tau polarisation in $e^+ e^- \rightarrow tau^+ tau^-$

work in progress

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ECFA meeting, October 2024

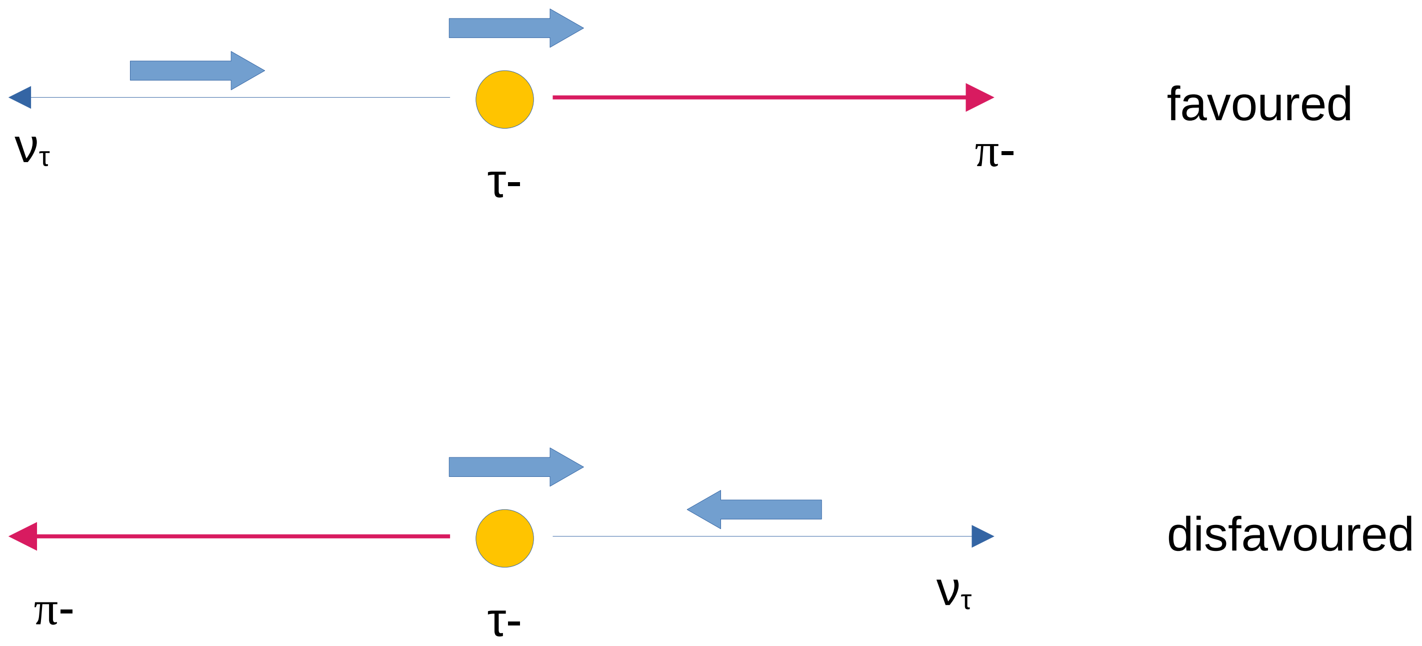
why study this process ?

high statistics, simple process
→ precise test of SM

access to tau spin
→ unique handle [together with $e^+ e^- \to t \bar{t}$]

what are the detector requirements ?

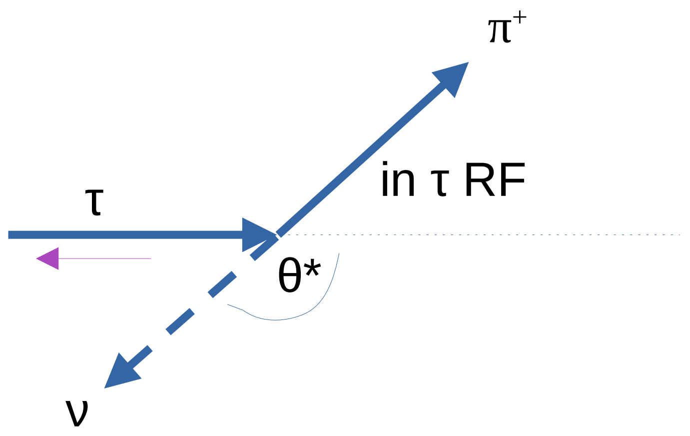
distribution of tau decay products reflect tau's spin orientation

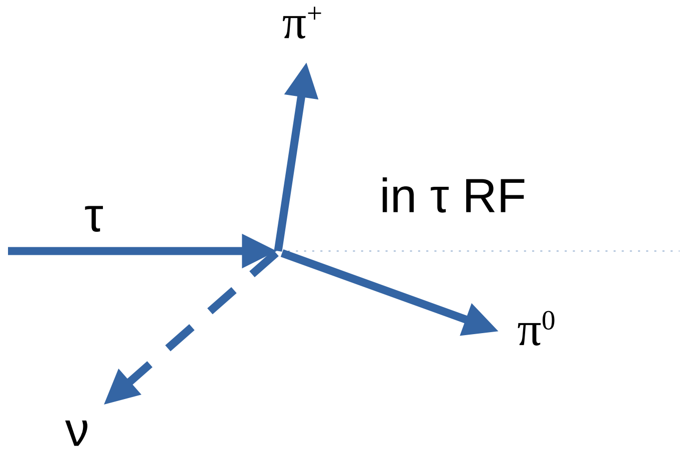


in this simplest tau decay, optimal spin direction estimator "polarimeter"

is the pion (or neutrino) momentum direction in the tau rest frame

tau polarimeter : estimator of spin orientation





neutrino carries tau's angular momentum
neutrino direction is optimal polarimeter

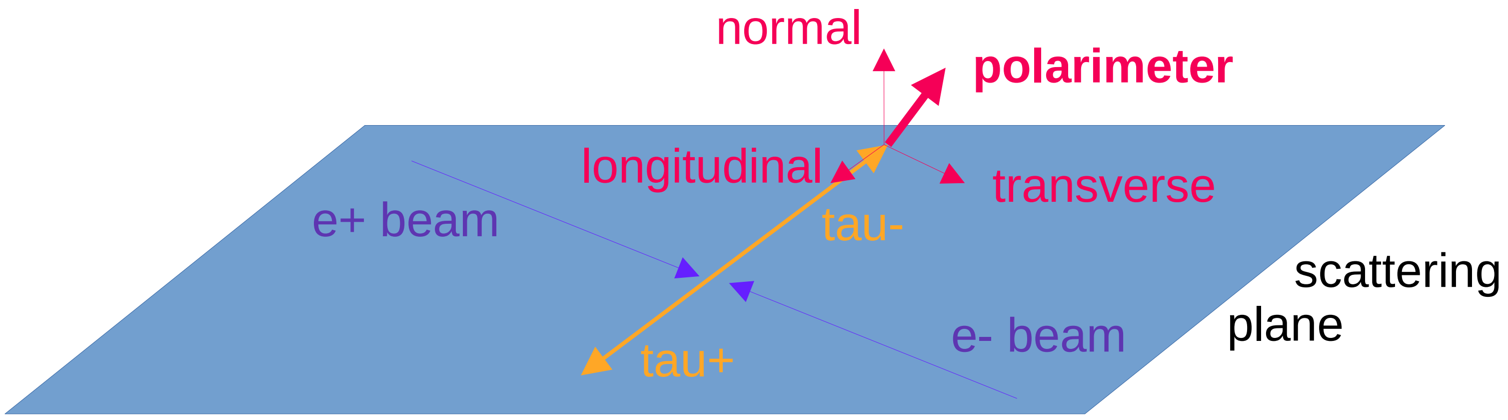
helicity ~ *longitudinal* polarisation ~ cos(θ*)

more complicated optimal polarimeter

$$\mathbf{h}(\tau^{\pm} \rightarrow \pi^{\pm}\pi^{0}\nu) \propto m_{\tau}(E_{\pi^{\pm}} - E_{\pi^{0}})(\mathbf{p}_{\pi^{\pm}} - \mathbf{p}_{\pi^{0}}) + \frac{1}{2}(p_{\pi^{\pm}} + p_{\pi^{0}})^{2}\mathbf{p}_{\nu},$$

to extract optimal polarimeters, need full decay kinematics, including π^0, neutrino
in principle polarimeters for all hadronic modes have same sensitivity,
extraction simplest for single- and double-pion decays
leptonic modes have reduced sensitivity [because of 2 neutrinos/decay]

polarimeter components



for “usual” tau polarisation measurement (LH or RH tau) → longitudinal component

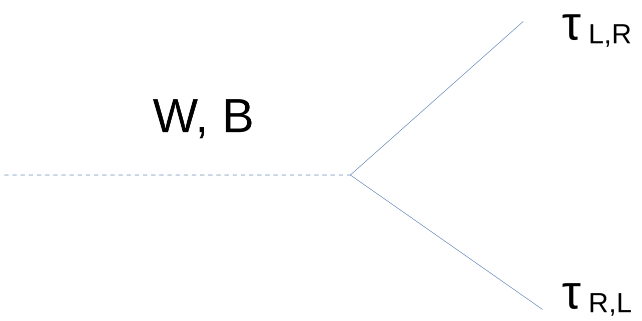
BSM effects on the e+e- → τ+τ- process : EFT approach

Dimension-Six Terms in the Standard Model Lagrangian*

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

$\psi^2 X \varphi$	
Q_{eW}	$(\bar{l}_p \sigma^{\mu\nu} e_r)\tau^I \varphi W^I_{\mu\nu}$
Q_{eB}	$(\bar{l}_p \sigma^{\mu\nu} e_r)\varphi B_{\mu\nu}$

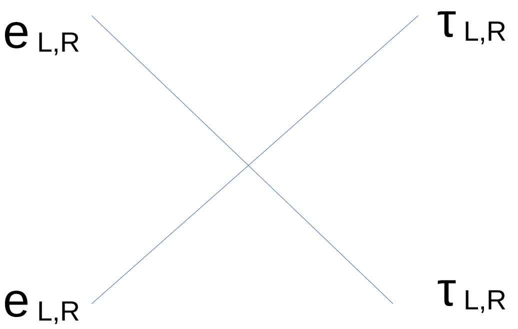
$(\bar{L}L)(\bar{L}L)$		$(\bar{R}R)(\bar{R}R)$		$(\bar{L}L)(\bar{R}R)$	
Q_{ll}	$(\bar{l}_p \gamma_\mu l_r)(\bar{l}_s \gamma^\mu l_t)$	Q_{ee}	$(\bar{e}_p \gamma_\mu e_r)(\bar{e}_s \gamma^\mu e_t)$	Q_{le}	$(\bar{l}_p \gamma_\mu l_r)(\bar{e}_s \gamma^\mu e_t)$



coupling of taus to W, B: mix L, R

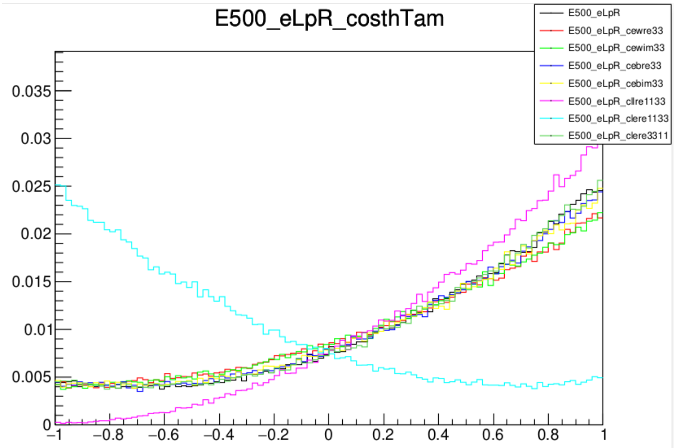
related to tau dipole moments

imaginary coefficients ~ CP violation

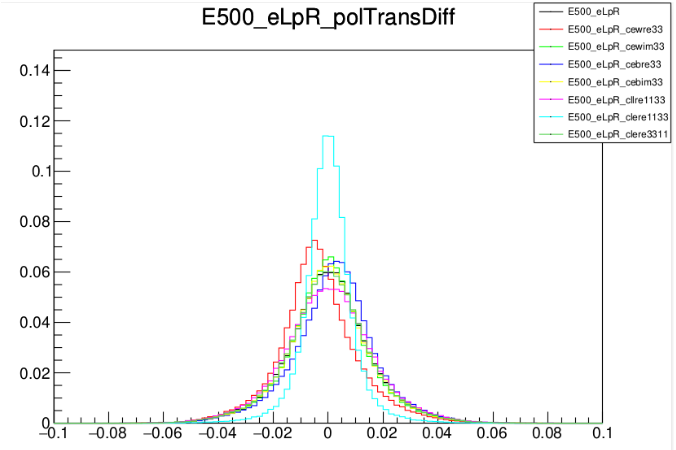


4-f coupling of electron and tau currents

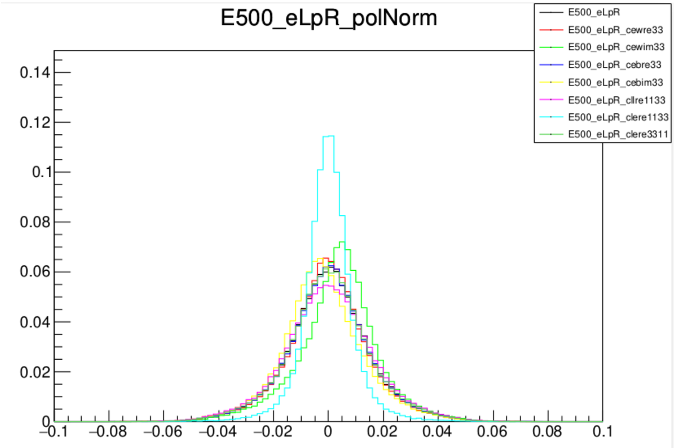
these SMEFT coefficients influence different distributions in different ways, for example:



cos (θ*)



difference of **transverse** polarimeters



sum of **normal** polarimeters

SM

Q_{eW}	$(\bar{l}_p \sigma^{\mu\nu} e_r)\tau^I \varphi W^I_{\mu\nu}$
Q_{eB}	$(\bar{l}_p \sigma^{\mu\nu} e_r)\varphi B_{\mu\nu}$

Re
Im
Re
Im

$(\bar{L}L)(\bar{L}L)$	
Q_{ll}	$(\bar{l}_p \gamma_\mu l_r)(\bar{l}_s \gamma^\mu l_t)$

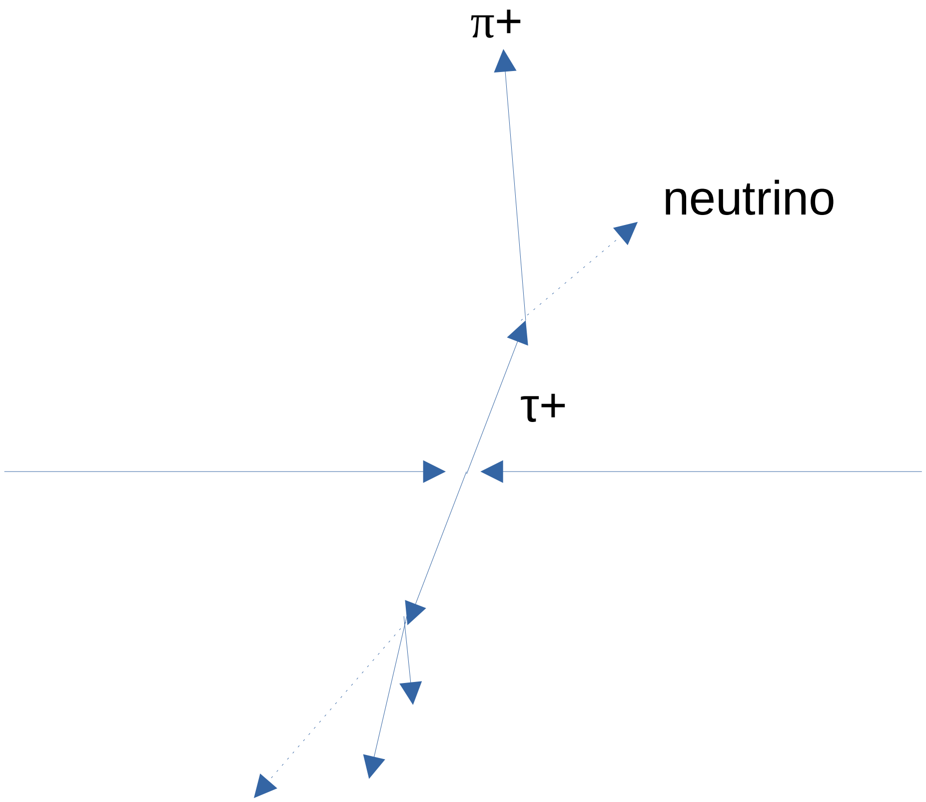
$(\bar{L}L)(\bar{R}R)$	
Q_{le}	$(\bar{l}_p \gamma_\mu l_r)(\bar{e}_s \gamma^\mu e_t)$

$(ee)_L(\tau\tau)_R$

$(ee)_R(\tau\tau)_L$

variations depend on Wilson coefficients, energy, beam polarisation, ...

can we access these polarimetric quantities?



→ 4-momentum conservation
→ tau candidates’ invariant mass

“cone method”
neutrino lies on cone around *visible* momentum
cone angle depends on p_{VIS}, m_τ, E_τ

if we know the
CM frame of τ+ τ- and
CM energy,
it’s a well constrained system

→ can extract tau direction,
decay kinematics,
”polarimeter”
[to within 2-fold ambiguity]

this applies when ISR is negligible:
at the Z-pole

kinematic unknowns and constraints in e e → tau tau,
away from the Z pole

at Z-pole: can assume known tau energy,
back-to-back topology

at higher energies need to take account of
(usually unseen) ISR

momentum/energy conservation (including ISR)

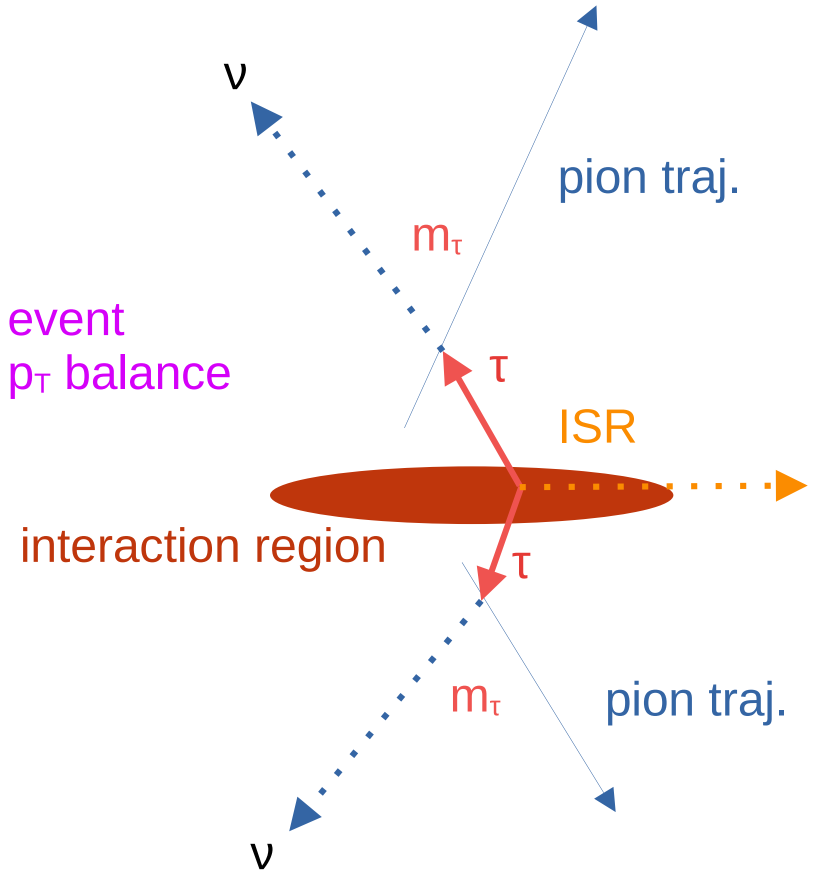
tau masses

impact parameters w.r.t. beam spot

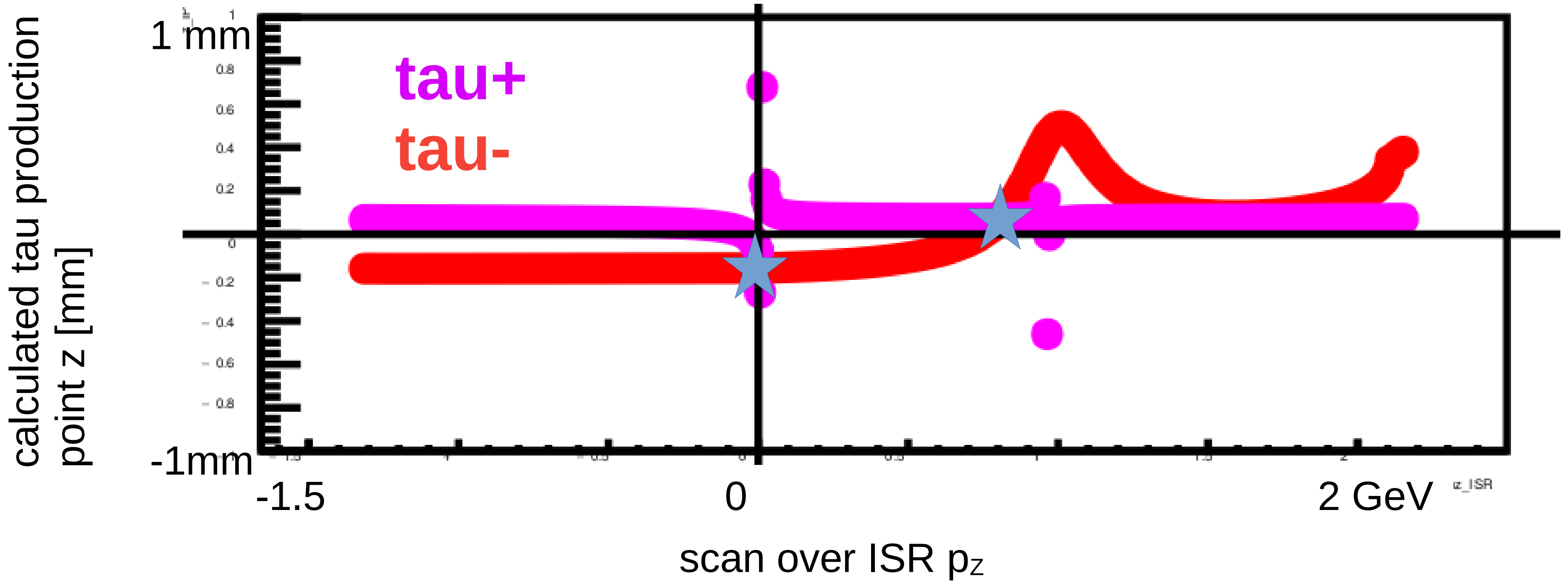
interaction region

under-constrained system
→ several possible solutions per event

scan across unseen ISR momentum, check for consistency



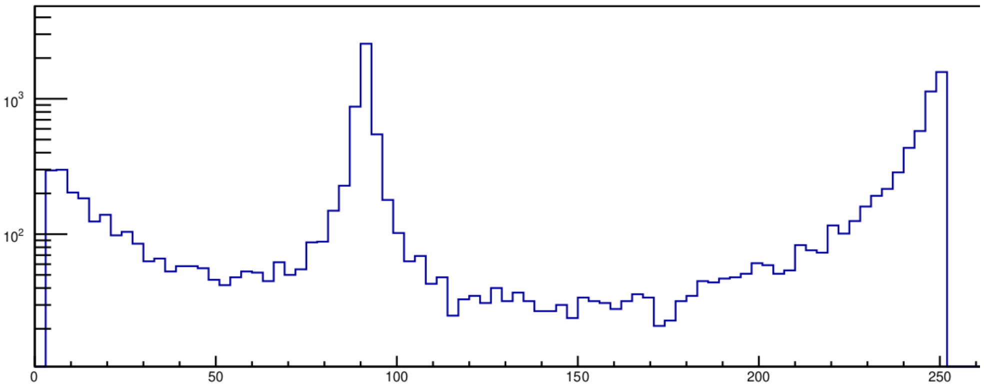
example, for one event



this event has **2 solutions**

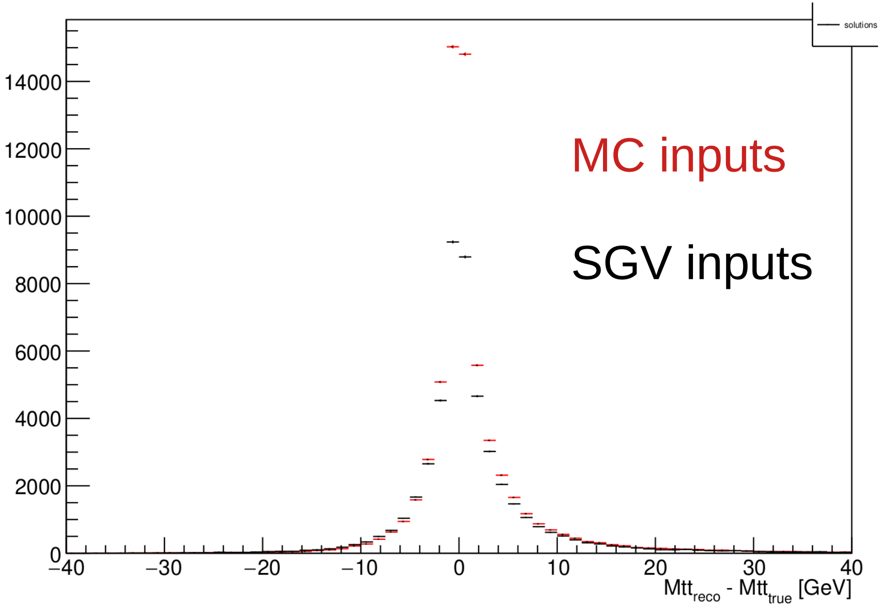
look at performance at 250 GeV using

- MC truth values of visible particle momenta
- fast detector simulation SGV [by M. Berggren, based on ILD]



m_Z 250 GeV

true distribution of $m_{\tau\tau}$



$m_{\tau\tau}$: reconstructed – true

resolution ~ GeV

efficiency smaller with SGV

look at performance at 250 GeV using
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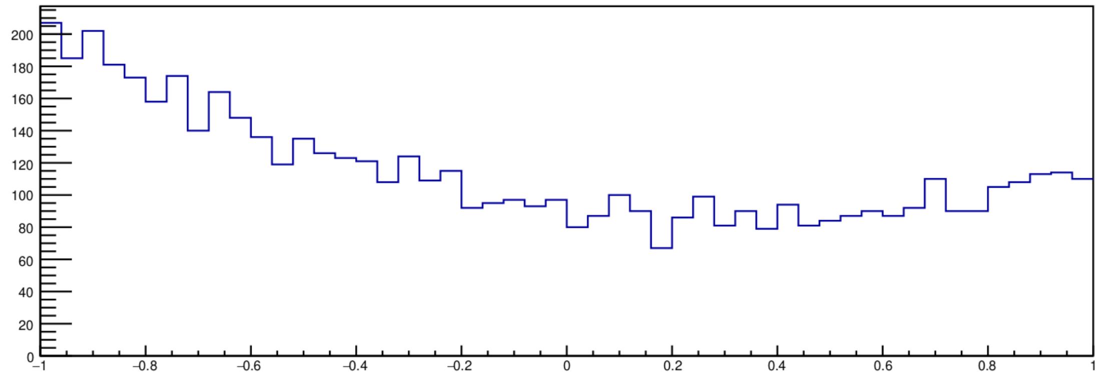
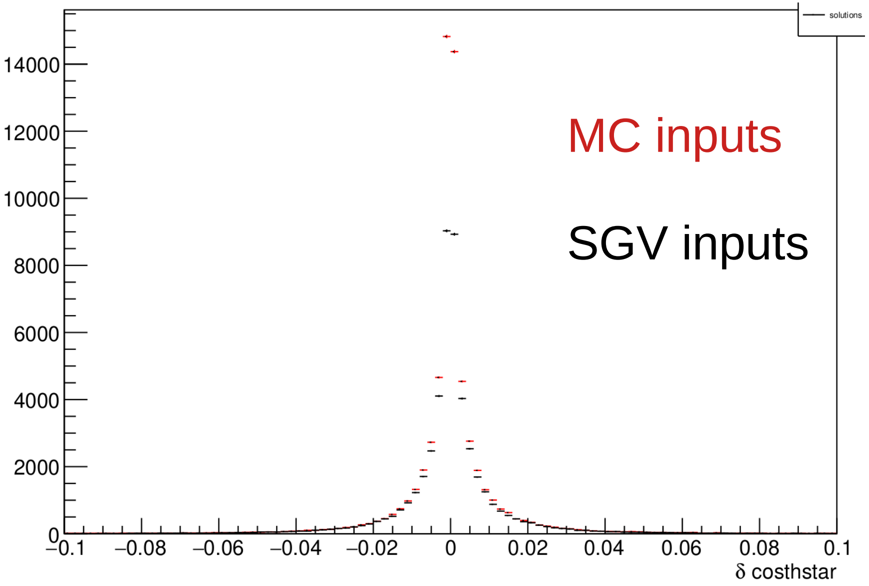


true distribution of CM scattering angle: cos θ*



cos θ* : reconstructed – true

resolution < 0.01

look at performance at 250 GeV using

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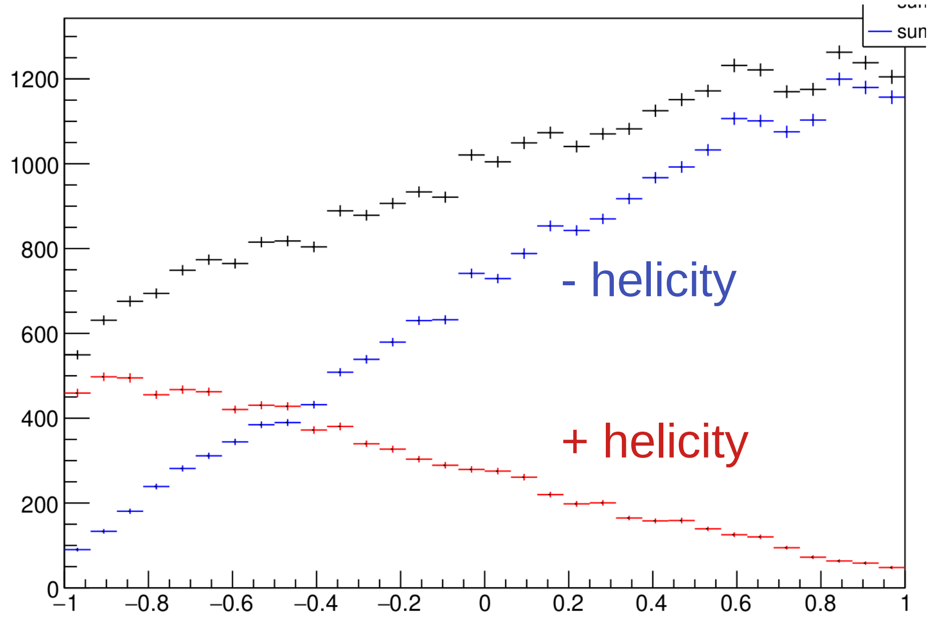
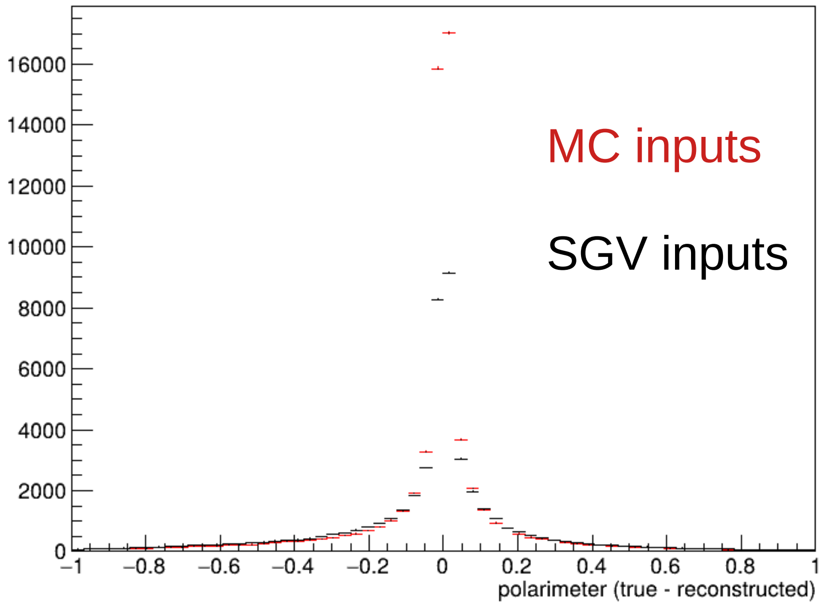


reconstructed longitudinal polarimeter component



long. polarimeter : true – reco

resolution < 0.1

Summary

tau polarisation (longitudinal, transverse) at high energy is a unique probe for BSM
- e.g. via constraints of SMEFT operator coefficients
- relation to weak dipole moments of tau

attempt to use maximal information to extract tau polarisation
- in continuum e+ e- → tau+ tau- : an under-constrained system

developed a rather (over-?) complicated method

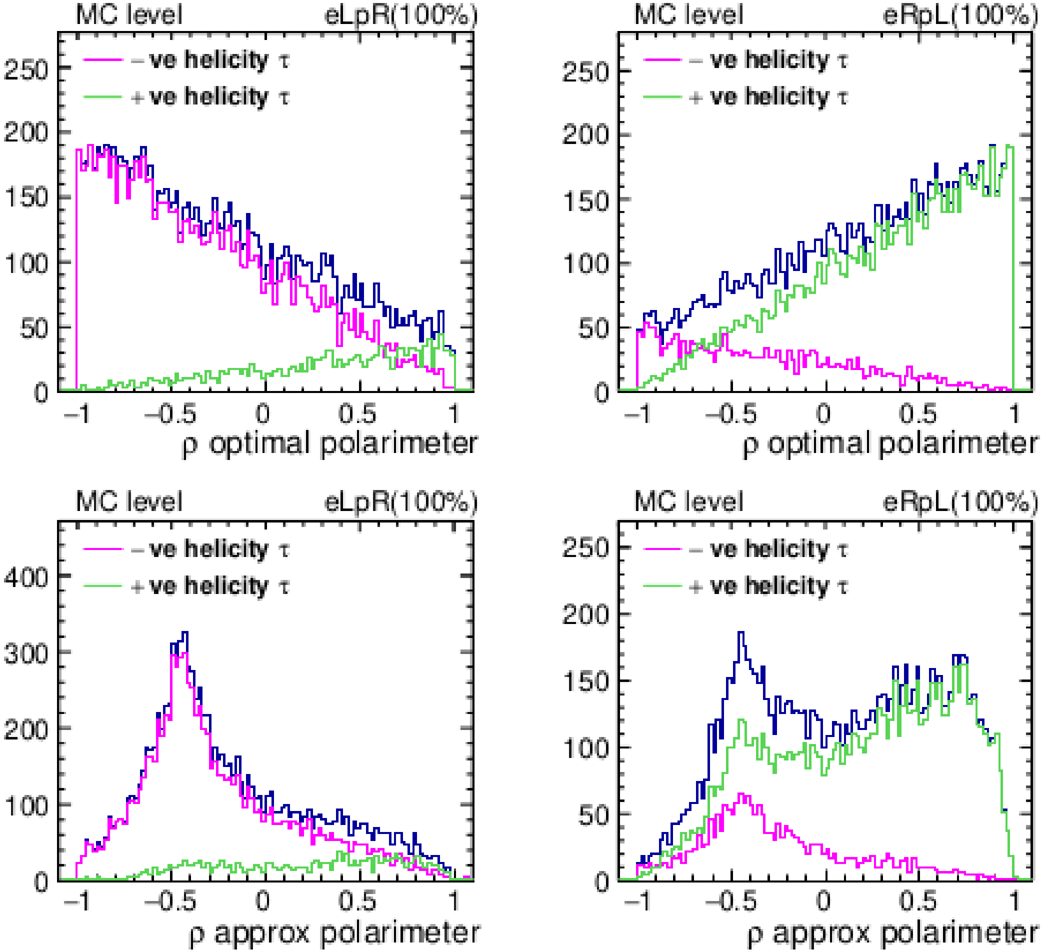
- it seems to work OK:
  - $m_{\tau\tau}$, scattering angle, polarimeter reconstructed with sufficient precision
- relies on several aspects of detector performance
  - impact parameter
  - π^0 reconstruction
  - track momentum
    - → now being investigated using fast detector simulation

no time for firm physics results for this ECFA strategy update...

backup

optimal: using neutrino momentum

approx: without



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**