tau spins in e+ e- → tau+ tau-

we have sensitivity to tau spin orientation in this process

can we use it to measure/constrain something interesting?

I’m starting to investigate…
...so probably many misunderstandings!

Daniel Jeans / KEK

lepton-photon coupling

$$\mathcal{M}_{\ell\bar{\ell}\gamma^*} = e\,Q_\ell\,\varepsilon_\mu(q)\,\bar{u}_\ell(\vec{p}\,')\left[F_1(q^2)\,\gamma^\mu + i\,\frac{F_2(q^2)}{2m_\ell}\,\sigma^{\mu\nu}q_\nu + \frac{F_3(q^2)}{2m_\ell}\,\sigma^{\mu\nu}\gamma_5\,q_\nu\right]u_\ell(\vec{p})$$

@ q2=0 : magnetic electric dipole moments

violates T and P

lepton-Z coupling

$$\mathcal{L}^Z_{\rm wdm} = -\frac{1}{2\sin\theta_W\cos\theta_W}\,Z_\mu\,\bar{\tau}\left[i\,\alpha^W_\tau\,\frac{e}{2m_\tau}\,\sigma^{\mu\nu}q_\nu + d^W_\tau\,\sigma^{\mu\nu}\gamma_5\,q_\nu\right]\tau$$

weak magnetic electric dipole moments

in EFT language, 2 relevant 6d operators

FTUV−00−0218 IFIC/00−17

Model independent bounds on the tau lepton electromagnetic and weak magnetic moments

Gabriel A. González-Sprinberg [a], Arcadi Santamaria [b] and Jordi Vidal [b]

$$\mathcal{O}_B = \frac{g'}{2\Lambda^2}\overline{L_L}\varphi\sigma_{\mu\nu}\tau_R B^{\mu\nu} \ ,$$

$$\mathcal{O}_W = \frac{g}{2\Lambda^2}\overline{L_L}\vec{\tau}\varphi\sigma_{\mu\nu}\tau_R \vec{W}^{\mu\nu} \ .$$

$$\mathcal{L}_{eff} = \alpha_B \mathcal{O}_B + \alpha_W \mathcal{O}_W + \text{h.c.} \ ,$$

α real: magnetic moment
imaginary: CP-violation “EDM”

$$\mathcal{L}_{eff} = \epsilon_\gamma \frac{e}{2m_Z}\overline{\tau}\sigma_{\mu\nu}\tau F^{\mu\nu} + \epsilon_Z \frac{e}{2m_Z s_W c_W}\overline{\tau}\sigma_{\mu\nu}\tau Z^{\mu\nu} + \left(\epsilon_W \frac{e}{2m_Z s_W}\overline{\nu_{\tau L}}\sigma_{\mu\nu}\tau_R W_+^{\mu\nu} + \text{h.c.}\right) \ ,$$

vary real & im parts of α_B α_W
(for taus only : don’t assume flavour symmetry)

Dimension-Six Terms in the Standard Model Lagrangian*

B. Grzadkowski[1], M. Iskrzyński[1], M. Misiak[1,2] and J. Rosiek[1]

X^3		φ^6 and $\varphi^4 D^2$		$\psi^2\varphi^3$	
Q_G	$f^{ABC}G^{A\nu}_{\mu}G^{B\rho}_{\nu}G^{C\mu}_{\rho}$	Q_{φ}	$(\varphi^\dagger\varphi)^3$	$Q_{e\varphi}$	$(\varphi^\dagger\varphi)(\bar{l}_p e_r \varphi)$
$Q_{\widetilde{G}}$	$f^{ABC}\widetilde{G}^{A\nu}_{\mu}G^{B\rho}_{\nu}G^{C\mu}_{\rho}$	$Q_{\varphi\Box}$	$(\varphi^\dagger\varphi)\Box(\varphi^\dagger\varphi)$	$Q_{u\varphi}$	$(\varphi^\dagger\varphi)(\bar{q}_p u_r \widetilde{\varphi})$
Q_W	$\varepsilon^{IJK}W^{I\nu}_{\mu}W^{J\rho}_{\nu}W^{K\mu}_{\rho}$	$Q_{\varphi D}$	$\left(\varphi^\dagger D^\mu\varphi\right)^\star\left(\varphi^\dagger D_\mu\varphi\right)$	$Q_{d\varphi}$	$(\varphi^\dagger\varphi)(\bar{q}_p d_r \varphi)$
$Q_{\widetilde{W}}$	$\varepsilon^{IJK}\widetilde{W}^{I\nu}_{\mu}W^{J\rho}_{\nu}W^{K\mu}_{\rho}$				
$X^2\varphi^2$		$\psi^2 X\varphi$		$\psi^2\varphi^2 D$	
$Q_{\varphi G}$	$\varphi^\dagger\varphi\, G^A_{\mu\nu}G^{A\mu\nu}$	Q_{eW}	$(\bar{l}_p\sigma^{\mu\nu}e_r)\tau^I\varphi W^I_{\mu\nu}$	$Q^{(1)}_{\varphi l}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{l}_p\gamma^\mu l_r)$
$Q_{\varphi\widetilde{G}}$	$\varphi^\dagger\varphi\,\widetilde{G}^A_{\mu\nu}G^{A\mu\nu}$	Q_{eB}	$(\bar{l}_p\sigma^{\mu\nu}e_r)\varphi B_{\mu\nu}$	$Q^{(3)}_{\varphi l}$	$(\varphi^\dagger i\overleftrightarrow{D}^I_\mu\varphi)(\bar{l}_p\tau^I\gamma^\mu l_r)$
$Q_{\varphi W}$	$\varphi^\dagger\varphi\, W^I_{\mu\nu}W^{I\mu\nu}$	Q_{uG}	$(\bar{q}_p\sigma^{\mu\nu}T^A u_r)\widetilde{\varphi}\, G^A_{\mu\nu}$	$Q_{\varphi e}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{e}_p\gamma^\mu e_r)$
$Q_{\varphi\widetilde{W}}$	$\varphi^\dagger\varphi\,\widetilde{W}^I_{\mu\nu}W^{I\mu\nu}$	Q_{uW}	$(\bar{q}_p\sigma^{\mu\nu}u_r)\tau^I\widetilde{\varphi}\, W^I_{\mu\nu}$	$Q^{(1)}_{\varphi q}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{q}_p\gamma^\mu q_r)$
$Q_{\varphi B}$	$\varphi^\dagger\varphi\, B_{\mu\nu}B^{\mu\nu}$	Q_{uB}	$(\bar{q}_p\sigma^{\mu\nu}u_r)\widetilde{\varphi}\, B_{\mu\nu}$	$Q^{(3)}_{\varphi q}$	$(\varphi^\dagger i\overleftrightarrow{D}^I_\mu\varphi)(\bar{q}_p\tau^I\gamma^\mu q_r)$
$Q_{\varphi\widetilde{B}}$	$\varphi^\dagger\varphi\,\widetilde{B}_{\mu\nu}B^{\mu\nu}$	Q_{dG}	$(\bar{q}_p\sigma^{\mu\nu}T^A d_r)\varphi\, G^A_{\mu\nu}$	$Q_{\varphi u}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{u}_p\gamma^\mu u_r)$
$Q_{\varphi WB}$	$\varphi^\dagger\tau^I\varphi\, W^I_{\mu\nu}B^{\mu\nu}$	Q_{dW}	$(\bar{q}_p\sigma^{\mu\nu}d_r)\tau^I\varphi\, W^I_{\mu\nu}$	$Q_{\varphi d}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{d}_p\gamma^\mu d_r)$
$Q_{\varphi\widetilde{W}B}$	$\varphi^\dagger\tau^I\varphi\,\widetilde{W}^I_{\mu\nu}B^{\mu\nu}$	Q_{dB}	$(\bar{q}_p\sigma^{\mu\nu}d_r)\varphi\, B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\widetilde{\varphi}^\dagger D_\mu\varphi)(\bar{u}_p\gamma^\mu d_r)$

Table 2: Dimension-six operators other than the four-fermion ones.

madgraph5_@NLO + SMEFTsim + TauDecay

http://madgraph.phys.ucl.ac.be/ https://smeftsim.github.io/ arXiv:1212.6247

e+ e- → tau+ tau-

(un)polarised beams

91/250 GeV cm energy (exact; no bs, isr)

tau → pi nu
pion momentum direction is spin analyser “polarimeter”

reconstruct polarimeters, look for sensitive observables

Dimension-Six Terms in the Standard Model Lagrangian*

B. Grzadkowski[1], M. Iskrzyński[1], M. Misiak[1,2] and J. Rosiek[1]

X^3		φ^6 and $\varphi^4 D^2$		$\psi^2\varphi^3$	
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$Q_{\widetilde{W}}$	$\varepsilon^{IJK}\widetilde{W}^{I\nu}_{\mu}W^{J\rho}_{\nu}W^{K\mu}_{\rho}$				
$X^2\varphi^2$		$\psi^2 X\varphi$		$\psi^2\varphi^2 D$	
$Q_{\varphi G}$	$\varphi^\dagger\varphi\, G^A_{\mu\nu}G^{A\mu\nu}$	Q_{eW}	$(\bar{l}_p\sigma^{\mu\nu}e_r)\tau^I\varphi W^I_{\mu\nu}$	$Q^{(1)}_{\varphi l}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{l}_p\gamma^\mu l_r)$
$Q_{\varphi\widetilde{G}}$	$\varphi^\dagger\varphi\,\widetilde{G}^A_{\mu\nu}G^{A\mu\nu}$	Q_{eB}	$(\bar{l}_p\sigma^{\mu\nu}e_r)\varphi B_{\mu\nu}$	$Q^{(3)}_{\varphi l}$	$(\varphi^\dagger i\overleftrightarrow{D}^I_\mu\varphi)(\bar{l}_p\tau^I\gamma^\mu l_r)$
$Q_{\varphi W}$	$\varphi^\dagger\varphi\, W^I_{\mu\nu}W^{I\mu\nu}$	Q_{uG}	$(\bar{q}_p\sigma^{\mu\nu}T^A u_r)\widetilde{\varphi}\, G^A_{\mu\nu}$	$Q_{\varphi e}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{e}_p\gamma^\mu e_r)$
$Q_{\varphi\widetilde{W}}$	$\varphi^\dagger\varphi\,\widetilde{W}^I_{\mu\nu}W^{I\mu\nu}$	Q_{uW}	$(\bar{q}_p\sigma^{\mu\nu}u_r)\tau^I\widetilde{\varphi}\, W^I_{\mu\nu}$	$Q^{(1)}_{\varphi q}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{q}_p\gamma^\mu q_r)$
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$Q_{\varphi\widetilde{B}}$	$\varphi^\dagger\varphi\,\widetilde{B}_{\mu\nu}B^{\mu\nu}$	Q_{dG}	$(\bar{q}_p\sigma^{\mu\nu}T^A d_r)\varphi\, G^A_{\mu\nu}$	$Q_{\varphi u}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{u}_p\gamma^\mu u_r)$
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Table 2: Dimension-six operators other than the four-fermion ones.

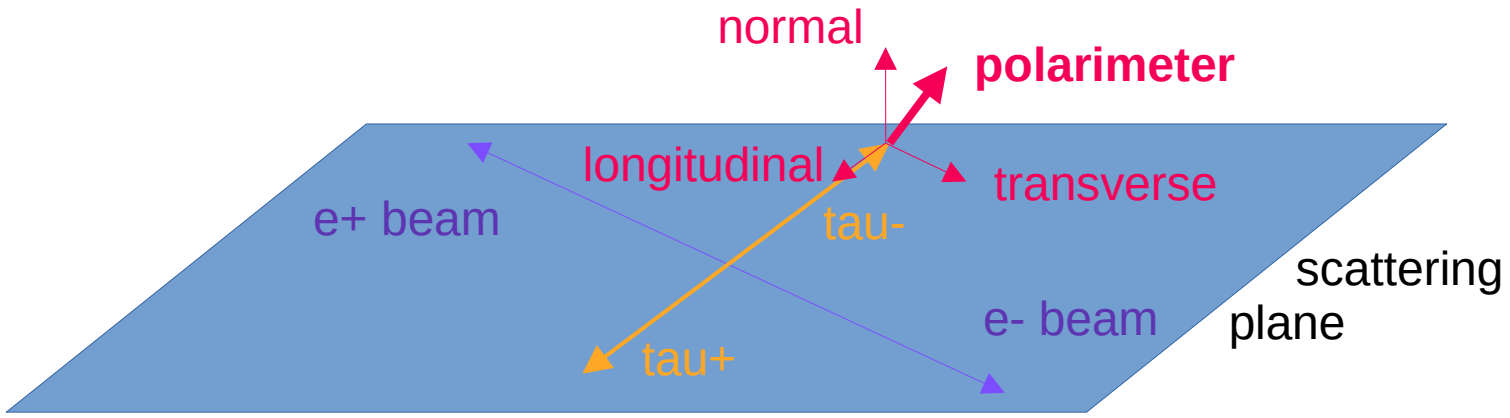
SMEFTsim 3.0 – a practical guide

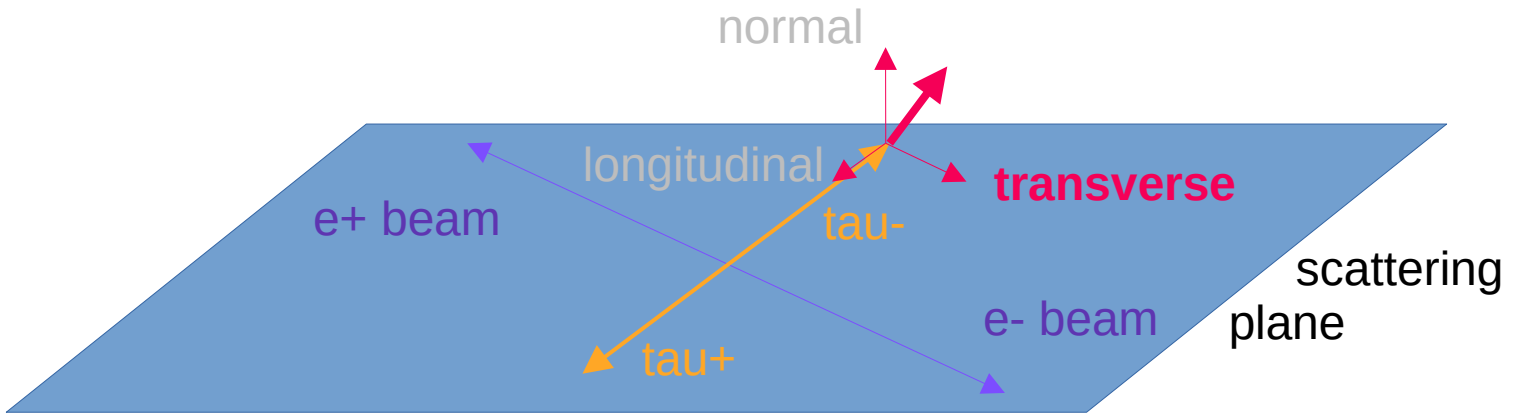
arXiv:2012.11343

coefficients in SMEFTsim (general model):

ceWRe33
ceWIm33
ceBRe33
ceBIm33

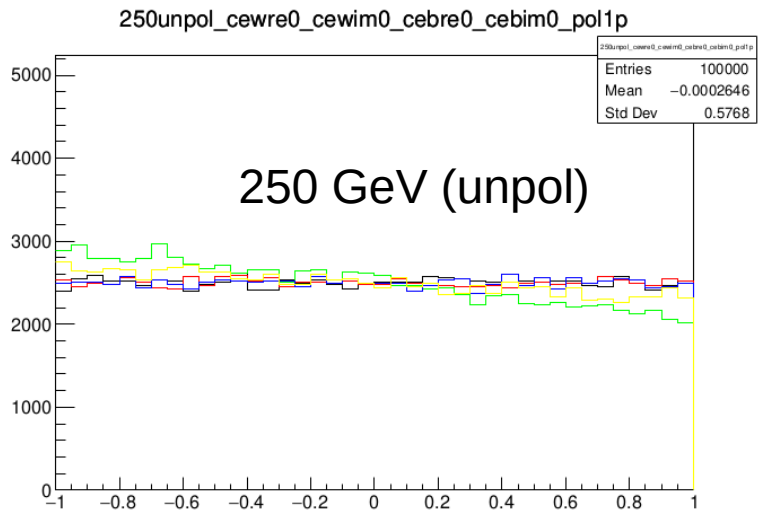
real/imag. tau-tau

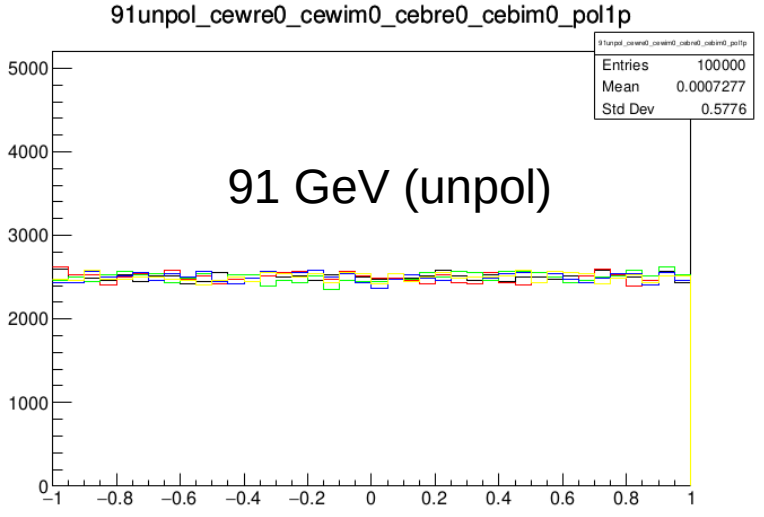

normal
polarimeter
longitudinal
transverse
e+ beam
tau-
scattering
plane
e- beam
tau+

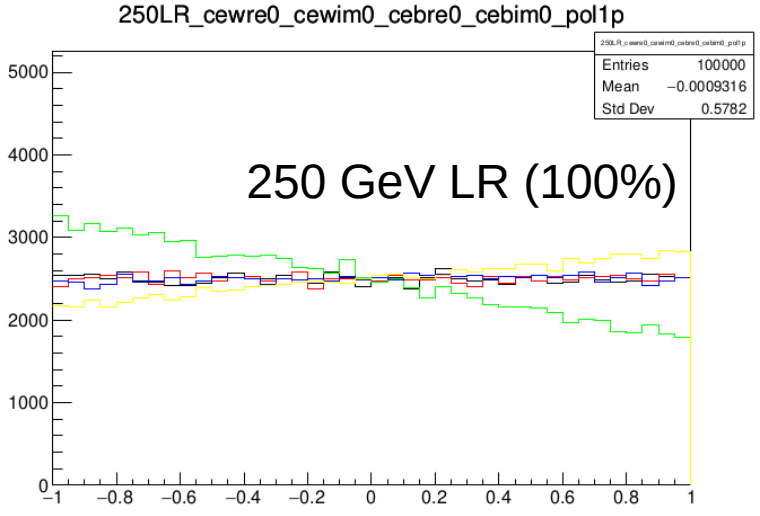

normal
longitudinal
transverse
e+ beam
tau-
scattering
plane
e- beam
tau+

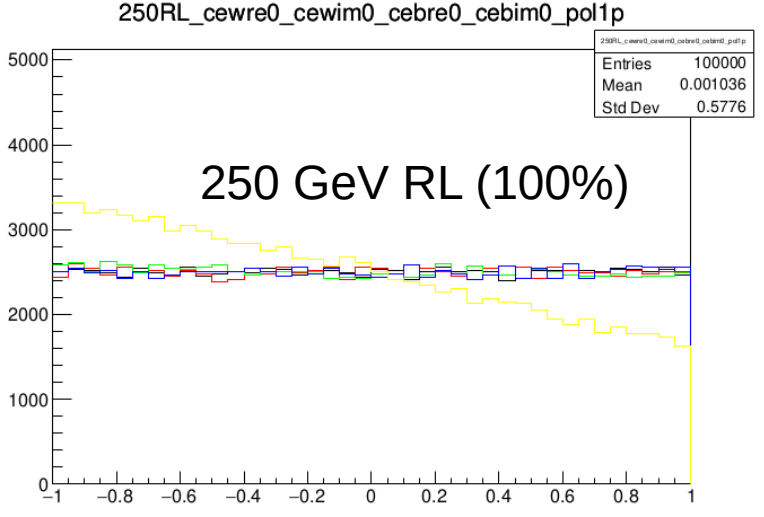
transverse pol
(tau+)

SM
cewre33=1
cewim33=1
cebre33=1
cebim33=1



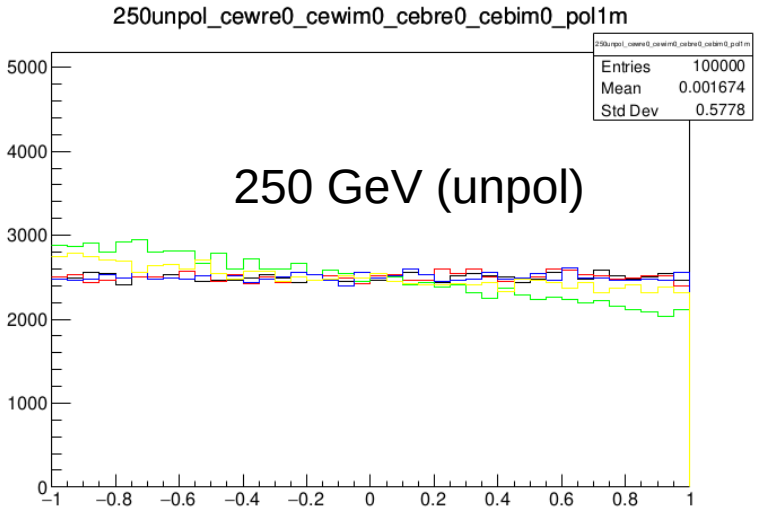


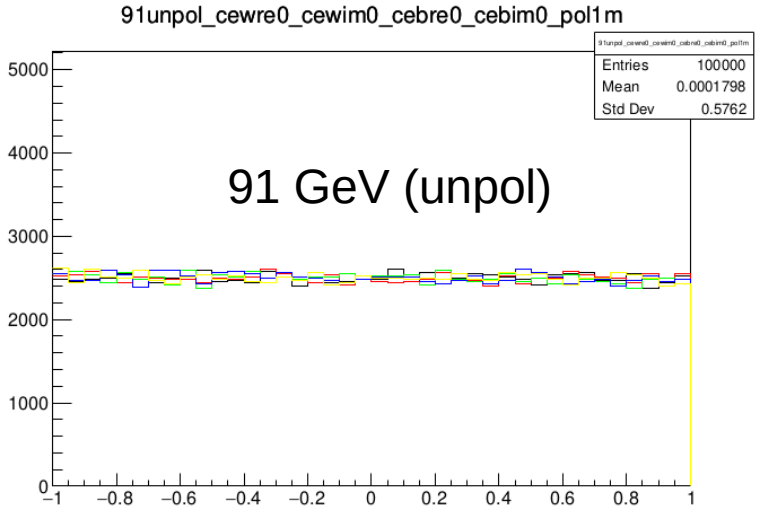


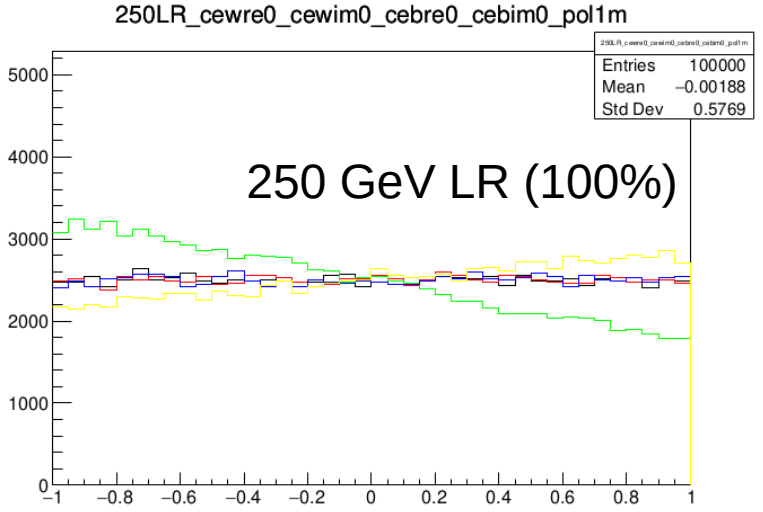


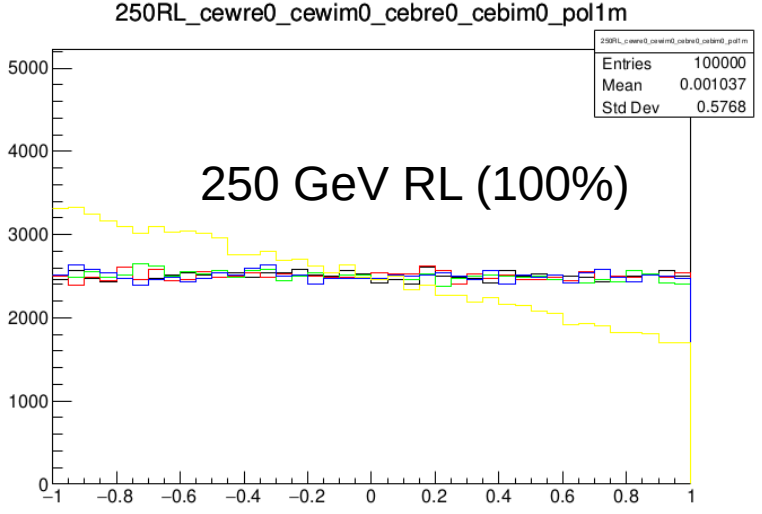
transverse pol
(tau-)

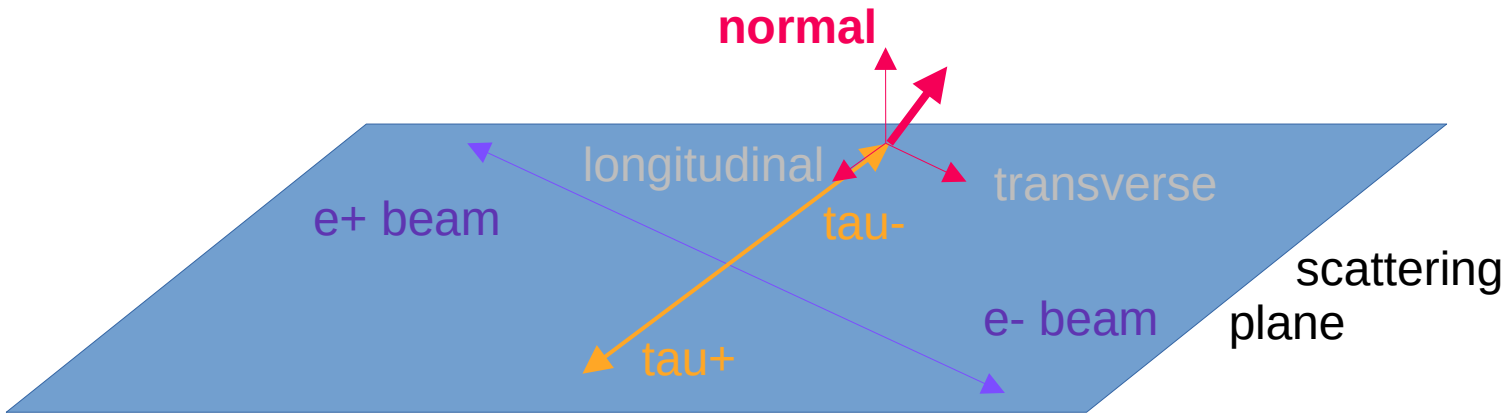
SM
cewre33=1
cewim33=1
cebre33=1
cebim33=1










normal
longitudinal
transverse
e+ beam
tau-
scattering
plane
e- beam
tau+

normal pol
(tau+)

SM
cewre33=1
cewim33=1
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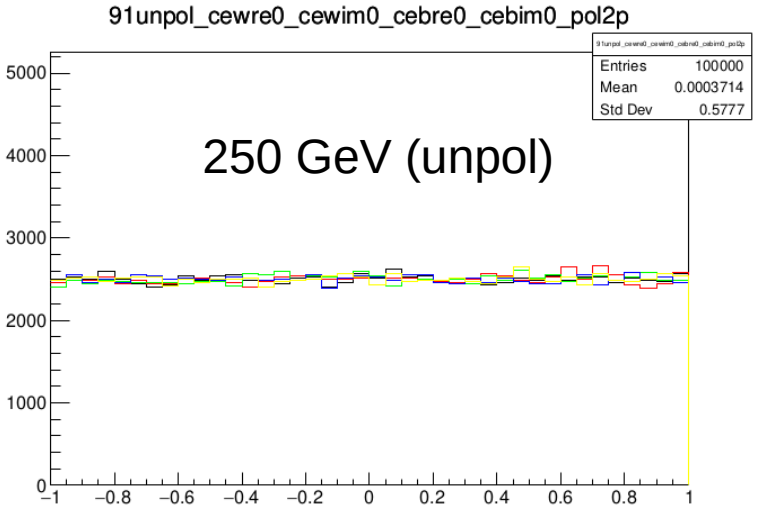

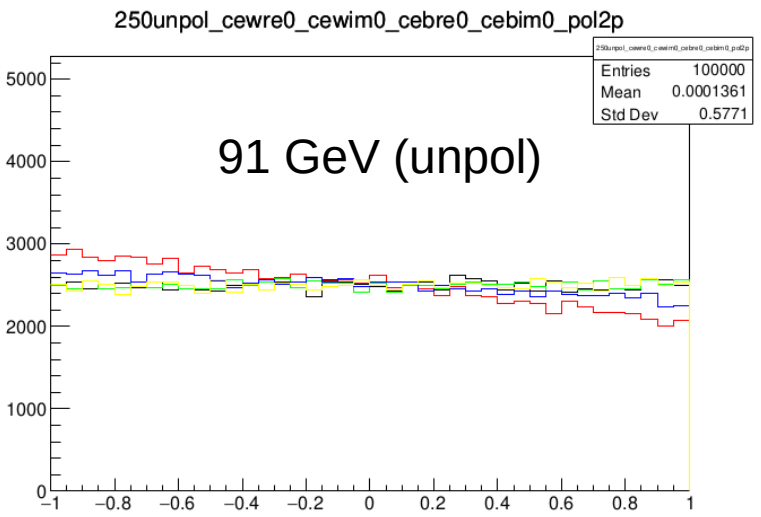

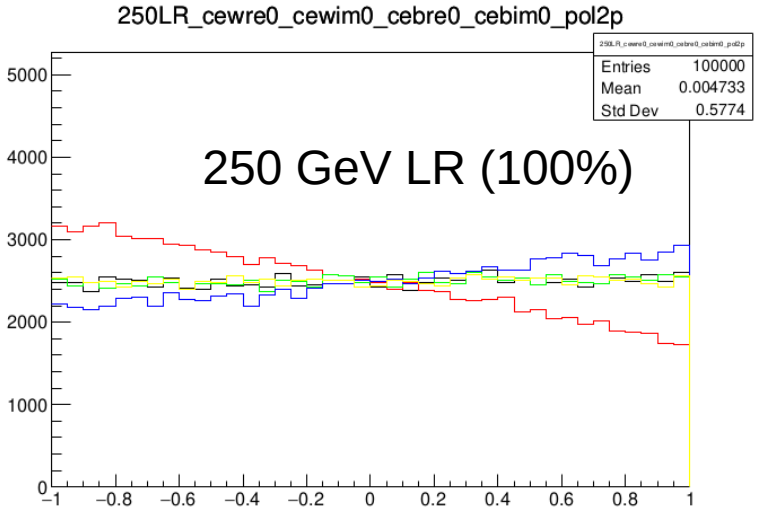

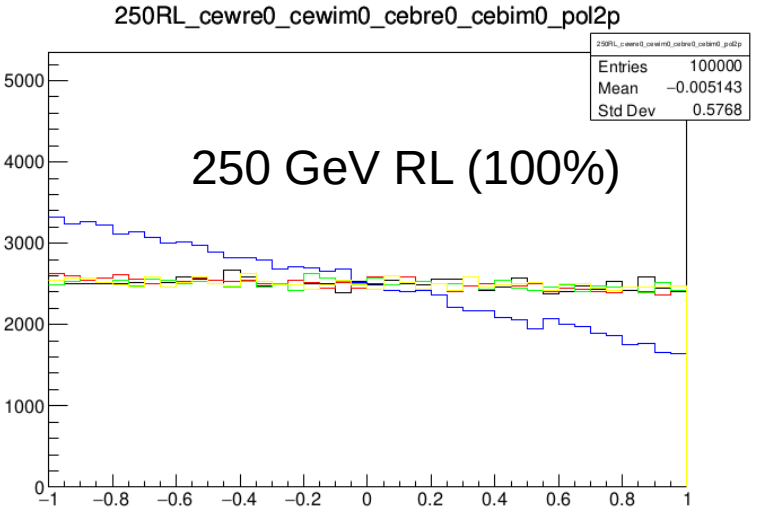

normal pol
(tau-)

SM
cewre33=1
cewim33=1
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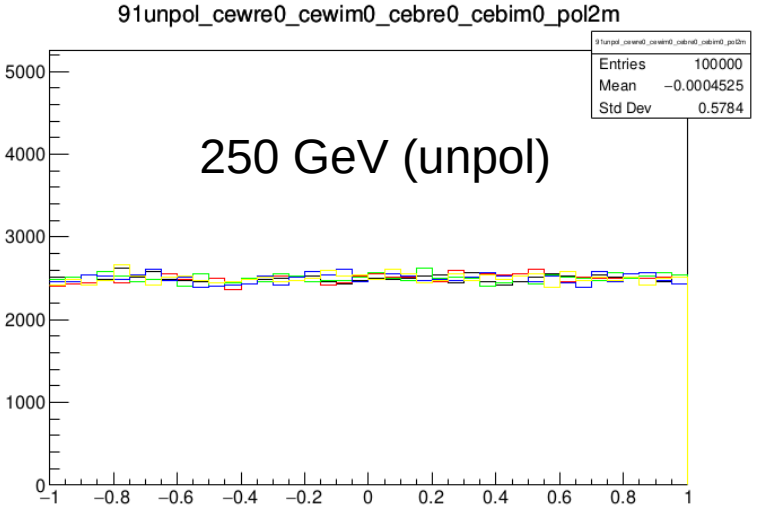
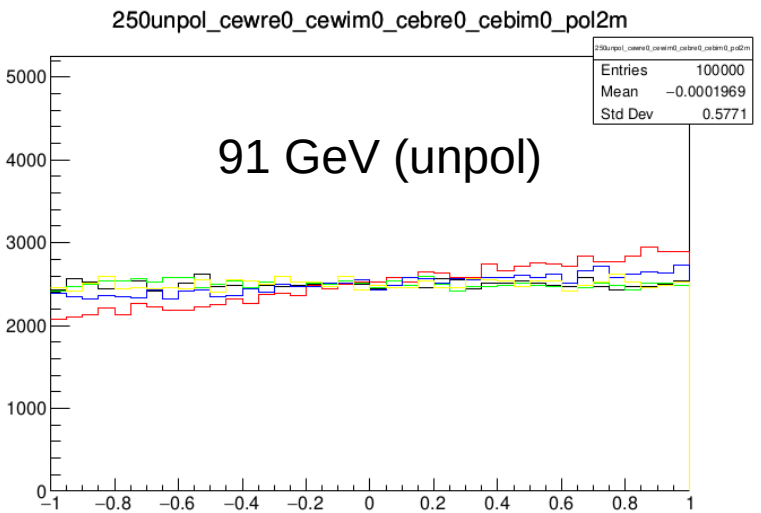
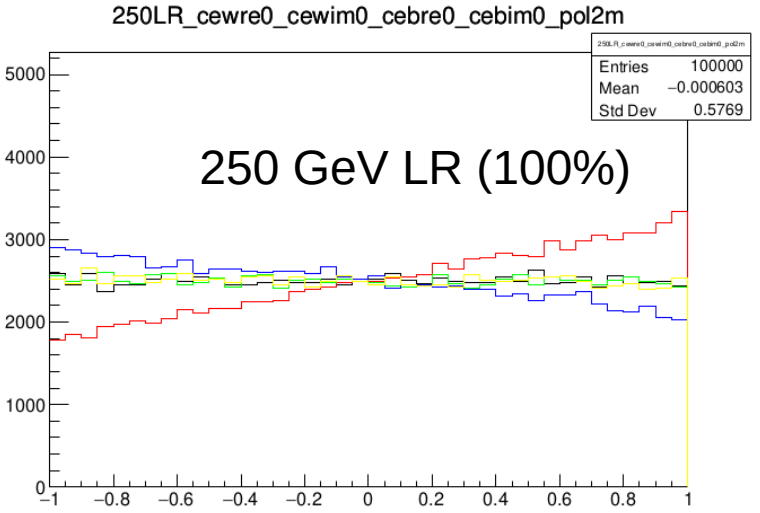
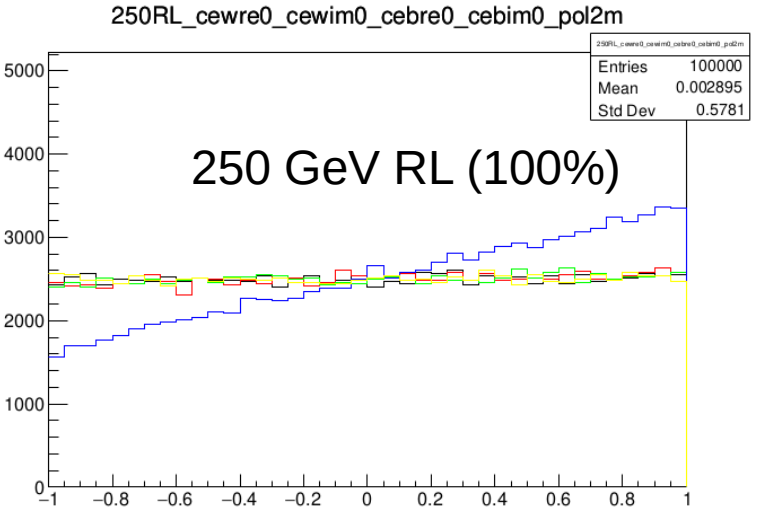
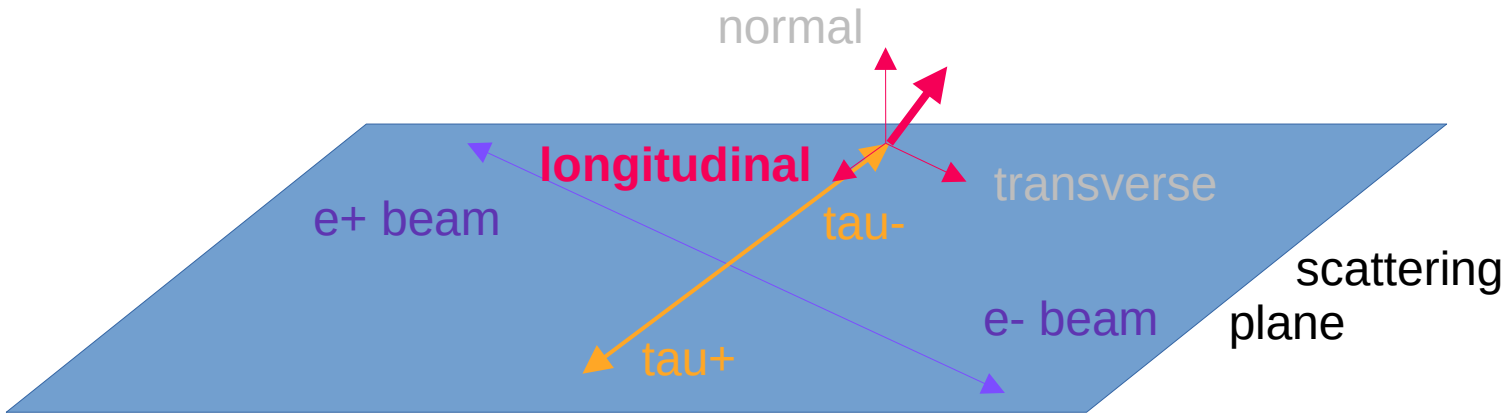
cebim33=1







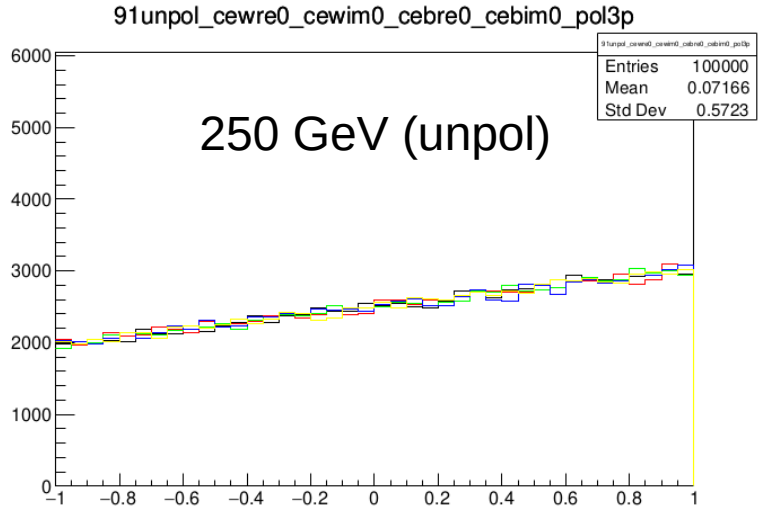


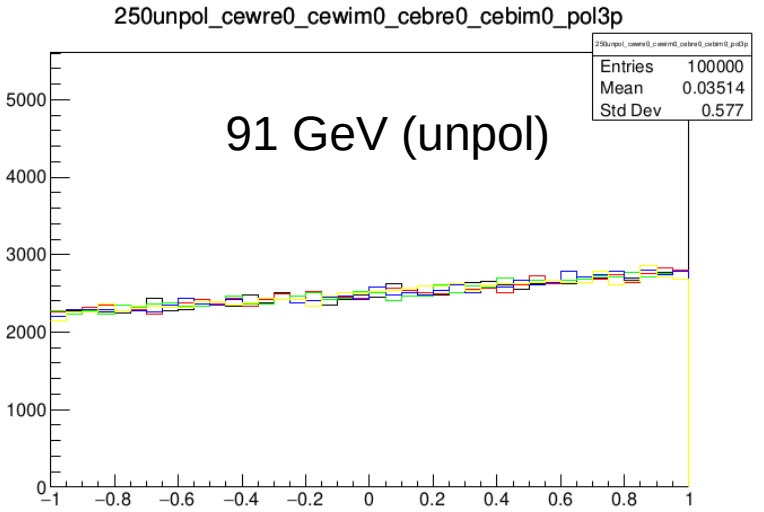


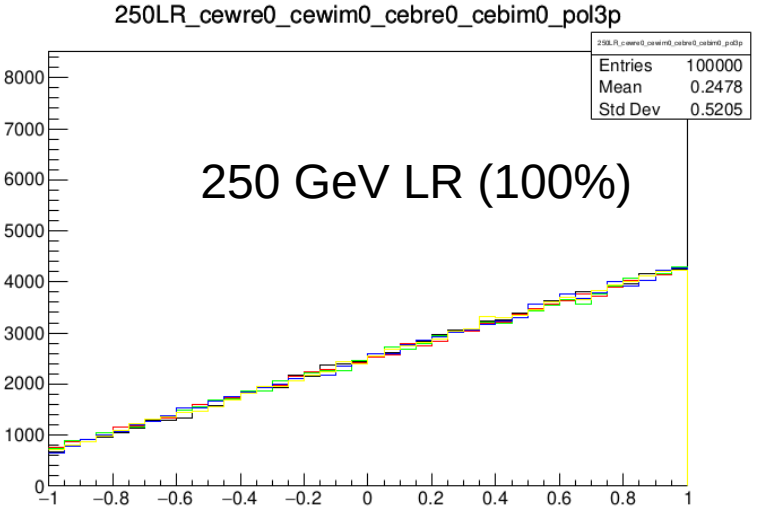
this is the “usual” tau polarisation measurement:
fraction of -ve / +ve helicity (≈ left- / right-handed) taus

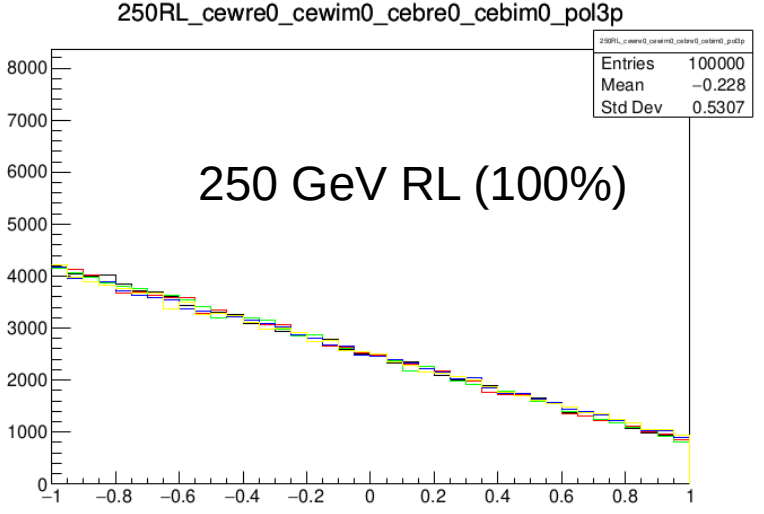
longitudinal pol
(tau+)

SM
cewre33=1
cewim33=1
cebre33=1
cebim33=1









summary

→ seems to be some sensitivity to 2 particular SMEFT couplings

→ potentially with CP violation

plans

→ better understanding

HD-THEP-91-7
KA-THEP-91-1

CP–VIOLATING EFFECTS IN Z DECAYS TO τ LEPTONS

W. Bernreuther*, G.W. Botz**
O. Nachtmann** and P. Overmann**

Table 1 Linearly independent CP-odd observables with rank $n \leq 2$ constructed from the momentum and spin observables of the $\tau^+ \tau^-$ final state in (2.1) where $1 \leq i, j \leq 3$ are the Cartesian vector indices. The CPT parity η_Θ of the operators $\mathcal{A}^{(i)}$ is defined in (2.5).

Table 1

i	$\mathcal{A}^{(i)}$	η_Θ
1	$\hat{\boldsymbol{k}}_+ \cdot (\boldsymbol{s}_+ - \boldsymbol{s}_-)$	$-$
2	$\hat{\boldsymbol{k}}_+ \cdot (\boldsymbol{s}_+ \times \boldsymbol{s}_-)$	$+$
3	$\boldsymbol{s}_+ - \boldsymbol{s}_-$	$-$
4	$\left[\hat{\boldsymbol{k}}_+ \cdot (\boldsymbol{s}_+ - \boldsymbol{s}_-) \right] \hat{\boldsymbol{k}}_+$	$-$
5	$(\boldsymbol{s}_+ \times \boldsymbol{s}_-) \times \hat{\boldsymbol{k}}_+$	$-$
6	$(\boldsymbol{s}_+ - \boldsymbol{s}_-) \times \hat{\boldsymbol{k}}_+$	$+$
7	$\boldsymbol{s}_+ \times \boldsymbol{s}_-$	$+$
8	$\left[\hat{\boldsymbol{k}}_+ \cdot (\boldsymbol{s}_+ \times \boldsymbol{s}_-) \right] \hat{\boldsymbol{k}}_+$	$+$
9	$\hat{k}_{+i} \, (\boldsymbol{s}_+ - \boldsymbol{s}_-)_j + (i \leftrightarrow j)$	$-$
10	$\left[\hat{\boldsymbol{k}}_+ \cdot (\boldsymbol{s}_+ - \boldsymbol{s}_-) \right] \left(\hat{k}_{+i} \, \hat{k}_{+j} - \frac{1}{3} \delta_{ij} \right)$	$-$
11	$\hat{k}_{+i} \, \left(\hat{\boldsymbol{k}}_+ \times (\boldsymbol{s}_+ \times \boldsymbol{s}_-) \right)_j + (i \leftrightarrow j)$	$-$
12	$\hat{k}_{+i} \, \left(\hat{\boldsymbol{k}}_+ \times (\boldsymbol{s}_+ - \boldsymbol{s}_-) \right)_j + (i \leftrightarrow j)$	$+$
13	$\left[\hat{\boldsymbol{k}}_+ \cdot (\boldsymbol{s}_+ \times \boldsymbol{s}_-) \right] \left(\hat{k}_{+i} \, \hat{k}_{+j} - \frac{1}{3} \delta_{ij} \right)$	$+$
14	$\hat{k}_{+i} \, (\boldsymbol{s}_+ \times \boldsymbol{s}_-)_j + (i \leftrightarrow j) - \frac{2}{3} \delta_{ij} \, (trace)$	$+$

η_Θ = "-" most interesting : "effect at tree level"

HD-THEP-92-60

The CP–violating electric and weak dipole moments of the tau lepton from threshold to 500 GeV

W. Bernreuther, O. Nachtmann, and P. Overmann

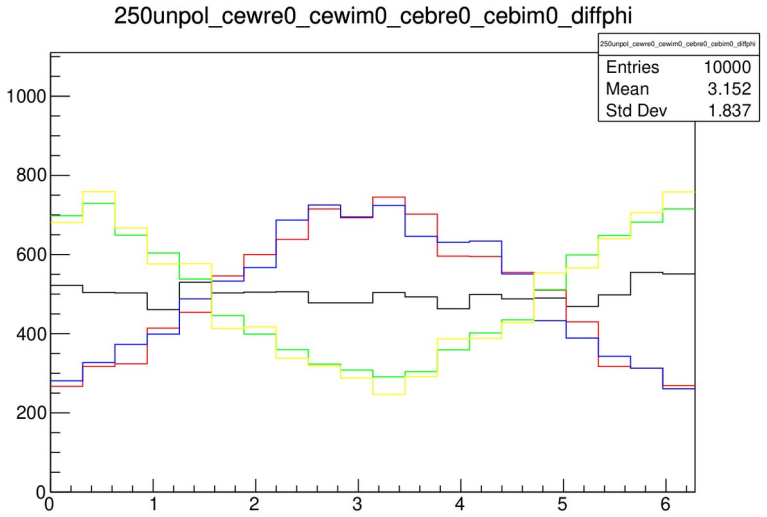
$\sqrt{s}$ [GeV]	$\tau^+\tau^-$events	$\Delta\mathrm{Re}d_\tau^\gamma$ [ecm]	$\Delta\mathrm{Im}d_\tau^\gamma$	$\Delta\mathrm{Re}d_\tau^Z$ [ecm]	$\Delta\mathrm{Im}d_\tau^Z$
3.67	2.4×10^7	2.4×10^{-16}	1.4×10^{-16}		
4.25	3.5×10^7	4.1×10^{-17}	1.9×10^{-17}		
10.58	5×10^7	0.9×10^{-18}	2.7×10^{-18}		
91.16	3.3×10^5			2.0×10^{-18}	3.4×10^{-17}
180	5000	1.5×10^{-16}	7.0×10^{-17}	1.1×10^{-17}	5.8×10^{-16}
500	5000	4.6×10^{-17}	2.4×10^{-17}	4.5×10^{-18}	2.9×10^{-16}

Tab. 2 1 s.d. accuracies obtainable in measuring the dipole form factors at c.m. energies between 3.67 GeV and 500 GeV.

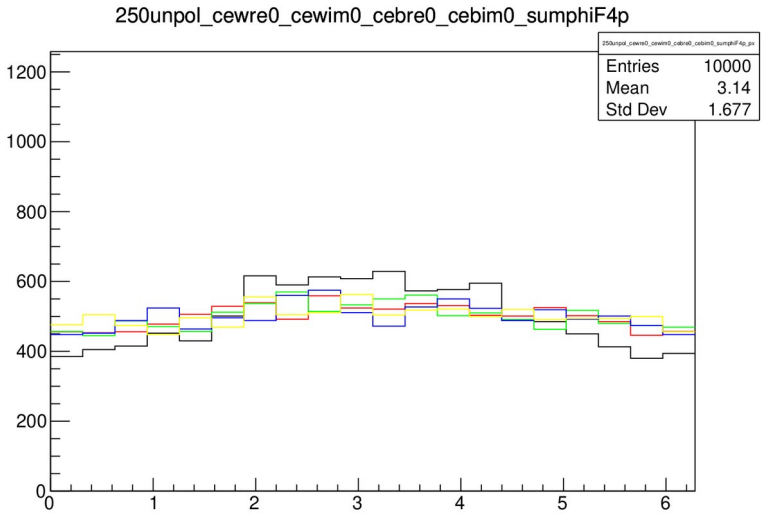
angle of transverse polarimeter components

SM
ceWRe33=10
ceWIm33=10
ceBRe33=10
ceBIm33=10

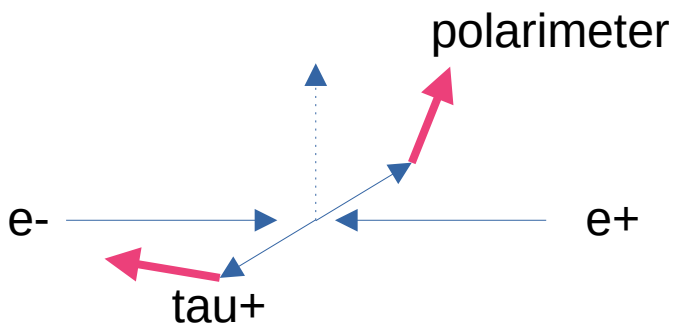
extremely large EFT coeffs

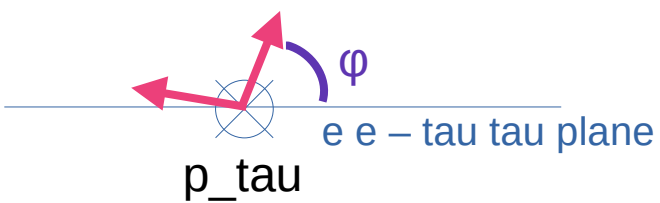


phi1 - phi2



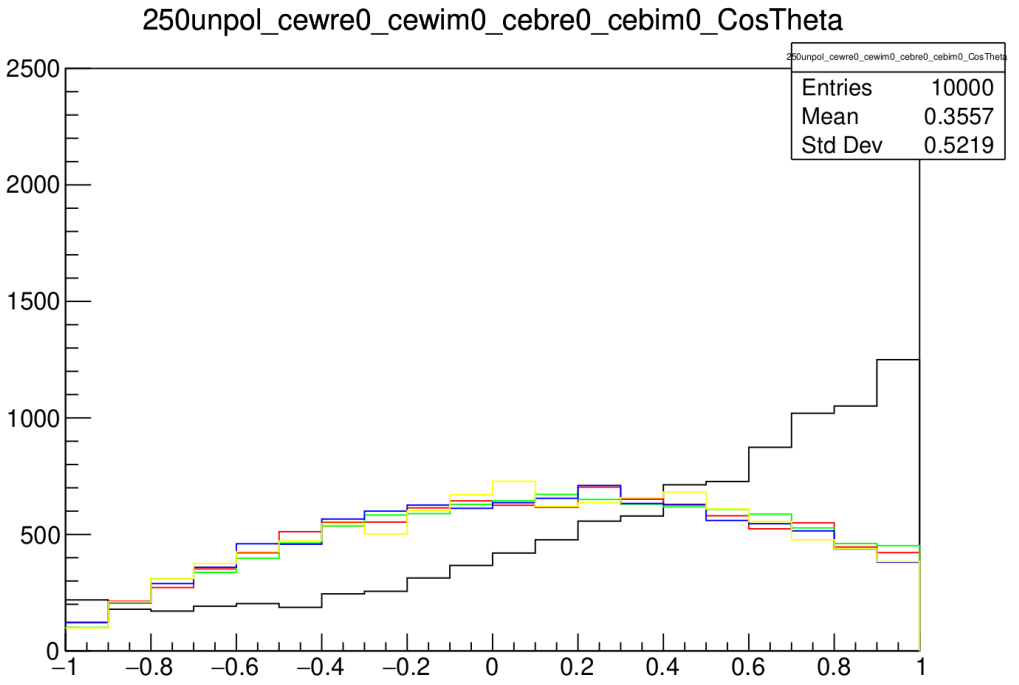
phi1 + phi2





tau scattering angle

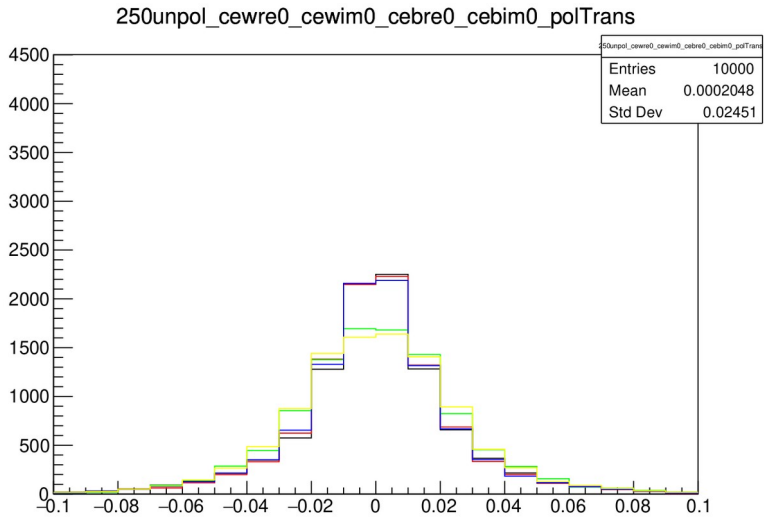
SM
cewre33=10
cewim33=10
cebre33=10
cebim33=10



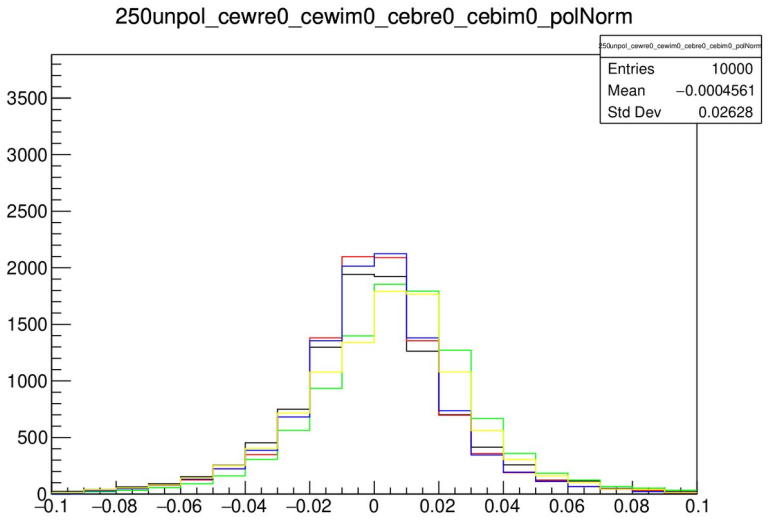
cos (theta_tau-)

tau-tau polarisation in different planes (sum of 2 tau polarimeters)

SM
cewre33=10
cewim33=10
cebre33=10
cebim33=10



polarisation (transverse)



polarisation (normal)

“in e-e : tau-tau plane”

“normal to e-e : tau-tau plane”

SM
cewre33=10
cewim33=10
cebre33=10
cebim33=10

some other CP-sensitive observables (which I don't really understand)