

TauSpinner Developments in Production of τ lepton pairs with high P_T jets at the LHC: the spin2 case

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 - Test of re-weighting
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Introduction

- HBSM H^+ to $\tau\nu$: Search for charged Higgs bosons in the τ +jets and τ +lepton final states from pp collision data recorded at $\sqrt{s} = 13$ TeV with the ATLAS experiment
- TauSpinner Developments in Production of τ lepton pairs with high P_T jets at the LHC: the spin2 case

Introduction

- Explore final states with τ lepton
- High mass of $\tau \rightarrow$ provide a sensitive window to physics beyond SM
- τ lepton signature can provide a powerful tool in many areas \rightarrow
 - 1- Studies of hard process characteristics
 - 2- Measurements of properties of Higgs boson
 - 3- **In a search for new physics.**
- TauSpinner algorithm provides a powerful tool for investigation of characteristics of final states with τ lepton

TauSpinner

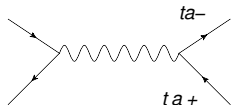
- TauSpinner is a tool that allows to modify the physics model of the Monte Carlo generated samples due to the changed assumptions of event production dynamics, but without the need of re-generating events.



- The only information used is the kinematics of final state, therefore it can be used both for Data and MC simulations
- TauSpinner calculate weight from input , Weights are ratios of matrix elements calculated for New and Old assumptions.

TauSpinner Program

- TauSpinner Program is commonly used by the LHC experiments :
 - TauSpinner (2→2) processes



- TauSpinner (2→4) processes - NEW !

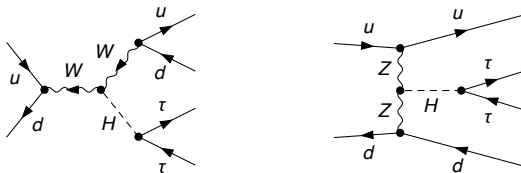


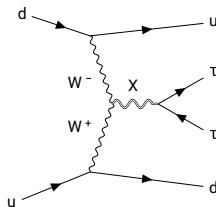
Figure: Depending on the initial state , tree level matrix elements are of the order of $\alpha_s \alpha_{EW}$ or α_{EW}^2 , sometimes involving triple WWZ coupling.

New development: Non-SM implementation

- I will discuss general implementation of Beyond SM processes, I am using a single example here.
- The algorithm is supposed to work for any modification of SM predictions (for production of 2 τ s and 2 jets)
- After I described how this model used for spin amplitudes calculation.
- Test of re-weighting

Case of Spin2

- The coupling of a massive spin 2 field to SM gauge bosons was already intensively studied in the literature in the context of an LHC phenomenology.
- A work dedicated to study of a Drell-Yan-like production of τ 's through a hypothetical spin 2 mediator X (2013). Building on this previous work, we extend it by studying the $X \rightarrow \tau^+\tau^-$ production and decay in the VBF topology.
- We don not comment on the origin of X state, (not claim it is connected to gravity) so we do not couple it to the entire energy-momentum tensor of the SM , not to ghosts, gauge fixing term, trace of X or Higgs boson kinetic term.



Incorporating MadGraph generated code for Non-SM into TauSpinner: Spin2 case

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

- In this work we focus on the coupling of X to EW gauge bosons and coupling to gluons would be studied better in Drell-Yan-Like configuration.
- This extension of the SM by a spin 2 field, including its coupling to quarks and tau leptons, is encoded into FeynRules model (FeynRules 2.0 - A complete toolbox for tree-level phenomenology, 1310.1921)
- The FeynRules model file, together with its UFO output (1108.2040)
- The UFO model is used to generate squared matrix elements using MadGraph5 the spin 2 has the support of the HELAS library

Incorporating MadGraph generated code for Non-SM into TauSpinner: Spin2 case

Implementation of new ME needs following steps:

- Generate spin2 process by Madgraph

(a) `import model spin2_w_CKM_UF0`

(b) by default, “multiparticles” containers include all massless partons

`p = g u c d s u~ c~ d~ s~`

`j = g u c d s u~ c~ d~ s~`

(c) generate spin 2 matrix elements

`generate p p > j j x QED<=99 QCD<=99 NPgg<=99 NPqq<=99
NPVV<=99, x > ta+ ta-`

(d) write the output to disk in MadGraph’s standalone mode using
output standalone "directory name" command

Incorporating MadGraph generated code for Non-SM into TauSpinner: Spin2 case

- The generated codes for the individual sub-processes are grouped in to subroutines, the proper changed applied:
 - (a) Depending on the flavor of initial state partons named properly
SUBROUTINE DCX_S2(P, I3, I4, H1, H2, ANS)
 - (b) Parameter H1 and H2 introduced as helicities of τ s
 - (c) The subroutines and internal functions generated by MadGraph have the same names for all sub-processes SMATRIX(P, ANS) → be unique for each sub-process. $u\bar{d} \rightarrow c\bar{d}X, X \rightarrow \tau^+\tau^-$ name is changed to UDX_CDX_S2(P, H1, H2, ANS)

Incorporating MadGraph generated code for Non-SM into TauSpinner: Spin2 case

- Apply the combinatorial and CP symmetries that allow us to reduce the number of parton subprocesses
 - (a) Check if Matrix Element can be set to zero
 - (b) Charge conservation imposes that for processes
 - (c) all necessary transformations (flipping the position of partons or invoking the CP transformation)

Test of matrix elements using fixed kinematical configuration

- For a point in phase space

```
P[0,i]= 500.0000000000    0.0000000000    0.0000000000    500.0000000000
P[1,i]= 500.0000000000    0.0000000000    0.0000000000   -500.0000000000
P[2,i]=  88.5500900000   -22.1003800000    40.0797900000   -75.8043700000
P[3,i]= 328.3248000000  -103.8482000000  -301.9295000000    76.4938500000
P[4,i]= 152.3663000000  -105.8795000000  -97.7082700000    49.5476900000
P[5,i]= 430.7588000000   231.8280000000   359.5580000000   -50.2371700000
```

```
ID-s= -4 -4 -4 -4 CP used= 1 ## VALUE: 5.4498795386e-11 ## Spin contr.: (+-)= 2.722e-11 (--)= 2.728e-11 (--)= 2.001e-15 (++)= 2.000e-15
ID-s= -4 -3 -4 -3 CP used= 1 ## VALUE: 2.4550857518e-12 ## Spin contr.: (+-)= 1.092e-12 (--)= 1.363e-12 (--)= 1.970e-17 (++)= 1.540e-17
ID-s= -4 -3 -4 -1 CP used= 1 ## VALUE: 1.7504240128e-14 ## Spin contr.: (+-)= 2.714e-15 (--)= 1.431e-14 (--)= 2.441e-16 (++)= 2.398e-16
ID-s= -4 -3 -3 -4 CP used= 1 ## VALUE: 5.2604665756e-11 ## Spin contr.: (+-)= 2.627e-11 (--)= 2.633e-11 (--)= 1.994e-15 (++)= 1.992e-15
ID-s= -4 -3 -3 -2 CP used= 1 ## VALUE: 3.5660092224e-16 ## Spin contr.: (+-)= 9.101e-18 (--)= 3.421e-16 (--)= 2.661e-18 (++)= 2.706e-18
ID-s= -4 -3 -2 -3 CP used= 1 ## VALUE: 1.8277516190e-14 ## Spin contr.: (+-)= 1.373e-15 (--)= 1.690e-14 (--)= 1.949e-18 (++)= 1.633e-18
ID-s= -4 -3 -2 -1 CP used= 1 ## VALUE: 9.6558861882e-16 ## Spin contr.: (+-)= 1.496e-16 (--)= 7.878e-16 (--)= 1.421e-17 (++)= 1.397e-17
ID-s= -4 -3 -1 -4 CP used= 1 ## VALUE: 1.0030302326e-15 ## Spin contr.: (+-)= 1.297e-16 (--)= 8.731e-16 (--)= 9.599e-20 (++)= 9.985e-20
ID-s= -4 -3 -1 -2 CP used= 1 ## VALUE: 1.8892558599e-17 ## Spin contr.: (+-)= 3.852e-19 (--)= 1.809e-17 (--)= 2.068e-19 (++)= 2.100e-19
ID-s= -4 -2 -4 -2 CP used= 1 ## VALUE: 4.2991410664e-12 ## Spin contr.: (+-)= 2.149e-12 (--)= 2.149e-12 (--)= 4.370e-16 (++)= 4.370e-16
ID-s= -4 -2 -2 -4 CP used= 1 ## VALUE: 5.0256296146e-11 ## Spin contr.: (+-)= 2.509e-11 (--)= 2.516e-11 (--)= 1.937e-15 (++)= 1.936e-15
ID-s= -4 -1 -4 -3 CP used= 1 ## VALUE: 2.0822426627e-14 ## Spin contr.: (+-)= 1.833e-15 (--)= 1.899e-14 (--)= 1.933e-19 (++)= 9.984e-20
ID-s= -4 -1 -4 -1 CP used= 1 ## VALUE: 4.3555086047e-12 ## Spin contr.: (+-)= 2.158e-12 (--)= 2.196e-12 (--)= 5.405e-16 (++)= 5.366e-16
ID-s= -4 -1 -3 -4 CP used= 1 ## VALUE: 7.2679264348e-16 ## Spin contr.: (+-)= 3.219e-16 (--)= 4.037e-16 (--)= 5.923e-19 (++)= 5.705e-19
```

- The agreement of at least 6 significant digit has been confirmed.

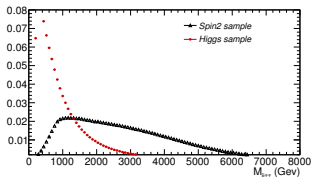
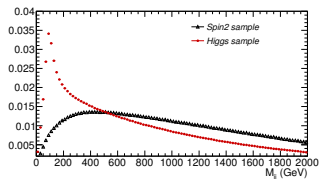
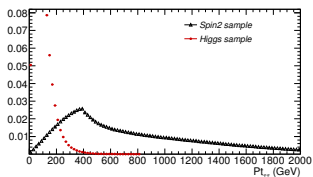
Test of re-weighting

- Samples for Spin2 and Higgs particle by Madgraph were generated (19 M).
- The parameters in TauSpinner initialized in consistent with generated sample.
- The spin weight ratio calculated by TauSpinner by *getWtNonSM* method
- Re-weighting applied on kinematical distribution

Test of re-weighting

Kinematical distributions which have significant difference for Higgs and Spin2 sample

Figure: The selections : $m_{jj\tau\tau} < 1500$ GeV , $m_{jj} < 800$ GeV and $P_T^{\tau\tau} < 600$ GeV



Weight distribution \rightarrow painful tails \rightarrow method limitation

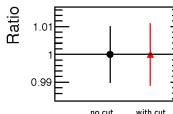
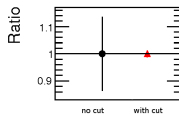
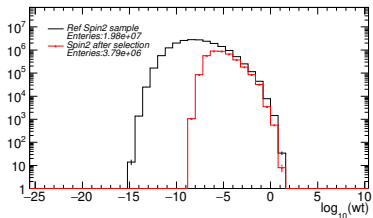
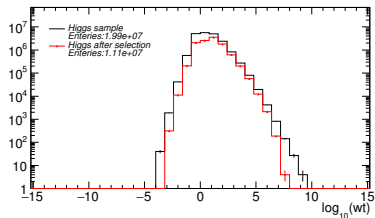


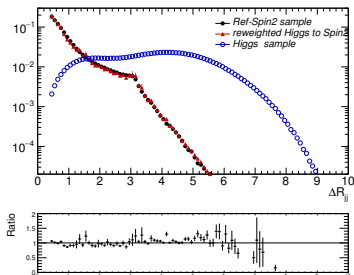
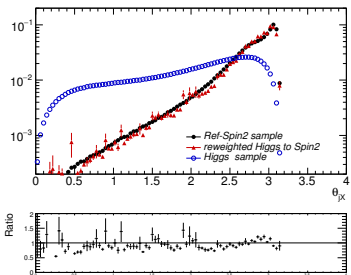
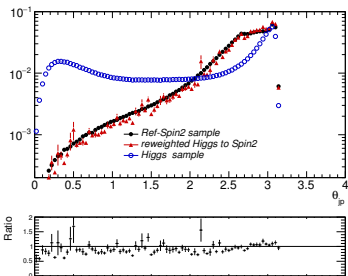
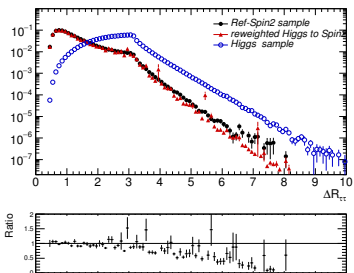
Figure: The ratio cross section for Higgs re-weighted to Spin2 and Spin2 samples in the left, and for Spin2 re-weighted to Higgs and Higgs samples in the right (different scale)

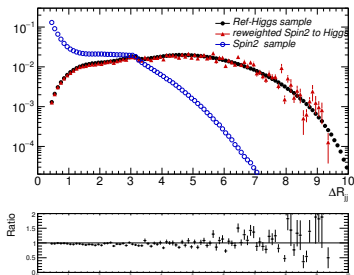
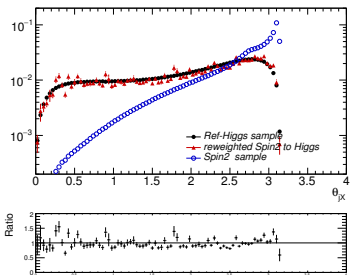
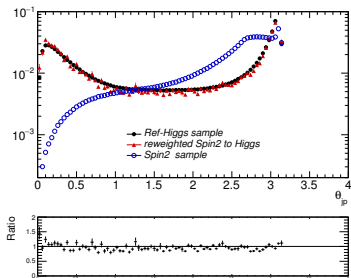
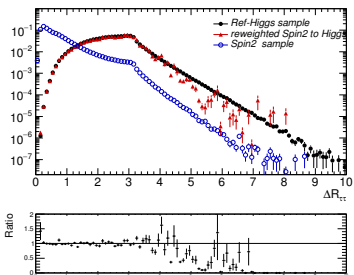
Kinematical distribution

- ΔR_{jj} : Opening angle between jets.
- $\Delta R_{\tau\tau}$: Opening angle between τ s.

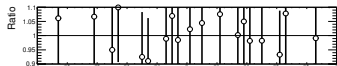
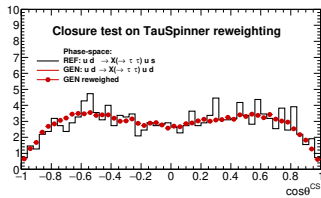
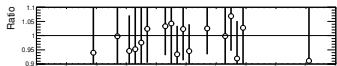
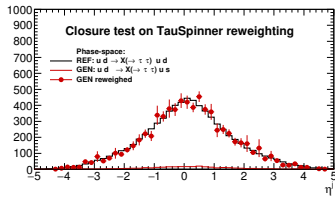
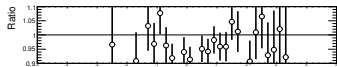
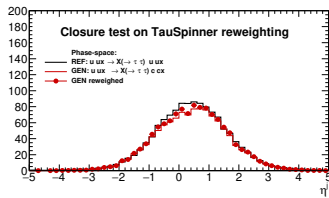
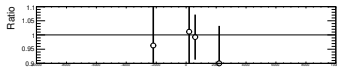
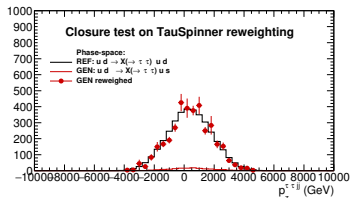
$$\Delta R_{\tau\tau} = \sqrt{(\eta_{\tau^+} - \eta_{\tau^-})^2 + (\phi_{\tau^+} - \phi_{\tau^-})^2}$$

- θ_{jP} : Angle between incoming parton and outgoing parton in the rest frame of jets.
- θ_{jX} : Angle between resonance and outgoing parton in the rest frame of jets.



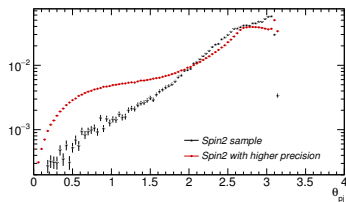
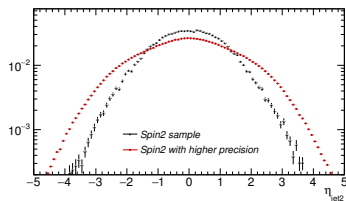


Clouser test on TauSpinner reweighting



Technical issues

In the case of Spin2 sample we encounter a problem related to accuracy of sample, the samples were produced by Madgraph5 based on MadEvent



Technical issues

- The event density of re-weighted sample may differ from the target by unacceptable large factor resulting few events with massively large weight than others
- This is the consequence of very narrow width of Higgs or X resonances.
- The physics of X would populate sizably much larger phase space than Higgs production, so the re-weighting algorithm need to be restricted to some regions of phase space than production of higgs.

Summary

- Implementation of Spin2 model and check the accuracy of ME calculation
- Creating a user provided matrix elements for production of τ lepton with 2 jets
- This is available in tauolapp.web.cern.ch/tauolapp/resources/TAUOLA.development.version/
- We have provided numerical test of the algorithm
- Material for publication is nearly ready, the tests are confirmed, except may be an overall normalization factor.