Systematics of TauSpinner for τ pair with two hard jets and its new development

Marzieh Bahmani

[1]IFJ-PAN , Poland

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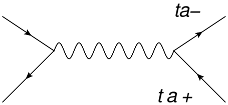
Introduction

- τ lepton signature can provide a powerful tool in many areas, like studies of hard process characteristics, measurements of properties of Higgs boson or in a search for new physics.
- TauSpinner is a tool that allows to modify the physics model of the Monte Carlo generated samples due to the changed assumptions of event production dynamics, but without the need of re-generating events.
- The events must feature kinematics of τ lepton production and its decay products, but information on initial partons is assumed to be unknown, and therefore presumed PDF configuration and matrix element for the hard process for calculating spin weight have been used instead.
- The only information used is the kinematics of final state, therefore it can be used both for Data and MC simulations

TauSpinner Program

- TauSpinner Program is commonly used by the LHC experiments :
  - TauSpinner $(2 \to 2)$ processes



  - TauSpinner $(2 \to 4)$ processes - NEW !

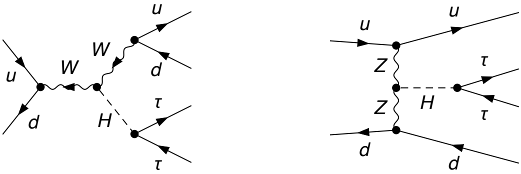


Figure: Depending on the initial state , tree level matrix elements are of the order of $\alpha_s \alpha_{EW}$ or α^2_{EW}, sometimes involving triple WWs coupling.

Systematic uncertainties of TauSpinner

- Systematic uncertainties on the average τ lepton polarization and other sensitive observable like visible energy fraction of π in the $\tau \rightarrow \pi\nu$ decays calculated using spin weight.
- Variations of the input parameter :QCD factorization and normalization scale used for cross-section calculations, QCD and EW couplings and parametrisation of the parton structure functions.
- Comparison of spin weight between (2→2) and (2→4) matrix element in p p→ $\tau\tau$ j j events.
- (10^6) of Drell-Yan events of p p→ $\tau\tau$ j j processes with no polarization generated with MadGraph 5 used.

EW correction, QCD scale and parton density function (PDF)

- Variants of initialization for (2→4) process

Type	EWSH=1 input: G_F, α_{QED}, M_z	EWSH=2 input: $G_F, sin(\theta_w)^2, M_z$	EWSH=3 input: G_F, M_W, M_z	EWSH=4 input: $G_F, M_W, M_z, sin(\theta_w)^2$
M_z	91.1882 GeV	91.1882 GeV	91.1882 GeV	91.1882 GeV
M_W	80.4190 GeV	79.9407 GeV	80.4189 GeV	80.4189 GeV
$sin(\theta_w)^2$	0.222246	0.231470	0.222246	0.231470
$1/\alpha_{QED}$	132.5070	128.7538	132.5069	127.2272
G_F	1.6639 10^{-5} GeV^{-2}	1.6639 10^{-5} GeV^{-2}	1.6639 10^{-5} GeV^{-2}	1.6639 10^{-5} GeV^{-2}

- 4 predefined choices for the scale μ^2 are available

scalePDFOpt=0	μ= 200 GeV
scalePDFOpt=1	$\mu = \sqrt{s}$
scalePDFOpt=2	$\mu = \Sigma m_T$, $m_T^2 = m^2 + P_\perp^2$
scalePDFOpt=3	$\mu = \Sigma E_\perp$, $E_\perp = E_{P_\perp} / \lvert \overline{P} \rvert$

$$\alpha_s(\mu^2) = \frac{\alpha_s(M_Z^2)}{1 + 4\pi\alpha_s(M_Z^2)(11 - 2N_f/3)\ln\frac{\mu^2}{M_Z^2}}$$

Systematic of the TauSpinner predictions

- τ polarization from LEP experiment: P = -0.145+-0.002
- There is no significant difference between the result calculated from (2→2) and (2→4) ME.
- the systematic of TauSpinner with respect to different QCD scale option is 3.6 percent.

Table: τ-lepton polarization in window 88 $< M_{\tau\tau} <$ 92 GeV for different EWSH

	EWSH=1	EWSH=2	EWSH=3	EWSH=4
$2 \to 4$	-0.2048 $\pm$ 0.0015	-0.1385 $\pm$ 0.0015	-0.2014 $\pm$ 0.0015	-0.1331 $\pm$ 0.0015
$2 \to 2$	-0.2063 $\pm$ 0.0015	-0.1407 $\pm$ 0.0015	-0.2055 $\pm$ 0.0015	-0.1412 $\pm$ 0.0015

Table: τ-lepton polarization in window 88$< M_{\tau\tau} <$92 GeV in different QCD scale

	scalePDFOpt=0	scalePDFOpt=1	scalePDFOpt=2	scalePDFOpt=3
$2 \to 4$	-0.1362 $\pm$ 0.0015	-0.1331 $\pm$ 0.0015	-0.1380 $\pm$ 0.0015	-0.1363 $\pm$ 0.0015
$2 \to 2$	-0.1368 $\pm$ 0.0015	-0.1412 $\pm$ 0.0015	-0.1377 $\pm$ 0.0015	-0.1378 $\pm$ 0.0015

- TauSpinner is interfaced with LHAPDF v6 library.

Table: τ-lepton polarization in the window 88$< M_{\tau\tau} <$ 92 GeV in different PDFsets

PDFsets	TauSpinner $2 \to 4$	TauSpinner $2 \to 2$
cteq6ll.LHpdf	-0.1331 $\pm$ 0.0015	-0.1412 $\pm$ 0.0015
MSTW2008nnlo90cl.LHgrid	-0.1354 $\pm$ 0.0015	-0.1379 $\pm$ 0.0015
CT10.LHgrid	-0.1338 $\pm$ 0.0016	-0.1368 $\pm$ 0.0016

- the systematic of TauSpinner with respect to different PDFsets is 1.7 percent.

Interference between QCD and EW sub-processes

Studied by artificially enhancing strong coupling in ME calculation

$\alpha_{QCD} = \alpha_S$:
$\sigma^{tot} = \sigma^{QCD} + \sigma^{EW} + \sigma^{I} = |ME|^2 = |\alpha_S \alpha_{EW} M_1 + \alpha_{EW}^2 M_2|^2 = |\alpha_S \alpha_{EW} M_1|^2 + |\alpha_{EW}^2 M_2|^2 + \alpha_{EW}^3 \alpha_S (M_1 M_2^* + M_1^* M_2)$

$\alpha_{QCD} = 2\alpha_S$:
$|ME|^2 = 4\sigma^{QCD} + \sigma^{EW} + 2\sigma^{I}$

$\alpha_{QCD}=0$:
$|ME|^2 = |\alpha_{EW}^2 M_2|^2 = \sigma^{EW}$

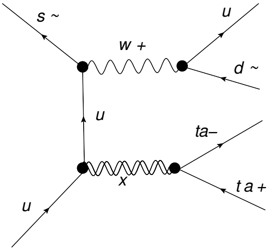
$$\frac{\sigma^{I}}{\sigma^{tot}} = \frac{1}{2}[4 - 3\frac{\sigma^{QCD}_{\alpha=0}}{\sigma^{tot}} - \frac{\sigma^{QCD}_{2\alpha_S}}{\sigma_{tot}}] \tag{1}$$

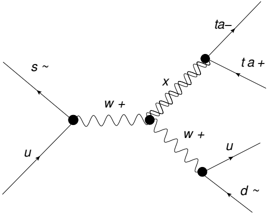
Sample without cut	σ(pb)	$(\sigma^{I}/\sigma^{tot})$
$\alpha^{QCD} = \alpha_s$	474581 $\pm$ 688.8	0.0101
$\alpha^{QCD} = 2\ \alpha_s$	1897110 $\pm$ 2753.9	0.0202
$\alpha^{QCD} = 0.0$	416.694 $\pm$ 7.693	0.0
Sample with Kinematical selection used for enhances EW sub-processes	**σ(pb)**	**$(\sigma^{I}/\sigma^{tot})$**
$\alpha^{QCD} = \alpha_s$	120602 $\pm$ 347.27	-0.0185
$\alpha^{QCD} = 2\ \alpha_s$	437487$\pm$ 1272.2	-0.037
$\alpha^{QCD} = 0.0$	16461.9 $\pm$ 76.69	0.0

Table: The cross section for different α_{QCD} used for ME calculation, and ratio of interference term for two different samples.

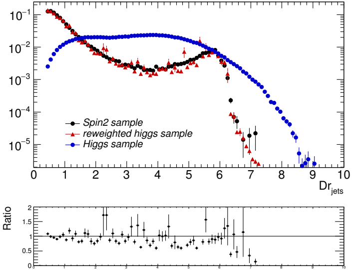
Non-Standard Model

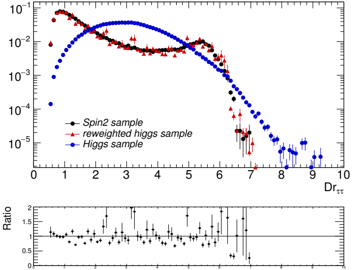
- Evidence of a new particle with mass 125 GeV decaying into a pair of τ leptons at LHC gains the interest in ascertaining its spin in this channel.
- Introducing non-standard states and couplings and study their effects in the vector-boson-fusion processes and exploiting the spin correlations of τ-lepton pair decay products can be useful for that.





Re-weighting (preliminary plots)





$$Dr_{\tau\tau} = \sqrt{(\eta_{\tau^+} - \eta_{\tau^-})^2 + (\phi_{\tau^+} - \phi_{\tau^-})^2} \quad (2)$$

$$Dr_{jj} = \sqrt{(\eta_{jet1} - \eta_{jet2})^2 + (\phi_{jet1} - \phi_{jet2})^2} \quad (3)$$

Summary

- The sample of events p p$\rightarrow \tau\tau$ j j generated without spin effect used for calculating spin weight, and helicity for τ lepton attributed for different numerical values of α_s, its variant and EWSH for (2$\rightarrow$2) and (2$\rightarrow$4).
- The interference between QCD and EW sub-processes were studied
- Recent development on non-standard model ME implementation in $\tau\tau$ j j `TauSpinner`.

For Further Reading I

Z. Czyczula, T. Przedzinski, Z. Was
Eur.Phys.J. **C72** (2012) 1988

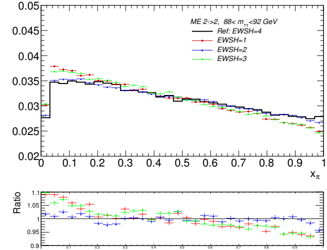
J.Kalinowski, W. Kotlarski, E. Richter-Was and Z. Was
1604.00964v1. 4 Apr 2016

S. Banerjee, J. Kalinowski, W. Kotlarski, T. Przedzinski and Z. Was
Eur. Phys. J. **C73** (2013) 2313

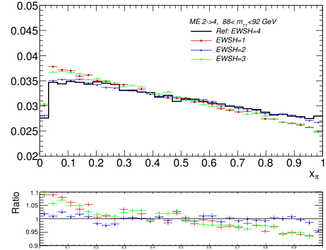
The ALEPH collaboration Eur.Phys.J. **C20** (2001) 401-430

Hopefully my publication will apear soon

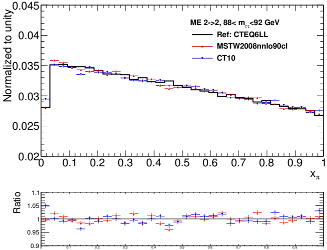
Backup



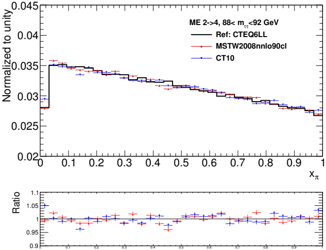
ME 2->2, 88< $m_{\tau\tau}$<92 GeV
Ref: EWSH=4
EWSH=1
EWSH=2
EWSH=3
x_π
Ratio



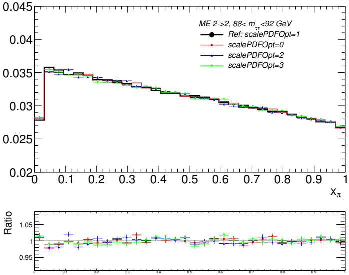
ME 2->4, 88< $m_{\tau\tau}$<92 GeV
Ref: EWSH=4
EWSH=1
EWSH=2
EWSH=3
x_π
Ratio



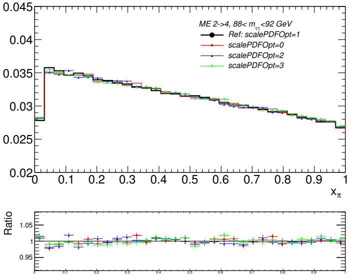
ME 2->2, 88< $m_{\tau\tau}$<92 GeV
Ref: CTEQ6LL
MSTW2008nnlo90cl
CT10
Normalized to unity
x_π
Ratio



ME 2->4, 88< $m_{\tau\tau}$<92 GeV
Ref: CTEQ6LL
MSTW2008nnlo90cl
CT10
Normalized to unity
x_π
Ratio



ME 2->2, 88< $m_{\tau\tau}$<92 GeV
Ref: scalePDFOpt=1
scalePDFOpt=0
scalePDFOpt=2
scalePDFOpt=3
x_π
Ratio



ME 2->4, 88< $m_{\tau\tau}$<92 GeV
Ref: scalePDFOpt=1
scalePDFOpt=0
scalePDFOpt=2
scalePDFOpt=3
x_π
Ratio

Selection at analysis level
P_t of jets > 50 GeV
P_t of jet1 > 30 GeV or $P_t$of jet2 > 30 GeV
η_{j1} -η_{j2} > 3.0
P_t of $\tau 1 > 25$ GeV or P_t of $\tau 2 > 25$ GeV
P_t of τs > 35 GeV
$\|\eta_{\tau 1}\| < 2.5$ or $\|\eta_{\tau 2}\| < 2.5$
Selection at generation level
P_t of jets > 50 GeV
P_t of leptons > 30 Gev
invariant mass of jets > 120 GeV
invariant mass of leptons > 120 GeV

Table: Kinematical selection for Z$\rightarrow \tau\tau$ jj samples at generation and analysis level.

Spin-2 boson ME implementation

Example of extension beyond SM including possibility to simulate spin correlation of spin 2 state decaying to tau-lepton pair. We start by extending the Lagrangian [3] by a set of dimension 5 operators, coupling of the spin 2 field X to gauge boson field, strength tensors B, W and G as

$$\mathcal{L} \ni \frac{1}{F} X_{\mu\nu} \left(g_{XBB} \; B^{\mu\rho} B_{\rho}{}^{\nu} + g_{XWW} W_i^{\mu\rho} W_{\rho}{}^{\nu} + g_{Xgg} G^{\mu\rho} G_{\rho}{}^{\nu} \right) . \qquad (4)$$

This model is used to generate squared matrix elements using `MadGraph5` After necessary changes , the ME were implemented in `TauSpinner` package as porototype "user implementation" ME.