

# **Higgs @ CMS**

**Contributions to European Strategy for Particle Physics**

# Preamble

**Heard already few times during this IRN**

The main inputs from Higgs@CMS to the European Strategy for Particle Physics 2020 is within the HL/HE-LHC Physics Workshop Working Groups<sup>1</sup> whose main outcome will be the YR by the end of 2018

Higgs studies are responsibility of the WG2 and a detailed draft Table of Contents<sup>2</sup> is worked on

<sup>1</sup> <https://twiki.cern.ch/twiki/bin/view/LHCPhysics/HLHELHCWorkshop>

<sup>2</sup> <https://twiki.cern.ch/twiki/bin/view/LHCPhysics/HLHEWG2>

## Precision Higgs boson physics

- Channels reach (boson-fermion)
- Probe of top Yukawa coupling
- Higgs boson couplings from combination of analyses
- Differential cross section measurements

## Di-Higgs production and Higgs boson self coupling

- Di-Higgs direct measurements
- Indirect probe of Higgs boson self-coupling

## Invisible decays of the Higgs boson

- Direct searches

## Higgs flavor and rare decays

- Exclusive Higgs decays
- LFV decays of the Higgs boson
- Yukawa constraints from distributions
- CP studie in Higgs boson couplings (tautau,VV)

## BSM Higgs bosons

- High-mass Higgs bosons (fermionic decays)
- Low-mass Higgs bosons (60 - 120 GeV)
- Exotic decays of the Higgs boson

## Vector Boson Scattering

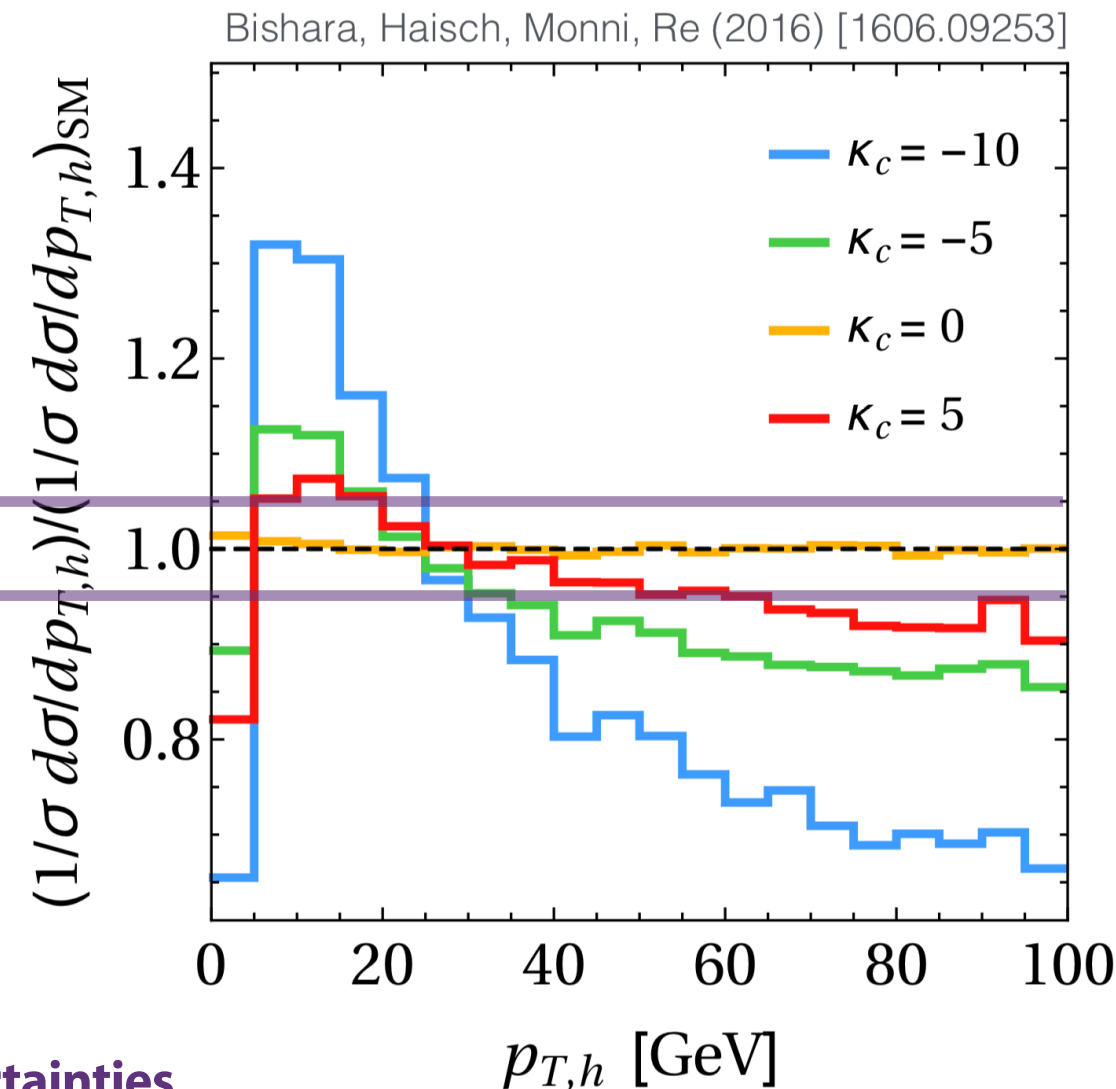
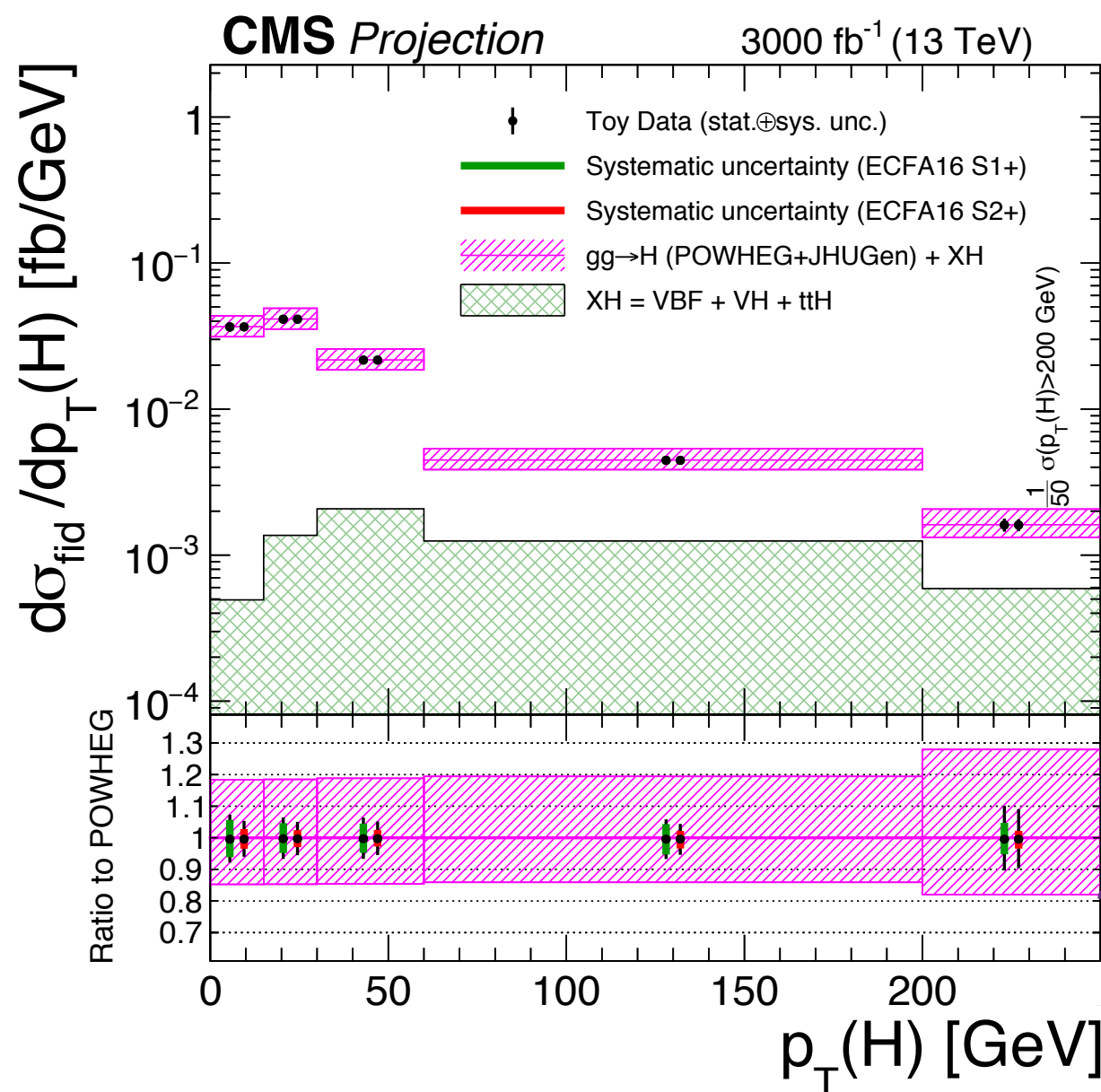
In the following I will highlight a minimal collection of topics where  contributions are substantial (we are either directly involved in the analyses or indirectly via the upgrade of CMS)

# Precision Higgs boson physics

**Cross section measurements are not hit as hard by the 'systematics wall'**

Transverse momentum  $p_T(H)$  is sensitivity to modifications of effective Higgs Yukawa couplings and finite top mass effects

Projection for  $H \rightarrow ZZ \rightarrow 4l$



~5% uncertainties

With 3/ab opens up possibilities for new measurements providing competitive limits on Higgs couplings ( $k_b, k_c, k_t, c_g$ )

# Di-Higgs production and Higgs boson self coupling

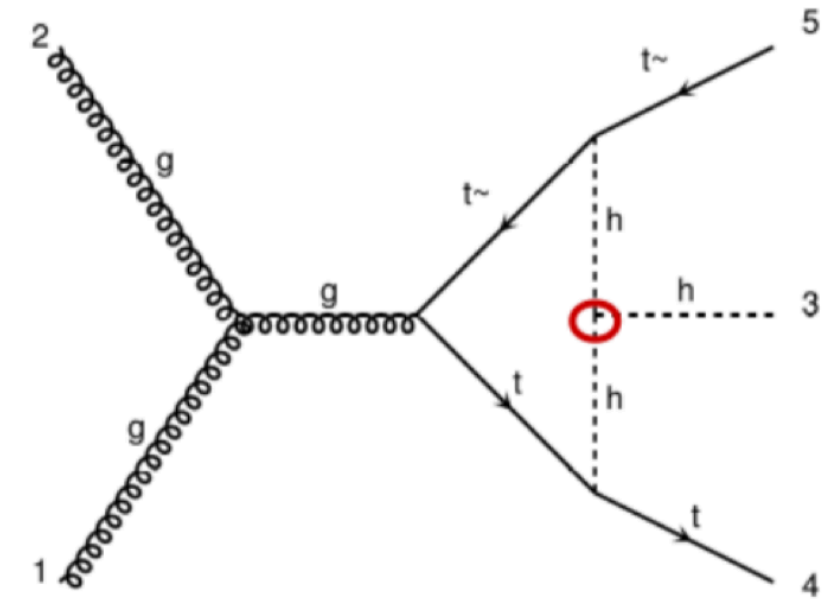
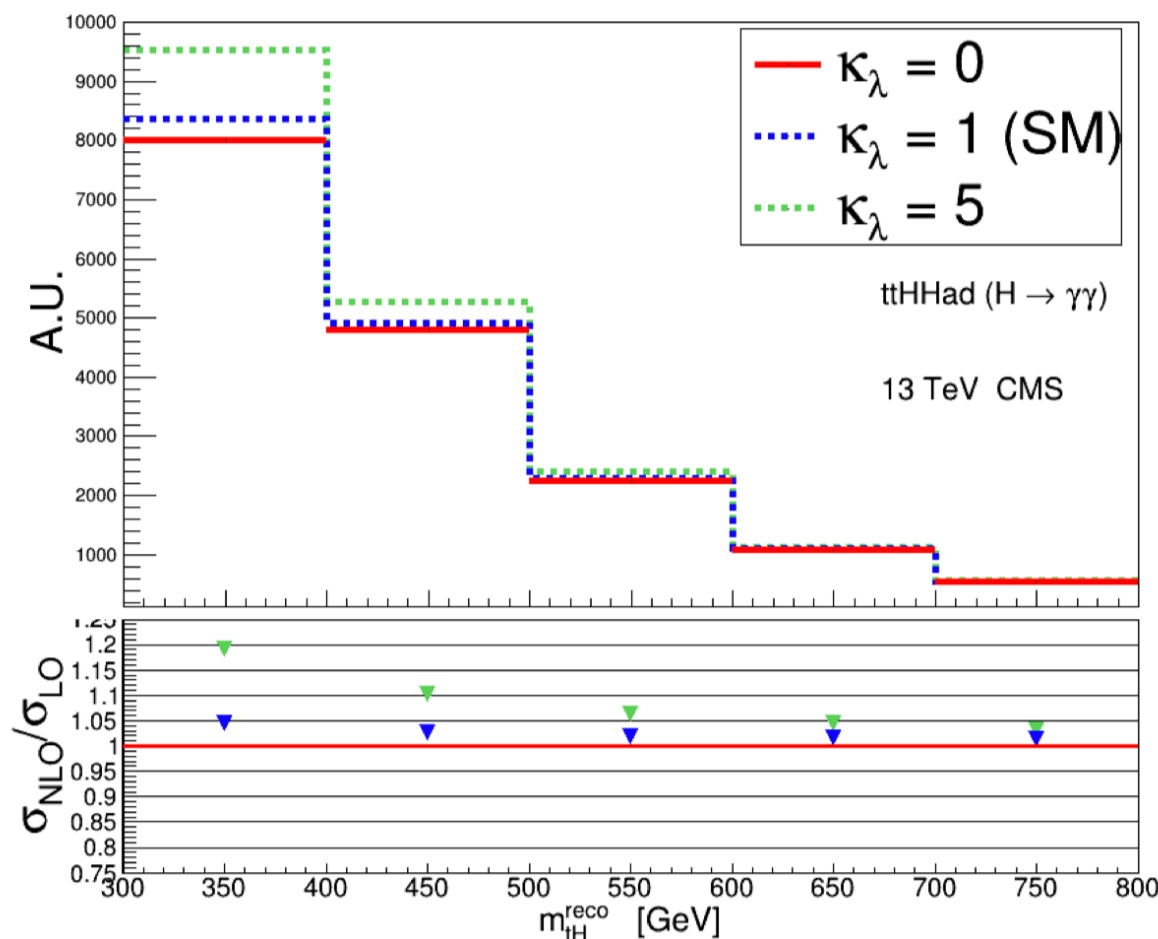
## Indirect probes of self couplings

Access  $\lambda_{HHH}$  via NLO EWK corrections  $\Rightarrow$  alternative to HH production and direct measurements

### Precision differential cross section measurements

Focus on associated production (VH, ttH) where the effects is larger

$ttH \rightarrow bjj \ bjj \ \gamma\gamma$  events



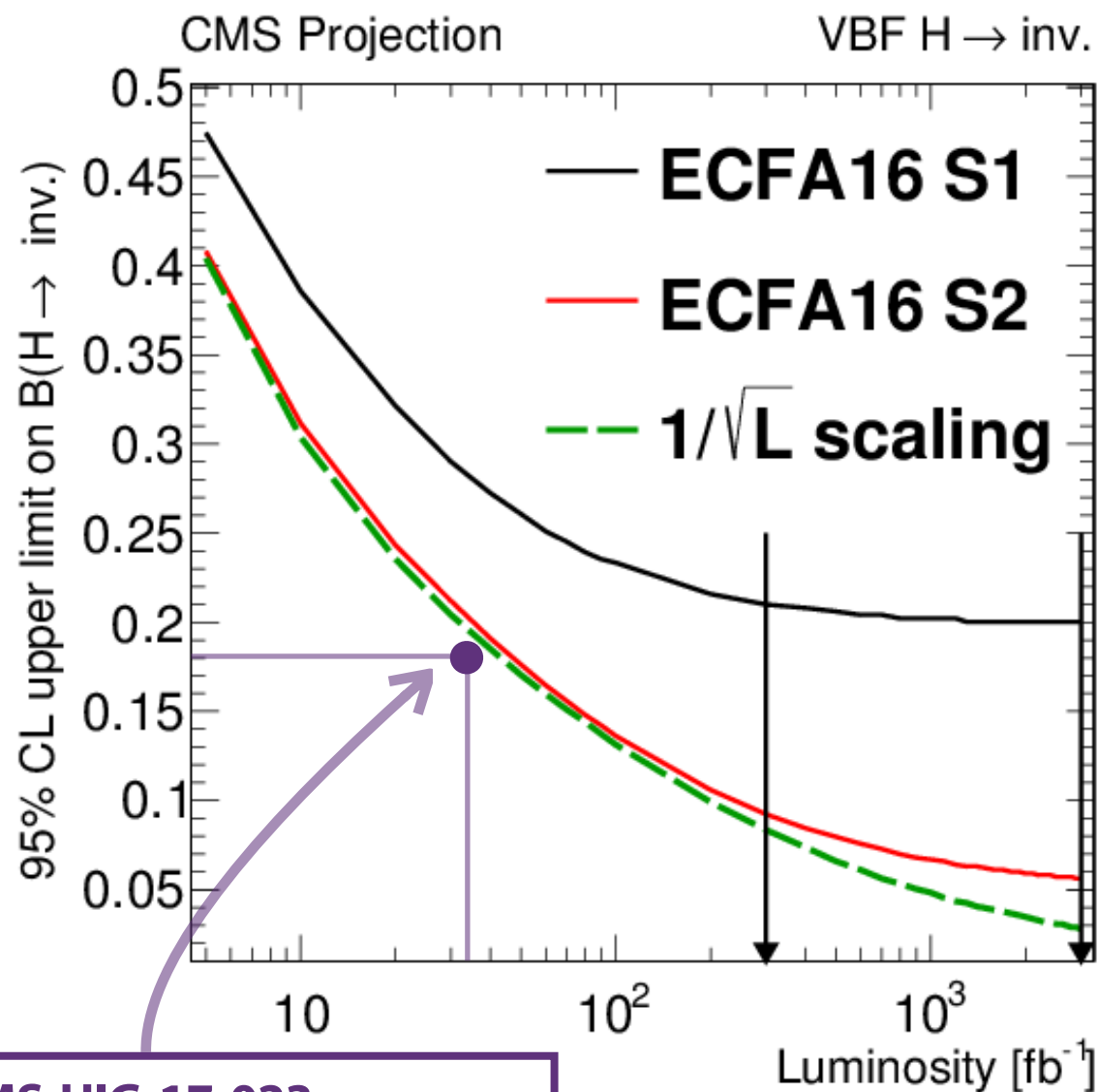
The SM cross section in bins of  $p_T(H)$  scales with  $\kappa_\lambda = \lambda_{HHH}/\lambda_{HHH}^{\text{SM}}$

$$\mu(\kappa_\lambda, C_1) = \frac{\sigma_{\text{NLO}}(\kappa_\lambda)}{\sigma_{\text{LO}}(\kappa_\lambda = 0)} \bigg|_{C_1} = \frac{1 + \kappa_\lambda C_1}{1 - \kappa_\lambda^2 \delta Z_H}$$

# Invisible decays of the Higgs boson

Either measure or put constrain on  $BR(H \rightarrow \text{invisible})$  is of utmost importance  
 $\Rightarrow$  Higgs-portal model: can be interpreted to dark matter constraint assuming the Higgs goes to WIMPs all the time  
 $\Rightarrow$  can show the room left to possible BSM decay

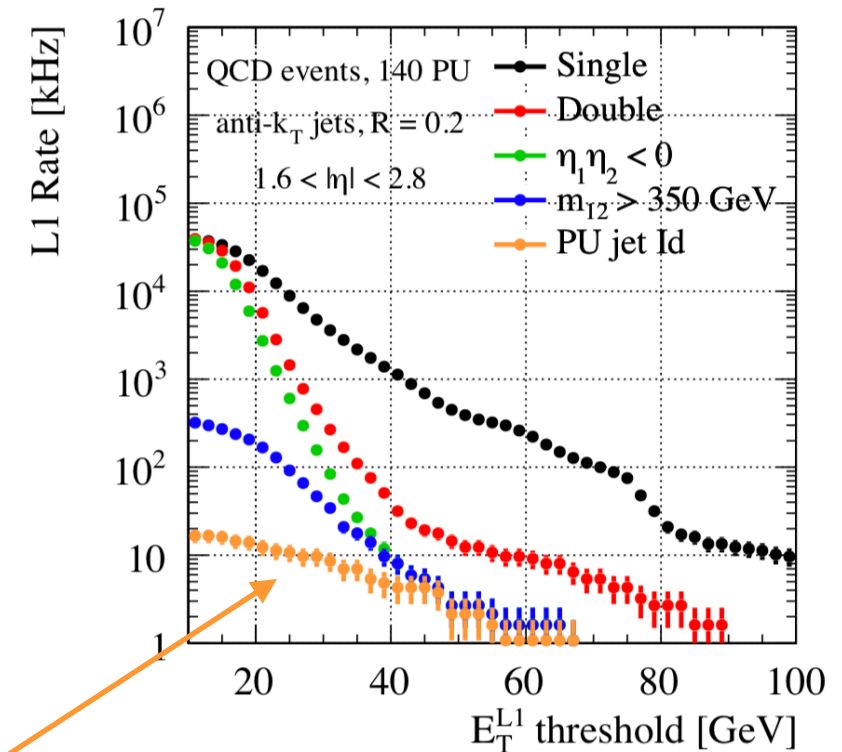
“Old” projection



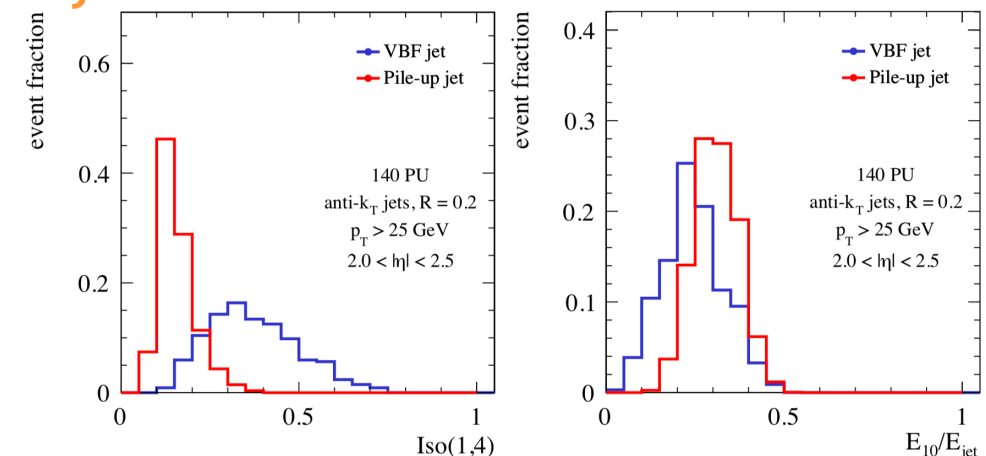
**CMS-HIG-17-023**  
**36/fb @ 13TeV in VBF**  
**Expected sensitivity < 18%**

Better performance...

...and in addition will benefit of HGCal!



PUjetID variables

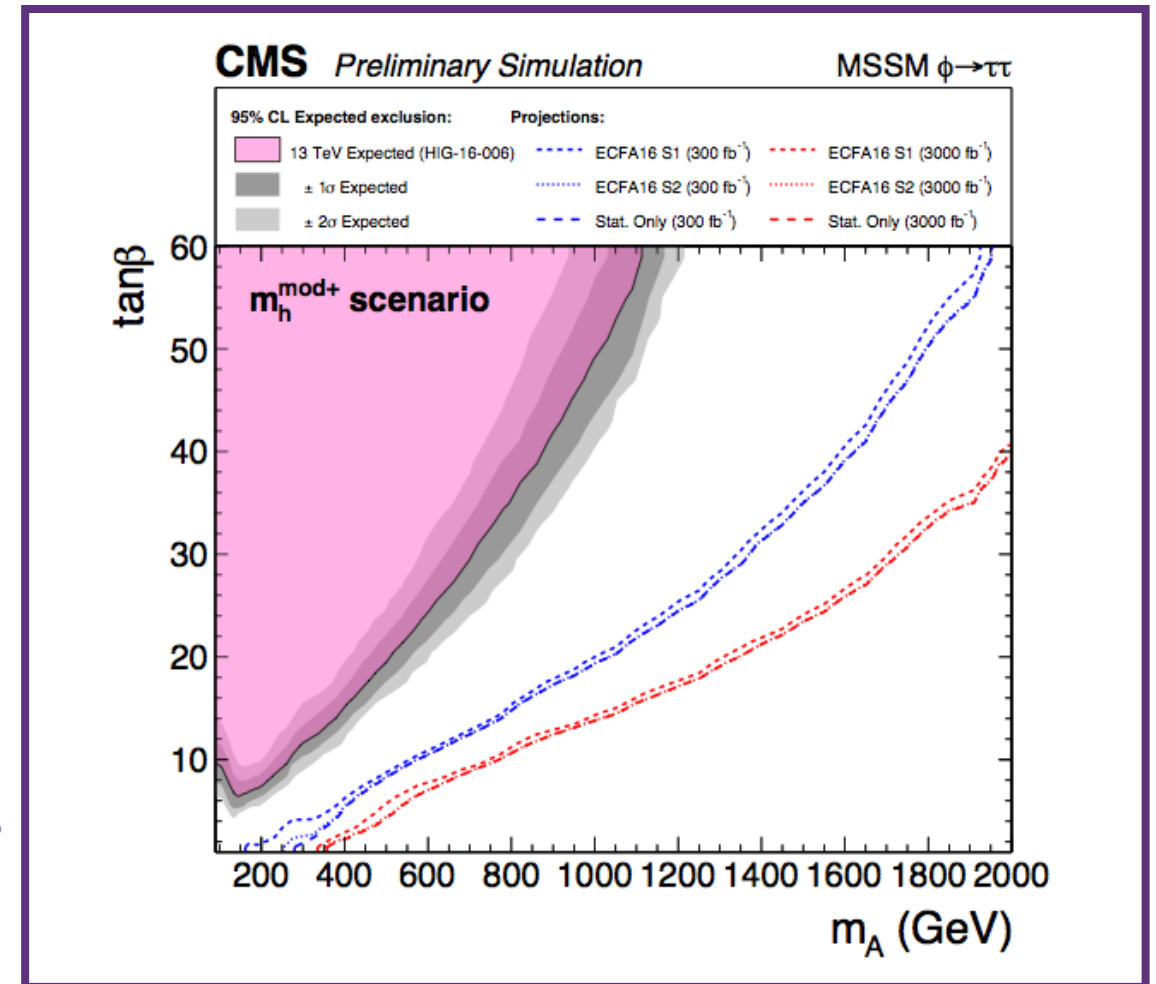
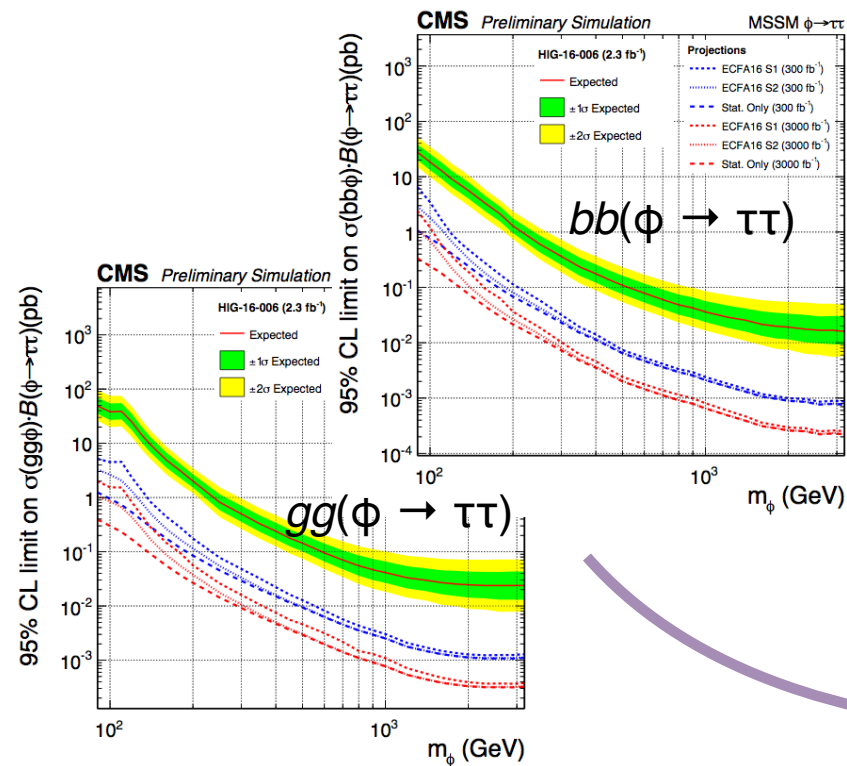


# BSM Higgs bosons

## Search for additional Higgs bosons : $H \rightarrow \tau\tau$

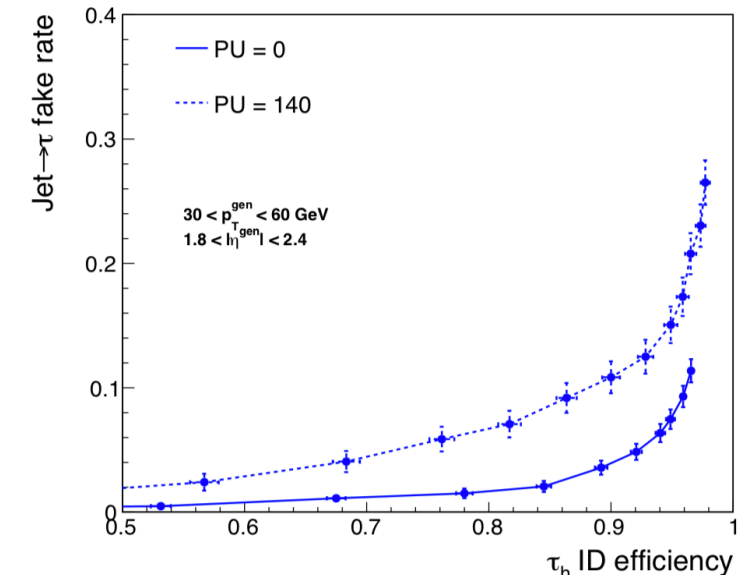
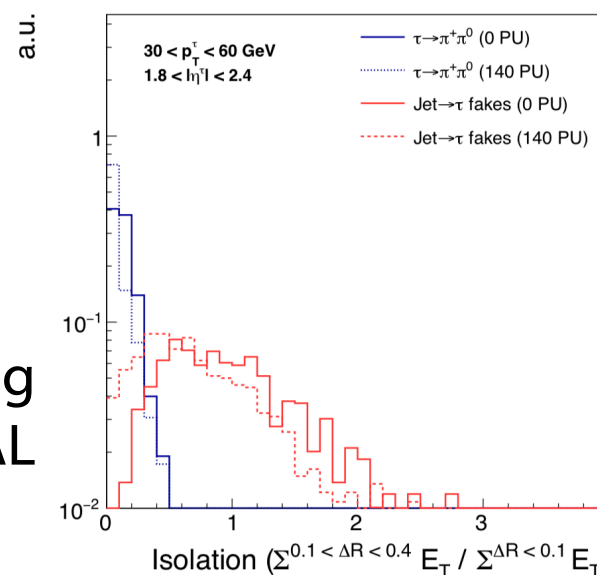
One of the most sensitive channels for constraining extended Higgs sectors

Model independent cross sections limits



...and again will profit of the upgraded CMS detector.

Identification of hadronically decaying tau leptons using only the HGCal

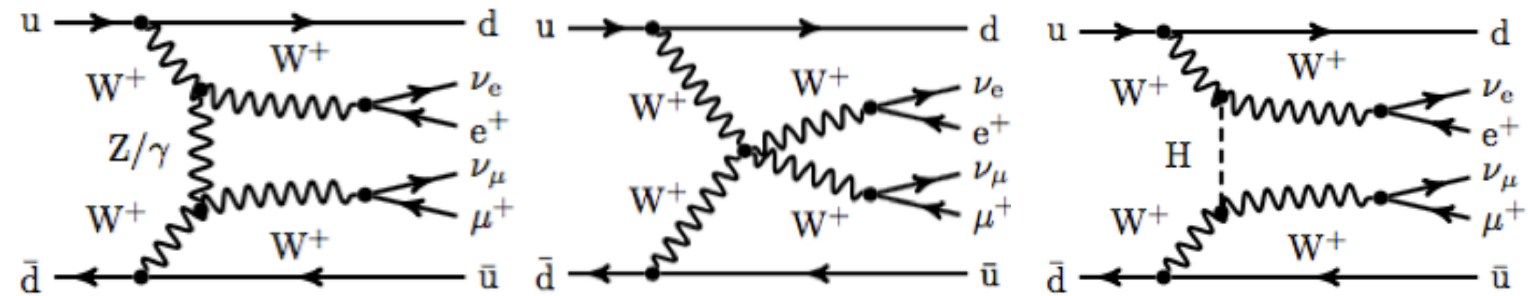




# Vector Boson Scattering (I)

In the SM,  $V_L V_L \rightarrow V_L V_L$  would violate unitarity at scattering energies  $> 1$  TeV ( $V=W,Z$ ) without the Higgs

Delicate cancellation at high scattering energies from interference with the Higgs exchange

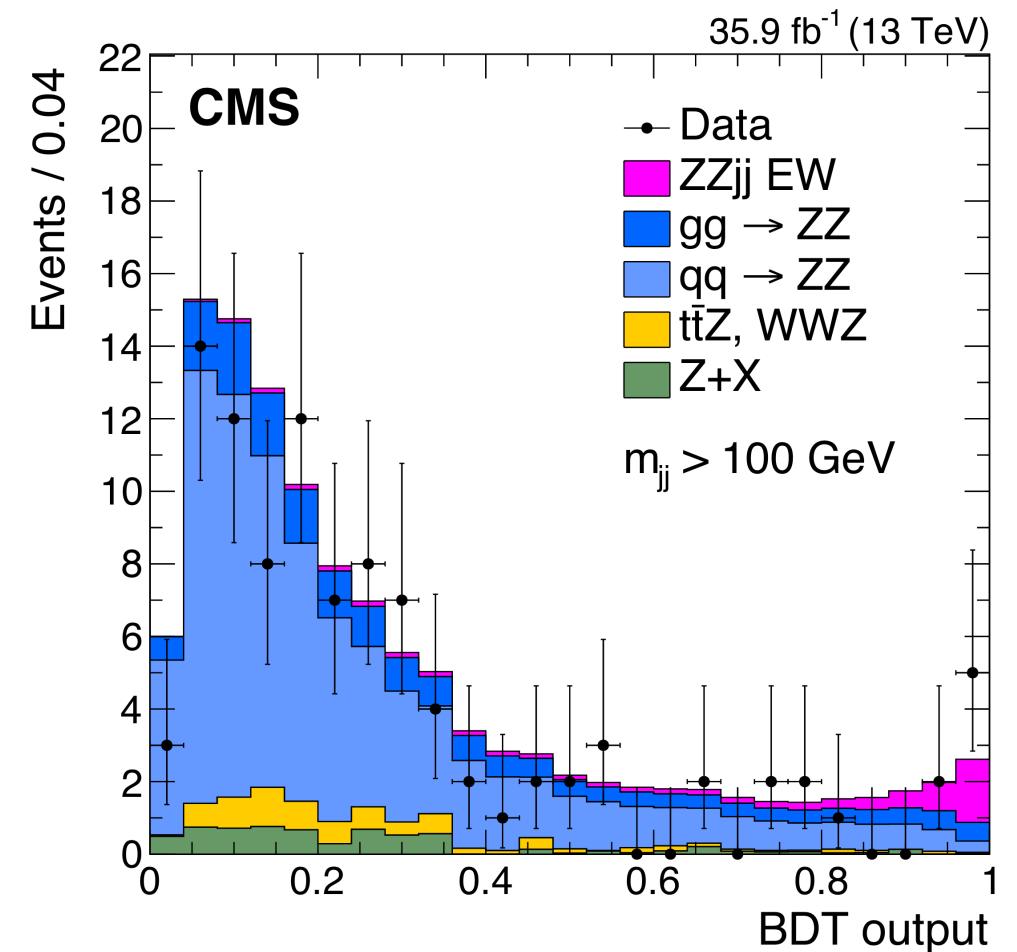


## LHC VBS VV results :

$W^\pm W^\pm jj$ : ATLAS evidence at 8 TeV (PRL 113 (2014) 141803)

$W^\pm W^\pm jj$ : CMS observation at 13 TeV (PRL 120 (2018) 081801)

$ZZjj$ : CMS first LHC result obtained on (PLB 774 (2017) 682)



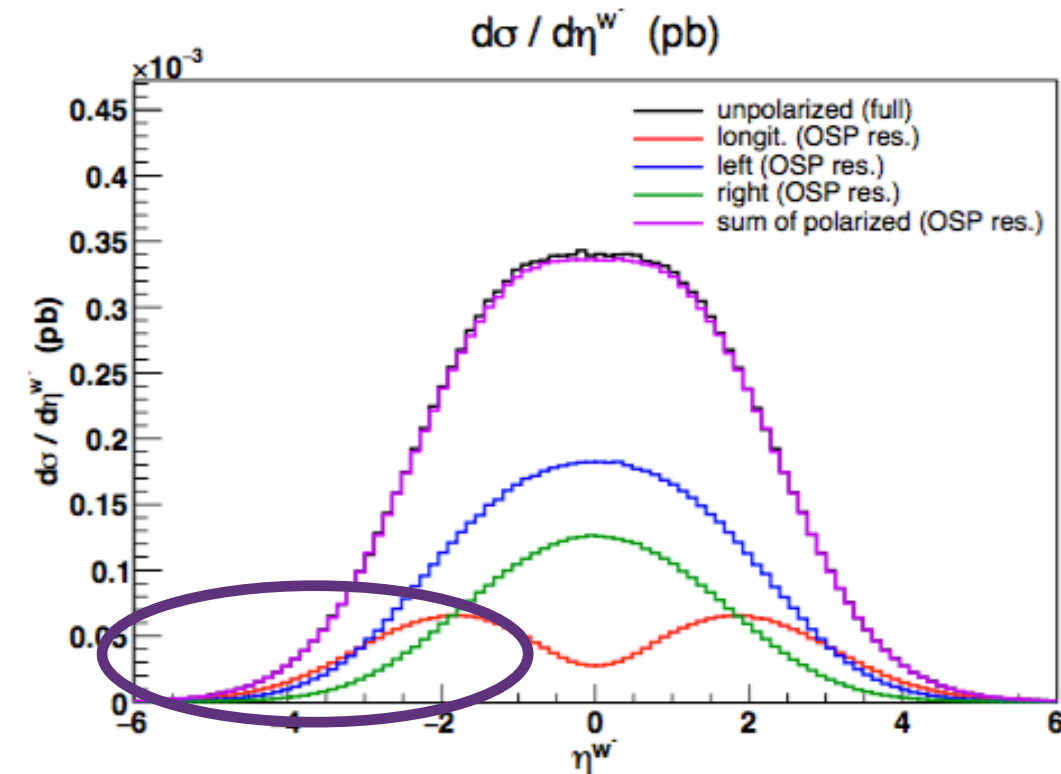
...but longitudinal scattering in VBS VV will only be accessible at HL-LHC



# Vector Boson Scattering Studies (II)

Recently emphasized that the  $V_L$  are dominantly produced in the forward region!

Excellent case for the planned increased acceptance of  $e$  and  $\mu$  at HL-LHC



arXiv:1710.09339v1

Wish list for Yellow Report:

**VBS  $W^\pm W^\pm$**  (LLR+TIFR+Univ. Wisconsin)

Highest S/B for VBS cross section but less handle to measure boson polarization due to the neutrinos

**VBS  $ZZ$**  (LLR + FESB Split)

Free of reducible background, full reconstruction of the final state but low statistics

In addition French participation to the **VBScan COST EU project**:  
VBS phenomenology, polarization measurement (LLR, LPNHE)