Detecting H->WW* Entanglement at LHC

F. FABBRI, T. MAURIN, J. HOWARTH

Analysis aim

- Investigate an experimental route to test the CGLMP on the spin state of H→WW* (see A. Barr talk)
  - Requires the reconstruction of the entire final state
    - Reconstruct the spin density matrix
    - Find a suitable reference frame
  - Very hard task in multi-leptonic (multi-neutrinos) final states

↓

Let's then try to use a semi-leptonic final state!!! →

Main problems

- Reconstruct the spin state
- Separate the signal from the overwhelming background

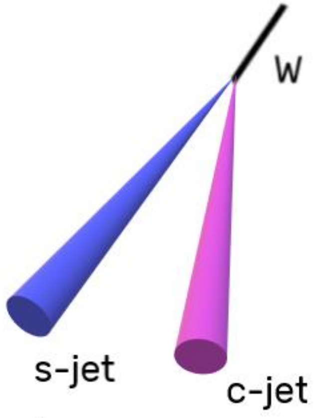
Analysis strategy – spin state reconstruction

- The spin of the W boson can be reconstructed using its decay products:

Spin analyzing power

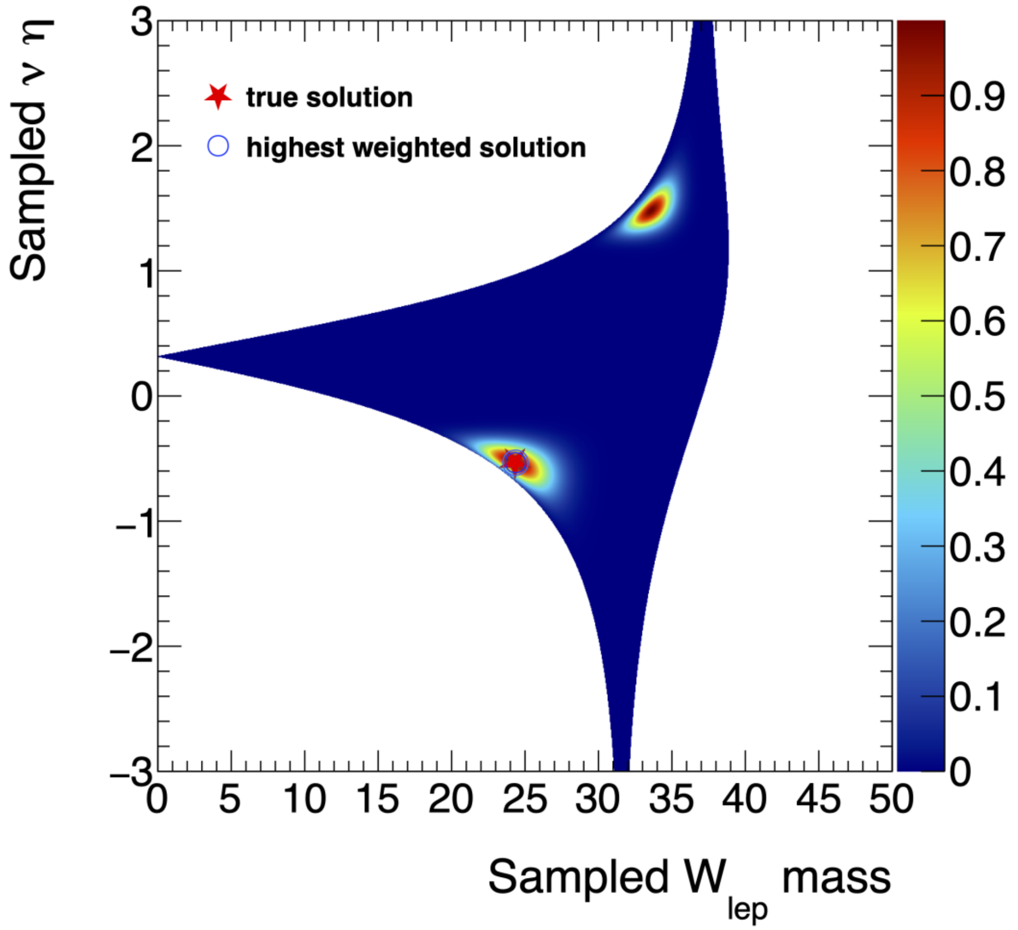
	b-quark	W^+	l^+	$\bar{d}$-quark or $\bar{s}$-quark	u-quark or c-quark
α_i (LO)	-0.410	0.410	1.000	1.000	-0.310
α_i (NLO)	-0.390	0.390	0.998	0.930	-0.310

  - The down-type quark can be used to extract information on the W spin
- s-originated quarks are difficult to identify, but the c-quark initialized jet can be identified
  - Use c-tagging to identify the sibling s-jet from hadronic W decay
  - This requirement force for the search of an on shell hadronic-W, and the mass is used to identify the hadronic W constituents



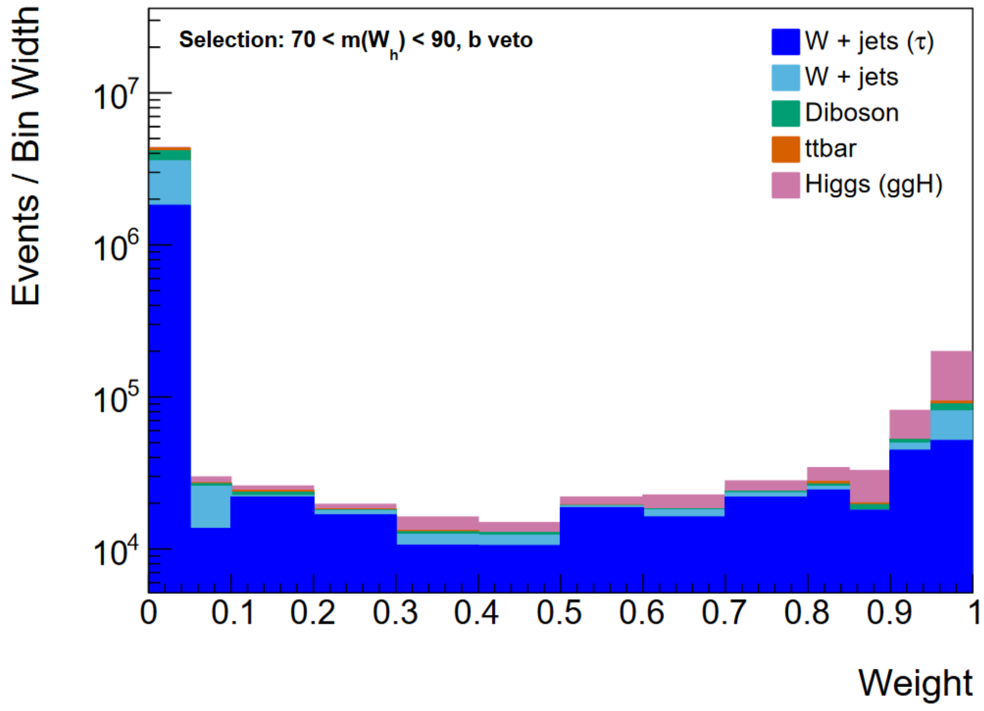
Analysis strategy – system reconstruction

- There are 2 incognita in the system: the longitudinal momentum of ν and the mass of the off-shell W.
  - Higgs and hadronic W mass are known
- Scan on possible values for the incognita and attribute a weight to each solution
- Method adapted from **the neutrino weighting**
  - Employed in top-pair reconstruction with 2 ν in the final state



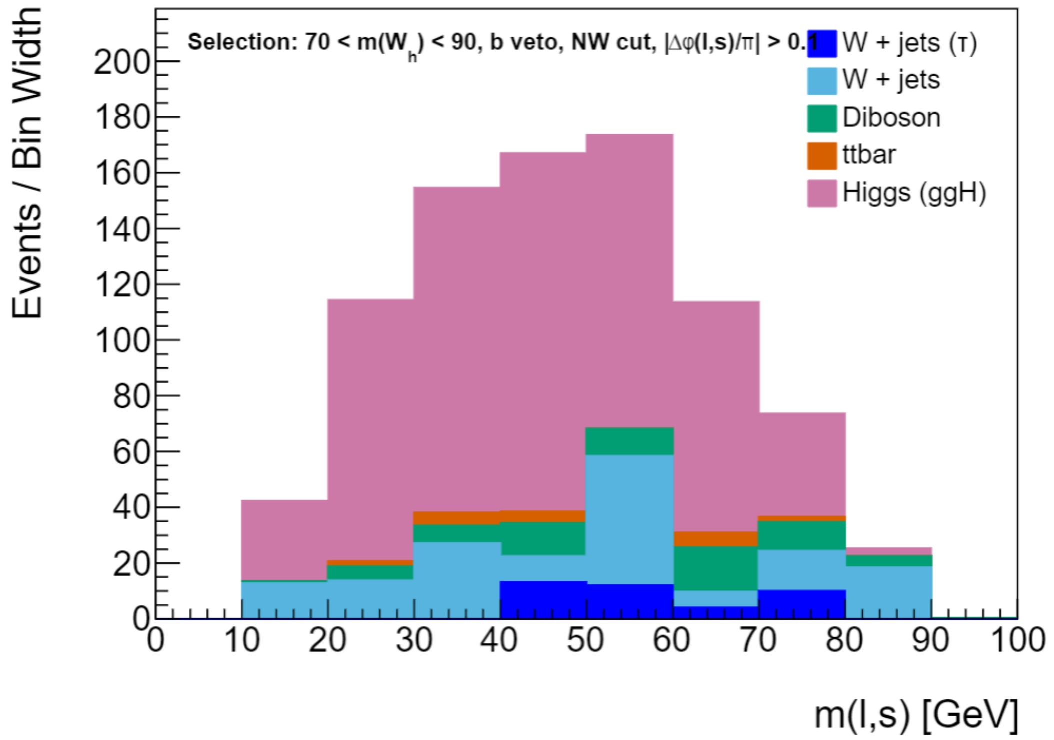
Analysis strategy – background separation

- The H→WW* process has never been measured in the semi-leptonic final state, due to the overwhelming W+jets and qq→WW bkg.
- Necessary to introduce a new method to suppress the background → **neutrino weighting!**
  - The events with a low maximum weight are discarded.
- Used in conjunction to other requirements:
  - Number of b-jets == 0
  - At least 1 c-jet
  - Hadronic W mass
  - Δφ(l,s)



Analysis strategy – background separation

- The H→WW* process has never been measured in the semi-leptonic final state, due to the overwhelming W+jets and qq→WW bkg.
- Necessary to introduce a new method to suppress the background → **neutrino weighting!**
  - The events with a low maximum weight are discarded.
- Used in conjunction to other requirements:
  - Number of b-jets == 0
  - At least 1 c-jet
  - Hadronic W mass
  - $\Delta\varphi(l,s)$



Realistic performances - I

Table 3: Numbers obtained by using p1 - p2 using values from [9]

Working point (pass—fail)	ϵ_b [%]	ϵ_c [%]	ϵ_l [%]	ϵ_c/ϵ_b
ATLAS DL1r *b*-tagger [9]				
85 / 77	8	18	3	2.25
85 / 70	15	28	3	1.87
85 / 60	25	35	3	1.40
77 / 70	7	10	0.51	1.43
77 / 60	17	17	0.69	1.00
70 / 60	10	7	0.18	0.70

- We want to understand if measuring W bosons entanglement is realistic with real detector performances
- C-tagging
  - Both ATLAS and CMS experiment have strategies to identify c-tagged jets
  - We can also use a combination of b-tagging efficiencies
  - Include also mis-identification of b-jets and light-jets cases
- Consider also all other inefficiencies (e.g. leptons)

Realistic performances - II

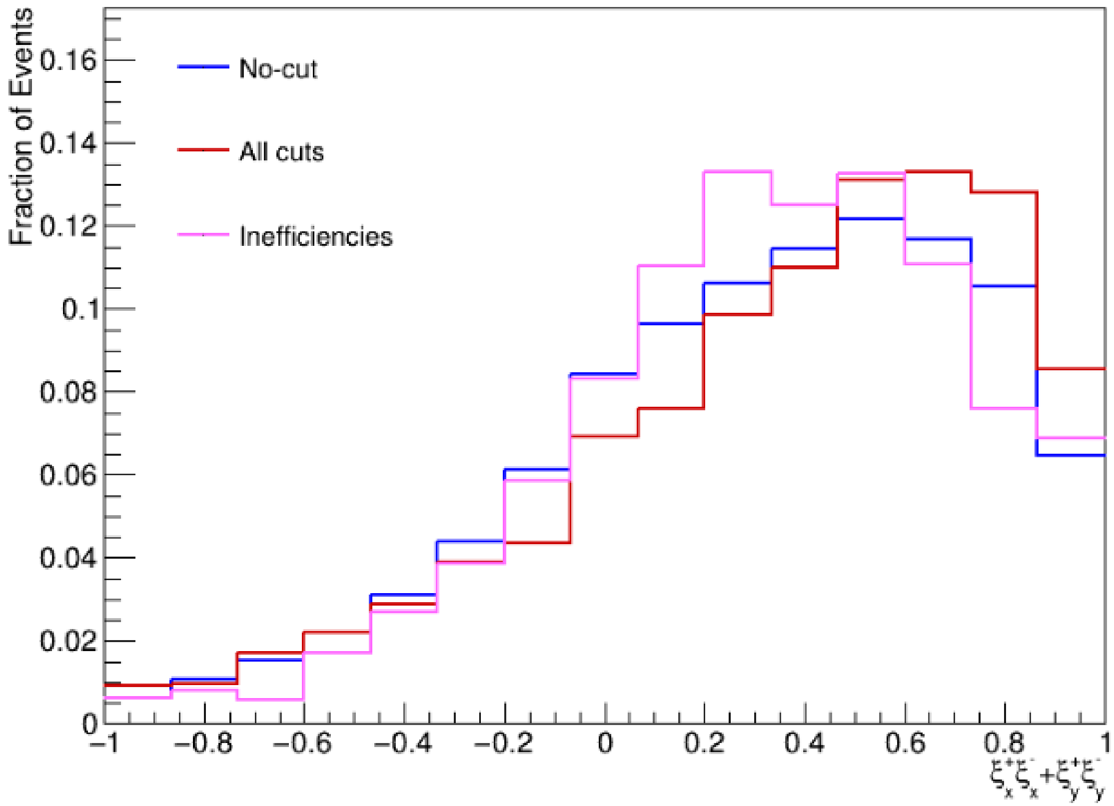
- Higgs and ttbar simulated using Powheg+Pythia8
- WW/WZ/ZZ and W+jets simulated using Sherpa
- Left columns contains all inefficiencies excluding c-tagging
  - Inefficiencies taken by published ATLAS papers
  - Parallelly working also on the CMS best c-tagging option
- Assumed 139 fb^{-1}

Process	Expected events					
	idealised			$\epsilon_c = 18\%$		
W + jets (τ)	396	$\pm$	6	71.2	$\pm$	1.1
W + jets	1480	$\pm$	20	266	$\pm$	3
$WW/WZ/ZZ$	646	$\pm$	13	116	$\pm$	2
$t\bar{t}$	183	$\pm$	13	33.1	$\pm$	2.4
Higgs	5950	$\pm$	80	1070	$\pm$	14
S/(S+B)	0.69			-		

Observables reconstruction

- Start from the variable introduced in A. Barr paper, but using semi-leptonic final state
  - Also use the same coordinate system

$$\mathrm{tr}(\rho \mathcal{B}^{xy}_{\mathrm{CGLMP}}) = \frac{8}{\sqrt{3}} \left\langle \xi^+_x \xi^-_x + \xi^+_y \xi^-_y \right\rangle_{\mathrm{av}} + 25 \left\langle \left((\xi^+_x)^2 - (\xi^+_y)^2 \right) \left((\xi^-_x)^2 - (\xi^-_y)^2 \right) \right\rangle_{\mathrm{av}} + 100 \left\langle \xi^+_x \xi^+_y \xi^-_x \xi^-_y \right\rangle_{\mathrm{av}} .$$



Conclusions and next steps

Employ the reconstructed final state to reconstruct angular variables needed to measure the bell inequality

Correct for detector and selection inefficiencies

Derive the value and associated uncertainties of the CGLMP related observables in 3 cases:

- Semi-leptonic final state (no selection)
- Semi-leptonic final state and ideal c-tagging performance
- Semi-leptonic final state and realistic performance