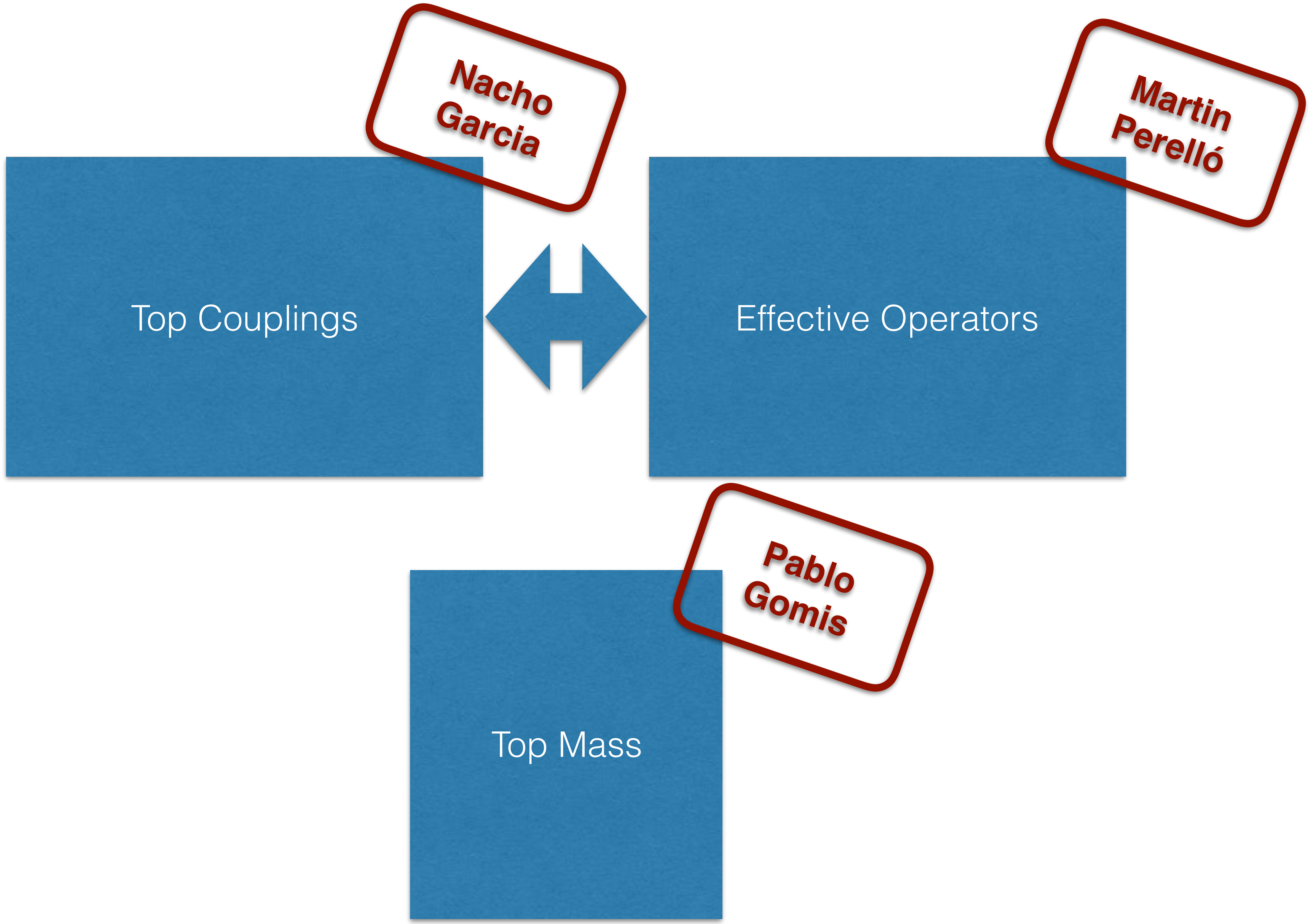
ILD ANALYSIS & SOFTWARE MEETING - 24TH MAY

TOP ANALYSIS ACTIVITIES @ IFIC-VALENCIA

M. BORONAT*, E. FULLANA*, J. FUSTER*, I. GARCÍA*, P. GOMIS*, M. PERELLÓ*, E. ROS*, M. A. VILLAREJO*, M. VOS*

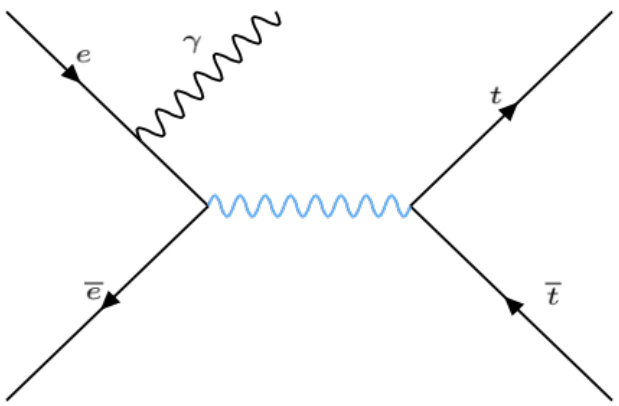

Nacho
Garcia
Martin
Perelló
Top Couplings
Effective Operators
Pablo
Gomis
Top Mass

Pablo Gomis

Top Mass

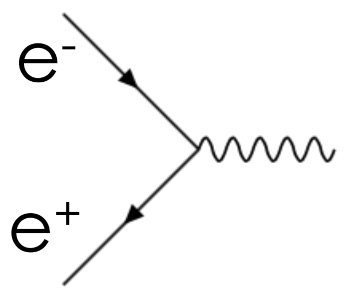
INTRODUCTION TO THE OBSERVABLE: ISR

- The idea is to measure the top-quark mass (m_t) measuring the differential cross section of the process $e^-e^+ \rightarrow$ ttbar γ_{ISR}



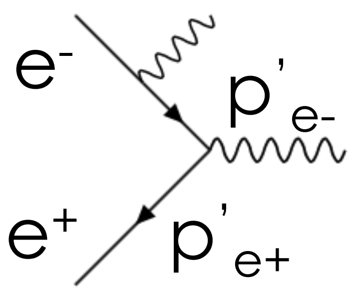
- The ttbar production cross section is sensitive to the center of mass energy and m_t

$$\sigma(e^+e^- \rightarrow t\bar{t}) = f(s, m_t)$$



$$s = (p_{e^-} + p_{e^+})^2$$

$$\sigma(e^+e^- \rightarrow t\bar{t}\gamma) = f(s', m_t)$$



$$s' = (p'_{e^-} + p'_{e^+})^2$$

- The emitted γ_{ISR} reduce the available energy for the ttbar production

- Therefore the ttbar production cross section is sensible to the emitted ISR photon energy in the ttbar + γ_{ISR} production

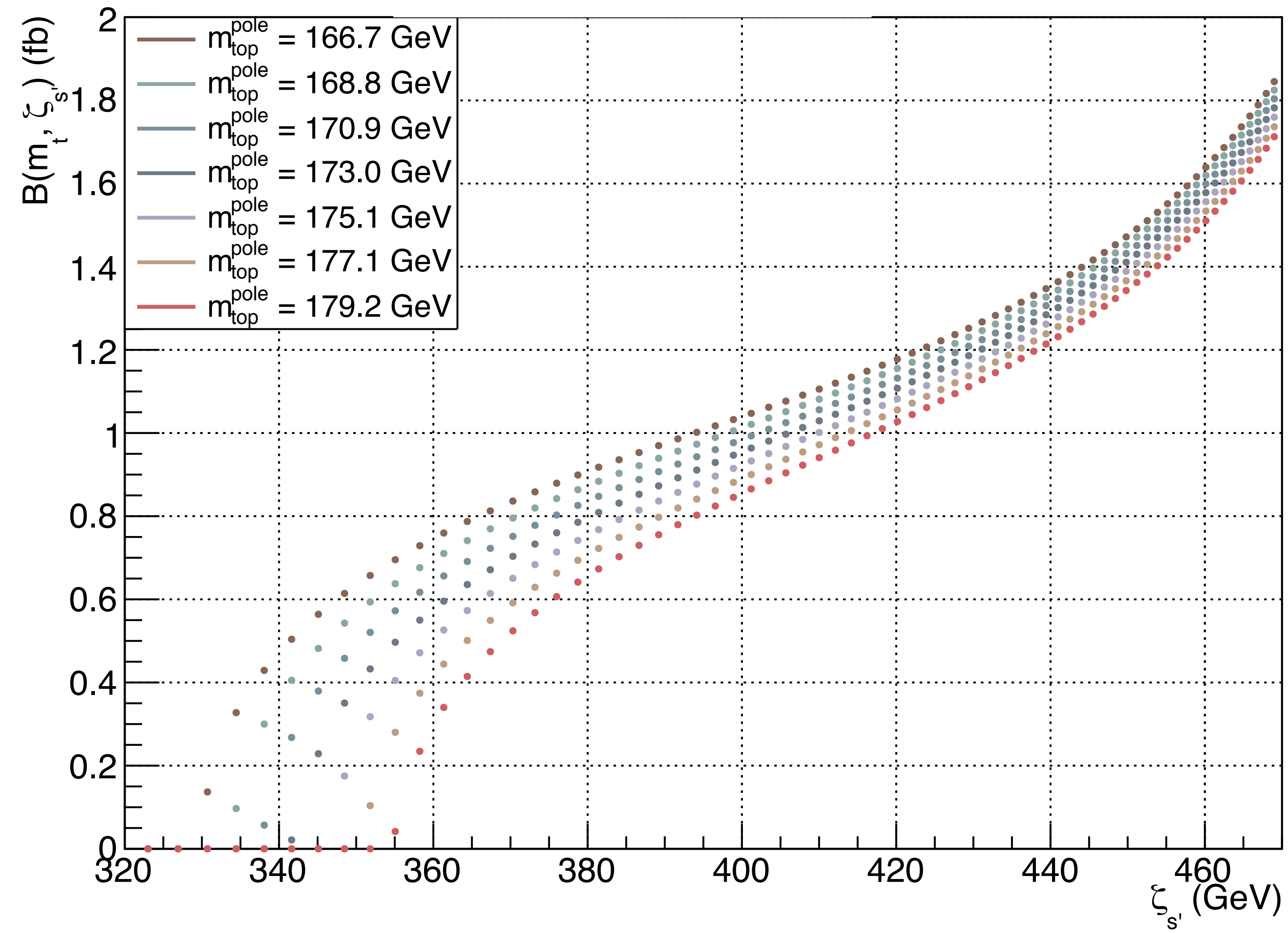
INTRODUCTION TO THE OBSERVABLE: ISR (II)

- m_t can be measured by counting the ttbar events produced for a certain s′ (i.e ISR energy photon, which can be measured with high precision)

- Our observable $B(m_t, \zeta_{s'})$ is the differential cross section of the ttbar production as a function of $\zeta_{s'} = \sqrt{s'}$

$$B(m_t, \zeta_{s'}) = \frac{d\sigma_{t\bar{t}\gamma}}{d\zeta_{s'}} \longrightarrow \zeta_{s'} = \sqrt{s'}$$

$$s' = s\left(1 - \frac{2E_\gamma}{\sqrt{s}}\right)$$



- The observable is more sensitive to m_t near the top production threshold, and the dependence diminishes as $\zeta_{s'}$ grows

PARTON LEVEL STUDY: RESULTS

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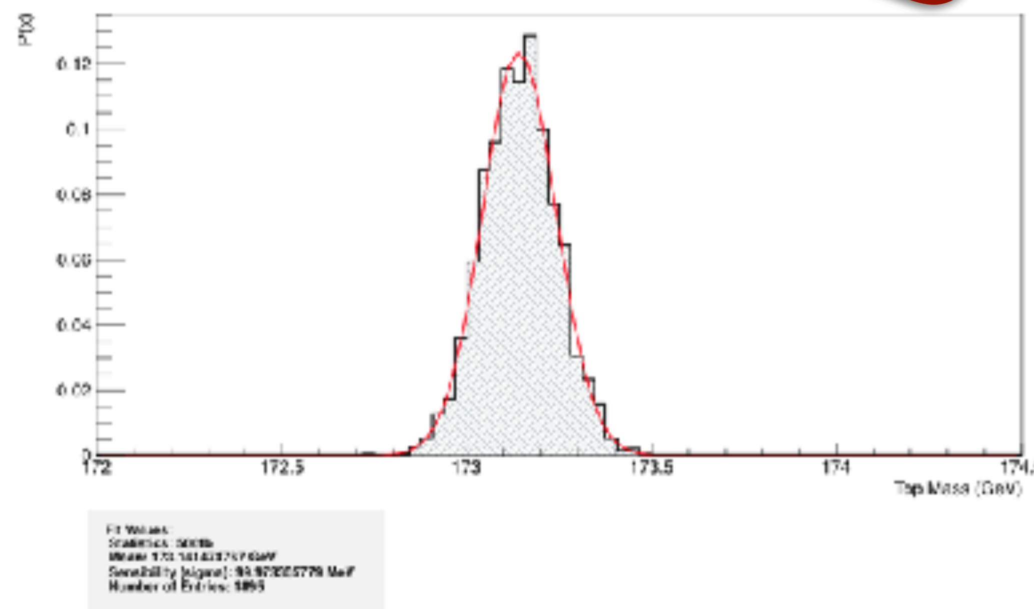
- From these template fits the top quark mass is estimated as the mean of the distribution and its error as the standard deviation
- The input MC mass is m_t = 173.1 GeV



s = 500 GeV	Reconstructed mass	
Integrated Luminosity	m_t (GeV)	Δm_t (MeV)
500 fb^{-1}	173.158	155
1000 fb^{-1}	173.140	103
2600 fb^{-1}	173.133	61

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Gomis

FULL SIMULATION STUDY: OUTLINE

NEXT STEPS

- **Take into account the uncertainty of the luminosity spectrum to properly evaluate the systematics due to the luminosity smearing**
  - I am currently doing it for 380GeV but we plan to include ILC configurations as well
- **Improvements in the theoretical model:**
  - Currently one model valid at the peak, one model valid at the tail
    - We need the proper overlap between the models

Martin Perelló

Effective Operators

Introduction

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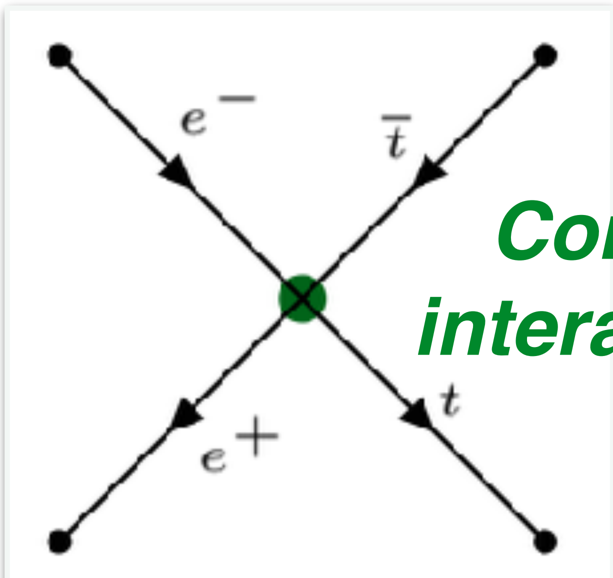
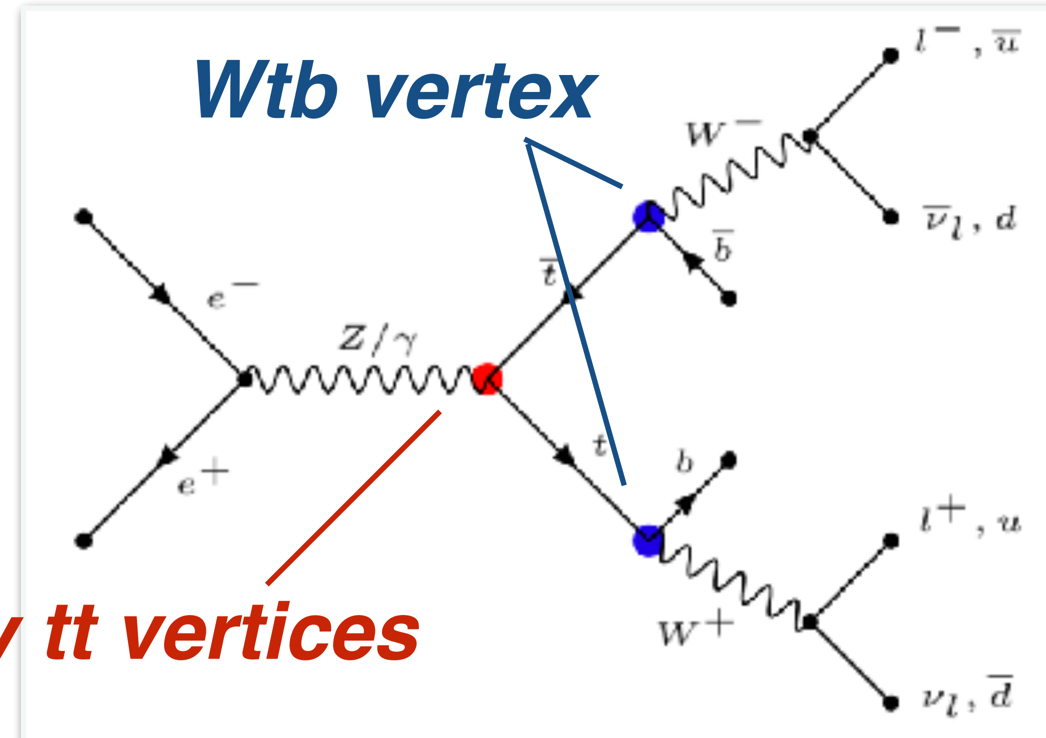
Effective Field Theory

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

dim-6 operators



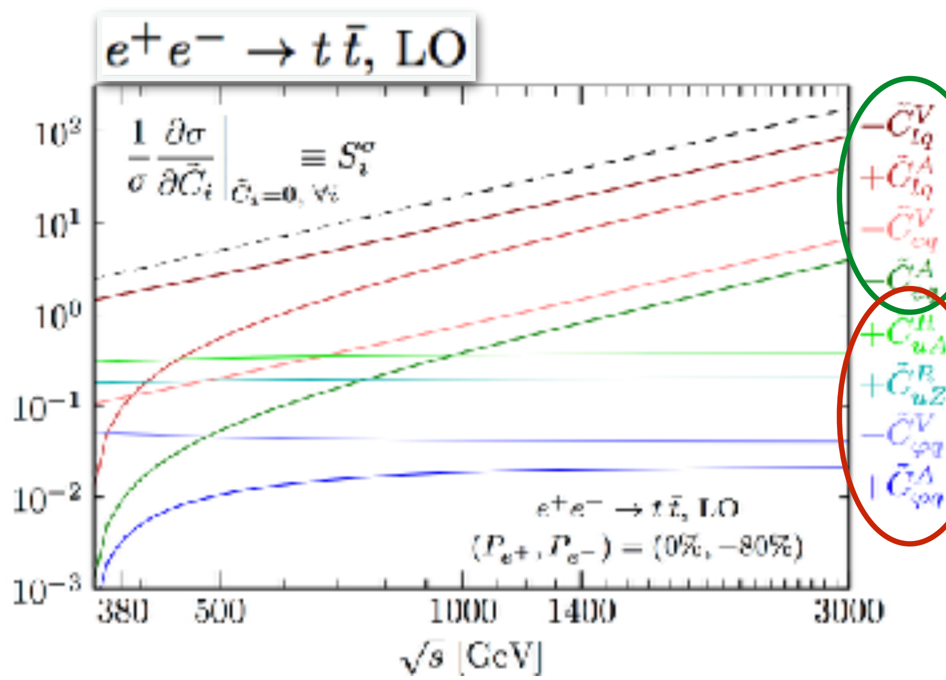
Contact interactions



Wtb vertex

Z/γ tt vertices

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



"contact-interactions" operators

"Z/g tt vertex" operators

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

Global fit

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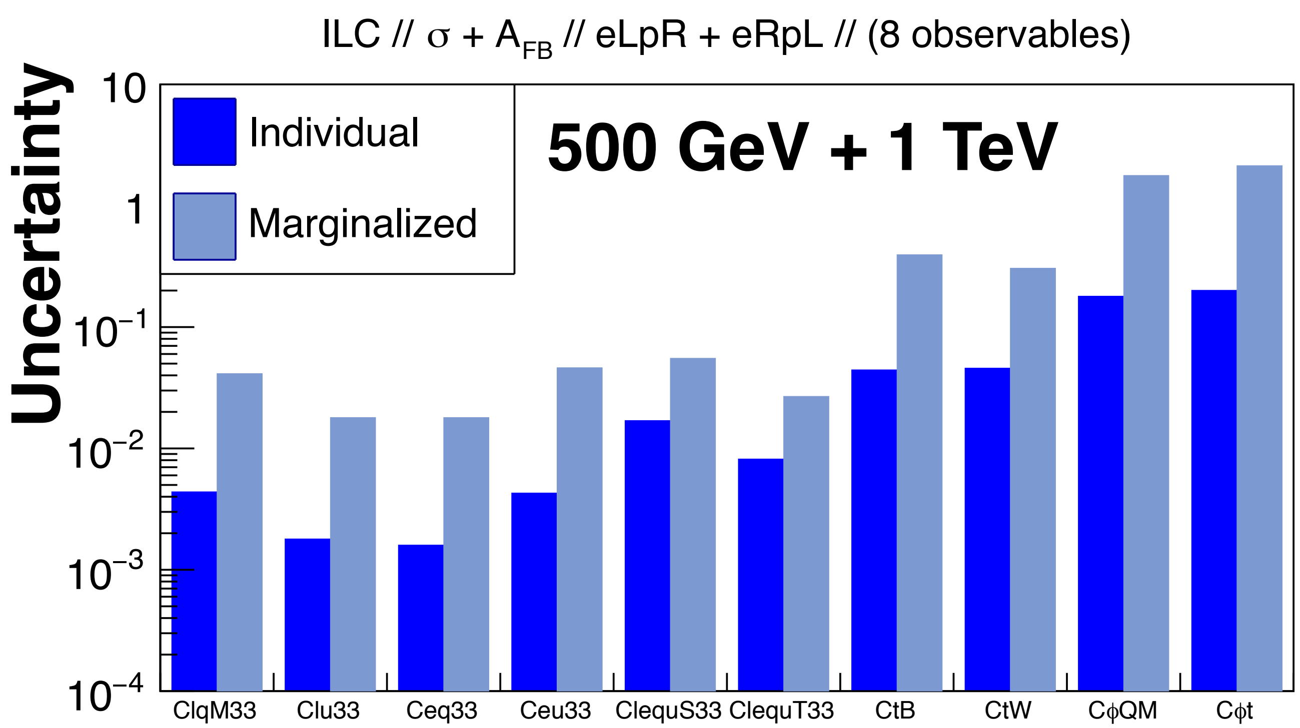
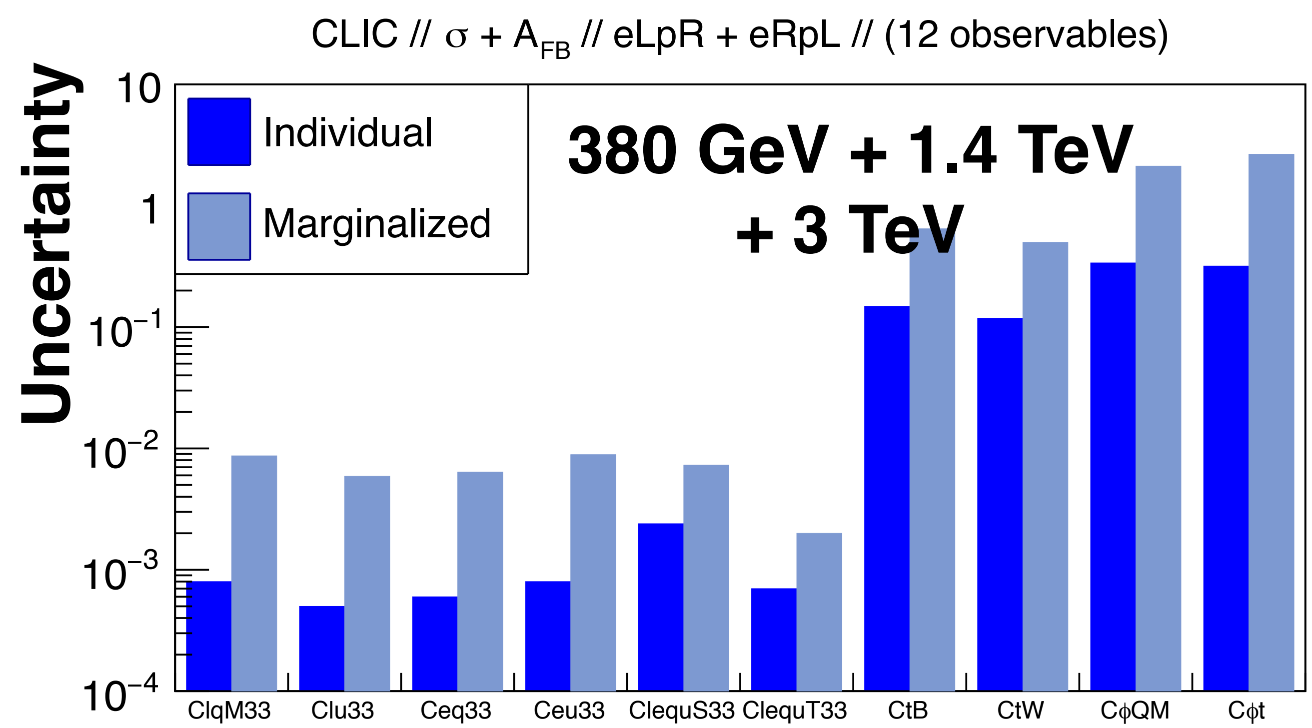
Central fit: **Afb** + **total cross-section** for the process $e^+e^- \to t\,\bar{t}$
2 different beam polarizations in a **realistic energy program**.

ILC $e^+e^- \to t\,\bar{t}$, LO **CLIC**





Collaboration with Gauthier Durieux (DESY) and Cen Zhang (BNL) - to be published

External inputs (now in progress)

Martin Perelló

- **CPV observables** for the electric and weak dipoles, **Im{CtW}** and **Im{CtB}**.

See next section ->

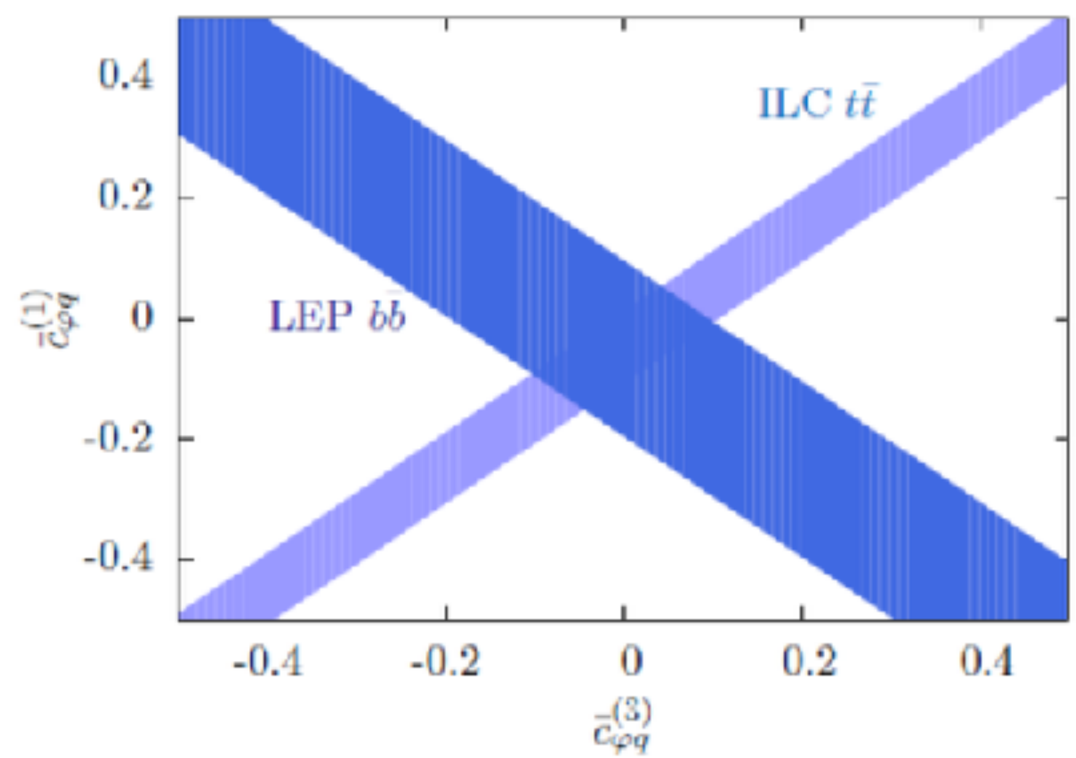
- **Complementarity bottom-top.**

Good for CphiQ(1) and CphiQ(3).

Single top production may help.

Extending the fit to the bottom sector can provide the additional constraint we need (but also adds further operators)

ArXiv:1704.01782

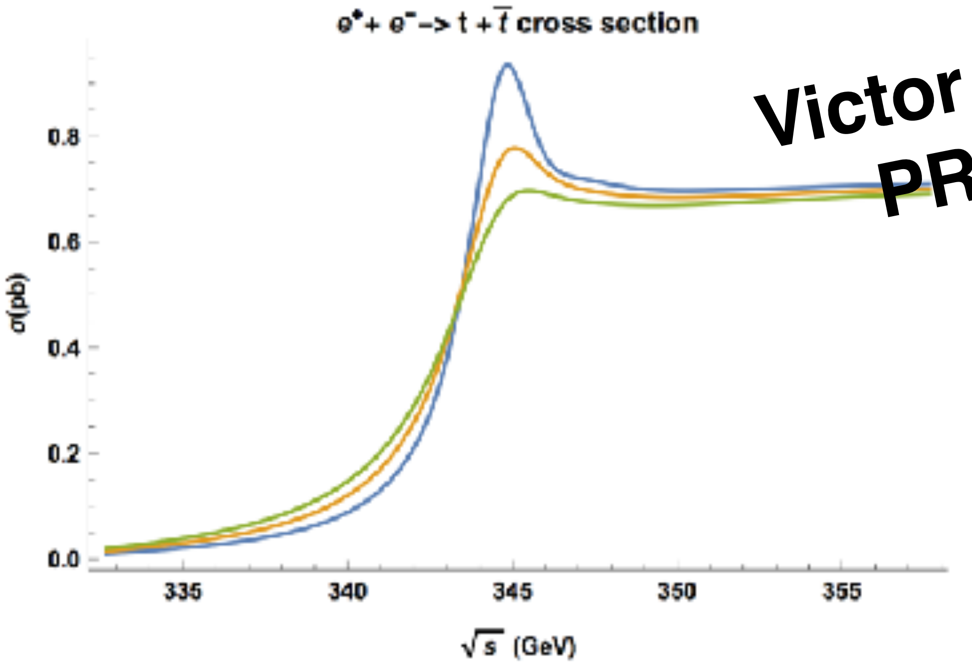


External inputs (now in progress)

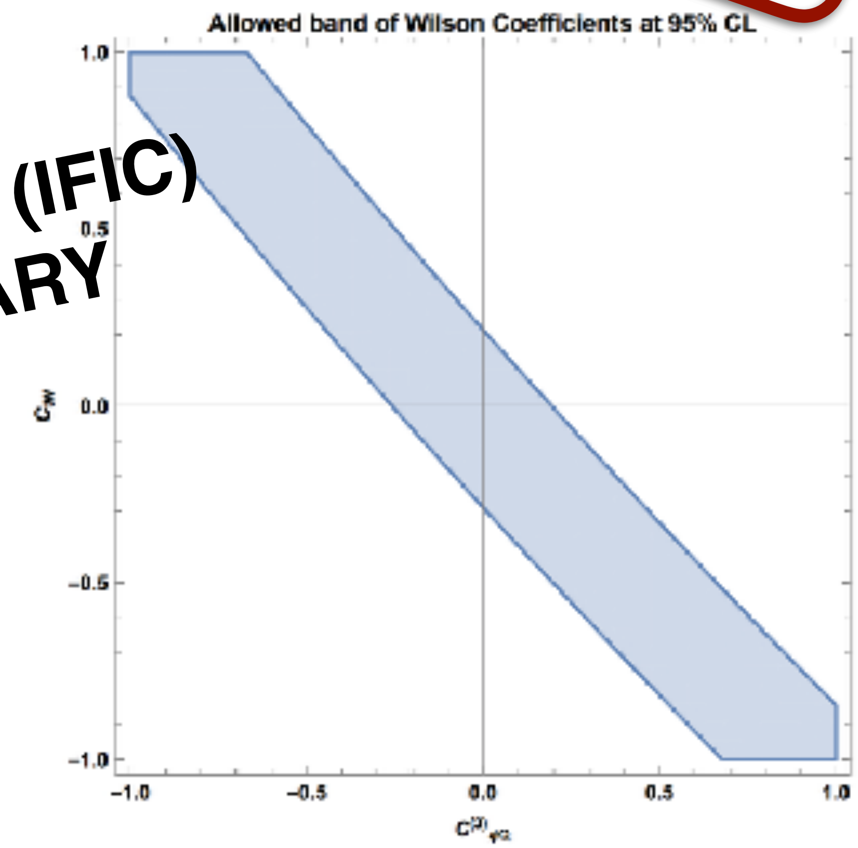
Martin Perelló

- **Top decay width** for **Re{CtW}** and **CphiQ(3)**.

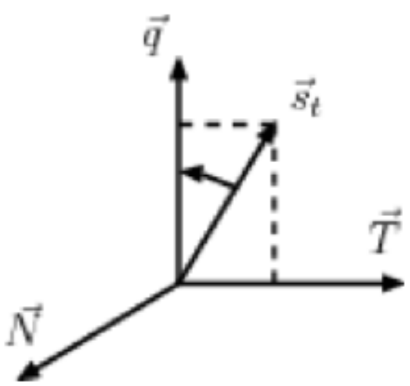
Good measurement at tt~ production threshold



Victor Miralles (IFIC)
PRELIMINARY



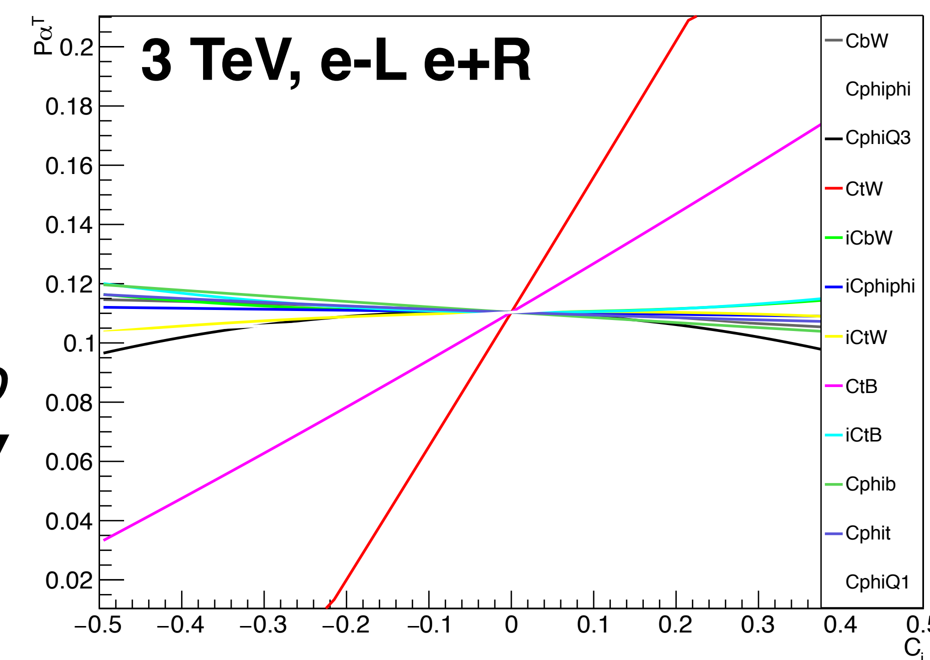
- **Top quark polarization at different axes**.



$$\vec{N} = \vec{s}_t \times \vec{q}$$
$$\vec{T} = \vec{q} \times \vec{N}.$$

$$\frac{1}{\Gamma}\frac{d\Gamma}{dcos\theta_{hel}} = \frac{1+\lambda_t cos\theta_{hel}}{2} = \frac{1}{2} + (2F_R - 1)\frac{cos\theta_{hel}}{2}$$

*In particular, the transverse axis helps to constrain **CtB** and **CtW** due to a higher sensitivity*



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Top Couplings

Top quark electroweak couplings

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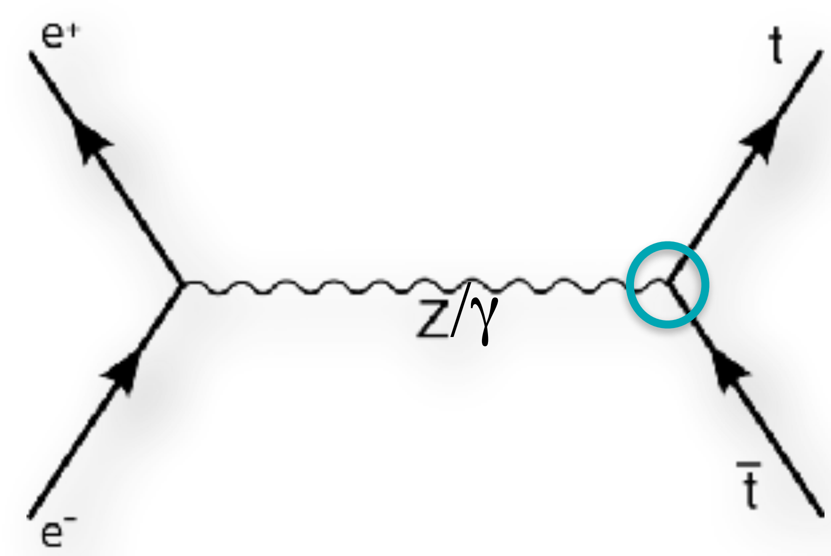
- **New physics** can **modify the electro-weak $t\bar{t}X$ vertex** described in the SM
- **e^+e^- colliders** allow to probe these vertices directly. The **leading-order** process $e^+e^- \rightarrow t\bar{t}$ goes directly through the **$t\bar{t}Z$ and $t\bar{t}\gamma$ vertices**



- ➡ *X = Z, γ*
- ➡ *V = Vector coupling*
- ➡ *A = Axial coupling*

- A **parametrisation of the $t\bar{t}X$ vertex** for on-shell t and t and off-shell γ, Z is:

$$\Gamma_{\mu}^{ttX}(k^2) = -ie\left\{\gamma_\mu\left(F_{1V}^{X}(k^2) + \gamma_5 F_{1A}^{X}(k^2)\right) + \frac{\sigma_{\mu\nu}}{2m_t}k^\nu\left(iF_{2V}^{X}(k^2) + \gamma_5 F_{2A}^{X}(k^2)\right)\right\}$$

Eur. Phys. J. C (2015) 75:512
DOI 10.1140/epjc/s10052-015-3746-5

CP-conserving couplings — **CP-violating couplings**

Optimal CP-odd observables

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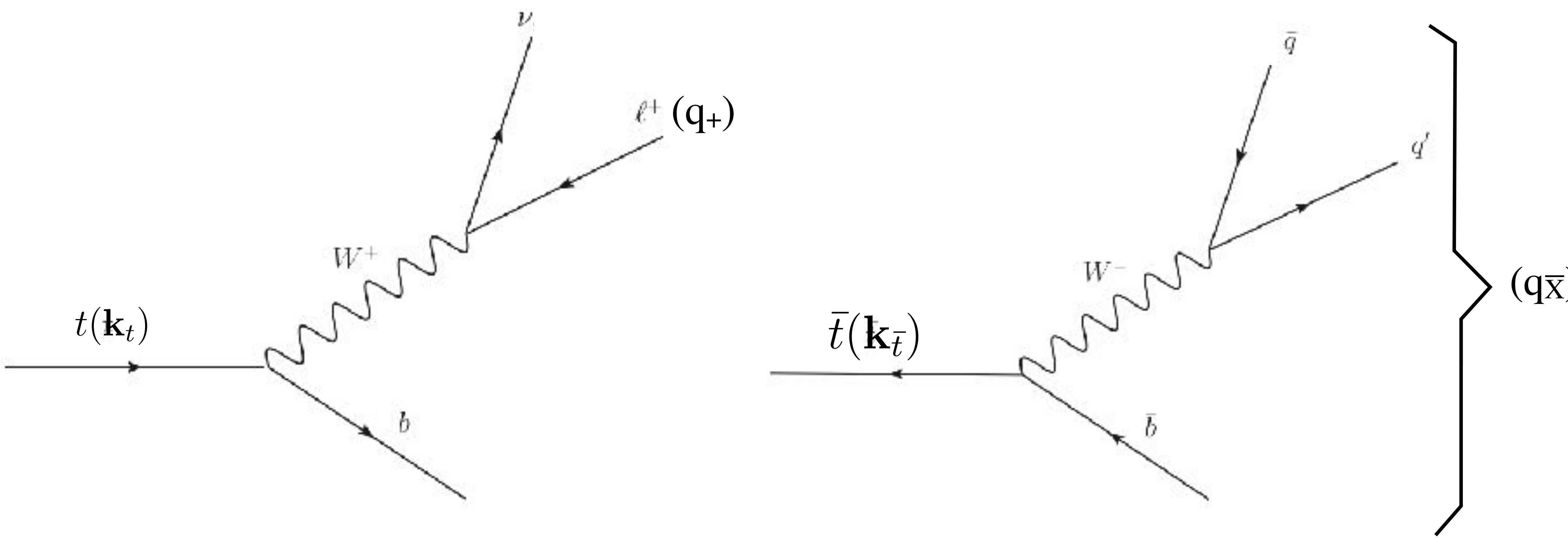
$$e^+(\mathbf{p}_+, P_{e^+}) + e^-(\mathbf{p}_-, P_{e^-}) \quad \rightarrow \quad t(\mathbf{k}_t) + \bar{t}(\mathbf{k}_{\bar{t}})$$

The **CP-violating effects** in e+e− → $t\bar{t}$ manifest themselves in specific **top-spin effects**, namely **CP-odd top spin-momentum correlations and $t\bar{t}$ spin correlations**.

$$t\ \bar{t} \quad \rightarrow \quad \ell^+(\mathbf{q}_+) + \nu_\ell + b + \overline{X}_{\rm had}(\mathbf{q}_{\bar{X}})$$

$$t\ \bar{t} \quad \rightarrow \quad X_{\rm had}(\mathbf{q}_X) + \ell^-(\mathbf{q}_-) + \bar{\nu}_\ell + \bar{b}$$



Lepton+jets final state
The **charged lepton** is the **best analyzer** of the **top spin**

Optimal CP-odd observables

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

$$\mathcal{O}_{+}^{Re} = (\hat{\mathbf{q}}_{\bar{X}} \times \hat{\mathbf{q}}_{+}^{*}) \cdot \hat{\mathbf{p}}_{+} \,,$$

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

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

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

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

$${\mathcal{A}_{\gamma,Z}^{Re}}^{\mathrm{L}} \quad {\mathcal{A}_{\gamma,Z}^{Re}}^{\mathrm{L}}$$

$${\mathcal{A}_{\gamma,Z}^{Im}}^{\mathrm{R}} \quad {\mathcal{A}_{\gamma,Z}^{Im}}^{\mathrm{R}}$$

Simulation samples (6f -> lepton+jets)

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Full simulation

ILC@500GeV

500fb^{-1}, P(e-)=$\mp$80%, P(e+)=$\mp$30% (ILC LumiUp 4ab^{-1})

CLIC@380GeV

500fb^{-1}, P(e-)=$\mp$80%

Loose timing cuts

CLIC@1.4TeV

1.5ab^{-1}, P(e-)=$\mp$80%

Tight timing cuts,

Efficiency inputs from Rickard and Martin top tagging studies

Fast Simulation

CLIC@3TeV

3ab^{-1}, P(e-)=$\mp$80%

Extrapolate numbers from low-energy stages results

Prospects for CP-violating form factors

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- The measurements at **hadron colliders** are expected to be considerably **less precise** than those that can be made at lepton colliders
- Nominal **ILC** and the **CLIC low-energy stages** have a very similar sensitivity to these form factors, reaching **limits of $|F_{2A}^{\gamma}|<0.01$** for the EDF
- Assuming that systematic uncertainties can be controlled to the required level, a luminosity upgrade of both machines **may bring a further improvement**