Developments of TauSpinner in Production of τ lepton pairs with high P_T jets for the spin2 case

Marzieh Bahmani
with J. Kalinowski, W. Kotlarski, E. Richter-Wąs and Z. Wąs

IFJ-PAN Krakow

September 2017

Outline

Introduction

Main projects:

- TauSpinner program
  - Systematic of TauSpinner in Production of jj$\tau\tau$ (2016) http://www.actaphys.uj.edu.pl/fulltext?series=Reg&vol=48&page=903
  - TauSpinner developments in Production of τ lepton pairs with high P_T jets at the LHC: the spin2 case (2017)

- 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(2017)

Motivation

- Explore final states with τ lepton
- High mass of τ $\rightarrow$ 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

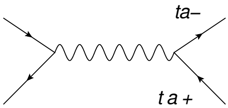
TauSpinner

- 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 !

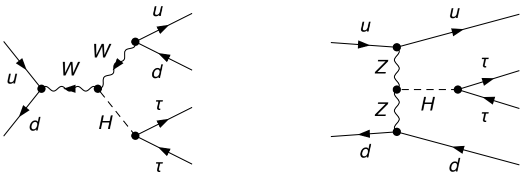


Figure: Depending on the initial state , tree level matrix elements are of the order of $\alpha_s \alpha_{EW}$ or α_{EW}^2, sometimes involving triple WWZ coupling.

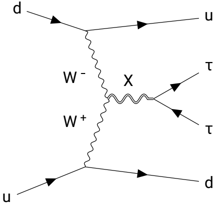
New development: Non-SM implementation

Things to be discussed:

- 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 τs and 2 jets)
- 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 $X \to \tau^+\tau^-$ production and decay in the VBF topology.
- We do 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

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

- 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_UFO`

(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 τs

(c) The subroutines and internal functions generated by MadGraph have the same names for all sub-processes `SMATRIX(P,ANS)`$\rightarrow$ 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 (10 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

Kinematical distribution

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

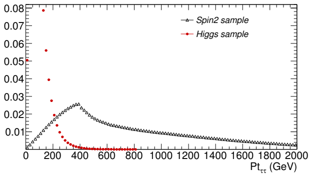
$$\Delta R_{\tau\tau} = \sqrt{(\eta_{\tau^+} - \eta_{\tau^-})^2 + (\phi_{\tau^+} - \phi_{\tau^-})^2}$$

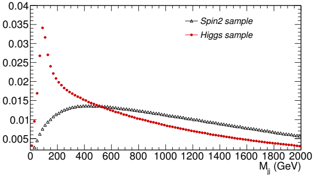
- θ_{jp}: Angle between incoming parton and outgoing parton in the rest frame of jets.
- θ_{jX}: Angle between resonance and outgoing parton in the rest frame of jets.

Test of re-weighting

Kinematical distributions which have significant difference for Higgs and Spin2 sample

Figure: The loose selections : $m_{jj\tau\tau} < 1500$ GeV , $m_{jj} < 800$ GeV and $P_T^{\tau\tau} < 600$ GeV. The VBF selection : $m_{jj\tau\tau} < 1500$ GeV , $m_{jj} < 800$ GeV and $100 < P_T^{\tau\tau} < 600$ GeV.





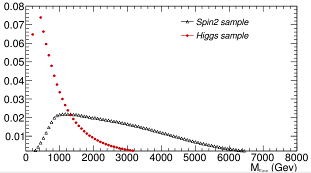
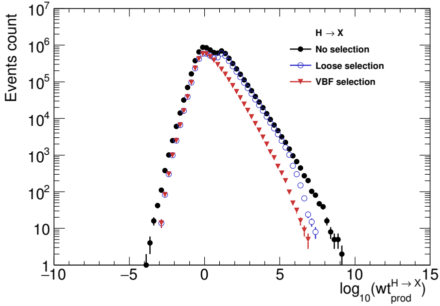
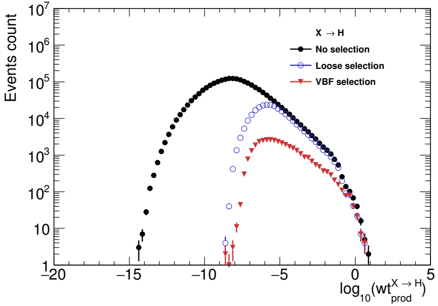


Table: Cross sections for the generated H production process and after its reweighting to the X production ($H \to \tau\tau$ block), and for the generated X production and after its reweighting to H production ($X \to \tau\tau$ block); acceptances with no, loose or VBF selections applied for generated and reweighted event samples are also shown.

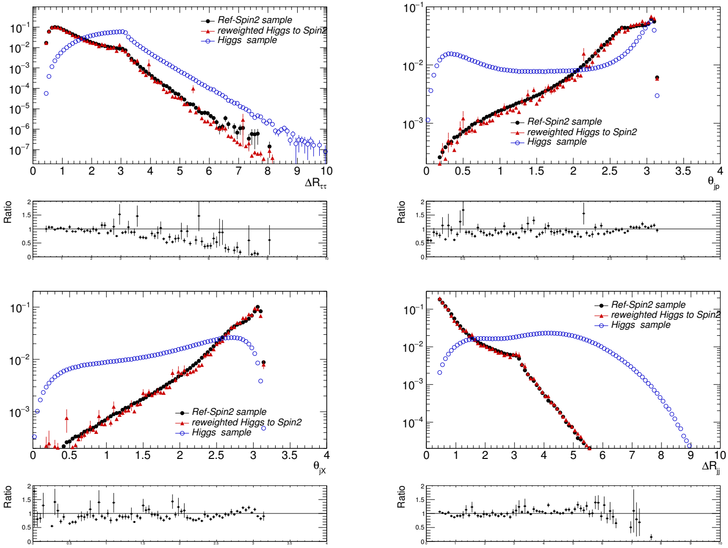
Events		No selection	Loose selection	VBF selection
	Acceptance	100%	73.8%	49.0%
$H \to \tau\tau$	σ [pb] (H)	$[2.033 \pm 0.064]\ 10^{-1}$	$[1.501 \pm 0.062]\ 10^{-1}$	$[1.004 \pm 0.045]\ 10^{-1}$
	σ [pb] ($H \to X$)	$[9.097 \pm 1.270]\ 10^{+2}$	$[1.187 \pm 0.038]\ 10^{+2}$	$[1.517 \pm 0.066]\ 10^{+1}$
	Acceptance	100%	13.0%	1.71%
$X \to \tau\tau$	σ [pb] (X)	$[9.097 \pm 0.0029]\ 10^{+2}$	$[1.178 \pm 0.001]\ 10^{+2}$	$[1.544 \pm 0.004]\ 10^{+1}$
	σ [pb] ($X \to H$)	$[2.023 \pm 0.0474]\ 10^{-1}$	$[1.478 \pm 0.031]\ 10^{-1}$	$[\ 9.75 \pm 0.309]\ 10^{-2}$

Distribution of weight



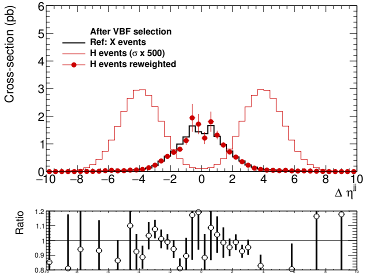


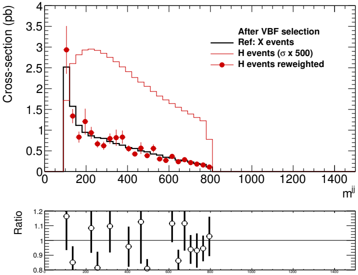
Kinematical distributions

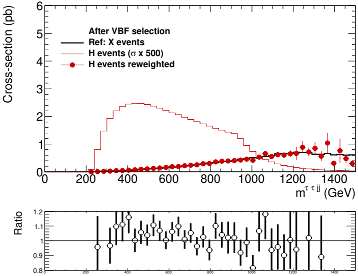


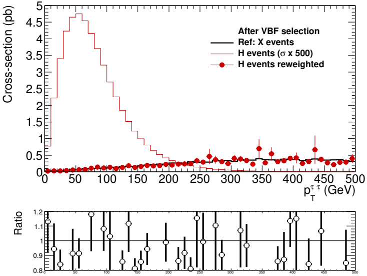
Distribution Normalized to cross section

The H sample reweighted to the X and compared with the X sample. The H and X widths are of 5.75 MeV. Selection cuts: Invariant mass of outgoing particles $m^{\tau\tau jj} < 1500$ GeV, invariant mass of jets system $100 < m^{jj} < 800$ GeV and $p_T^{\tau\tau} < 600$ GeV






After VBF selection
Ref: X events
H events (σ x 500)
H events reweighted
Cross-section (pb)
m^{τ τ jj} (GeV)
Ratio


After VBF selection
Ref: X events
H events (σ x 500)
H events reweighted
Cross-section (pb)
p_T^{τ τ} (GeV)
Ratio

Summary and conclusion

- 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: arXiv:1708.03671 ,the tests are confirmed.
- We are working also on testing spin structure of the Spin2 resonance using `TauSpinner`.