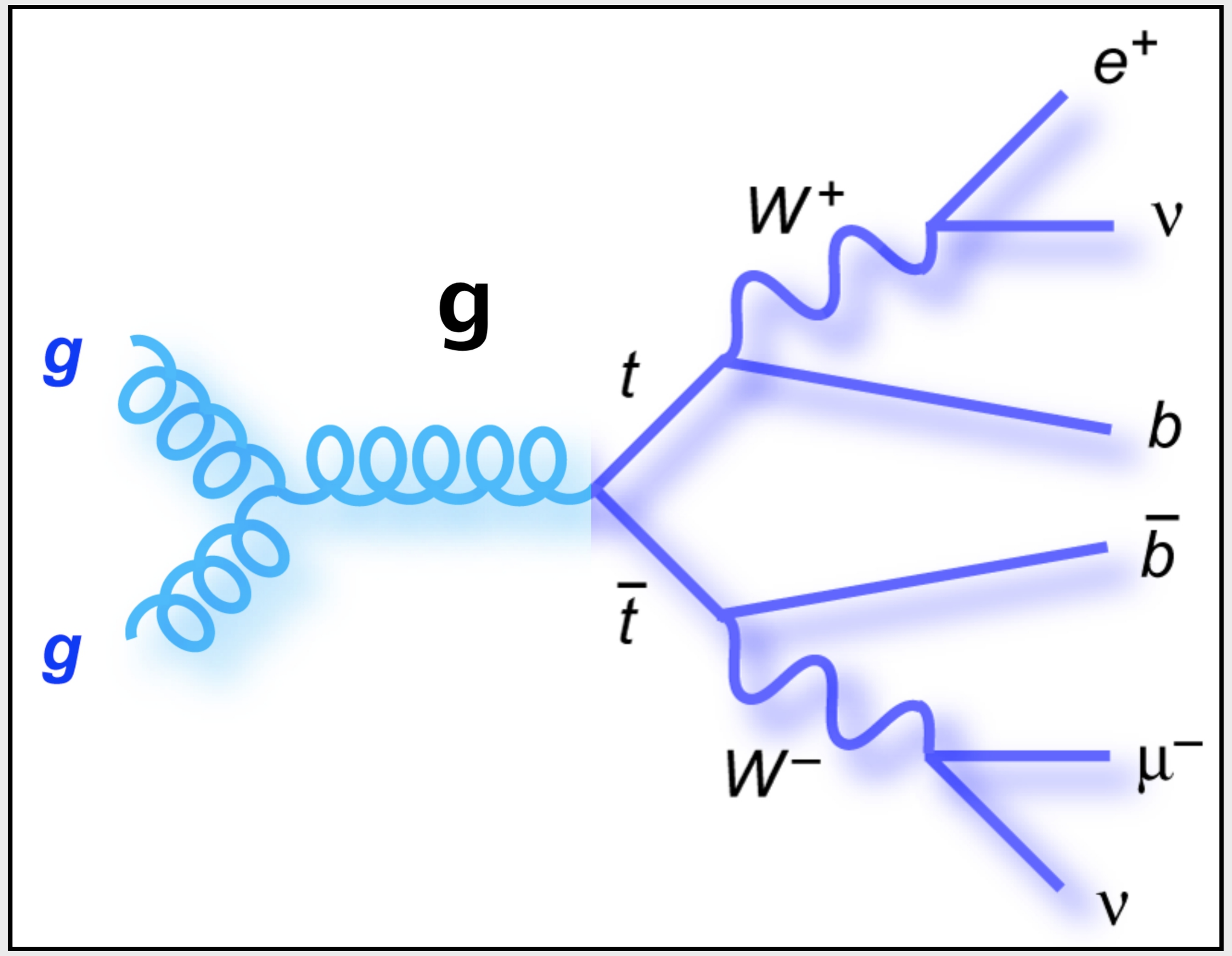

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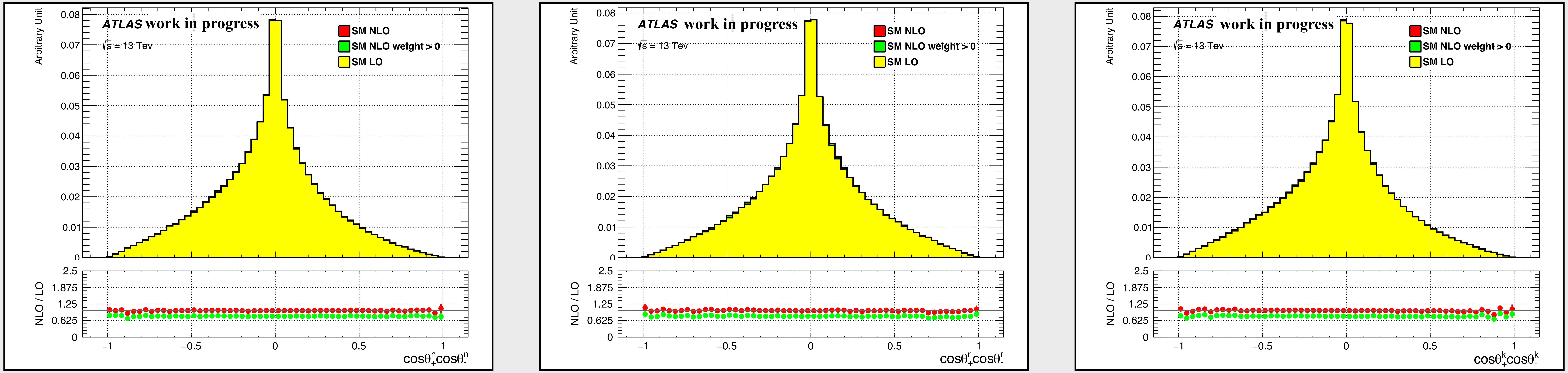
Spin Correlations

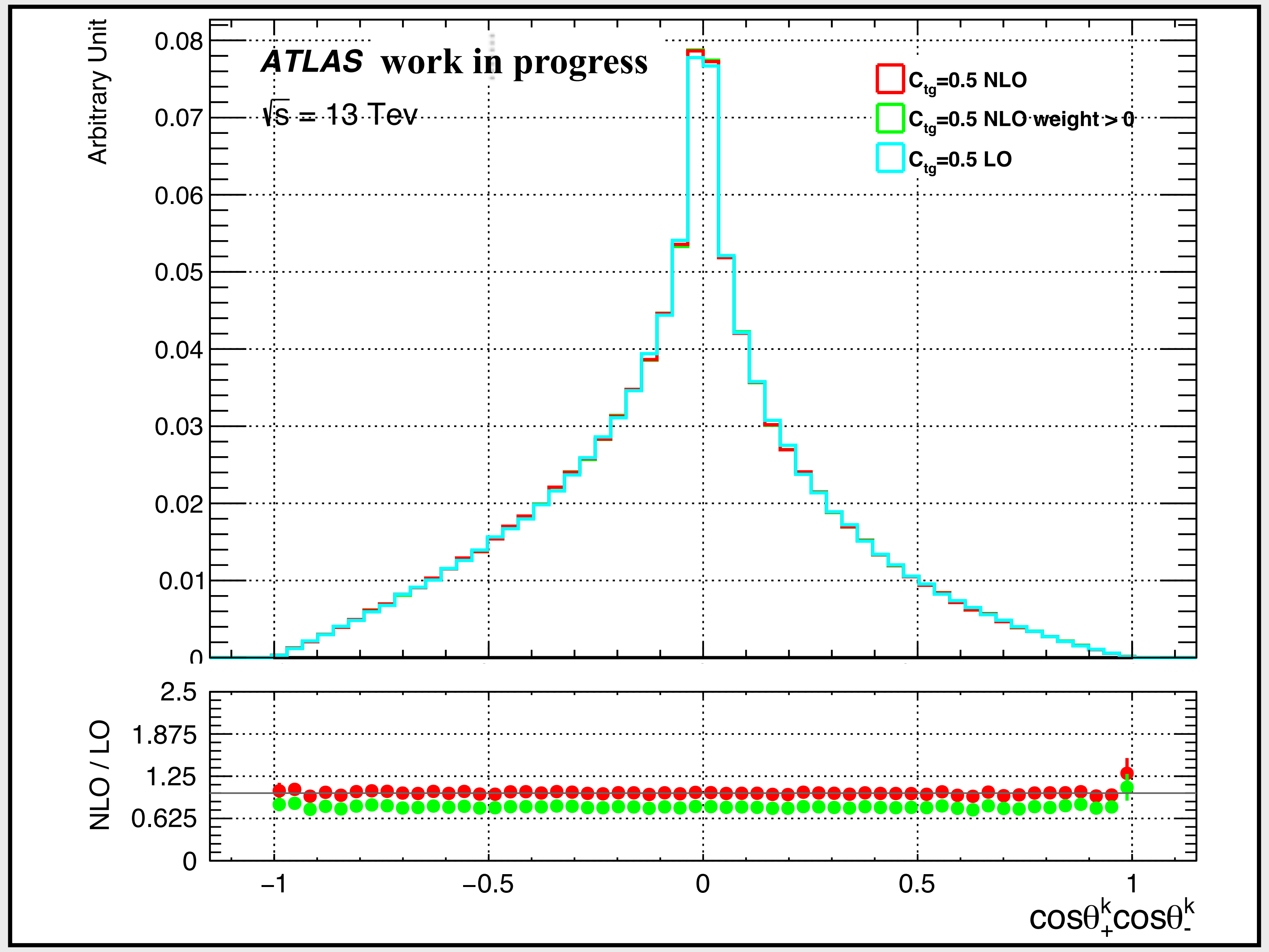
Distributions for the correlation of top spins along each axis (probing diagonal of $\mathbf{C}(\mathbf{a}, \mathbf{b})$ matrix)

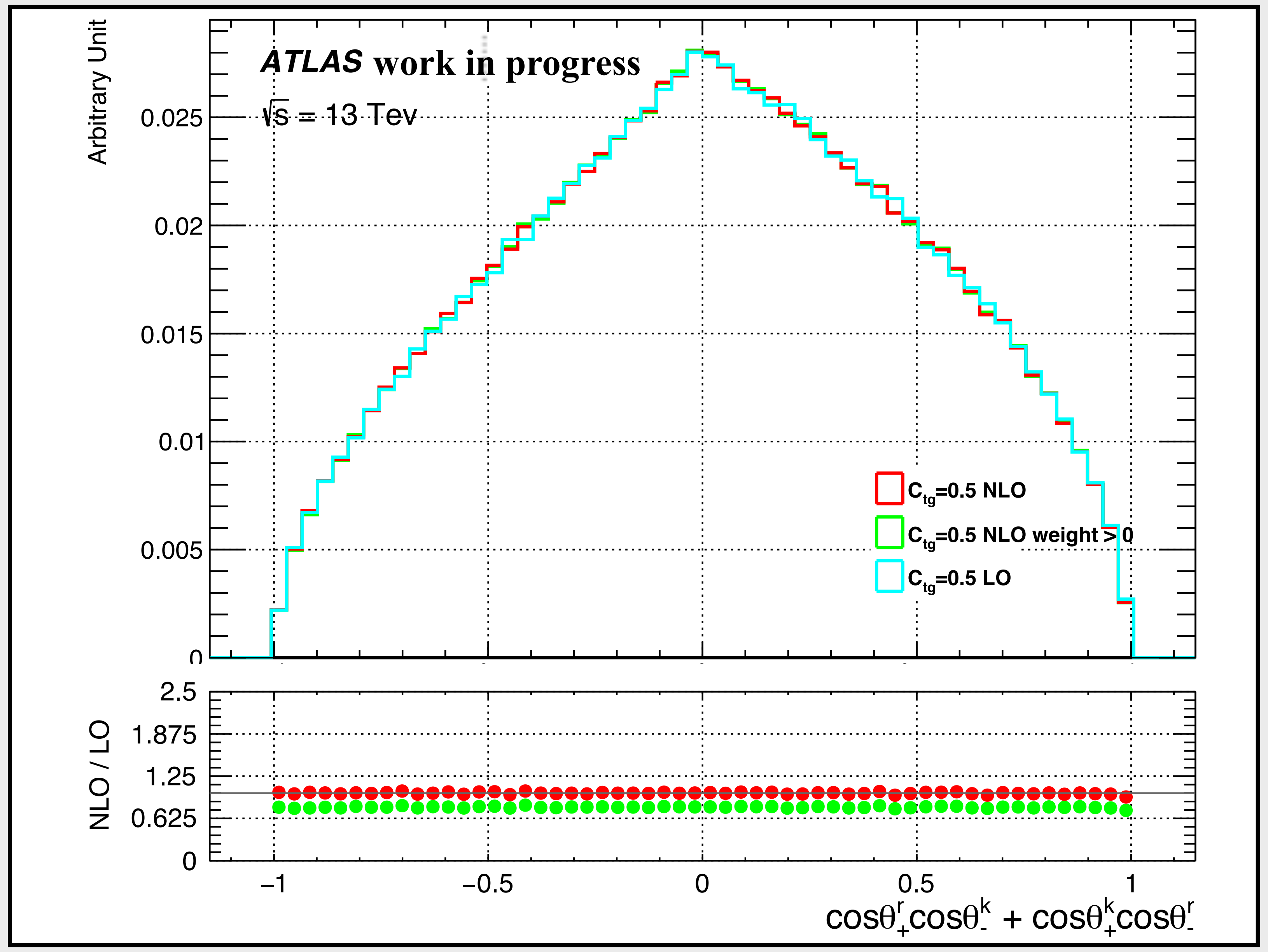


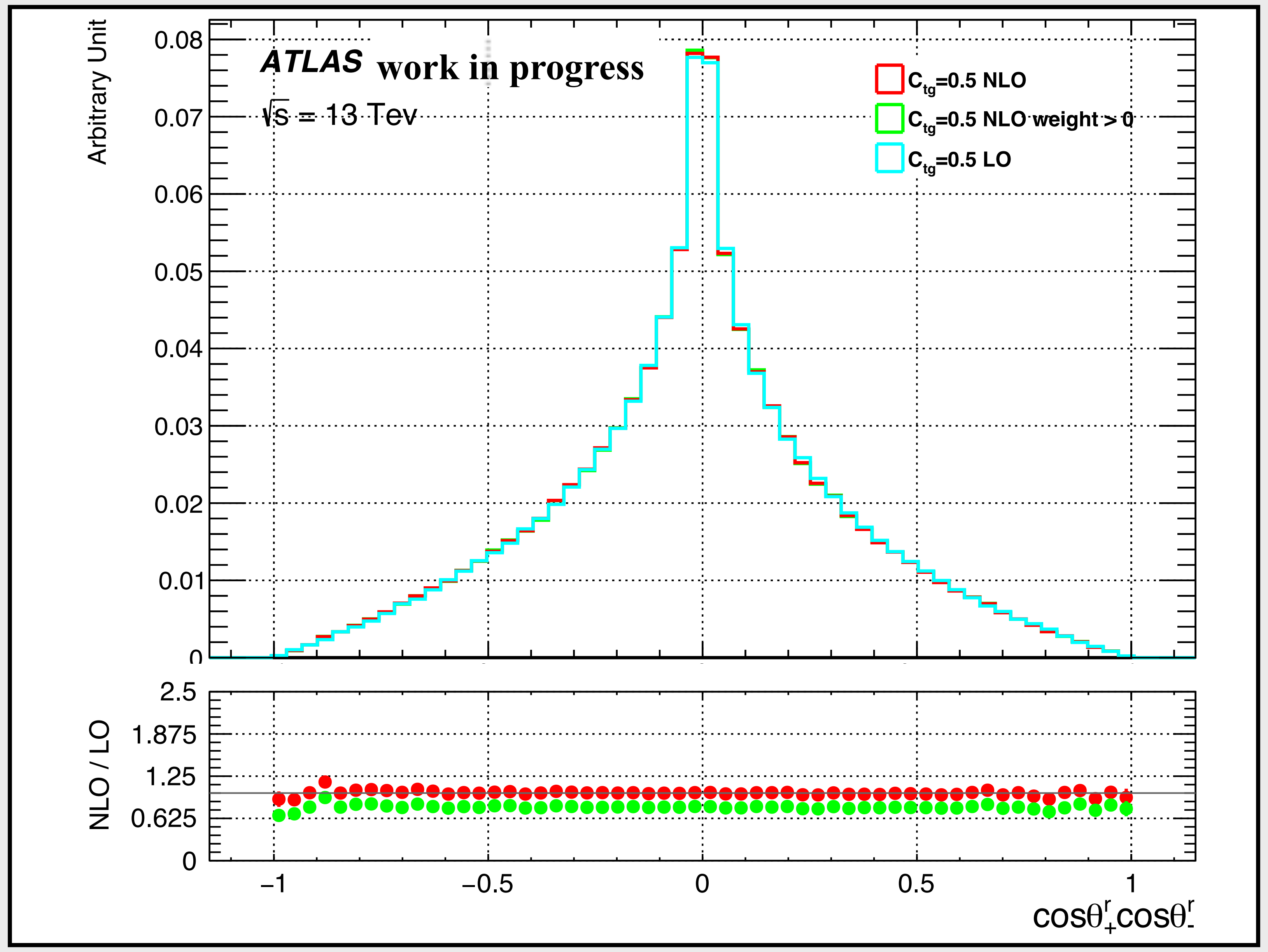
Spin correlations along each axis consistent with SM expectations (NLO from 1508.05271)

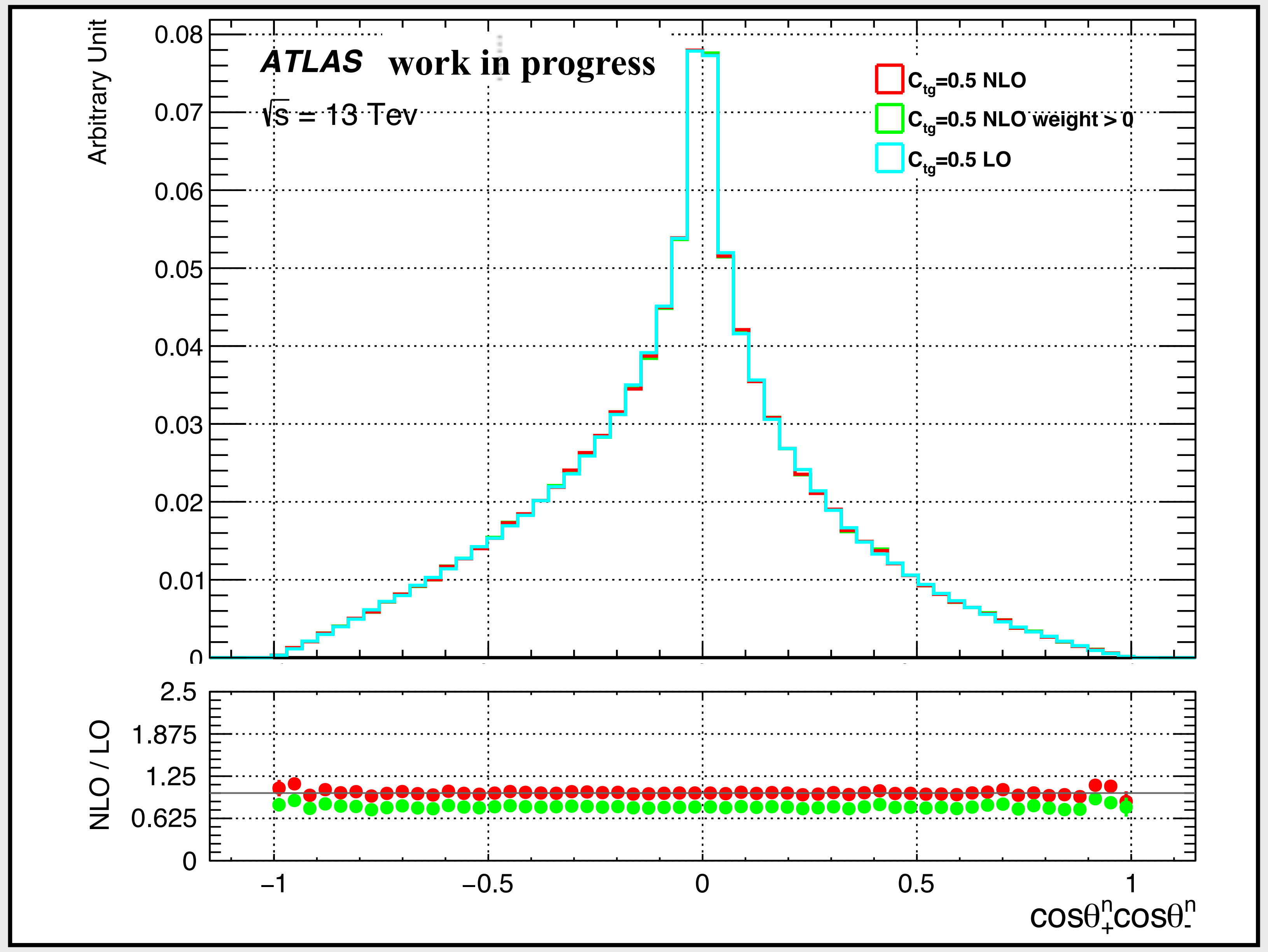
Spin Correlation Vs Ctg

- Spin correlation :
  - The impact of Ctg at NLO/LO is low, except C(r,k)+C(k,r).
  - For other spin corrections observables, the effect is very low or not observed.









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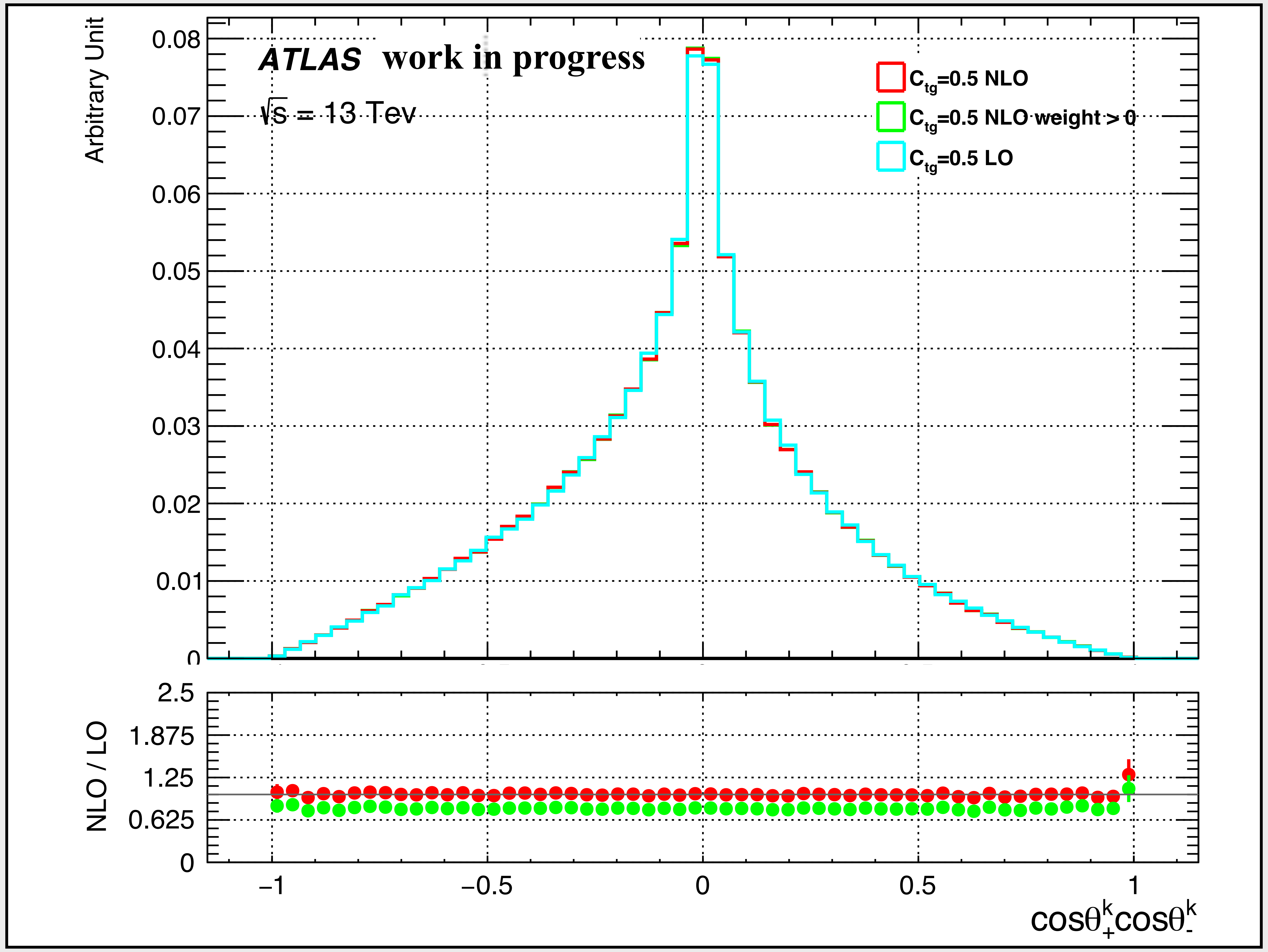
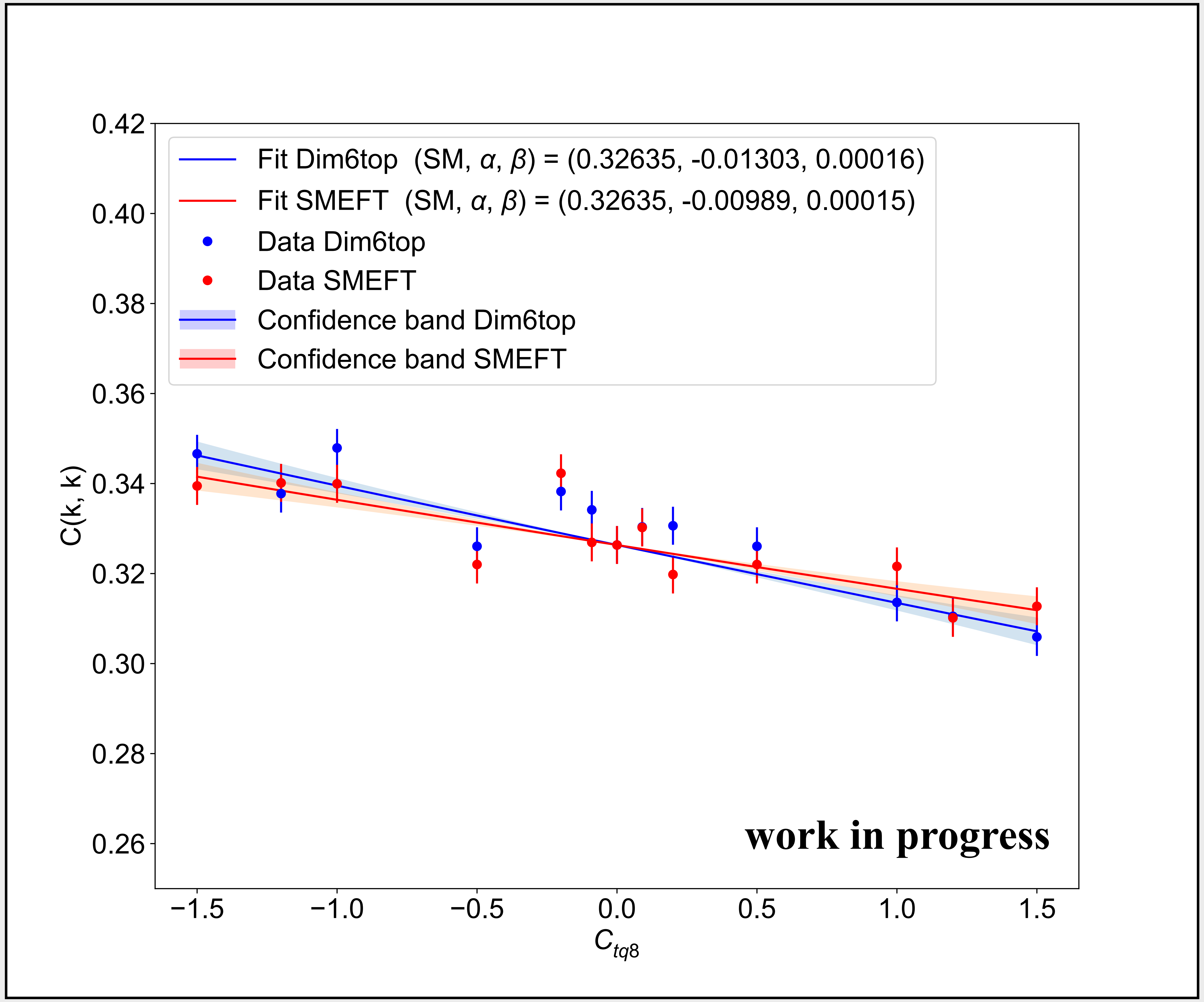


α_i/Λ^2 and β_i/Λ^4 at LO : C(k,k)



- ☑ Dim6Top and SMEFT model are used to generate MC sample

Which Wilson coefficients affects $t\bar{t}$ production the most ?

- ☑ 18 operator expect to affect $t\bar{t}$ process :
  - 4-quark (2-heavy, 2-light) operator
  - Heavy quark boson

- ☑ We Can not prob gluon self-coupling cG in dim6top or SMEFT@NLO

parameter	$t\bar{t}$	single t
$C_{Qq}^{1,8}$	Λ^{-2}	–
$C_{Qq}^{3,8}$	Λ^{-2}	Λ^{-4} $[\Lambda^{-2}]$
C_{tu}^{8}, C_{td}^{8}	Λ^{-2}	–
$C_{Qq}^{1,1}$	Λ^{-4} $[\Lambda^{-2}]$	–
$C_{Qq}^{3,1}$	Λ^{-4} $[\Lambda^{-2}]$	Λ^{-2}
C_{tu}^{1}, C_{td}^{1}	Λ^{-4} $[\Lambda^{-2}]$	–
C_{Qu}^{8}, C_{Qd}^{8}	Λ^{-2}	–
C_{tq}^{8}	Λ^{-2}	–
C_{Qu}^{1}, C_{Qd}^{1}	Λ^{-4} $[\Lambda^{-2}]$	–
C_{tq}^{1}	Λ^{-4} $[\Lambda^{-2}]$	–
$C_{\phi Q}^{-}$	–	–
$C_{\phi Q}^{3}$	–	Λ^{-2}
$C_{\phi t}$	–	–
$C_{\phi tb}$	–	Λ^{-4}
C_{tZ}	–	–
C_{tW}	–	Λ^{-2}
C_{bW}	–	Λ^{-4}
C_{tG}	Λ^{-2}	$[\Lambda^{-2}]$

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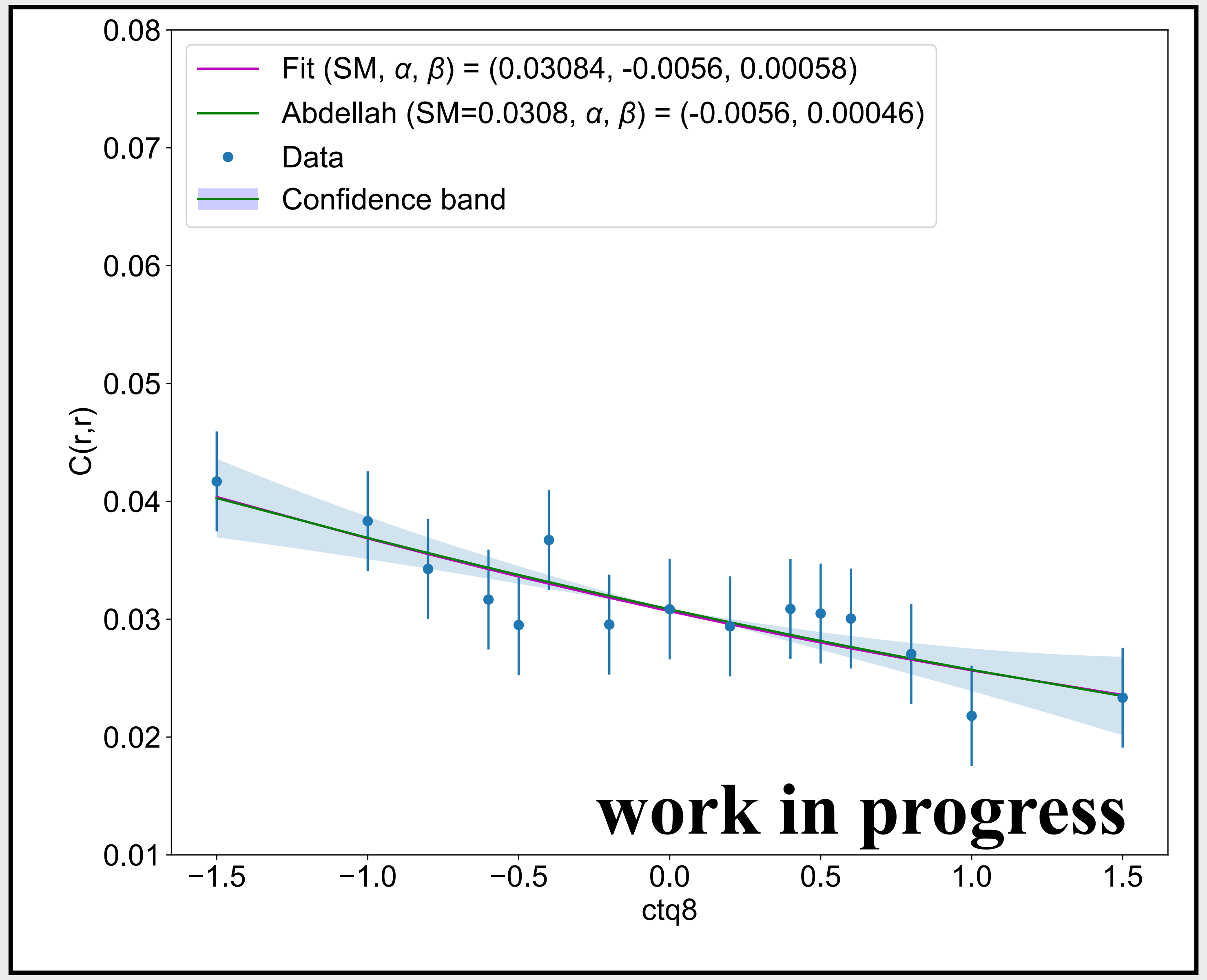
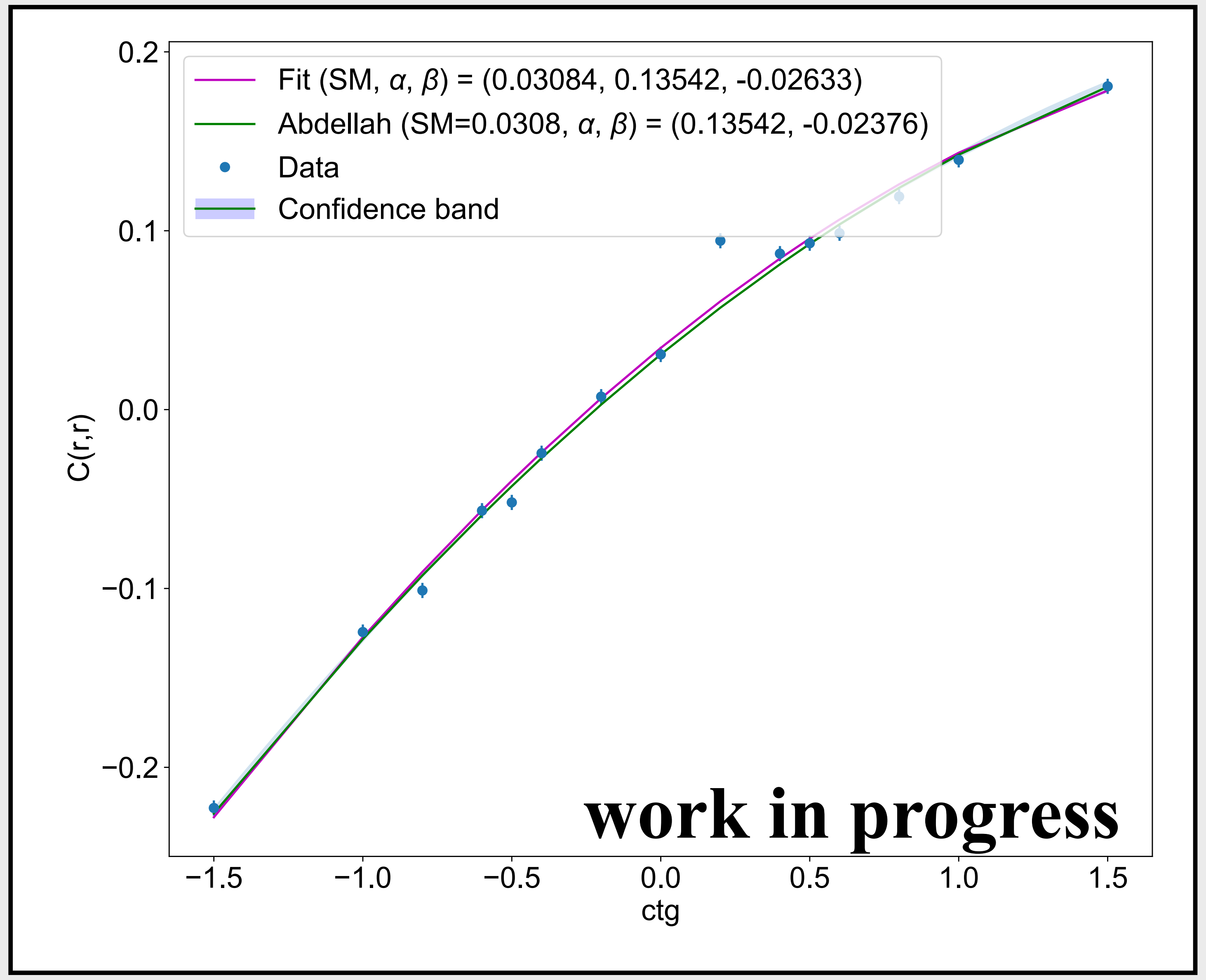
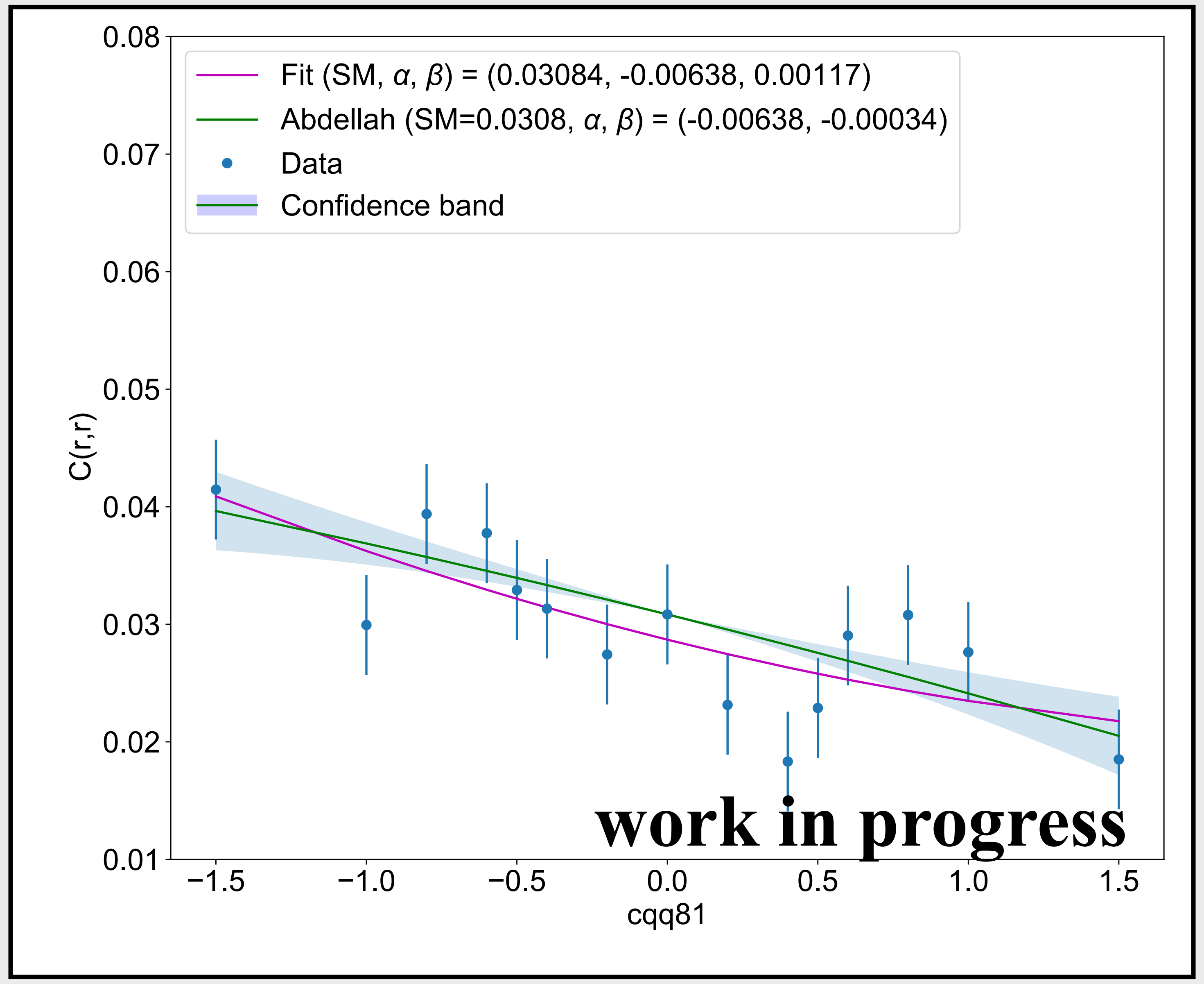
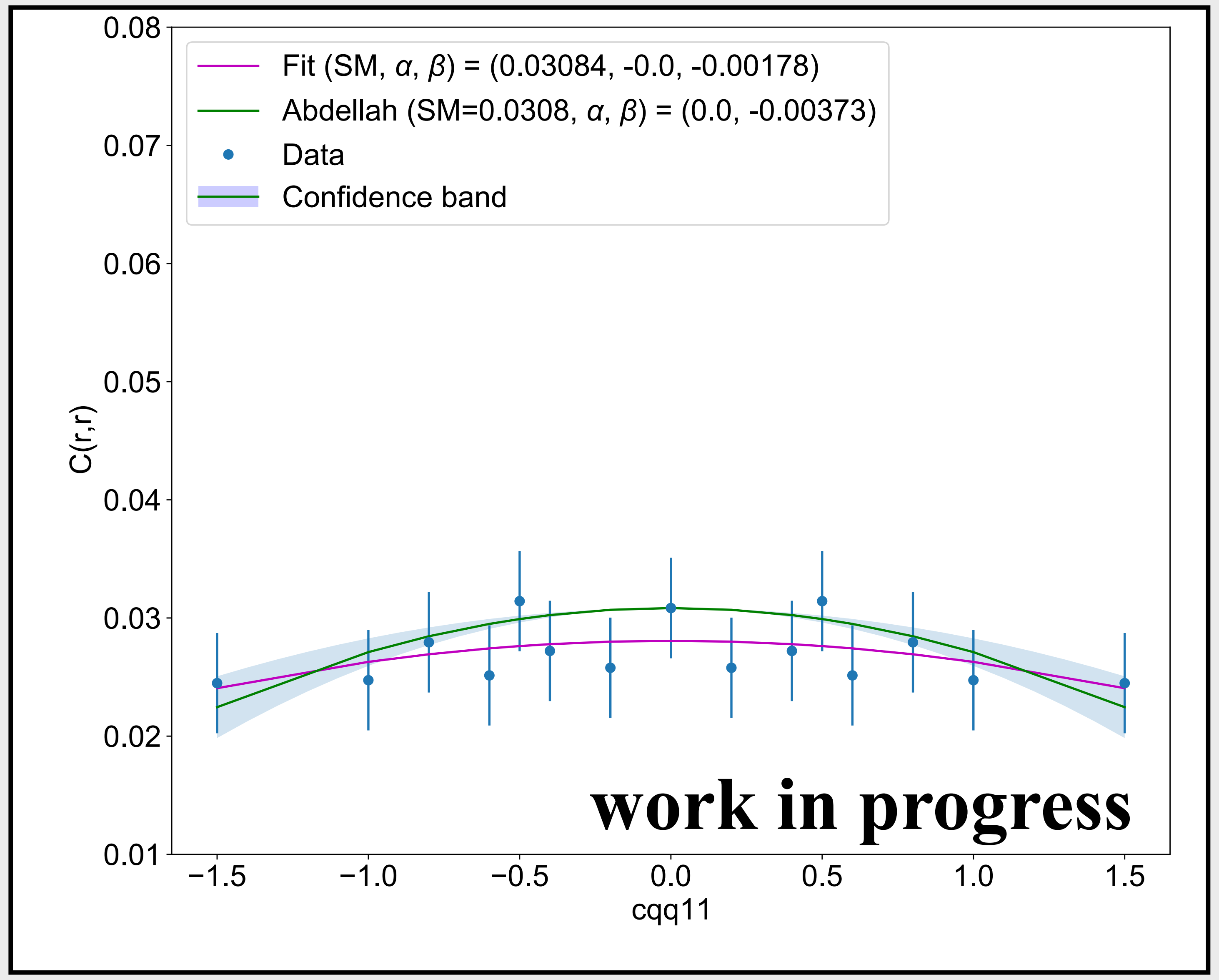
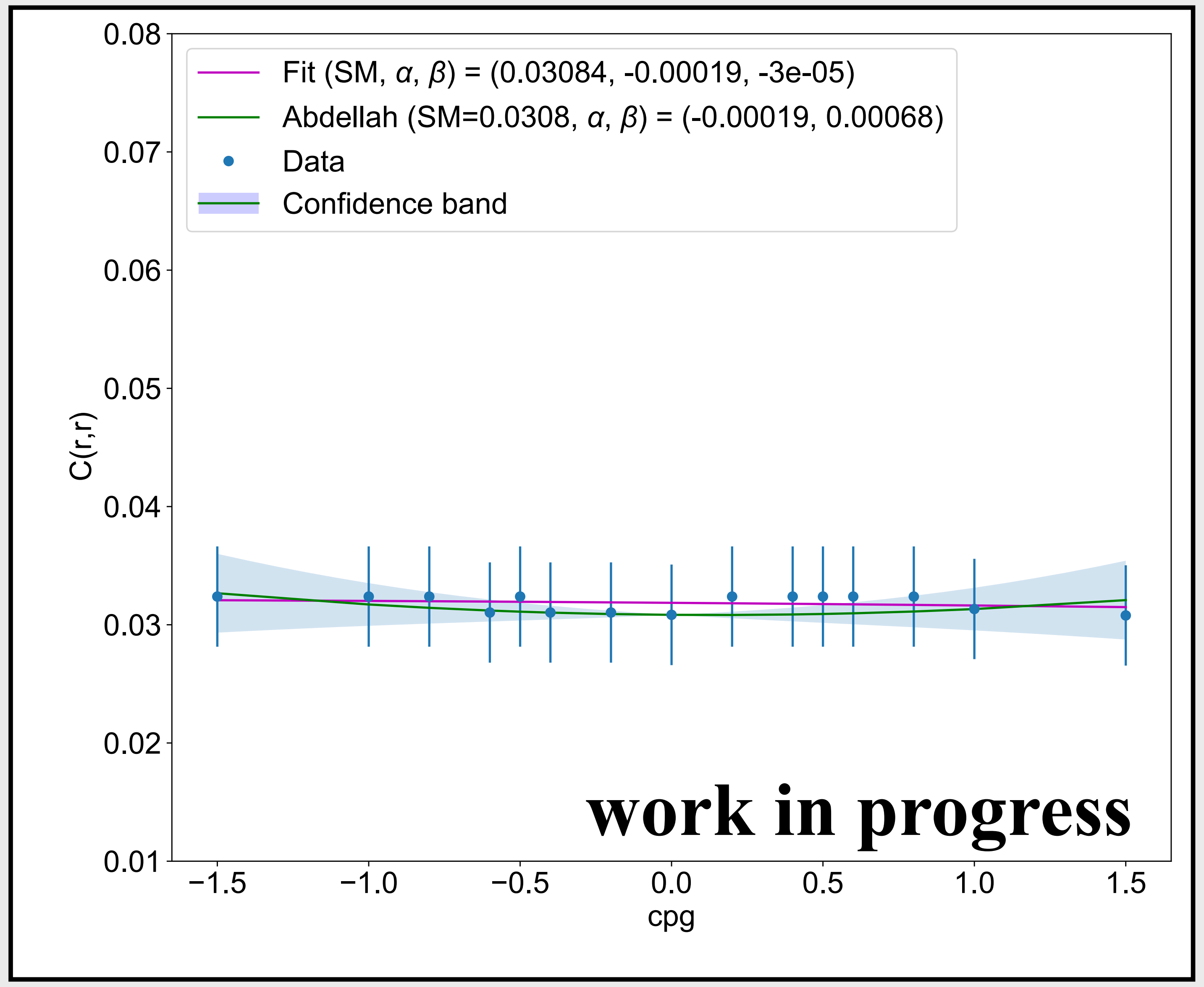
α_i/Λ^2 and β_i/Λ^4 at LO : C(r,r)



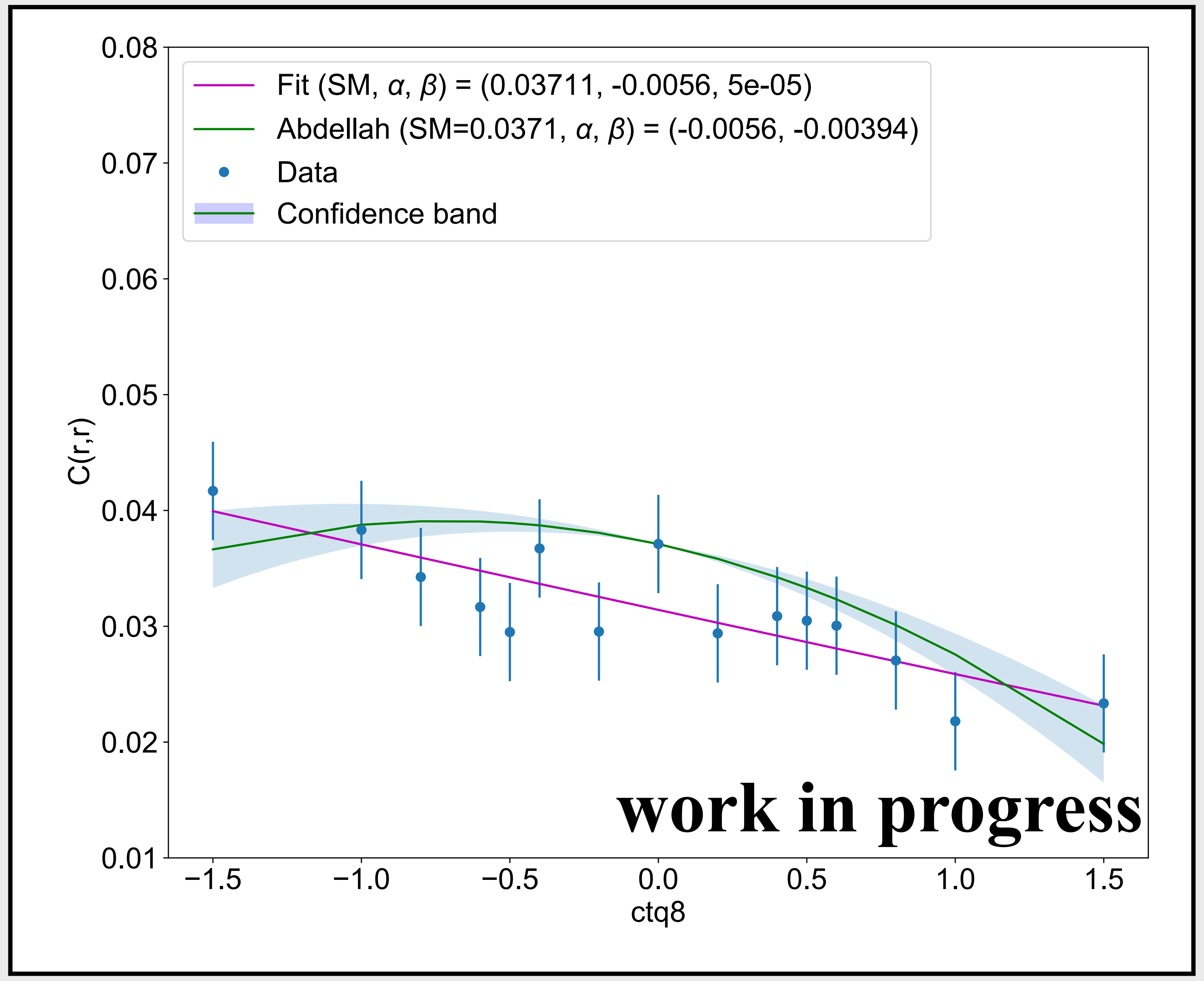


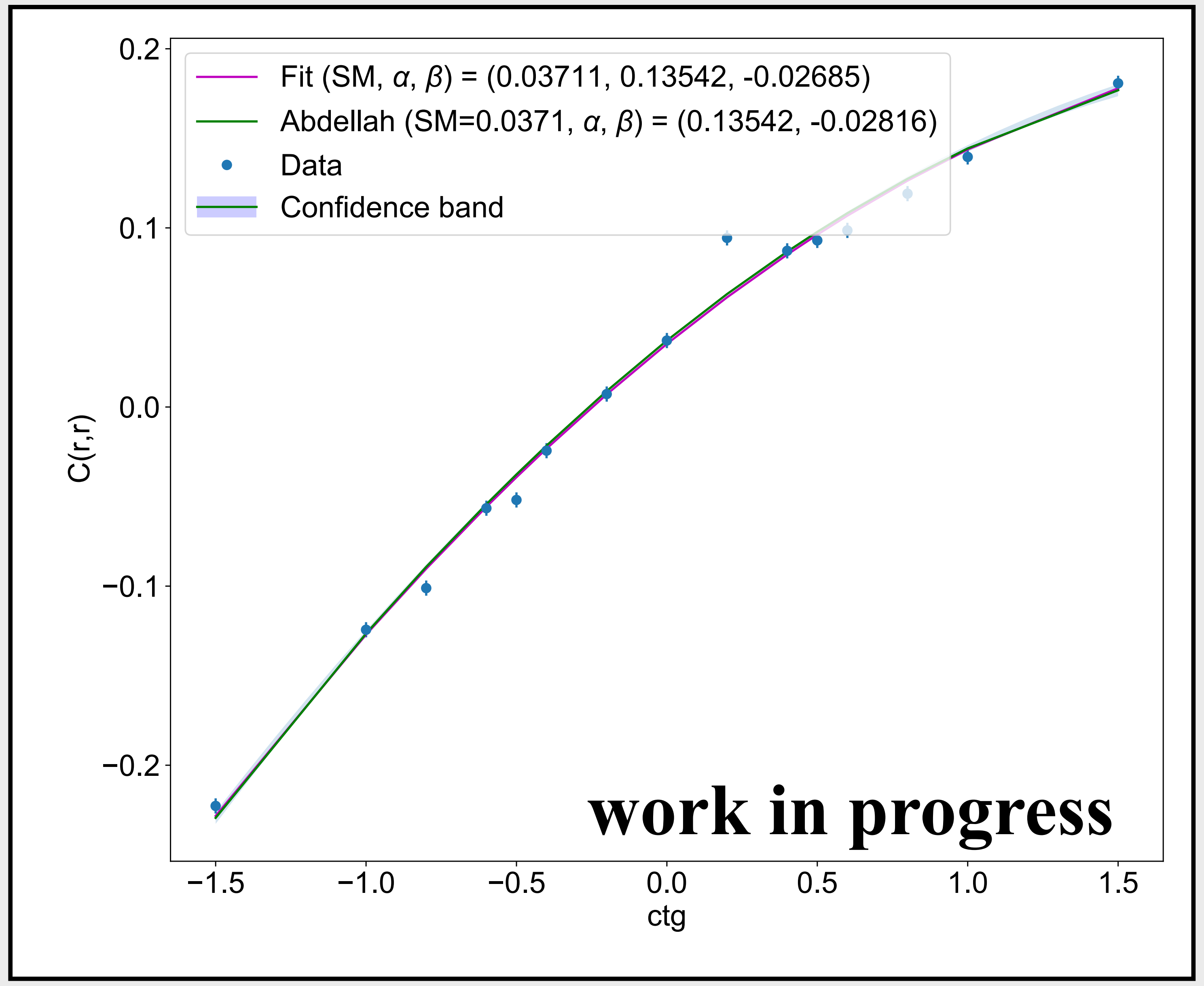


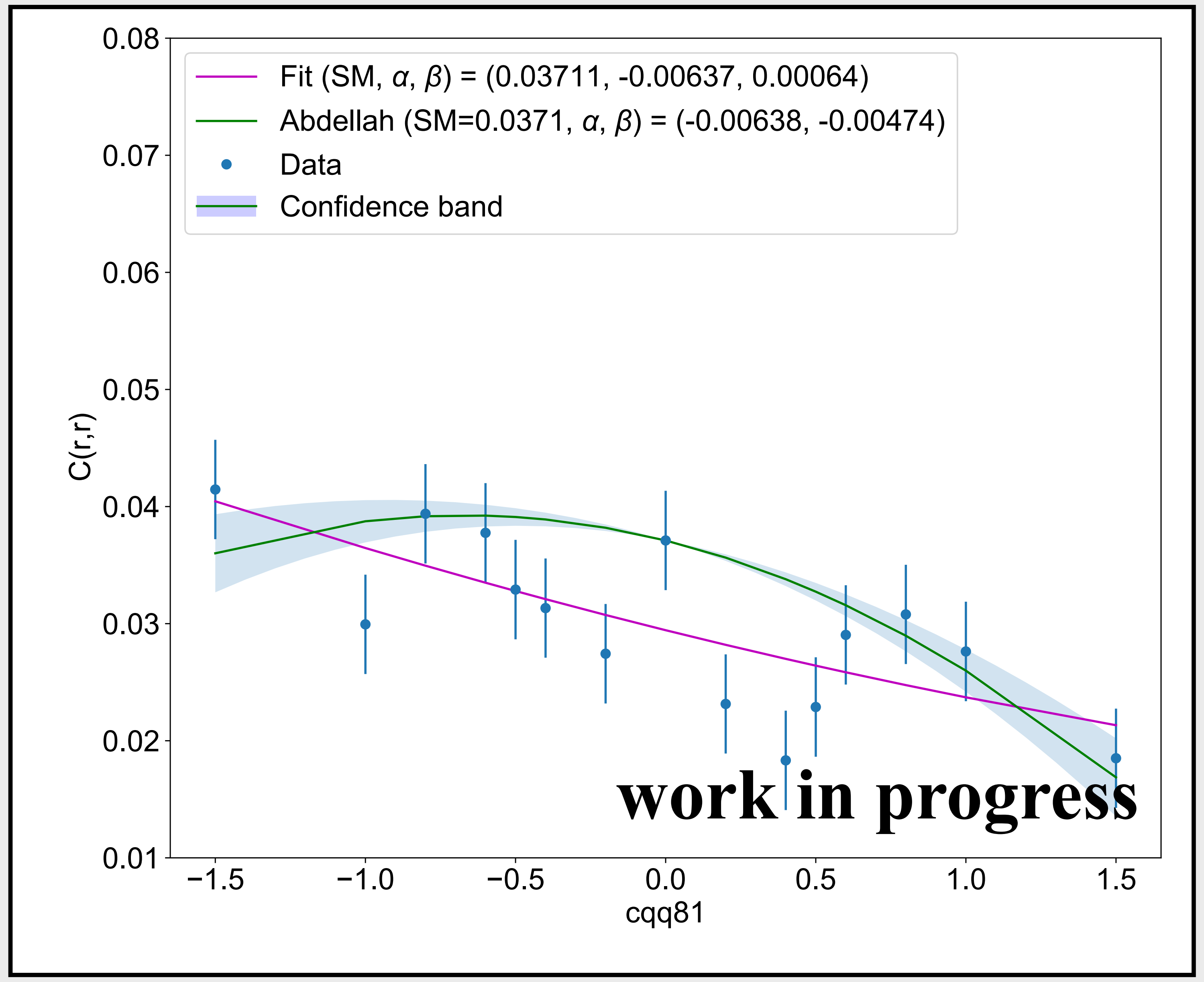


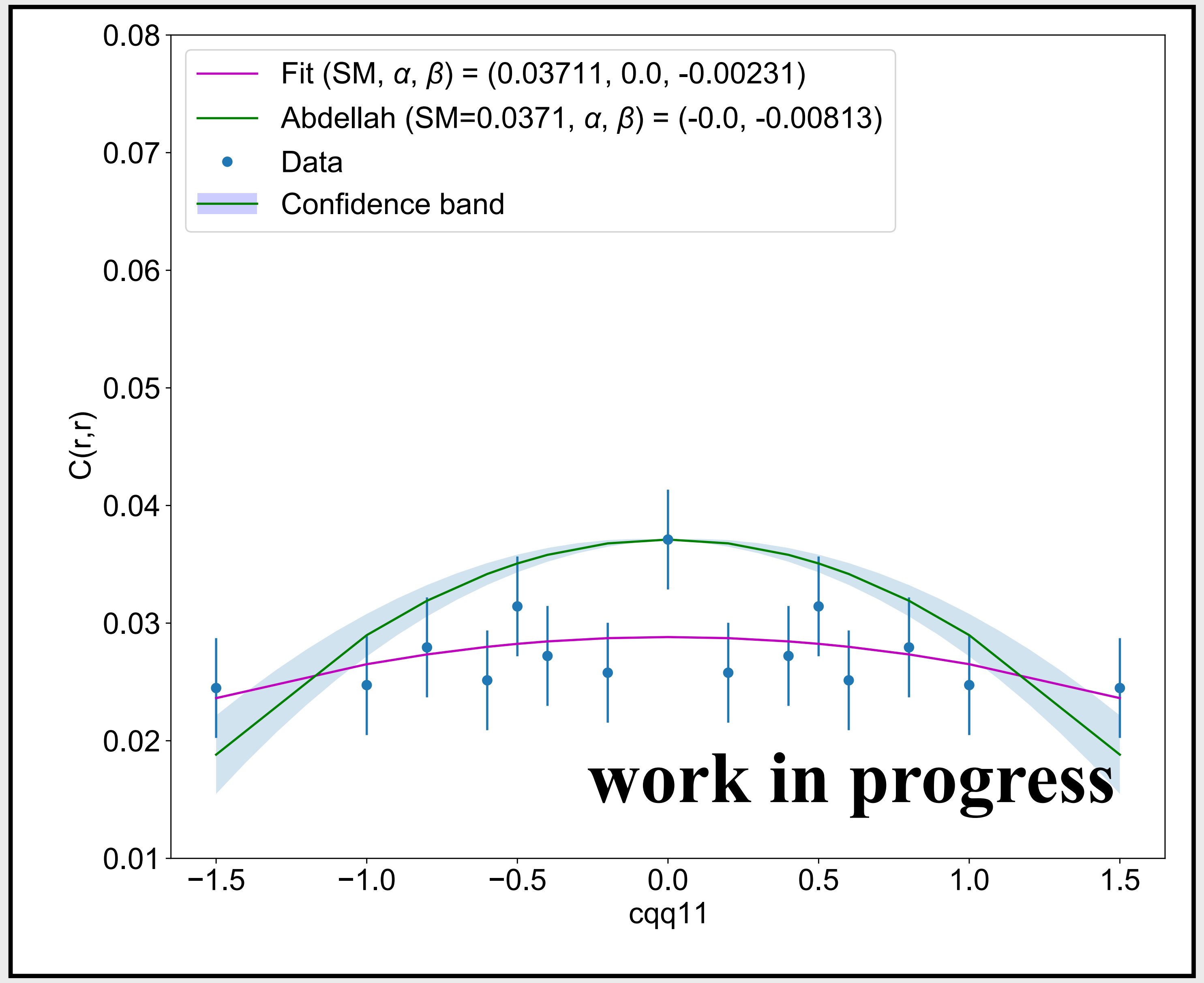


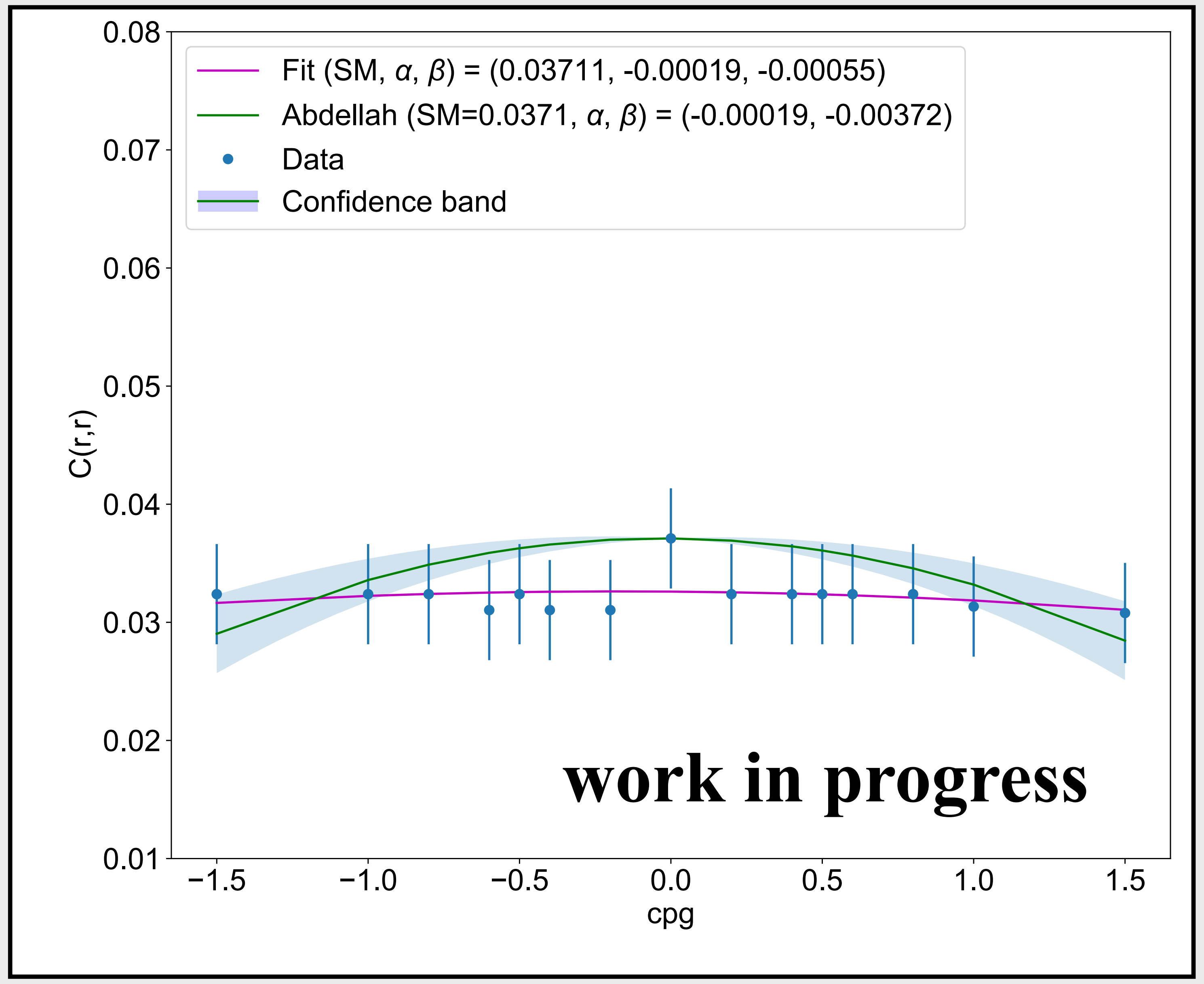
α_i/Λ^2 and β_i/Λ^4 at LO : C(r,r)











α_i/Λ^2 and β_i/Λ^4 at LO : C(k,k)