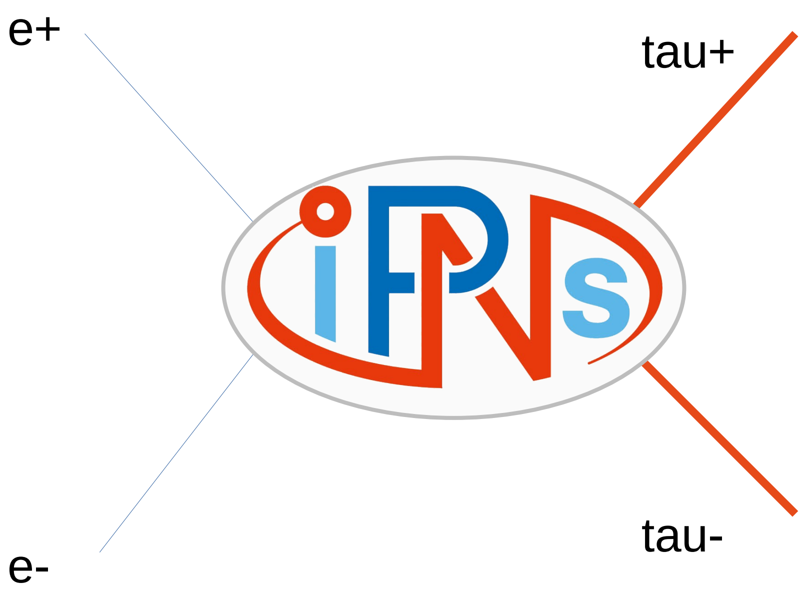
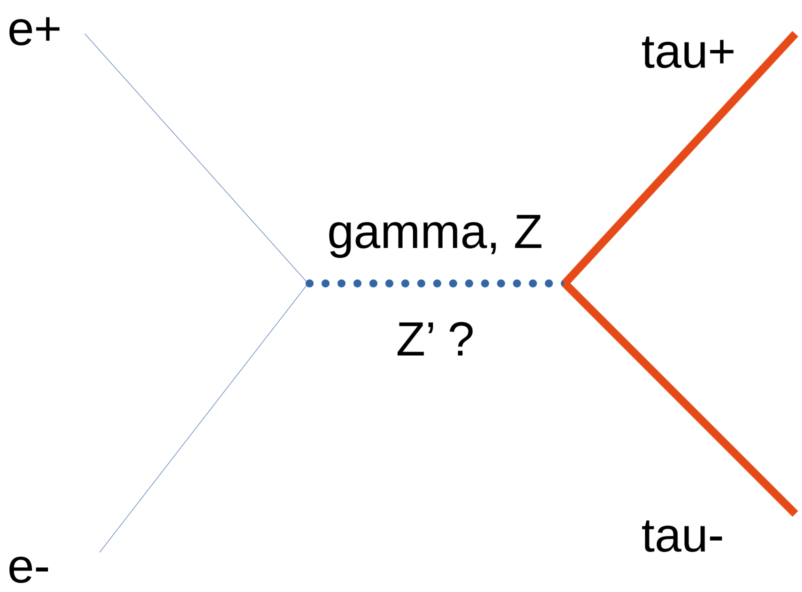
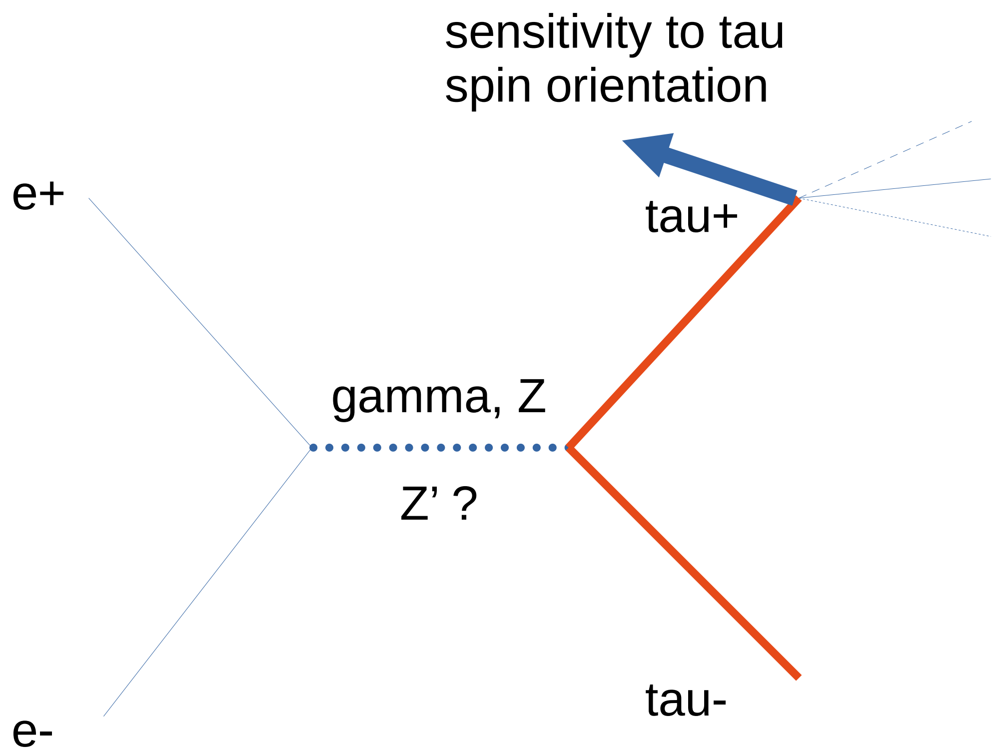


Daniel Jeans / KEK @ ILC-Japan general physics meeting, 20 Dec 2023


e+
tau+
gamma, Z
Z' ?
tau-
e-


sensitivity to tau
spin orientation
e+
tau+
gamma, Z
Z' ?
tau-
e-

tau spins in e+ e- $\rightarrow$ tau+ tau-

we have sensitivity to tau spin orientation in this process

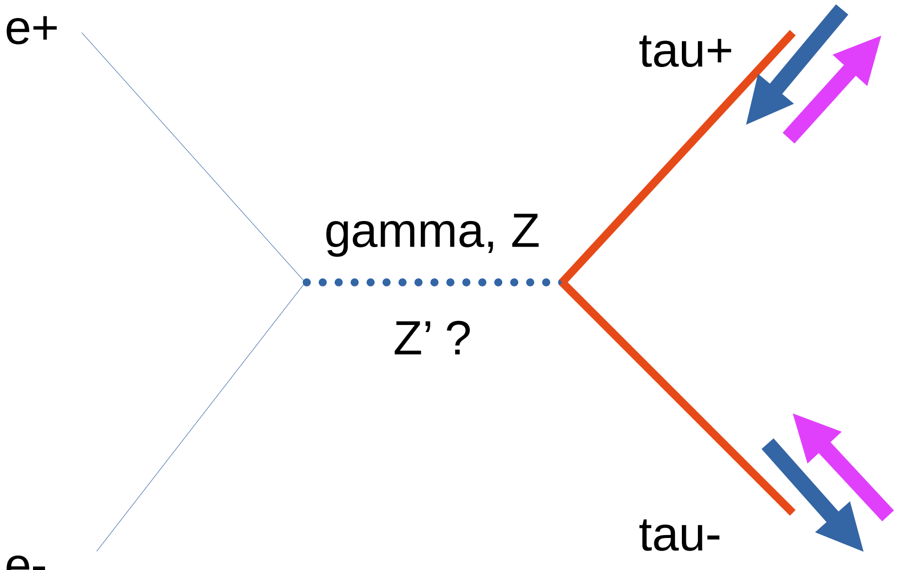
can we use it to measure/constrain something interesting?

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

no results, just some plots at generator level

(longitudinal) tau polarisation: are final state taus more Left or Right-handed ?
we have sensitivity to tau helicity through decays ~ chirality L, R at high energy

in SM,	photon	couplings to **L** and **R** are identical
	Z	couplings to **L** and **R** are very different → A_{LR}
	Z'	" " " depend on model



at linear collider, initial beams are polarised. test universality e ↔ tau for A_{LR}?
assume universality, extract beam polarisation ?

beyond the “standard” longitudinal polarisation

lepton-photon coupling

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

@ $q^2=0$: magnetic ”g-2” electric ”EDM” 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

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]

in EFT language, 2 relevant 6d operators for these EDM & MDM

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

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

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

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

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

vary Re & 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]

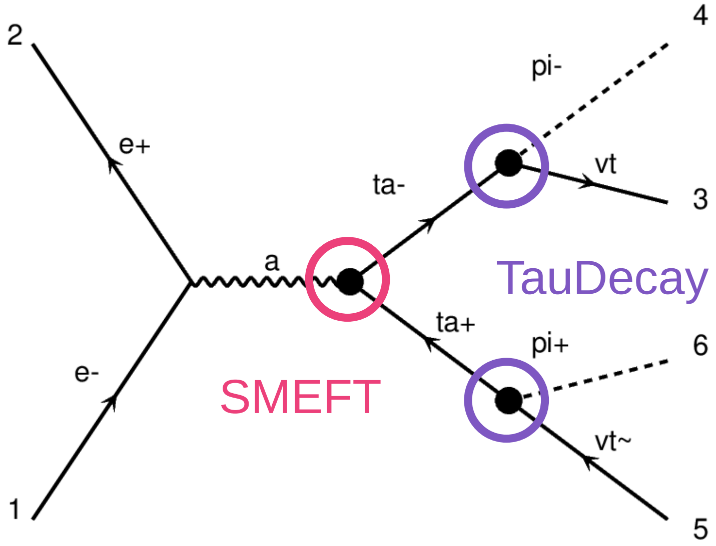
X^3		φ^6 and $\varphi^4 D^2$		$\psi^2\varphi^3$	
Q_G	$f^{ABC} G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	Q_φ	$(\varphi^\dagger\varphi)^3$	$Q_{e\varphi}$	$(\varphi^\dagger\varphi)(\bar l_p e_r \varphi)$
$Q_{\widetilde G}$	$f^{ABC} \widetilde G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$Q_{\varphi\Box}$	$(\varphi^\dagger\varphi)\Box(\varphi^\dagger\varphi)$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

```
Process: e- e+ > ta- ta+ , ( ta- > vt pi- ) , ( ta+ > vt~ pi+ )
         QED=2
         NP=1
Model:   SMEFTsim_general_MwScheme_UFO__taudecay_UFO
```



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, 500 GeV cm energy (exact; no beamstrahlung, ISR)

simplest tau decay: 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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$X^2\varphi^2$		$\psi^2 X\varphi$		$\psi^2\varphi^2 D$	
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$Q_{\varphi\widetilde G}$	$\varphi^\dagger\varphi\, \widetilde G^A_{\mu\nu} G^{A\mu\nu}$	Q_{eB}	$(\bar l_p \sigma^{\mu\nu} e_r)\varphi B_{\mu\nu}$	$Q_{\varphi l}^{(3)}$	$(\varphi^\dagger i\overleftrightarrow{D}^I_\mu \varphi)(\bar l_p \tau^I \gamma^\mu l_r)$
$Q_{\varphi W}$	$\varphi^\dagger\varphi\, W^I_{\mu\nu} W^{I\mu\nu}$	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}	$(\bar q_p \sigma^{\mu\nu} u_r)\tau^I \widetilde\varphi\, W^I_{\mu\nu}$	$Q_{\varphi q}^{(1)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar q_p \gamma^\mu q_r)$
$Q_{\varphi B}$	$\varphi^\dagger\varphi\, B_{\mu\nu} B^{\mu\nu}$	Q_{uB}	$(\bar q_p \sigma^{\mu\nu} u_r)\widetilde\varphi\, B_{\mu\nu}$	$Q_{\varphi q}^{(3)}$	$(\varphi^\dagger i\overleftrightarrow{D}^I_\mu \varphi)(\bar q_p \tau^I \gamma^\mu q_r)$
$Q_{\varphi\widetilde B}$	$\varphi^\dagger\varphi\, \widetilde B_{\mu\nu} B^{\mu\nu}$	Q_{dG}	$(\bar q_p \sigma^{\mu\nu} T^A d_r)\varphi\, G^A_{\mu\nu}$	$Q_{\varphi u}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar u_p \gamma^\mu u_r)$
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Table 2: Dimension-six operators other than the four-fermion ones.

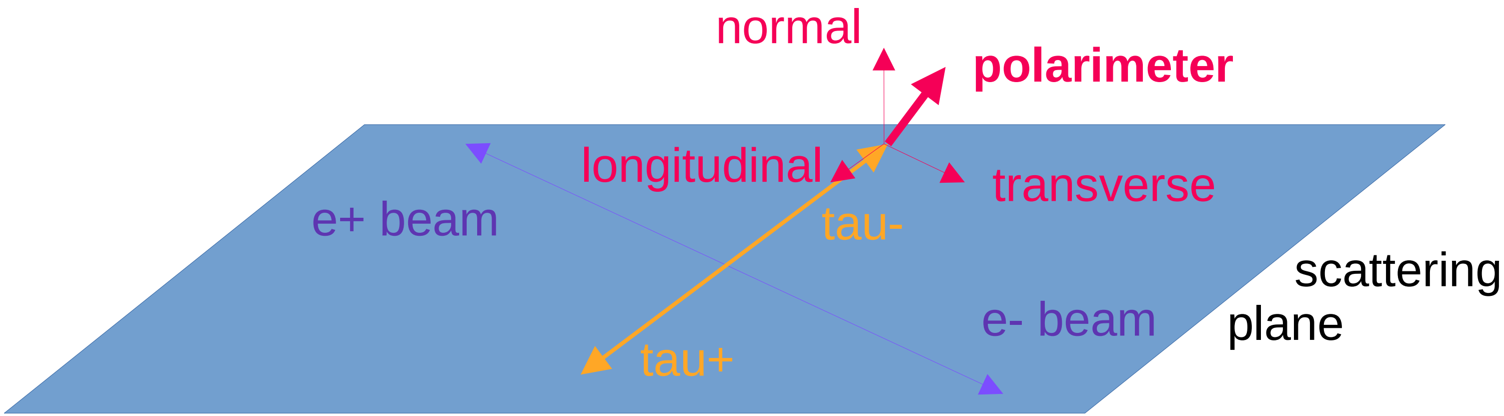
SMEFTsim 3.0 – a practical guide

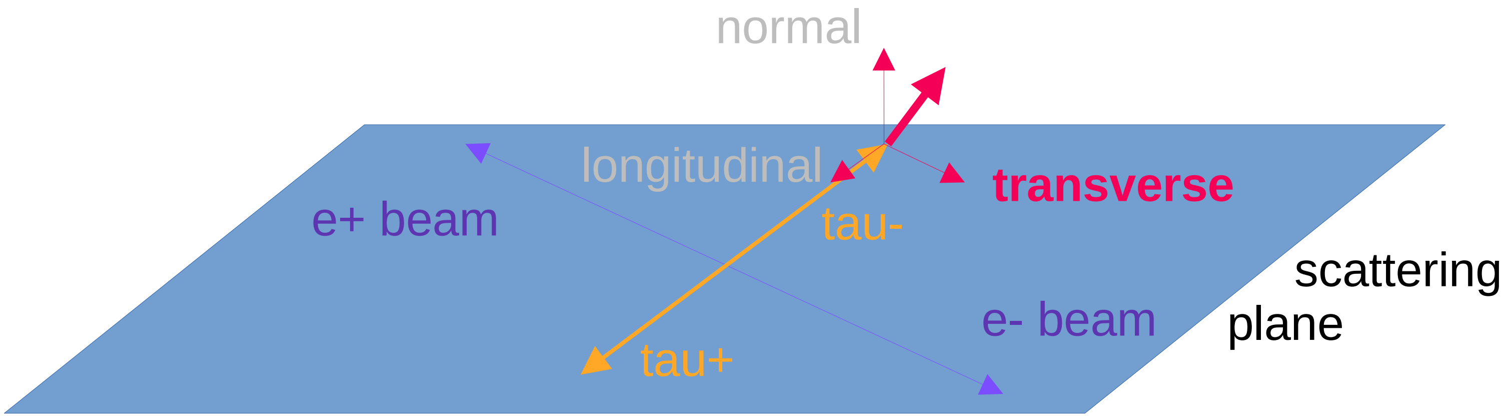
arXiv:2012.11343

coefficients in SMEFTsim (general model):

ceWRe33
ceWIm33
ceBRe33
ceBIm33

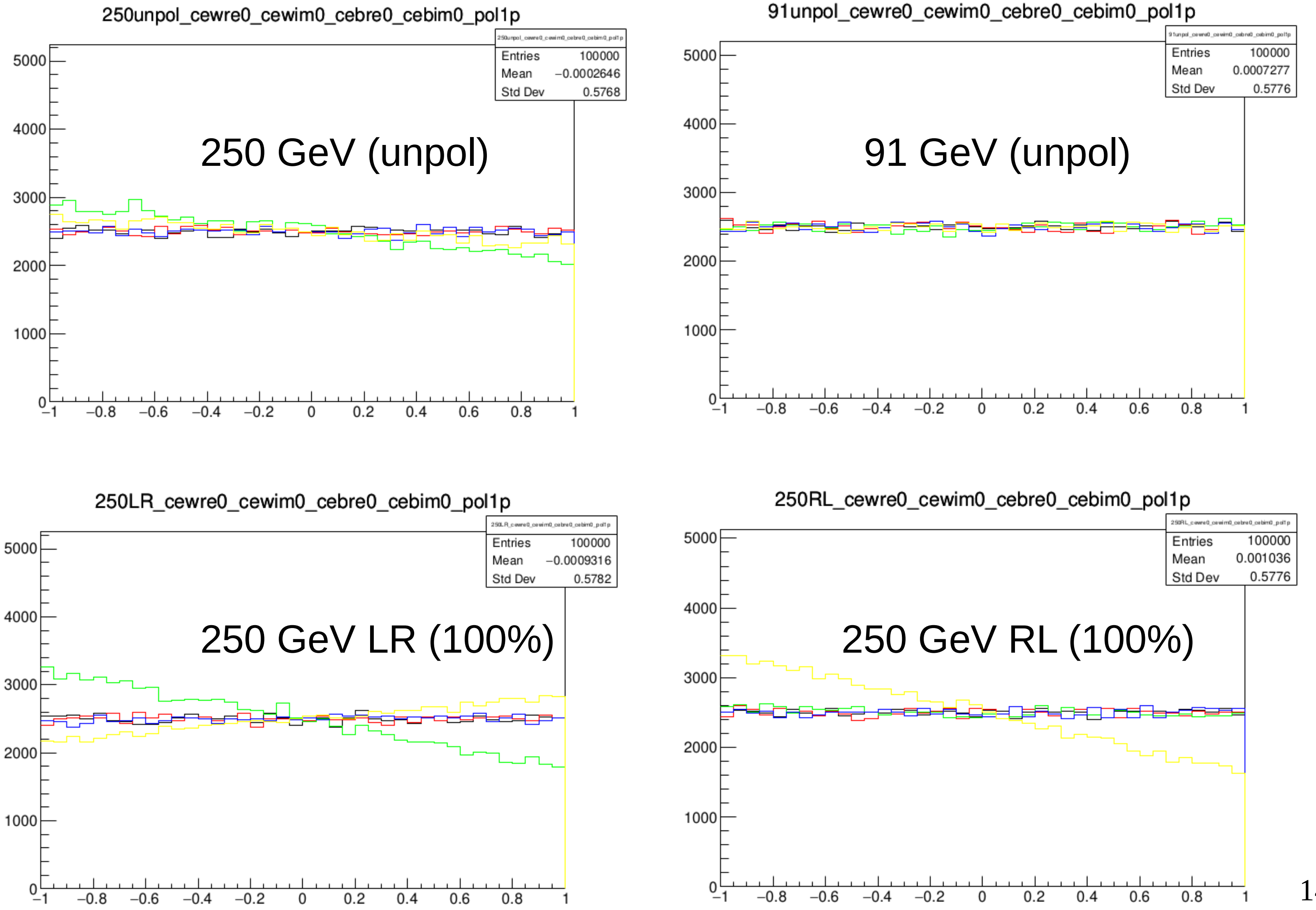
real/imag. tau-tau


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


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

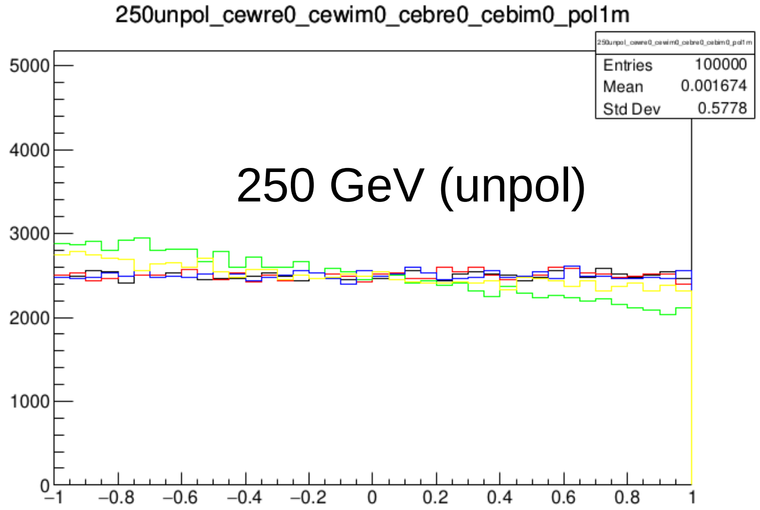
transverse pol
(tau+)

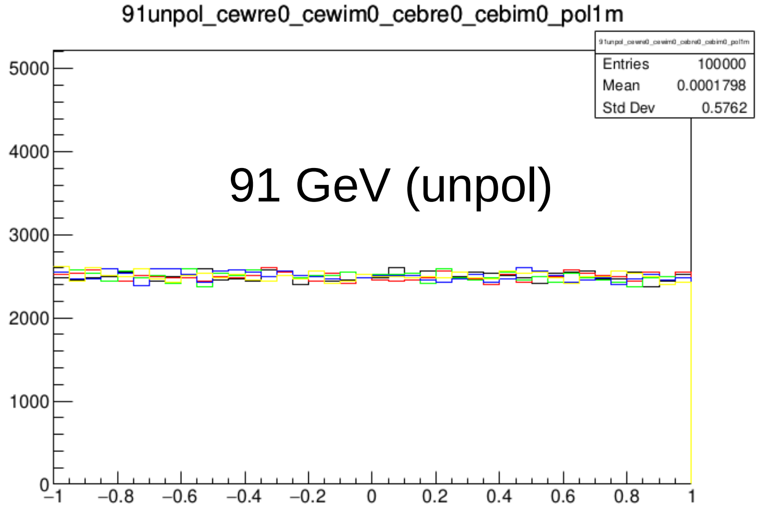
SM
cewre33=1
all others 0
cewim33=1
cebre33=1
cebim33=1

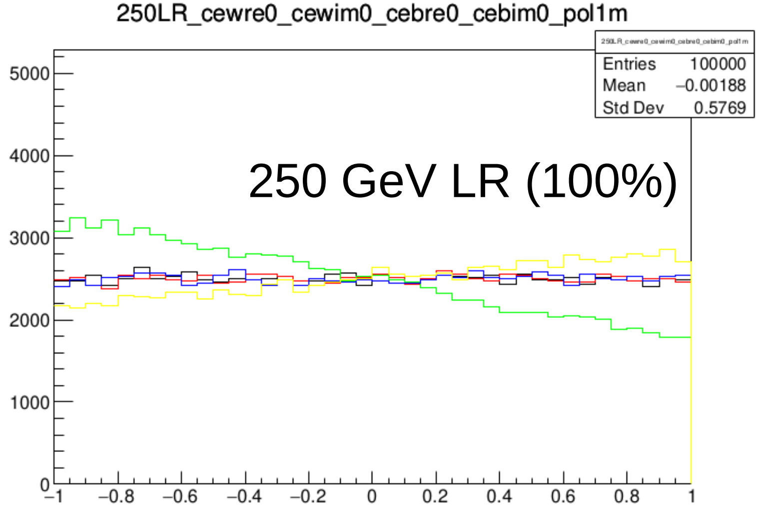


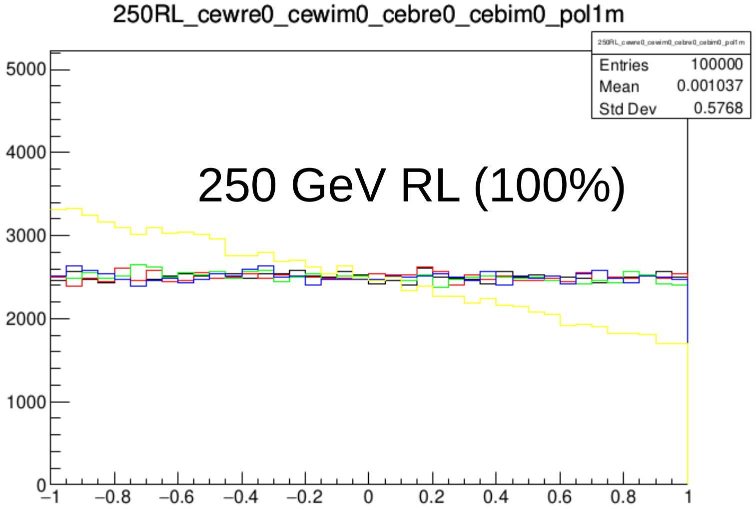
transverse pol
(tau-)

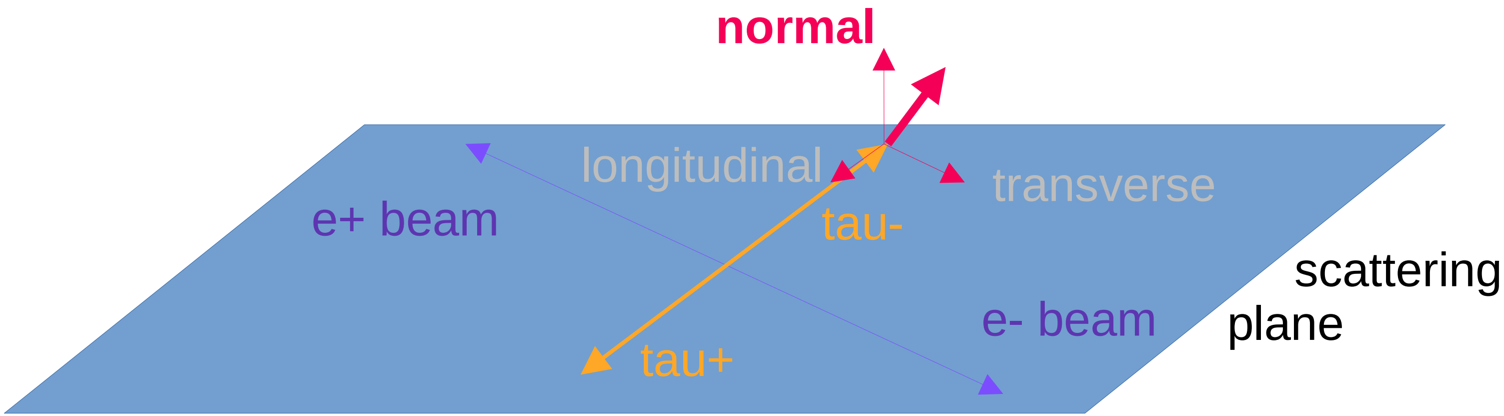
SM
cewre33=1
cewim33=1
cebre33=1
cebim33=1





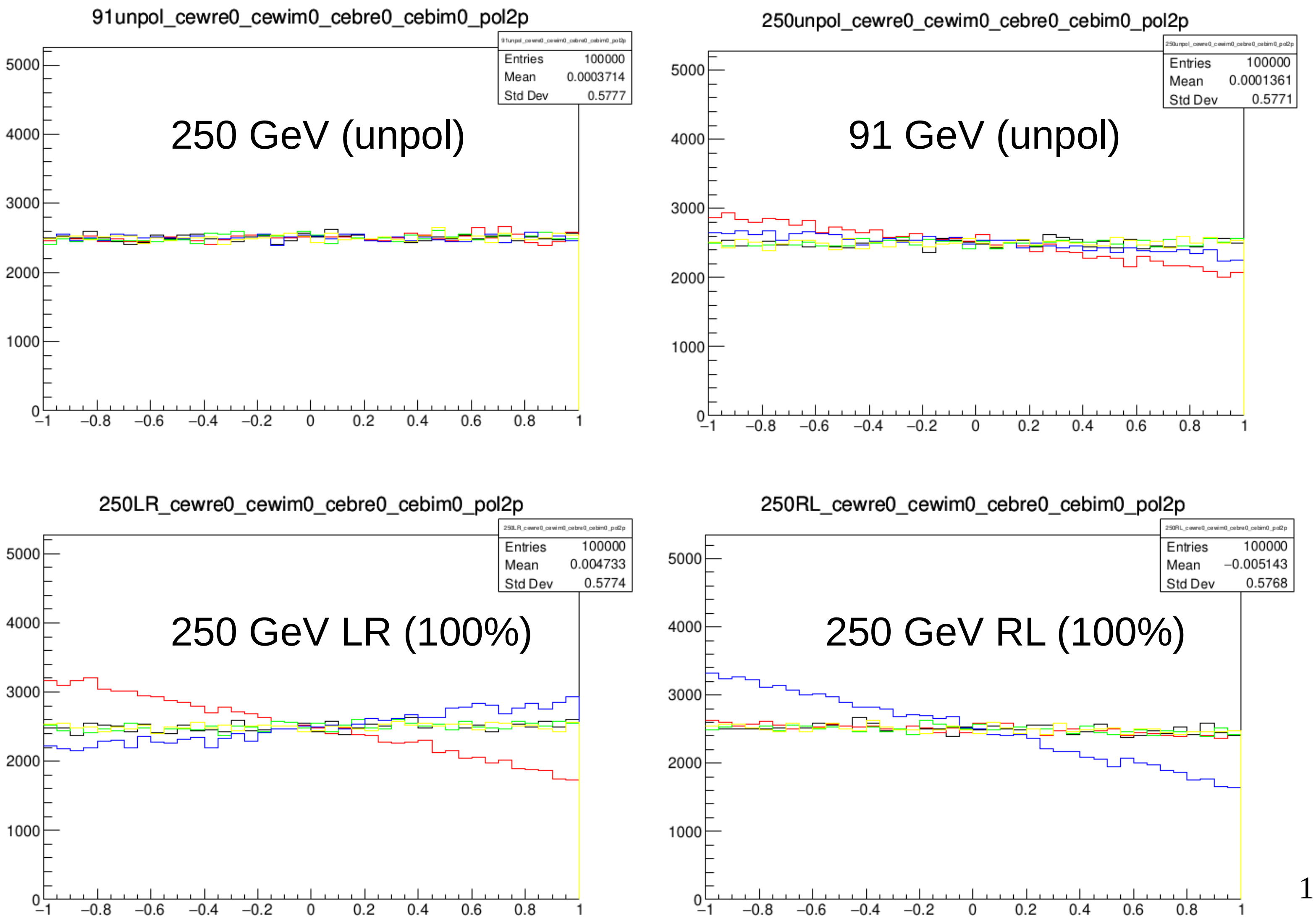




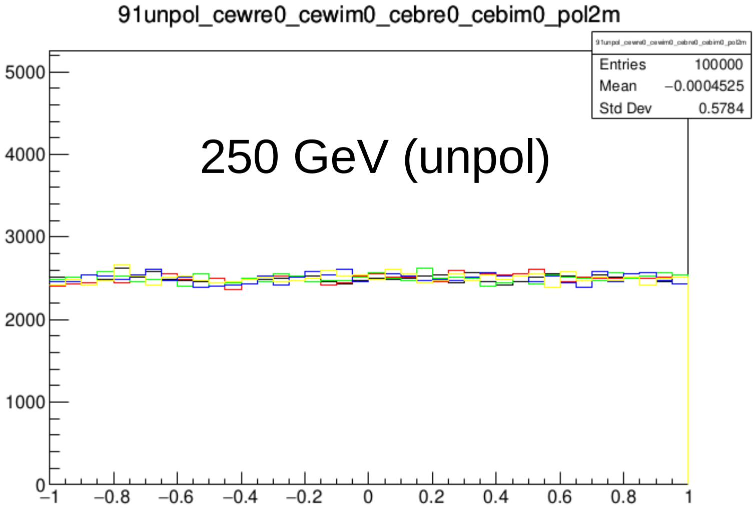

normal
longitudinal
transverse
e+ beam
tau-
scattering
plane
e- beam
tau+

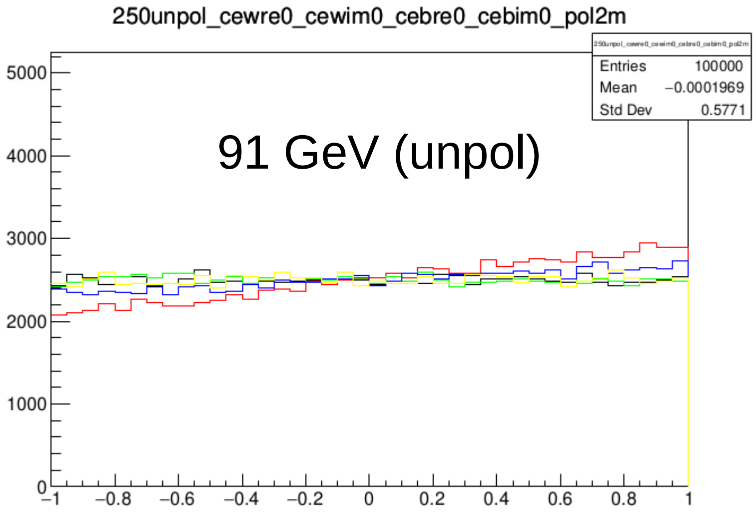
normal pol
(tau+)

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



normal pol
(tau-)





SM
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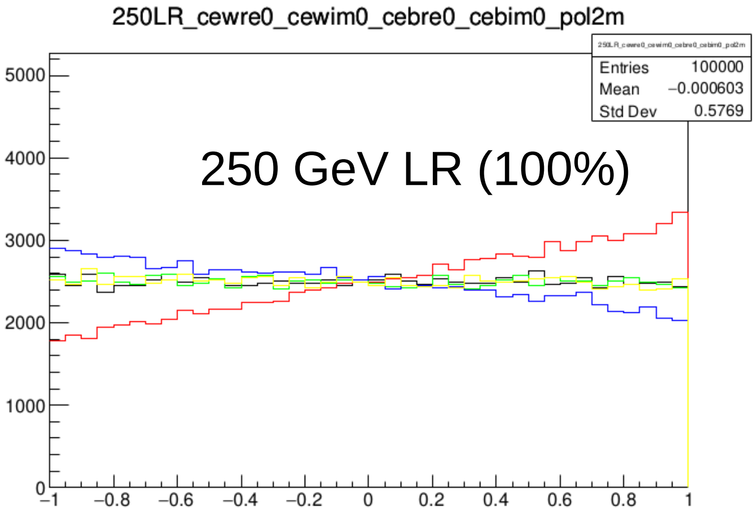
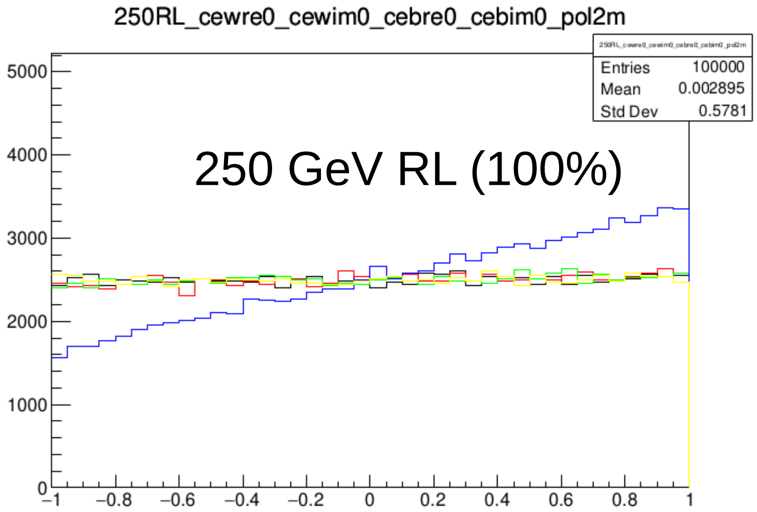
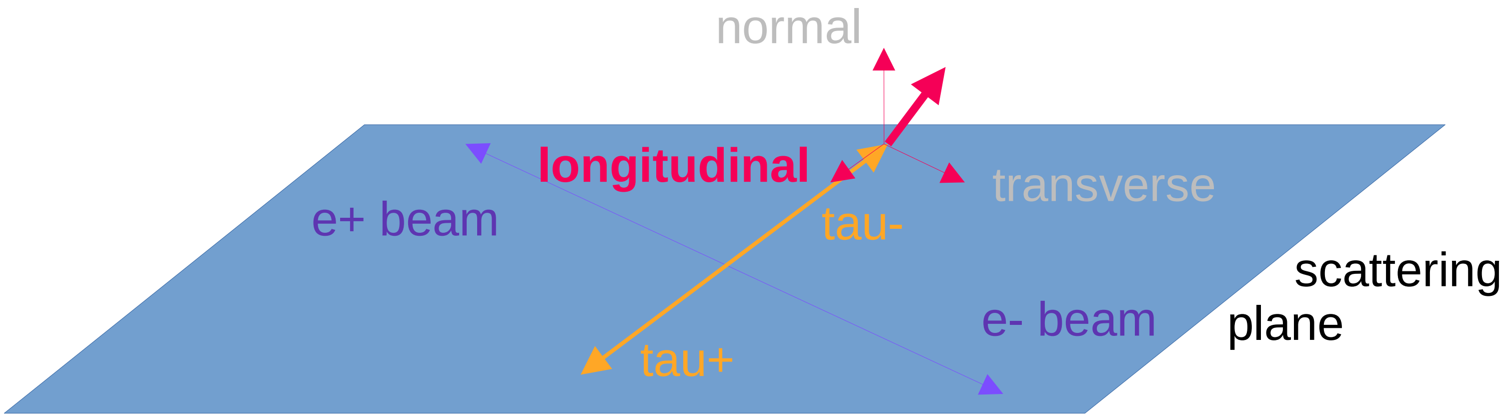
cebim33=1





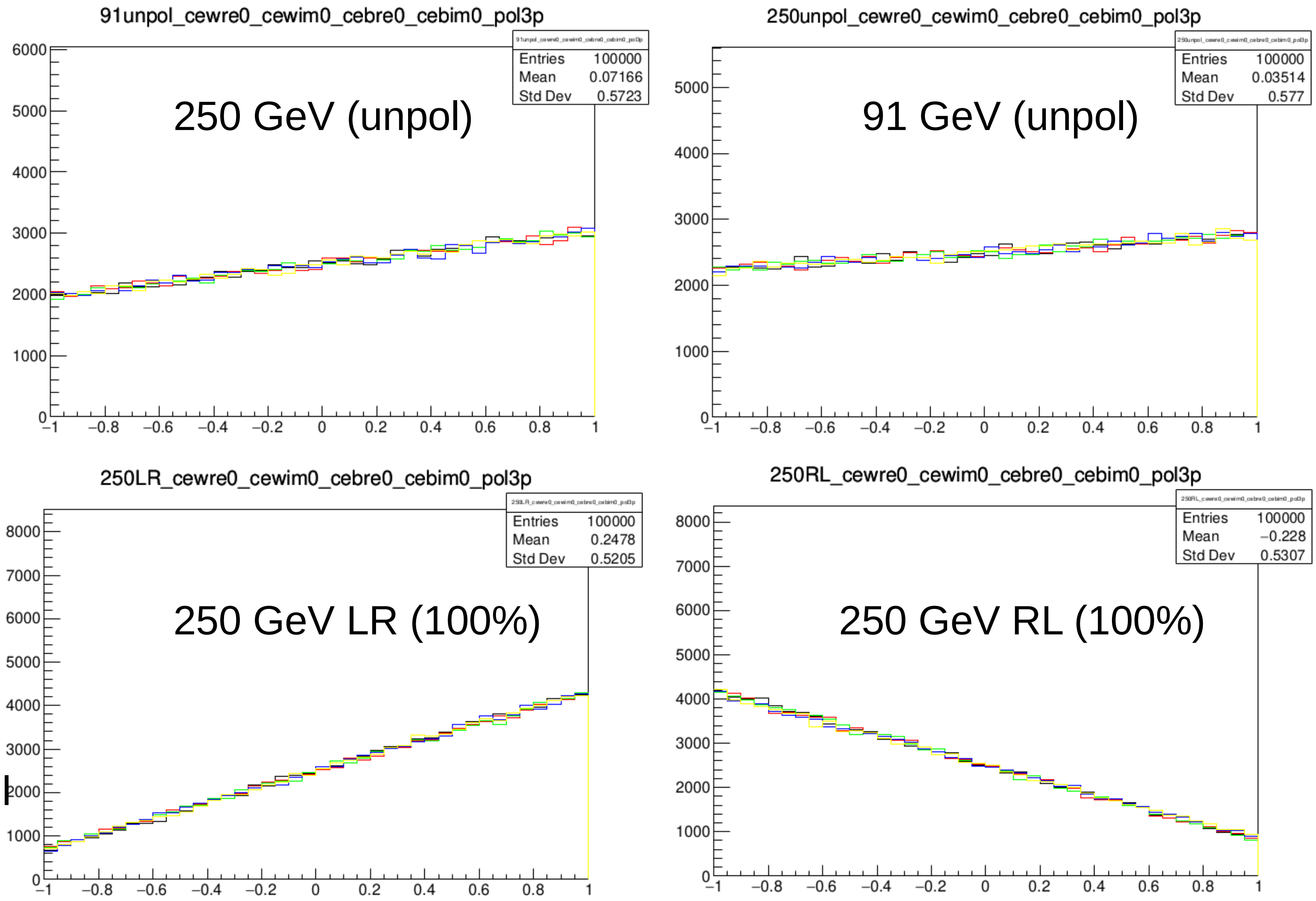


this is the "usual" tau polarisation measurement:
fraction of -ve / +ve helicity (≈ left- / right-handed) taus

longitudinal pol (tau+)

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

these SMEFT coefficients have no effect, but others will
→ investigate more



can also construct explicitly CP-odd observables:

understand connection to SMEFT approach

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

η_Θ = “-” most interesting : “effect at tree level”

summary

→ tau spin orientation in e+e- → tau+ tau- has some sensitivity to
2 particular SMEFT couplings

→ potentially with CP violation

plans

→ improve my understanding

→ continue full reconstruction of e+ e- → tau+ tau- final state
(Yumino’s thesis work)