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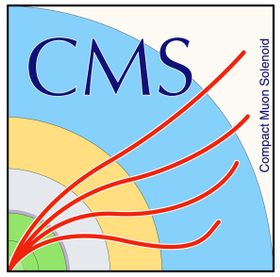
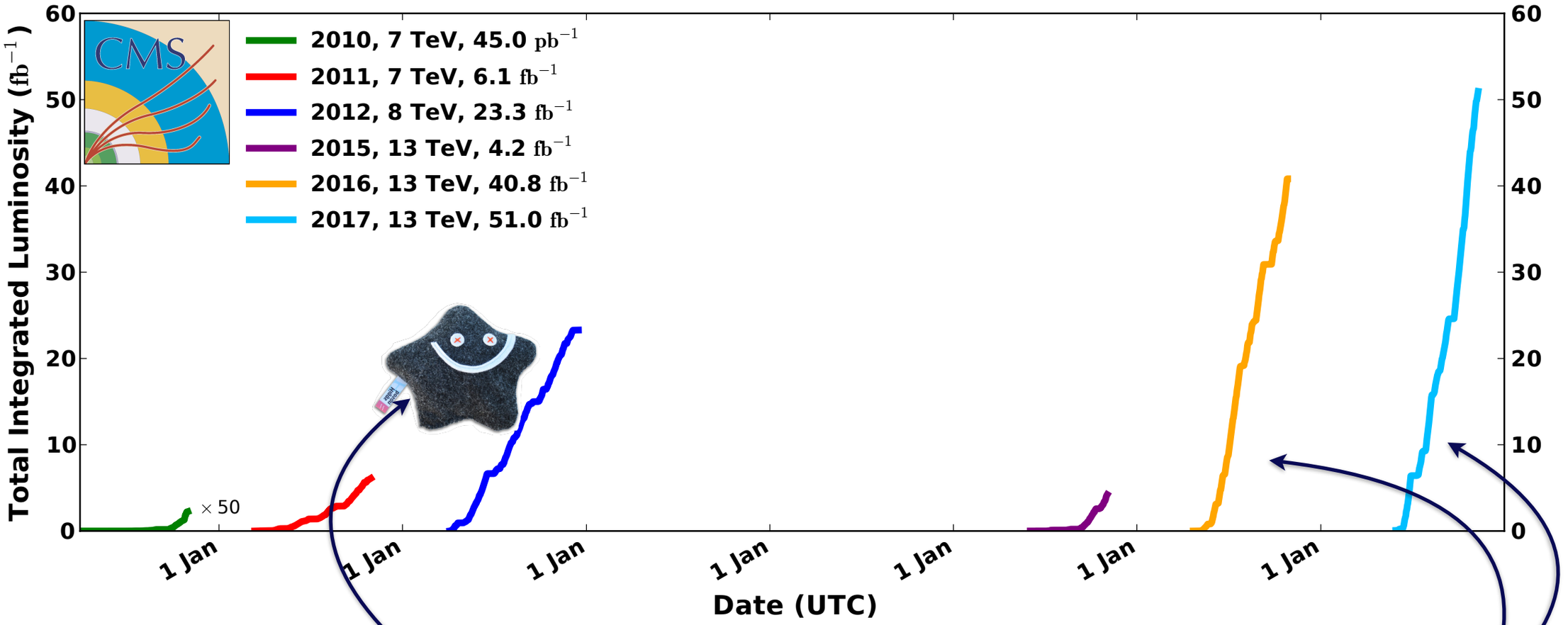


H→γγ at CMS

Ed Scott

IOP APP and HEPP conference, 27th March 2018

Where are we?



- Higgs discovery in 2012
- Confirmed it looks **qualitatively** similar to the SM expectation
- Now want to **precisely characterise Higgs properties**

- Large CMS Run 2 datasets can test compatibility with SM
- Today focus on **H→γγ results using 35.9fb^{-1} data from 2016**

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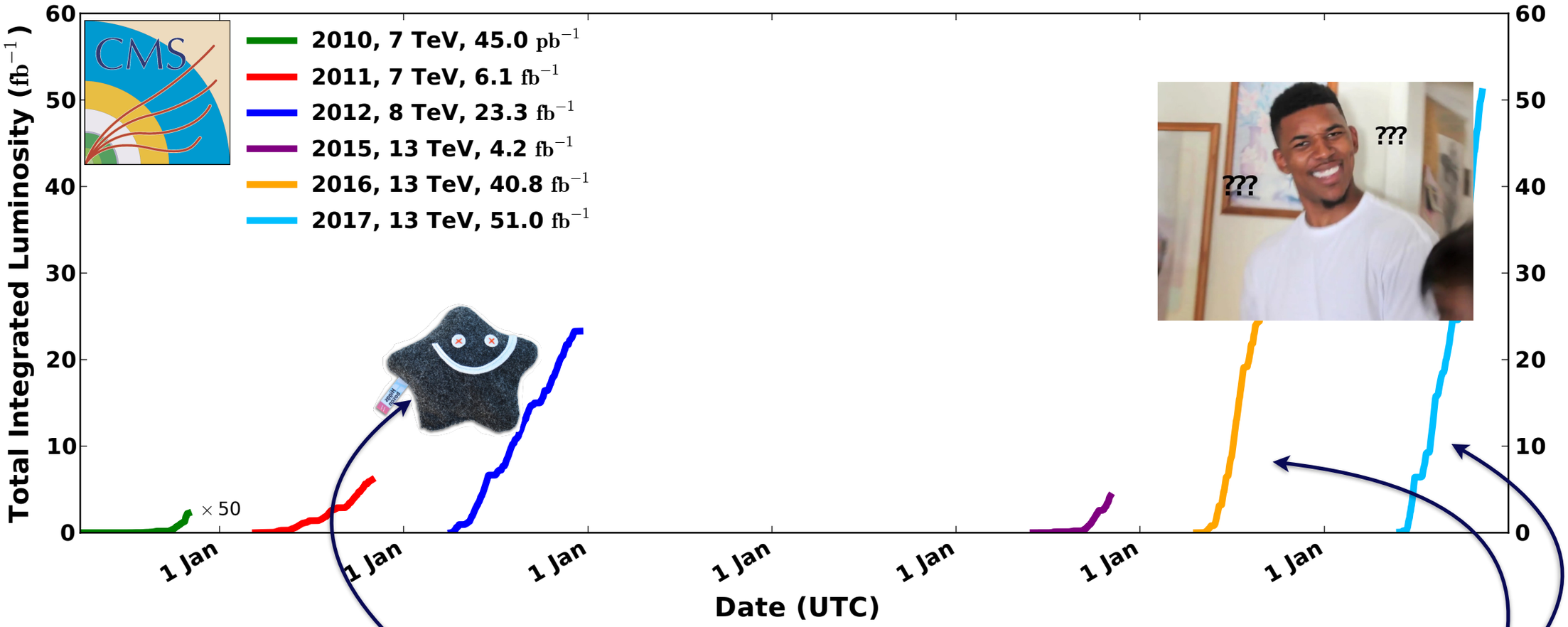

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What have we measured?

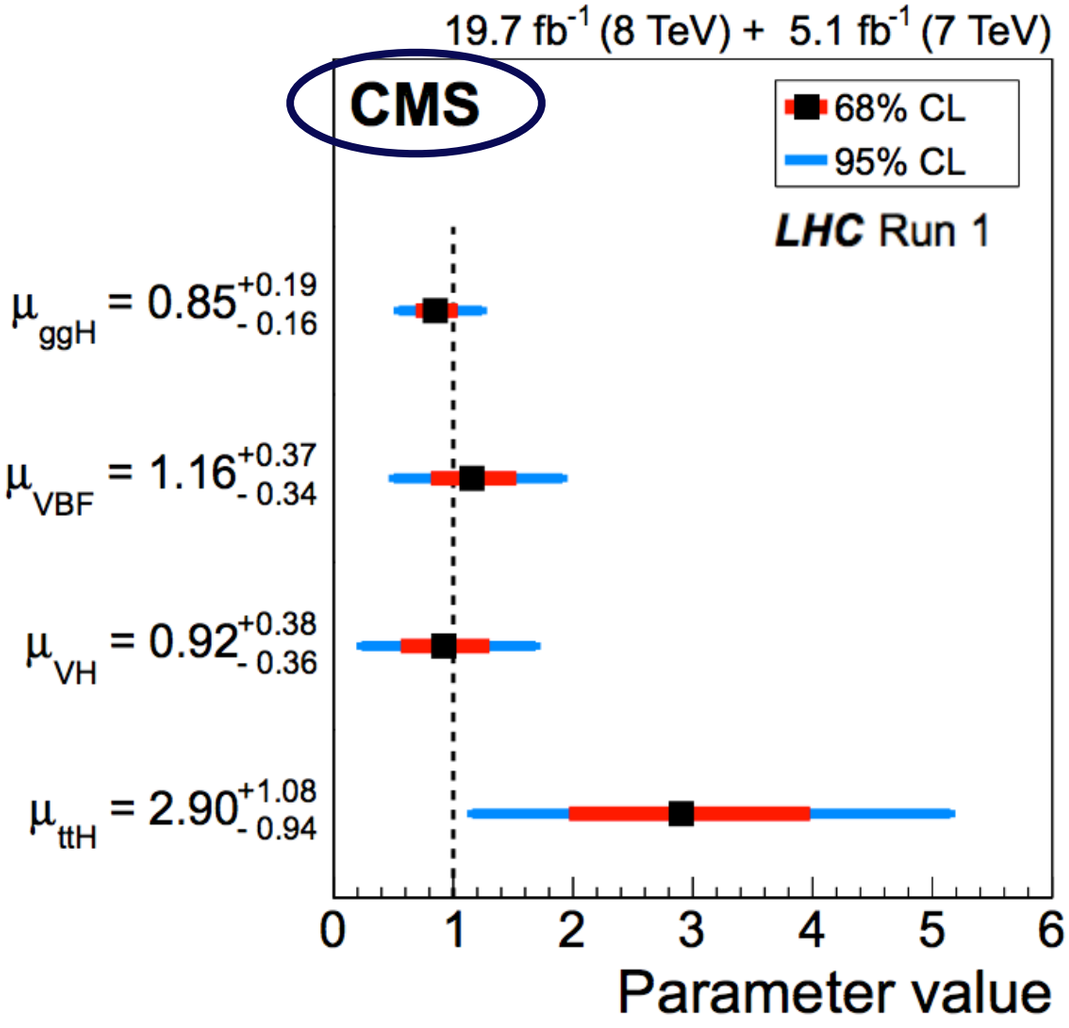
$$\mu_i = \frac{\sigma_i}{(\sigma_i)_{\mathrm{SM}}} \quad \text{or} \quad \kappa_j^2 = \Gamma^j / \Gamma^j_{\mathrm{SM}}$$

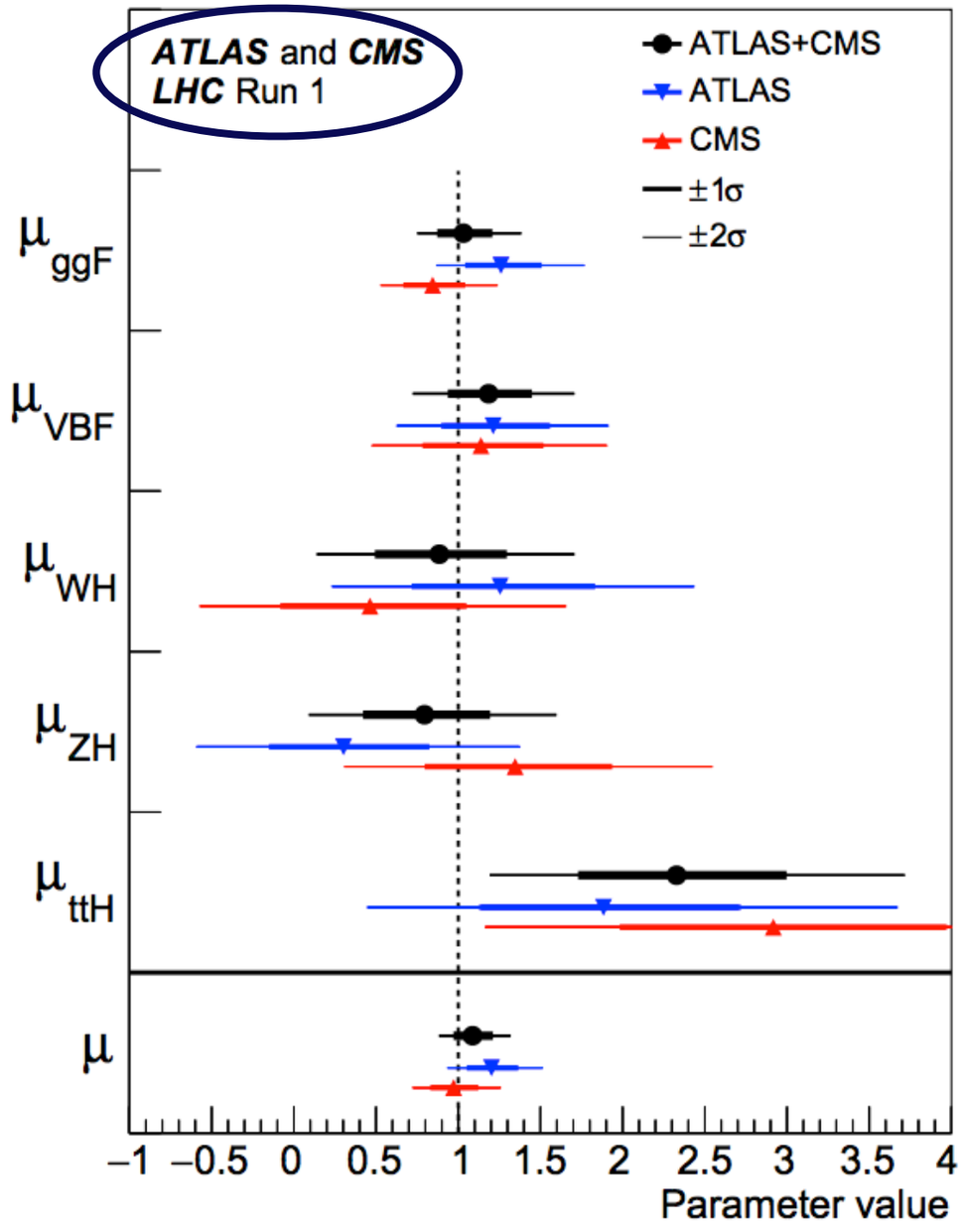
- Traditional per-process coupling modifiers μ_i, for i = ggH, VBF, ttH, etc.
- LO-motivated κ framework that modifies Higgs' couplings to SM particles
  - applies for both production and decay
  - additional effective coupling modifiers, $\boldsymbol{\kappa_g}$ **and** $\boldsymbol{\kappa_\gamma}$, describe the loop processes for ggH production and $\gamma\gamma$ decay respectively
  - BSM contributions can cause deviations here at O(few%) level

Introduced here and in YR3

What have we measured?

- **Higgs sector now precision physics**
- CMS combination of Run 1 results
- Includes γγ, ZZ, WW, ττ and bb channels





- **World's most precise measurement: the ATLAS + CMS combination**

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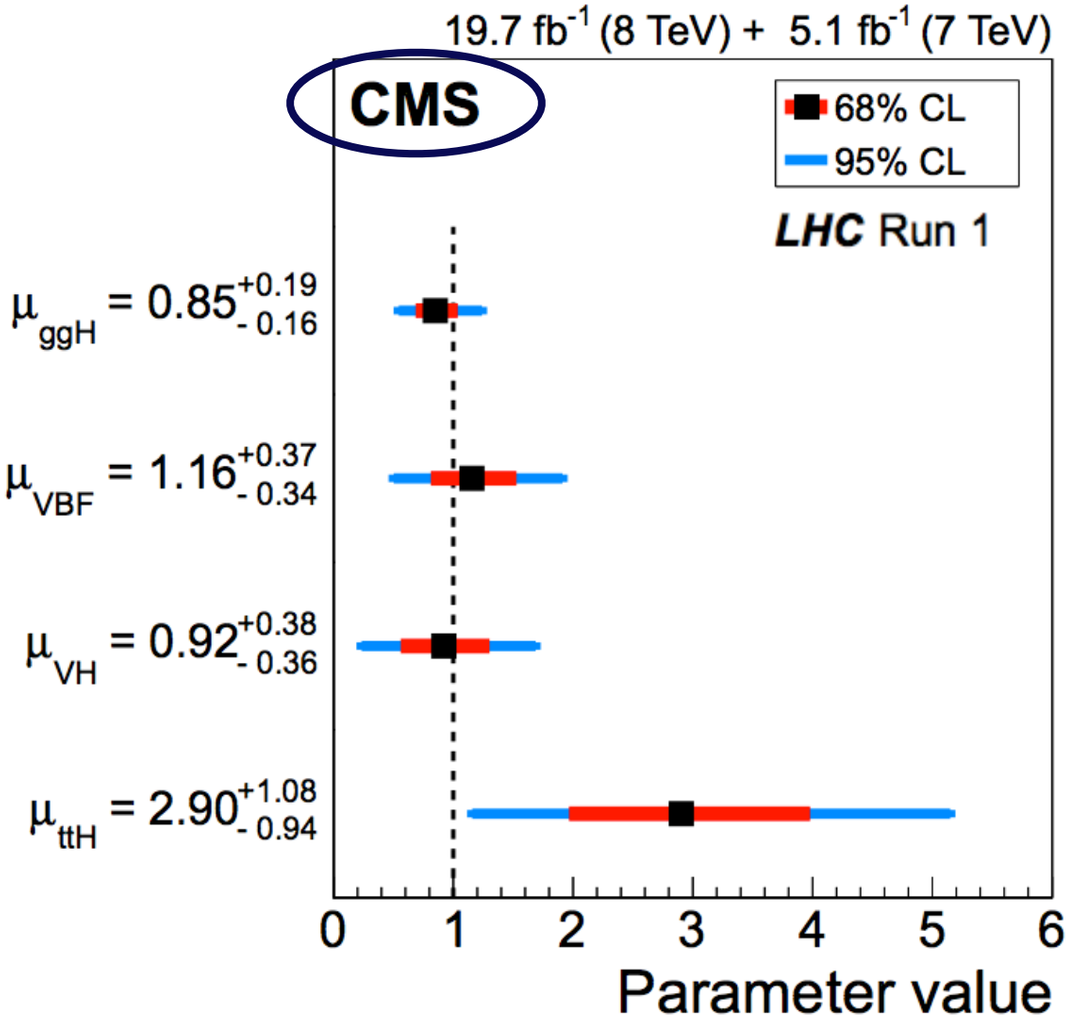

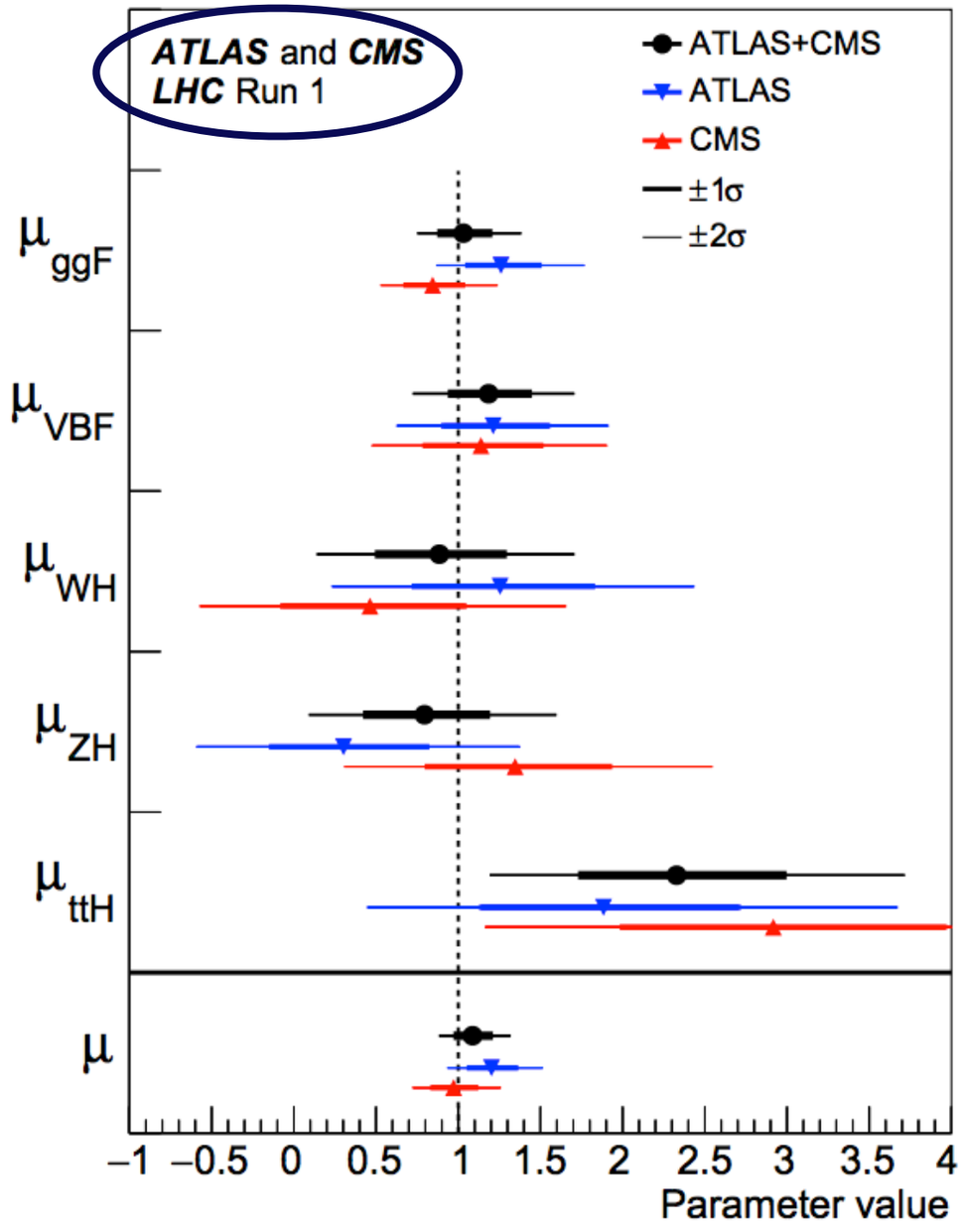

- ~~**World's most precise measurement: the ATLAS + CMS combination**~~
  See later slides!

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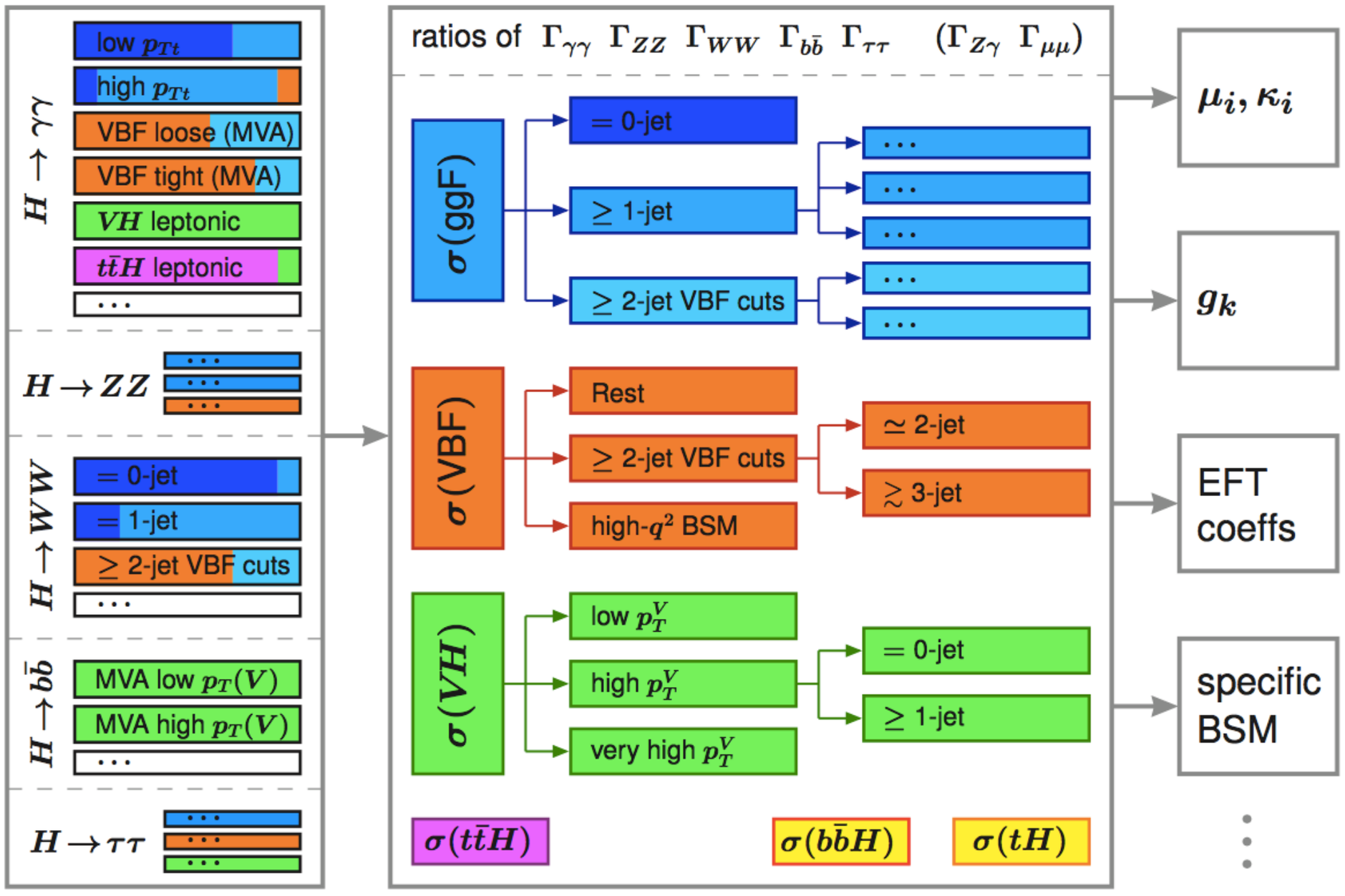
What will we measure?



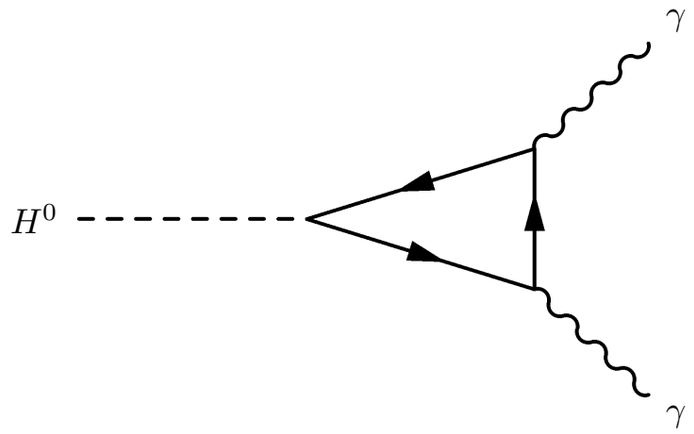
- Results can then be re-interpreted with new theories
- Kinematic regions isolate BSM effects
- And provide coherent framework for combination of channels & experiments

- **Simplified Template Cross-section (STXS)** framework aims to minimise measurements' dependence on theory

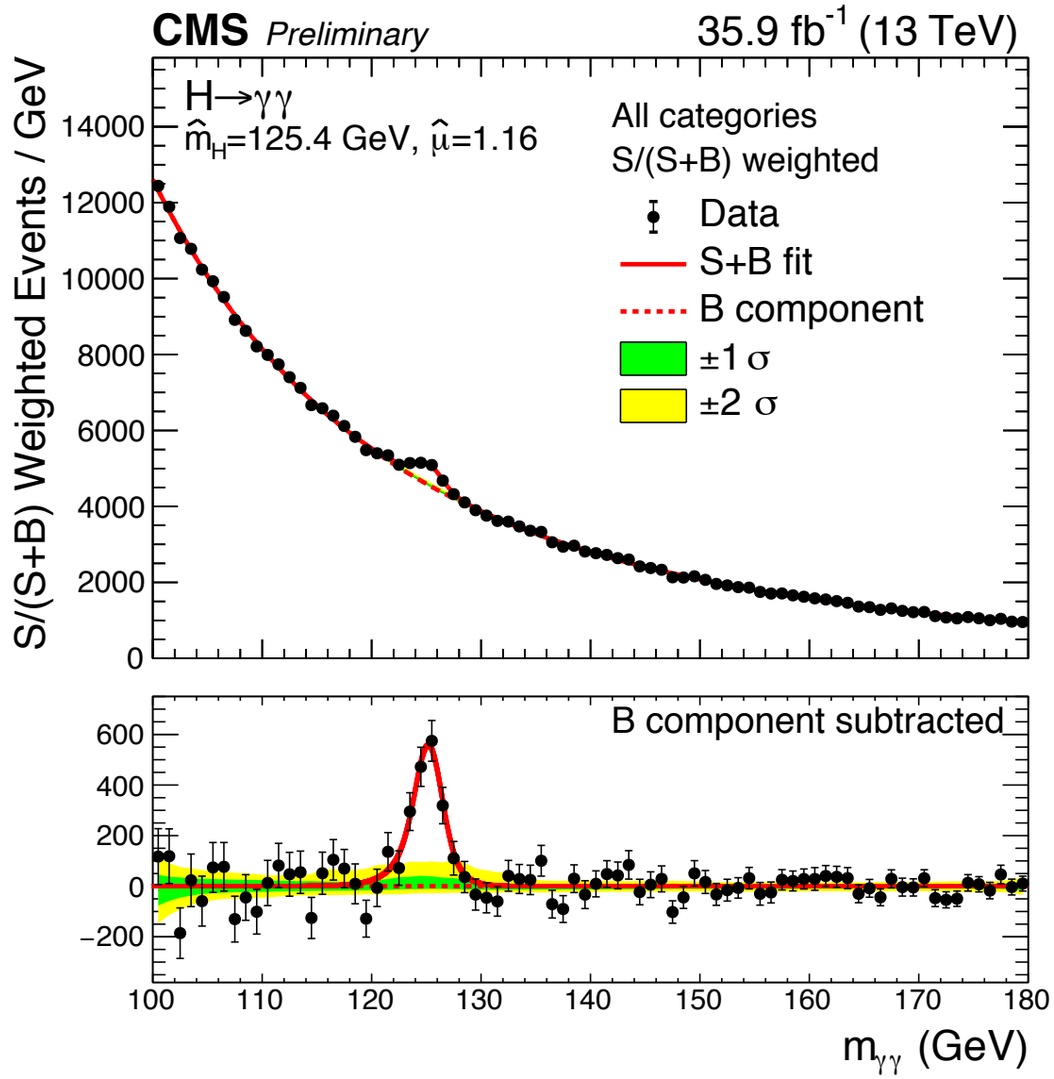
From YR4

H→γγ: Overview

- High resolution channel
- Key to discovery despite low BR (~0.2%)
- Now ideal for performing precision measurements of Higgs properties



- Select events with two well-isolated photons with $p_T > 30$ (20) GeV for (sub)leading, $|\eta| < 2.5$
- Additional scaled cut on (sub)lead photon $p_T > m_{\gamma\gamma}/3$ $(m_{\gamma\gamma}/4)$
- Fit small signal peak on large falling background in categories



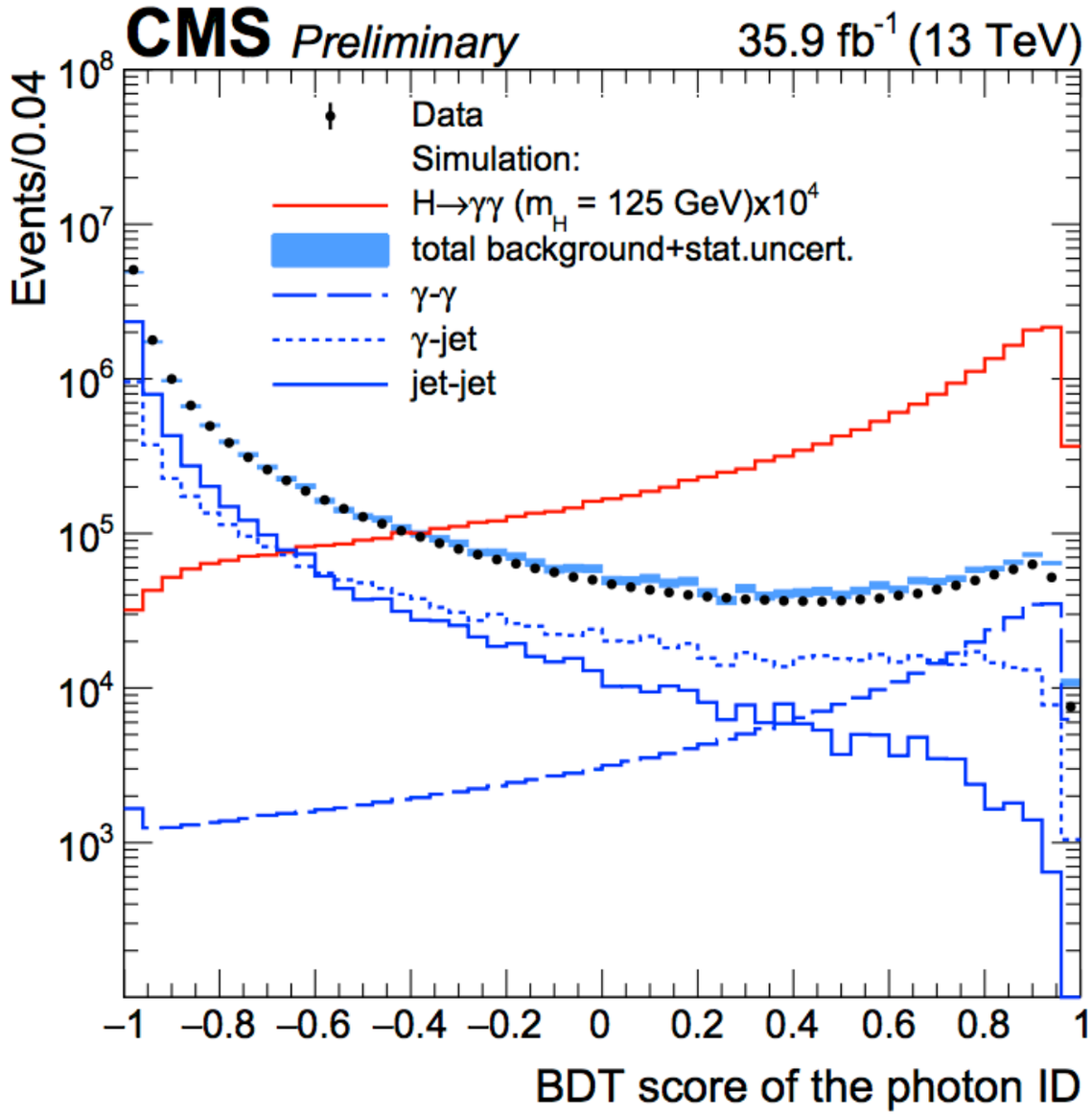
H→γγ: Strategy

- **Identify photons using a BDT**
- Discriminates between real and fakes using shower shape & isolation

- **Another BDT for vertex selection**
- Inputs are track recoil variables
- Negligible effect on resolution if within 1cm of true position

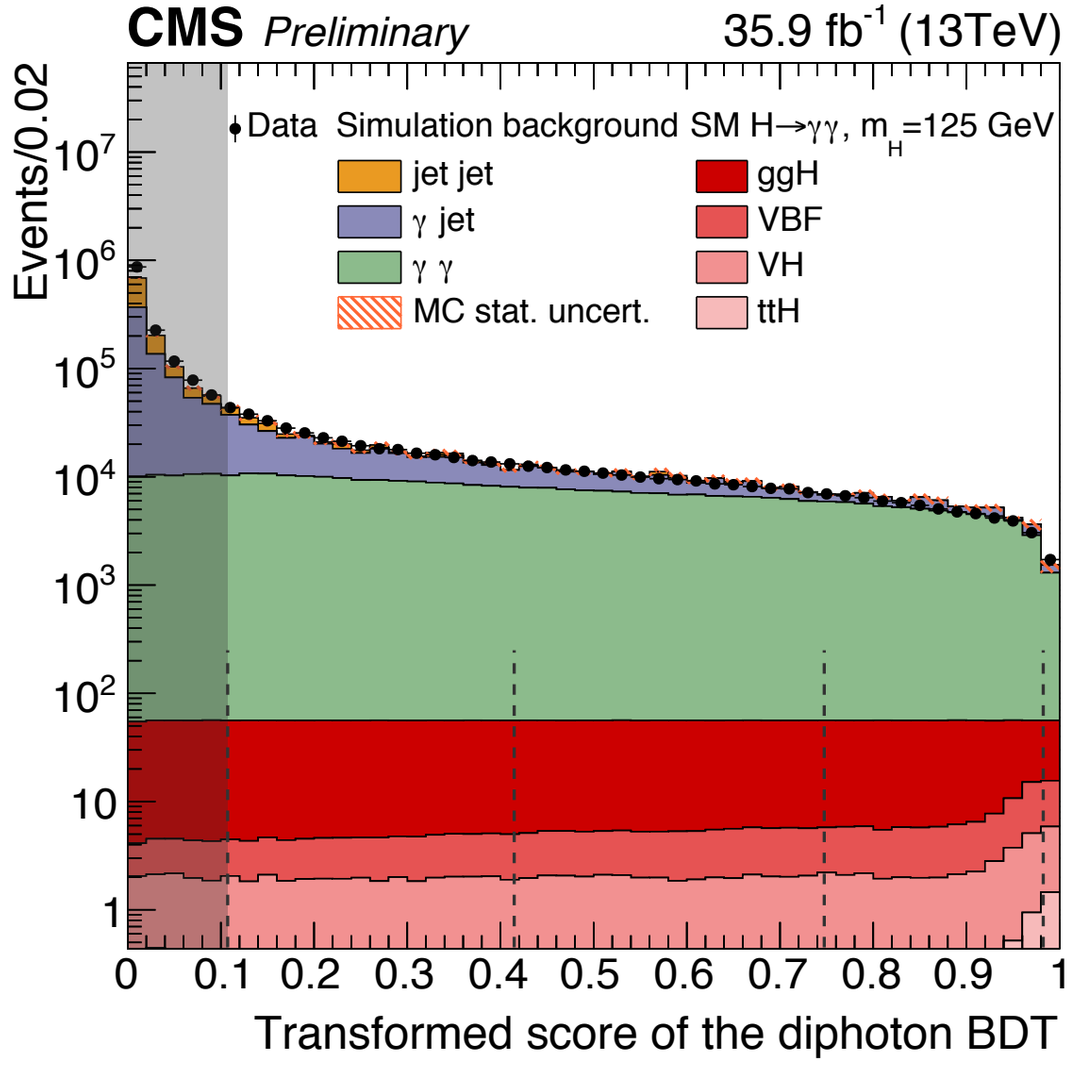
- **Quality of diphotons quantified with third BDT**
- Used to classify events by S/B

$$m_{\gamma\gamma} = \sqrt{2E_1E_2(1-\cos\theta)}$$



H→γγ: Strategy

- **Event Classification:** tag events using additional objects present → target different production modes
- Improves S/B
- Enables measurement of per-process signal strengths



- Untagged events (mostly ggH) further separated by S/B → improves overall sensitivity

ttH leptonic → VH leptonic → ttH hadronic →

→ VBF 0-2 → VH hadronic → Untagged 0-3

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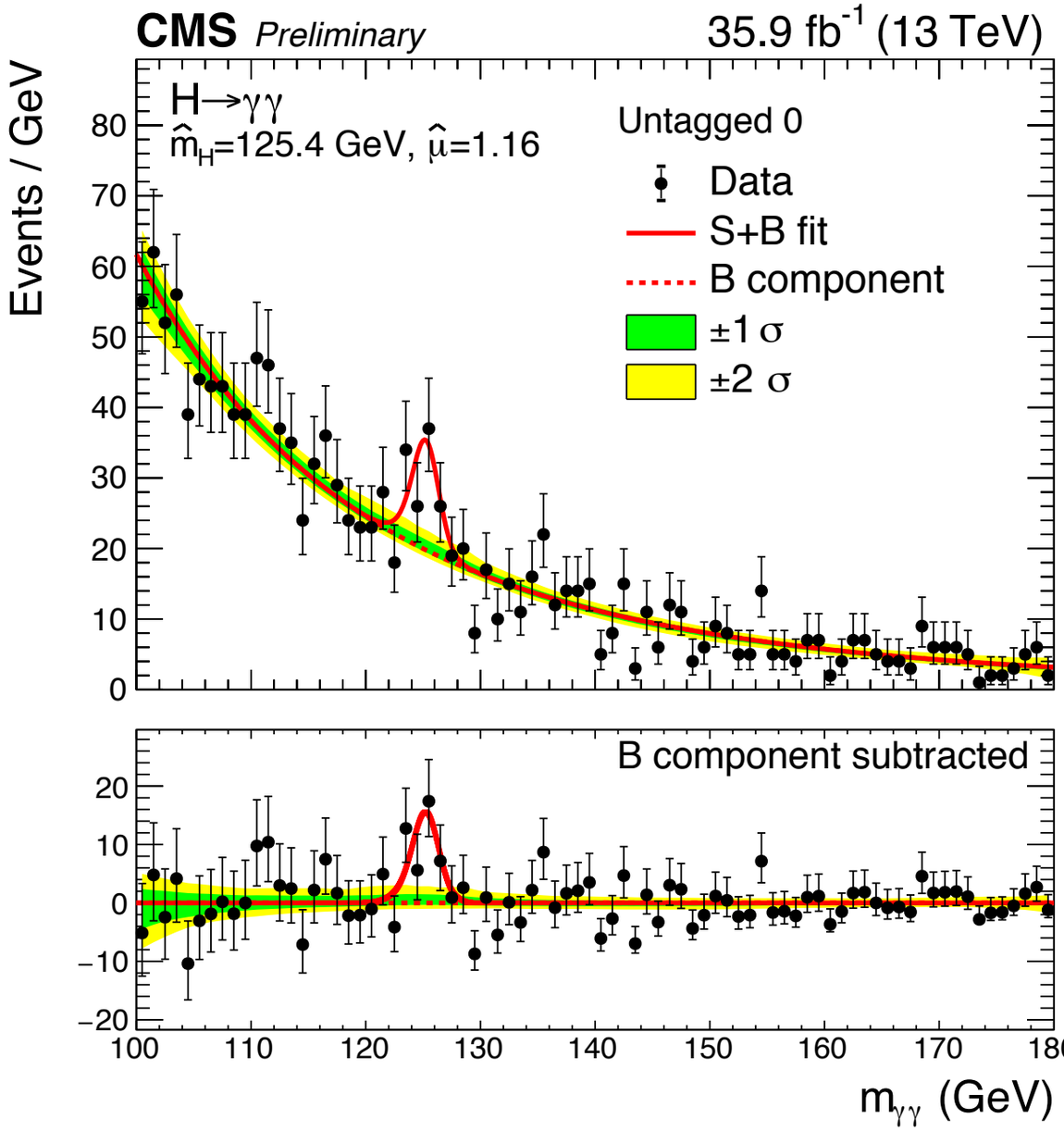
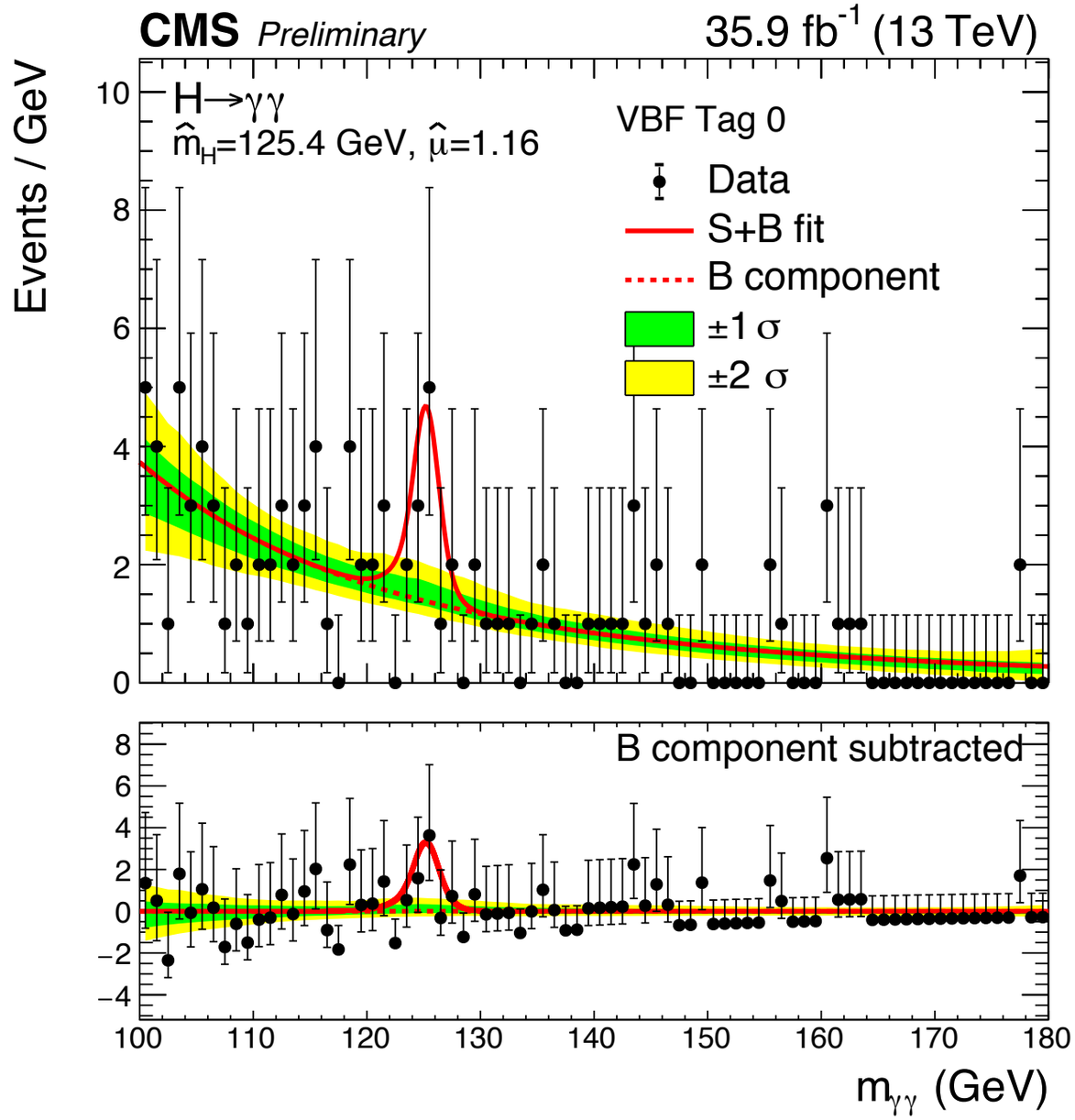
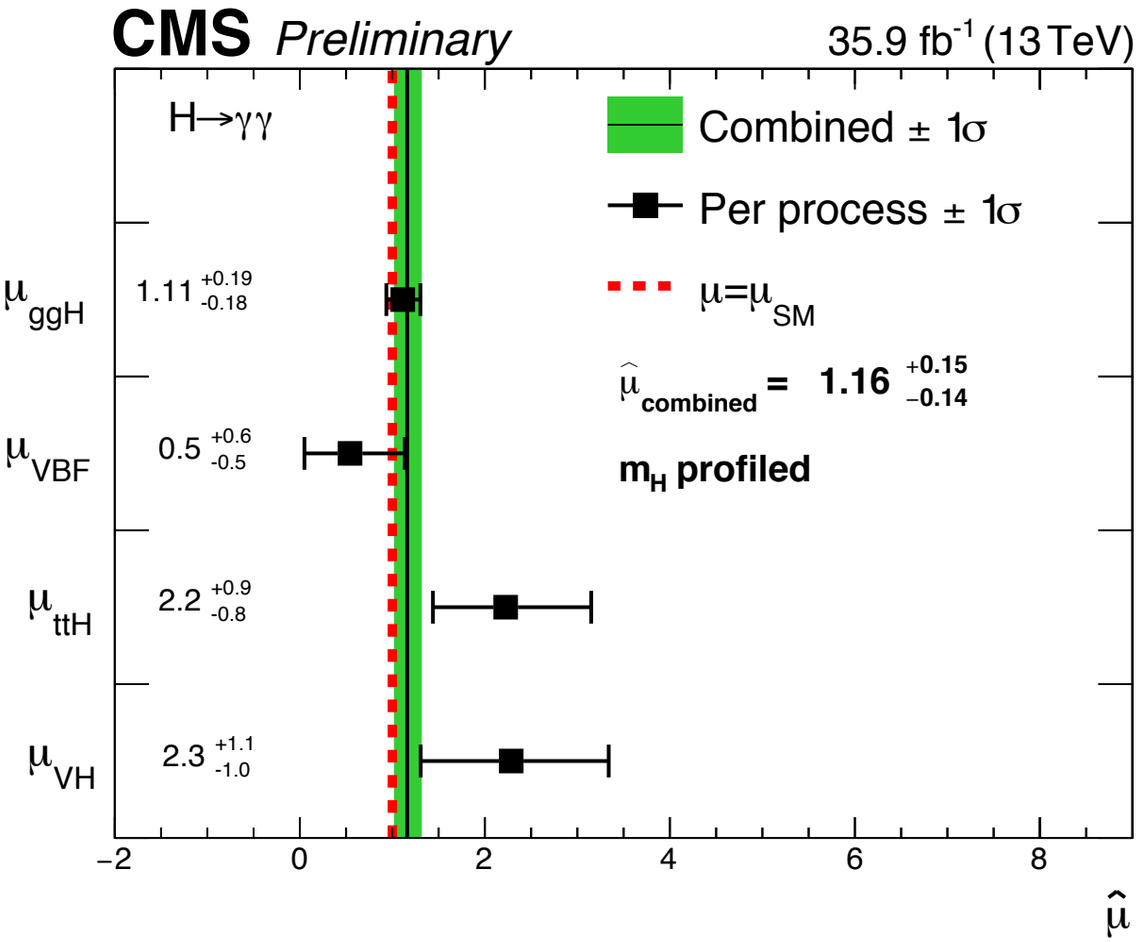
H→γγ: Distributions

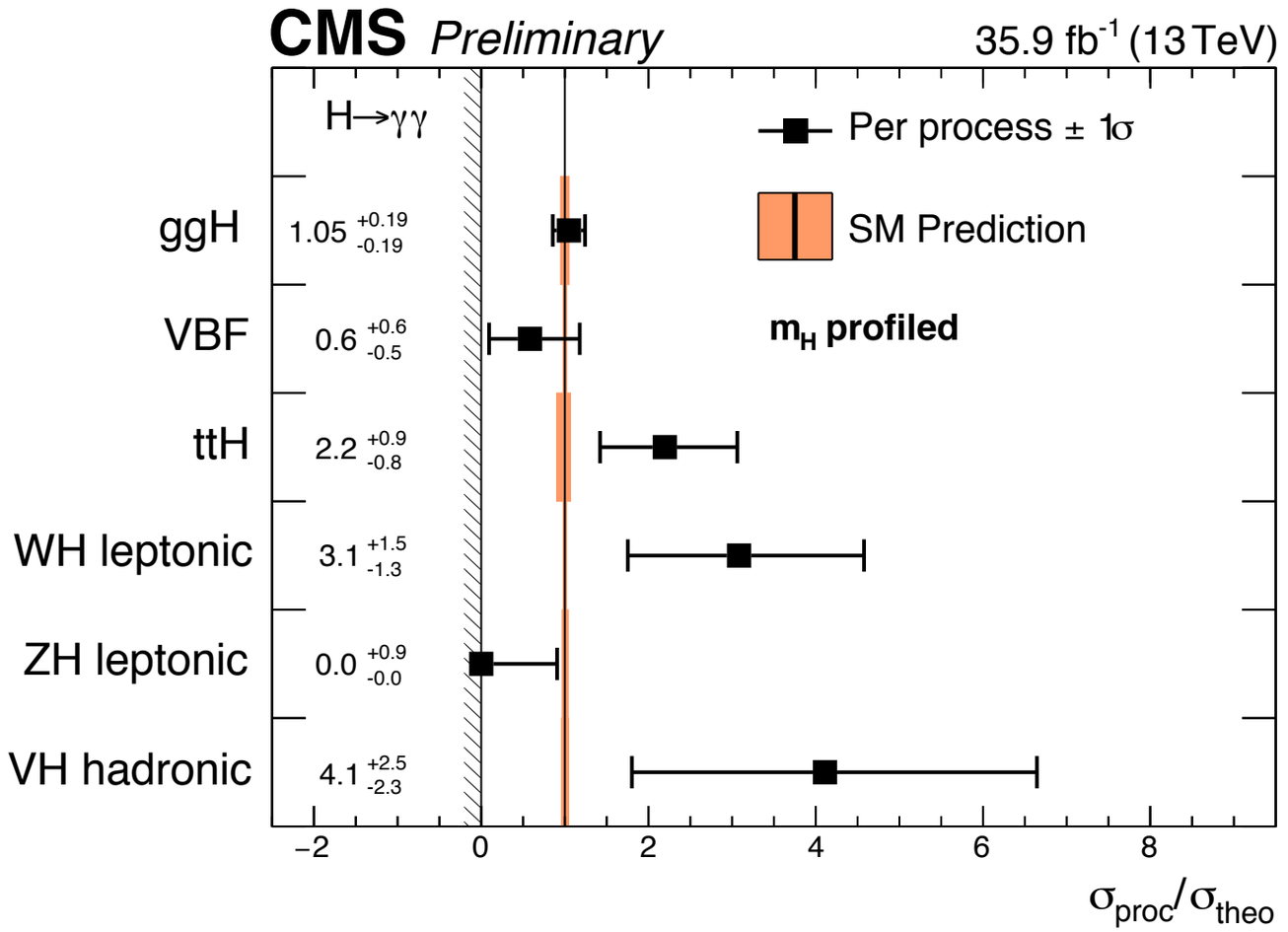




- Simultaneously fit all categories
- These show result of fit for overall signal strength μ

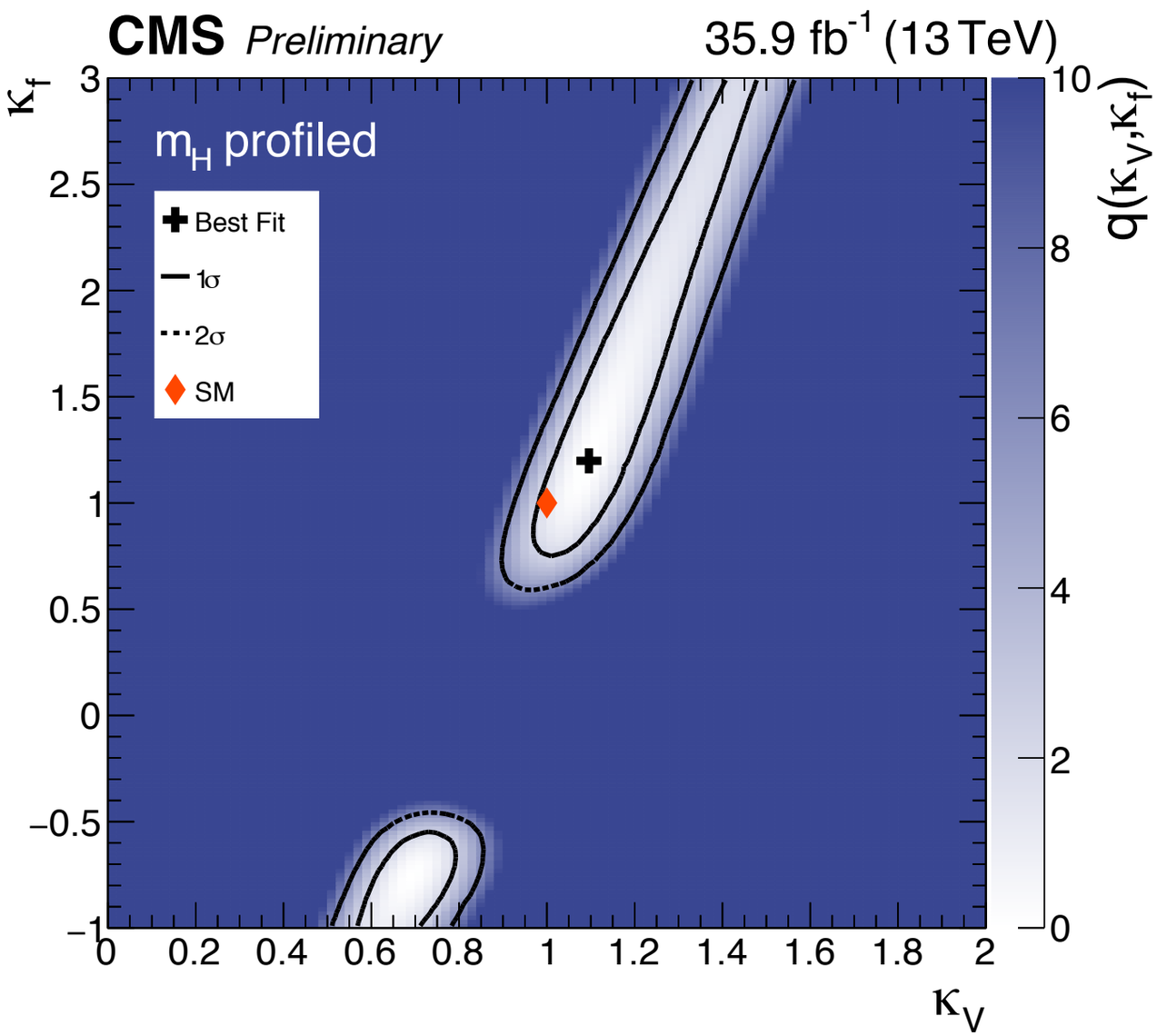
H→γγ: Results

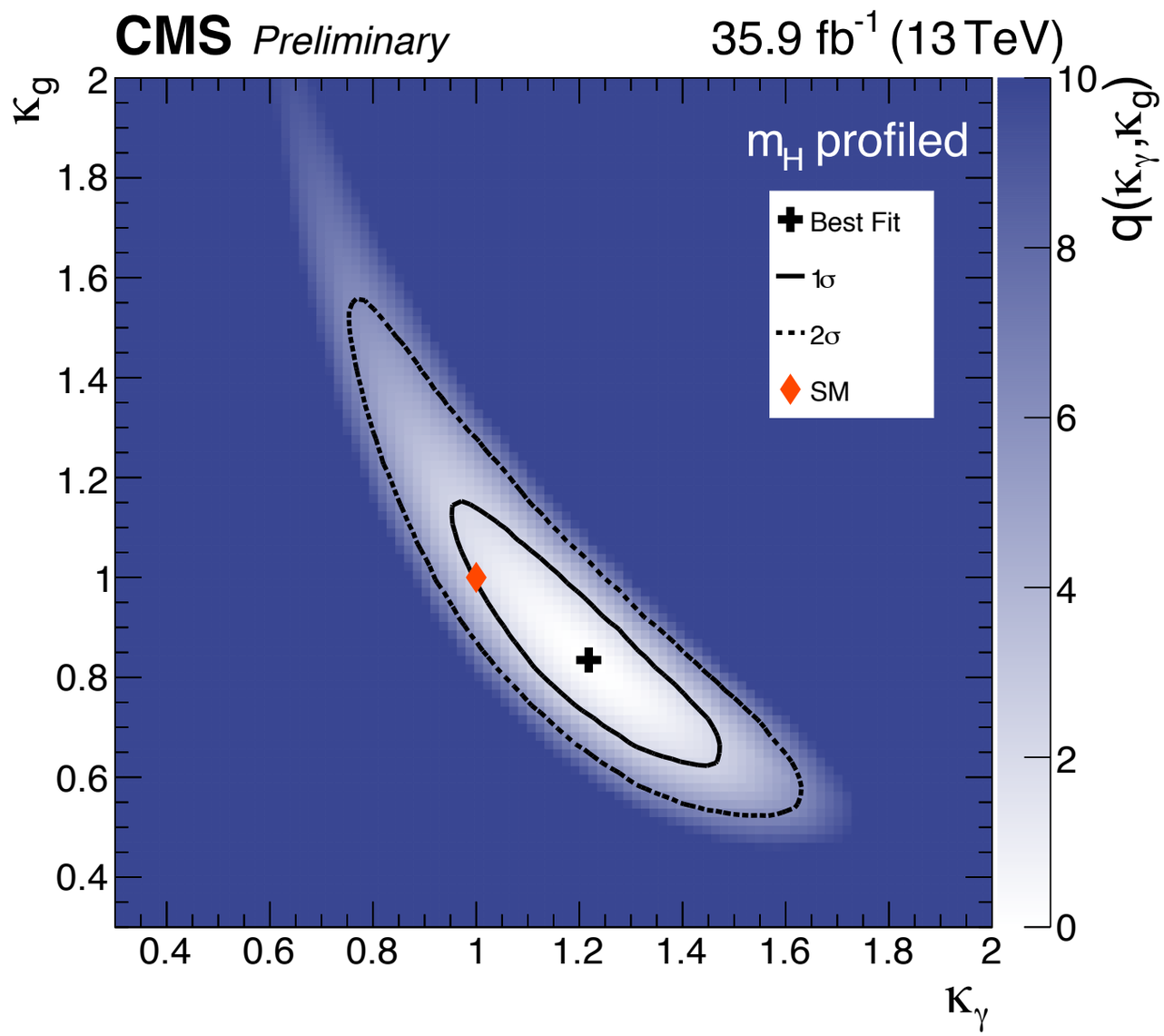




- Per-process μ on LHS, including 3.3σ significance for ttH (wrt μ=0)
- Stage 0 Simplified Template Cross-Section measurement on RHS

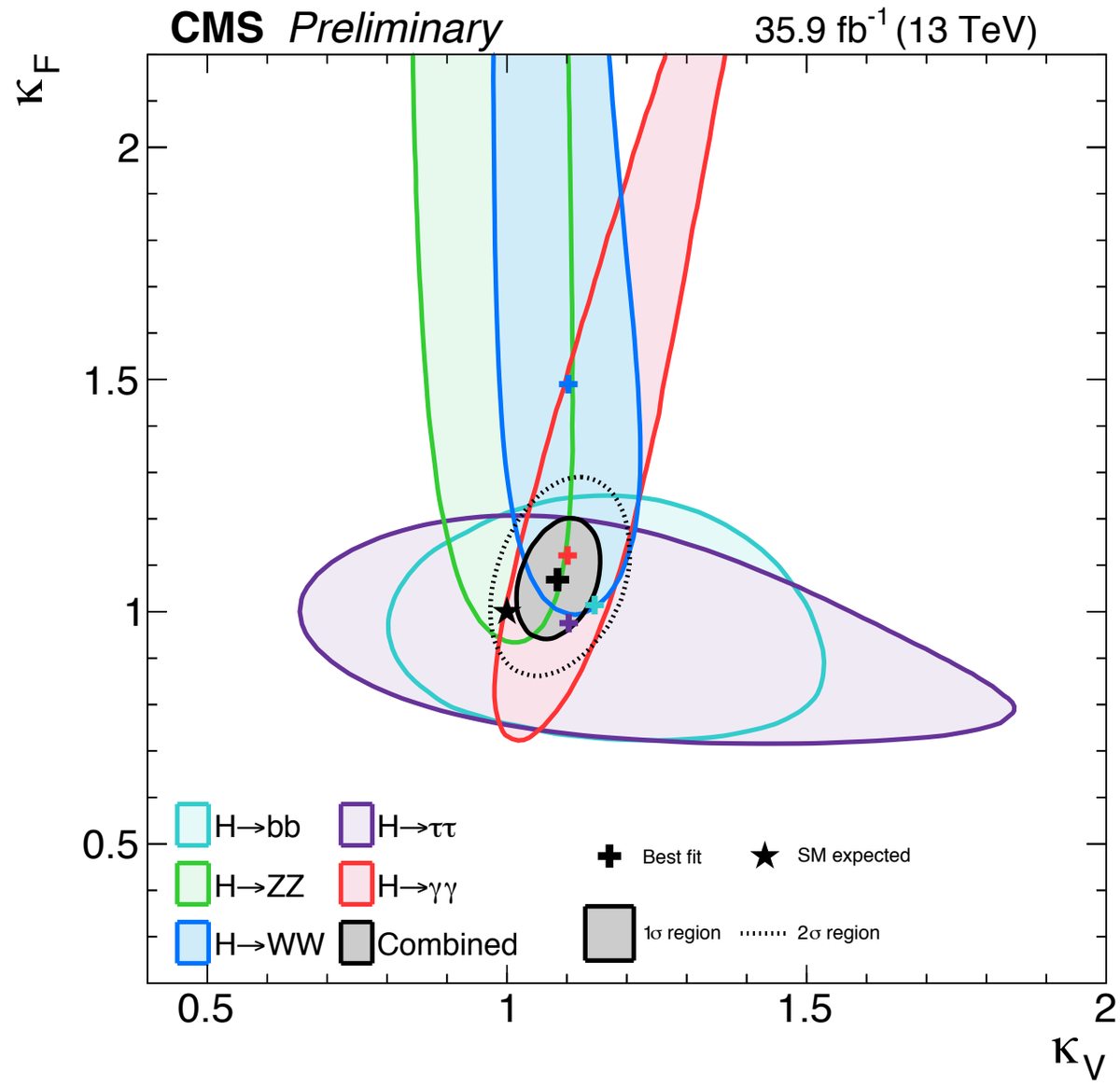
H→γγ: Results





- Coupling to fermions vs vector bosons on LHS
- Effective coupling to gluons vs photons on RHS

Higgs combination



- Combination of 2016 results to produce world-best precision measurements:

$$\mu = 1.17^{+0.10}_{-0.10} = 1.17^{+0.06}_{-0.06}\,(\text{stat.})\,^{+0.06}_{-0.05}\,(\text{sig. th.})\,^{+0.06}_{-0.06}\,(\text{other sys.})$$

- Channels included are γγ, ZZ, WW, ττ, bb, and μμ

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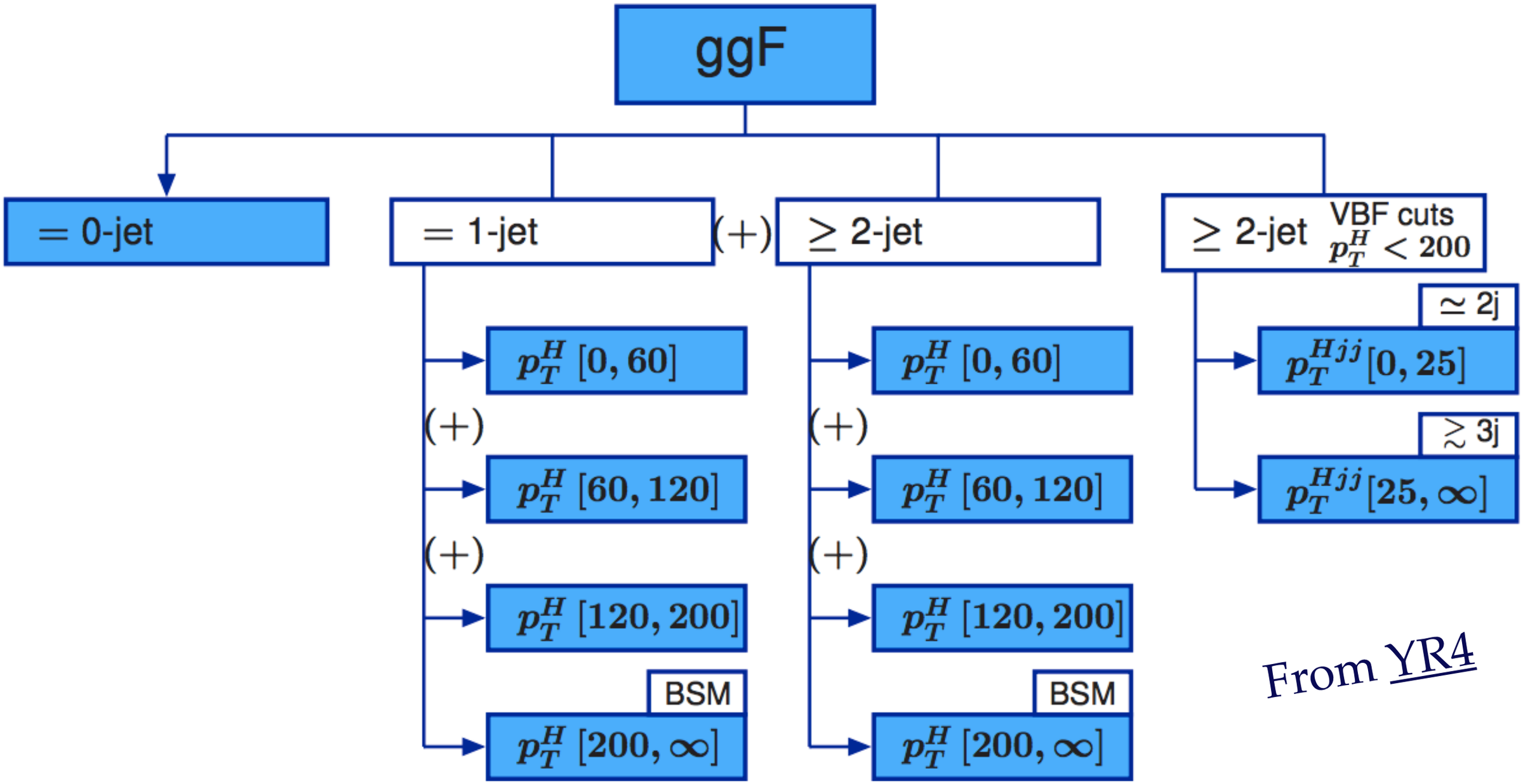
STXS stage 1 - ggH



- p_T and nJet bins, isolating BSM effects and separating VBF phase space
- in practice, may need to combine bins for reasonable sensitivity (+)

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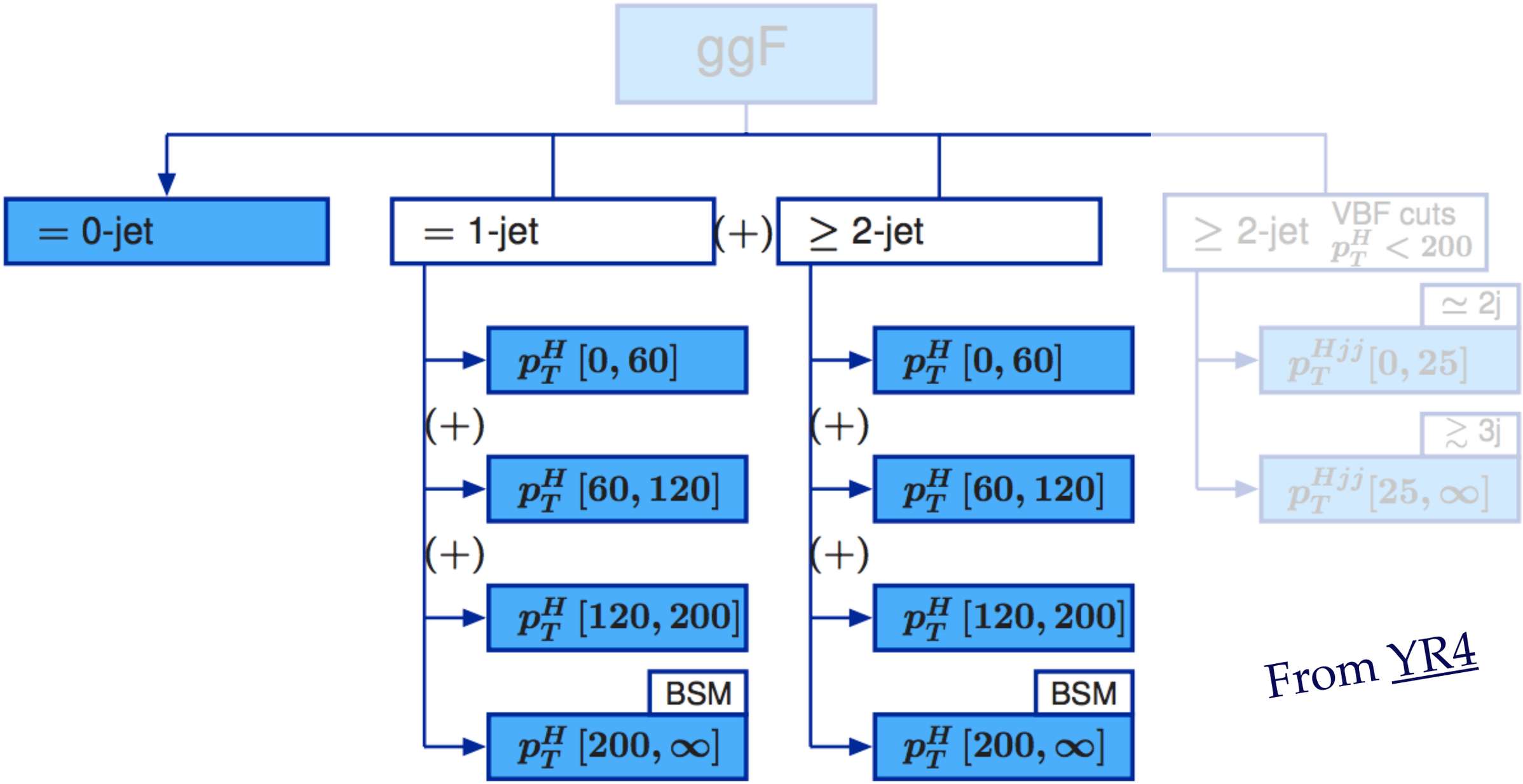
STXS stage 1 - ggH

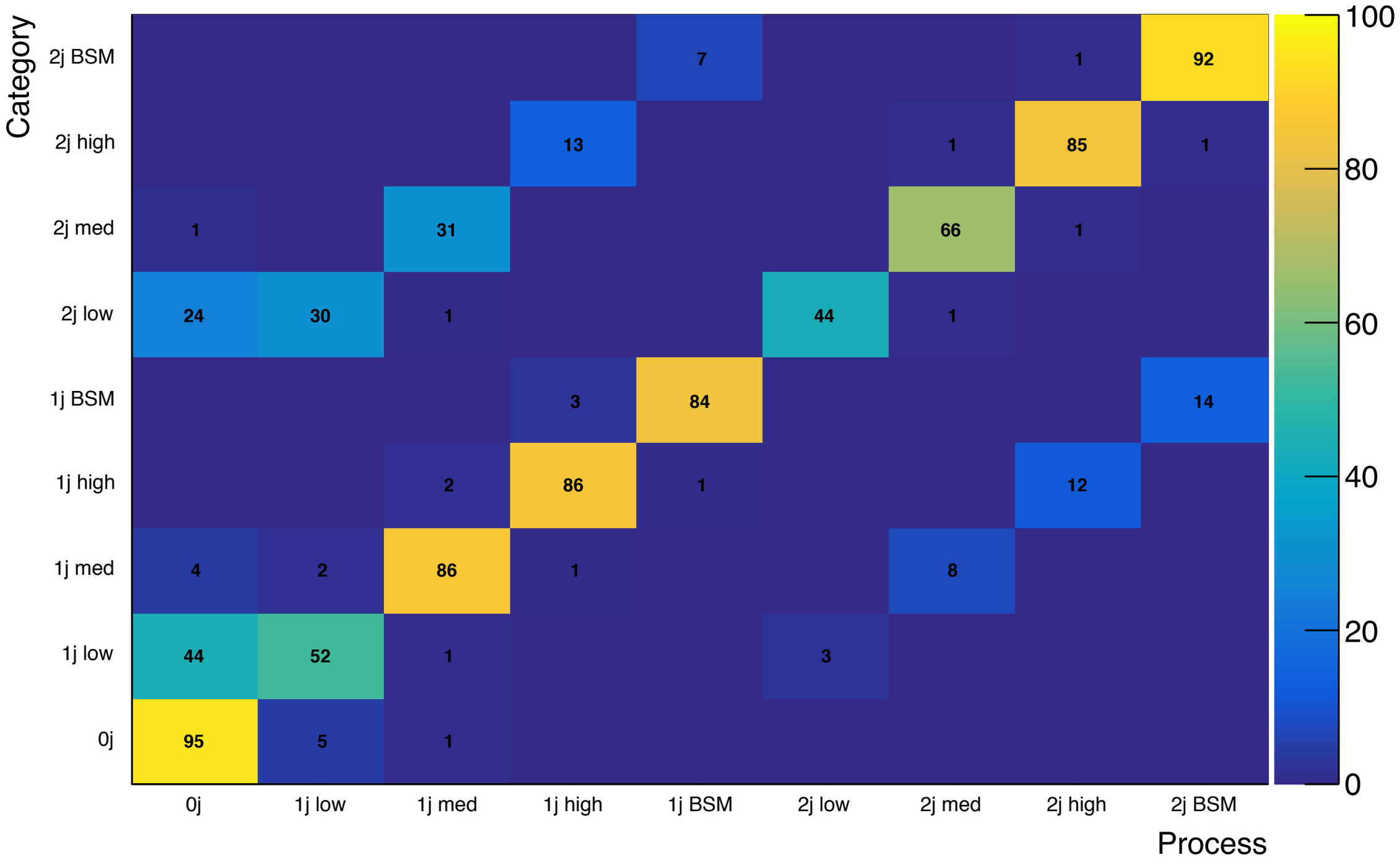


From YR4

- p_T and nJet bins, isolating BSM effects and separating VBF phase space
- Focus on this phase space for illustration

STXS stage 1

Purity matrix



Summary

- Higgs physics has now pivoted from discovery to precision measurements
- Run 2 well under way: with just the 2016 dataset, CMS has surpassed the precision of the full Run 1 combined Higgs measurements
- The Higgs continues to stubbornly behave as SM-like as possible
  - but if there are deviations, we will find them
- Moving forward, measure Stage 1 processes in the STXS framework

BACKUP

CMS detector

CMS DETECTOR

Total weight	: 14,000 tonnes
Overall diameter	: 15.0 m
Overall length	: 28.7 m
Magnetic field	: 3.8 T

STEEL RETURN YOKE
12,500 tonnes

SILICON TRACKERS
Pixel (100x150 μm) ~16m² ~66M channels
Microstrips (80x180 μm) ~200m² ~9.6M channels

SUPERCONDUCTING SOLENOID
Niobium titanium coil carrying ~18,000A

MUON CHAMBERS
Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
Endcaps: 468 Cathode Strip, 432 Resistive Plate Chambers

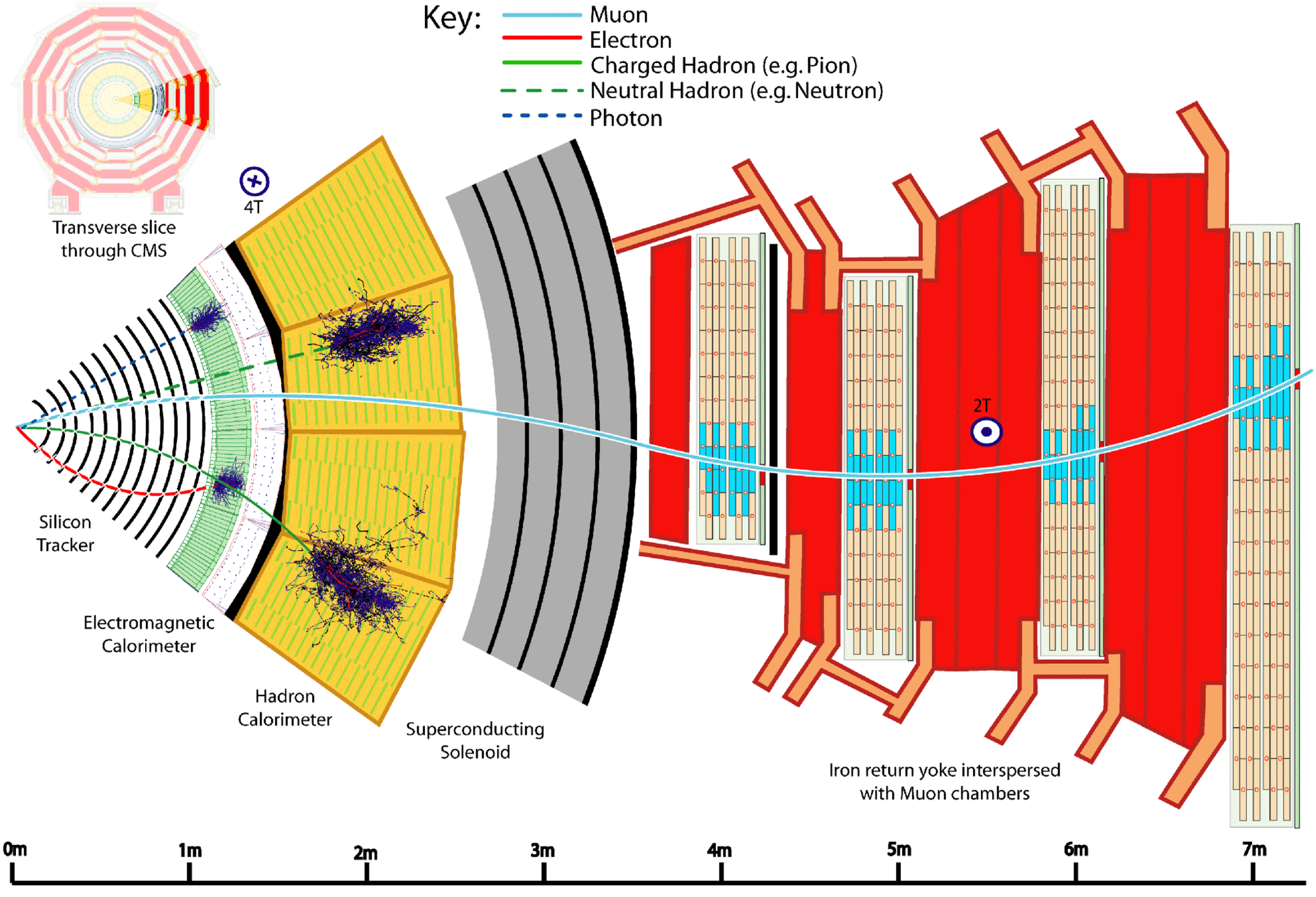
PRESHOWER
Silicon strips ~16m² ~137,000 channels

FORWARD CALORIMETER
Steel + Quartz fibres ~2,000 Channels

CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
~76,000 scintillating $PbWO_4$ crystals

HADRON CALORIMETER (HCAL)
Brass + Plastic scintillator ~7,000 channels

CMS detector



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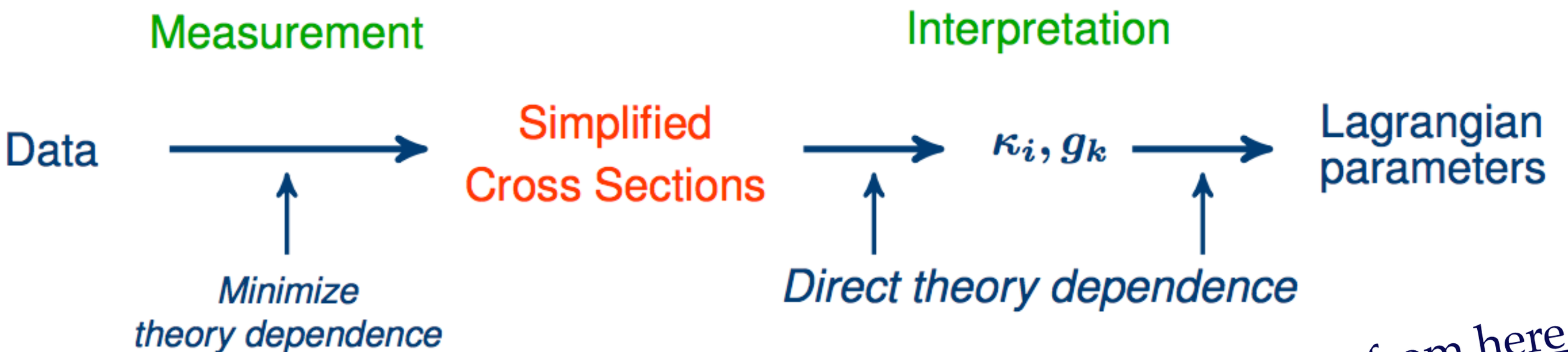
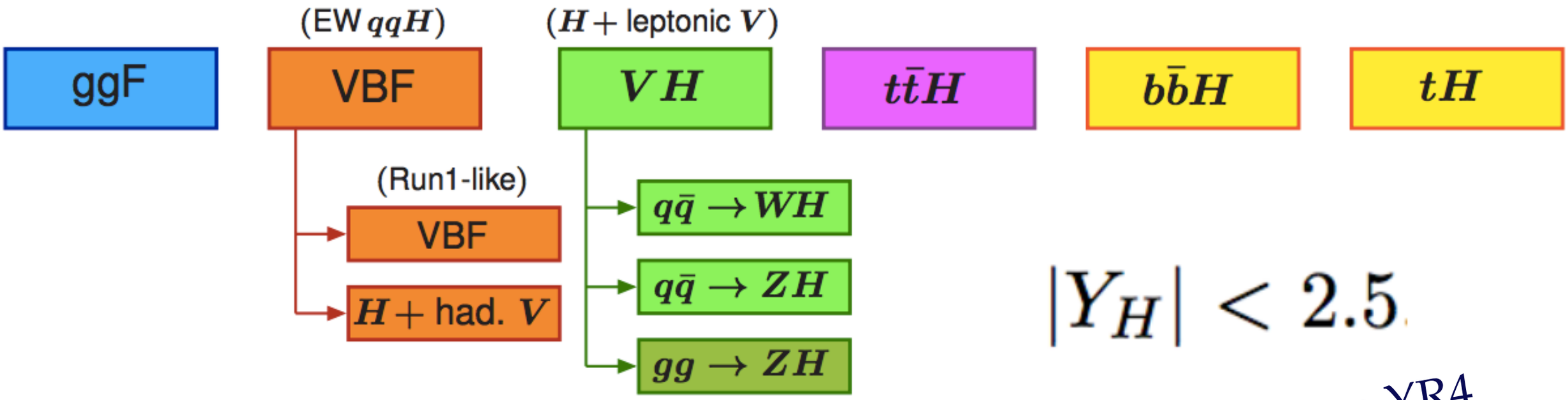


Diagram from here

What do we measure?



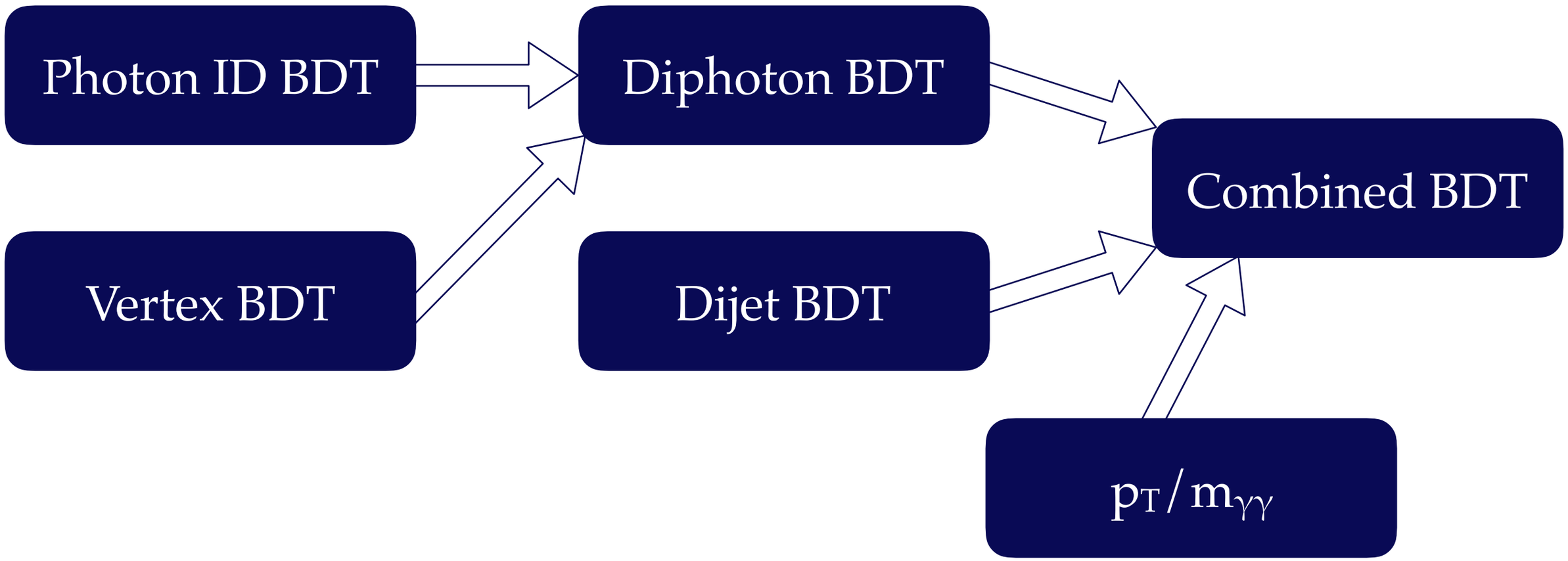
$$|Y_H| < 2.5$$

From YR4

- Simplified Template Cross-section (STXS) framework aims to minimise measurements' dependence on theory
- Useful in long-term, especially for re-interpretation

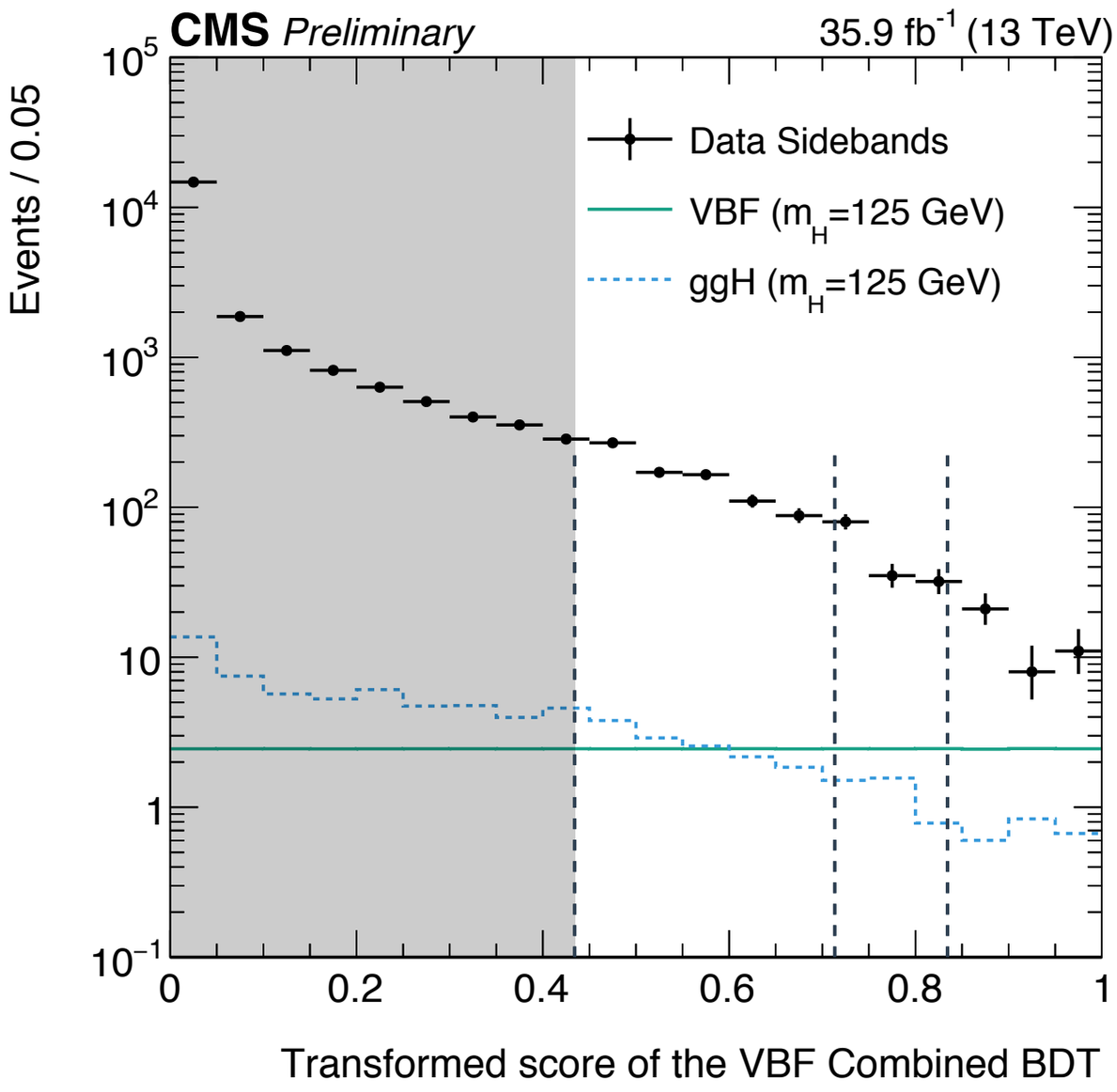
- Stage 0 bins closely mirror Run 1 process definitions
  - theory uncertainties on overall yield factored out of measurement
  - CMS results generally include these for the 2016 results

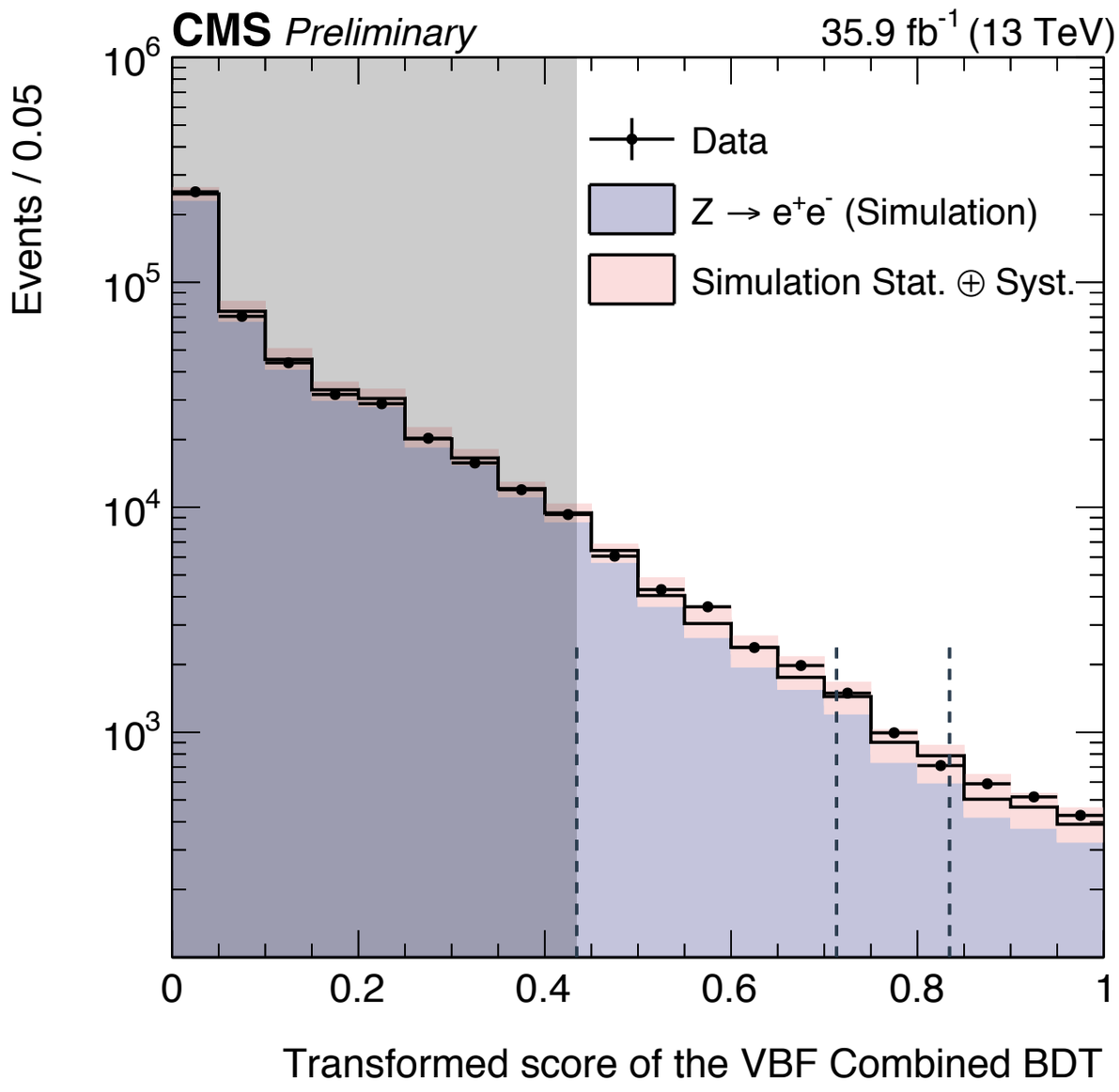
$H \rightarrow \gamma\gamma$: VBF tags



- Diphoton and dijet BDT combined to classify VBF events
- Inputs to dijet BDT include jet p_T and $\Delta\eta$, m_{jj}, additional angular variables ($\Delta\phi_{jj,\gamma\gamma}$, $\Delta\phi jj$, min ΔR(jet,photon), and centrality)
- VBF preselection: jet $p_T > 40$ (30) GeV, $m_{jj} > 250$ GeV

$H \rightarrow \gamma\gamma$: VBF tags





- VBF tags defined using two-step BDT process, where the dijet BDT is combined with the diphoton BDT - cut on resulting distribution
- Validation using both $m_{\gamma\gamma}$ sidebands and $Z \rightarrow ee$ events with dijets

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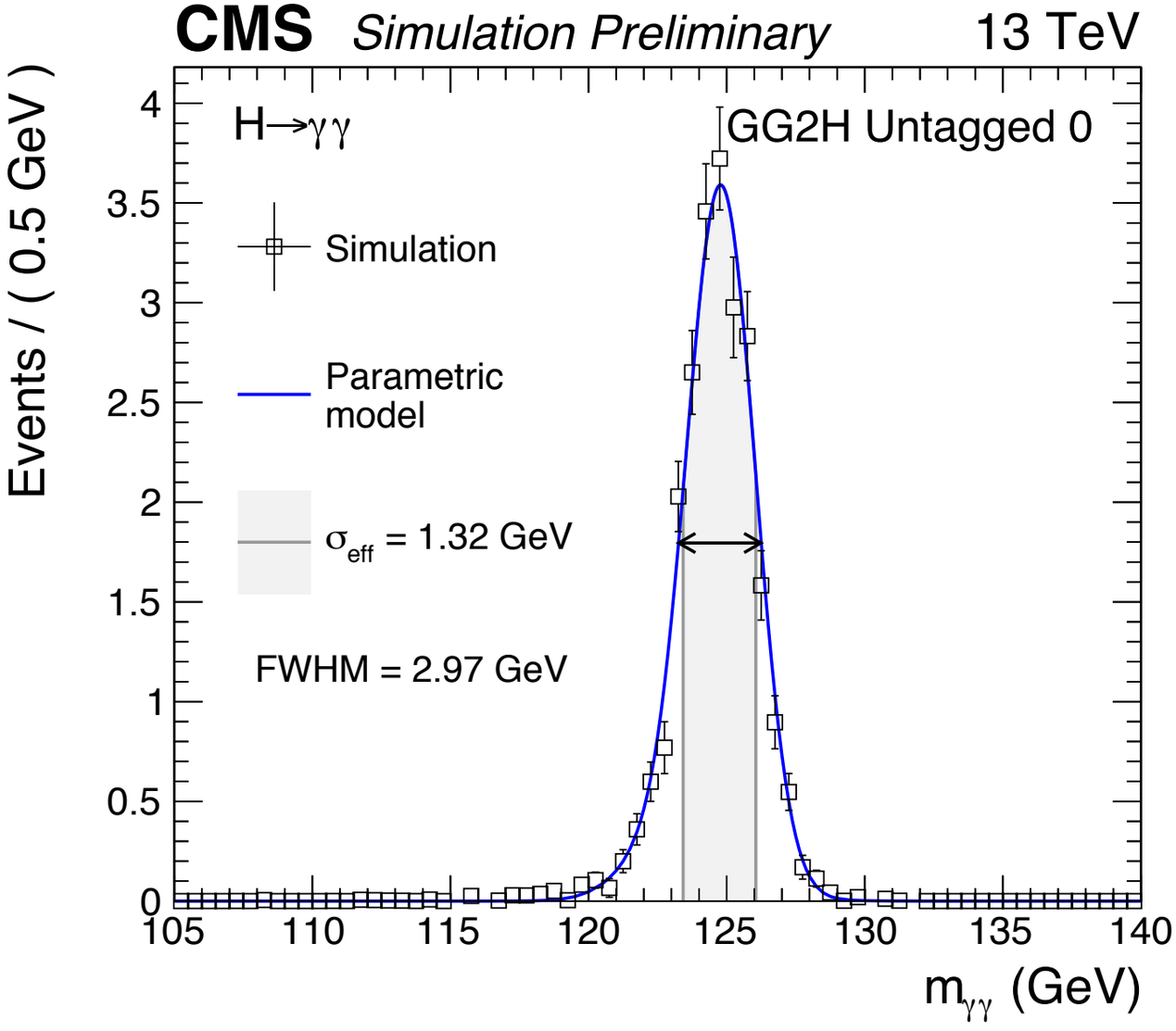
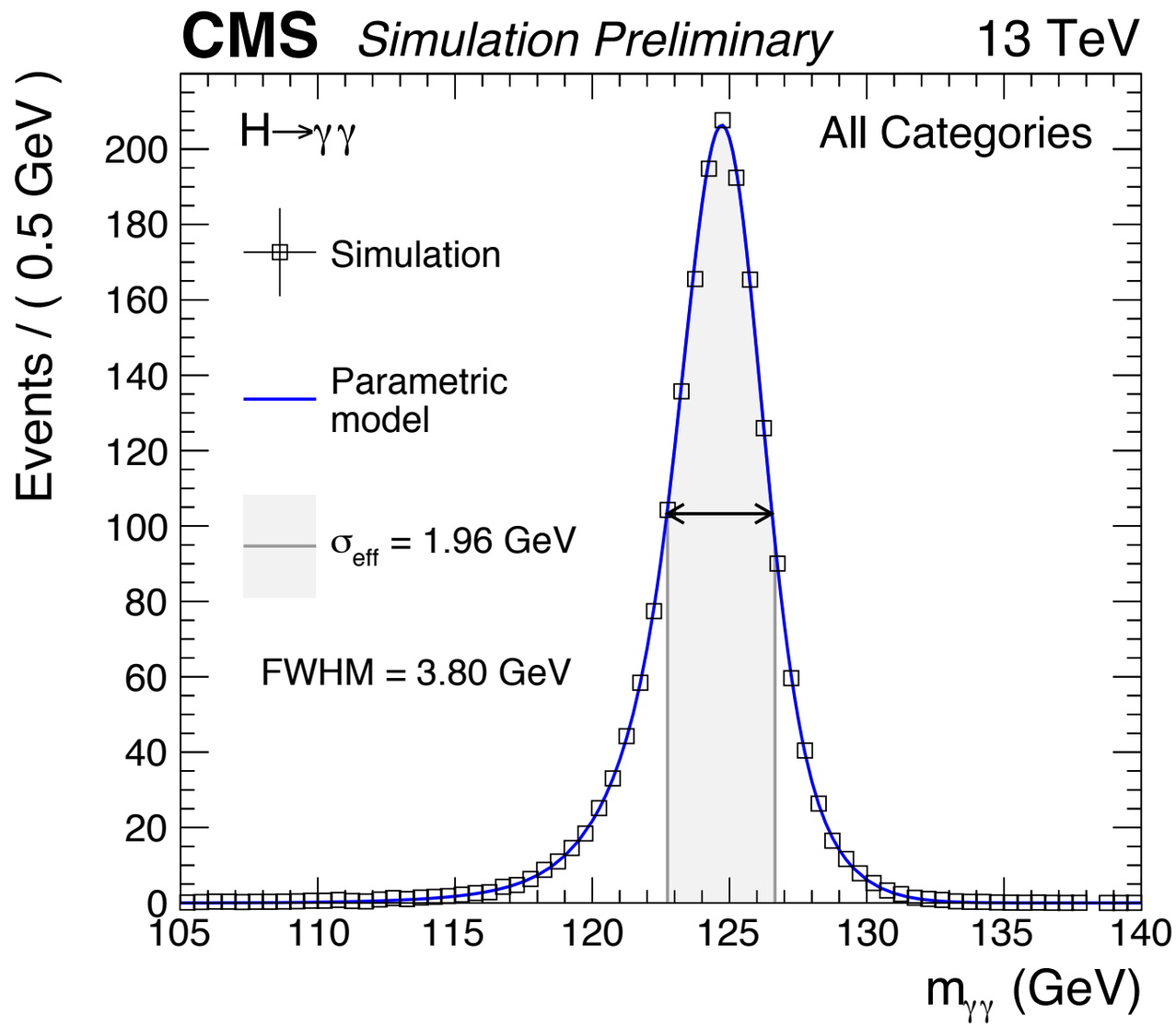
H→γγ: Signal Model

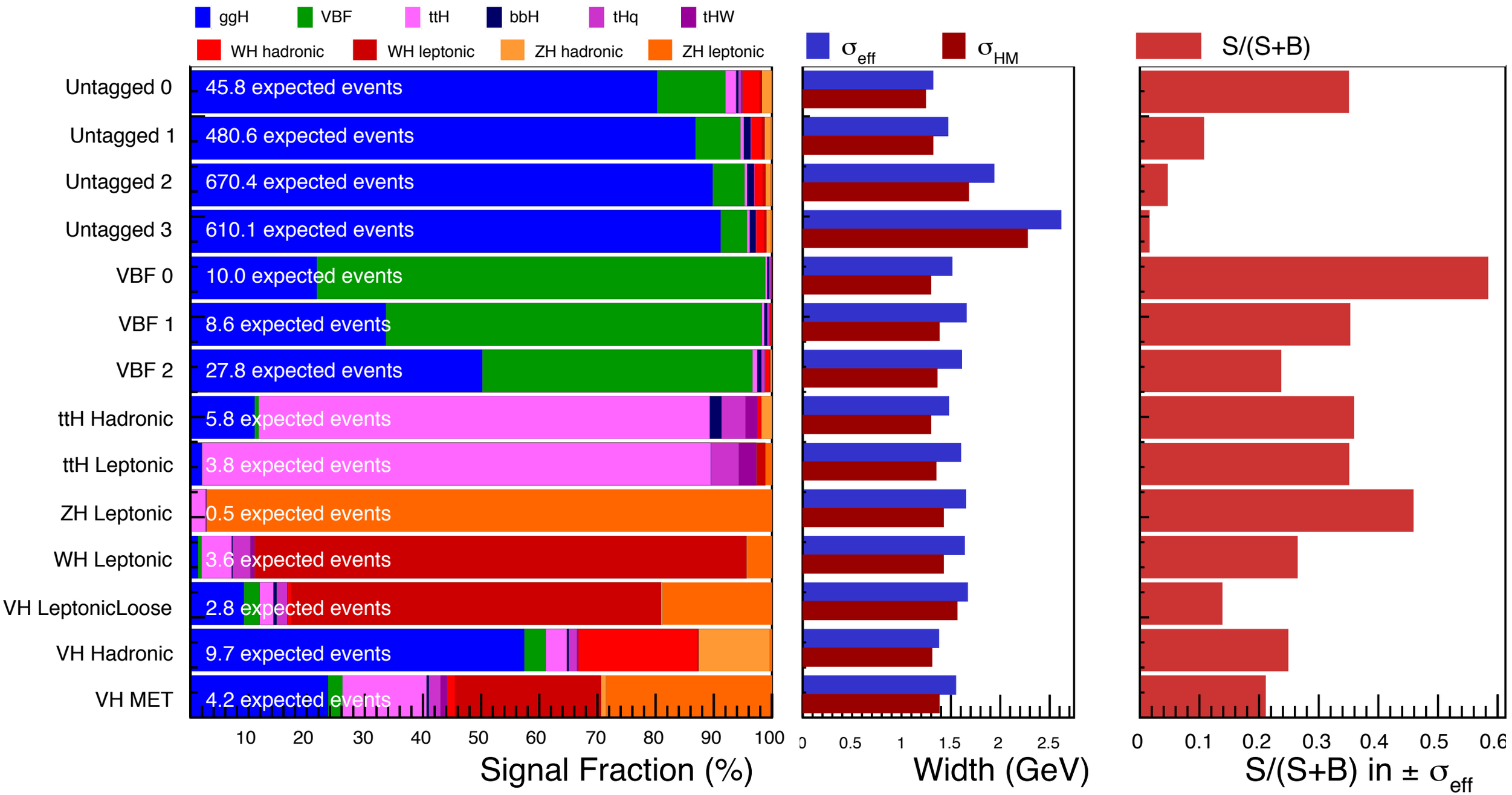




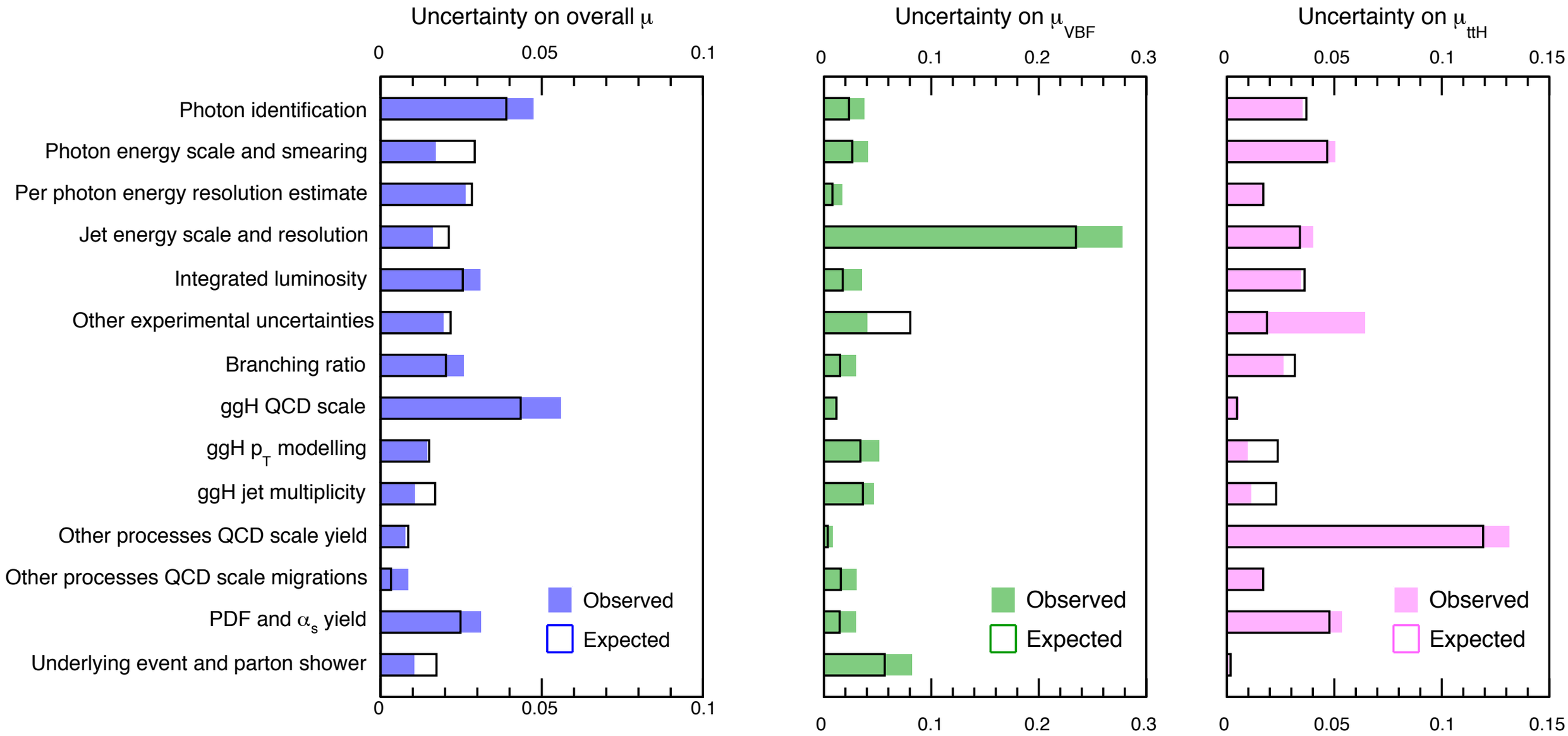
- Signal parametric in m_H
- Built individually for each process and tag

H→γγ: Signal Model

CMS *Preliminary* H→γγ 35.9 fb^{-1} (13 TeV)



H→γγ: Uncertainties



- Systematic uncertainties almost equal to statistical with 2016 dataset, for the overall and ggH signal strengths

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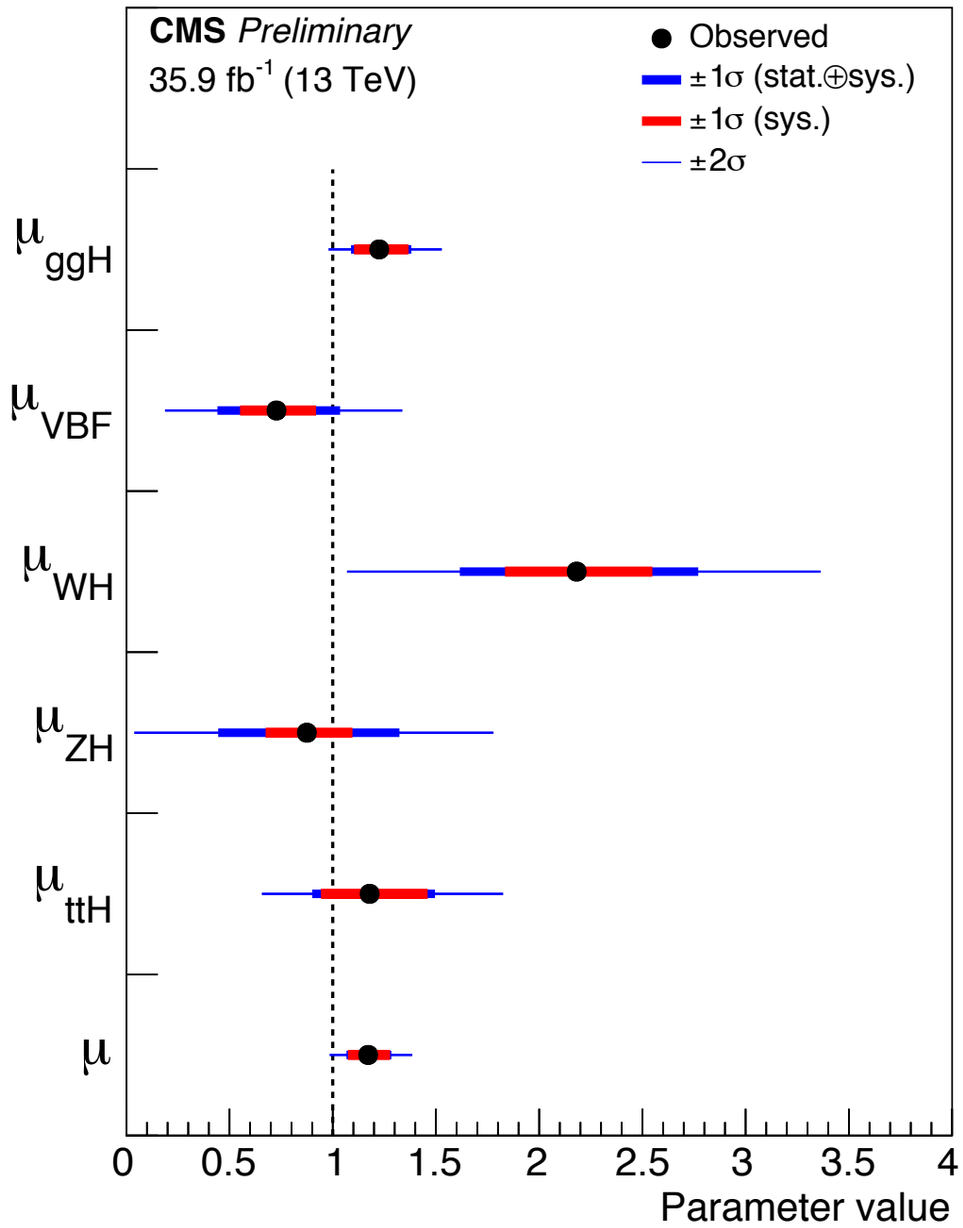
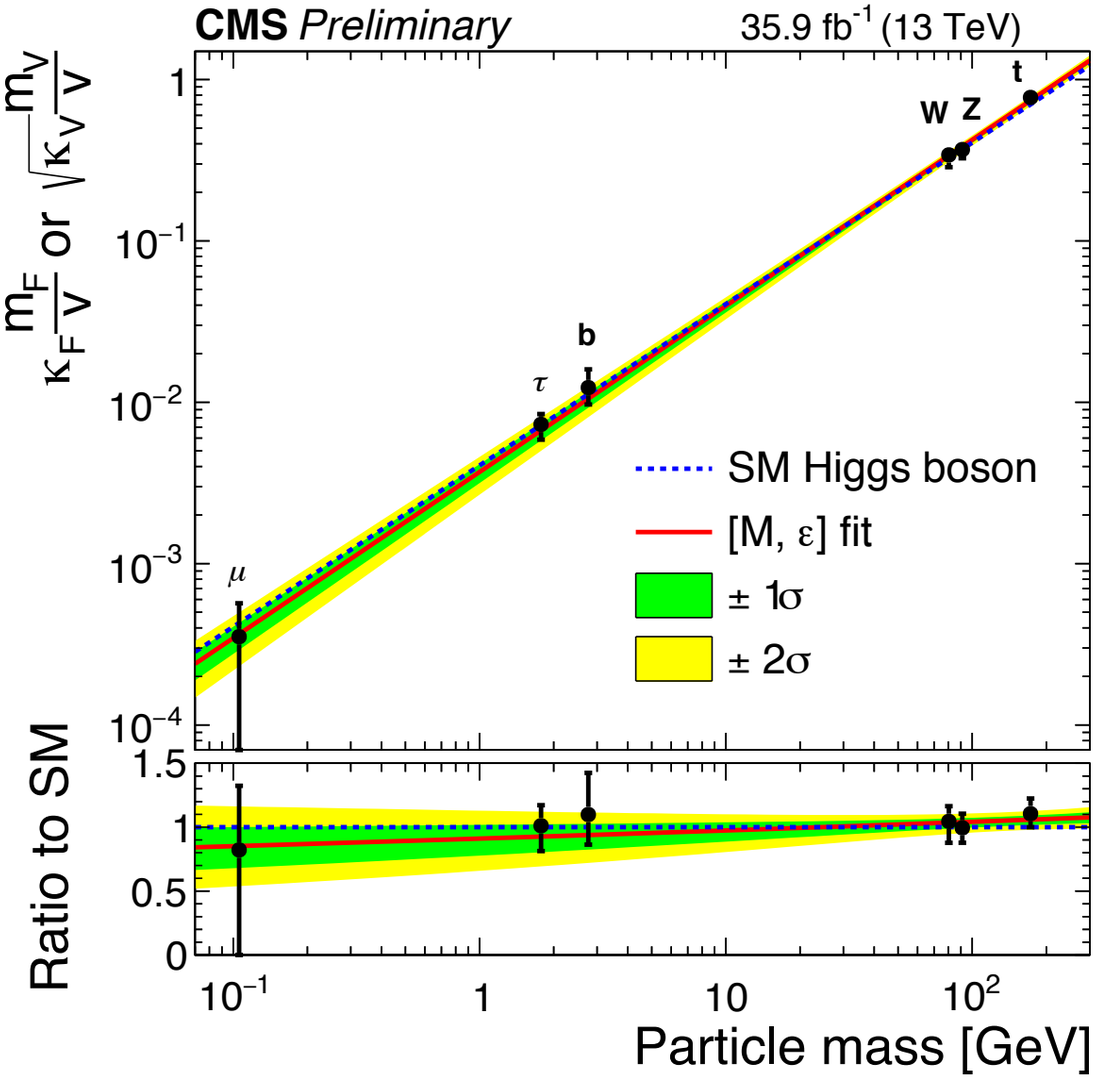
Higgs combination





- Combination of 2016 results to produce world-best coupling measurements
- Channels included are: γγ, ZZ, WW, ττ, bb, μμ (and invisible, sometimes)

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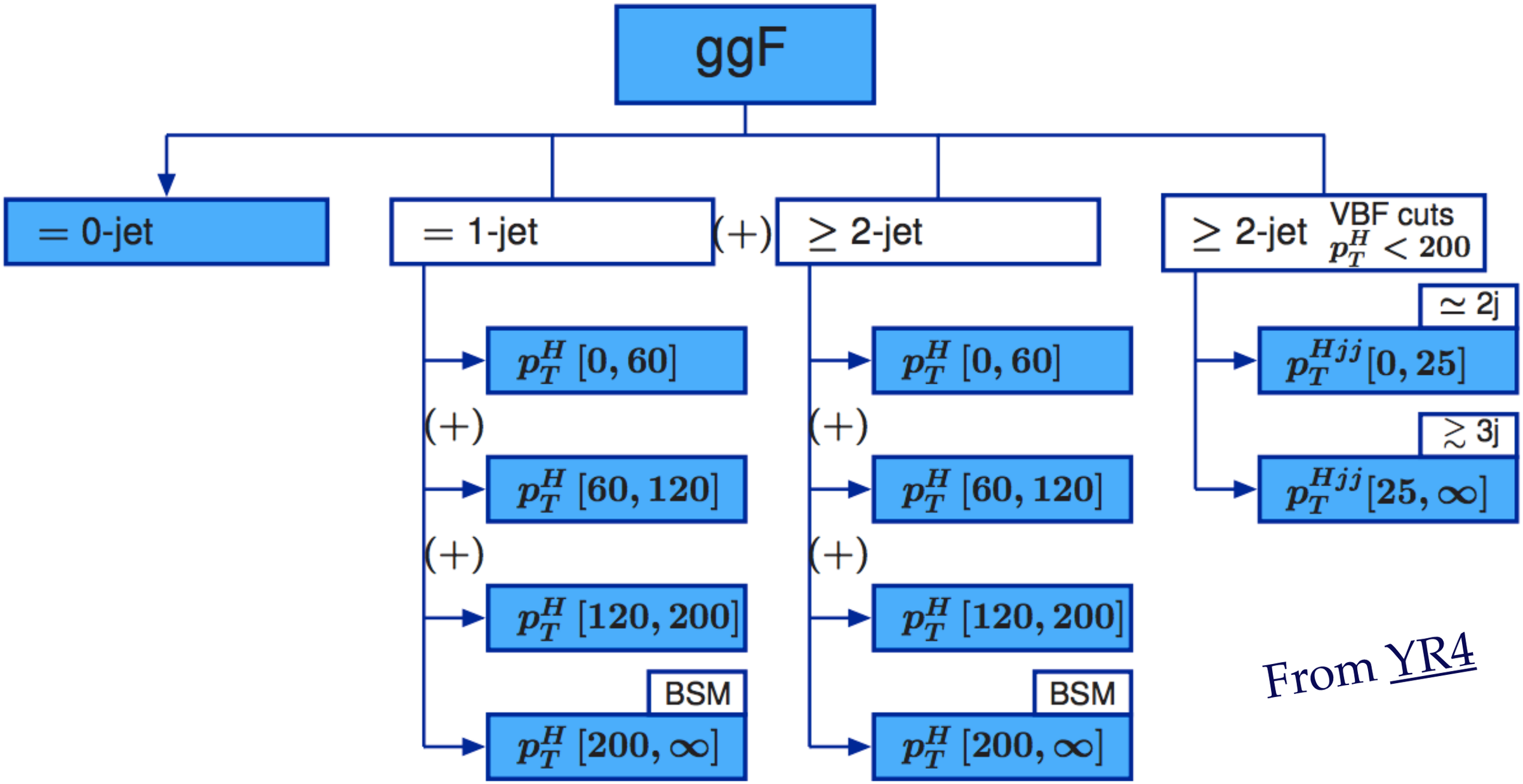
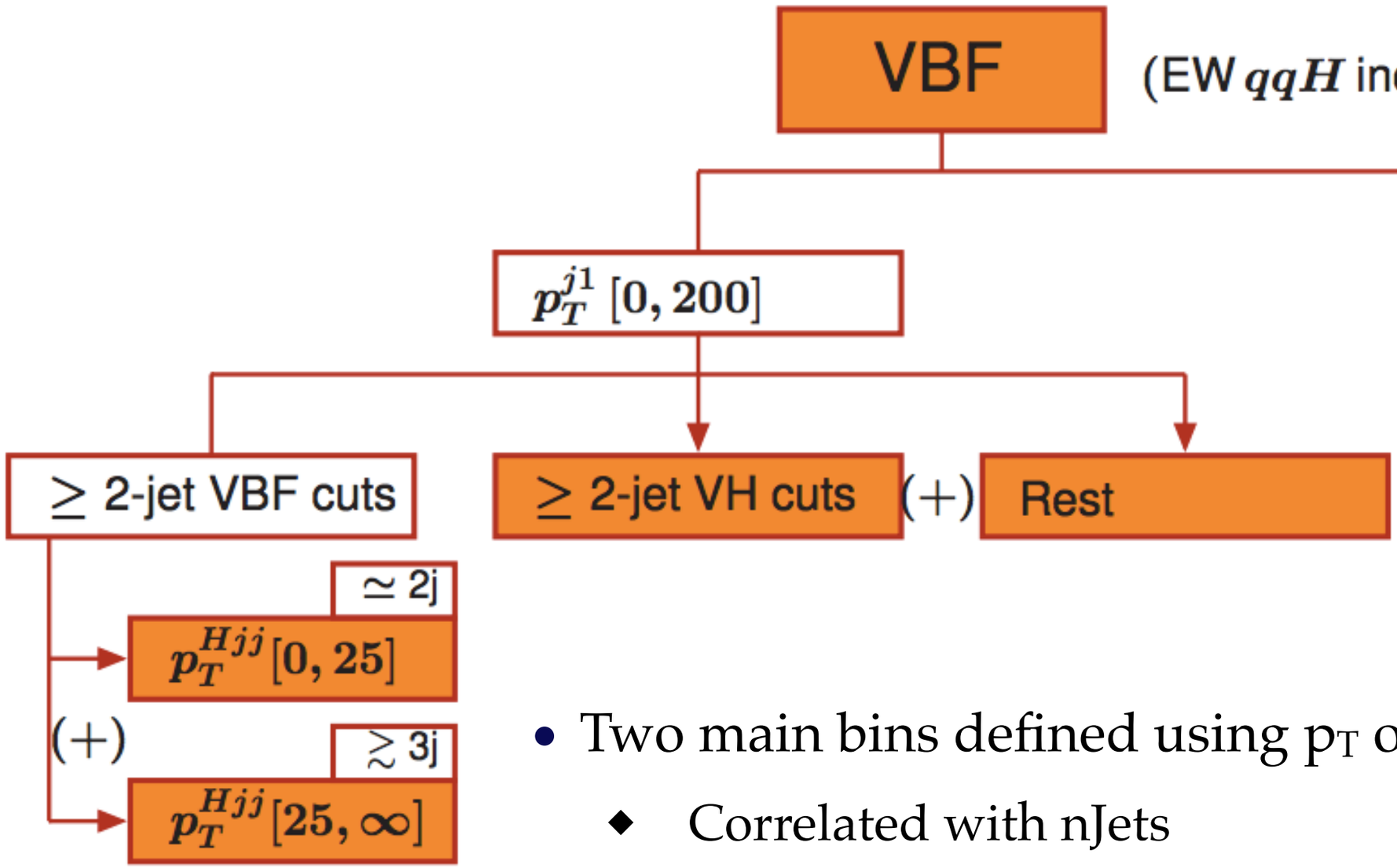
STXS stage 1 - ggH



- p_T and nJet bins, isolating BSM effects and separating VBF phase space

STXS stage 1 - VBF

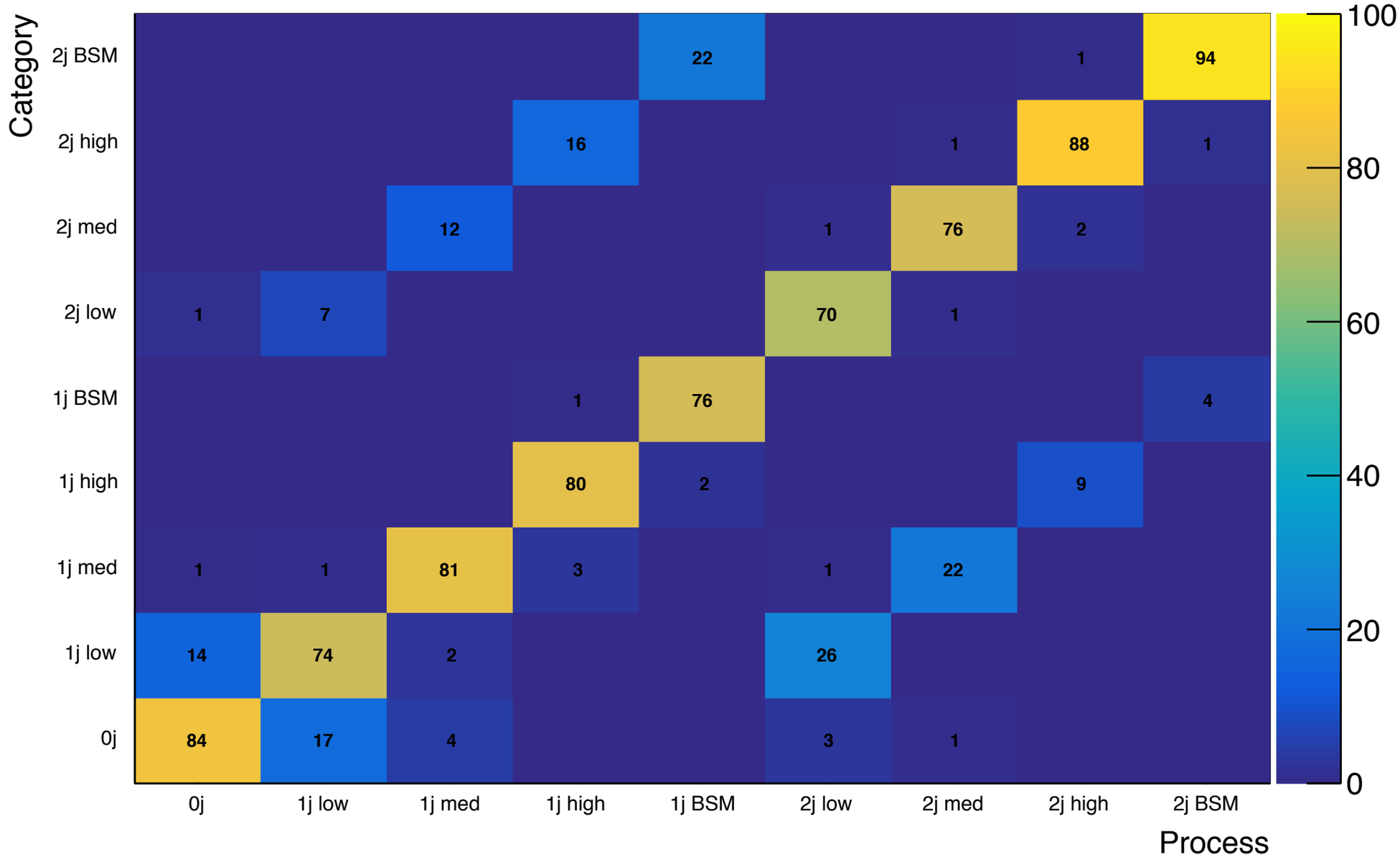


From YR4

- Two main bins defined using p_T of H+dijet system
  - Correlated with nJets
- Interesting for future analyses: discrimination between VBF and ggH+2-jets

STXS stage 1

Migration matrix



- This slide: "Migration" matrix, normalised by processes/columns