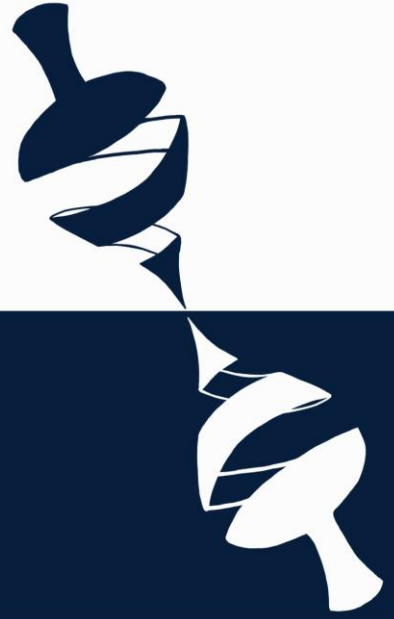

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

INFN

Are Quantum Observables sensitive to CP violation in $t\bar{t}$ pairs?

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Quantum Observables in High Energy Physics

- Density operator for two spin ½ particles:

$$\rho_{(\frac{1}{2},\frac{1}{2})} = \frac{1}{4}\left(\mathbb{I}\otimes\mathbb{I} + B_i\tau_i\otimes\mathbb{I} + \bar{B}_i\,\mathbb{I}\otimes\tau_i + C_{ij}\tau_i\otimes\tau_j\right) \longrightarrow$$

Single-particle polarizations — Correlations

Quantum Observables

- $t\bar{t}$ **pairs** in collider experiments:
  - $\tau_{decay} < \tau_{hadr.}, \tau_{spin-flip.}$;
  - Precise correlation between the $t(\bar{t})$ spin – direction of flight of decay products:

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

Particle	α
b	$-0.3925(6)$
W^+	$0.3925(6)$
ℓ^+	$0.999(1)$
$\bar{d},\ \bar{s}$	$0.9664(7)$
$u,\ c$	$-0.3167(6)$

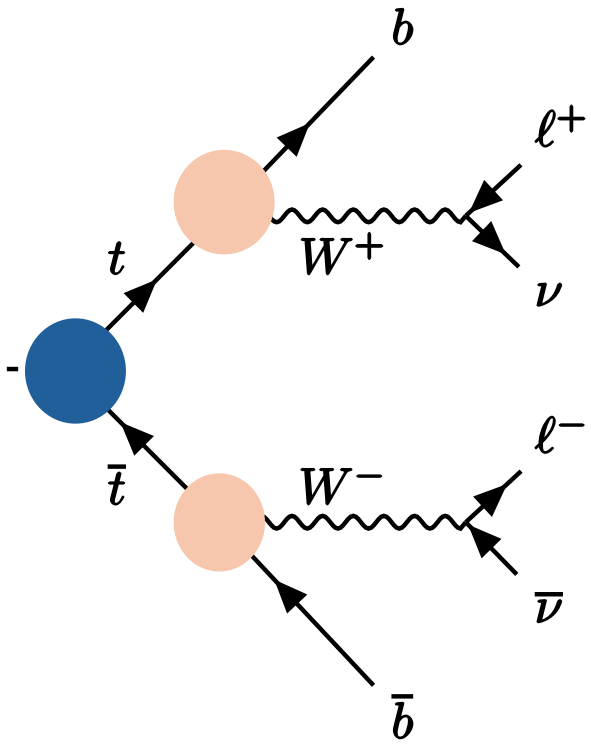
- Reconstruction of the state → **quantum state tomography**:

$$d\sigma \sim Tr[\rho_{t\bar{t}}(\rho^{Decay,t}\otimes\rho^{Decay,\bar{t}})^T] \longrightarrow$$

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta_i} = \frac{1}{2}\left[1+\alpha_\ell B_i\cos\theta_i\right]$$

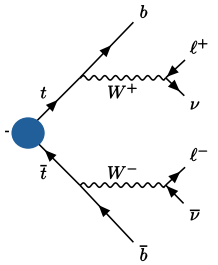
$$\frac{1}{\sigma}\frac{d\sigma}{d(\cos\theta_i\cos\bar{\theta}_j)} = \frac{1}{2}(1+\alpha_\ell\alpha_{\bar{\ell}}C_{ij}\cos\theta_i\cos\bar{\theta}_j)ln\left(\frac{1}{|\cos\theta_i\cos\bar{\theta}_j|}\right)$$

New Physics and CP-violation in $t\bar{t}$ pairs

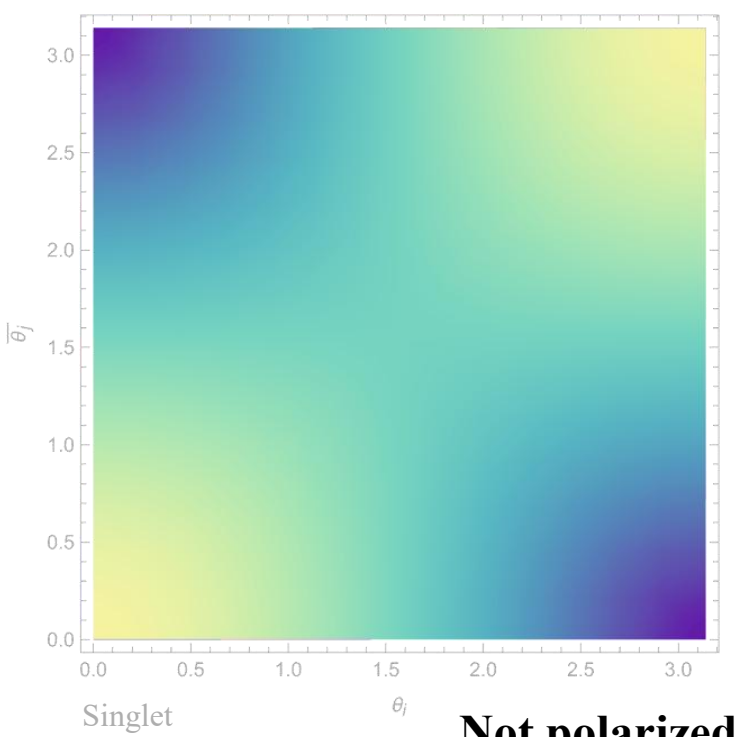


$$d\sigma \sim Tr[\rho_{t\bar{t}}(\rho^{Decay,t} \otimes \rho^{Decay,\bar{t}})^T]$$

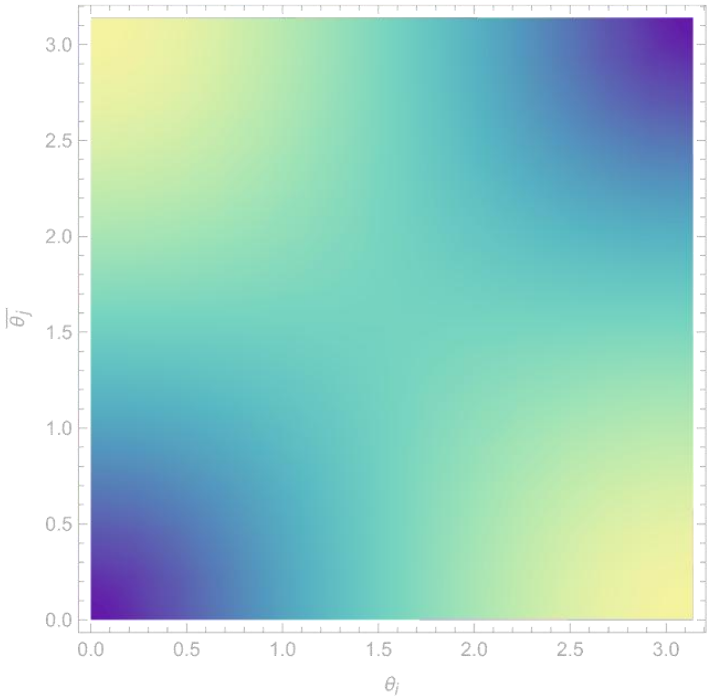
New Physics and CP-violation in production



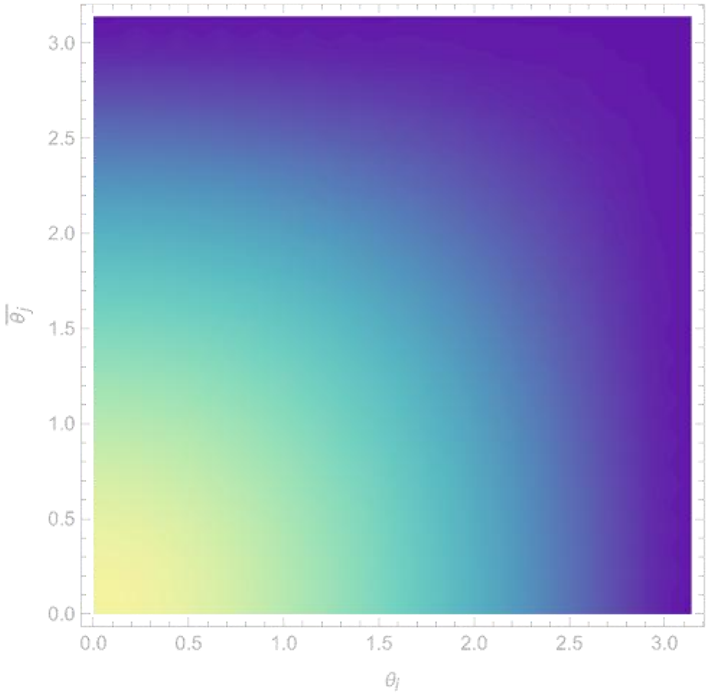
$$\frac{4}{\sigma(\beta)}\frac{d\sigma}{d\cos\theta_i\; d\cos\bar{\theta}_j} = 1 + \alpha_\ell B_i \cos\theta_i + \bar{\alpha}_\ell \bar{B}_j \cos\bar{\theta}_j + \alpha_\ell \bar{\alpha}_\ell C_{ij} \cos\theta_i \cos\bar{\theta}_j$$

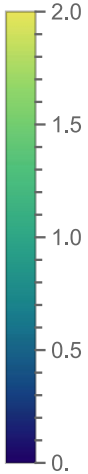


Singlet



Not polarized but highly correlated

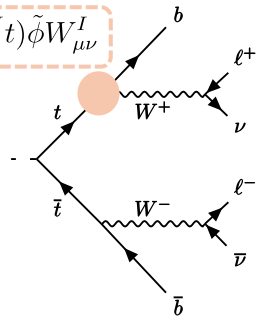




Polarized and highly correlated

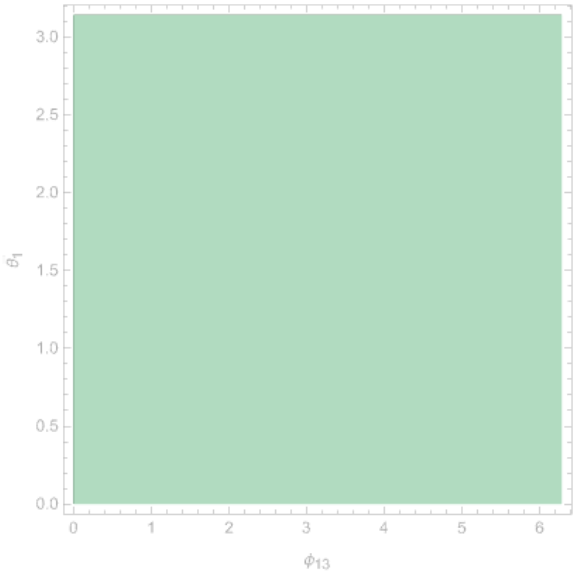
New Physics and CP-violation in decay

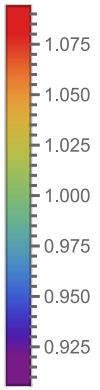
$\mathcal{O}_{tW} = (\bar{q}\sigma^{\mu\nu}\tau^I t)\tilde{\phi}W^I_{\mu\nu}$



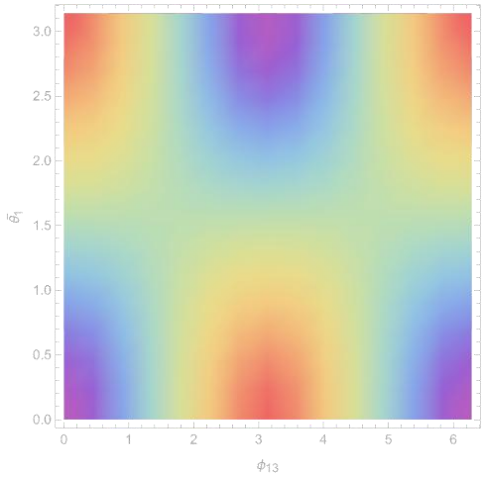
$$\frac{4\pi}{\sigma}\frac{d\sigma}{d\phi_{13}d\cos\bar{\theta}_1}$$

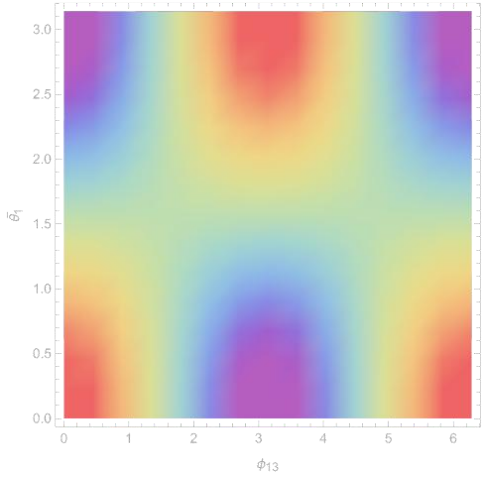
Standard Model





Without CP-violation





With CP-violation