Search for signatures of a new neutral scalar in the W^+W^- channel with semileptonic final states at the LHC

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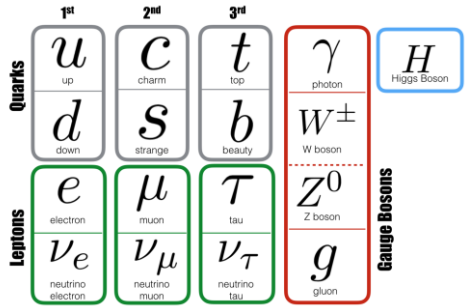
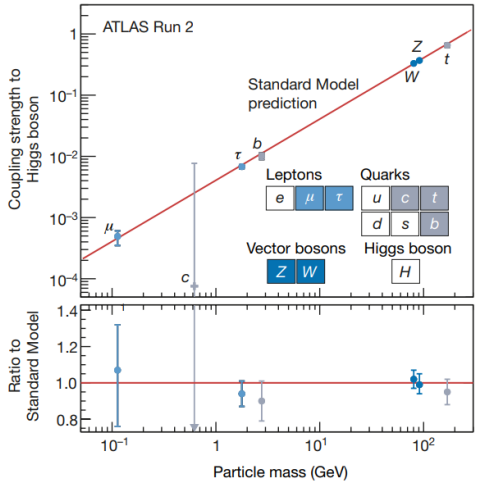
Introduction: Higgs sector in Standard Model

4 July 2012: announcement of the discovery of a new fundamental particle, the Higgs boson.

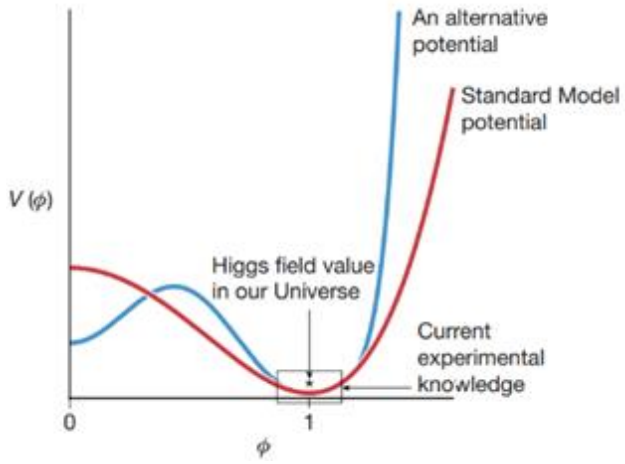
Standard Model: simplest model to describe fundamental interactions.



Open problems in Higgs sector in SM:



- **Precision**: couplings to other particles known with a maximal precision of 5-20% or not measured yet→ in this range other models are viable, also composite ones.
- **Shape of the potential**: we are unable to explore the potential for the Higgs field for different values of the field → different shapes are consistent with the current data.



Introduction: Higgs and open questions

The Standard Model does not give a complete description of the nature**:**

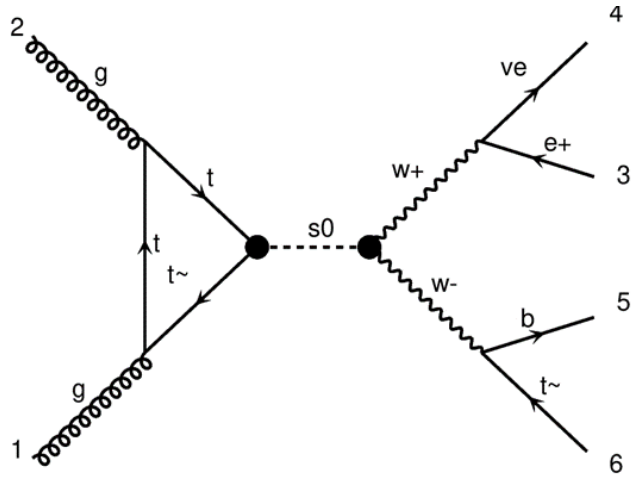
- **Dark Matter** → Inert 2HDM can provide a viable candidate of Dark Matter .
- **Early Universe Inflation, baryonic asymmetry, cosmological phase transition.**
- **Is the Higgs an elementary particle or a composite object? What is the origin of the pattern of masses in the SM matter?**
- **Hierarchy between weak, strong and gravitational interactions.**

→ Beyond Standard Model Theories.

Search of a new heavy scalar in the W^+W^- channel with semileptonic final states

Model with a new neutral scalar :

- Simplest model to enlarge the Higgs sector;
- Capability of remap specific processes into more complex BSM frameworks.



W^+W^- channel with semileptonic final state:

- Analysis in the same channel with dileptonic final state published in 2022 by the CMS collaboration (*Search for high mass resonances decaying into W+W− in the dileptonic final state with 138 fb−1 of proton-proton collisions at* $\sqrt{s} = 13$ *TeV*, CMS PAS HIG-20-016);
- CMS Florece group currently working on the semileptonic → provide simulations with more flexibility on BSM parameters.

Research strategy

Simulation of events using **MadGraph5_aMC@NLO.**

- Necessity a UFO model for NLO calculation containing the new particle S;
- Selection of processes to analyze → starting point is the **gluon-gluon fusion** (will be followed by the vector-boson fusion);
- Selection of the processes to generate → **separation of signal and interference**, parton level events (neglecting hadronization and detector simulation);
- Selection of **BSM parameters** → starting point will be SM-like couplings, MS=600GeV, WS=100GeV;
- Generation of events at a p-p collider and analysis of the kinematic informations in the **LHE** file → prediction on the expected events.

Model Lagrangian

$$\mathcal{L} = \mathcal{L}_{SM} + \mathcal{L}_{hMOD} + \mathcal{L}_{S}$$

SM Lagrangian: diagonal CKM ,4FNS.

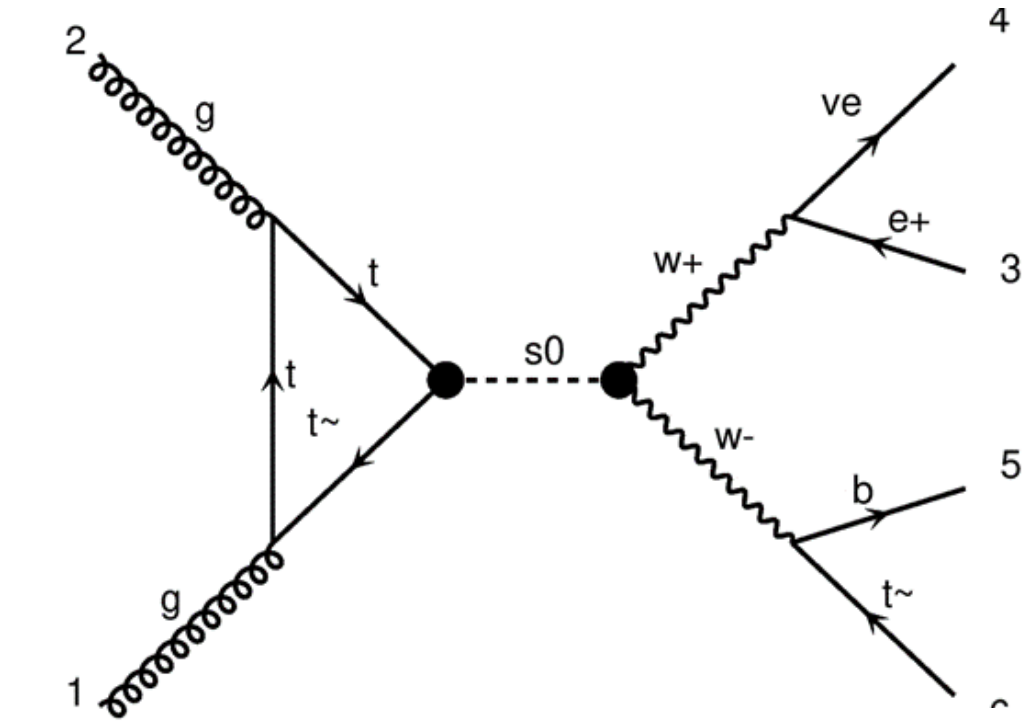
Higgs modified additive couplings (massive quarks, EW bosons)
→ **free independent parameters** .

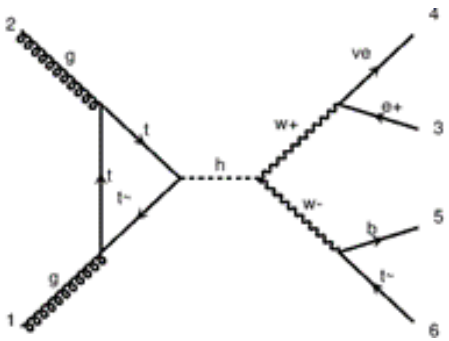
Lagrangian for the new scalar S (s0 in UFO):

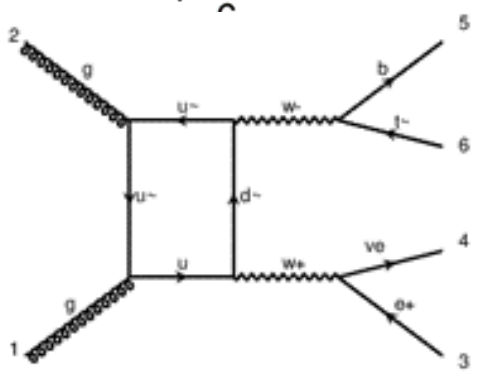
- neutral under the $U_{EM}(1)$ and SU(3) symmetry groups;
- interacting with the EW bosons, Higgs boson and SM matter;
- mass, width and couplings **free independent parameters** .

```
s0 = Particle(pdg_code = 6100001,
              name = 's0',
              antiname = 's0',
              spin = 1,
              color = 1,
              mass = Param.MS10,
              width = Param.WS10,
              texname = 's0',
              antitexname = 's0',
              charge = 0,
              GhostNumber = 0,
              LeptonNumber = 0,
              Y = 0)
```

Process: gluon-gluon fusion with SM-like couplings for S

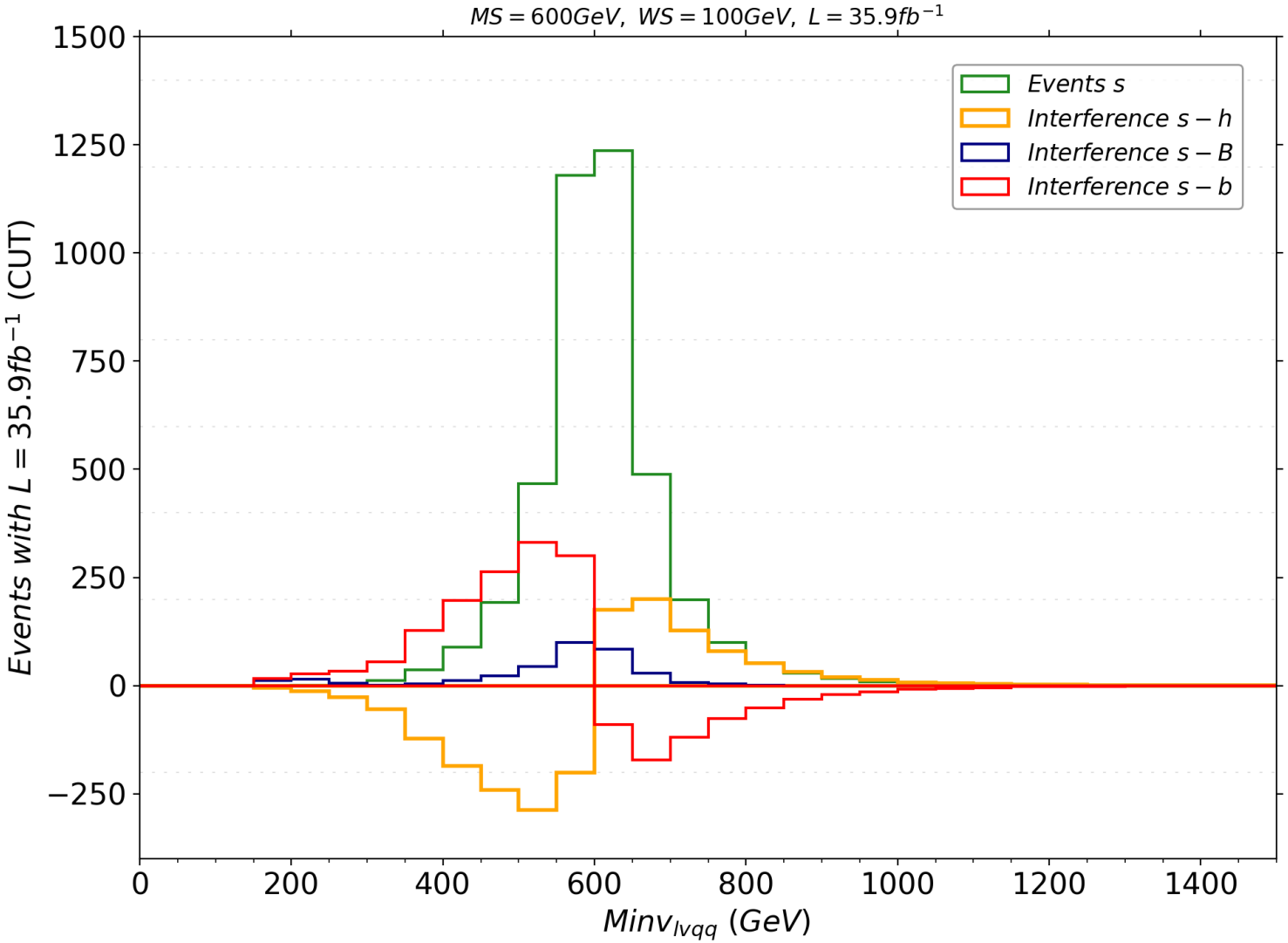


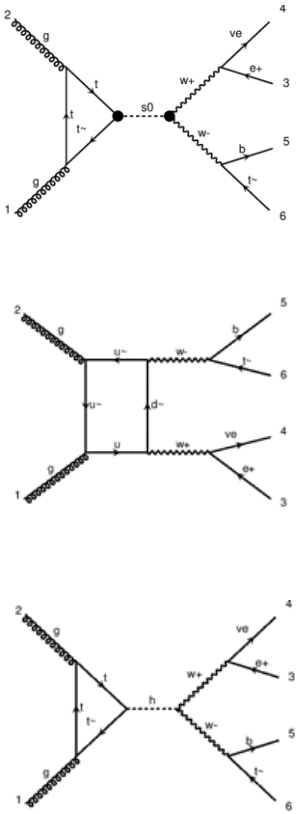




hMOD with SM values (for interference generation, otherwise zero)
1.000000e+00 # KHWW
0.987913e+00 # KHTT
0.026995e+00 # KHBB
S0 with SM-like couplings:
-0.019088e+00 # KS10rD3x3
-0.698560e+00 # KS10rU3x3
1.000000e+00 # KS10WW
S0 mass and width (in GeV) :
6.000000e+02 # MS10
1.000000e+02 # WS10
PDF:
lhapdf 315000 (NNPDF31_lo_as_0118 (315000))
Energy of each proton beam:
6500.0 GeV
Cuts:
pT(v) > 30 GeV
pT(l) > 25 GeV
η(l) < 2.5

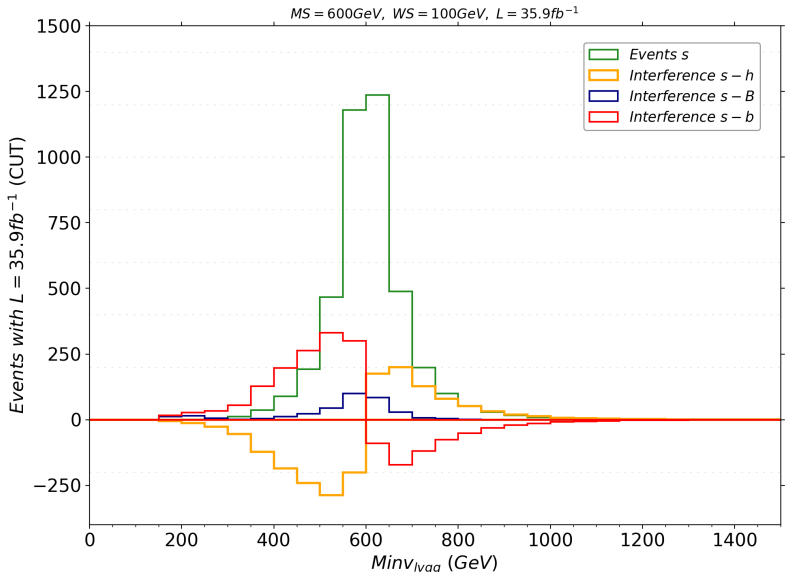
Process: gluon-gluon fusion with SM-like couplings for S

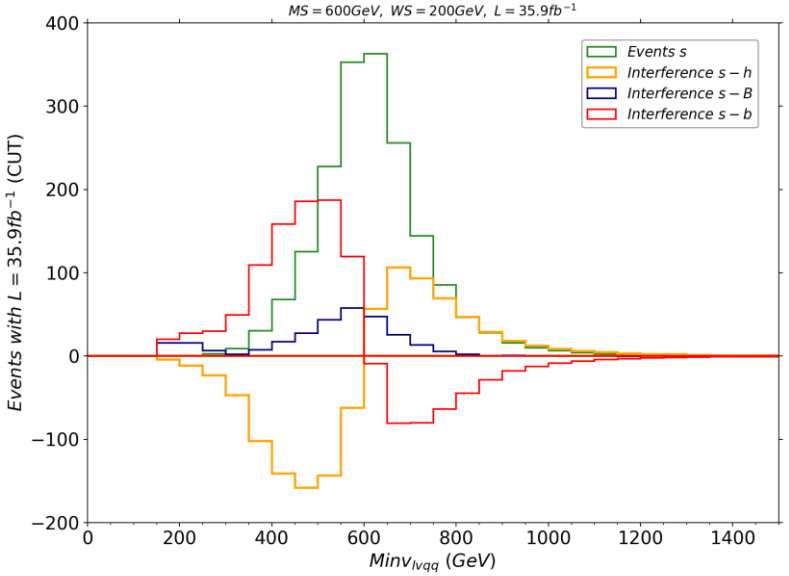


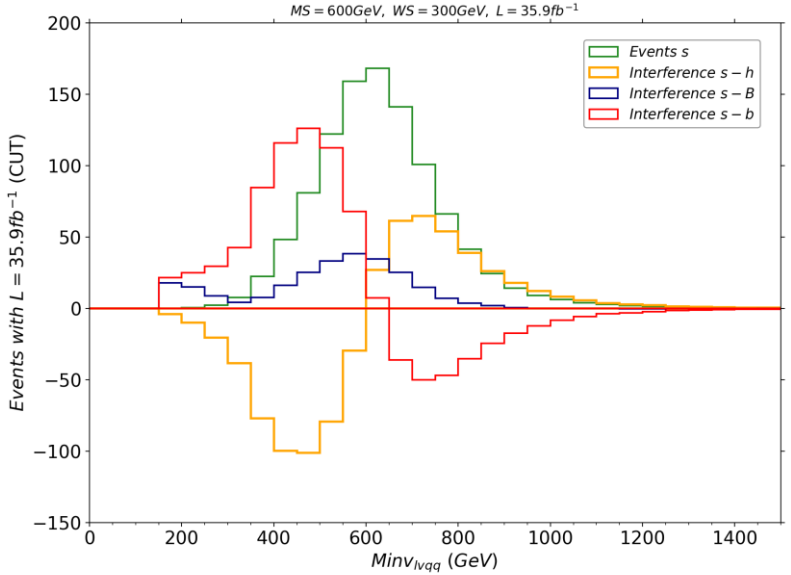


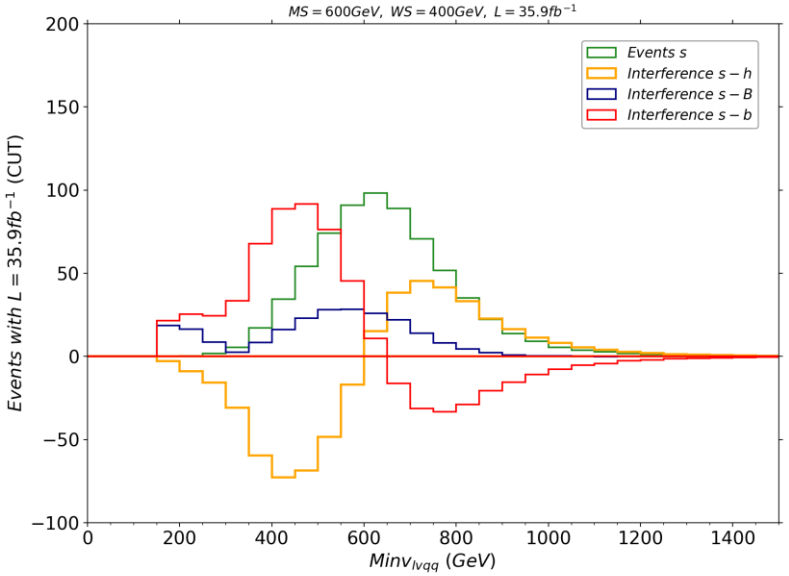
Graph definitions:

- h = SM Higgs
- B = SM background
- b = SM background without the Higgs


MS = 600GeV, WS = 100GeV, L = 35.9fb⁻¹
Events s
Interference s – h
Interference s – B
Interference s – b
Events with L = 35.9fb⁻¹ (CUT)
Minv_lvaa (GeV)


MS = 600GeV, WS = 200GeV, L = 35.9fb⁻¹
Events s
Interference s – h
Interference s – B
Interference s – b
Events with L = 35.9fb⁻¹ (CUT)
Minv_lvqq (GeV)


MS = 600GeV, WS = 300GeV, L = 35.9fb⁻¹
Events s
Interference s – h
Interference s – B
Interference s – b
Events with L = 35.9fb⁻¹ (CUT)
Minv_lvqq (GeV)

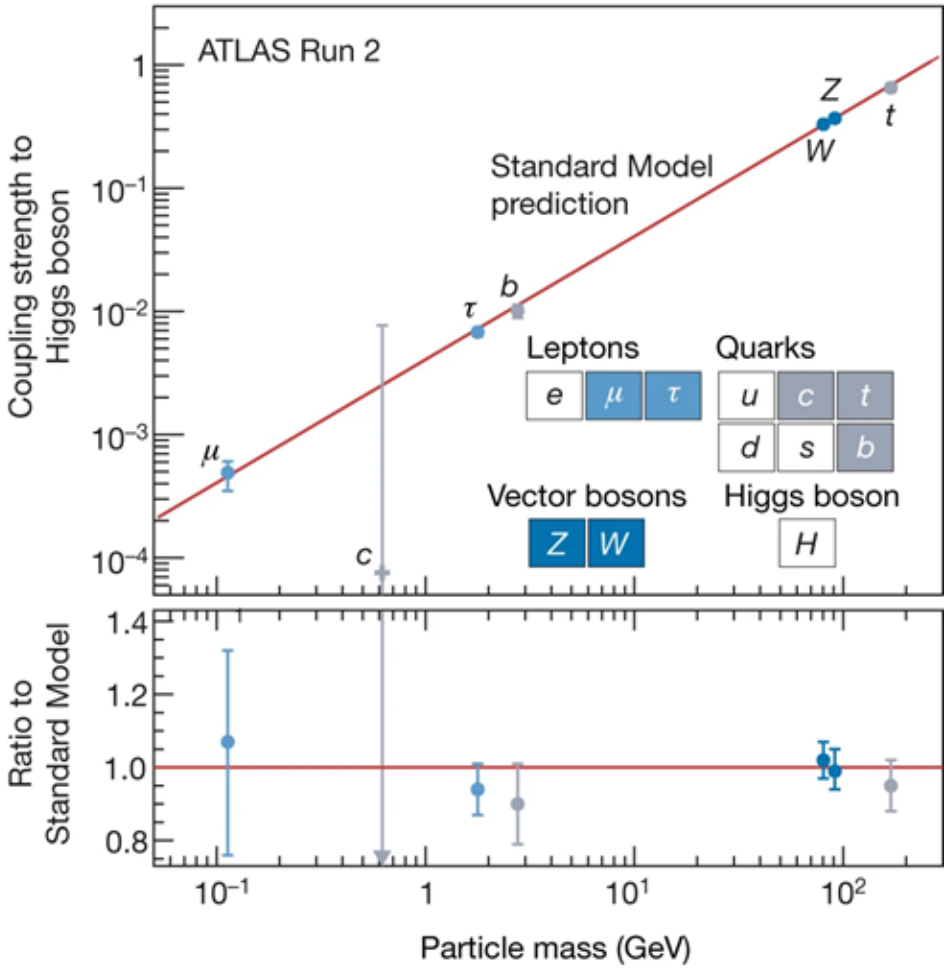

MS = 600GeV, WS = 400GeV, L = 35.9fb⁻¹
Events s
Interference s – h
Interference s – B
Interference s – b
Events with L = 35.9fb⁻¹ (CUT)
Minv_lvqq (GeV)

Setting couplings

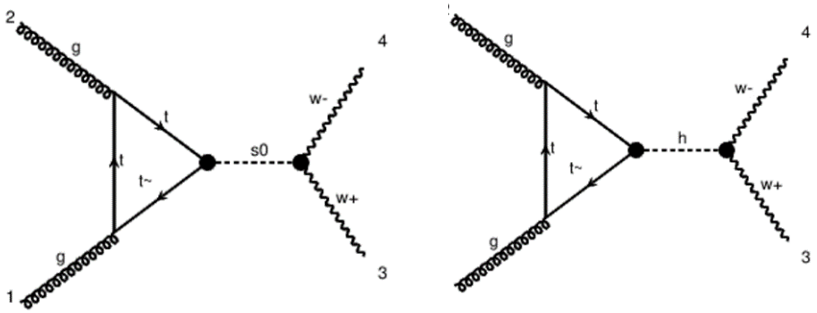
Changing couplings

- Selecting couplings for vertices with S;
- Modification of couplings with h using the $\mathbf{h_{MOD}}$ couplings → the value must still be consistent with the current limits measured for h couplings (higher precision on hWW coupling) .

Remapping into BSM models → new parameters may not be all independent and free, being function of more fundamental parameters of those models.



Example: 2HDM type I remapping



- **2HDM** → two SU(2) Higgs doublets with a potential defined by 7 free real parameters (no CP violation);
- **Type I** → all quarks couple to the same doublet;
- Two Independent parameters **α**, **β** (rotation angles);
- Mass eigenstates → 5 physical massive scalars: two charged, one neutral pseudoscalar and **two neutral scalars** .

The S, h particles in our UFO model represent the physical massive neutral scalars in a 2HDM type I.

→

BSM couplings depend only on **two** free parameters.

- $g_{hWW} = sin(\alpha - \beta) g_{H_{SM}WW}$
- $g_{SWW} = -cos(\alpha - \beta) g_{H_{SM}WW}$
- $g_{hZZ} = sin(\alpha - \beta) g_{H_{SM}ZZ}$
- $g_{SZZ} = -cos(\alpha - \beta) g_{H_{SM}ZZ}$
- $g_{h\bar{t}t} = (\frac{cos\alpha}{sin\beta}) g_{H_{SM}\bar{t}t}$
- $g_{S\bar{t}t} = (\frac{sin\alpha}{sin\beta}) g_{H_{SM}\bar{t}t}$
- $g_{h\bar{b}b} = (\frac{cos\alpha}{sin\beta}) g_{H_{SM}\bar{b}b}$
- $g_{S\bar{b}b} = (\frac{sin\alpha}{sin\beta}) g_{H_{SM}\bar{b}b}$

Future analysis:

- Simulations with different values of the couplings, included the 2HDM case.
- Simulations of vector-boson fusion processes.
- Inclusion of coupling modification of the third generation quarks and of new heavy fermions in the loops as predicted in Composite Higgs Models.

Thank you for your attention

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Backslides

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Model: couplings and coupling orders

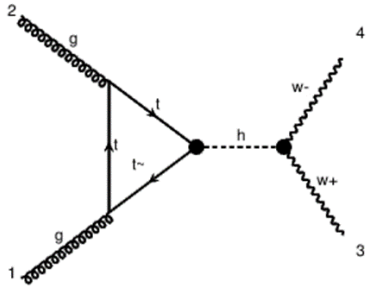
Each vertex has an associated coupling order:

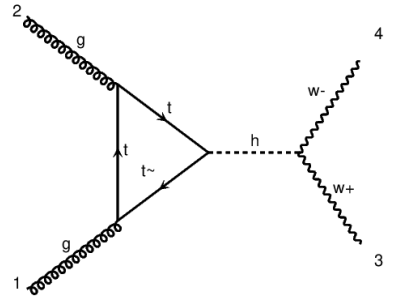
- SM: QCD, QED
- Mod. Higgs: HBBMOD, HTTMOD, HWWMOD, HZZMOD
- SO : SFF, SVV

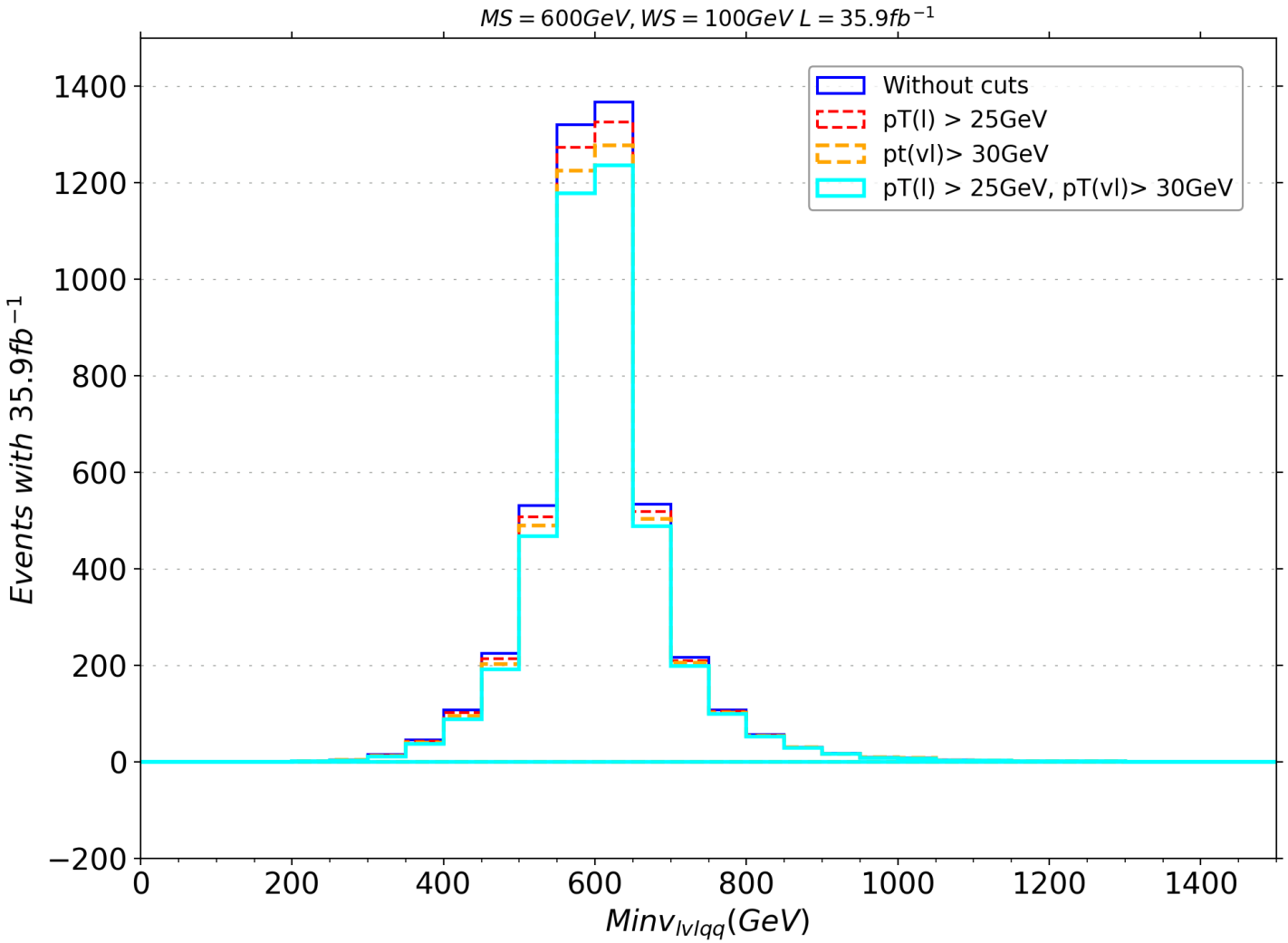
- Generation of BSM processes
- Generation of interference terms (capability of MadGraph5_aMC@NLO)

All coupling of BSM are free parameters.

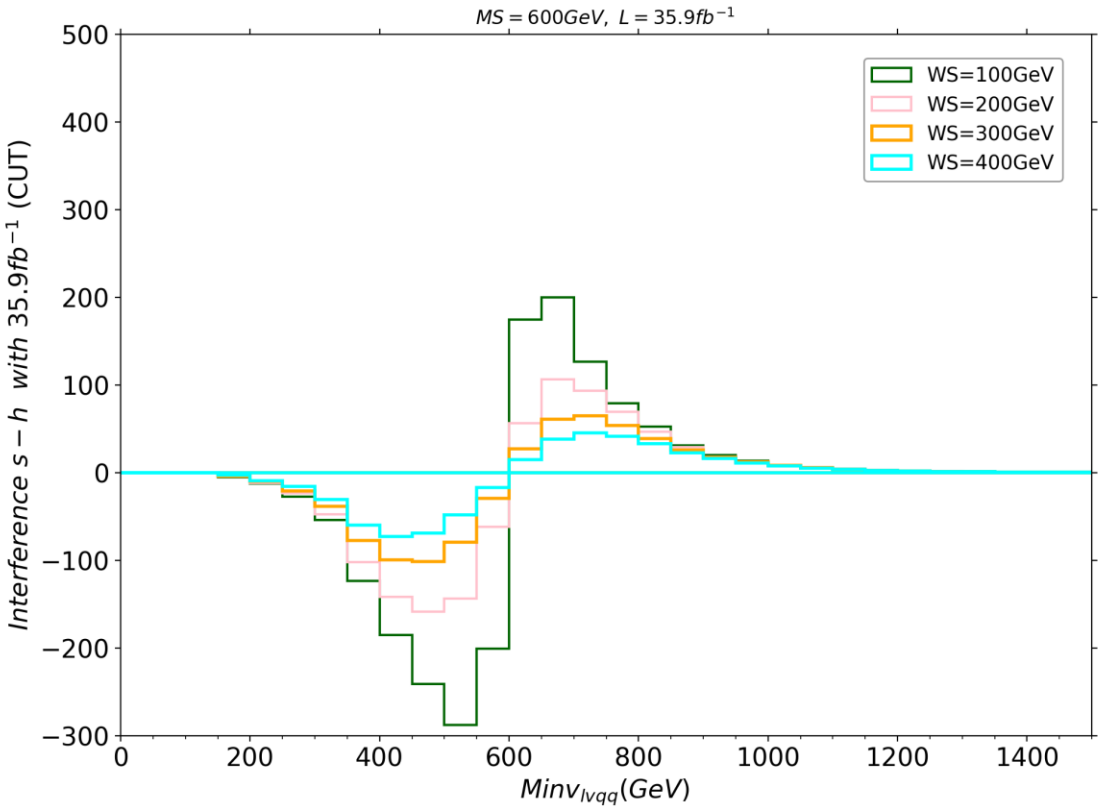
Lorentz structure of some interaction can be chosen.

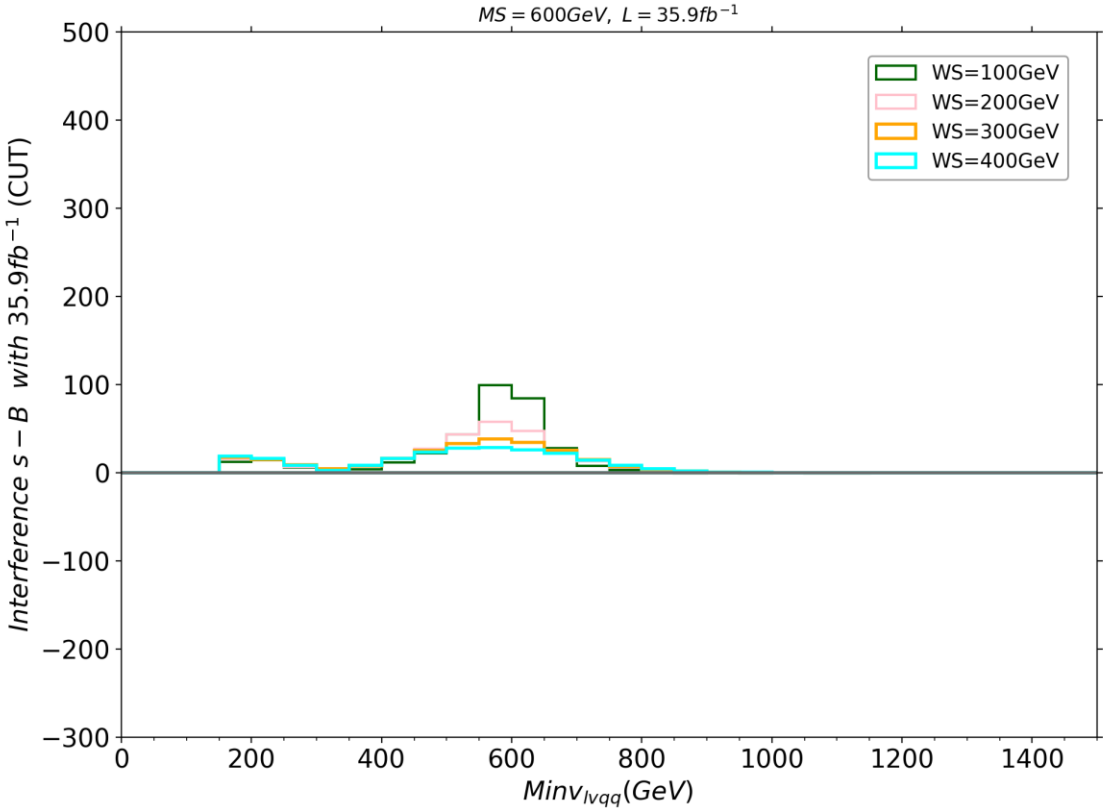


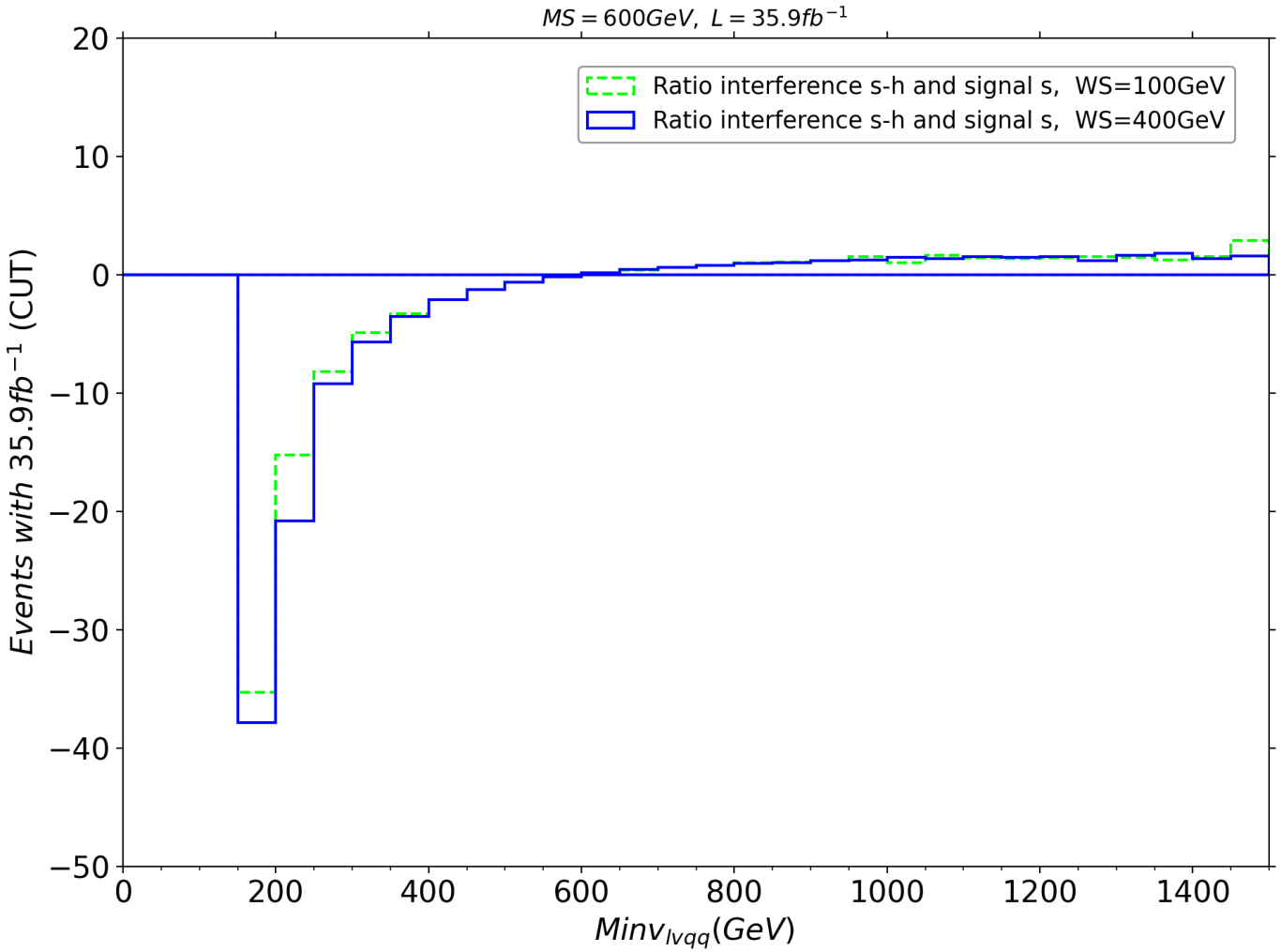


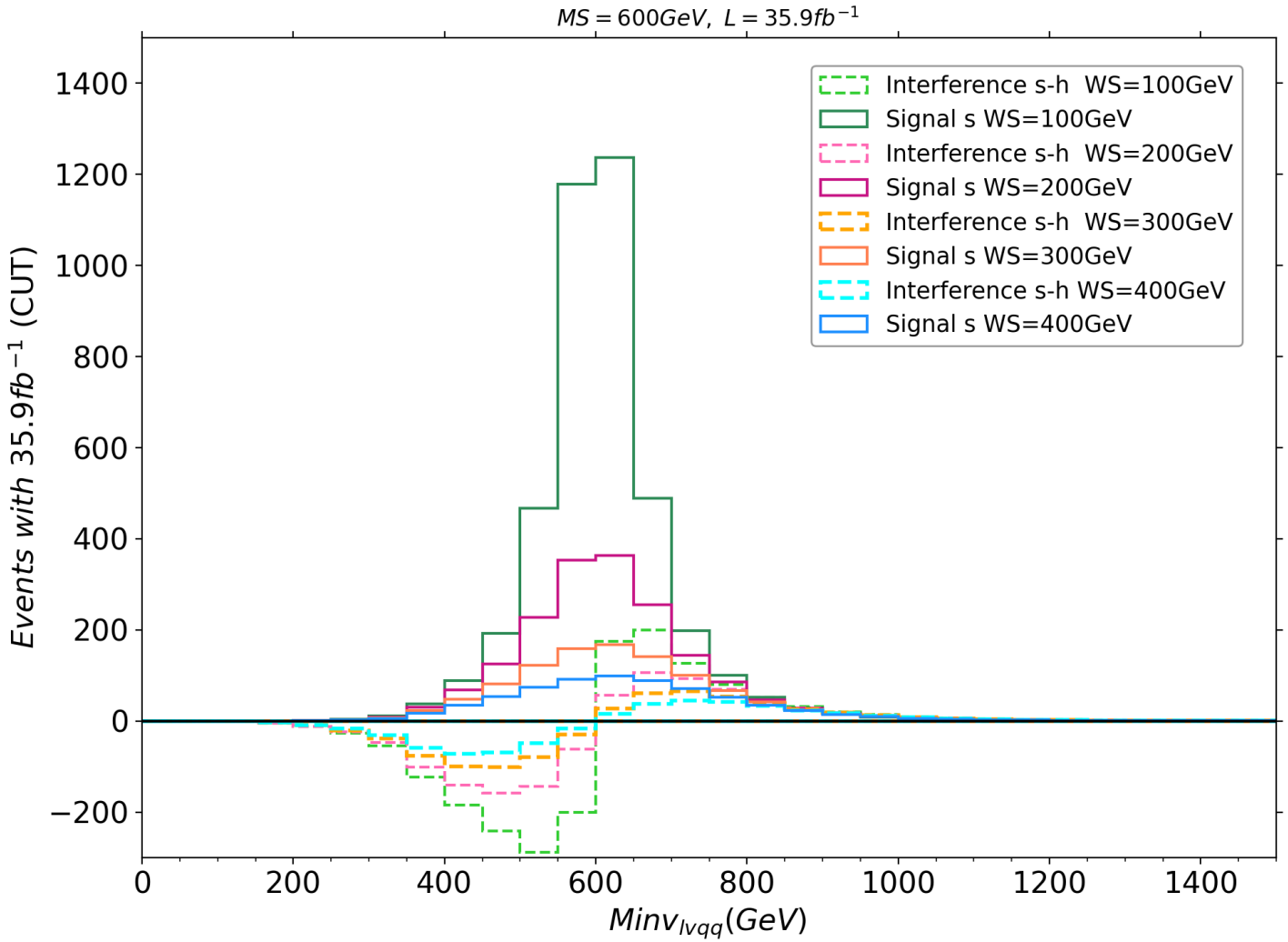

$MS = 600GeV, WS = 100GeV\ L = 35.9fb^{-1}$
Without cuts
pT(l) > 25GeV
pt(vl)> 30GeV
pT(l) > 25GeV, pT(vl)> 30GeV
$Events\ with\ 35.9fb^{-1}$
$Minv_{lvlqq}(GeV)$
1400
1200
1000
800
600
400
200
0
−200
0
200
400
600
800
1000
1200
1400

Process: gluon-gluon fusion with SM-like coupling for S






$MS = 600GeV,\ L = 35.9fb^{-1}$
Ratio interference s-h and signal s, WS=100GeV
Ratio interference s-h and signal s, WS=400GeV
$Events\ with\ 35.9fb^{-1}\ (CUT)$
$Minv_{lvqq}(GeV)$
20
10
0
−10
−20
−30
−40
−50
0
200
400
600
800
1000
1200
1400


$MS = 600GeV,\ L = 35.9fb^{-1}$
Interference s-h WS=100GeV
Signal s WS=100GeV
Interference s-h WS=200GeV
Signal s WS=200GeV
Interference s-h WS=300GeV
Signal s WS=300GeV
Interference s-h WS=400GeV
Signal s WS=400GeV
$Events\ with\ 35.9fb^{-1}\ (CUT)$
$Minv_{lvqq}(GeV)$
1400
1200
1000
800
600
400
200
0
−200
0
200
400
600
800
1000
1200
1400