Study of Non-Resonant HH Production in WWZZ Decay Mode at CMS Experiment

Antra Gaile[1] on behalf of the CMS Collaboration

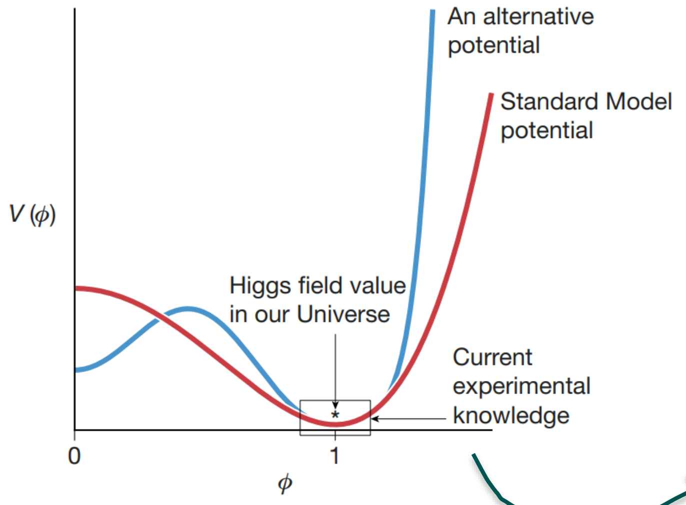
1 - Riga Technical University, Faculty of Natural Sciences and Technology, Institute of Particle Physics and Accelerator Technologies, Riga, Latvia

16.10.2024

Why HH – why Higgs boson pairs?

The measurement of the pair production of Higgs bosons can probe its **self-coupling**, crucial for probing Higgs potential, testing of the **electroweak symmetry breaking** (and not only!)

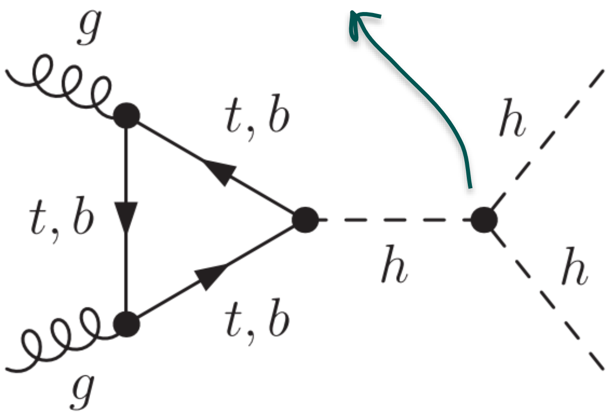
For more why's stay tuned for Torben's talk!



$$\mathcal{L} = \frac{m_H^2}{2} H^2 + \lambda_3 H^3 + \lambda_4 H^4$$

$\lambda_3^{BSM} = ?$

$$\lambda_3^{SM} = \frac{m_H^2}{2v^2}$$

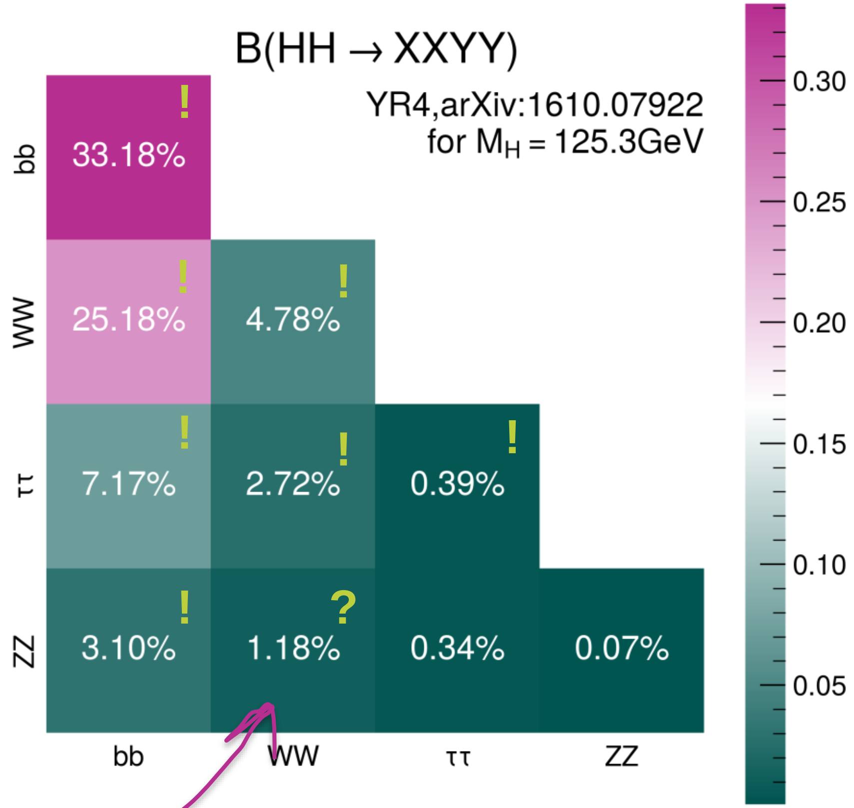


A tight chase!
1 HH event per 1000 H events ($\sigma_{ggF+VBF}^{SM} = 32.78\ fb$)
$N(@200/fb) \approx 6500$ events

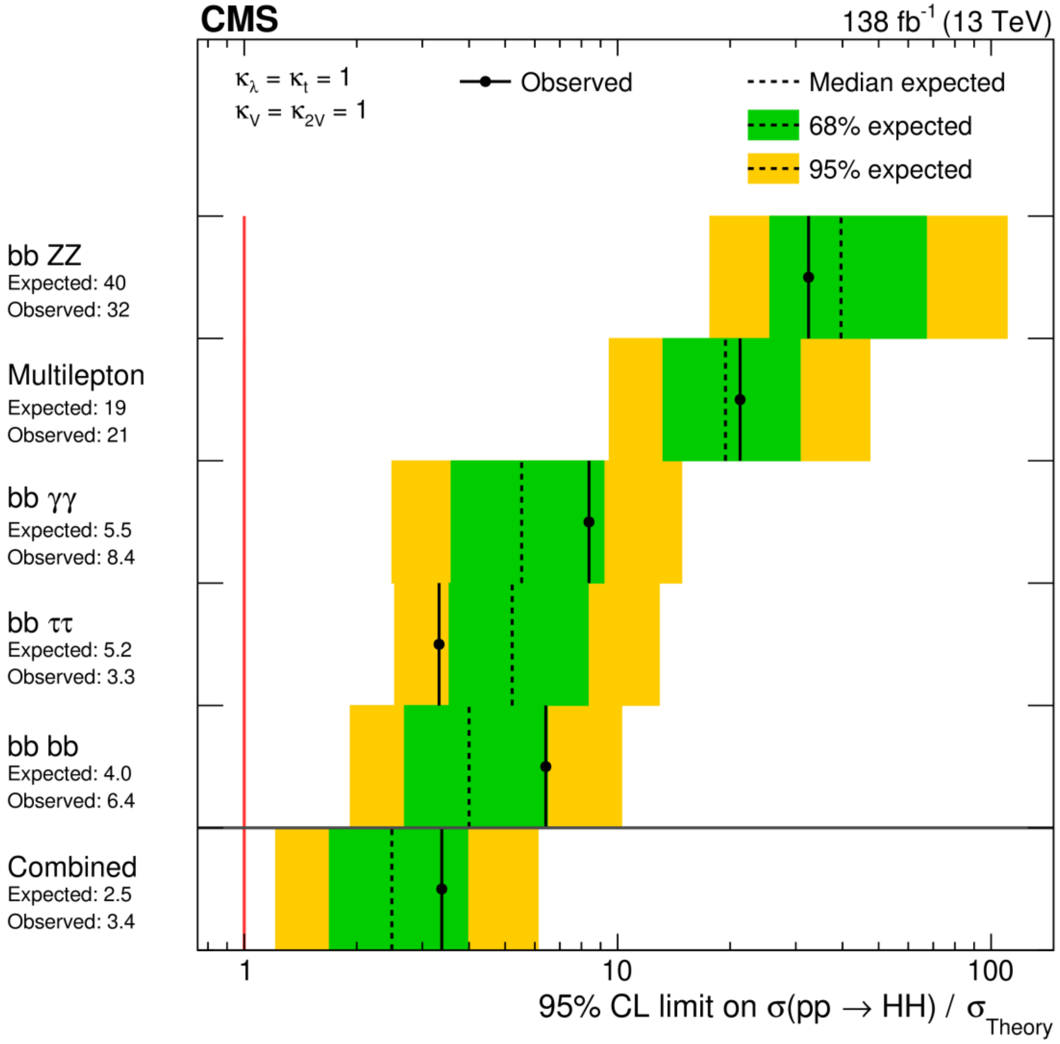
Figure from: Salam, G.P., Wang, LT. & Zanderighi, G. The Higgs boson turns ten. Nature 607, 41–47 (2022). https://doi.org/10.1038/s41586-022-04899-4

Endgoal: combine multiple HH channels

Many channels investigated for Run2 balancing between the **purity of the final state** and the **branching ratio** of the HH decay for the given channel



@200/fb
$N \approx 80$
events



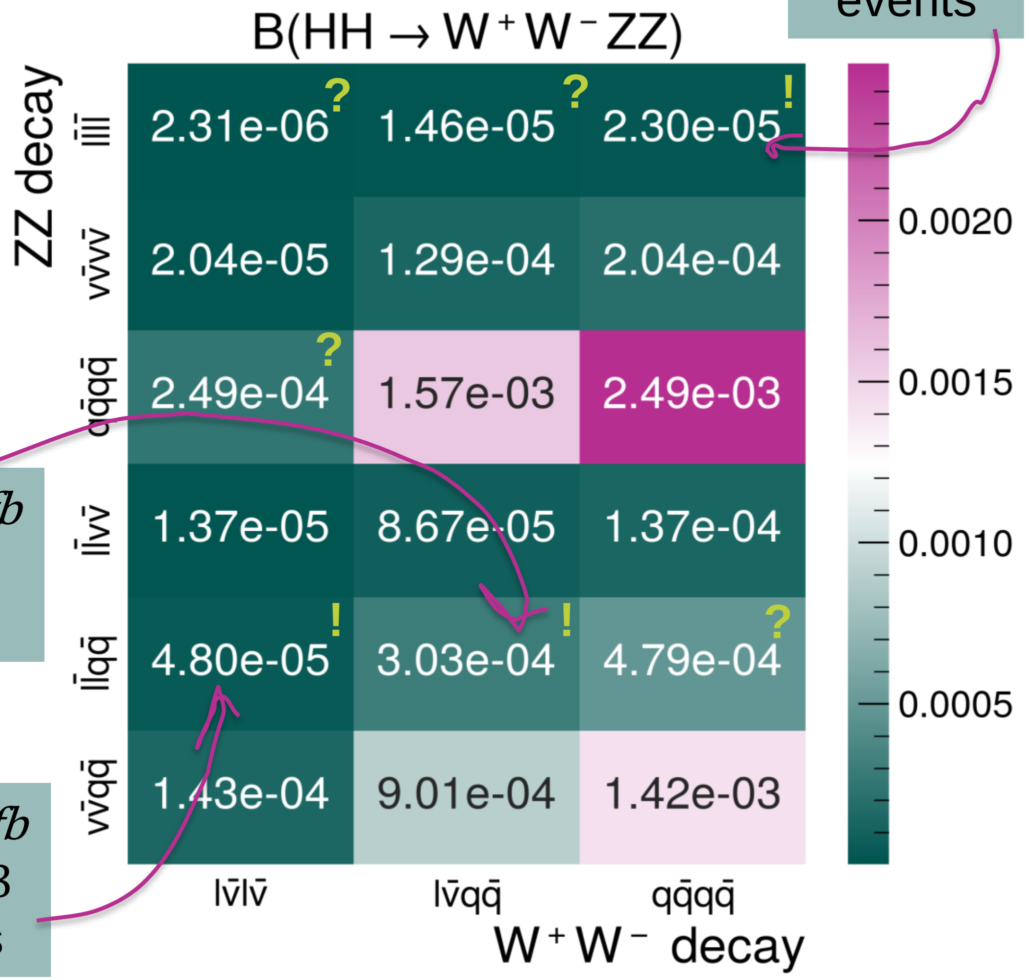
Limit plot from: The CMS Collaboration. A portrait of the Higgs boson by the CMS experiment ten years after the discovery. *Nature* **607**, 60–68 (2022). https://doi.org/10.1038/s41586-022-04892-x

Non-resonant HH→WWZZ decay channel

- Branching ratio B(HH→WWZZ) =1.2%
- First analysis in LHC to tackle this channel!

- **Clean** leptonic states
- **Good** signal/ background ratio expected
- **Targeting multilepton and multijet decays**, avoiding ν decays but still dealing with multiple objects (leptons, jets and missing transverse energy from neutrinos)

- Similar analysis was performed by ATLAS on the WWWW channel with $36fb^{-1}$, leading to an observed (expected) upper limit on $\frac{\sigma}{\sigma_{SM}}$ of 160



@200/fb
$N \approx 0.15$
events

@200/fb
$N \approx 2$
events

@200/fb
$N \approx 0.3$
events

The ATLAS collaboration, Search for Higgs boson pair production in the WW(*)WW(*) decay channel using ATLAS data recorded at $\sqrt{s}$= 13 TeV. J. High Energ. Phys. 2019, 124 (2019). https://doi.org/10.1007/JHEP05(2019)124

Analysis Strategy

- DATA: Run3 Run2
- MONTE CARLO (MC):
  - Signal ggHHto4V
  - Backgrounds WWZZ without di-Higgs | WWW, WWZ, WZZ, ZZZ | WW, WZ, ZZ | ttW, ttZ, tt+jets | tttt, ttVV | ttH, VH | DY+jets, W+jets

- STRATEGY
  - **Categorize** events using simple cuts;
  - **Estimate** DY+Jets, W+jets and ttbar backgrounds from control region in data;
  - Extract the signal in each category from a dedicated boosted decision tree (**BDT**);
  - Use a simple **cut-and-count** to estimate signal and background yields (no shape analysis).

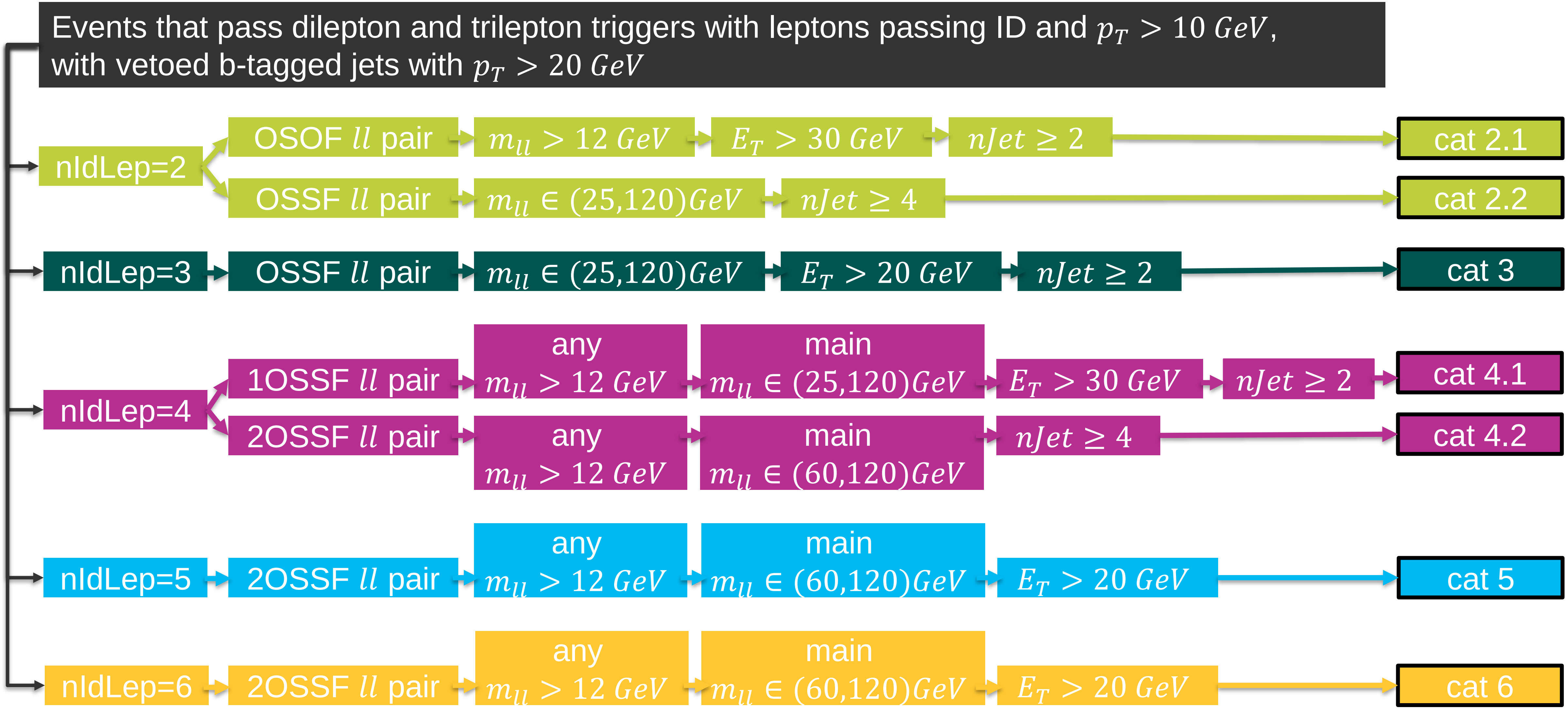
Lepton identification follows other analysis

Electrons	
Observable	Tight
Cone-p_T	> 10 GeV
$\lvert\eta\rvert$	< 2.5
$\lvert d_{xy}\rvert$	< 0.05 cm
$\lvert d_z\rvert$	< 0.1 cm
d/σ_d	< 8
I_e	$< 0.4 \times p_T$
$\sigma_{i\eta i\eta}$	$< \{ 0.011 / 0.030 \}$
H/E	< 0.10
1/E - 1/p	> -0.04
Conversion rejection	✓
Missing hits	$= 0$
EGamma POG MVA	>WP-loose

Muons	
Observable	Tight
p_T	> 10 GeV
$\lvert\eta\rvert$	< 2.4
$\lvert d_{xy}\rvert$	< 0.05 cm
$\lvert d_z\rvert$	< 0.1 cm
d/σ_d	< 8
I_μ	$< 0.4 \times p_T$
PF muon	>WP-medium

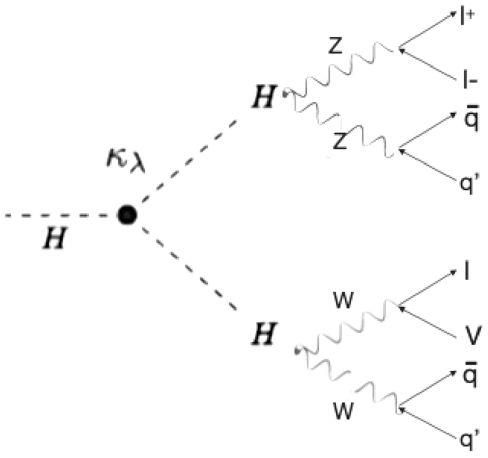
+MVA TTH identification

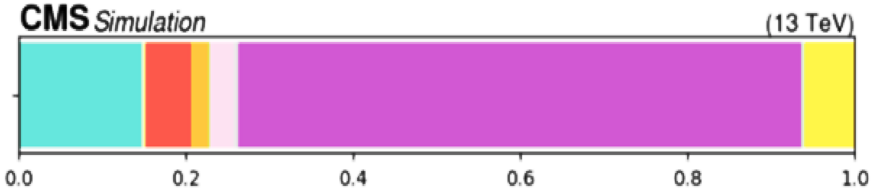
Categorisation aimed at high signal efficiency



OS – opposite sign; OF – opposite flavour; SF – same flavour

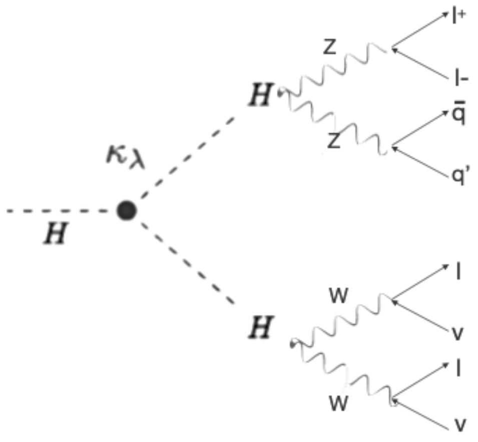
First focus – 3 and 4 lepton categories

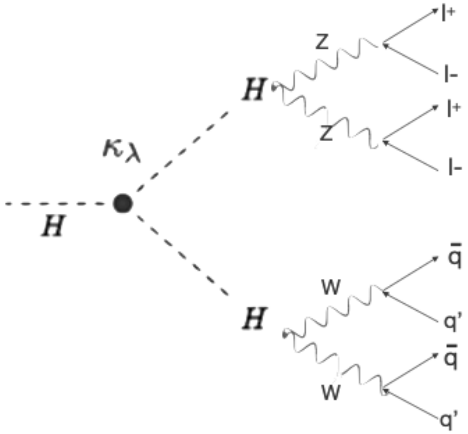


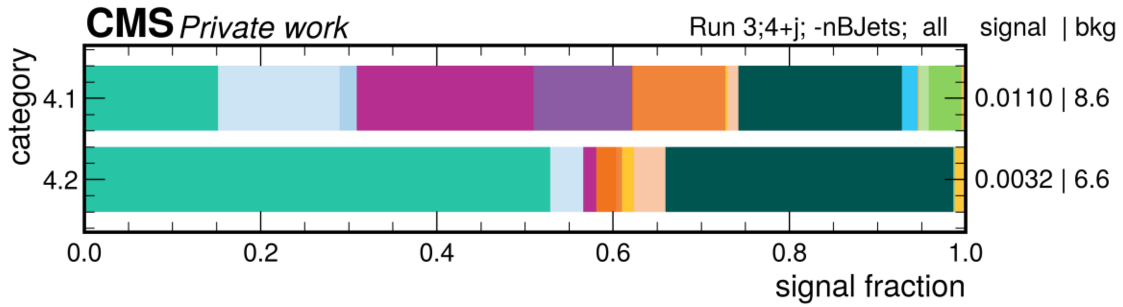


signal | bkg
0.0683 | 816.6

Dominant backgrounds after preselection:
• WZ, DY and ZZ



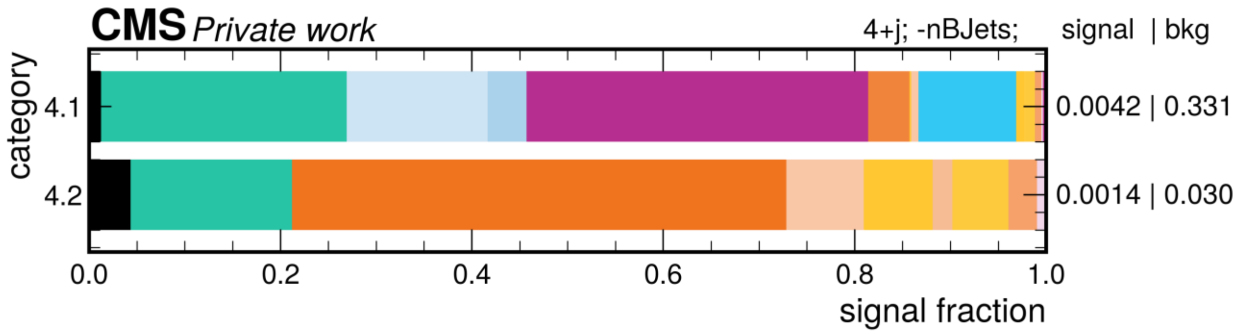


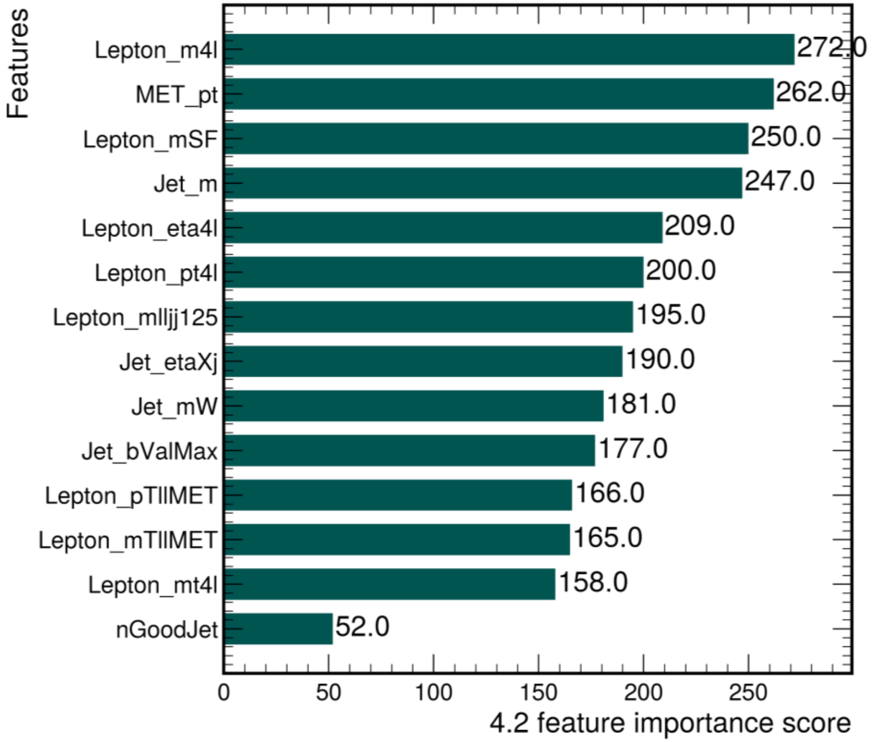


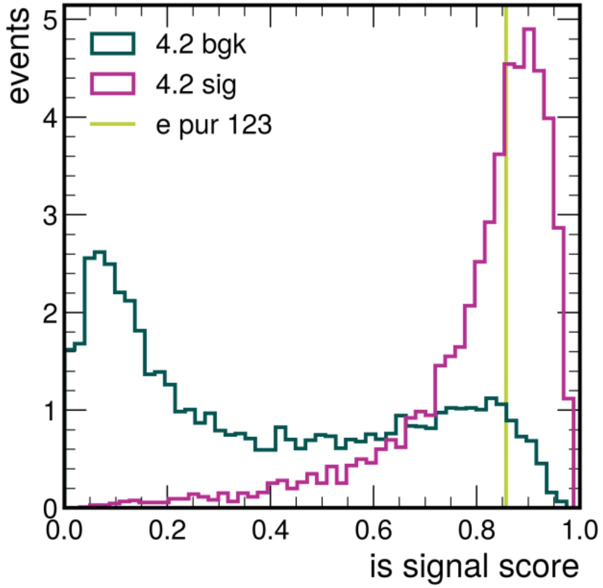
Dominant backgrounds after preselection:
• ZZ, DY, TTZ and ZH

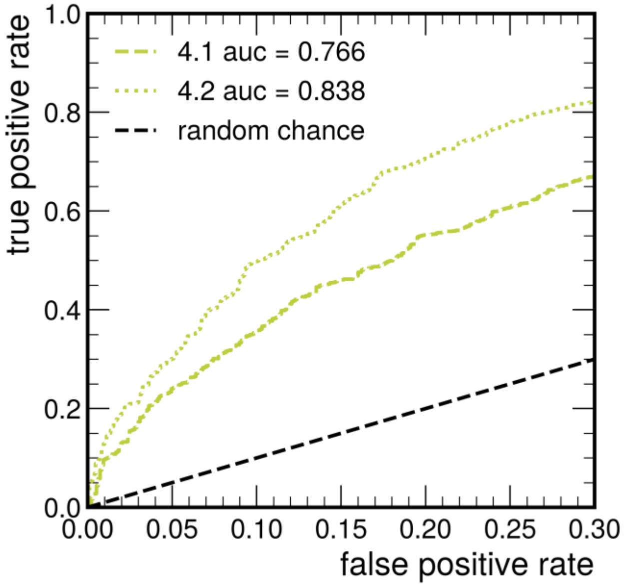
Trained a BDT for signal extraction

- 14 parameters
- Privately generated signal samples
- Globally generated background 'soup'









BDT – boosted decision tree

Preliminary limit has expected sensitivity

- mean expected limit:

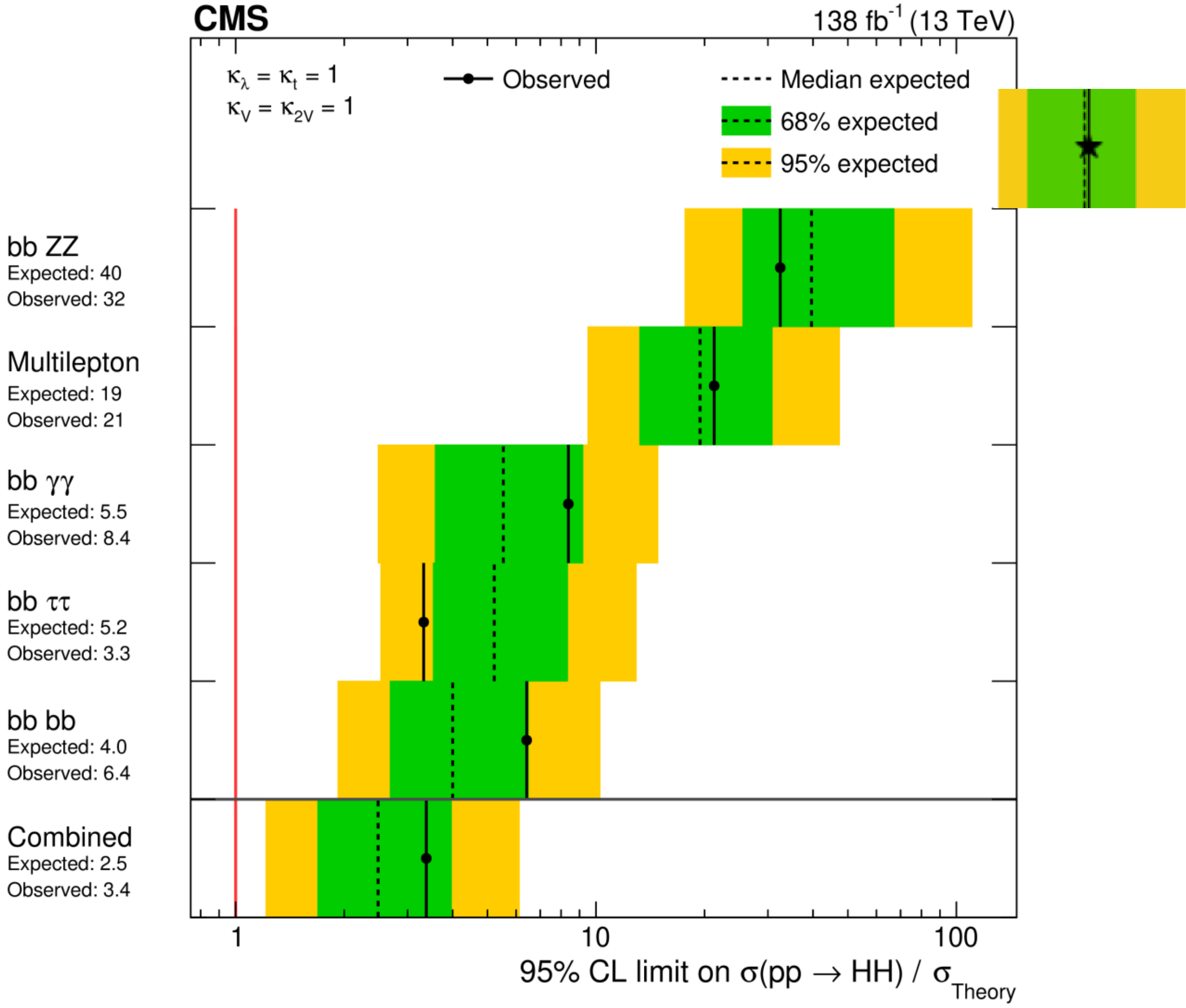
  r < 249.969 +/- 2.74285 @ 95%CL
- median expected limit:

  r < 242.992 @ 95%CL
- 68% expected band:

  167.807 < r < 338.134
- 95% expected band:

  138.533 < r < 464.443

- A simple counting experiment with the signal and overall background yields, only 3 input bins
- **Very preliminary results** with only statistical uncertainty + lumi nuisance



Conclusions and Next Steps

- HH → WWZZ → leptons + jets analysis **could join HH analyses in view of combination** as is unique not only in CMS but also LHC;
- Categorisation is defined;
- Dedicated BDT per category for signal extraction is developed;
- First estimate of upper limit set!

Ongoing

- Checking for **data and MC agreement** in control regions;
- Developing data driven background estimates.

Next

- Implement and update corrections;
- Cover **full Run 2 and early Run 3** (2022, 2023).

Questions?

Let us know your thoughts!
cms-hh-wwzz@cern.ch