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Characterizing a Higgs-like resonance at the LHC

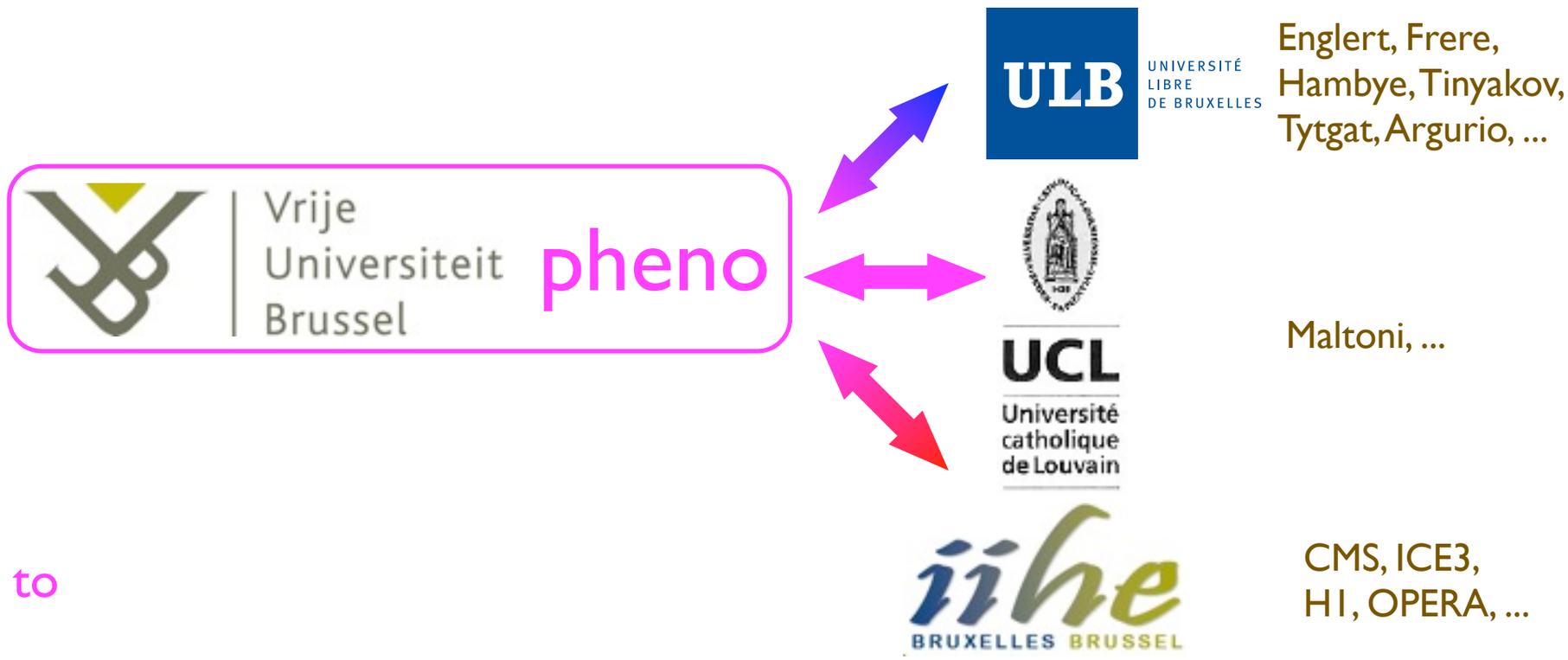
Kentarou Mawatari

(Vrije Universiteit Brussel and International Solvay Institutes)

K.Hagiwara, Q.Li, KM, JHEP07(2009)101 [arXiv:0905.4314]
C.Englert, D.Goncalves-Netto, KM, T.Plehn, JHEP01(2013)148 [arXiv:1212.0843]
P. de Aquino, F.Maltoni, KM, M.Zaro et al, on-going project

Phenomenology group at the Vrije Universiteit Brussel

- Since October 2010, to make a chain between the theoretical and experimental groups at the VUB.



- Contact to
  - http://we.vub.ac.be/dntk/GOA.html
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Phenomenology group at the Vrije Universiteit Bru

- Since October 2010, to make a chain b
  theoretical and experimental groups at

Vrije Universiteit Brussel **pheno**

ULB Université Libre de Bruxelles — Englert, Frere, Hambye, Tinyakov, Tytgat, Argurio, ...

Maltoni, ...

UCL Université catholique de Louvain

iihe Bruxelles Brussel — CMS, ICE3, H1, OPERA, ...

: to

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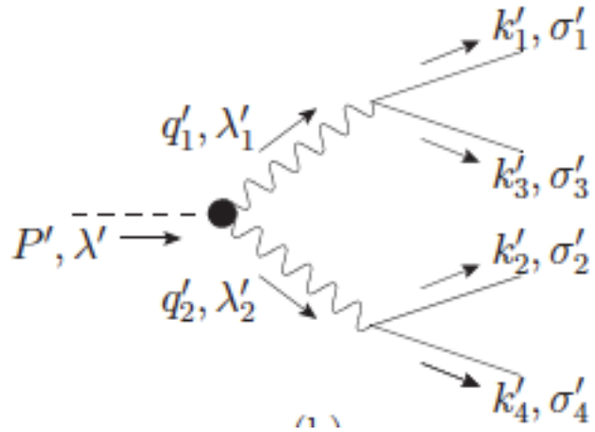
Is it the Brout-Englert-Higgs boson?

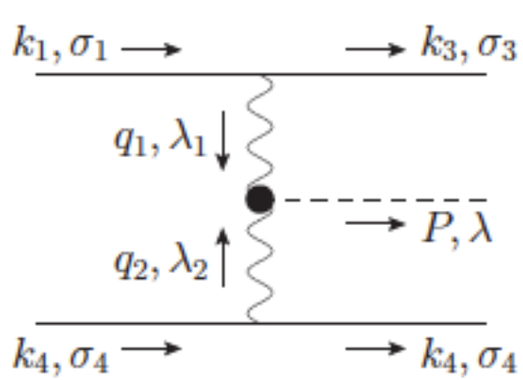
- Spin-0, 1, or 2?
- Parity-even, odd, or mixed?
  - different XVV and Xff tensor structures
- Only after the operator/Lagrangian basis is fixed, we can determine the corresponding coupling strength.

How can we get the spin/parity information?

- mass and angular distributions in X→ZZ→4l.



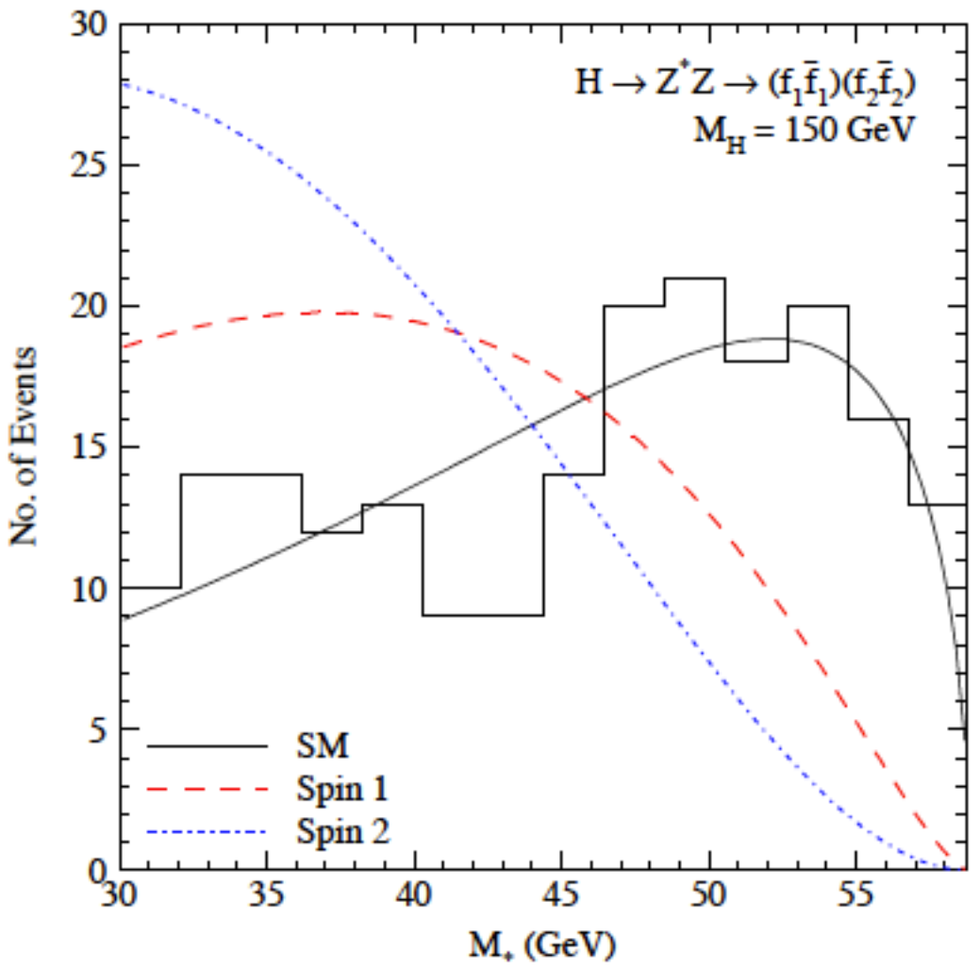
- di-jet distributions in pp→Xjj, vector-boson-fusion (VBF).

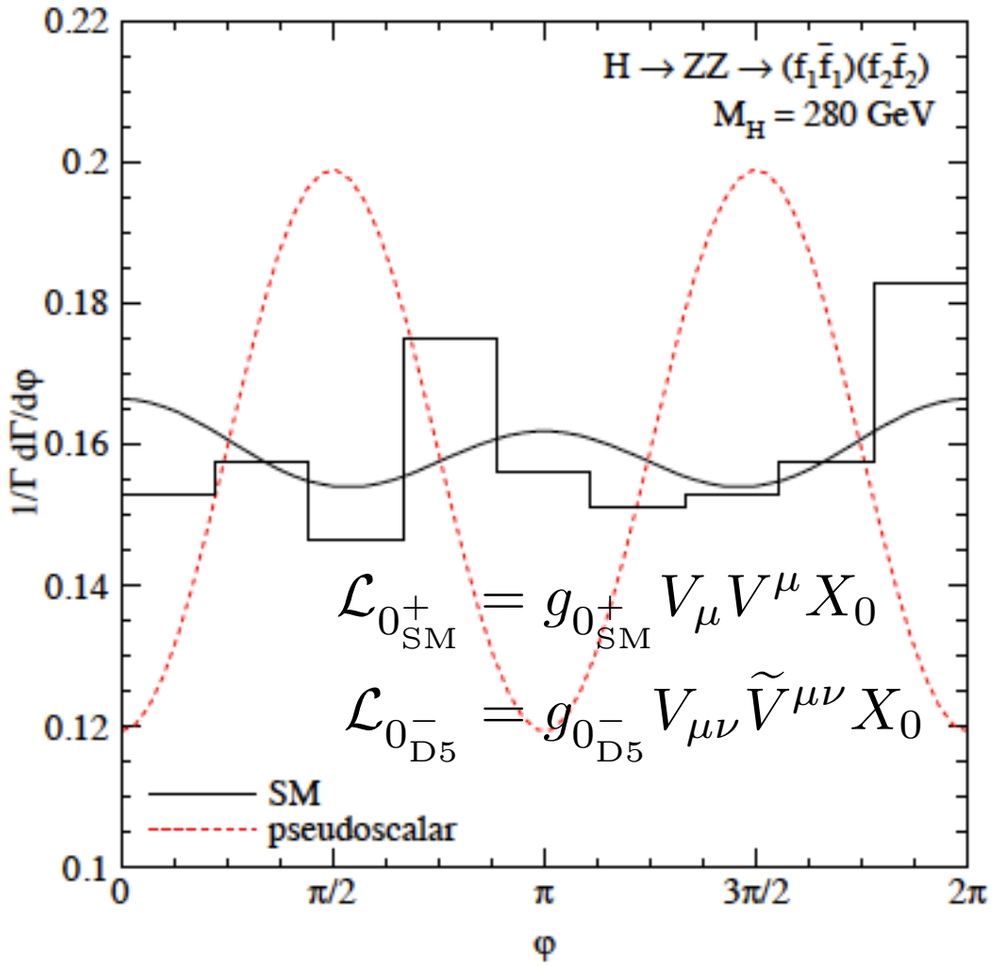


- X→γγ
- X→ττ

X→VV decay

Choi, Miller, Muhlleitner, Zerwas (2003)

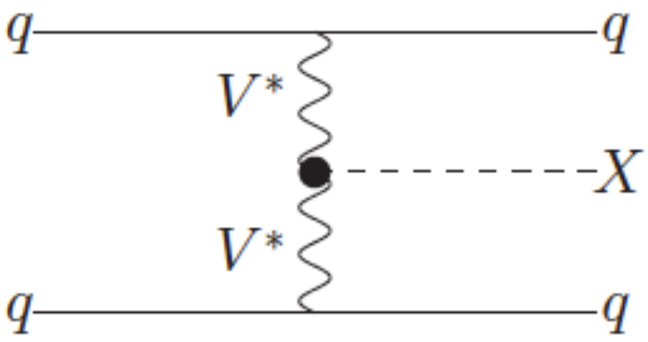




The off-shell Z mass and the azimuthal correlations between the Z decay planes reflect the XVV tensor structures.

Xjj production -- vector boson fusion

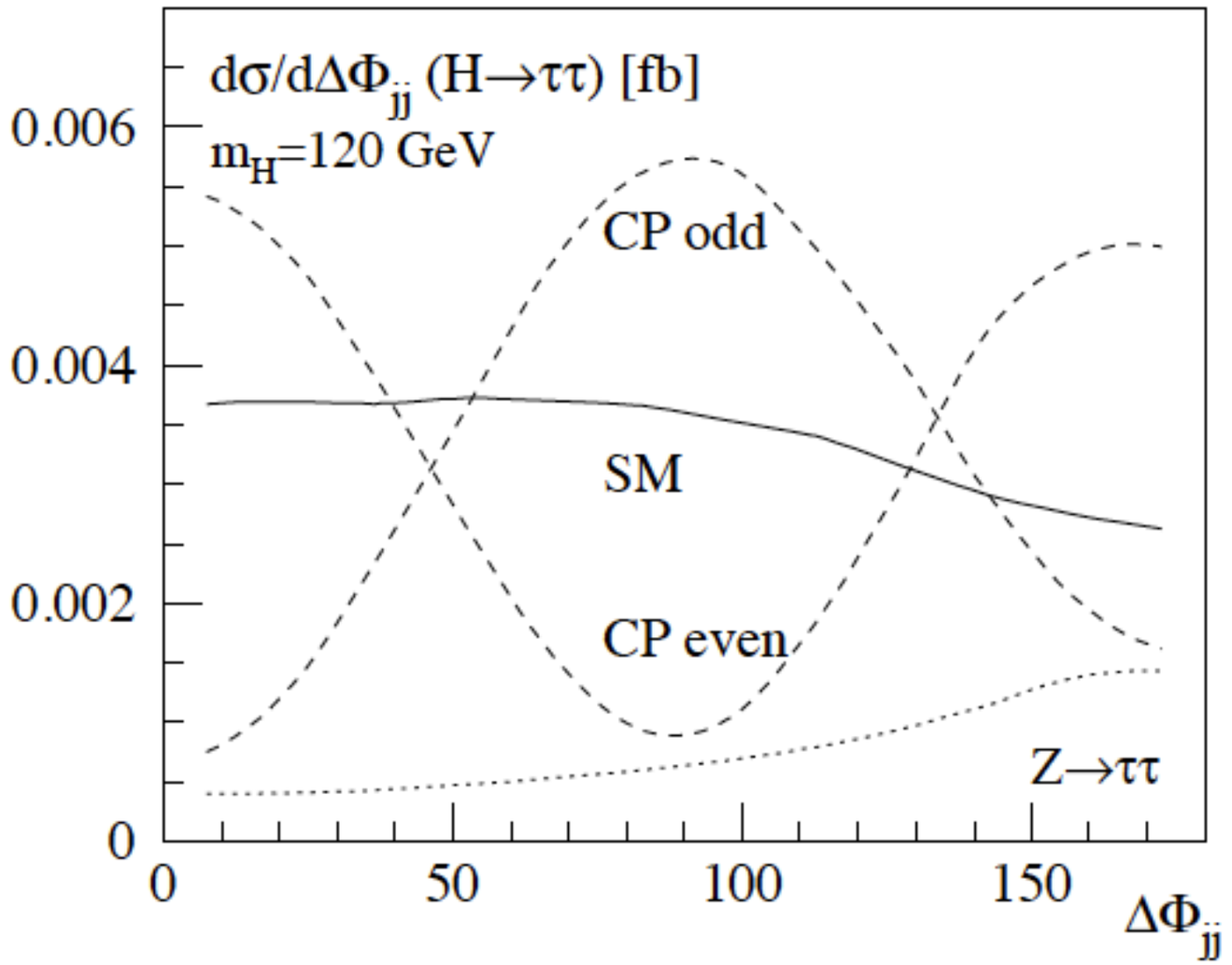
Plehn, Rainwater, Zeppenfeld (2002)



$$\mathcal{L}_{0^+_{\rm SM}} = g_{0^+_{\rm SM}} V_\mu V^\mu X_0$$

$$\mathcal{L}_{0^+_{\rm D5}} = g_{0^+_{\rm D5}} V_{\mu\nu} V^{\mu\nu} X_0$$

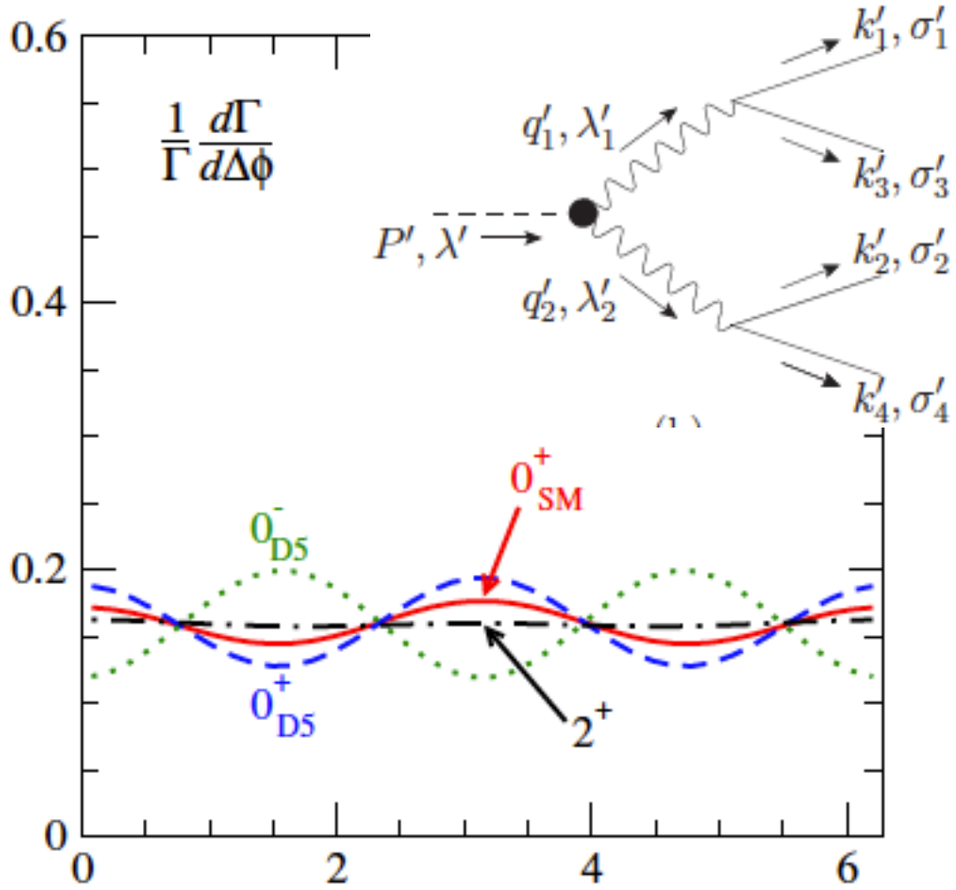
$$\mathcal{L}_{0^-_{\rm D5}} = g_{0^-_{\rm D5}} V_{\mu\nu} \tilde{V}^{\mu\nu} X_0$$

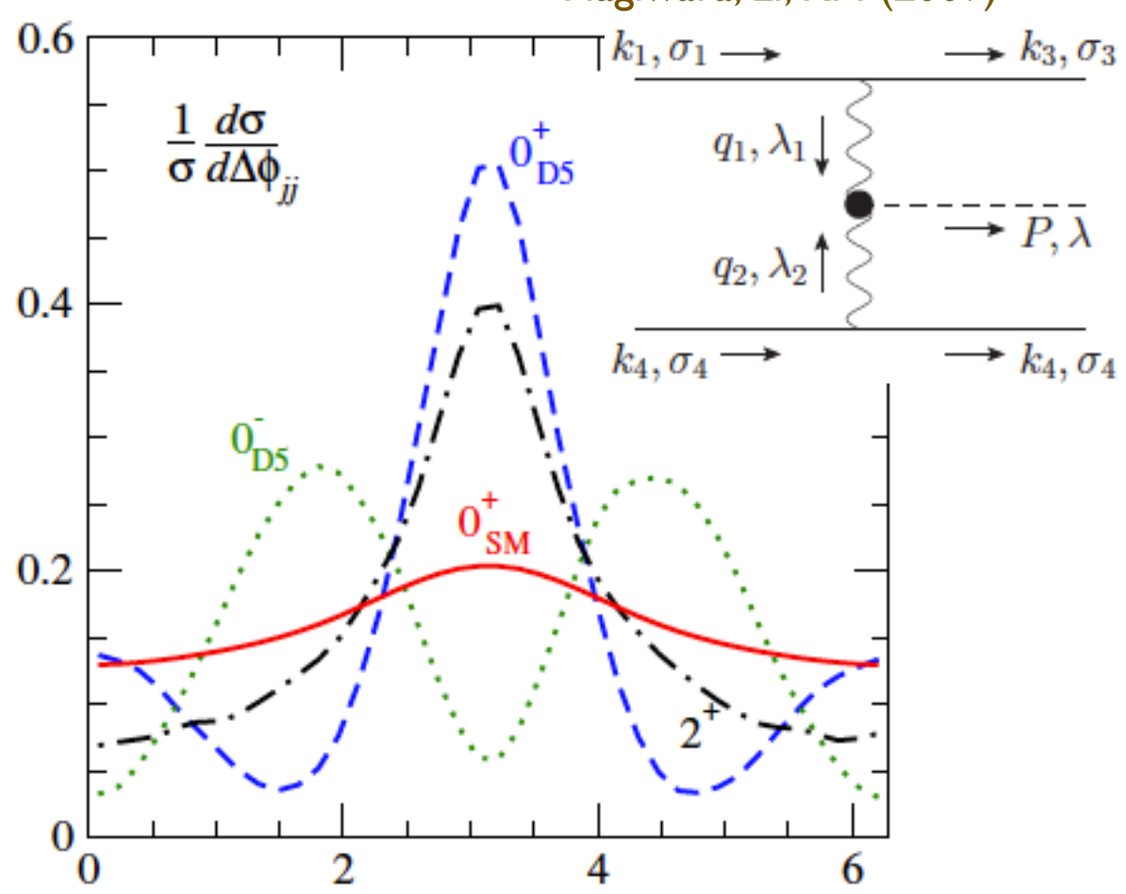


The azimuthal correlations between the forward tagging jets reflect the XVV tensor structures.

X→VV decay vs. VBF production

Hagiwara, Li, KM (2009)





$d\sigma/d\Delta\phi \sim$ const. for $0^+_{\rm SM}$, $\quad d\sigma/d\Delta\phi \sim 1 \pm A\cos 2\Delta\phi$ for $0^\pm_{\rm D5}$

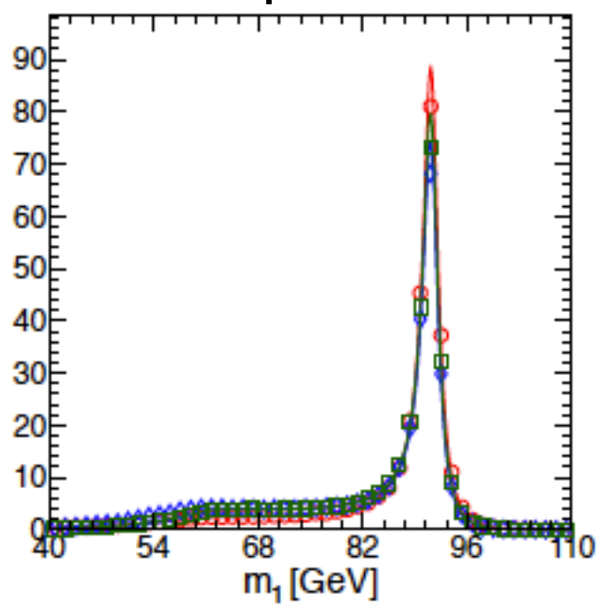
Nontrivial azimuthal correlations can be explained as the quantum interference among different helicity states of the intermediate vector-bosons.

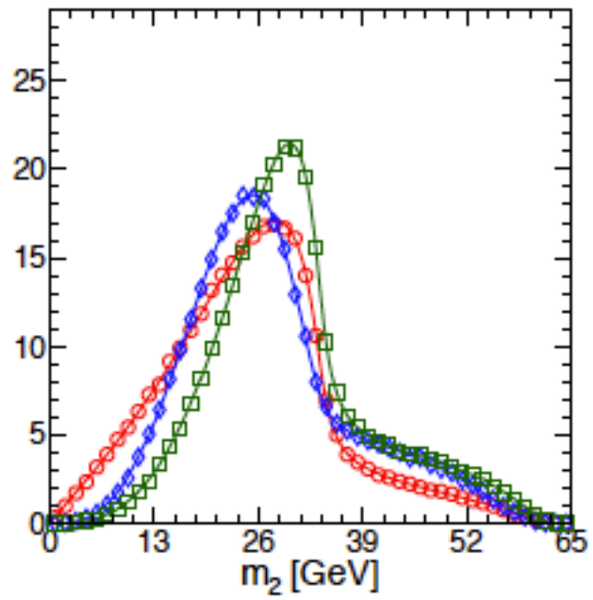
X→VV decay at m_X=126GeV

mass distributions

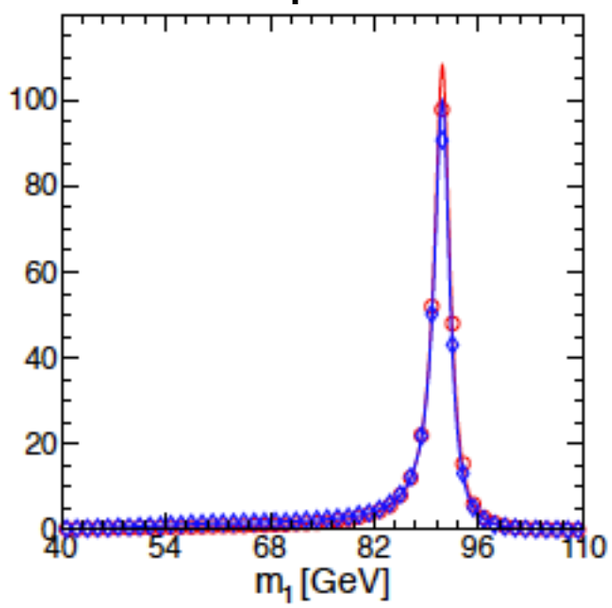
Bolognese et al. (2012): JHU-Generator

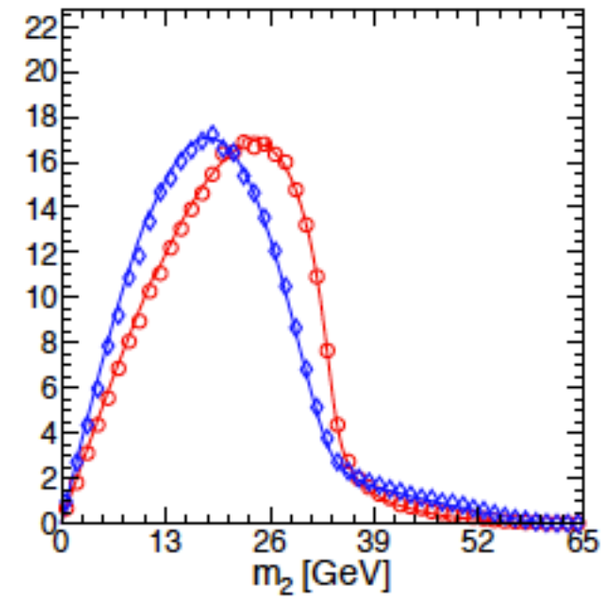
spin-0



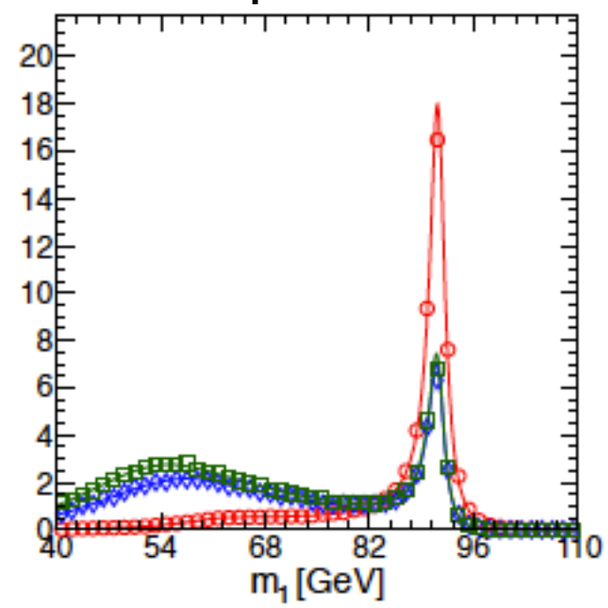


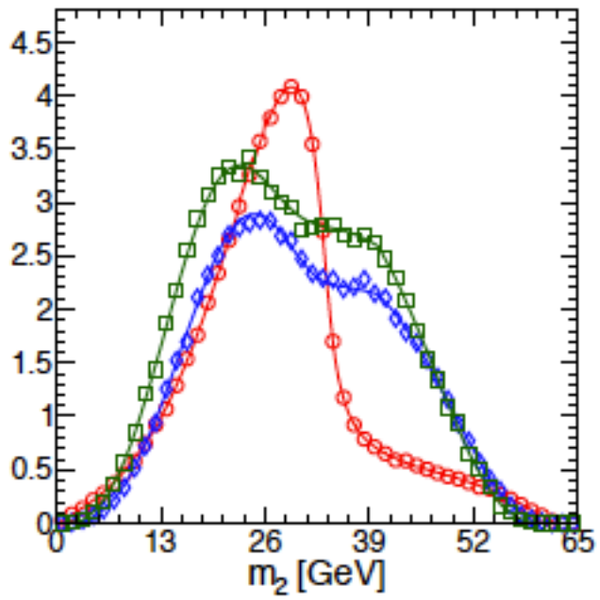
spin-1





spin-2





X→VV decay at m_X=126GeV

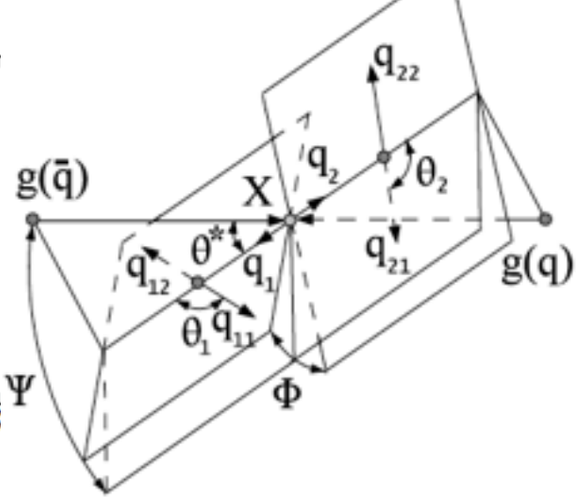
angular distributions

Bolognese et al. (2012): JHU-Generator

spin-2

spin-1

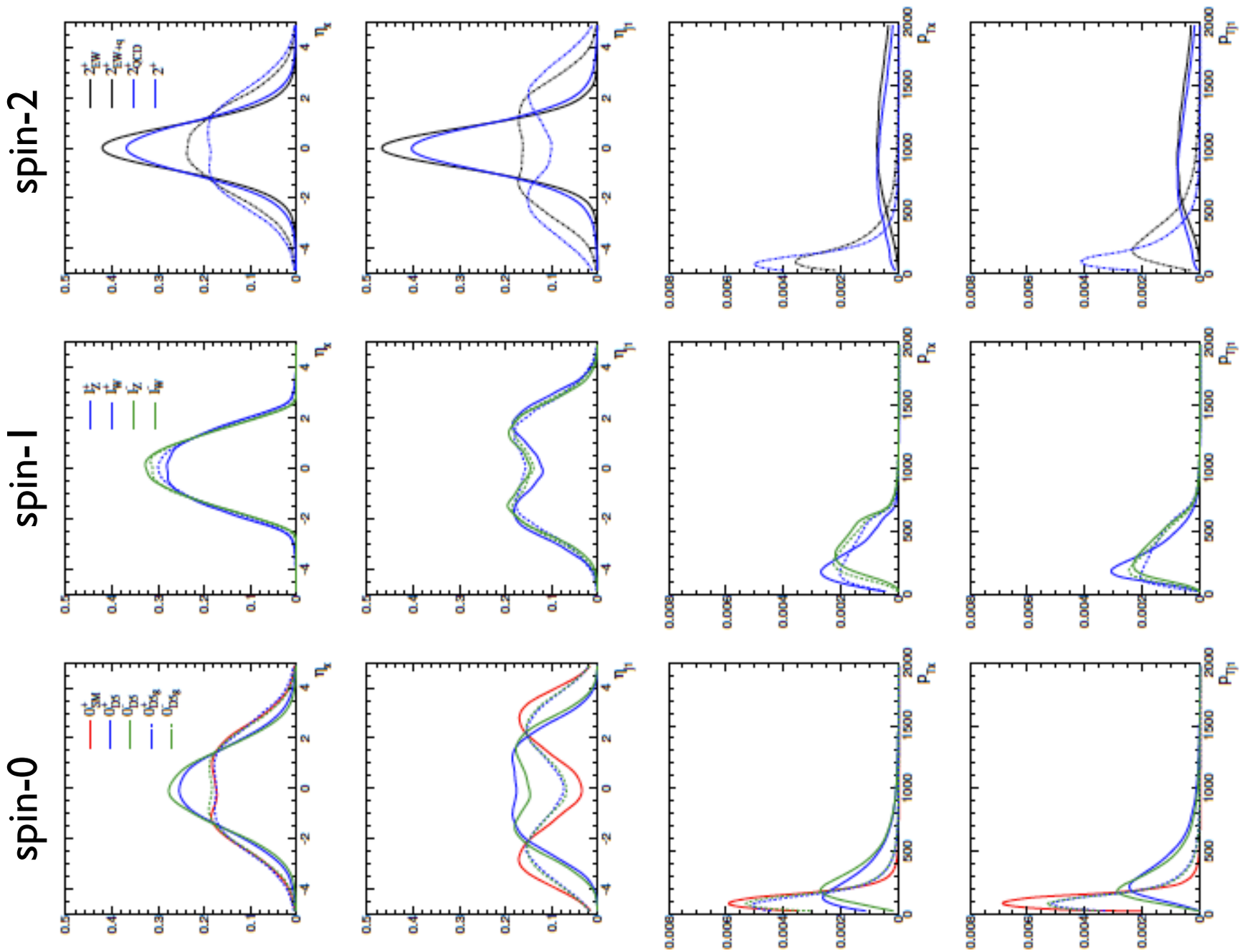
spin-0



VBF production at m_X=126GeV

X/jet distributions

Englert, Goncalves-Netto, KM, Plehn (2013)



$\sqrt{s} = 14$ TeV

$p_{T_j} > 20$ GeV

$\Delta R_{jj} > 0.6$

$|\eta_j| < 5$

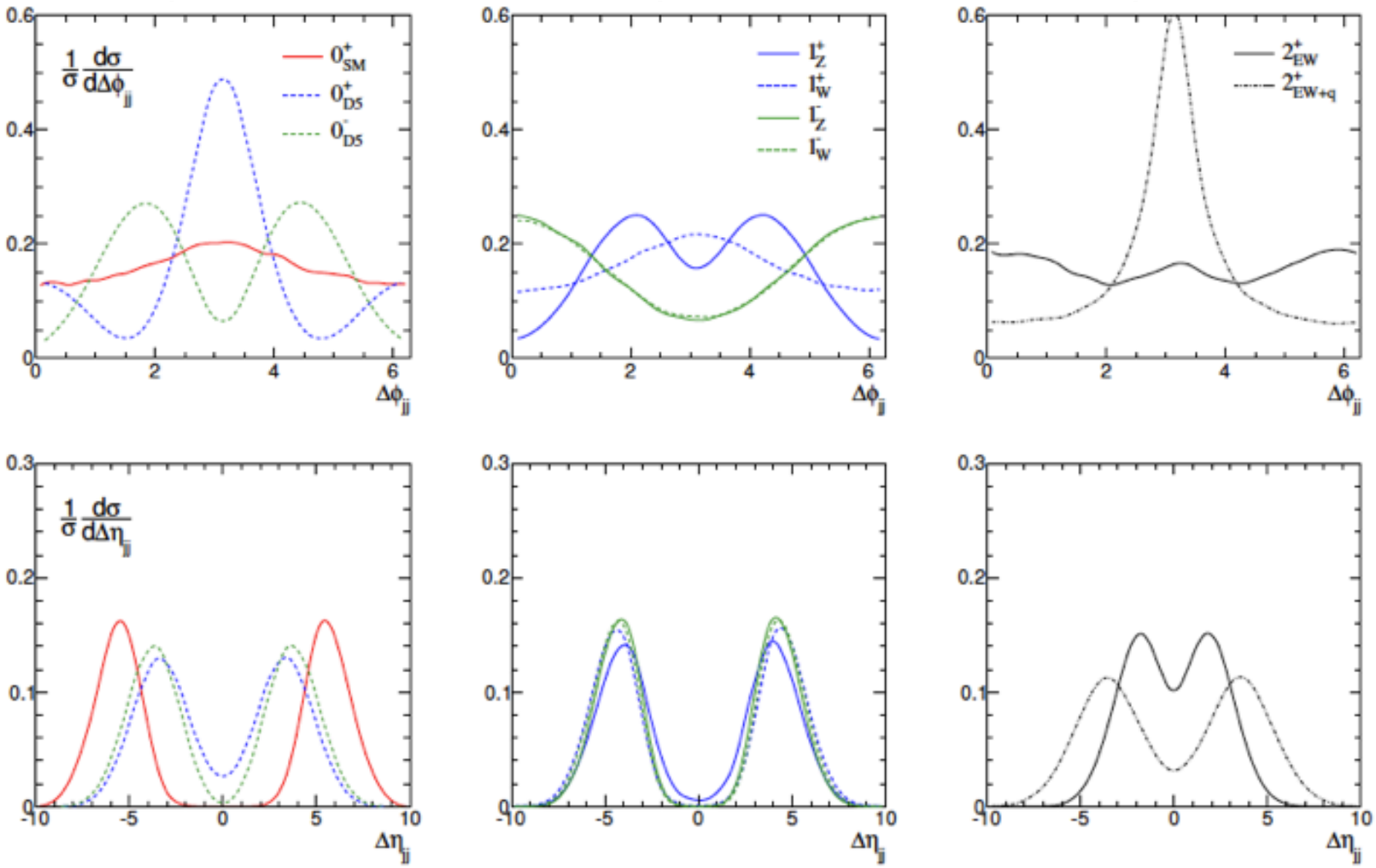
$m_{jj} > 600$ GeV

VBF production at m_X=126GeV

di-jet correlations

Englert, Goncalves-Netto, KM, Plehn (2013)

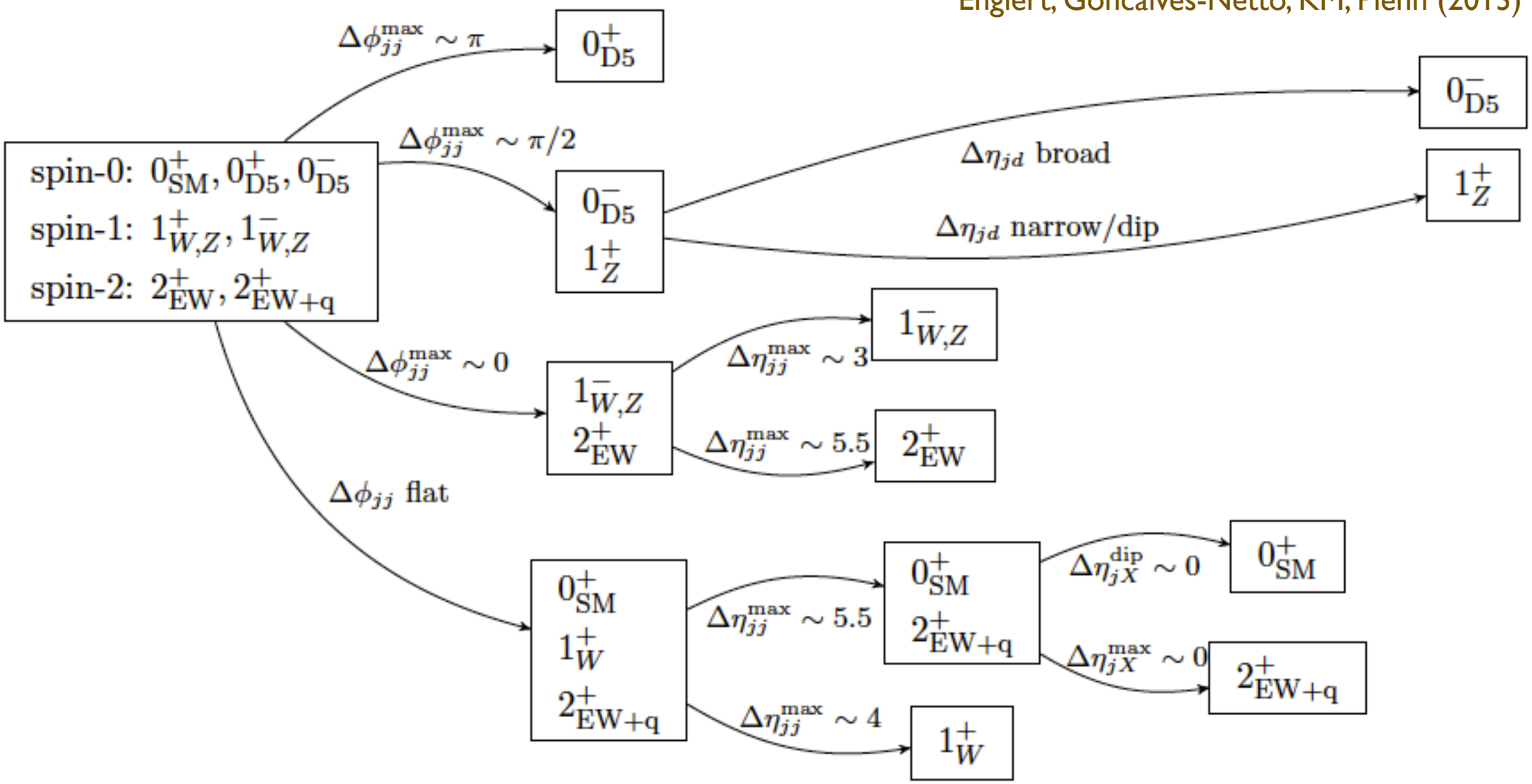
spin-0 | spin-1 | spin-2



$\Delta\eta$ as well as $\Delta\Phi$ are the powerful observables.

Obs-by-obs based strategy in VBF

Englert, Goncalves-Netto, KM, Plehn (2013)



The di-jet correlations are the most decisive, in particular to separate the different scalar coupling structures.

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$X(J^P)$ characterization
with FeynRules

Artoisenet, de Aquino, Frederix, Maltoni, Mandal, Mathews, KM, Ravindran, Seth, Torrielli, Zaro (on-going)

- Effective Lagrangians have been implemented via FeynRules by including all minimal (even higher) dimension operators for J=0,1,2.
  e.g. the X-Z-Z interactions:

$$\mathcal{L}_0 = \left[\cos\alpha\left(\kappa_{\rm SM} g_{HZZ} Z_\mu Z^\mu - \frac{1}{4}\frac{\kappa_V}{\Lambda} Z_{\mu\nu} Z^{\mu\nu}\right) - \sin\alpha \frac{1}{4}\frac{\kappa_V}{\Lambda} Z_{\mu\nu}\tilde{Z}^{\mu\nu}\right] X_0$$

$$\mathcal{L}_1 = \left[- \kappa_{V_3}(\partial^\nu Z_\mu) Z_\nu - \kappa_{V_5}\epsilon_{\mu\nu\rho\sigma} Z^\nu (\partial^\rho Z^\sigma)\right] X_1^\mu$$

$$\mathcal{L}_2 = \left[- \frac{\kappa_V}{\Lambda} T^Z_{\mu\nu} - \frac{\kappa_{V_1}}{\Lambda^3}(\partial_\nu(\partial_\mu \frac{1}{4} Z_{\rho\sigma} Z^{\rho\sigma})) - \frac{\kappa_{V_2}}{\Lambda^3}(\partial_\nu(\partial_\mu \frac{1}{4} Z_{\rho\sigma}\tilde{Z}^{\rho\sigma}))\right] X_2^{\mu\nu}$$

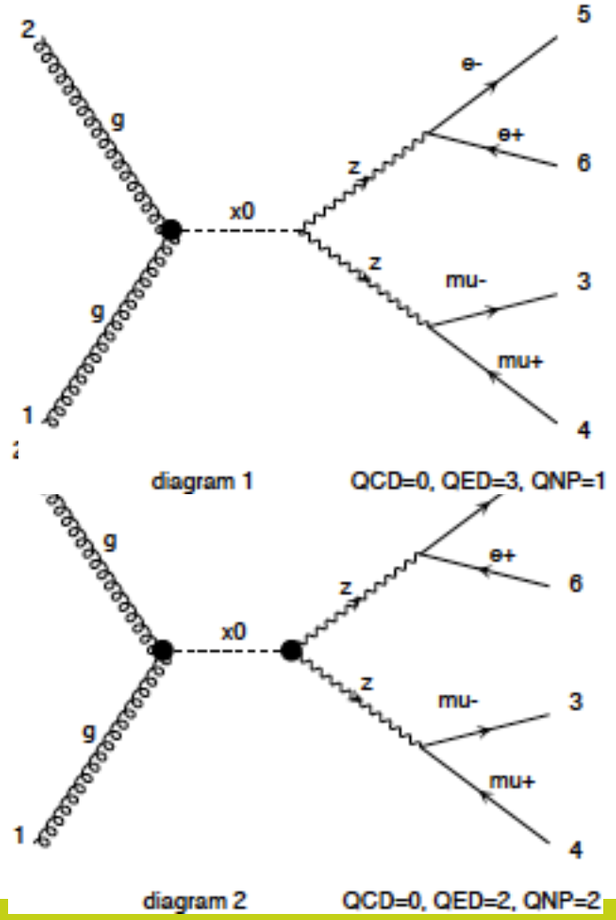
  - κ_i : dimensionless coupling parameters
  - $\cos\alpha$: mixing between 0^+ and 0^- parameters
  - Λ : theory cutoff scale

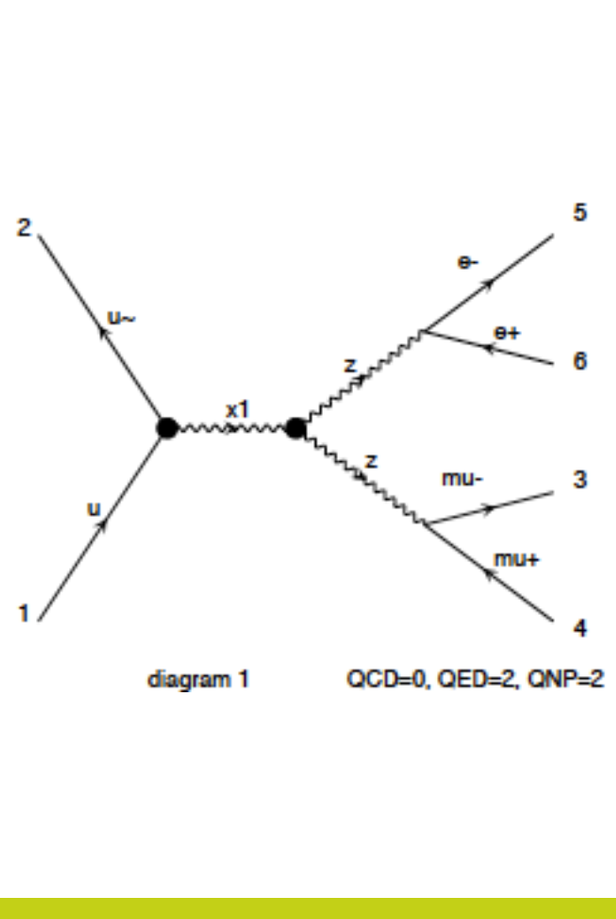
$X(J^P)$ characterization
with MadGraph5

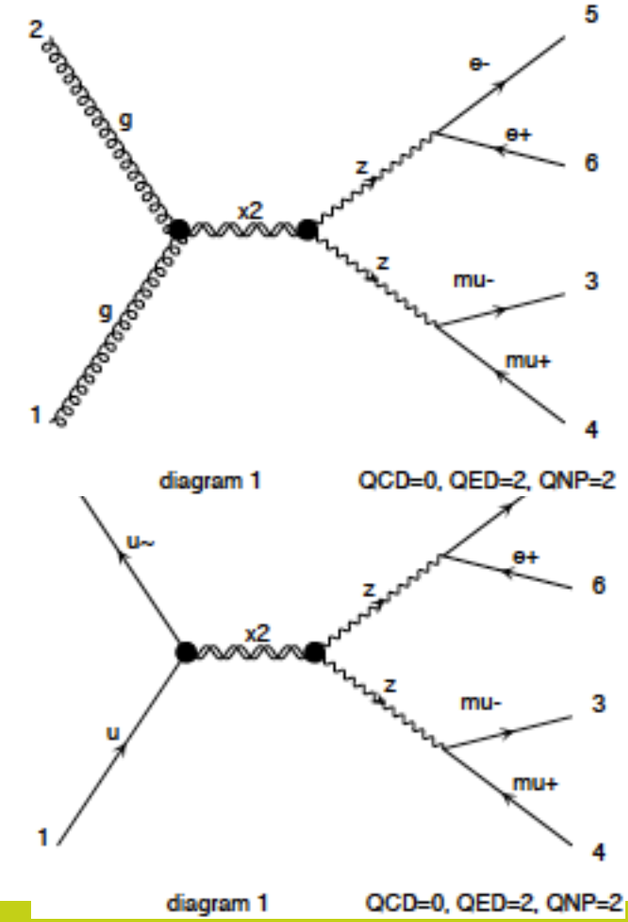
Artoisenet, de Aquino, Frederix, Maltoni, Mandal, Mathews, KM, Ravindran, Seth, Torrielli, Zaro (on-going)

- In MadGraph5:

```
./bin/mg5
>import model XCharac
>generate p p > x0, x0 > mu- mu+ e- e+
>output
>launch
```







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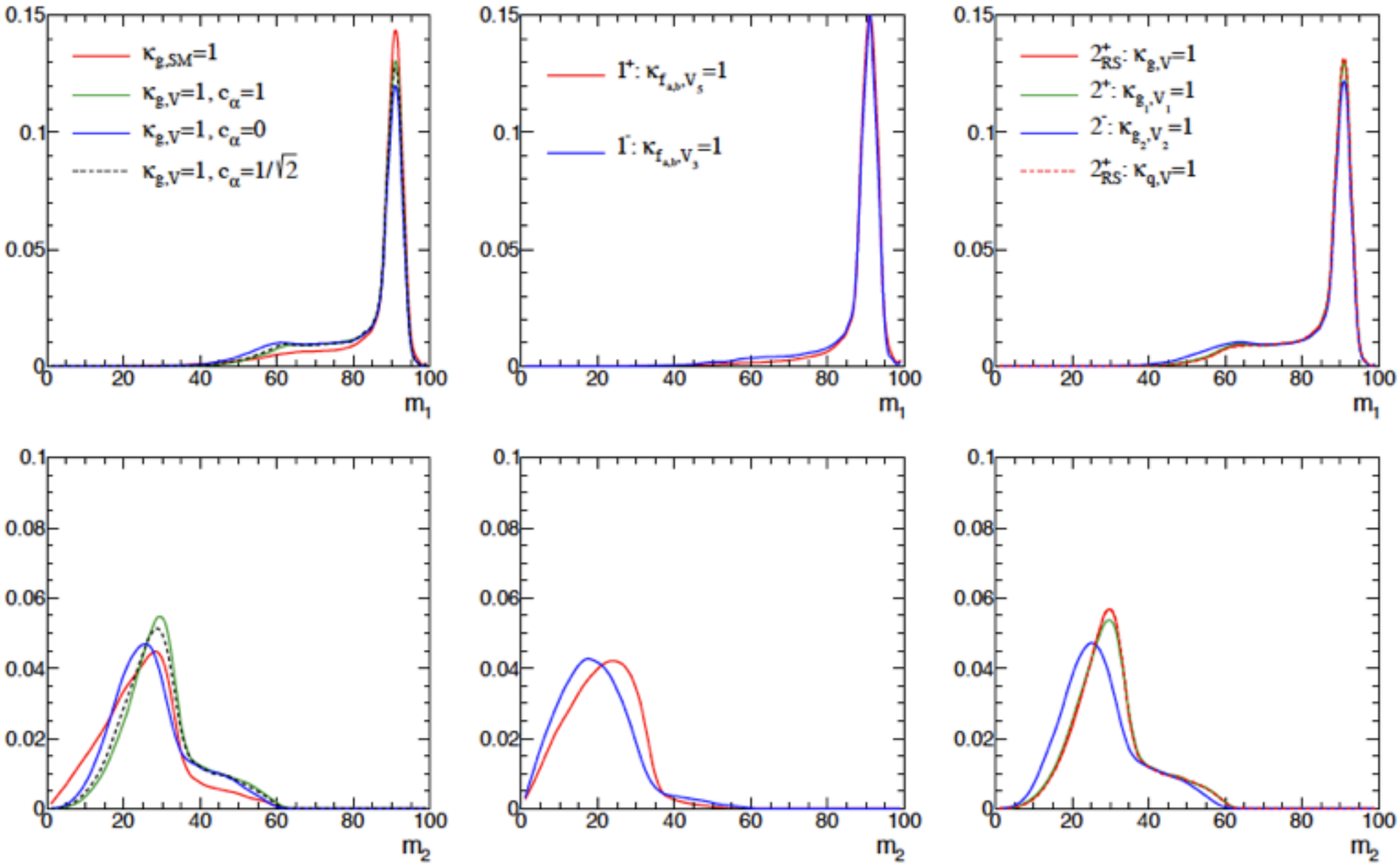
$X(J^P)$ characterization
with MadGraph5

Artoisenet, de Aquino, Frederix, Maltoni, Mandal, Mathews, KM, Ravindran, Seth, Torrielli, Zaro (on-going)

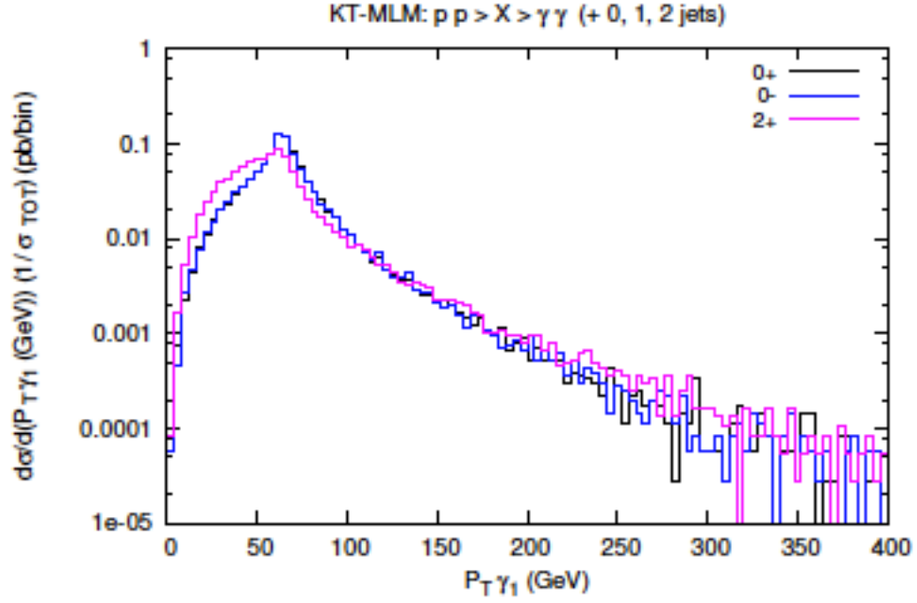
- In MadGraph5:

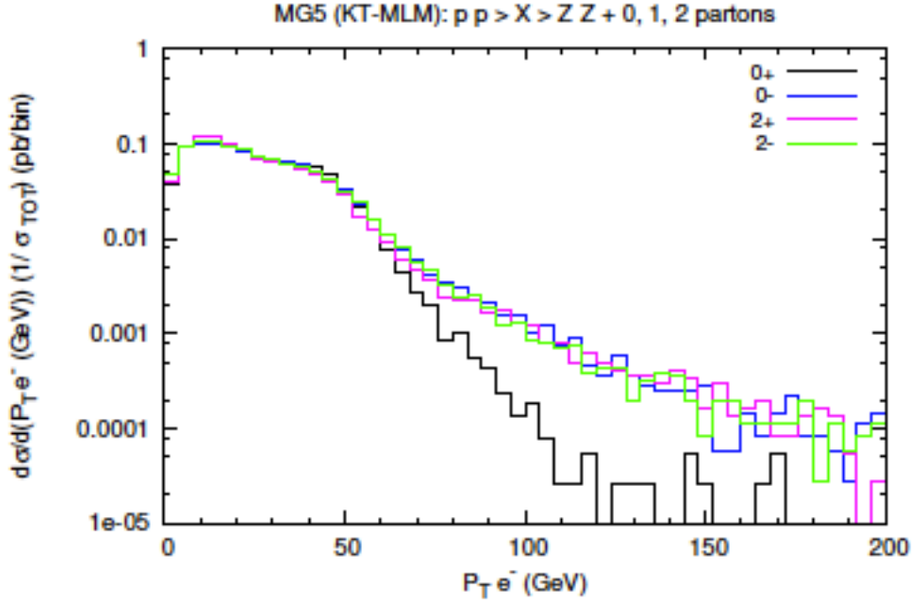


X(J^P) characterization
with ME-PS merging and MadWeight

Artoisenet, de Aquino, Frederix, Maltoni, Mandal, Mathews, KM, Ravindran, Seth, Torrielli, Zaro (on-going)

- It allows us to generate any tree-level process of interest, including all spin correlations, possible interference with backgrounds and to build inclusive samples via MatrixElement-PartonShower merging.



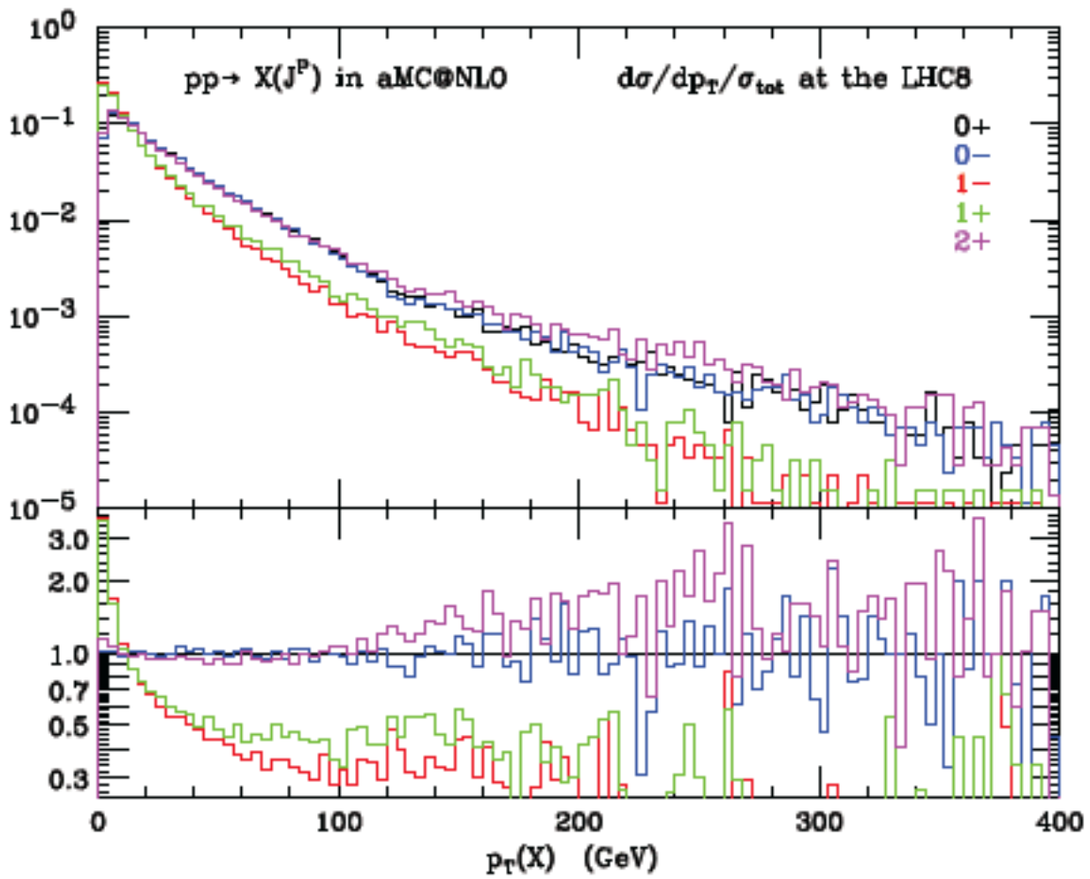


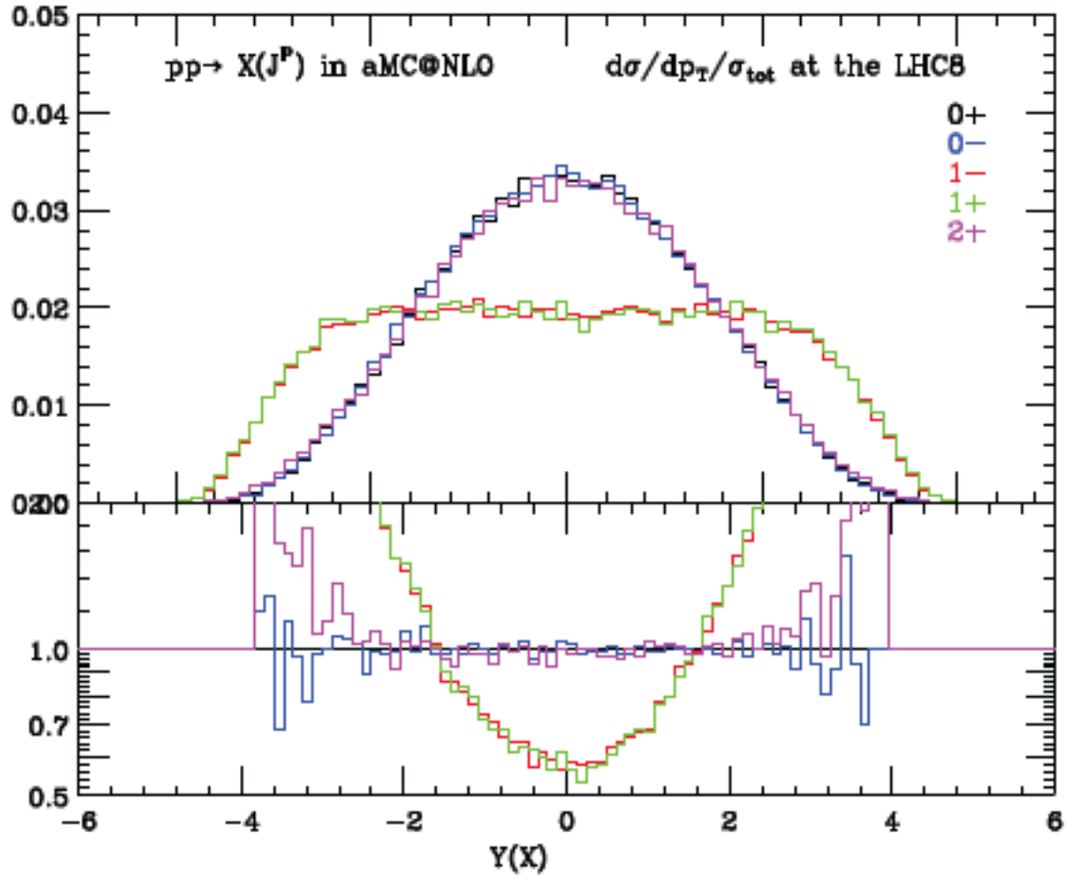
- With MadWeight, one can automatically build likelihoods via the Matrix-Element-Method.

X(J^P) characterization
with aMC@NLO

Artoisenet, de Aquino, Frederix, Maltoni, Mandal, Mathews, KM, Ravindran, Seth, Torrielli, Zaro (on-going)

- Furthermore, X(J^P) events can be generated at the next-to-leading order (NLO) with aMC@NLO.





Outlook

- After the discovery of a Higgs-like resonance at the LHC, the main focus of the analyses will be the determination of the Higgs Lagrangian.
- This includes
  - the structure of the operators, linked to the spin/parity of the 'Higgs' boson.
  - an independent measurement of the coupling strength.

- We presented a comprehensive study in VBF, as comparing with the $X \to ZZ$ decay, and showed that the di-jet correlations are the most distinctive observables.
- The various MC tools are ready for the X characterization study.