

HIGGS SPIN AND CP AT THE LHC

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DIS2014
WARSAW

THE SHAPE OF THE HIGGS I:
IS IT A SCALAR? HIGGS QUANTUM NUMBERS

HOW DO WE KNOW THE
HIGGS-CANDIDATE
IS A SCALAR?

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IS A **SCALAR**?

AFTER RESONANCE DISCOVERY,
QUANTUM NUMBERS DISCOVERY

HOW DO WE KNOW THE
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IS A **SCALAR**?

AFTER RESONANCE DISCOVERY,
QUANTUM NUMBERS DISCOVERY

THE DECAY TO PHOTON-PHOTON **RULES OUT $S=1$**
(ON-SHELL)

IT COULD BE **$JPC=0+,0-,2+,...$**

MODEL BUILDING MOTIVATION FOR
PSEUDO-SCALAR ($0-$)

AND

MASSIVE GRAVITON ($2+$)

**MODEL BUILDING INTERLUDE:
KK GRAVITON AS A HIGGS IMPOSTOR?**

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WARPED EXTRA-DIMENSIONS

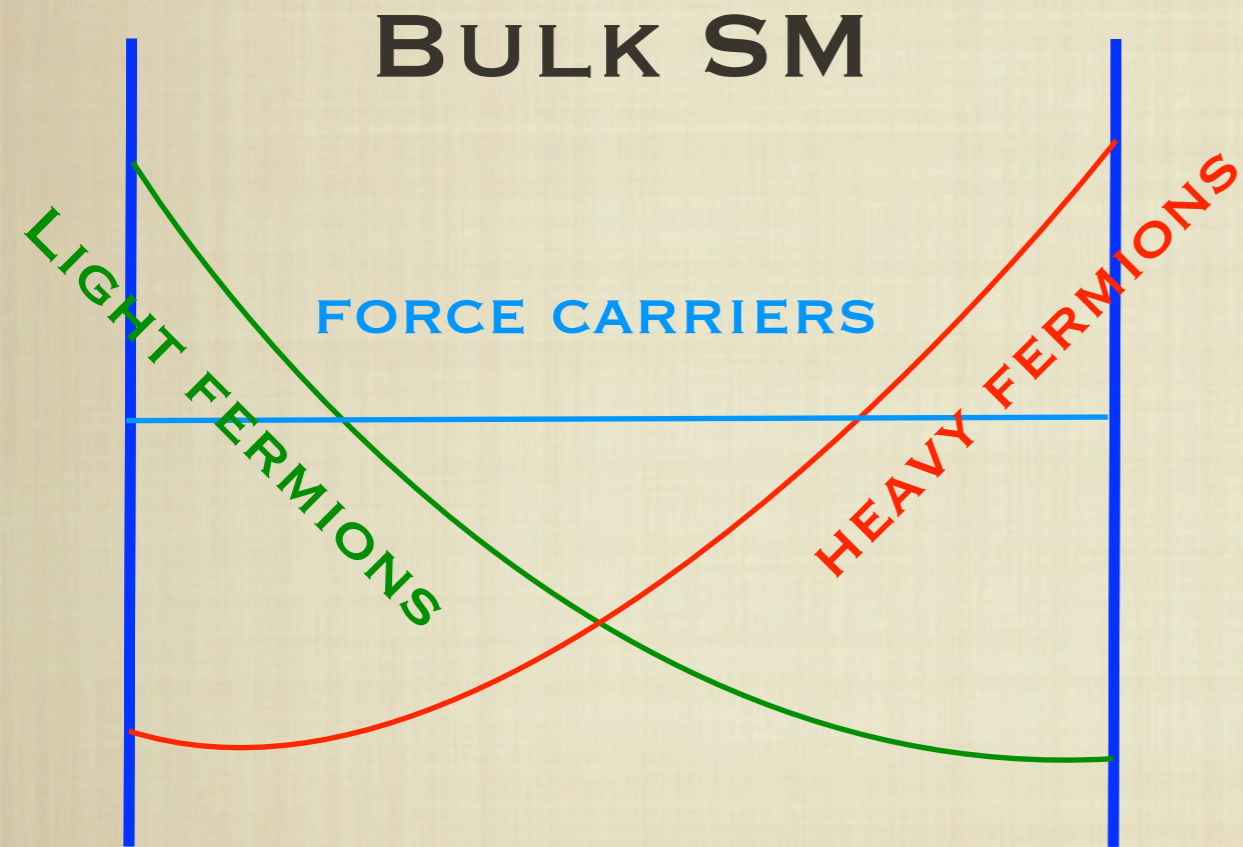
5D SPACETIME

4D MANIFOLD

EXTRA DIMENSION

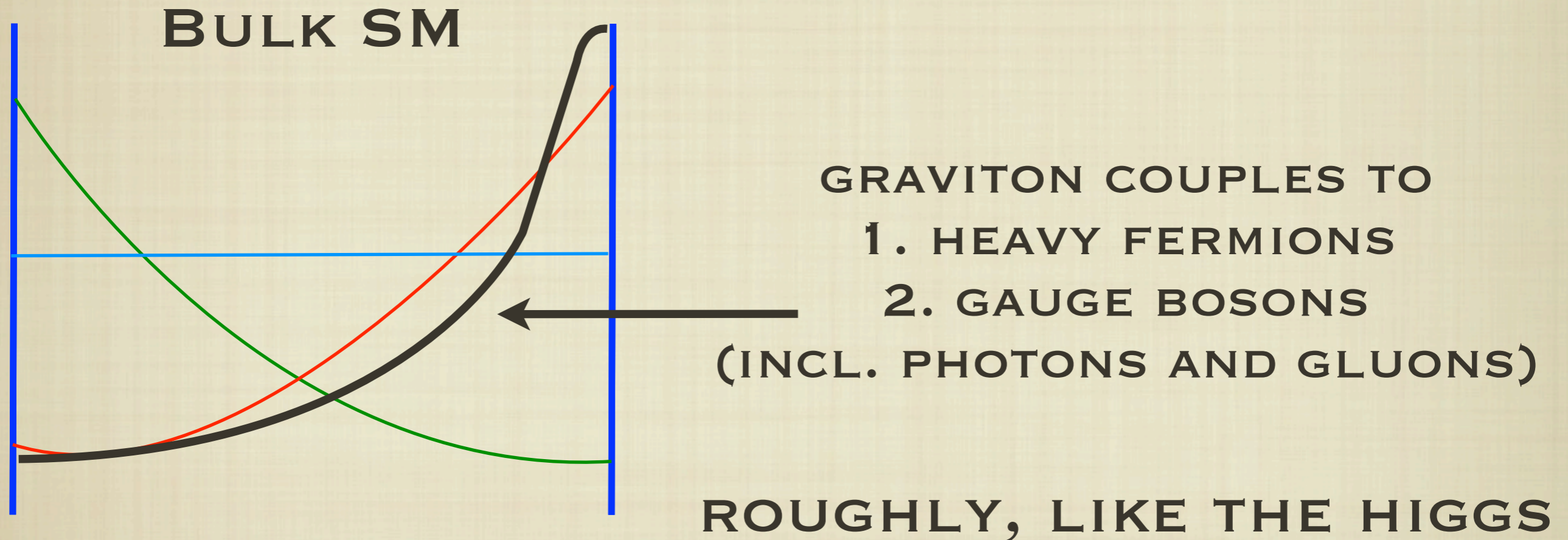
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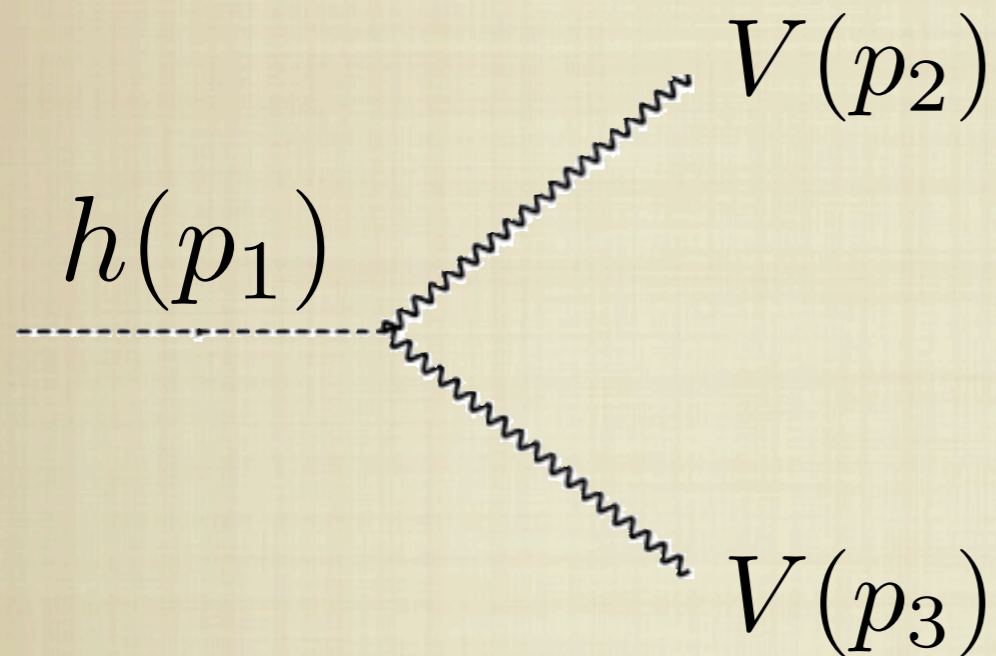
SAME GOES FOR A COMPOSITE SECTOR

HOW DO WE TELL APART EXPERIMENTALLY
THE 0^- AND 2^+ FROM THE 0^+ HYPOTHESIS?

THE **FORM** OF THE COUPLINGS

HOW DO WE TELL APART EXPERIMENTALLY
THE 0^- AND 2^+ FROM THE 0^+ HYPOTHESIS?

THE **FORM** OF THE COUPLINGS



0^+

$$m_V^2 \eta^{\mu\nu}$$

0^-

$$\epsilon^{\mu\nu\alpha\beta} p_{2,\alpha} p_{3,\beta}$$

DIFFERENT KINEMATIC DISTRIBUTIONS

WHAT ABOUT THE $2+$ CASE?

LOTS OF ARBITRARINESS?

RS-LIKE, MINIMAL GRAVITON?

WHAT ABOUT THE 2+ CASE?

LOTS OF ARBITRARINESS?

RS-LIKE, MINIMAL GRAVITON?

ANY 2+ RESONANCE (LIKE F2 IN QCD)

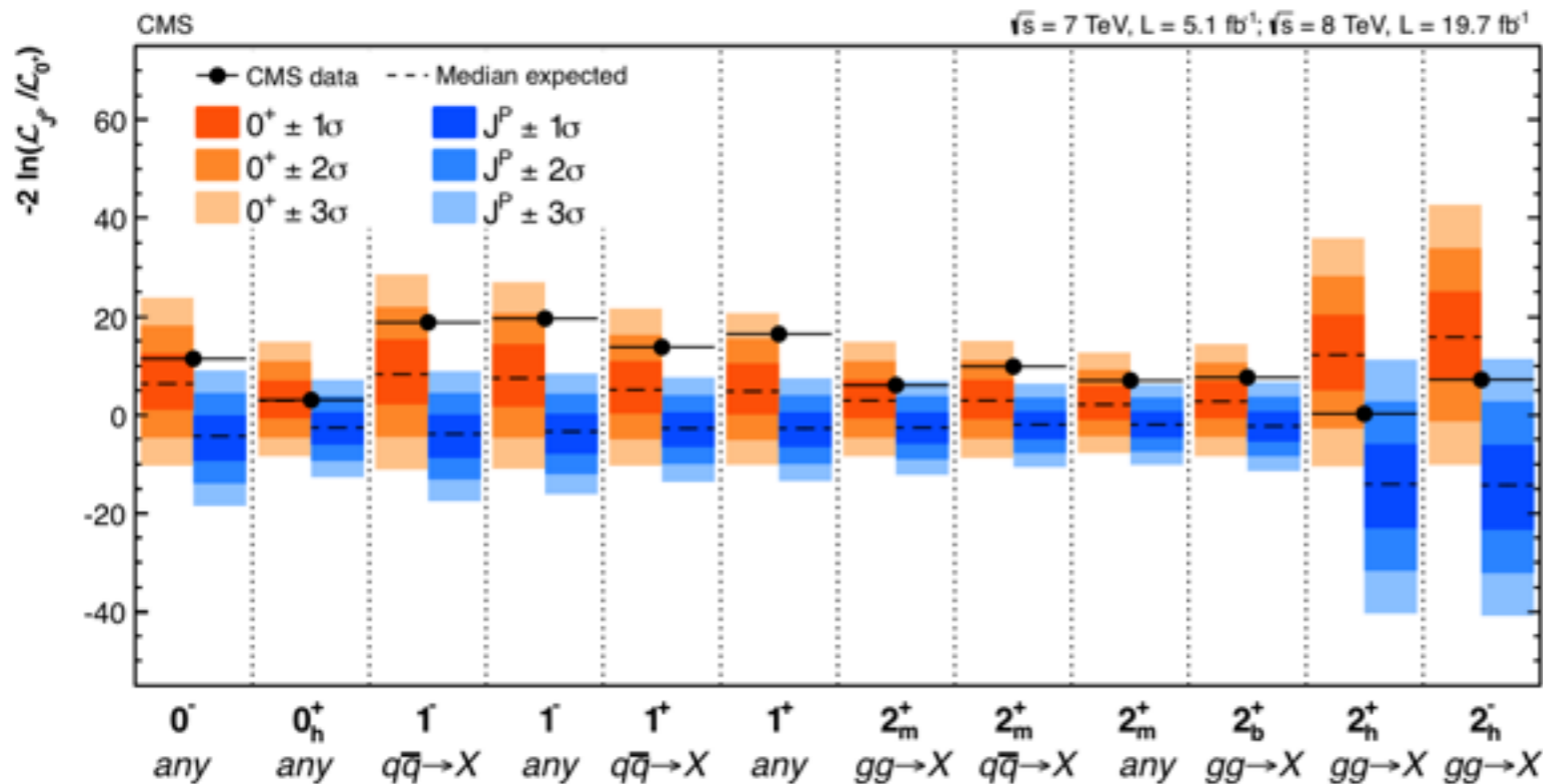
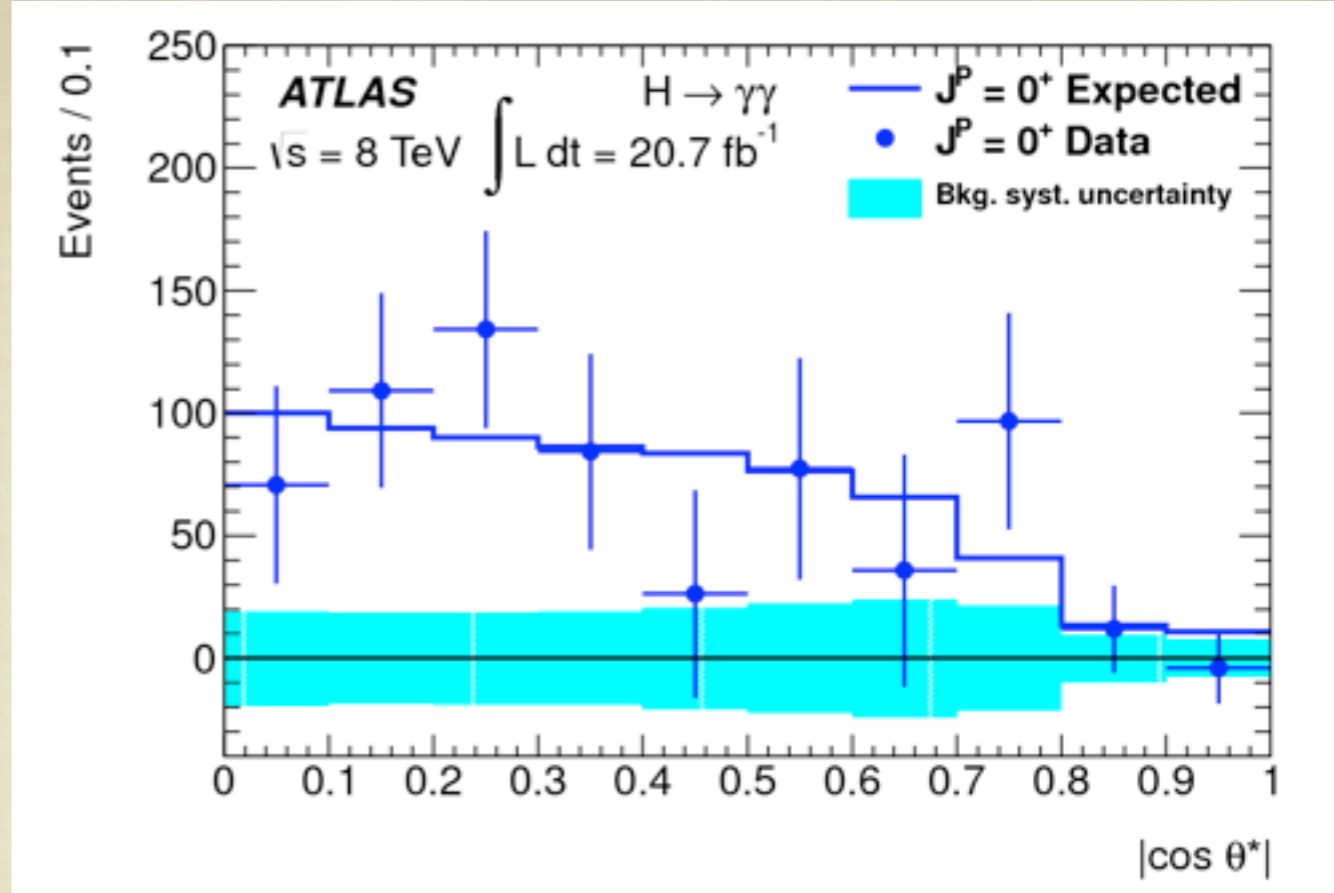
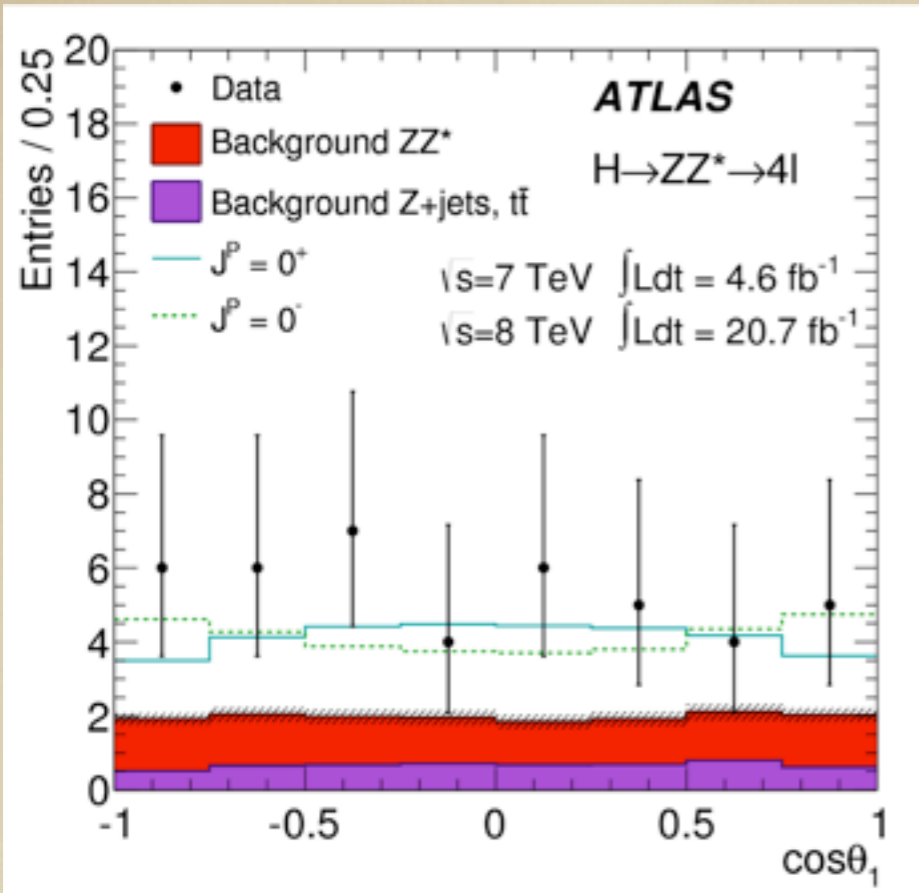
IF LORENTZ+GAUGE+CP INVARIANCE :

RESONANCE FROM EXTRA-DIMENSIONS OR
FROM A COMPOSITE SECTOR WOULD HAVE THE
SAME **FORM** OF INTERACTIONS

(CONSISTENT W/ ADS/CFT)

GUIMARAES, FOK, LEWIS, VS

1203.2917



**NON- 0^+
HYPOTHESIS
EXCLUDED AT
98% OR MORE
DETAILS: TALKS
LATER**

IS THAT IT?

**THE SHAPE OF THE HIGGS II:
NEW PHYSICS IN KINEMATIC DISTRIBUTIONS**

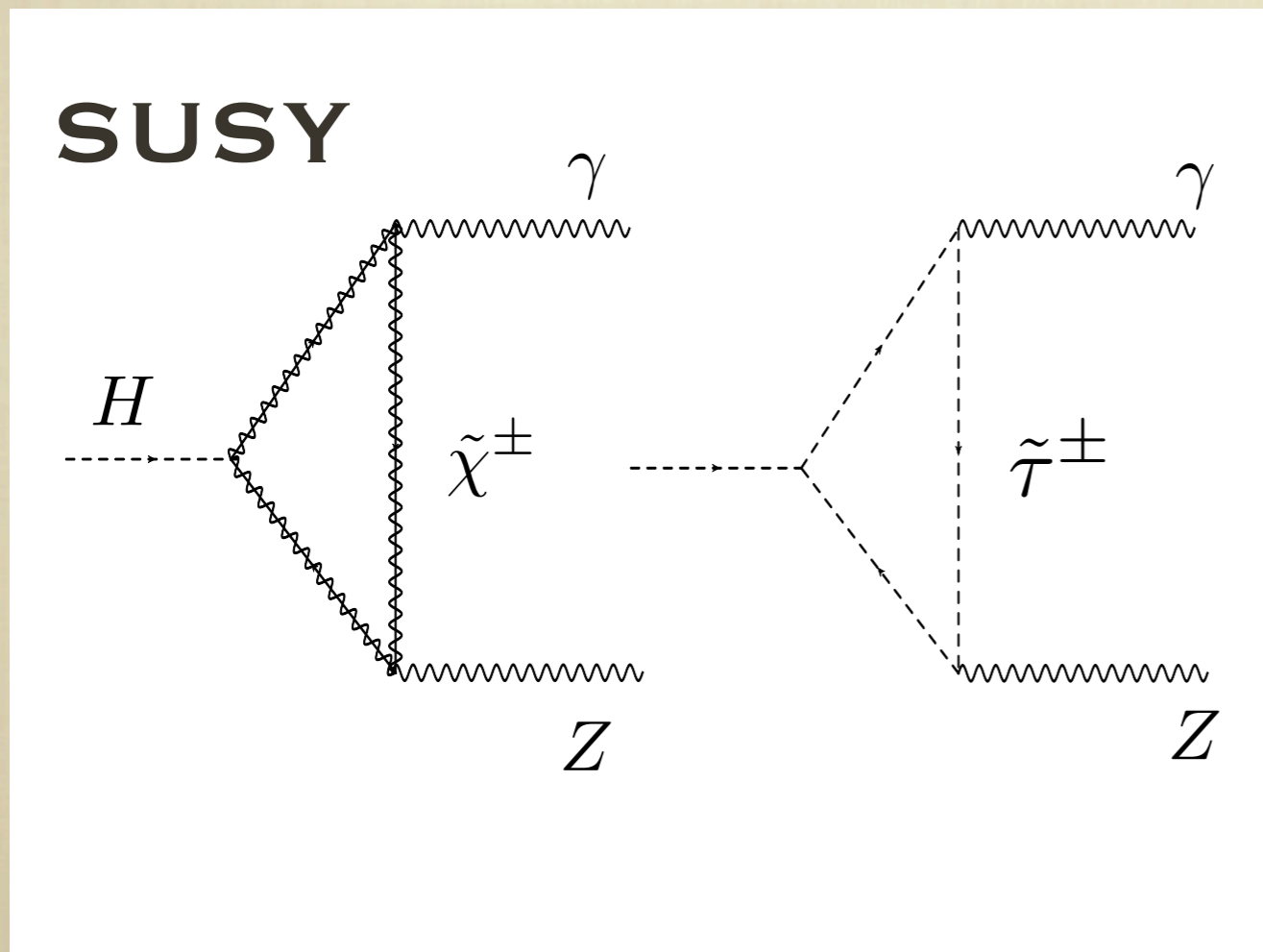
NEW PHYSICS TALKING TO THE HIGGS

FORM COUPLINGS OF THE HIGGS

IF NP IS HEAVY
EFFECTIVE THEORY

$$\mathcal{L}_{eff} = \sum_i \frac{f_i}{\Lambda^2} \mathcal{O}_i$$

EXAMPLE



$$\mathcal{O}_W = (D_\mu \Phi)^\dagger \widehat{W}^{\mu\nu} (D_\nu \Phi)$$

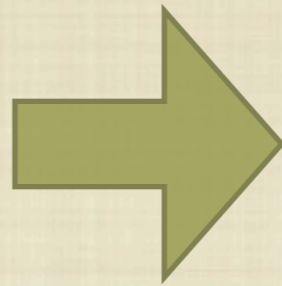
$$\mathcal{O}_B = (D_\mu \Phi)^\dagger (D_\nu \Phi) \widehat{B}^{\mu\nu}$$

$$\mathcal{O}_{WW} = \Phi^\dagger \widehat{W}^{\mu\nu} \widehat{W}_{\mu\nu} \Phi$$

$$\mathcal{O}_{BB} = (\Phi^\dagger \Phi) \widehat{B}^{\mu\nu} \widehat{B}_{\mu\nu}$$

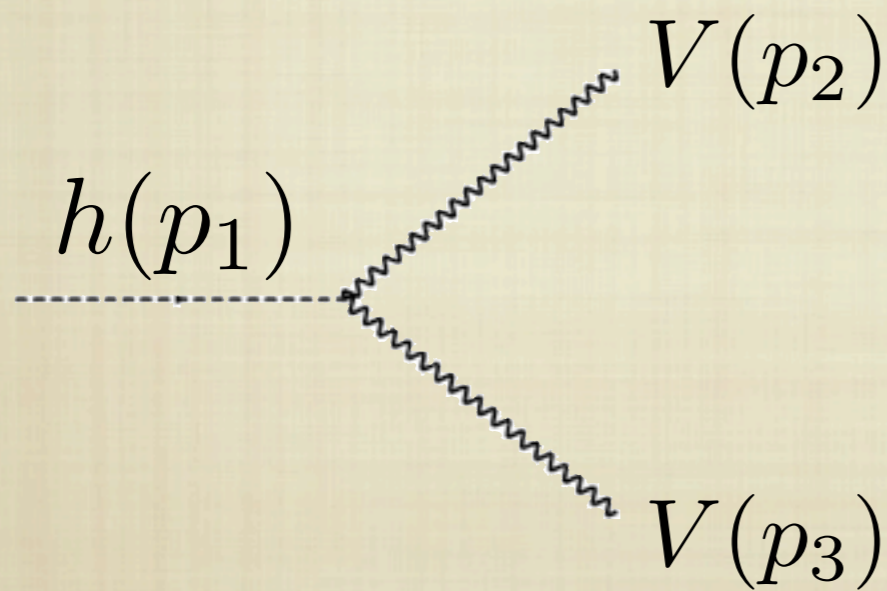
HIGGS ANOMALOUS COUPLINGS

EFT GENERATES
 HVV INTERACTIONS
 WITH MORE
 DERIVATIVES



$$\begin{aligned}
 & -\frac{1}{4} h \underline{g_{hVV}^{(1)}} V_{\mu\nu} V^{\mu\nu} \\
 & -h \underline{g_{hVV}^{(2)}} V_\nu \partial_\mu V^{\mu\nu} \\
 & -\frac{1}{4} h \underline{\tilde{g}_{hVV}} V_{\mu\nu} \tilde{V}^{\mu\nu}
 \end{aligned}$$

EX. FEYNMAN RULE IF $M_H > 2M_V$



$$i\eta_{\mu\nu} \left(\underline{g_{hVV}^{(1)}} \left(\frac{\hat{s}}{2} - m_V^2 \right) + 2 \underline{g_{hVV}^{(2)}} m_V^2 \right)$$

$$-i \underline{g_{hVV}^{(1)}} p_3^\mu p_2^\nu$$

$$-i \underline{\tilde{g}_{hVV}} \epsilon^{\mu\nu\alpha\beta} p_{2,\alpha} p_{3,\beta}$$

**NEW PHYSICS SEARCHES
HIGGS ANOMALOUS COUPLINGS**

FORM OF THE COUPLING

(ANGULAR CORRELATIONS, PT DISTRIBUTIONS...)

SAME TECHNIQUES AS USED FOR HIGGS QNS

LHC EXCLUDES RESONANCE 100% 0- OR 2+ OR OTHER EXOTIC QNS

ADMIXTURE OF 0+ AND OTHER QNS?

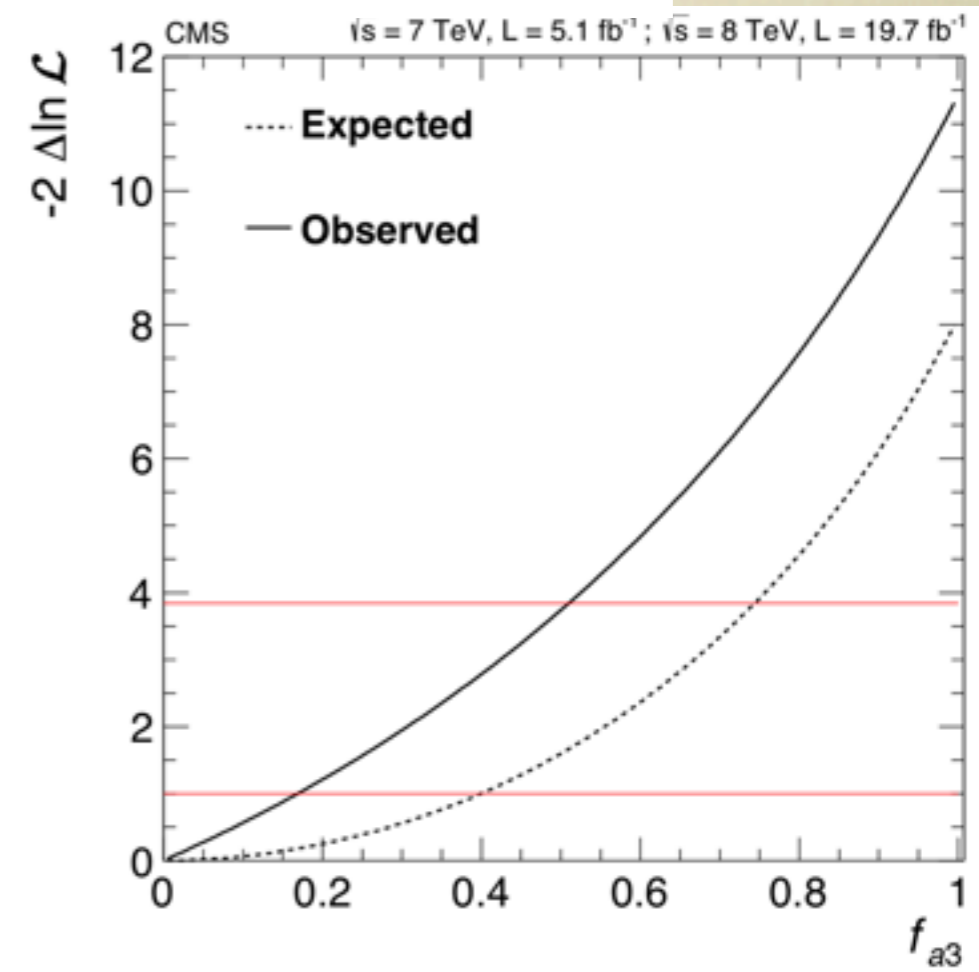
$$A(H \rightarrow ZZ) = v^{-1} \left(a_1 m_Z^2 \epsilon_1^* \epsilon_2^* + a_2 f_{\mu\nu}^{*(1)} f^{*(2),\mu\nu} + a_3 f_{\mu\nu}^{*(1)} \tilde{f}^{*(2),\mu\nu} \right)$$

HIGGS ANOM COUPLINGS

BOUNDS ON HIGGS EFT

GODBOLE, MOHAN,

MUHLLEITNER, VS. IN PREP.



$$f_{a3} = \frac{|a_3|^2 \sigma_3}{|a_1|^2 \sigma_1 + |a_2|^2 \sigma_2 + |a_3|^2 \sigma_3'}$$

FRAMEWORK FOR HEFT

HIGGS BRs

EHDECAY

CONTINO, GHEZZI, GROJEAN, MUHLLEITNER AND SPIRA.

1303.3876

PRODUCTION RATES AND KINEMATIC DISTRIBUTIONS

DEPEND ON CUTS

NEED RADIATION AND DETECTOR

EFFECTS

SIMULATION TOOLS

A COUPLE OF TOOLS

1. FEYNRULES HEFT AND TGCS

ALLOUL, FUKS, VS. 1310.5150

LINKS TO CALCHEP, LOOPTOOLS, MADGRAPH...

HDOs->**MADGRAPH**-> **PYTHIA...** -> **FASTSIM/FULLSIM**

2. QCD NLO HEFT TGCS

VS AND WILLIAMS. IN PREP.

MCFM AND POWHEG

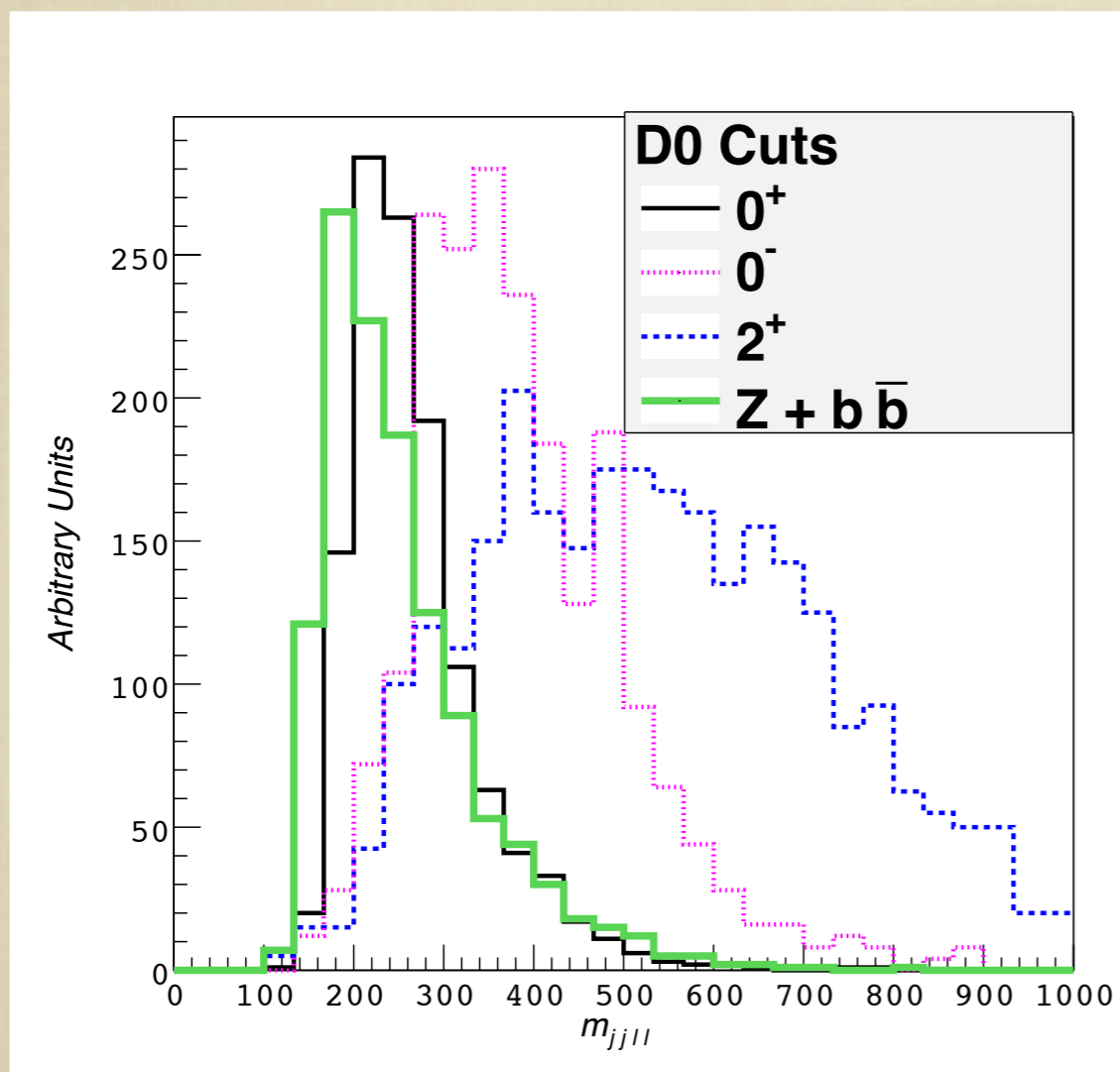
PYTHIA, HERWIG... -> **FASTSIM/FULLSIM**

EXAMPLE. ASSOCIATED PRODUCTION

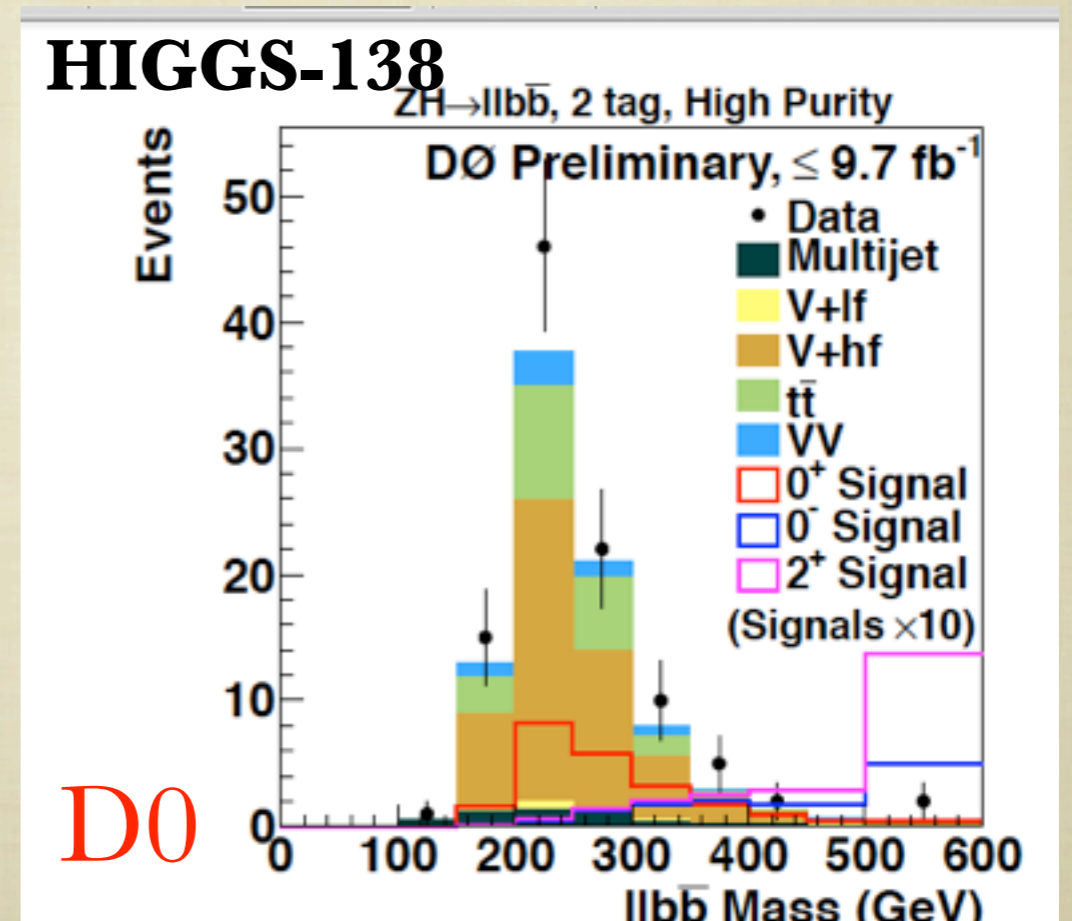
AP IS VERY SENSITIVE TO THE **FORM** OF THE COUPLING

TEST JCP OF THE HIGGS

$$m_{Vh}$$



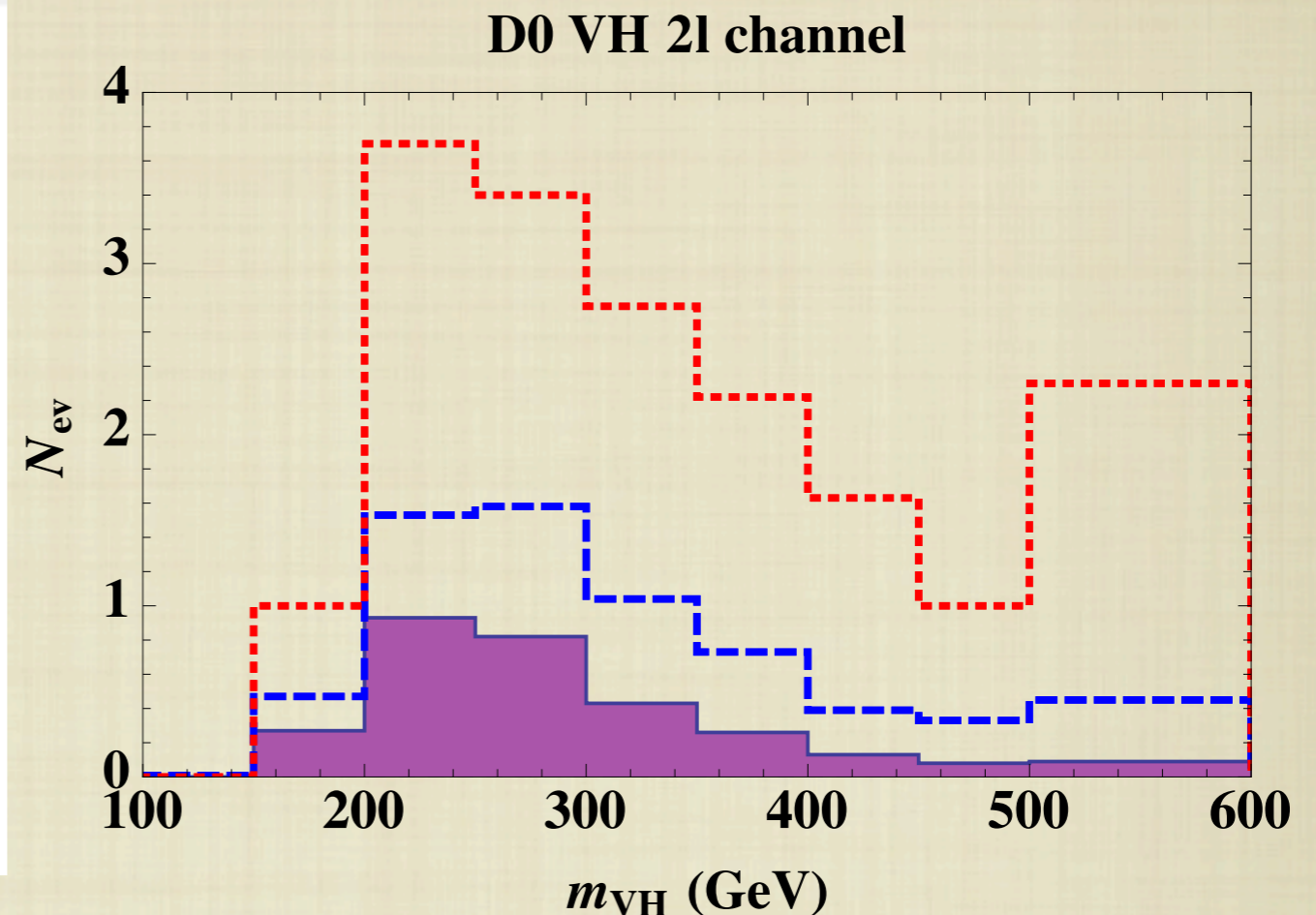
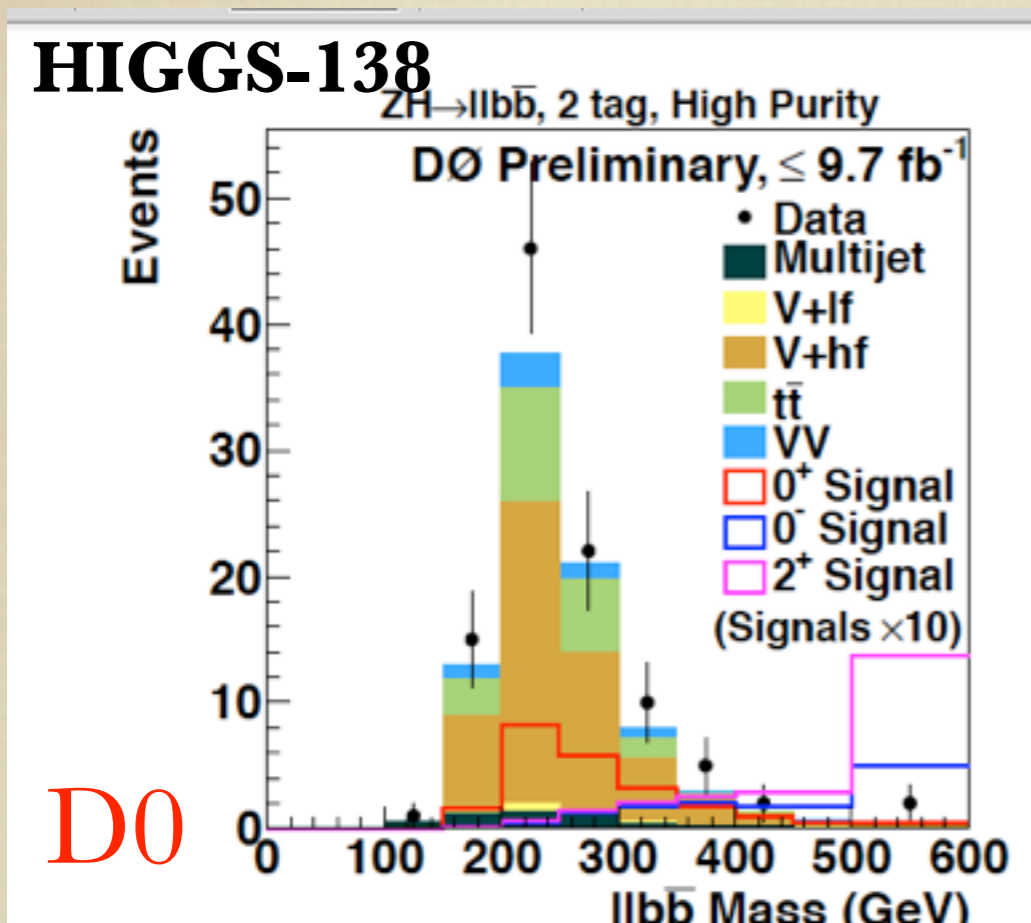
HIGGS-138



D0

EXAMPLE. ASSOCIATED PRODUCTION

HIGGS EFT DIFFERENT FORM OF THE COUPLING



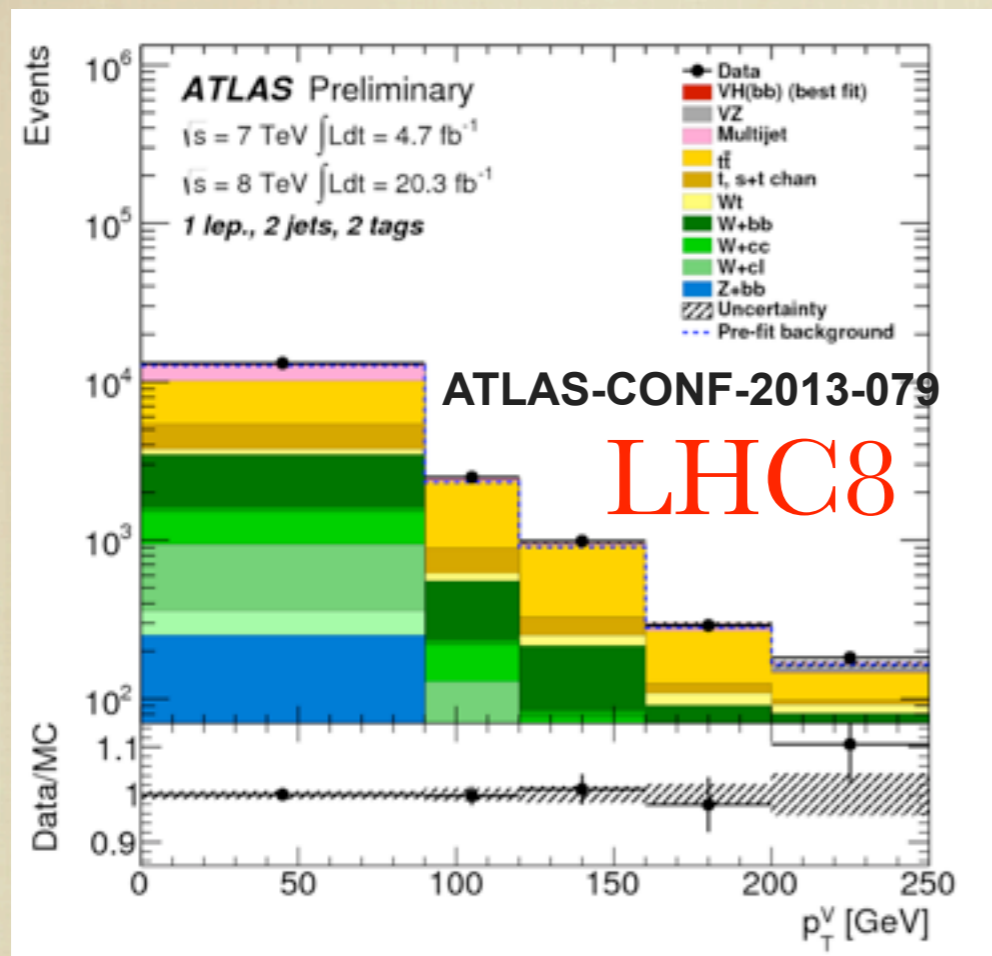
FEYNRULES \rightarrow MG5 \rightarrow PYTHIA \rightarrow DELPHES3
VALIDATE SM/BGS \Rightarrow EXPECTATION FOR EFT

LAST BIN CONSTRAINT BETTER THAN D0 SIGNAL STRENGTH

ELLIS, VS, YOU. 1404.3667

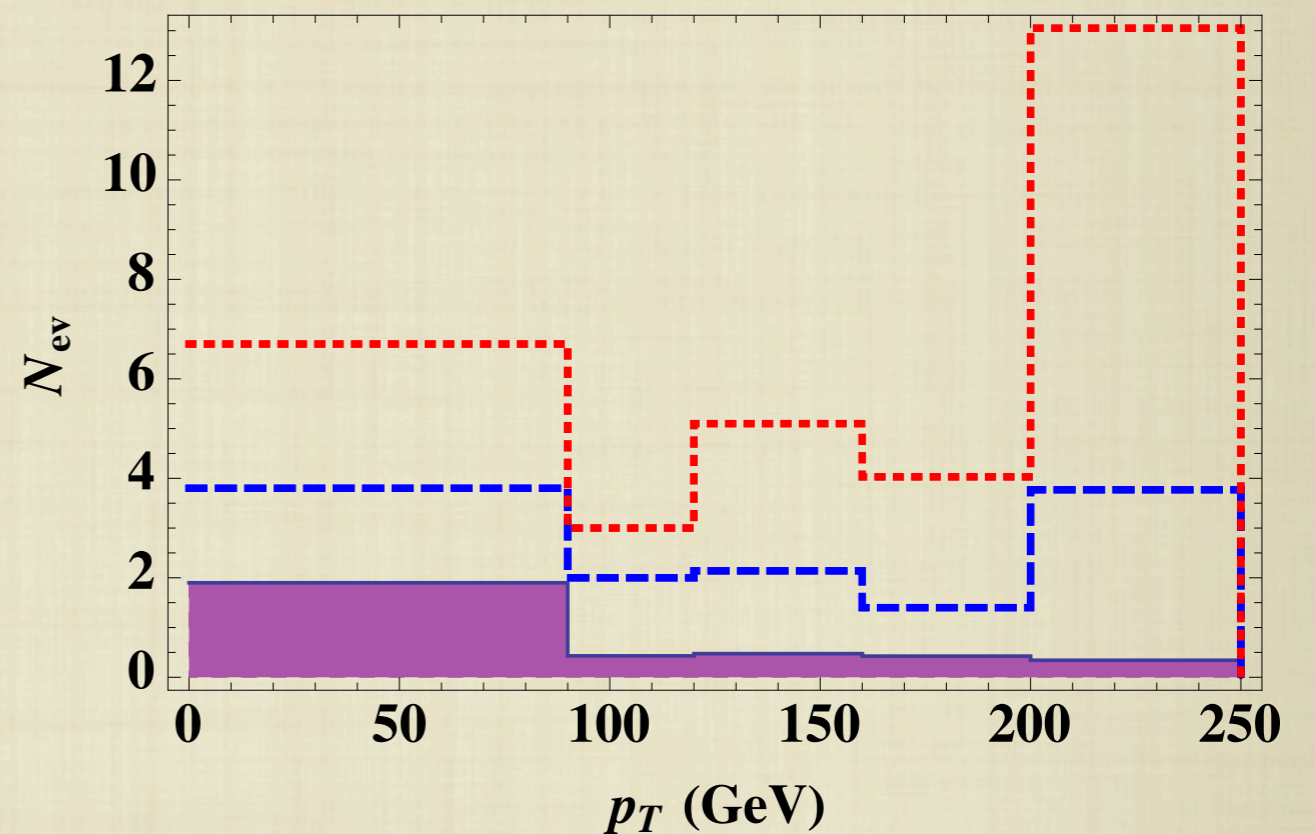
EXAMPLE. ASSOCIATED PRODUCTION

LHC DATA SHOULD BE EVEN BETTER



only p_T^V available

LHC8 ATLAS VH



FEYNRULES -> MG5-> PYTHIA->DELPHES3
VERIFIED FOR SM/BGS => EXPECTATION FOR EFT

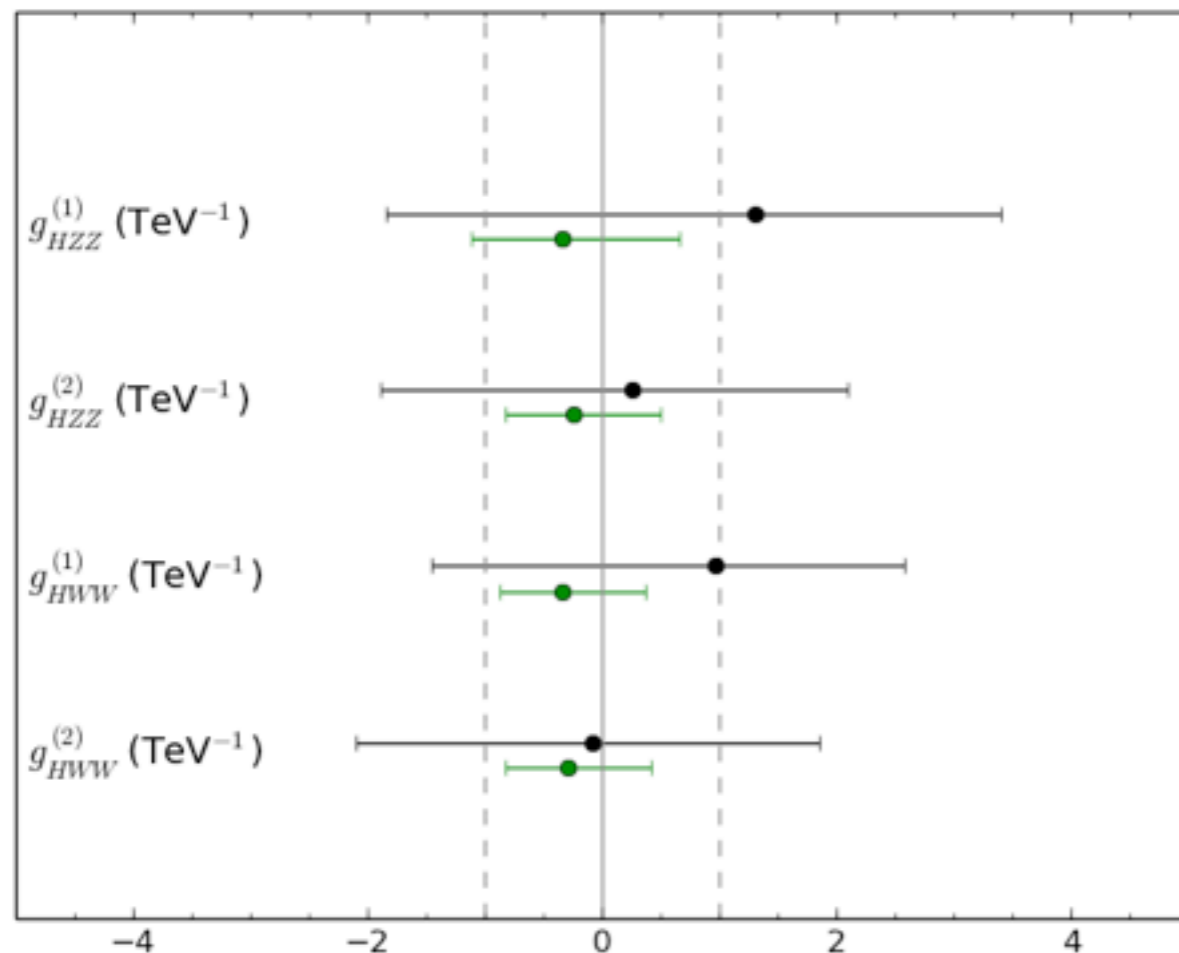
ELLIS, VS, YOU. 1404.3667

GLOBAL FIT USING SIGNAL STRENGTHS **AND** KINEMATICS OF AP

HIGGS' ANOMALOUS COUPLINGS

$$\mathcal{L} \supset -\frac{1}{4}g_{HZZ}^{(1)}Z_{\mu\nu}Z^{\mu\nu}h - g_{HZZ}^{(2)}Z_\nu\partial_\mu Z^{\mu\nu}h$$

$$-\frac{1}{2}g_{HWW}^{(1)}W^{\mu\nu}W_{\mu\nu}^\dagger h - \left[g_{HWW}^{(2)}W^\nu\partial^\mu W_{\mu\nu}^\dagger h + \text{h.c.}\right],$$



**MOST UP-TO-DATE
LIMITS**

**USE OF KINEMATIC
DISTRIBUTIONS
CRUCIAL**

black global fit

green one-by-one fit

CONCLUSIONS

AFTER THE DISCOVERY, THE REAL FUN COMES!

CHARACTERIZATION OF THE RESONANCE

LEARNING ABOUT THE
SHAPE OF THE HIGGS-PARTICLE

IS IT A SCALAR? BASICALLY, YES

**MANIFESTATION OF SUSY, COMPOSITENESS,
EXTRA-DIMENSIONS?** HIGGS ANOMALOUS
COUPLINGS

HOW DO WE LOOK FOR IT? TECHNIQUES USED IN
HIGGS QNs USEFUL AS WELL, COMPLEMENTARY
TO DIRECT SEARCHES