EFT fit on top quark EW couplings

M. Perelló Roselló, M. Vos (IFIC - U. Valencia/CSIC)
P. Roloff, R. Ström (CERN)
G. Durieux (DESY), C. Zhang (IHEP)

Acknowledging input/contributions from:

M. Boronat, J. Fuster, I. García, P. Gomis, E. Ros (IFIC - U. Valencia/CSIC)

R. Pöschl, F. Richard (Orsay, LAL)

Outline

Introduction

Observables

Full-simulation

Results on the global fit based on CLIC

Introduction

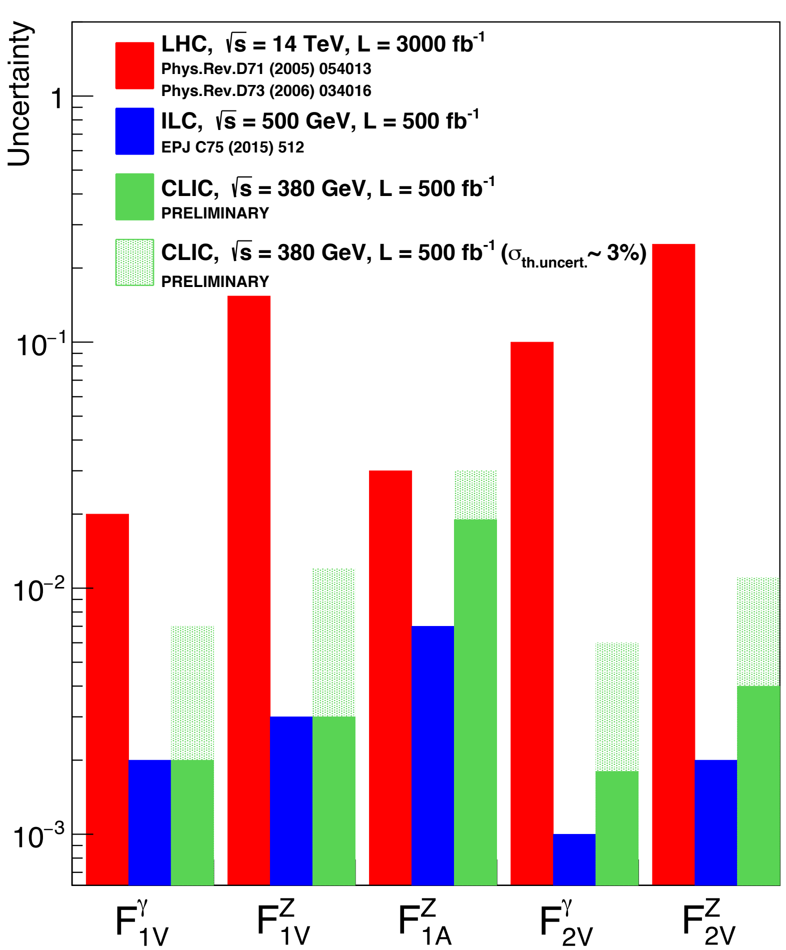
Top quark couplings: form factors

Objective: to study the potential of a global fit in the top EW sector.

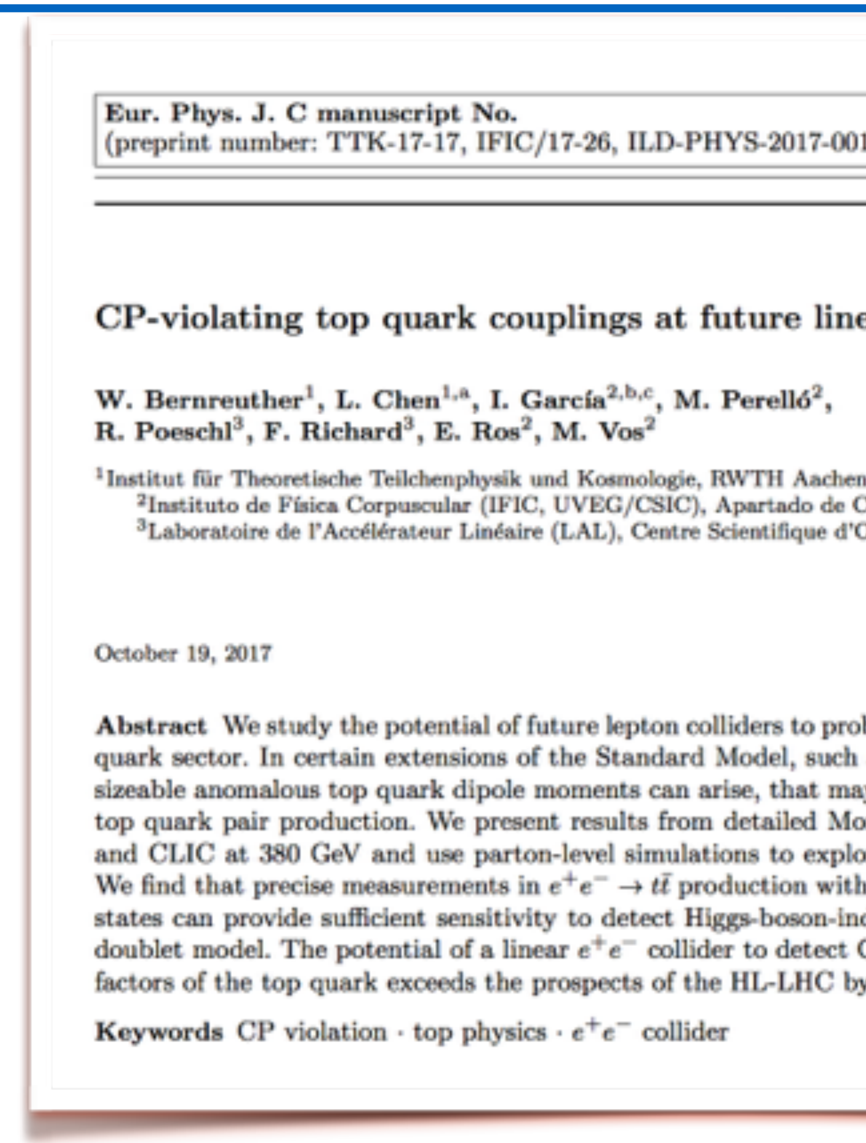
Form-factors
$$\Gamma_{\mu}^{t\bar{t}X}(k^2,q,\bar{q}) = ie\left\{\gamma_\mu\left(\underline{F_{1V}^X(k^2)} + \gamma_5 \underline{F_{1A}^X(k^2)}\right) - \frac{\sigma_{\mu\nu}}{2m_t}(q+\bar{q})^\nu\left(i\underline{F_{2V}^X(k^2)} + \gamma_5 \underline{F_{2A}^X(k^2)}\right)\right\}$$

CP Conserving **CPV**

CLIC baseline document (arXiv:1608.07537) and arXiv:1505.06020



arXiv:1710.06737



Eur. Phys. J. C manuscript No.
(preprint number: TTK-17-17, IFIC/17-26, ILD-PHYS-2017-001, CLICdp-PUB-2017-003)

CP-violating top quark couplings at future linear e^+e^- colliders

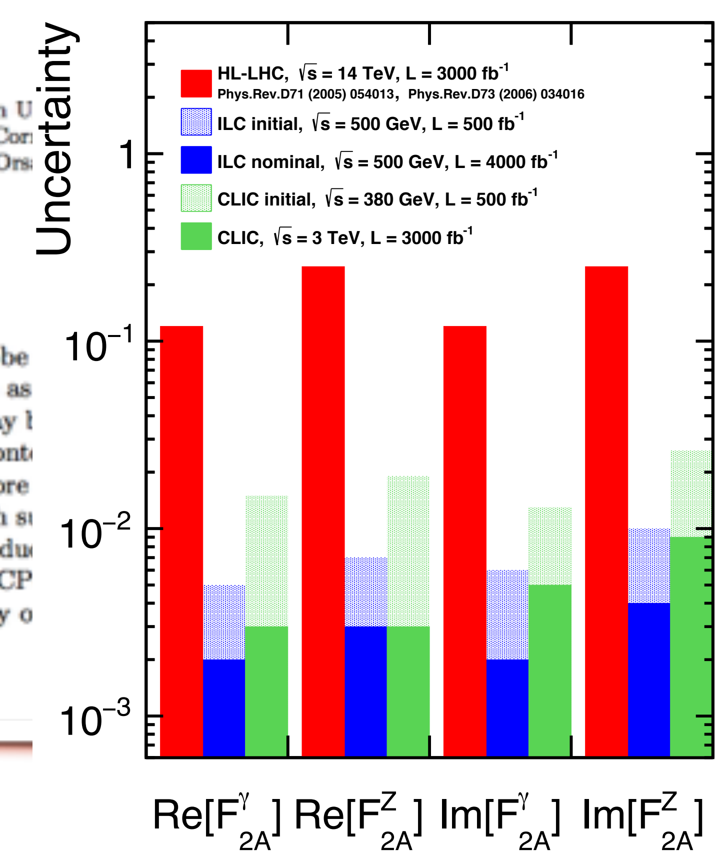
W. Bernreuther[1], L. Chen[1,a], I. García[2,b,c], M. Perelló[2], R. Poeschl[3], F. Richard[3], E. Ros[2], M. Vos[2]

[1]Institut für Theoretische Teilchenphysik und Kosmologie, RWTH Aachen U
[2]Instituto de Física Corpuscular (IFIC, UVEG/CSIC), Apartado de Cor
[3]Laboratoire de l'Accélérateur Linéaire (LAL), Centre Scientifique d'Ors

October 19, 2017

Abstract We study the potential of future lepton colliders to probe quark sector. In certain extensions of the Standard Model, such as sizeable anomalous top quark dipole moments can arise, that may l top quark pair production. We present results from detailed Mont and CLIC at 380 GeV and use parton-level simulations to explore We find that precise measurements in $e^+e^- \to t\bar{t}$ production with s states can provide sufficient sensitivity to detect Higgs-boson-indu doublet model. The potential of a linear e^+e^- collider to detect CP factors of the top quark exceeds the prospects of the HL-LHC by o

Keywords CP violation · top physics · e^+e^- collider



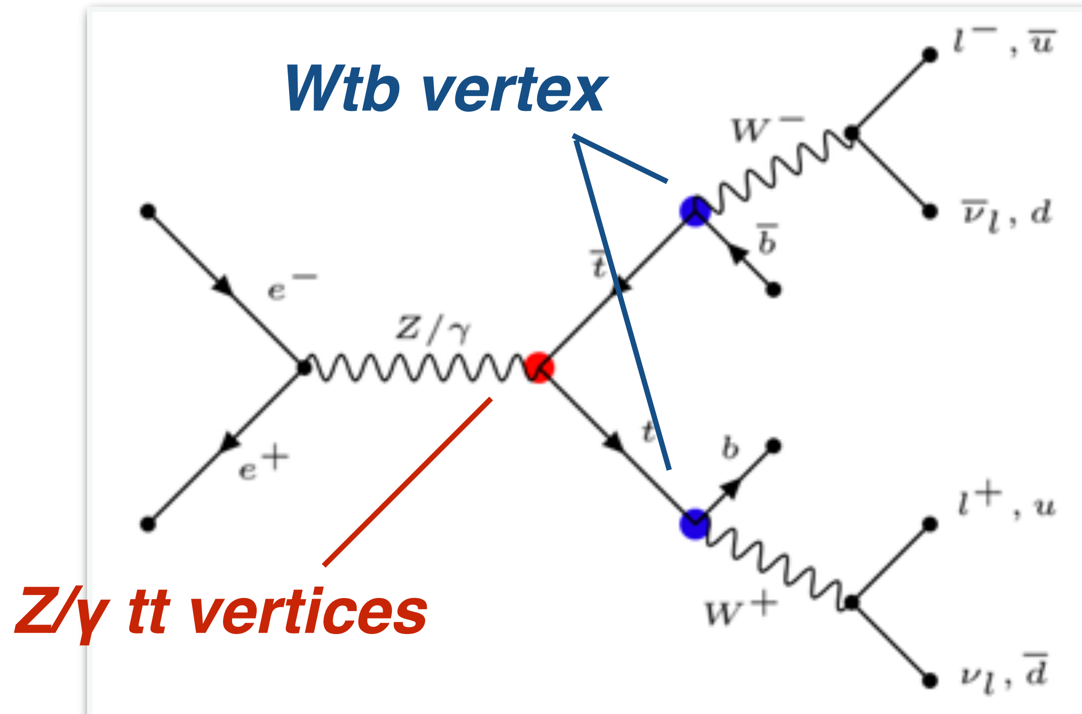
Top quark couplings: EFT

Effective Field Theory

$$\mathcal{L}_{eff} = \mathcal{L}_{SM} + \frac{1}{\Lambda^2}\sum_i C_i O_i + \mathcal{O}\left(\Lambda^{-4}\right)$$

$$\begin{aligned}
O^1_{\varphi q} &\equiv \tfrac{y_t^2}{2} \quad \bar{q}\gamma^\mu q \quad \varphi^\dagger i\overleftrightarrow{D}_\mu\varphi \\
O^3_{\varphi q} &\equiv \tfrac{y_t^2}{2} \quad \bar{q}\tau^I\gamma^\mu q \quad \varphi^\dagger i\overleftrightarrow{D}^I_\mu\varphi \\
O_{\varphi u} &\equiv \tfrac{y_t^2}{2} \quad \bar{u}\gamma^\mu u \quad \varphi^\dagger i\overleftrightarrow{D}_\mu\varphi \\
O_{\varphi ud} &\equiv \tfrac{y_t^2}{2} \quad \bar{u}\gamma^\mu d \quad \varphi^T\epsilon\, iD_\mu\varphi
\end{aligned}$$

$$\begin{aligned}
O_{uG} &\equiv y_t g_s \quad \bar{q}T^A\sigma^{\mu\nu}u \quad \epsilon\varphi^* G^A_{\mu\nu} \\
O_{uW} &\equiv y_t g_W \quad \bar{q}\tau^I\sigma^{\mu\nu}u \quad \epsilon\varphi^* W^I_{\mu\nu} \\
O_{dW} &\equiv y_t g_W \quad \bar{q}\tau^I\sigma^{\mu\nu}d \quad \epsilon\varphi^* W^I_{\mu\nu} \\
O_{uB} &\equiv y_t g_Y \quad \bar{q}\sigma^{\mu\nu}u \quad \epsilon\varphi^* B_{\mu\nu}
\end{aligned}$$

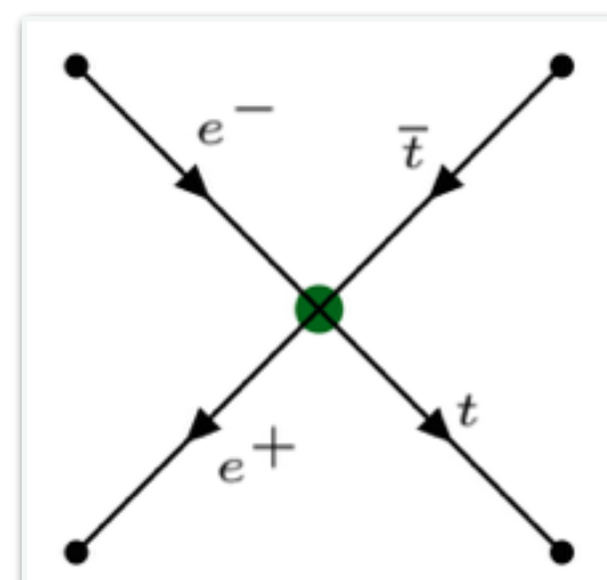


Contact interactions

$$\begin{aligned}
O^1_{lq} &\equiv \bar{q}\gamma_\mu q \quad \bar{l}\gamma^\mu l \\
O^3_{lq} &\equiv \bar{q}\tau^I\gamma_\mu q \quad \bar{l}\tau^I\gamma^\mu l \\
O_{lu} &\equiv \bar{u}\gamma_\mu u \quad \bar{l}\gamma^\mu l \\
O_{eq} &\equiv \bar{q}\gamma_\mu q \quad \bar{e}\gamma^\mu e \\
O_{eu} &\equiv \bar{u}\gamma_\mu u \quad \bar{e}\gamma^\mu e
\end{aligned}$$

$$O^T_{lequ} \equiv \bar{q}\sigma^{\mu\nu}u\;\epsilon\;\bar{l}\sigma_{\mu\nu}e$$

$$\begin{aligned}
O^S_{lequ} &\equiv \bar{q}u\;\epsilon\;\bar{l}e \\
O_{ledq} &\equiv \bar{d}q \quad \bar{l}e
\end{aligned}$$



Different EFT basis

Transformation between effective operators and form-factors:

$$F^{Z}_{1,V} - F^{Z,SM}_{1,V} = \frac{1}{2}\left(\underline{C^{(3)}_{\varphi Q} - C^{(1)}_{\varphi Q} - C_{\varphi t}}\right)\frac{m_t^2}{\Lambda^2 s_W c_W} = -\frac{1}{2}\underline{C^{V}_{\varphi q}}\frac{m_t^2}{\Lambda^2 s_W c_W}$$

$$F^{Z}_{1,A} - F^{Z,SM}_{1,A} = \frac{1}{2}\left(\underline{-C^{(3)}_{\varphi Q} + C^{(1)}_{\varphi Q} - C_{\varphi t}}\right)\frac{m_t^2}{\Lambda^2 s_W c_W} = -\frac{1}{2}\underline{C^{A}_{\varphi q}}\frac{m_t^2}{\Lambda^2 s_W c_W}$$

$$F^{Z}_{2,V} = \left(\underline{\mathrm{Re}\{C_{tW}\}c_W^2 - \mathrm{Re}\{C_{tB}\}s_W^2}\right)\frac{4m_t^2}{\Lambda^2 s_W c_W} = \mathrm{Re}\{\underline{C_{uZ}}\}\frac{4m_t^2}{\Lambda^2}$$

$$F^{\gamma}_{2,V} = \left(\underline{\mathrm{Re}\{C_{tW}\} + \mathrm{Re}\{C_{tB}\}}\right)\frac{4m_t^2}{\Lambda^2} = \mathrm{Re}\{\underline{C_{uA}}\}\frac{4m_t^2}{\Lambda^2}$$

$$[F^{Z}_{2,A}, F^{\gamma}_{2,A}] \propto \underline{[\mathrm{Im}\{C_{tW}\}, \mathrm{Im}\{C_{tB}\}]}$$

We can change to an alternative basis (**Vector/Axial - Vector**)

10 operators in the global fit:
- 4 CP-conserving ttX vertices
- 2 CP-violating ttX vertices
- 4 contact interactions

Conversion to V/A - V basis in contact interactions:

$$\boxed{\begin{aligned} C^{V}_{lq} &\equiv C_{lu} + C^{(1)}_{lq} - C^{(3)}_{lq} & \qquad C^{V}_{eq} &\equiv C_{eu} + C_{eq} \\ C^{A}_{lq} &\equiv C_{lu} - C^{(1)}_{lq} + C^{(3)}_{lq} & \qquad C^{A}_{eq} &\equiv C_{eu} - C_{eq} \end{aligned}}$$

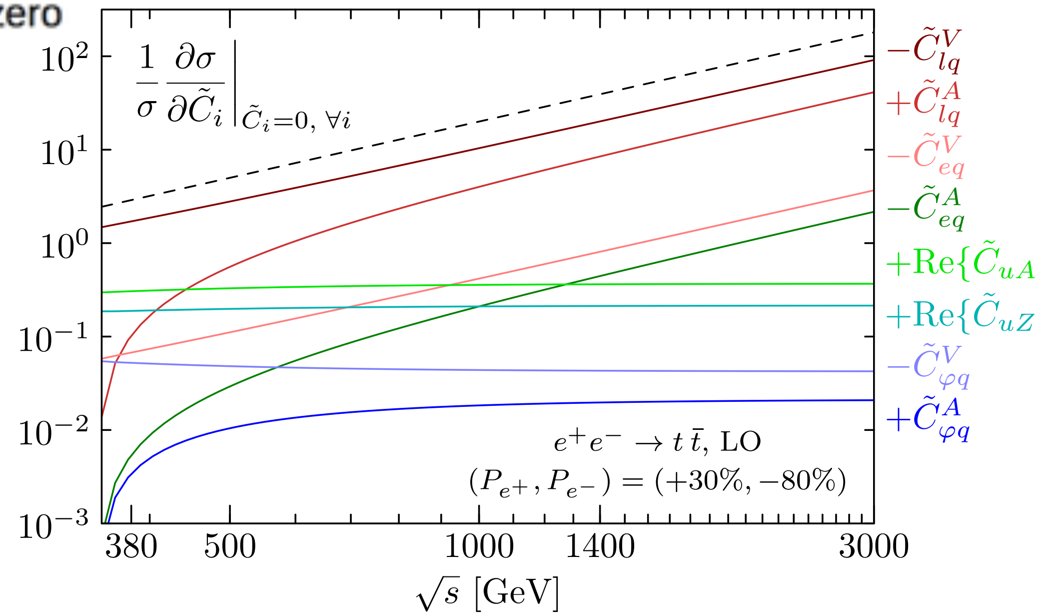
Observables

Observables sensitivity: A_{FB} + cross-section

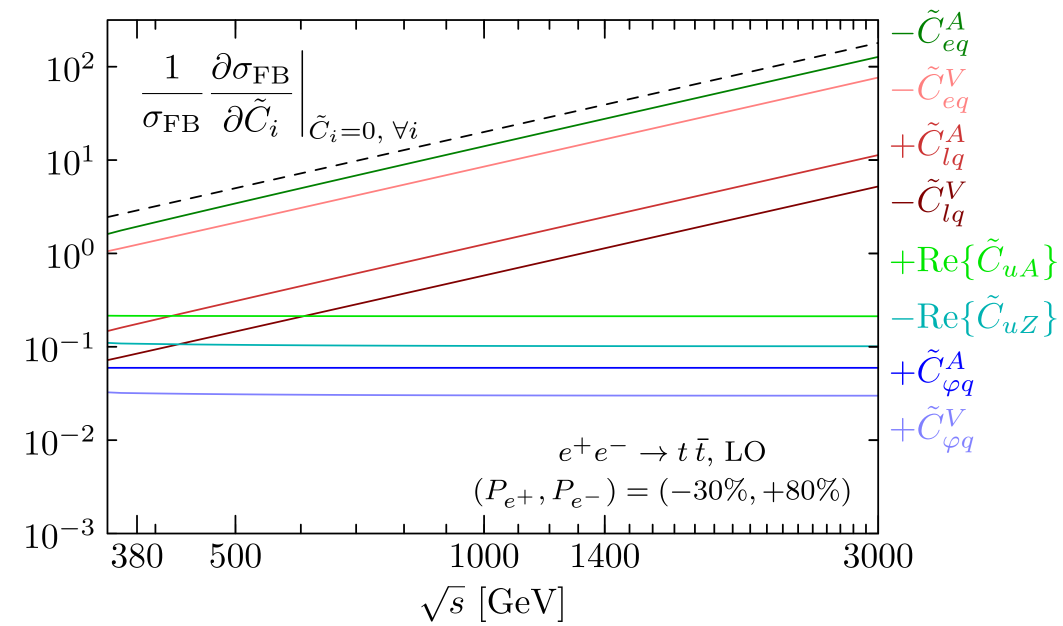
$e^+e^- \to t\,\bar{t}$, LO **Durieux, Perelló, Vos, Zhang, to be published**

Sensitivity:
Relative change in cross-section due to non-zero operator coefficient
$\Delta\sigma$ (C) / σ / ΔC

Cross-section



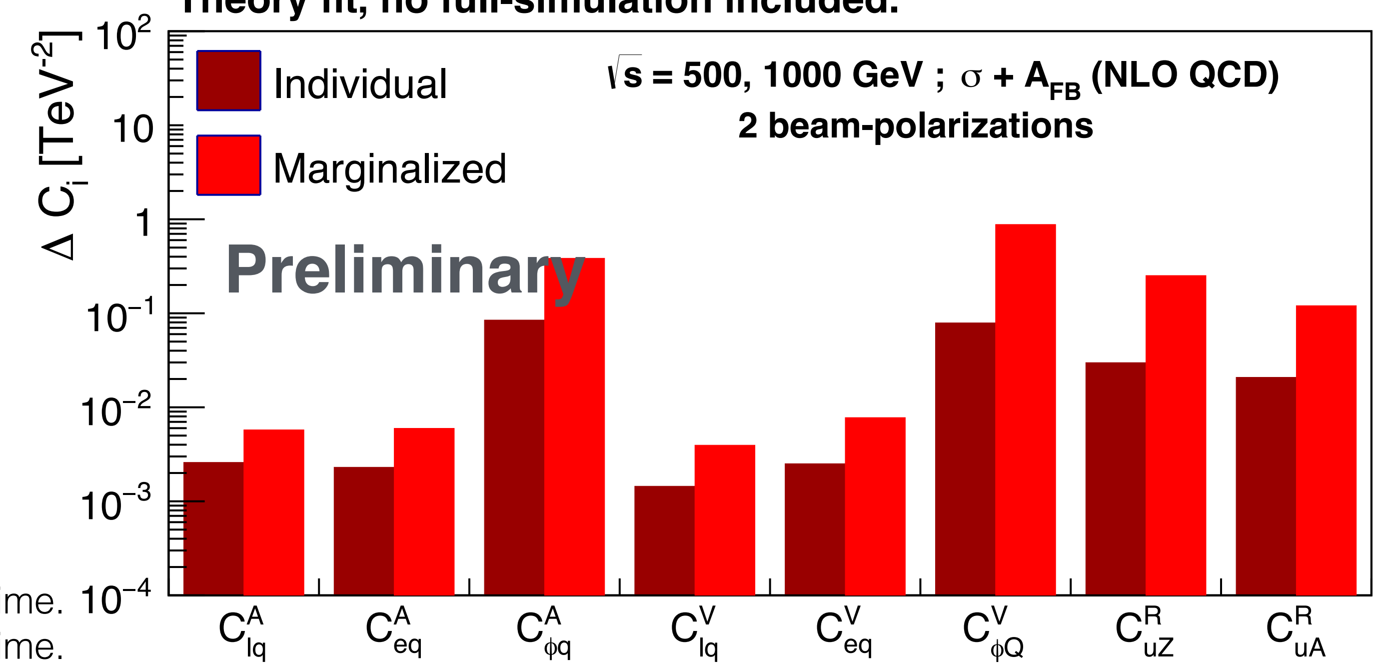
Forward-backward asymmetry



(multi-) TeV operation provides better sensitivity to contact-interaction operators.

Need for new observables to reduce the difference between individual and marginalized fits

Theory fit, no full-simulation included.



Individual: assuming variation in only 1 parameter each time.
Marginalized: assuming variation in all the parameters at the same time.

CPV observables in the global fit arXiv:1710.06737

The **CP-violating effects** in e+e− → tt̄ manifest themselves in specific **top-spin effects**, namely **CP-odd top spin-momentum correlations and tt̄ spin correlations**.

$$e^+(\mathbf{p}_+, P_{e^+}) + e^-(\mathbf{p}_-, P_{e^-}) \quad \rightarrow \quad t(\mathbf{k}_t) + \bar{t}(\mathbf{k}_{\bar{t}})$$

$$\begin{aligned} t\ \bar{t} &\rightarrow \ell^+(\mathbf{q}_+) + \nu_\ell + b + \overline{X}_{\rm had}(\mathbf{q}_{\bar{X}}) \\ t\ \bar{t} &\rightarrow X_{\rm had}(\mathbf{q}_X) + \ell^-(\mathbf{q}_-) + \bar{\nu}_\ell + \bar{b} \end{aligned}$$

- **CP-odd observables** are defined with the **four momenta available in tt semi-leptonic decay channel**

$$\begin{aligned} \mathcal{O}_+^{Re} &= (\hat{\mathbf{q}}_{\bar{X}} \times \hat{\mathbf{q}}_+^*) \cdot \hat{\mathbf{p}}_+ \,, \\ \mathcal{O}_+^{Im} &= -[1 + (\frac{\sqrt{s}}{2m_t} - 1)(\hat{\mathbf{q}}_{\bar{X}} \cdot \hat{\mathbf{p}}_+)^2]\hat{\mathbf{q}}_+^* \cdot \hat{\mathbf{q}}_{\bar{X}} + \frac{\sqrt{s}}{2m_t}\hat{\mathbf{q}}_{\bar{X}} \cdot \hat{\mathbf{p}}_+ \hat{\mathbf{q}}_+^* \cdot \hat{\mathbf{p}}_+ \end{aligned}$$

- The way to **extract** the **CP-violating form factor** is to construct **asymmetries sensitive to CP-violation effects**

$$\mathcal{A}^{Re} = \langle \mathcal{O}_+^{Re} \rangle - \langle \mathcal{O}_-^{Re} \rangle = \boxed{c_\gamma(s)} \mathrm{Re} F_{2A}^\gamma + \boxed{c_Z(s)} \mathrm{Re} F_{2A}^Z$$

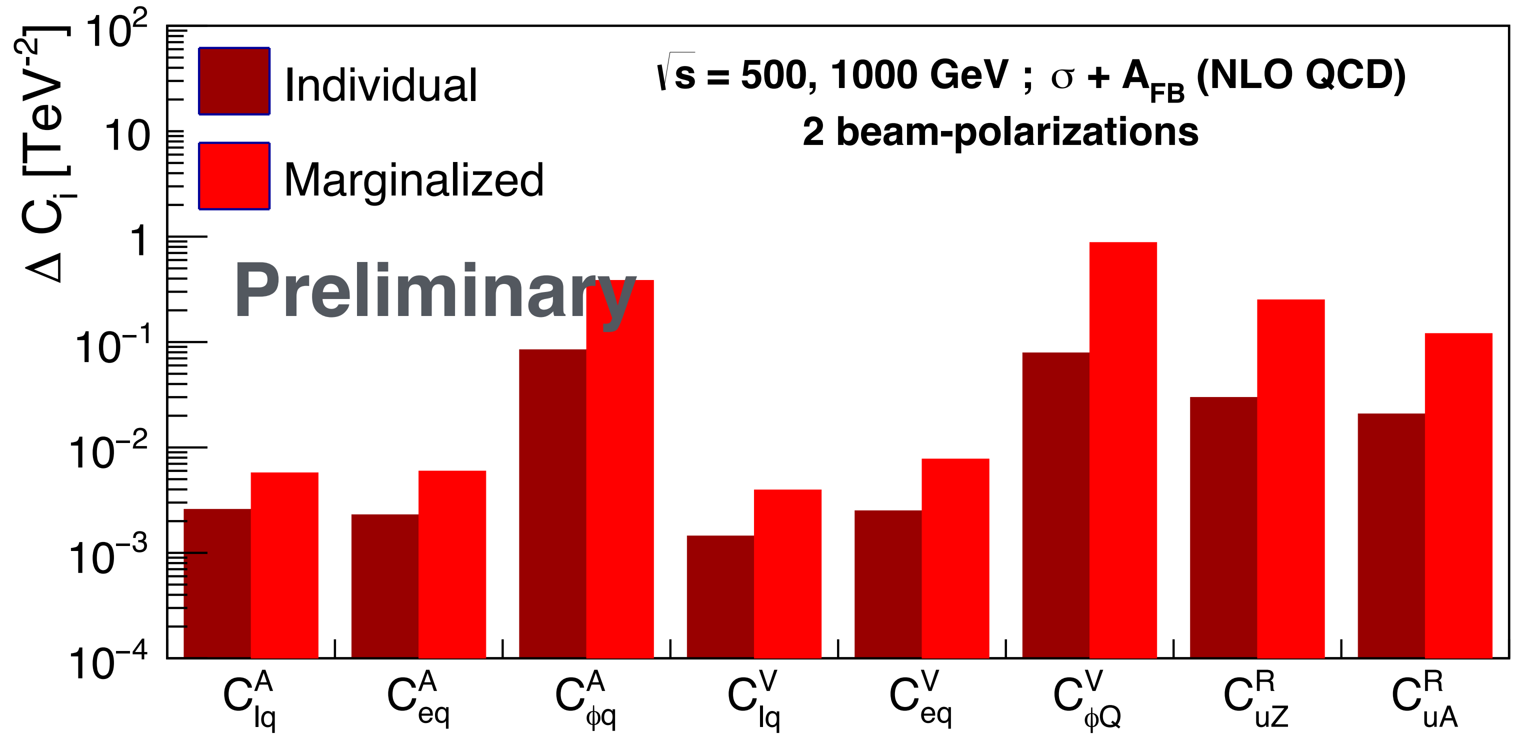
$$\mathcal{A}^{Im} = \langle \mathcal{O}_+^{Im} \rangle - \langle \mathcal{O}_-^{Im} \rangle = \boxed{\tilde{c}_\gamma(s)} \mathrm{Im} F_{2A}^\gamma + \boxed{\tilde{c}_Z(s)} \mathrm{Im} F_{2A}^Z$$

$$\boxed{\begin{array}{cc} {\mathcal{A}^{Re}_{\gamma,Z}}^{\text{L}} & {\mathcal{A}^{Re}_{\gamma,Z}}^{\text{L}} \\ {\mathcal{A}^{Im}_{\gamma,Z}}^{\text{R}} & {\mathcal{A}^{Im}_{\gamma,Z}}^{\text{R}} \end{array}}$$

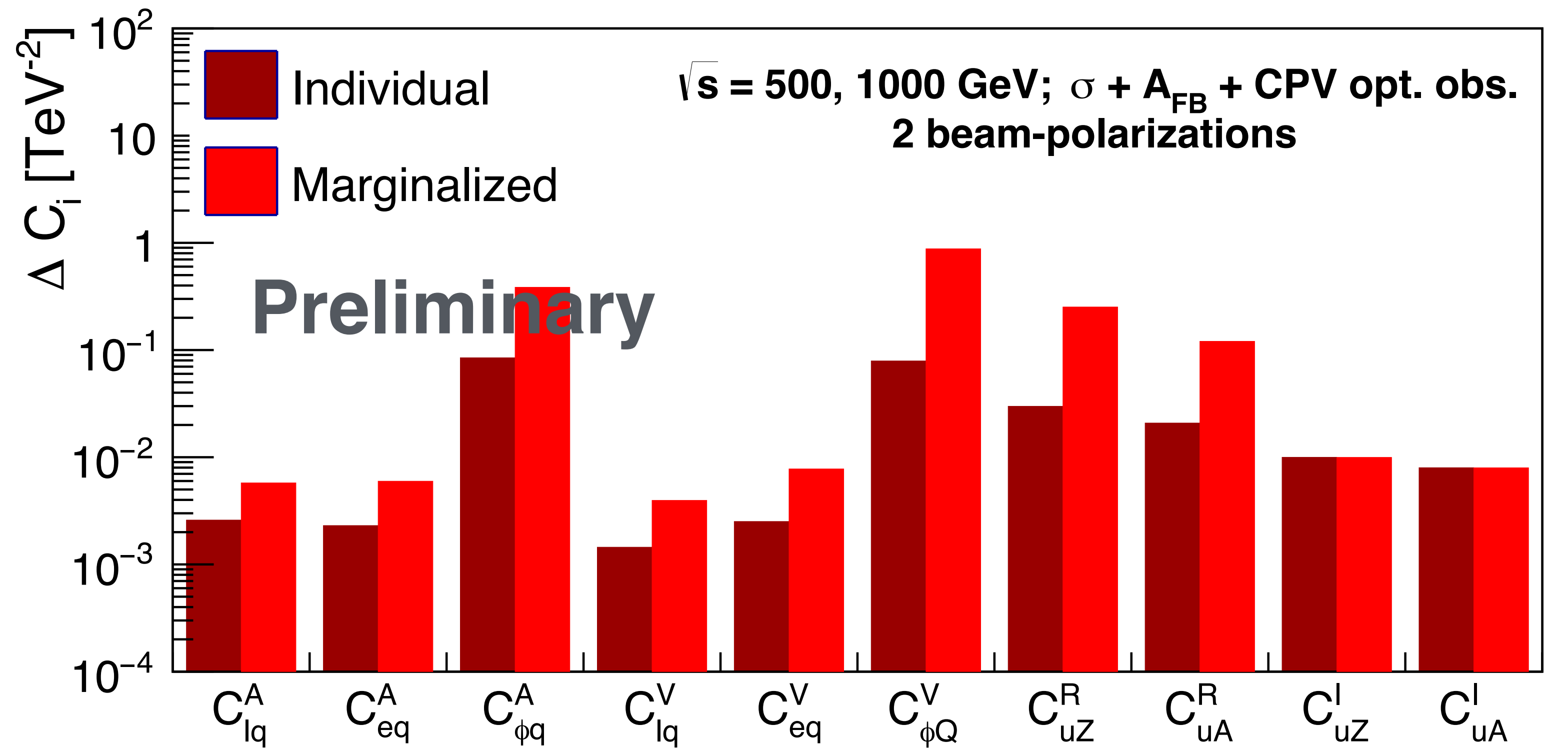
CPV observables in the global fit arXiv:1710.06737

Including CPV observables in the EFT global fit doesn't solve the problem

We still need to improve the marginalized fit



Theory fit, no full-simulation included.



Individual: assuming variation in only 1 parameter each time.
Marginalized: assuming variation in all the parameters at the same time.

Statistically optimal observables

G. Durieux @TopLC 2017:

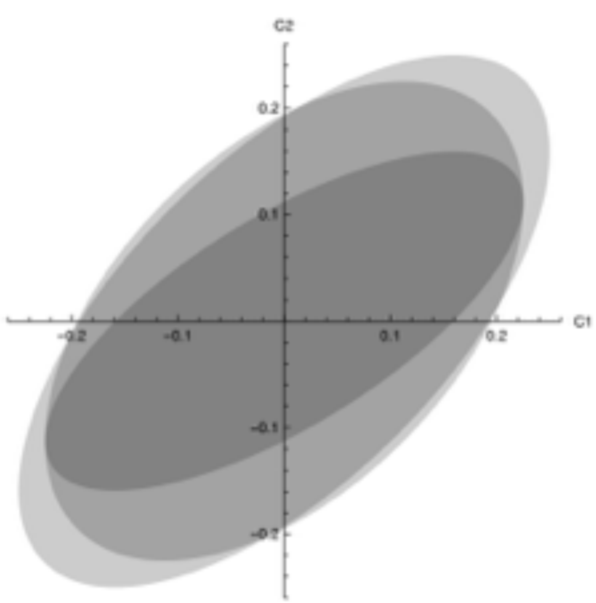
https://indico.cern.ch/event/595651/contributions/2573918/

Statistically optimal observables

[Atwood,Soni '92]
[Diehl,Nachtmann '94]

minimize the one-sigma ellipsoid in EFT parameter space.
(*joint efficient* set of estimators, saturating the Rao-Cramér-Fréchet bound: $V^{-1} = I$)

For small C_i, with a phase-space distribution $\sigma(\Phi) = \sigma_0(\Phi) + \sum_i C_i\, \sigma_i(\Phi)$,
the statistically optimal set of observables is: $O_i(\Phi) = \sigma_i(\Phi)/\sigma_0(\Phi)$.



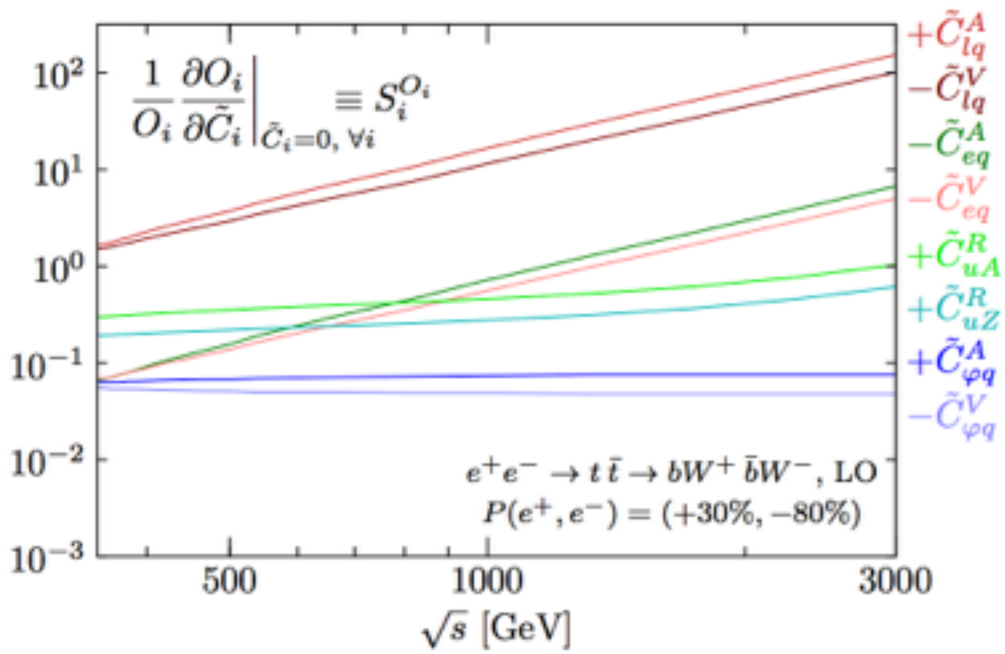
e.g. $\sigma(\phi) = 1 + \cos(\phi) + C_1 \sin(\phi) + C_2 \sin(2\phi)$

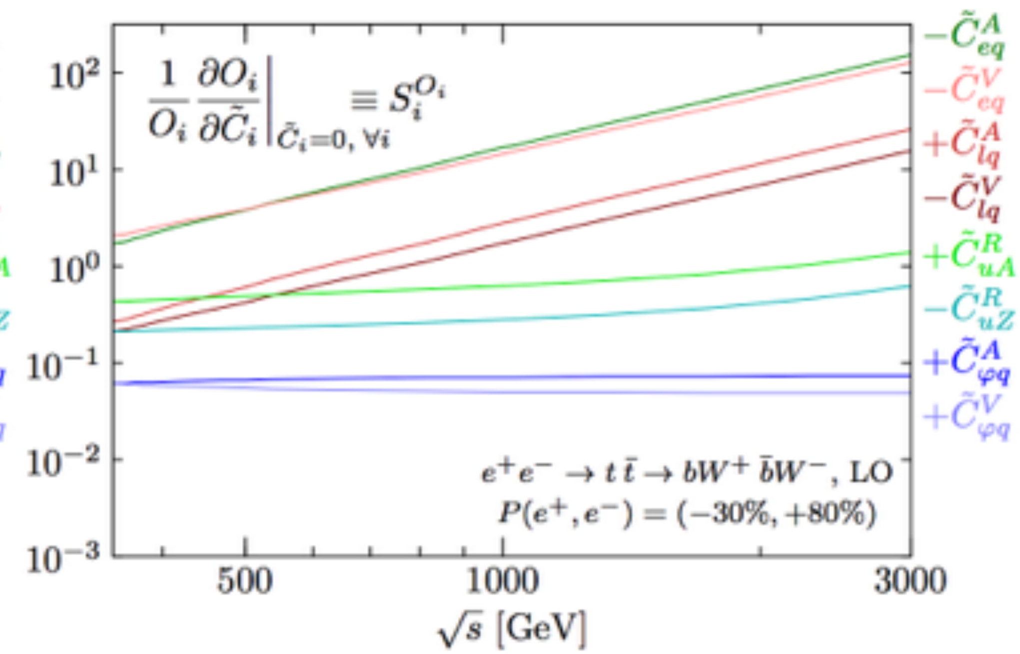
1. asymmetries: $O_i \sim \text{sign}\{\sin(i\phi)\}$
2. moments: $O_i \sim \sin(i\phi)$
3. statistically optimal: $O_i \sim \dfrac{\sin(i\phi)}{1+\cos\phi}$

$\Longrightarrow$ area ratios 1.9 : 1.7 : 1

Previous applications in $e^+e^- \to t\,\bar{t}$:
[Grzadkowski, Hioki '00] [Janot '15] [Khiem et al '15]

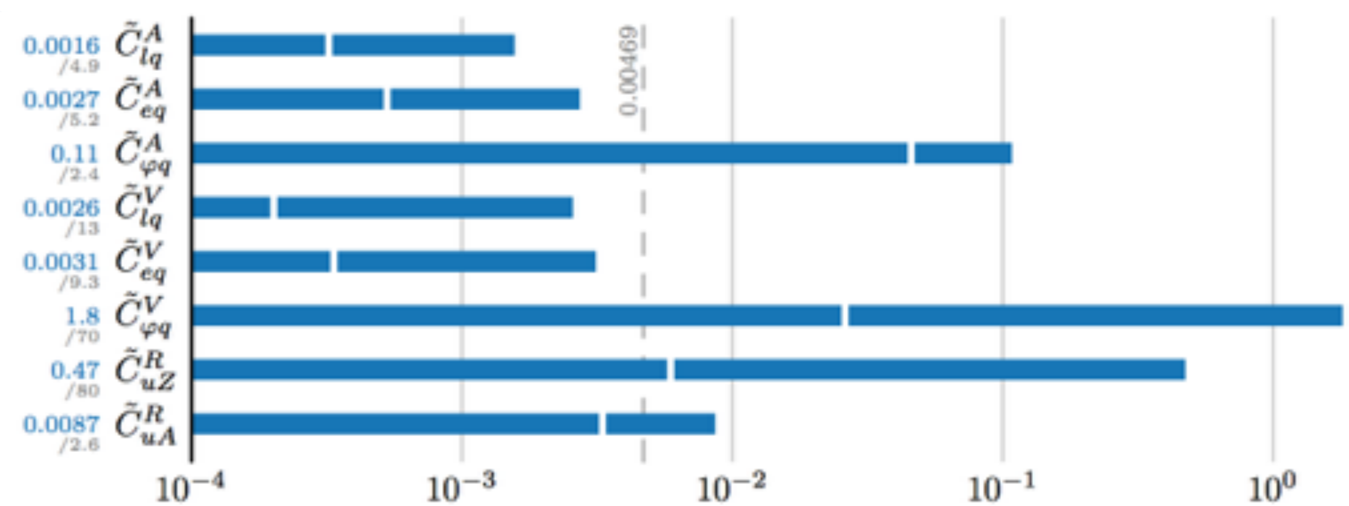
Statistically optimal observables sensitivities



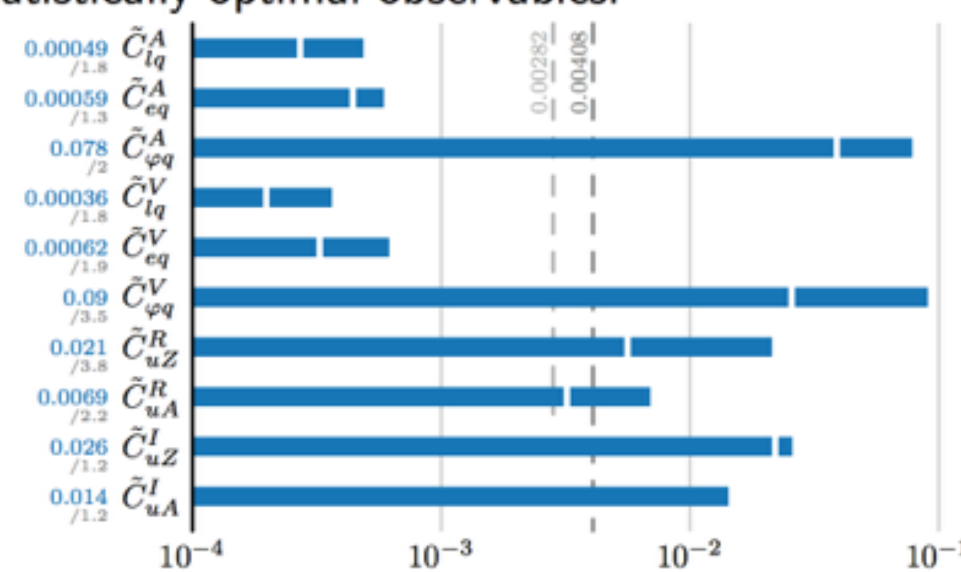


Comparison in the global limits (500GeV + 1TeV for 2 pols.):

$\sigma + A_{FB}$



Statistically optimal observables:



- **Even better individual limits**
- **Global limits within a factor 1.3 to 3.5**

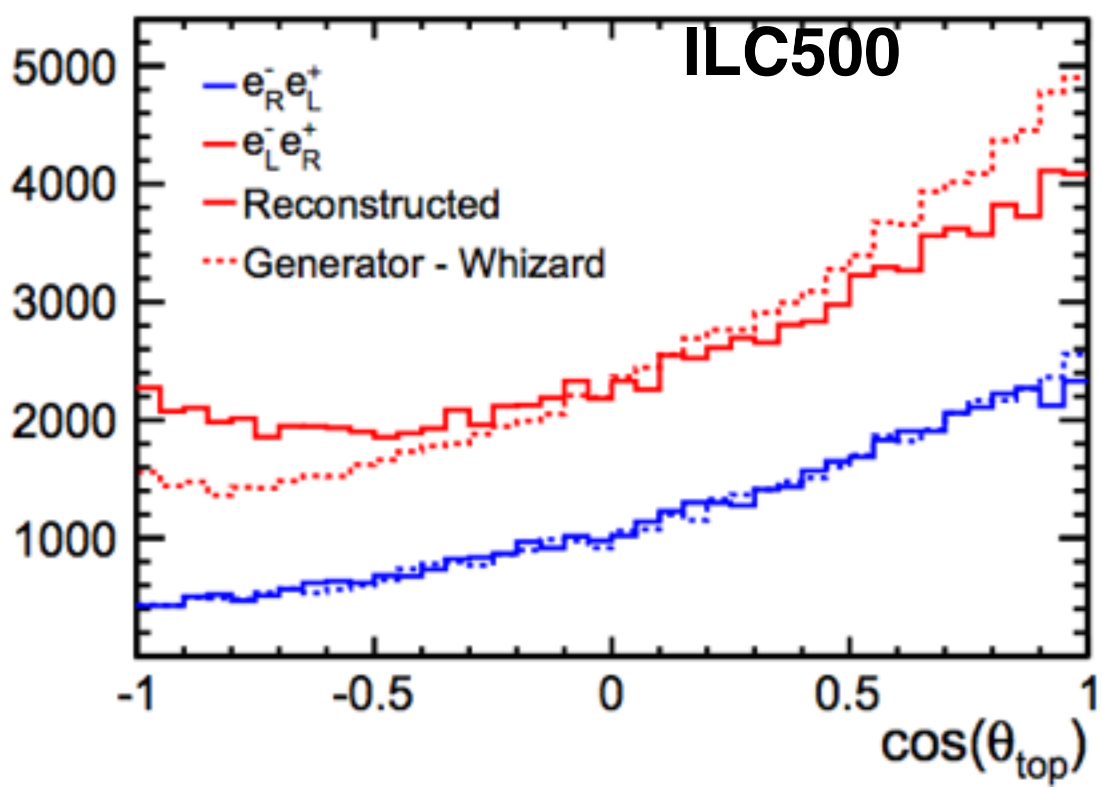
Full-simulation

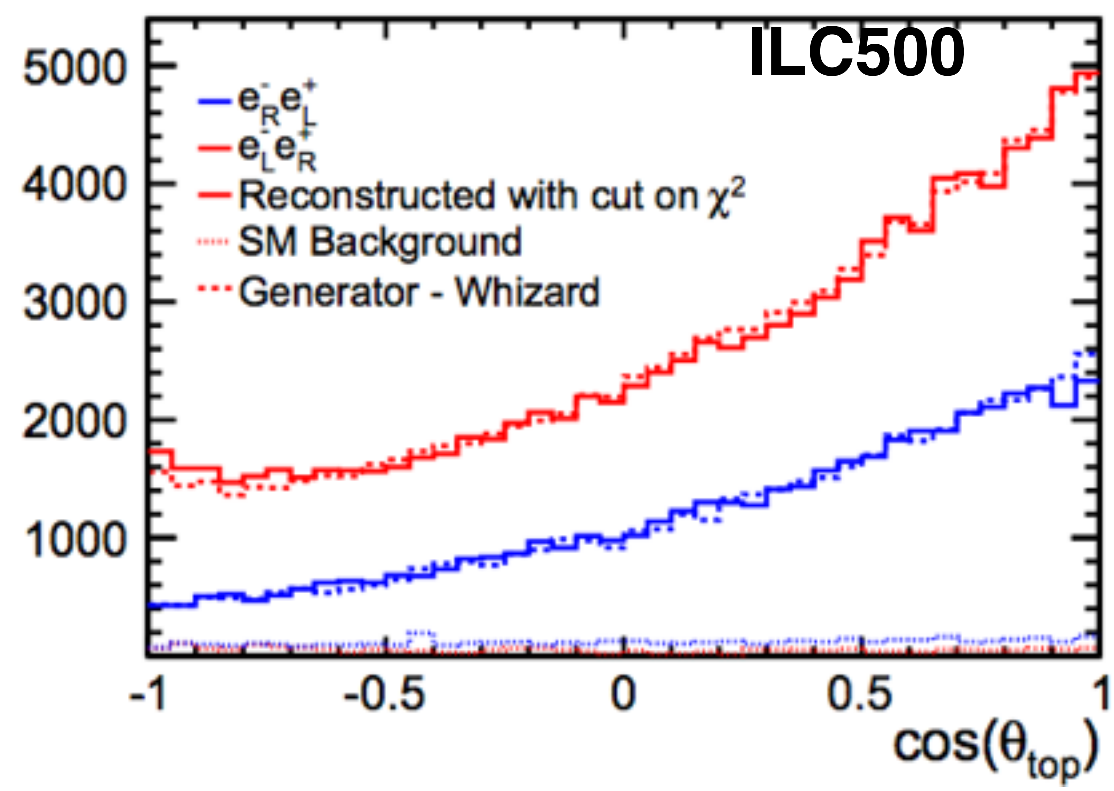
Full-simulation: low energies

Studies at CLIC380 and ILC500 included in I. Garcia thesis
(https://cds.cern.ch/record/2239794?ln=en)

- **Resolved analysis for a semileptonic tt decay** - Production near threshold (lower effective centre-of-mass due to ISR, beamstrahlung), use b-tagging, search for W, or 3 jets with a combined invariant mass near m_t

Problem on migrations (bad W-b pairing) in some angular distributions, solved using a quality cut with the consequent penalty in efficiency.





Full-simulation: low energies

Studies at CLIC380 and ILC500 included in I. Garcia thesis
(https://cds.cern.ch/record/2239794?ln=en)

- **Resolved analysis** - Production near threshold (lower effective centre-of-mass due to ISR, beamstrahlung), use b-tagging, search for W, or 3 jets with a combined invariant mass near m_t

Results for CLIC380 have been revisited for the CLICdp top paper

ILC@500GeV L=500fb^{-1} [arXiv:1505.06020]

$\mathcal{P}_{e^-}, \mathcal{P}_{e^+}$	$(\delta\sigma/\sigma)_{\text{stat.}}$ (%)	$(\delta A^t_{\text{FB}}/A^t_{\text{FB}})_{\text{stat.}}$ (%)
−0.8, +0.3	0.47	1.8
+0.8, −0.3	0.63	1.3

CLIC@380GeV L=500fb^{-1}

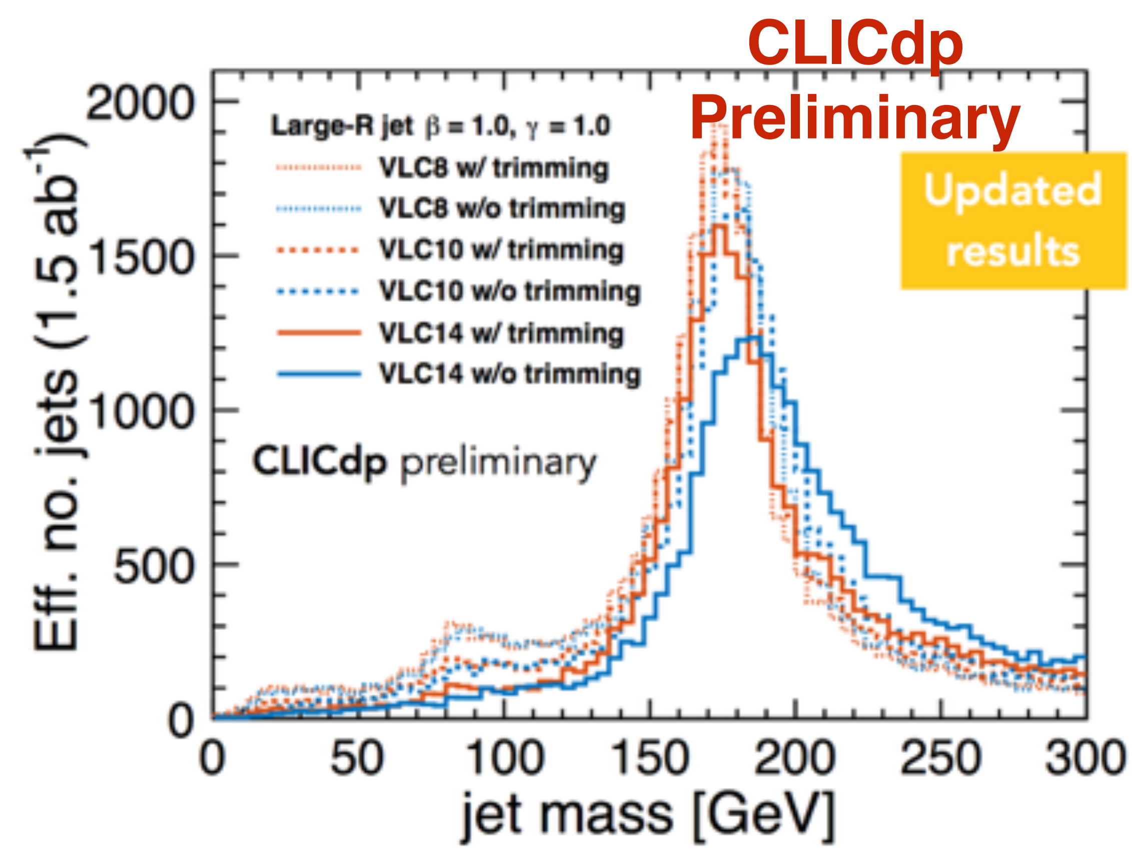
$\sqrt{s}$	380 GeV[a]	
P(e$^-$)	-80%	+80%
$\sigma_{t\bar{t}}$ [fb]	161.00	75.97
stat. unc. [fb]	1.04	0.75
A_{FB}	0.1761	0.206
stat. unc.	0.0090	0.0085

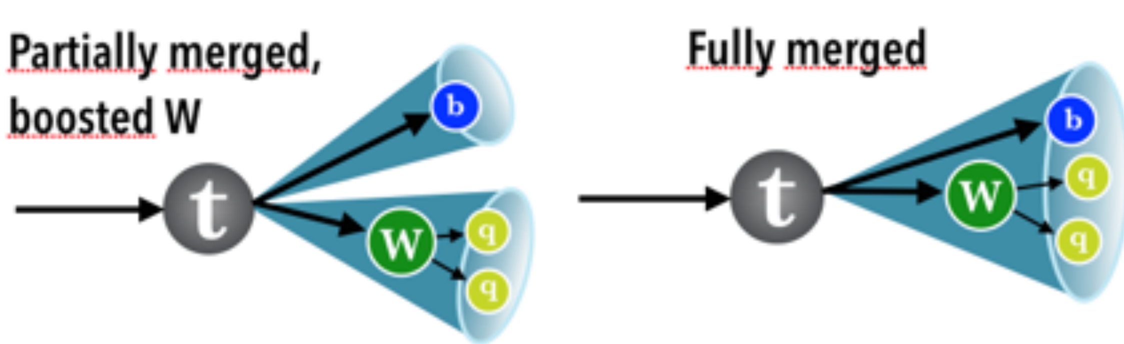
CLICdp Preliminary

Full-simulation: high energies

- Collimated decay products - Identify and correctly assign the top decay products
- **Boosted analysis -** Standard identification techniques may not work: b-tagging not foreseen, tracks are very close to each other, W decay products not isolated from each other or b-jet,
  - Idea: tag tops by identifying prongy sub-structure

Optimization in jet clustering parameters
Fully-hadronic decay mode reconstruction



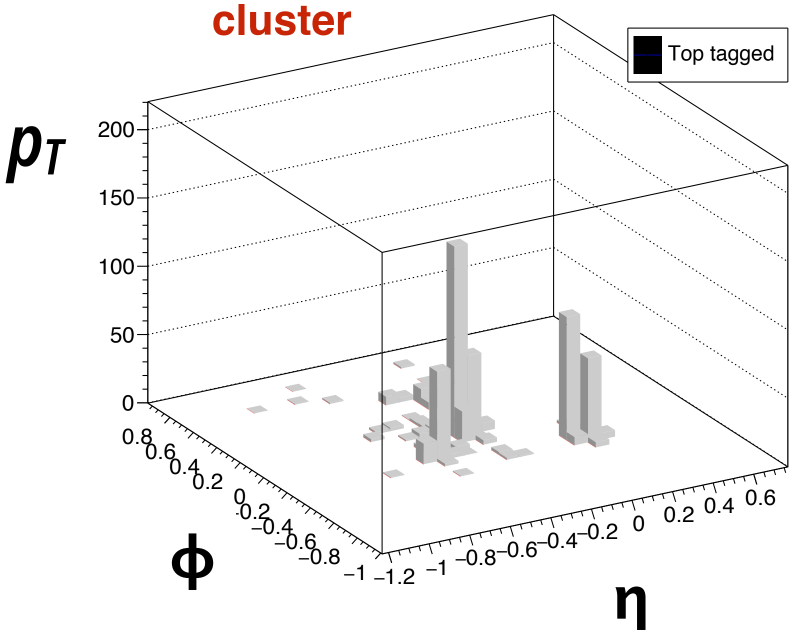


- Jet clustering (incl. trimming)
  - 2 exclusive large-R jets
- Jet tagging:
  - Parsing sub-structure
- Flavour-tagging (sub-jet, fat-jet)

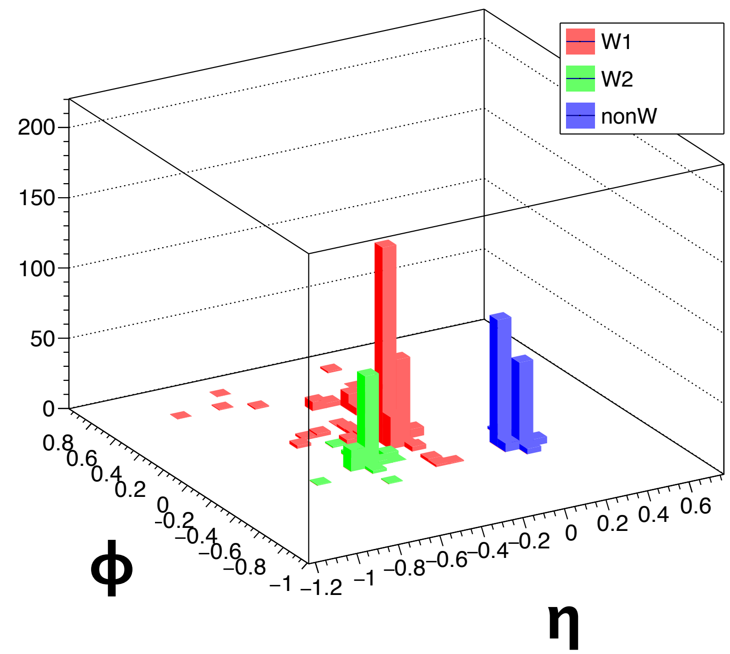
Parsing sub-structure

Jet de-clustering (FastJet extension), **DOI: 10.1103/PhysRevLett.101.142001**

Parsing through jet cluster



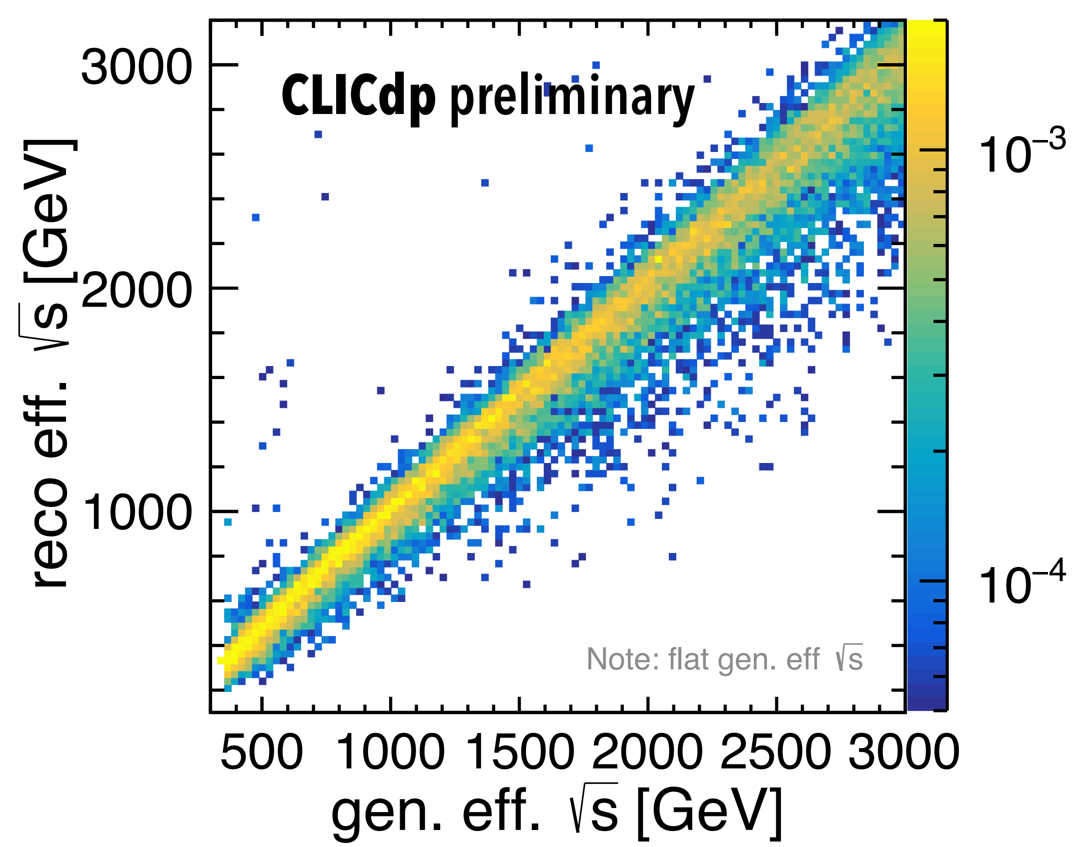
Three subjects identified



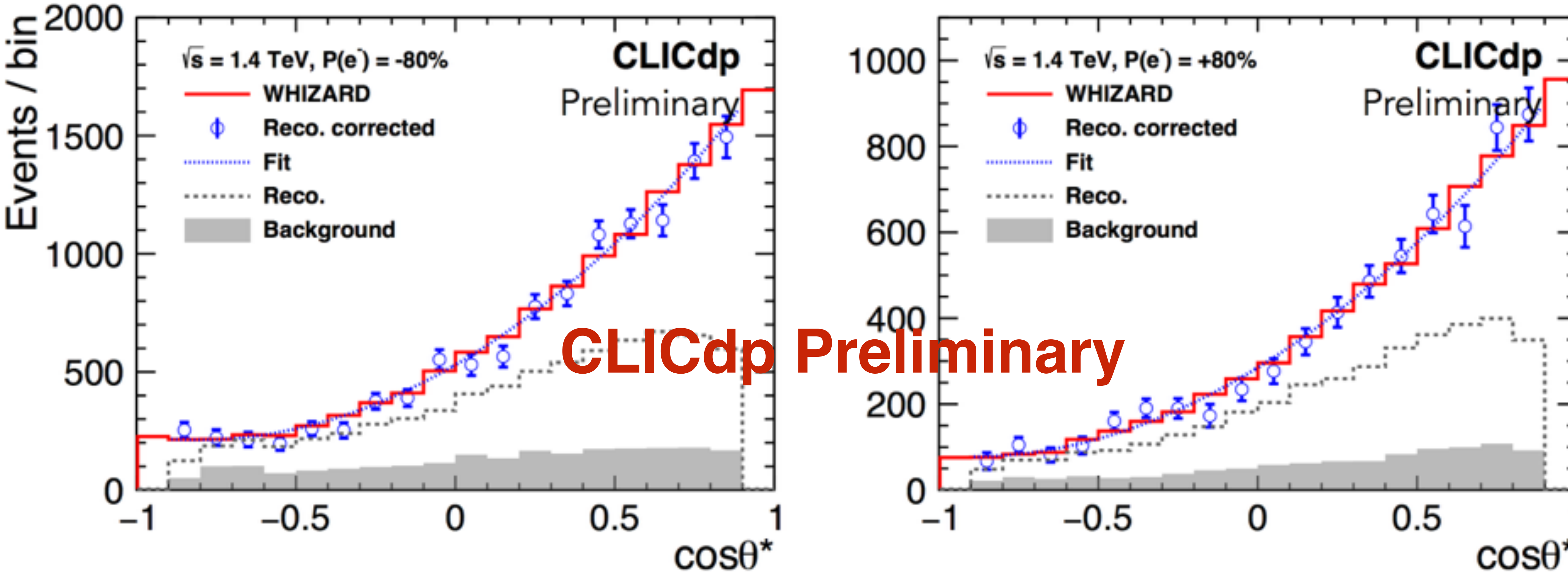
- VLC jet clustering algorithm (R=1.5, β=1, γ=1) + trimming
- "JH Top Tagger"
- kinematic cuts ($m_t \in$ [145,205] GeV, $m_W \in$ [65,95] GeV)

Event selection

- Technical cut (gen. level) in √s' (same cut can be done at reconstruction level)
- 1 isolated lepton, 1 top tagged jet ("JH Top Tagger")
- Flavour tagging (fat-jet / sub-jet) → BDT
- Exploiting kinematics of semi-leptonic side → BDT



Full-simulation: high energies



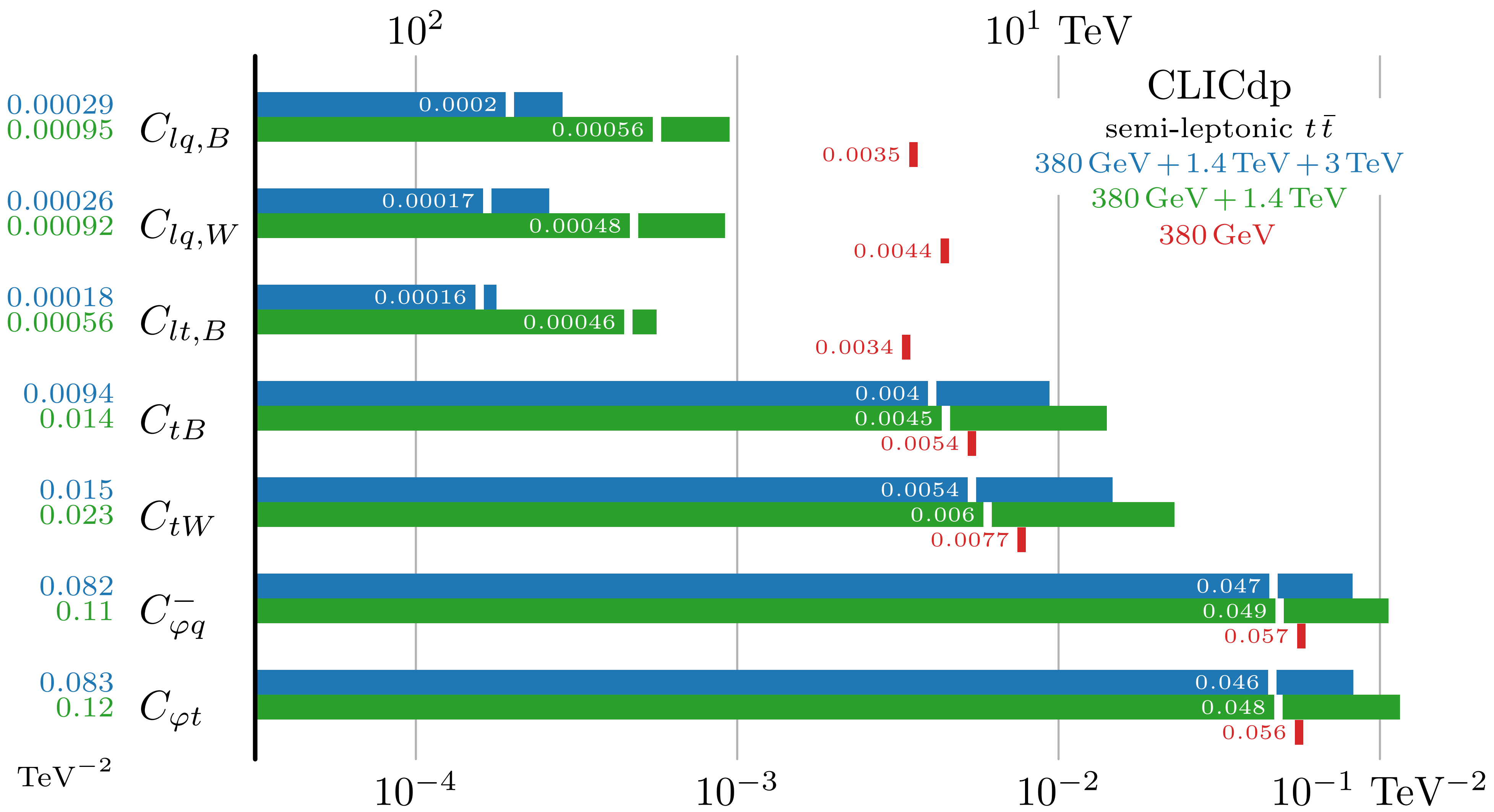
Numerical results will appear soon in the CLICdp top quark paper

Results based on CLIC

Results based on CLIC

Top-philic basis (arXiv:1802.07237)

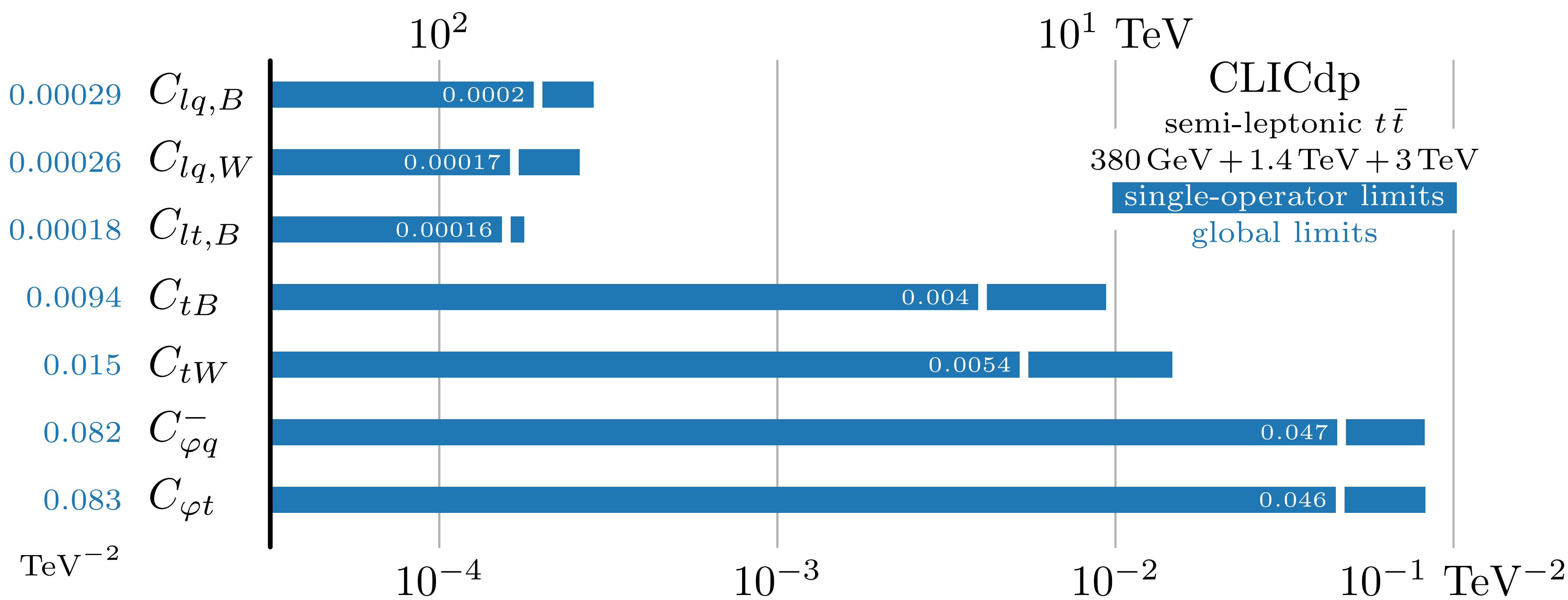
A top-philic scenario is obtained by assuming that new physics couples dominantly to the left-handed doublet and right- handed up-type quark singlet of the third generation as well as to bosons.



Results based on CLIC

Top-philic basis (arXiv:1802.07237)

A top-philic scenario is obtained by assuming that new physics couples dominantly to the left-handed doublet and right- handed up-type quark singlet of the third generation as well as to bosons.

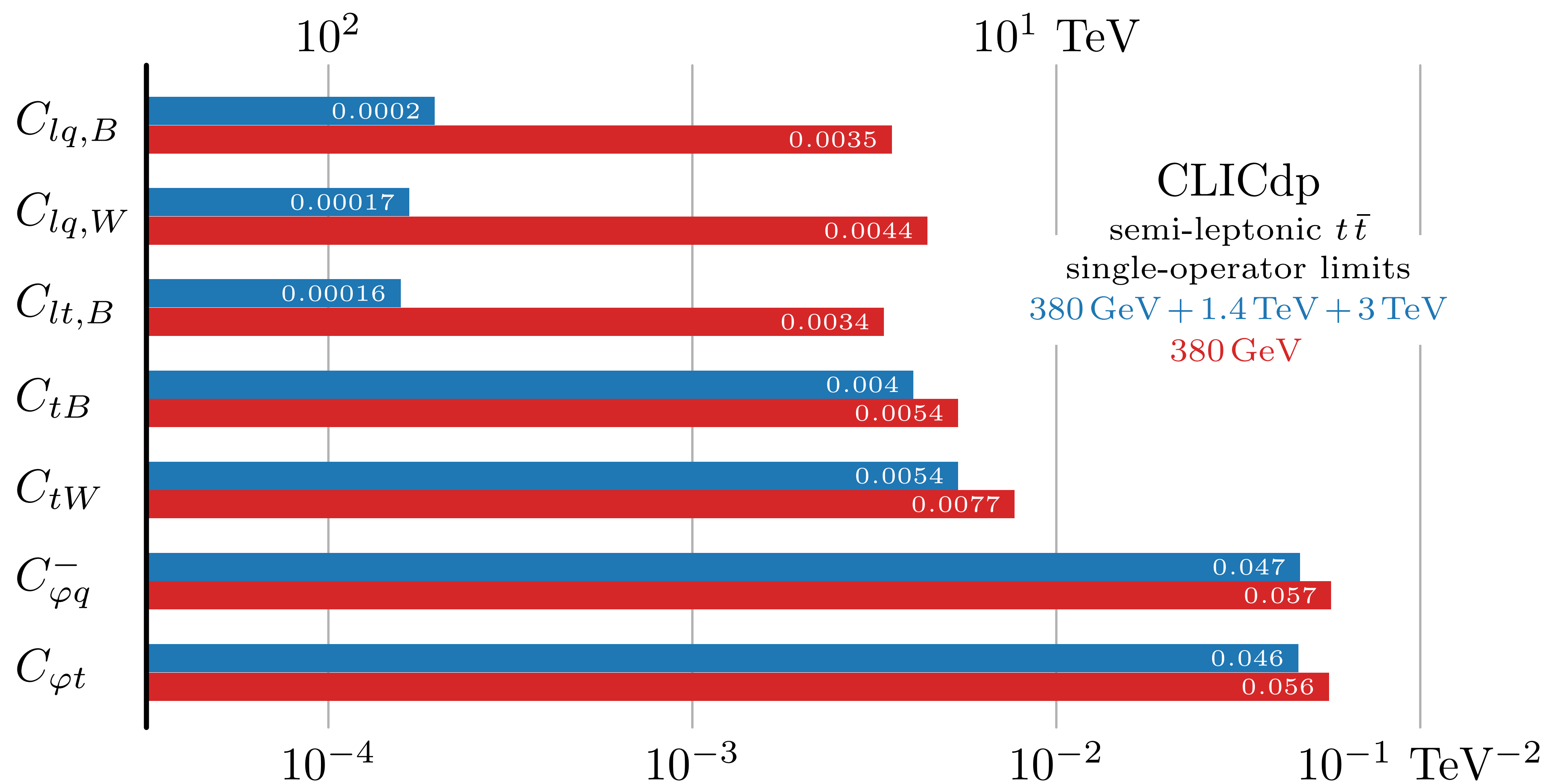


Difference between individual and marginalised limit lower than a factor 2 for 4-fermion operators and lower than a factor 4 for 2-fermion

Results based on CLIC

Top-philic basis (arXiv:1802.07237)

A top-philic scenario is obtained by assuming that new physics couples dominantly to the left-handed doublet and right- handed up-type quark singlet of the third generation as well as to bosons.



CLIC at high energy has a great potential to constrain 4-fermion operators

Conclusions

- Cross-section + A_{FB} are not enough for global EFT fit.
- CP-odd operators well constrained by CP-odd optimal observables.
- Optimal observables seem to be the proper solution to the global fit.
- Results on the global fit ready for the CLICdp top quark paper.
- Preparing pheno paper including ILC scenario.

Back up

Some technical numbers at reconstruction
https://cds.cern.ch/record/2239794?ln=en

CLIC380 (Repository https://twiki.cern.ch/twiki/bin/view/CLIC/MonteCarloSamplesForTopPhysics)

- Jet clustering: VLC algorithm (R=1.6, β = 0.8, γ = 0.8).

ILC500

- Jet clustering: VLC algorithm (R=1.2, β = 0.8, γ = 0.8).

Collider	**ILC**	**CLIC**
Sample	$e^+e^- \to l^\pm \nu b\bar{b}q'\bar{q}$	$e^+e^- \to 6f(t\bar{t}$ compatible)
$\sqrt{s}$ [GeV]	500	380
Luminosity [fb^{-1}]	500	500
$P(e^-), P(e^+)$	$\mp 1, \pm 1$	$\mp 0.8, 0$
Detector model	ILD_o1_v05 [54]	CLIC_ILD_CDR [53]
Number of BX	1	300
Background	1.7 $\gamma\gamma \to$ hadrons / BX	0.0464 $\gamma\gamma \to$ hadrons / BX

[53] L. Linssen, A. Miyamoto, M. Stanitzki and H. Weerts, Physics and Detectors at CLIC: CLIC Conceptual Design Report, 1202.5940.
[54] H. Abramowicz et al., The International Linear Collider Technical Design Report - Volume 4: Detectors, 1306.6329.

CPV: Optimal CP-odd observables

The **CP-violating effects** in e+e− → tt̄ manifest themselves in specific **top-spin effects**, namely **CP-odd top spin-momentum correlations and tt̄ spin correlations**.

$$e^+(\mathbf{p}_+, P_{e^+}) + e^-(\mathbf{p}_-, P_{e^-}) \quad \rightarrow \quad t(\mathbf{k}_t) + \bar{t}(\mathbf{k}_{\bar{t}})$$

$$\begin{aligned} t\ \bar{t} &\rightarrow \ell^+(\mathbf{q}_+) + \nu_\ell + b + \overline{X}_{\text{had}}(\mathbf{q}_{\bar{X}}) \\ t\ \bar{t} &\rightarrow X_{\text{had}}(\mathbf{q}_X) + \ell^-(\mathbf{q}_-) + \bar{\nu}_\ell + \bar{b} \end{aligned}$$

- **CP-odd observables** are defined with the **four momenta available in tt semi-leptonic decay channel**

$$\begin{aligned} \mathcal{O}_+^{Re} &= (\hat{\mathbf{q}}_{\bar{X}} \times \hat{\mathbf{q}}_+^*) \cdot \hat{\mathbf{p}}_+ \,, \\ \mathcal{O}_+^{Im} &= -[1 + (\frac{\sqrt{s}}{2m_t} - 1)(\hat{\mathbf{q}}_{\bar{X}} \cdot \hat{\mathbf{p}}_+)^2]\hat{\mathbf{q}}_+^* \cdot \hat{\mathbf{q}}_{\bar{X}} + \frac{\sqrt{s}}{2m_t}\hat{\mathbf{q}}_{\bar{X}} \cdot \hat{\mathbf{p}}_+ \hat{\mathbf{q}}_+^* \cdot \hat{\mathbf{p}}_+ \end{aligned}$$

- The way to **extract** the **CP-violating form factor** is to construct **asymmetries sensitive to CP-violation effects**

$$\mathcal{A}^{Re} = \langle \mathcal{O}_+^{Re} \rangle - \langle \mathcal{O}_-^{Re} \rangle = \boxed{c_\gamma(s)} \mathrm{Re}F_{2A}^\gamma + \boxed{c_Z(s)} \mathrm{Re}F_{2A}^Z$$

$$\mathcal{A}^{Im} = \langle \mathcal{O}_+^{Im} \rangle - \langle \mathcal{O}_-^{Im} \rangle = \boxed{\tilde{c}_\gamma(s)} \mathrm{Im}F_{2A}^\gamma + \boxed{\tilde{c}_Z(s)} \mathrm{Im}F_{2A}^Z$$

$$\boxed{\begin{array}{cc} {\mathcal{A}^{Re}_{\gamma,Z}}^{\mathrm{L}} & {\mathcal{A}^{Re}_{\gamma,Z}}^{\mathrm{L}} \\ {\mathcal{A}^{Im}_{\gamma,Z}}^{\mathrm{R}} & {\mathcal{A}^{Im}_{\gamma,Z}}^{\mathrm{R}} \end{array}}$$

CPV: Coefficients vs sqrt(s)

The sensitivity of A_{Re}/A_{Im} to F_{2A} increases strongly with the c.o.m. energy

$$P_{e^-} = -1\ ,\ P_{e^+} = +1$$

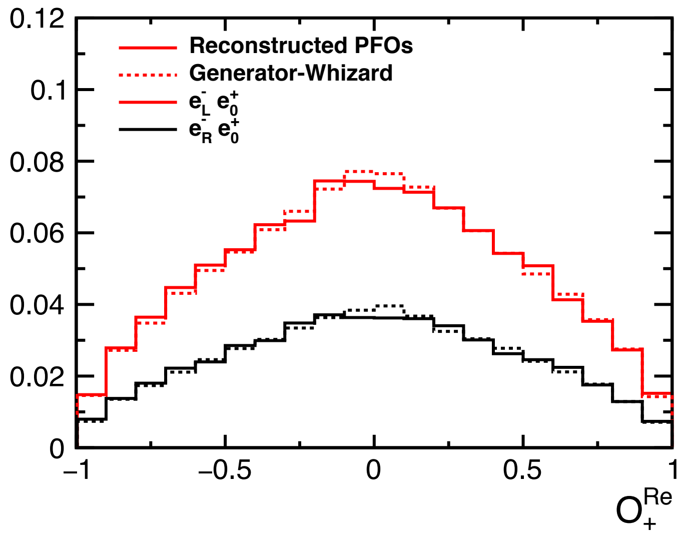
c.m. energy $\sqrt{s}$ [GeV]	$c_\gamma(s)$	$c_Z(s)$	$\tilde{c}_\gamma(s)$	$\tilde{c}_Z(s)$
380	0.245	0.173	0.232	0.164
500	0.607	0.418	0.512	0.352
1000	1.714	1.151	1.464	0.983
1400	2.514	1.681	2.528	1.691
3000	5.589	3.725	10.190	6.791

$$P_{e^-} = +1,\ P_{e^+} = -1$$

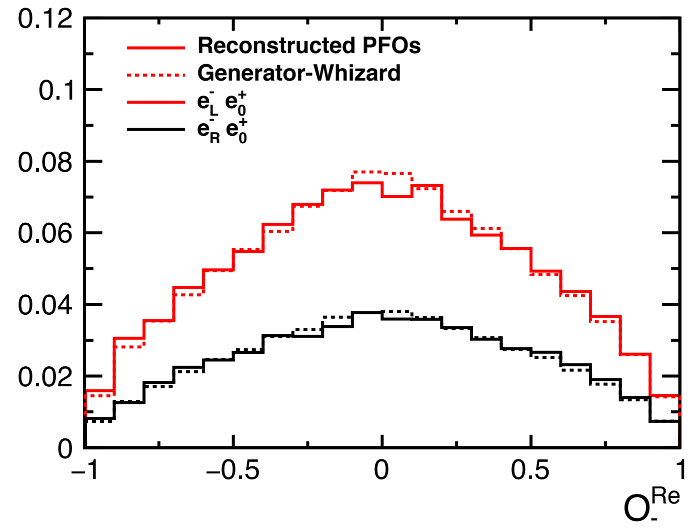
c.m. energy $\sqrt{s}$ [GeV]	$c_\gamma(s)$	$c_Z(s)$	$\tilde{c}_\gamma(s)$	$\tilde{c}_Z(s)$
380	-0.381	0.217	0.362	-0.206
500	-0.903	0.500	0.761	-0.422
1000	-2.437	1.316	2.081	-1.124
1400	-3.549	1.909	3.569	-1.920
3000	-7.845	4.205	14.302	-7.667

Thanks to Bernreuther

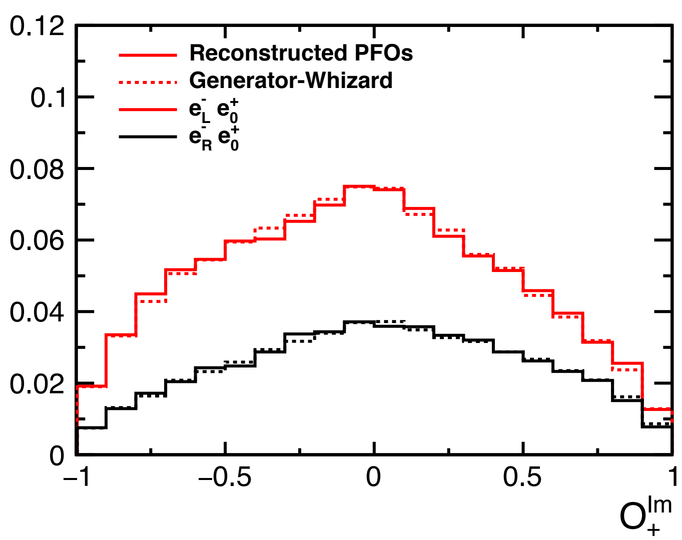
CPV: Full-simulation: CLIC@380GeV



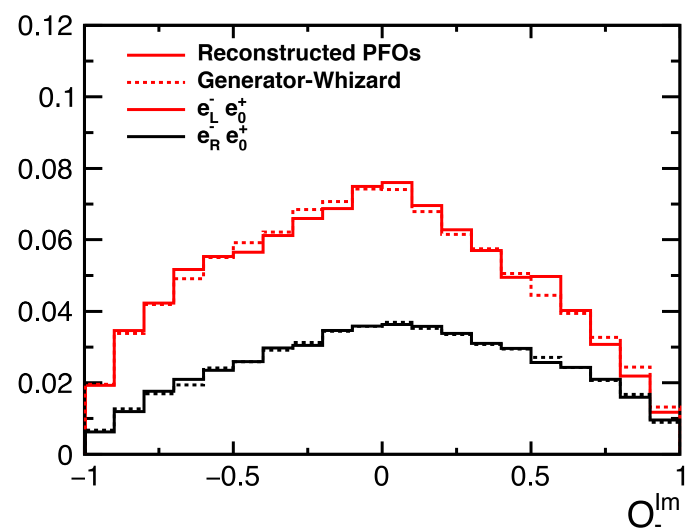
(a) $\mathcal{O}^{Re}_+$



(b) $\mathcal{O}^{Re}_-$



(c) $\mathcal{O}^{Im}_+$



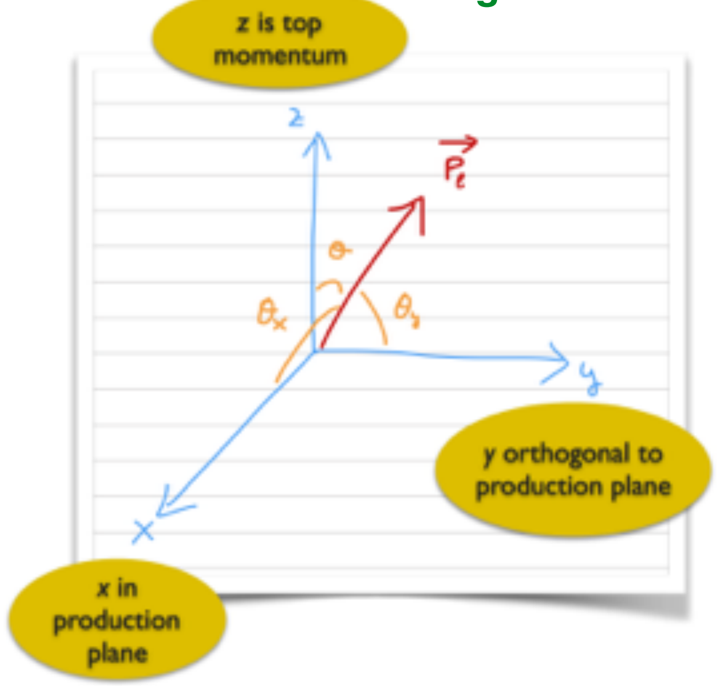
(d) $\mathcal{O}^{Im}_-$

polarization	e_L^- ($P_{e^-} = -0.8$)	e_R^- ($P_{e^-} = +0.8$)
$\mathcal{A}^{Re}$	-0.00006 $\pm$ 0.003	0.0072 $\pm$ 0.003
$\mathcal{A}^{Im}$	0.0004 $\pm$ 0.003	-0.0019 $\pm$ 0.003

- Distributions are **centered at zero**
- **Differences** between reconstructed and generated events are **very small**.
- Any **distortions** in the reconstructed distributions are **expected to cancel in the asymmetries** A_{Re} and A_{Im}
- **Asymmetries** are **compatible with zero** within the statistical error

Top quark polarization at different axes

J. A. Aguilar-Saavedra and J. Bernabeu. [arXiv:1005.5382].



$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta} = \frac{1}{2}(1+\alpha P_3\cos\theta)$$

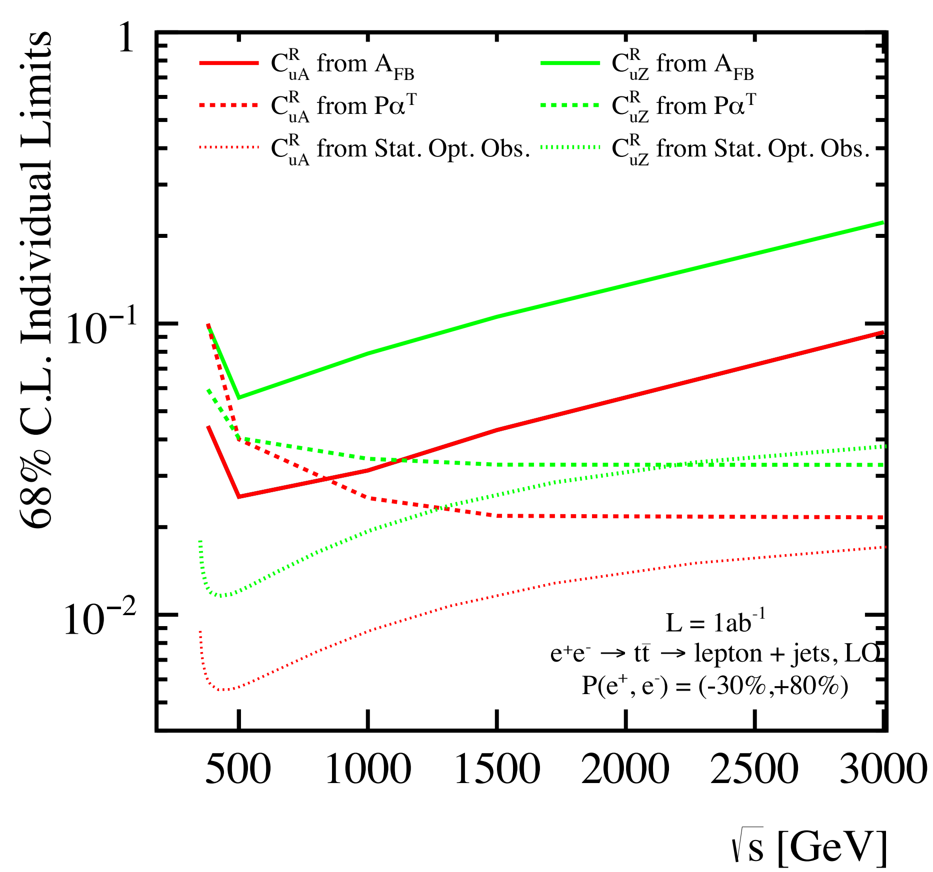
$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta_x} = \frac{1}{2}(1+\alpha P_1\cos\theta_x)$$

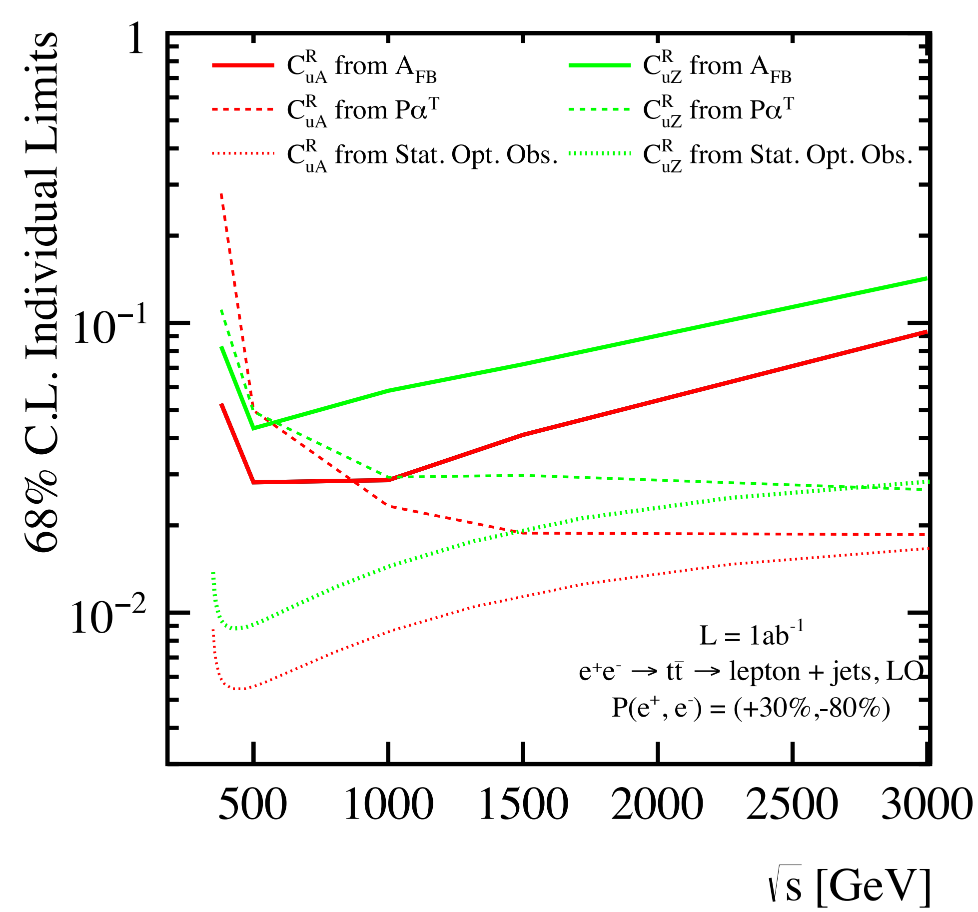
$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta_y} = \frac{1}{2}(1+\alpha P_2\cos\theta_y)$$

Studied process

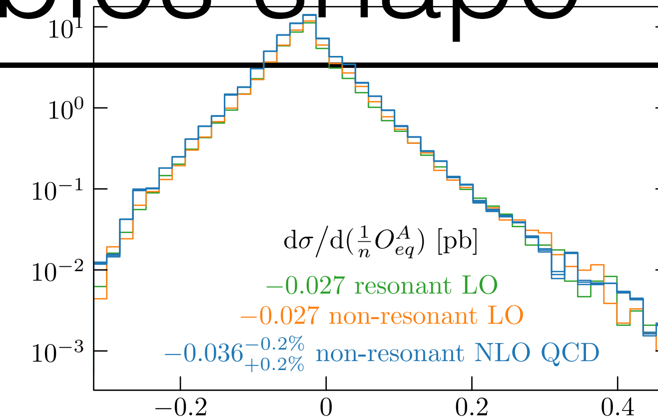
$$e^-e^+ \to t\bar{t} \to W^+bW^-\bar{b} \to l\nu b\bar{b}q\bar{q}$$

Top polarization in the transverse axis *(perpendicular to the top flight direction in the production plane)* provides good sensitivity to the real part of dipoles operators (CuA and CuZ).





Statistically optimal observables shape



Example for 500 GeV (e-, e+) = (-0.8, 0.3)

Theory uncertainties under study

Generated plots