Funded by

Top-beauty synergies @ FCC-ee

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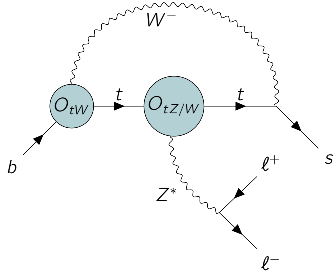
Motivation

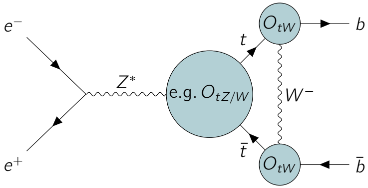
- SMEFT approach to connect modifications at top- and beauty scales with common set of operators → Anomalies at $\mathcal{O}(m_B)$ and $\mathcal{O}(m_Z)$ translate to higher energy scale

- $\mathcal{O}(m_B) \sim 5$ GeV



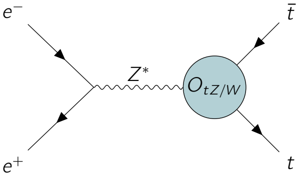
$\Rightarrow b \to s$ FCNCs

- $\mathcal{O}(m_Z) \sim 90$ GeV



$\Rightarrow \approx 1\,\%$ of R_b in the SM

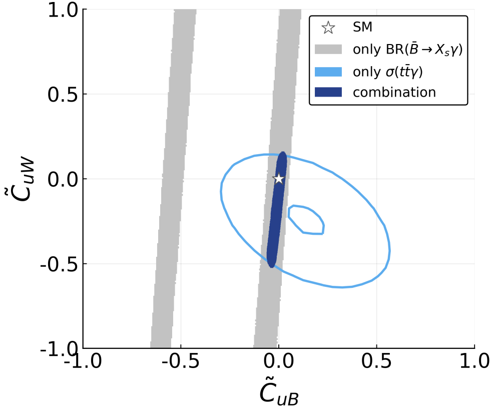
- $\mathcal{O}(m_t) \sim 350$ GeV



$\Rightarrow$ Modification of e. g. the t forward-backward asym.

Motivation

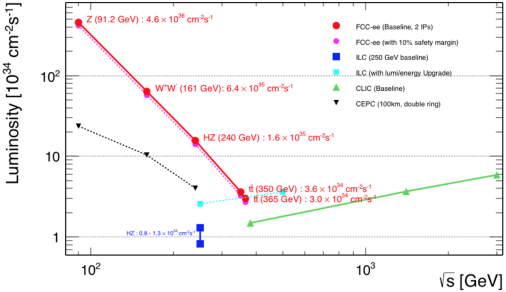
- Combination of top- and beauty observables: synergies in global SMEFT fits [1]
- More operators can be probed at once + different collider setups can be tested
- High precision and variety of observables is the key to extract tight constraints
  → **To which extent can FCC-ee bring improvements?**



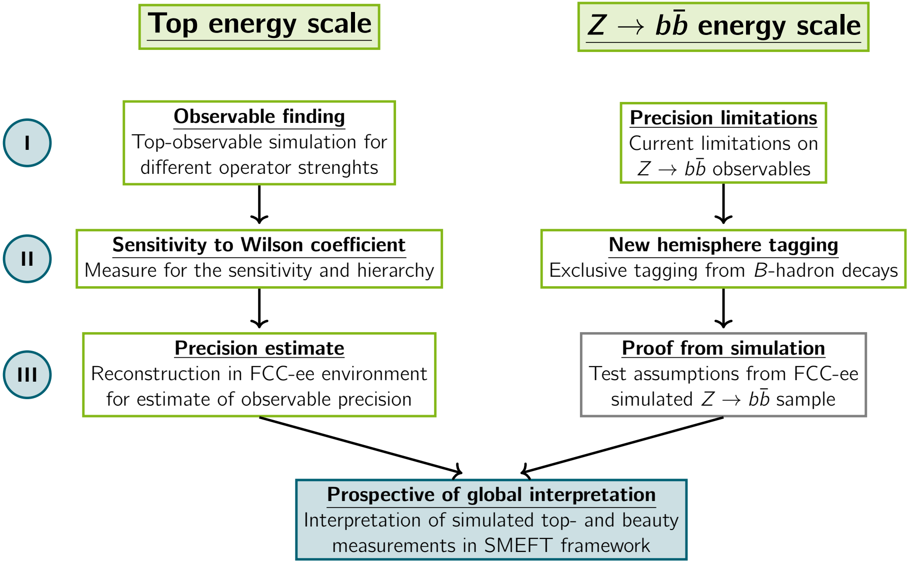
$t + b$-observables: Removes flat directions in parameter space.

Motivation

- FCC-ee (run-plan) offers ideal environment to study $Z \to b\bar{b}$ and top-observables at one machine
- Especially Z-pole run with $\mathcal{O}(10^{12})$ events offers unrivaled precision and possibilities
- Deviations on $Z \to b\bar{b}$ observables/scale translate to top-energy scale



Phase	$\sqrt{s}$ / GeV	Event statistics
Z^0	$88 - 95$	$5 \cdot 10^{12}$ ($10^6 \cdot$ LEP)
W^+W^-	$158 - 192$	$3 \cdot 10^8$ ($10^4 \cdot$ LEP)
Z^0H	240	10^6
$t\bar{t}$	$345 - 365$	10^6



Top energy scale

$Z \to b\bar{b}$ energy scale

I

Observable finding
Top-observable simulation for different operator strenghts

Precision limitations
Current limitations on $Z \to b\bar{b}$ observables

II

Sensitivity to Wilson coefficient
Measure for the sensitivity and hierarchy

New hemisphere tagging
Exclusive tagging from B-hadron decays

III

Precision estimate
Reconstruction in FCC-ee environment for estimate of observable precision

Proof from simulation
Test assumptions from FCC-ee simulated $Z \to b\bar{b}$ sample

Prospective of global interpretation
Interpretation of simulated top- and beauty measurements in SMEFT framework

SMEFT framework

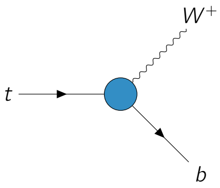
- SMEFT allows to **merge energy scales** to access BSM physics
- Build operators out of SM fields for higher energy scales Λ and small couplings

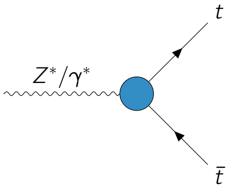
$$\mathcal{L}_{\text{SMEFT}} = \underbrace{\mathcal{L}_{\text{SM}}}_{\text{dim. 4}} + \mathcal{O}(O^{(5)}) + \frac{1}{\Lambda^2} \sum_i C_i^{(6)} O^{(6)} + \dots$$

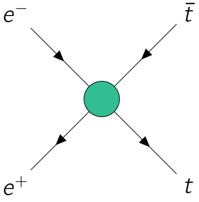
- Dimension-6 operators affect processes including top production and decay:

  Two-heavy O_{tW}, O_{tZ}, O_{tG}, $O_{\varphi q}^{(3,-)}$, $O_{\varphi t}$

  Four-fermion $O_{qe}^{(1)}$, $O_{te}^{(1)}$, $O_{tl}^{(1)}$



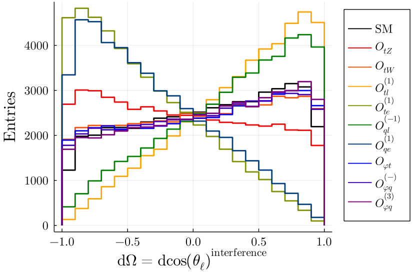


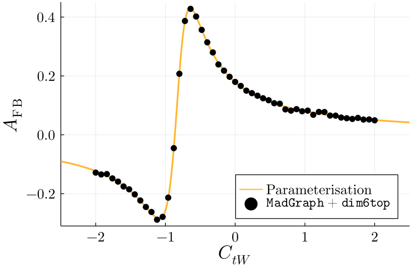


Ⓘ Observable finding

Two approaches: Optimal observables & parametrisation of observables

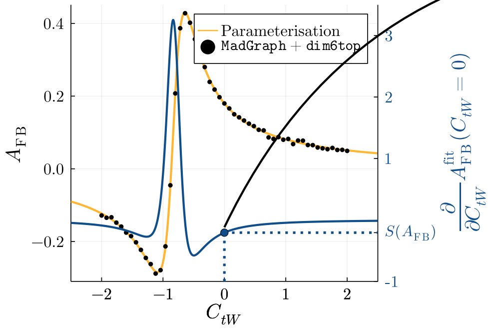
1. **Deviation in the phase space** dΩ by final state objects of a process
   - Angular information $\mathrm{d}\cos(\theta_{\ell^\pm, b^\pm})$
   - Energy information $\mathrm{d}x_{\ell^\pm}$
2. Several **top-production and decay observables** simulated (`MadGraph` + `dim6top`):
   - Asymmetries: $A_{\mathrm{FB}}, A_{|\Delta\phi_{\ell\ell}|}, A_{\cos(\varphi)}$
   - Decay width: Γ_t
   - W-helicity fractions: $F_{\mathrm{L}}, F_0, F_{\mathrm{R}}$
   - Spin correlations: $\underline{\underline{B}}, \vec{C}$
   - Cross sections: $\sigma_{t\bar{t}}, \sigma_{t\bar{t}b\bar{b}}, \sigma_{t\bar{t}\ell\bar{\ell}}, \sigma_t, \sigma_{t\bar{t}j}$

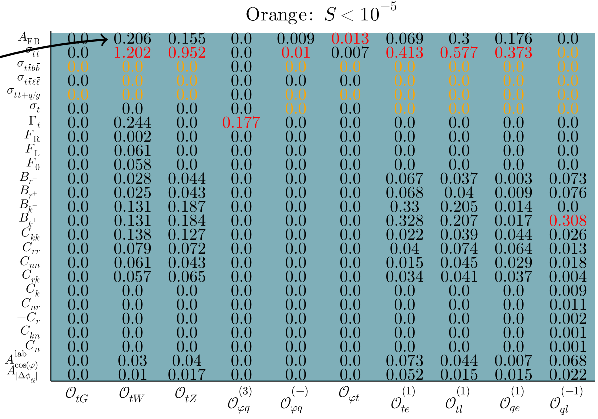




Ⓘ Sensitivity to Wilson coefficient

- **First derivative** (gradient) evaluated at $C_i = 0$ as sensitivity measure
- Procedure for all observables $\otimes$ operators



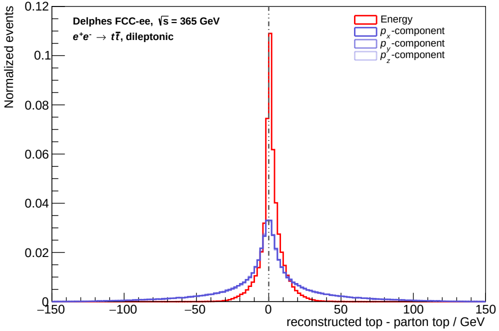


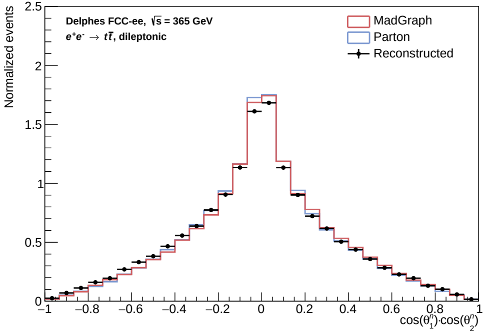
Orange: $S < 10^{-5}$

	$\mathcal{O}_{tG}$	$\mathcal{O}_{tW}$	$\mathcal{O}_{tZ}$	$\mathcal{O}^{(3)}_{\varphi q}$	$\mathcal{O}^{(-)}_{\varphi q}$	$\mathcal{O}_{\varphi t}$	$\mathcal{O}^{(1)}_{te}$	$\mathcal{O}^{(1)}_{tl}$	$\mathcal{O}^{(1)}_{qe}$	$\mathcal{O}^{(-1)}_{ql}$
A_{FB}	0.0	0.206	0.155	0.0	0.009	0.013	0.069	0.3	0.176	0.0
$\sigma_{t\bar{t}}$	0.0	1.202	0.952	0.0	0.01	0.007	0.413	0.577	0.373	0.0
$\sigma_{t\bar{t}b\bar{b}}$	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
$\sigma_{t\bar{t}\ell\bar{\ell}}$	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
$\sigma_{t\bar{t}+q/g}$	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
σ_t	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Γ_t	0.0	0.244	0.0	0.177	0.0	0.0	0.0	0.0	0.0	0.0
F_{R}	0.0	0.002	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F_{L}	0.0	0.061	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F_0	0.0	0.058	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B_{r^-}	0.0	0.028	0.044	0.0	0.0	0.0	0.067	0.037	0.003	0.073
B_{r^+}	0.0	0.025	0.043	0.0	0.0	0.0	0.068	0.04	0.009	0.076
B_{k^-}	0.0	0.131	0.187	0.0	0.0	0.0	0.33	0.205	0.014	0.0
B_{k^+}	0.0	0.131	0.184	0.0	0.0	0.0	0.328	0.207	0.017	0.308
C_{kk}	0.0	0.138	0.127	0.0	0.0	0.0	0.022	0.039	0.044	0.026
C_{rr}	0.0	0.079	0.072	0.0	0.0	0.0	0.04	0.074	0.064	0.013
C_{nn}	0.0	0.061	0.043	0.0	0.0	0.0	0.015	0.045	0.029	0.018
C_{rk}	0.0	0.057	0.065	0.0	0.0	0.0	0.034	0.041	0.037	0.004
C_k	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.009
C_{nr}	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.011
$-C_r$	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.002
C_{kn}	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.001
C_n	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.001
$A^{\mathrm{lab}}_{\cos(\varphi)}$	0.0	0.03	0.04	0.0	0.0	0.0	0.073	0.044	0.007	0.068
$A_{\lvert\Delta\phi_{\ell\ell}\rvert}$	0.0	0.01	0.017	0.0	0.0	0.0	0.052	0.015	0.015	0.022

Precision estimate

- Reconstruction of $t\bar{t}$-system + observables at FCC-ee holds challenges
- Considered decay modes: **semileptonic** and **fully leptonic** decay
- Examples: Top 4-vector reconstruction vs. $C_{nn} = -9\langle\cos(\theta_1^n)\cos(\theta_2^n)\rangle$ distribution

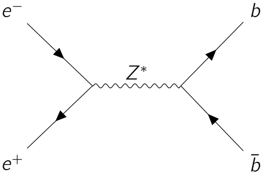




- Next step: estimate of uncertainty (WIP) as input for global SMEFT interpretation

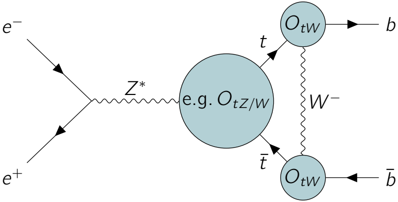
Measurements at the Z-pole: R_b

- Running down the scale to $Z \to b\bar{b}$: R_b and A^b_{FB} with the largest pull from EWPO fit
- Potential for SM-deviation in R_b: $\frac{\Delta R_b^{\mathrm{LEP}}}{R_b^{\mathrm{tree}} - R_b^{\mathrm{SM}}} \approx 40\,\%$



Tree-level contribution.

$\oplus$



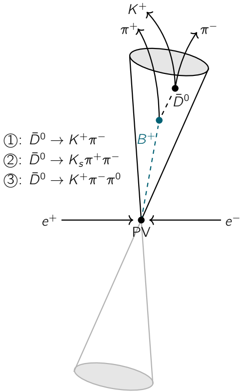
Zbb-vertex correction, contribution $\approx 1\,\%$.

- $\mathcal{O}(10^{12})$ $Z \to b\bar{b}$ events @FCC-ee: Measurements systematically limited
  Goal: reduce systematic uncertainty to scale of statistical uncertainty
- LEP-times: Systematic uncertainties dominated by *udsc*-physics + MC statistics

(II) New hemisphere tagging

Exclusive b-hadron tagging

Select the hemispheres by exclusively tag *b*-hadrons with a potential purity of $P = 100\,\%$ and an efficiency of $\varepsilon \approx 1\,\%$



①: $\bar{D}^0 \to K^+\pi^-$
②: $\bar{D}^0 \to K_s\pi^+\pi^-$
③: $\bar{D}^0 \to K^+\pi^-\pi^0$

Motivation for an exclusive tagger

- Suppose $N^{Z\to\text{had}} = 10^{12}$. An exclusive double-tagger with $\varepsilon_b \approx 1\,\%$ $\to \Delta R_b^{\text{excl.}}(\text{stat}) \approx 4.6 \cdot 10^{-5}$ at FCC-ee: factor 20 wrt. LEP
- Systematic uncertainty reduces to $\to \Delta R_b^{\text{excl.}}(\text{syst.}) \sim \sqrt{\Delta\text{MC}_{\text{stat}}^2 + \Delta\text{Evt.sel}^2 + \Delta\text{Trk.}^2 + \Delta udsc^2 + \Delta\text{hem.corr.}^2}$
- Hemisphere-correlation uncertainty present for standard tagger mostly reduced by excl. tagger

ⓘ New hemisphere tagging: Next steps

1. Estimate the **purity of the exclusive tagger** in several cases:
   - Fully charged final state particles: $B^{\pm} \rightarrow K^{+}\pi^{+}\pi^{-}$
   - Final states with K_s: $\bar{D}^0 \rightarrow K_s\pi^{-}\pi^{+}$
   - Final states with one π^0: $\bar{D}^0 \rightarrow K^{+}\pi^{-}\pi^{0}$

   → Place requirements on K_s tracking and π^0 calorimetric reconstruction
2. Add up the modes and verify, that $\varepsilon_b = 1\,\%$ can be reached
3. **Estimate hemisphere-correlation uncertainty** sources for exclusive tagger
4. Use of the exclusive tagger **simultaneously with standard taggers**

   → Study the correlation between them
5. Similar work to be developed for A_{FB}^{b}

Conclusions and Outlook

- Anomalies at m_B and m_Z-energy scale: **modifications at top-energy scale**
  → SMEFT approach provides a common set of operators to connect both
- **Combination** of different scales showed synergies in global interpretations: **to which extent can FCC-ee improve?**
- Top-energy scale studies: Found sensitive observables to dimension-6 operators
  → Evaluate the precision at FCC-ee from simulation
- Z-pole measurements systematically limited
  → **Novel b-hadron double-tagging technique** for R_b determination (to be confirmed from simulation)
  → Further application on A_{FB}^{b} measurement planned

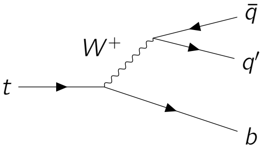
Backup

Estimation of top observables at FCC-ee

- Use official FCC-ee simulated samples of $\sqrt{s} = 365\,\text{GeV}$ $e^+e^- \to t\bar{t} \to$ *all* collisions
- Focus on semileptonic and dileptonic decay on parton & reconstructed level

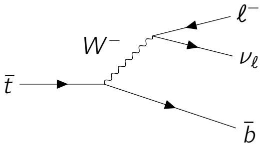
Semileptonic

- 1 isolated lepton $\ell \in [e, \mu]$ with $p_\ell > 20\,\text{GeV}$
- Missing energy
- Exactly 4 jets, 2 of them b-tagged (80 % efficiency each)



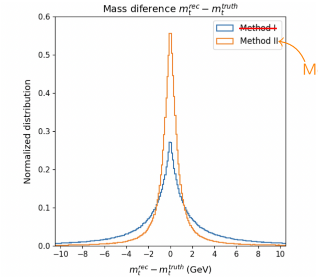
Dileptonic

- 2 isolated leptons $\ell \in [e, \mu]$ with $p_\ell > 20\,\text{GeV}$
- Missing energy
- Exactly 2 jets, both b-tagged (80 % efficiency each)



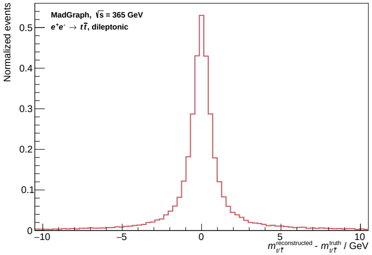
Reconstructing the dileptonic final state

- Ex. methods to fully reconstruct $t\bar{t}$-system [4]→ only verified on generator-level
- Based on 4-momentum conservation: $P_0 = P_{\ell_1} + P_{\ell_2} + P_\nu + P_{\bar{\nu}} + P_{j_1} + P_{j_2}$, P_i: input 4-vector, $P_0 = (\sqrt{s}, 0, 0, 0)^\top$
- Not enough to fix six ν-momentum components: Minimisation w.r.t. m_t and m_W
- *Generator-level*: Event energy $\Sigma E_i = \sqrt{s_i} = 365\,\text{GeV}$ known → Reproduce results



Method II applied

Publication reference.



Generator-level: Feasibility tests.

Reconstructing the dileptonic final state

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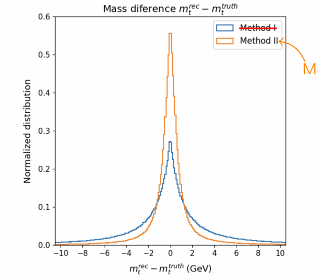
- Based on 4-momentum conservation: $P_0 = P_{\ell_1} + P_{\ell_2} + P_\nu + P_{\bar{\nu}} + P_{j_1} + P_{j_2}$,
  P_i: input 4-vector, $P_0 = (\sqrt{s}, 0, 0, 0)^\top$
- Not enough to fix six ν-momentum components: Minimisation w.r.t. m_t and m_W
- *Reco-level*: Event energy not known $\Sigma E_i \neq \sqrt{s_i}$, because ME $\neq E_{\nu_1} + E_{\nu_2}$



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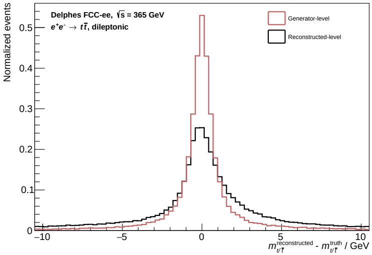
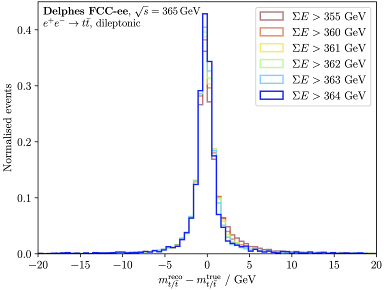


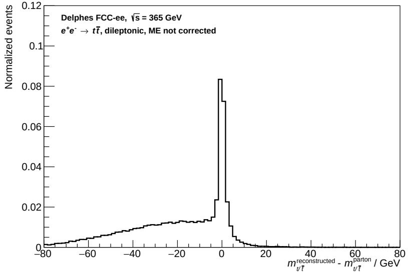
Reco-level: Naively assume $P_0 = 365$ GeV.

Reconstructing the dileptonic final state

- Reason for asymmetry: Total event energy not exactly determinable
- Cross-check: Cuts during reconstruction on ΣE remove asymmetries (left plot)
- Use event-wise knowledge: $P_0 = P_{\ell_1} + P_{\ell_2} + P_{\mathrm{ME}} + P_{j_1} + P_{j_2}$
  → Asymmetry gets worse, too less energy for reconstruction



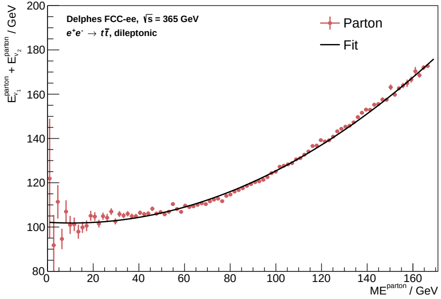
Cuts on the total event energy.



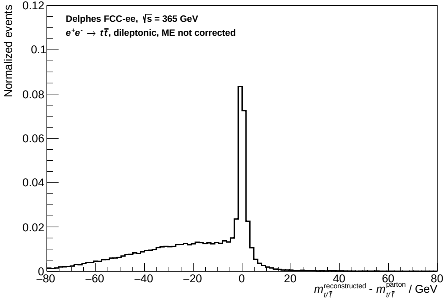
Reco-level: Use accessible event energy for P_0.

Reconstructing the dileptonic final state

- Ansatz: Find correlation between ME and $E_{\nu_1} + E_{\nu_2}$ with parton-level information
- Correct reconstructed ME with fitted dependence: $\mathrm{ME}^{\text{corr.}} = p_0^{\text{fit}} \cdot \mathrm{ME}^2 + p_1^{\text{fit}} \cdot \mathrm{ME} + p_2^{\text{fit}}$
- Use corrected, event-wise knowledge: $P_0^{\text{corr.}} = P_{\ell_1} + P_{\ell_2} + P_{\mathrm{ME}^{\text{corr.}}} + P_{j_1} + P_{j_2}$



Fit 2$^{\text{nd}}$ degree polynom.

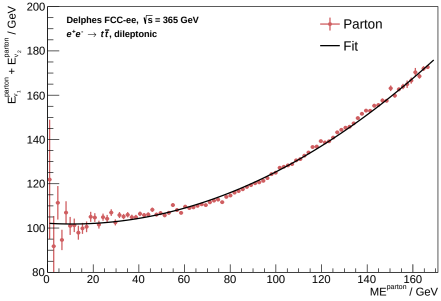


Reco-level: Uncorrected P_0.

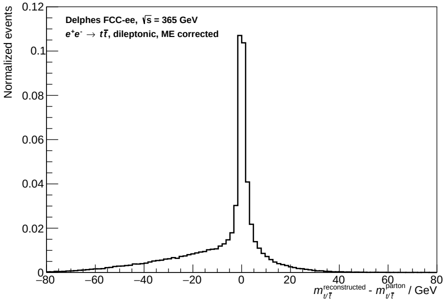
Reconstructing the dileptonic final state

- Ansatz: Find correlation between ME and $E_{\nu_1} + E_{\nu_2}$ with parton-level information
- Correct reconstructed ME with fitted dependence: $\mathrm{ME}^{\text{corr.}} = p_0^{\text{fit}} \cdot \mathrm{ME}^2 + p_1^{\text{fit}} \cdot \mathrm{ME} + p_2^{\text{fit}}$
- Use corrected, event-wise knowledge: $P_0^{\text{corr.}} = P_{\ell_1} + P_{\ell_2} + P_{\mathrm{ME}^{\text{corr.}}} + P_{j_1} + P_{j_2}$

→ Does not lead to hoped improvements



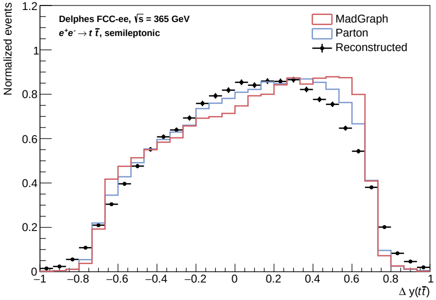
Fit 2nd degree polynom.



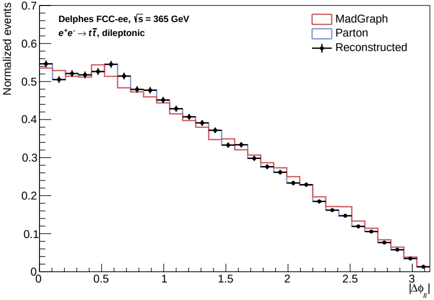
Reco-level: Corrected $P_0^{\text{corr.}}$.

Observables

- Examples: $\Delta y_{t\bar{t}}$- and $|\Delta\phi_{\ell\ell}|$-distributions to extract A_{FB} and $A_{|\Delta\phi_{\ell\ell}|}$ resp.
- Distributions compared for `MadGraph` and FCC-ee samples on parton- and reco-level
- For `MadGraph`: No ISR and BES taken into account
- Prepare ground to draw similar conclusions as on generator level



$\Delta y_{t\bar{t}}$-distribution to compute A_{FB}.

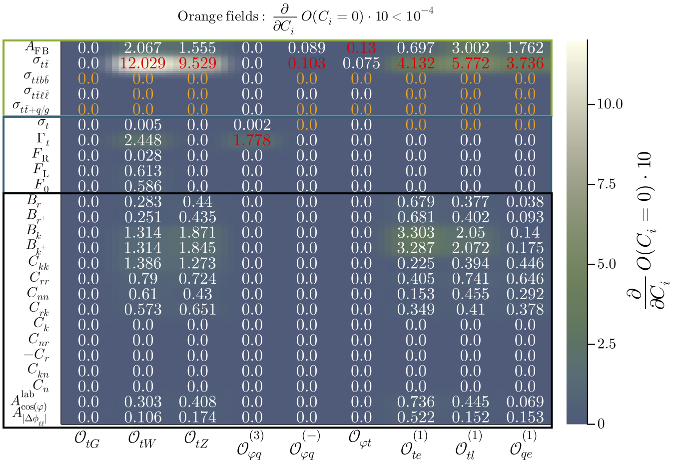


$|\Delta\phi_{\ell\ell}|$-distribution.

Summary: sensitivites from gradients

- Gradient sensitivites in matrix and most sensitive observable per operator highlighted

- Several processes dominated by $t\bar{t}$ production
- Decay predominantly via Wtb vertex with O_{tW} and $O_{\varphi q}^{(3)}$
- Both: Composition of production and decay



Orange fields : $\frac{\partial}{\partial C_i} O(C_i = 0) \cdot 10 < 10^{-4}$

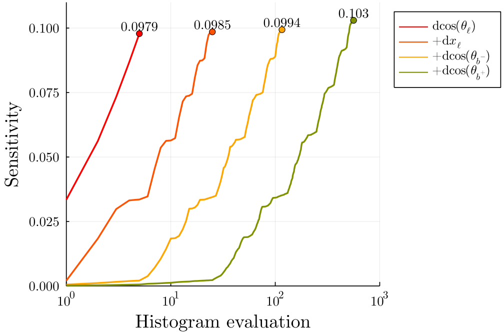
	$\mathcal{O}_{tG}$	$\mathcal{O}_{tW}$	$\mathcal{O}_{tZ}$	$\mathcal{O}_{\varphi q}^{(3)}$	$\mathcal{O}_{\varphi q}^{(-)}$	$\mathcal{O}_{\varphi t}$	$\mathcal{O}_{te}^{(1)}$	$\mathcal{O}_{tl}^{(1)}$	$\mathcal{O}_{qe}^{(1)}$
A_{FB}	0.0	2.067	1.555	0.0	0.089	0.13	0.697	3.002	1.762
$\sigma_{t\bar{t}}$	0.0	12.029	9.529	0.0	0.103	0.075	4.132	5.772	3.736
$\sigma_{t\bar{t}b\bar{b}}$	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
$\sigma_{t\bar{t}\ell\bar{\ell}}$	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
$\sigma_{t\bar{t}+q/g}$	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
σ_t	0.0	0.005	0.0	0.002	0.0	0.0	0.0	0.0	0.0
Γ_t	0.0	2.448	0.0	1.778	0.0	0.0	0.0	0.0	0.0
F_{R}	0.0	0.028	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F_{L}	0.0	0.613	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F_0	0.0	0.586	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B_{r^-}	0.0	0.283	0.44	0.0	0.0	0.0	0.679	0.377	0.038
B_{r^+}	0.0	0.251	0.435	0.0	0.0	0.0	0.681	0.402	0.093
B_{k^-}	0.0	1.314	1.871	0.0	0.0	0.0	3.303	2.05	0.14
B_{k^+}	0.0	1.314	1.845	0.0	0.0	0.0	3.287	2.072	0.175
C_{kk}	0.0	1.386	1.273	0.0	0.0	0.0	0.225	0.394	0.446
C_{rr}	0.0	0.79	0.724	0.0	0.0	0.0	0.405	0.741	0.646
C_{nn}	0.0	0.61	0.43	0.0	0.0	0.0	0.153	0.455	0.292
C_{rk}	0.0	0.573	0.651	0.0	0.0	0.0	0.349	0.41	0.378
C_k	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_{nr}	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
$-C_r$	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_{kn}	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_n	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
$A^{\mathrm{lab}}_{\cos(\varphi)}$	0.0	0.303	0.408	0.0	0.0	0.0	0.736	0.445	0.069
$A_{\lvert\Delta\phi_{\ell\ell}\rvert}$	0.0	0.106	0.174	0.0	0.0	0.0	0.522	0.152	0.153

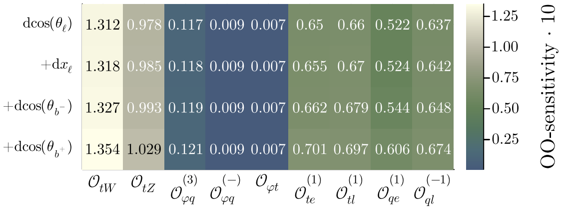
Method II: Sensitivities from optimal observables

Preliminary

- Sensitivity follows as $S_{ii} = \frac{w_i^2}{w_{\mathrm{SM}}\left(\sigma_i^{\mathrm{MG}}\right)^2} \sum_{m=1}^{n_{\mathrm{bins}}} \left(\frac{\mathrm{d}\sigma_i}{\mathrm{d}\Omega_m}\right)^2 \Big/ \frac{\mathrm{d}\sigma_{\mathrm{SM}}}{\mathrm{d}\Omega_m}$
- Each dimension of the phase-space adds up information, but: curse of dimensionality
- Tradeoff between number of bins and number of entries, here: $N_{\mathrm{bins}}/\text{dimension} = 5$

Here: Dimension-dependent evaluation for C_{tZ}



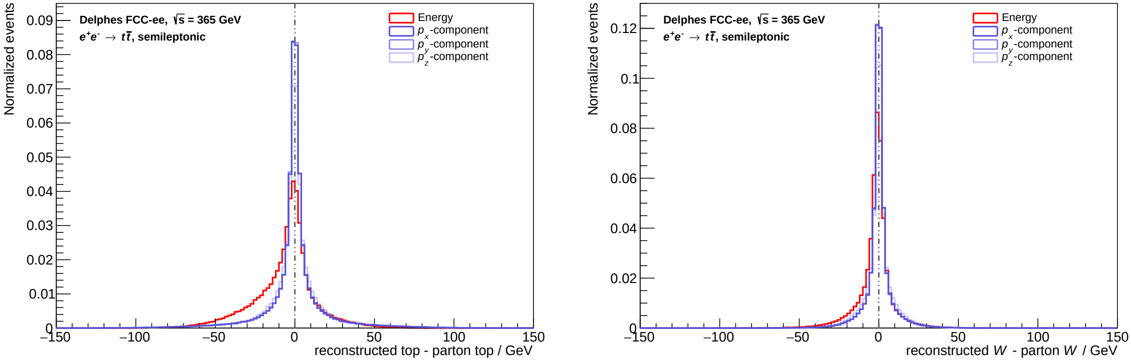


	$\mathcal{O}_{tW}$	$\mathcal{O}_{tZ}$	$\mathcal{O}_{\varphi q}^{(3)}$	$\mathcal{O}_{\varphi q}^{(-)}$	$\mathcal{O}_{\varphi t}$	$\mathcal{O}_{te}^{(1)}$	$\mathcal{O}_{tl}^{(1)}$	$\mathcal{O}_{qe}^{(1)}$	$\mathcal{O}_{ql}^{(-1)}$
$\mathrm{dcos}(\theta_\ell)$	1.312	0.978	0.117	0.009	0.007	0.65	0.66	0.522	0.637
$+\mathrm{d}x_\ell$	1.318	0.985	0.118	0.009	0.007	0.655	0.67	0.524	0.642
$+\mathrm{dcos}(\theta_{b^-})$	1.327	0.993	0.119	0.009	0.007	0.662	0.679	0.544	0.648
$+\mathrm{dcos}(\theta_{b^+})$	1.354	1.029	0.121	0.009	0.007	0.701	0.697	0.606	0.674

Collection of the OO-sensitivities S_{ii} for the different operators i.

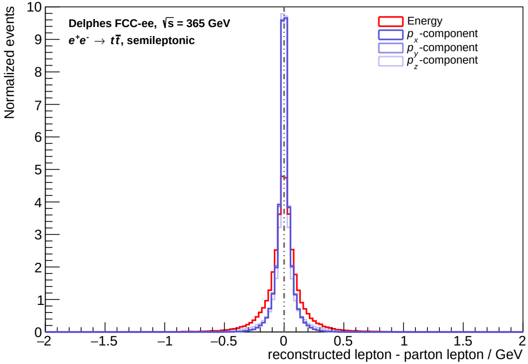
Final state objects – semileptonic

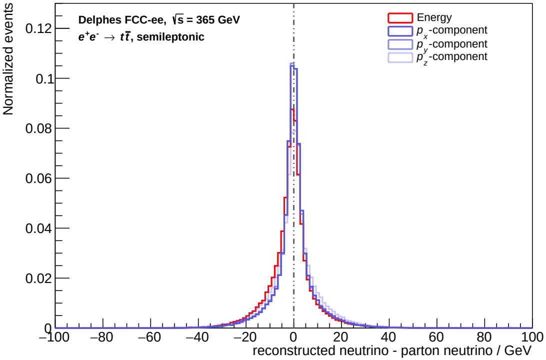
- Final state object resolution plots, showing $x^{\text{reco}} - x^{\text{parton}}, \; x \in [E, p_x, p_y, p_z]$
- Here: $t/\bar{t}$ and $W^{\pm}$



Final state objects – semileptonic

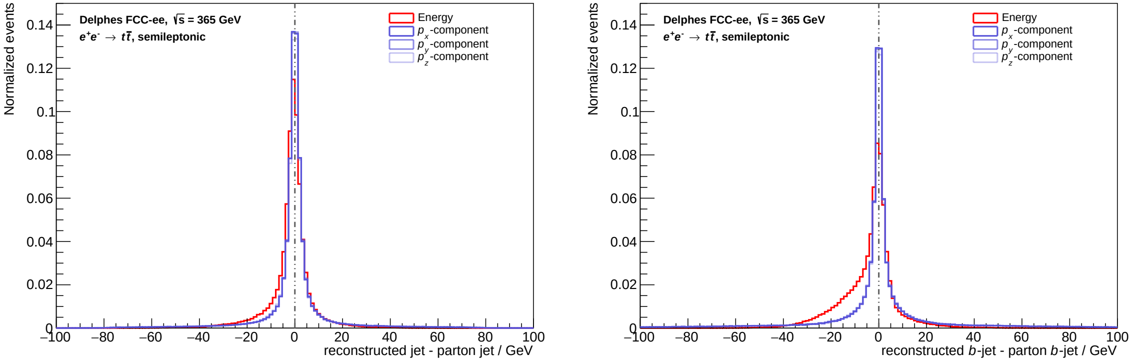
- Final state object resolution plots, showing $x^{\text{reco}} - x^{\text{parton}}, \ x \in [E, p_x, p_y, p_z]$
- Here: ℓ and ν_ℓ





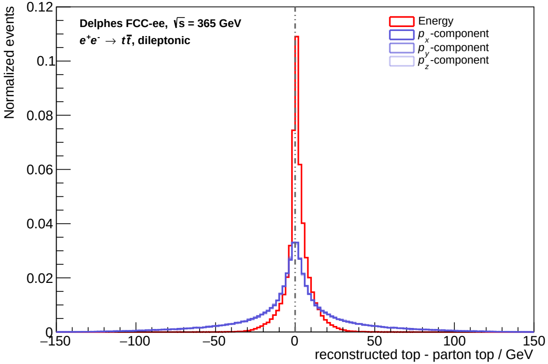
Final state objects – semileptonic

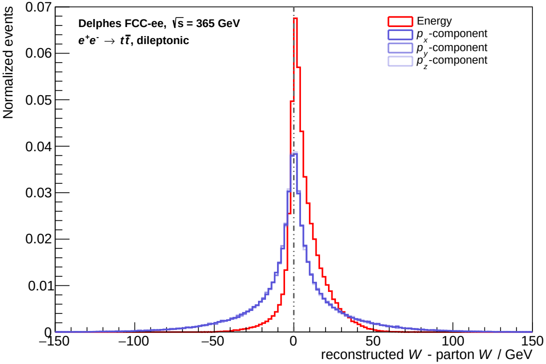
- Final state object resolution plots, showing $x^{\text{reco}} - x^{\text{parton}}$, $x \in [E, p_x, p_y, p_z]$
- Here: light jets and b-jets



Final state objects – dileptonic

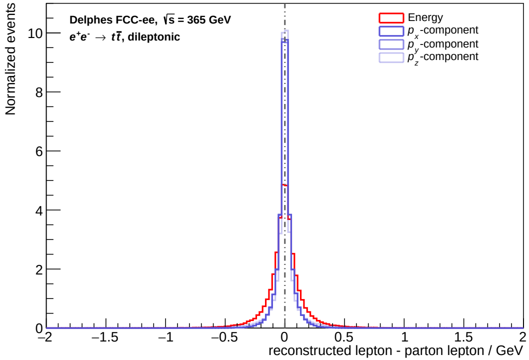
- Final state object resolution plots, showing $x^{\text{reco}} - x^{\text{parton}}$, $x \in [E, p_x, p_y, p_z]$
- Here: $t/\bar{t}$ and $W^{\pm}$

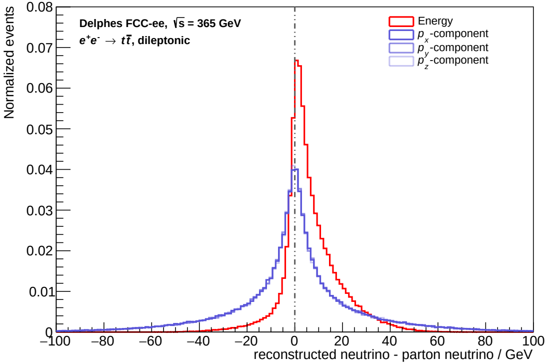




Final state objects – dileptonic

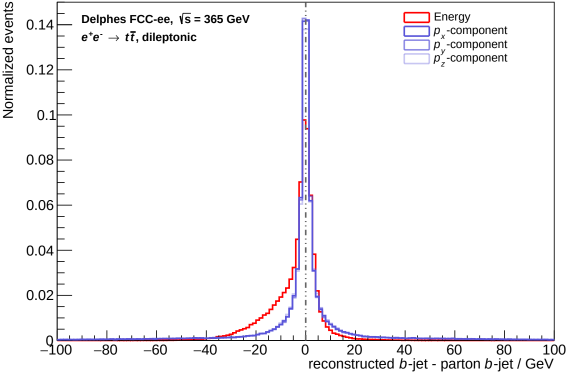
- Final state object resolution plots, showing $x^{\text{reco}} - x^{\text{parton}}$, $x \in [E, p_x, p_y, p_z]$
- Here: ℓ and ν_ℓ





Final state objects – dileptonic

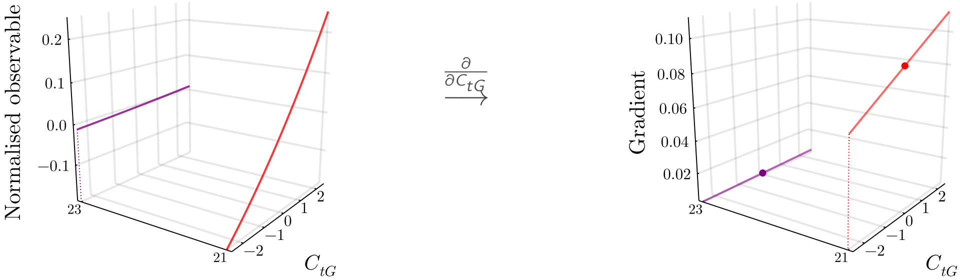
- Final state object resolution plots, showing $x^{\text{reco}} - x^{\text{parton}}$, $x \in [E, p_x, p_y, p_z]$
- Here: *b*-jets



Parameterisations – operator-wise

- Here: C_{tG}

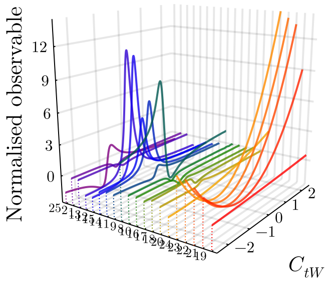
Label	21	23
Observable	$\sigma_{t\bar{t}j}$	$\sigma_{t\bar{t}b\bar{b}}$



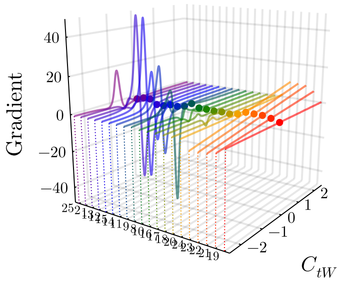
Parameterisations – operator-wise

- Here: C_{tW}

1	2	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
$A_{\lvert\Delta\phi_{\ell\ell}\rvert}$	$A^{\text{lab}}_{\cos(\varphi)}$	C_{rk}	$-C_r$	C_{nr}	C_k	B_{k+}	B_{k-}	B_{r+}	B_{r-}	F_0	F_{L}	F_{R}	Γ_t	σ_t	$\sigma_{t\bar{t}j}$	$\sigma_{t\bar{t}\ell\bar{\ell}}$	$\sigma_{t\bar{t}b\bar{b}}$	$\sigma_{t\bar{t}}$	A_{FB}



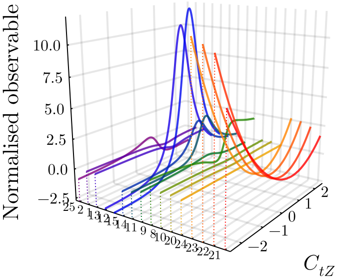
$$\xrightarrow{\frac{\partial}{\partial C_{tW}}}$$



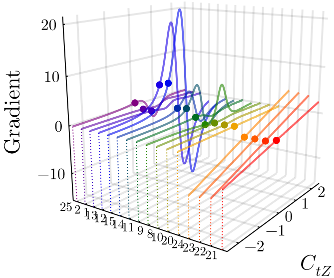
Parameterisations – operator-wise

- Here: C_{tZ}

1	2	8	9	10	11	12	13	14	15	21	22	23	24	25
$A_{\lvert\Delta\phi_{\ell\ell}\rvert}$	$A^{\mathrm{lab}}_{\cos(\varphi)}$	C_{rk}	$-C_r$	C_{nr}	C_k	B_{k+}	B_{k-}	B_{r+}	B_{r-}	$\sigma_{t\bar{t}j}$	$\sigma_{t\bar{t}\ell\bar{\ell}}$	$\sigma_{t\bar{t}b\bar{b}}$	$\sigma_{t\bar{t}}$	A_{FB}



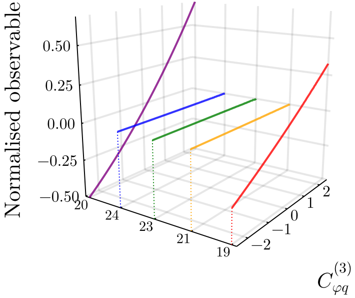
$$\xrightarrow{\frac{\partial}{\partial C_{tZ}}}$$



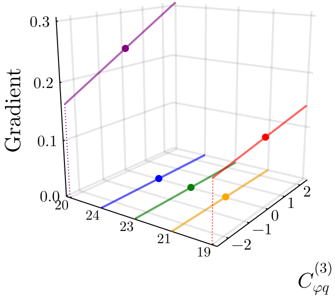
Parameterisations – operator-wise

- Here: $C_{\varphi q}^{(3)}$

Label	19	20	21	23	24
Observable	Γ_t	σ_t	$\sigma_{t\bar{t}j}$	$\sigma_{t\bar{t}b\bar{b}}$	$\sigma_{t\bar{t}}$



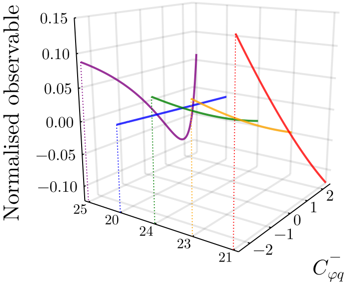
$$\xrightarrow{\frac{\partial}{\partial C_{\varphi q}^{(3)}}}$$



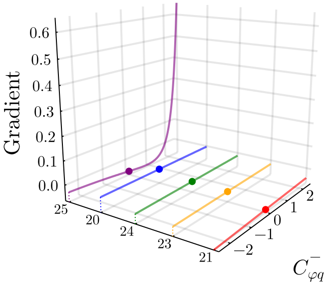
Parameterisations – operator-wise

- Here: $C_{\varphi q}^{(-)}$

Label	20	21	23	24	25
Observable	σ_t	$\sigma_{t\bar{t}j}$	$\sigma_{t\bar{t}b\bar{b}}$	$\sigma_{t\bar{t}}$	A_{FB}



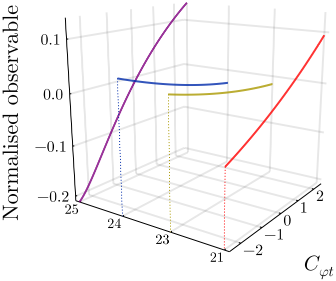
$$\xrightarrow{\frac{\partial}{\partial C_{\varphi q}^{(-)}}}$$



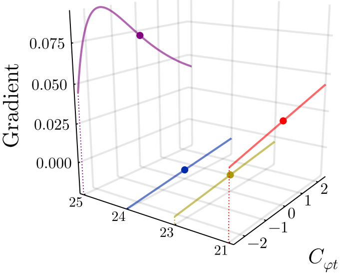
Parameterisations – operator-wise

- Here: $C_{\varphi t}$

Label	21	23	24	25
Observable	$\sigma_{t\bar{t}j}$	$\sigma_{t\bar{t}b\bar{b}}$	$\sigma_{t\bar{t}}$	A_{FB}



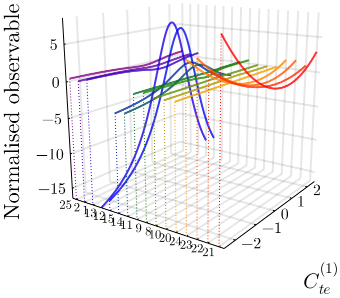
$$\xrightarrow{\frac{\partial}{\partial C_{\varphi t}}}$$



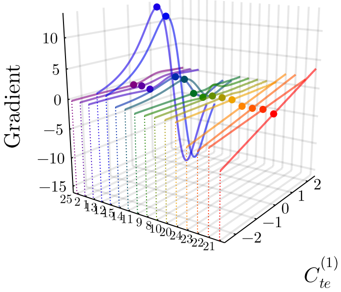
Parameterisations – operator-wise

- Here: $C_{te}^{(1)}$

1	2	8	9	10	11	12	13	14	15	21	22	23	24	25
$A_{\lvert\Delta\phi_{\ell\ell}\rvert}$	$A^{\mathrm{lab}}_{\cos(\varphi)}$	C_{rk}	$-C_r$	C_{nr}	C_k	B_{k+}	B_{k-}	B_{r+}	B_{r-}	$\sigma_{t\bar{t}j}$	$\sigma_{t\bar{t}\ell\bar{\ell}}$	$\sigma_{t\bar{t}b\bar{b}}$	$\sigma_{t\bar{t}}$	A_{FB}



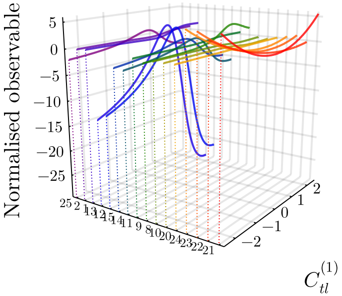
$$\xrightarrow{\frac{\partial}{\partial C_{te}^{(1)}}}$$



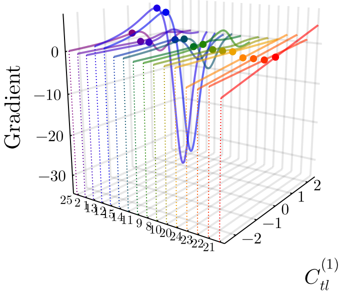
Parameterisations – operator-wise

- Here: $C_{tl}^{(1)}$

1	2	8	9	10	11	12	13	14	15	21	22	23	24	25
$A_{\|\Delta\phi_{\ell\ell}\|}$	$A^{\text{lab}}_{\cos(\varphi)}$	C_{rk}	$-C_r$	C_{nr}	C_k	B_{k+}	B_{k-}	B_{r+}	B_{r-}	$\sigma_{t\bar{t}j}$	$\sigma_{t\bar{t}\ell\bar{\ell}}$	$\sigma_{t\bar{t}b\bar{b}}$	$\sigma_{t\bar{t}}$	A_{FB}



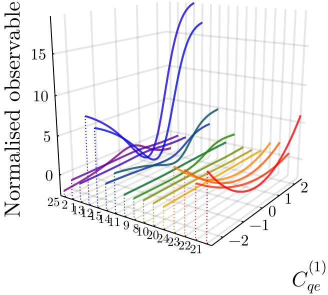
$$\xrightarrow{\frac{\partial}{\partial C_{tl}^{(1)}}}$$



Parameterisations – operator-wise

- Here: $C_{qe}^{(1)}$

1	2	8	9	10	11	12	13	14	15	21	22	23	24	25
$A_{\lvert\Delta\phi_{\ell\ell}\rvert}$	$A^{\mathrm{lab}}_{\cos(\varphi)}$	C_{rk}	$-C_r$	C_{nr}	C_k	B_{k+}	B_{k-}	B_{r+}	B_{r-}	$\sigma_{t\bar{t}j}$	$\sigma_{t\bar{t}\ell\bar{\ell}}$	$\sigma_{t\bar{t}b\bar{b}}$	$\sigma_{t\bar{t}}$	A_{FB}



$$\xrightarrow{\frac{\partial}{\partial C_{qe}^{(1)}}}$$