Measurements of Higgs cross sections and differential distributions in the H→ττ final state from CMS
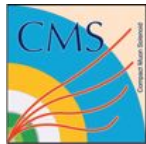
Oct 21st 2021

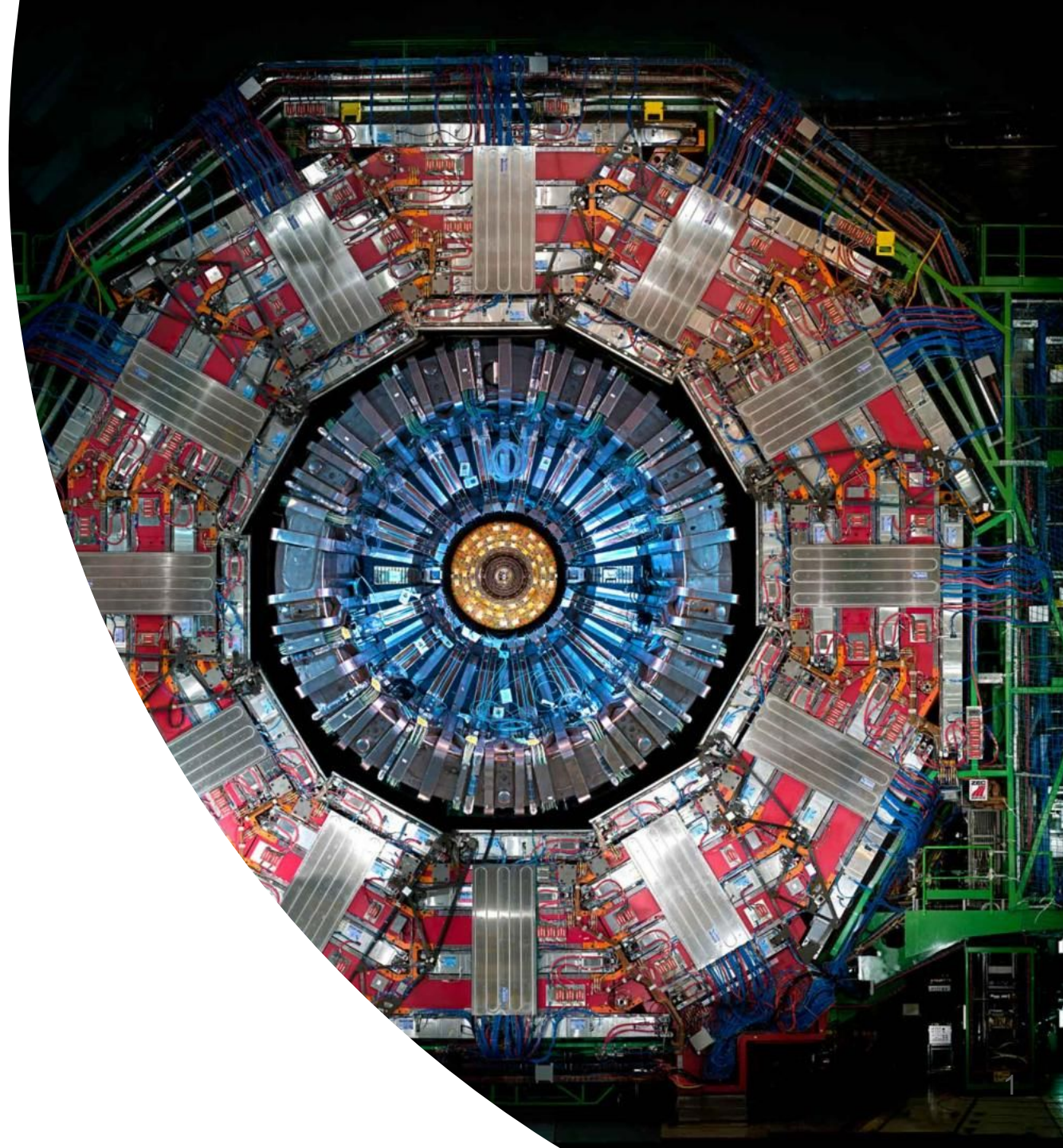**HIGGS 2021, Stony Brook, NY**
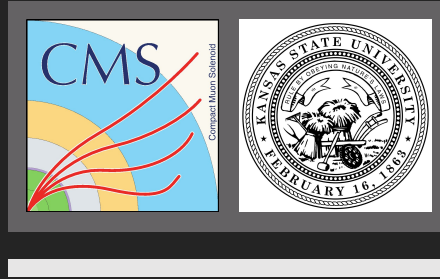https://indico.cern.ch/event/1030068/contributions/4513180/

Doyeong Kim 김 도 영
Kansas State University

Introduction to SM H→ττ Analyses

Introduction

H→ττ Overview

- The properties of the Yukawa coupling to tau leptons can be directly probed using H→ττ

- **Pros:**
  - ○ H→ττ has relatively high BR and is quite clear that is beneficial to probe regions of phase space with small cross sections e.g VBF-like phase space, boosted Higgs

- **Challenges:**
  - ○ Taus are unstable and decay to leptons or hadrons plus neutrinos
  - ○ Reconstruction of exact Higgs system is challenging due to neutrinos
  - ○ Analyses presented today use 4 most sensitive final states (out of 6): $\tau_h\tau_h$, $\mu\tau_h$, $e\tau_h$, and $e\mu$
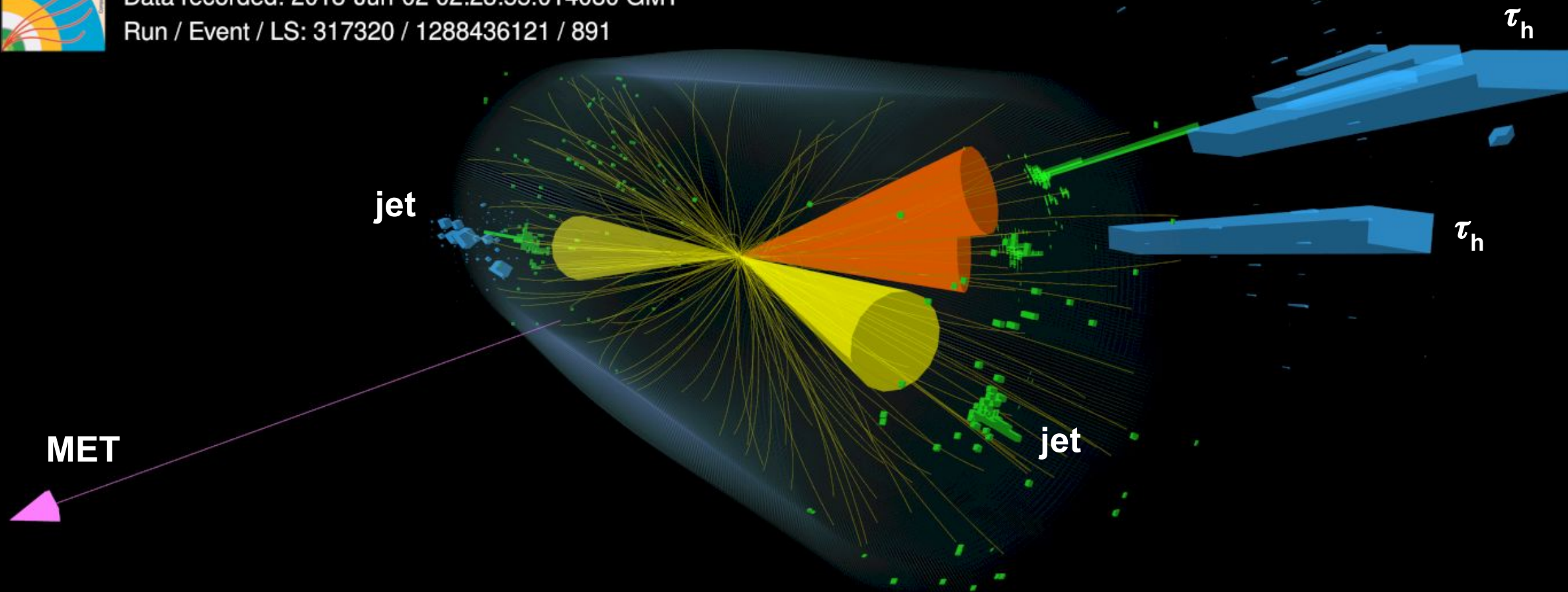
CERN Yellow Report 4

→ Make tau analyses harder
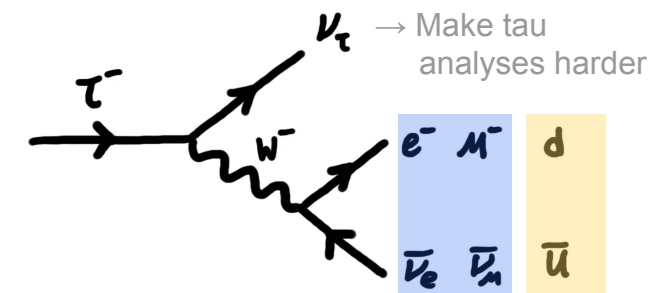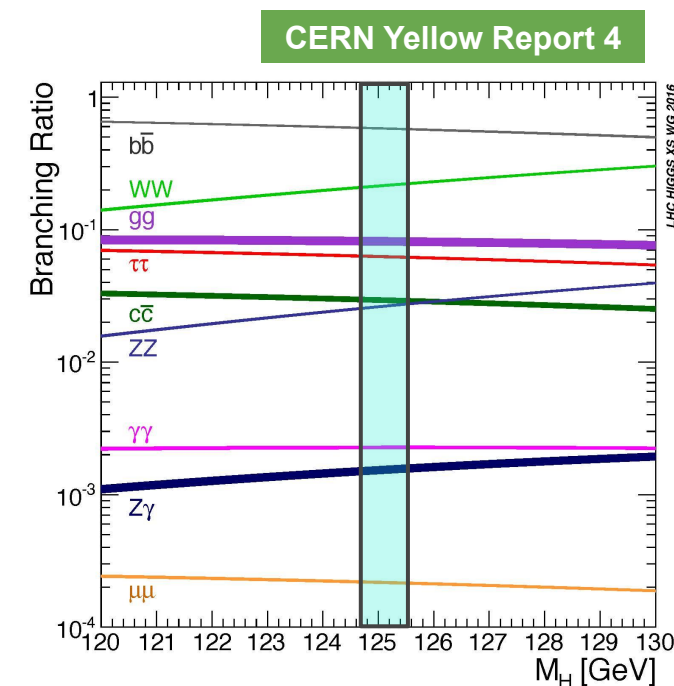
Introduction   **VBF-like Event in H→ττ Hadronic Deday Channel**

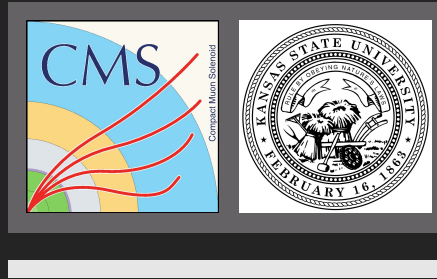**Introduction** | **Tau Identification & Backgrounds Modelling**

Tau Identification in CMS

- Leptonic decay taus: reconstructed with standard CMS e/μ identification

- Hadronic decay taus:

  - HPS(hadron plus strips algorithm) identifies charged hadrons and clusters together e/γ from π^0 decays into "strips"

  - Reject fake taus from jets, e and μ using multiclass DNN based algorithm

Backgrounds Modelling

- Events with 2 real taus: largest irreducible bkg. mainly from Z→ττ ▮

  - Estimated using hybrid-data-driven method: μ→τ embedding method

- Events with jet misidentified as τ$_h$: second largest irreducible bkg. ▮

  - Estimated using data driven method: fake rate method

- All the rest of bkg. estimated from MC ▮

- ~90% of bkg. estimated from data-driven methods

 - reduce systematic and statistics uncertainties, have better description of jets

Bkg. Composition & Estimation Methods

MC (2%)
Fake factor (36%)
Embedding (62%)
τ$_h$τ$_h$
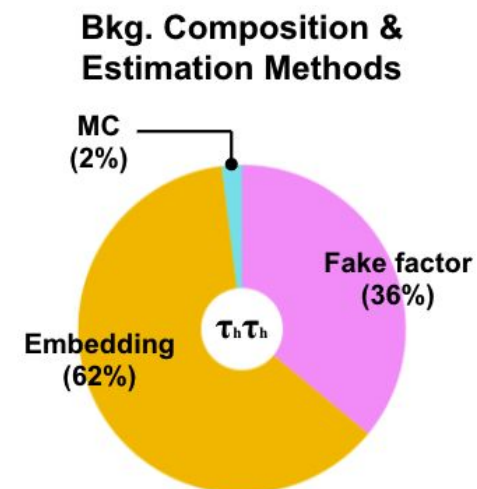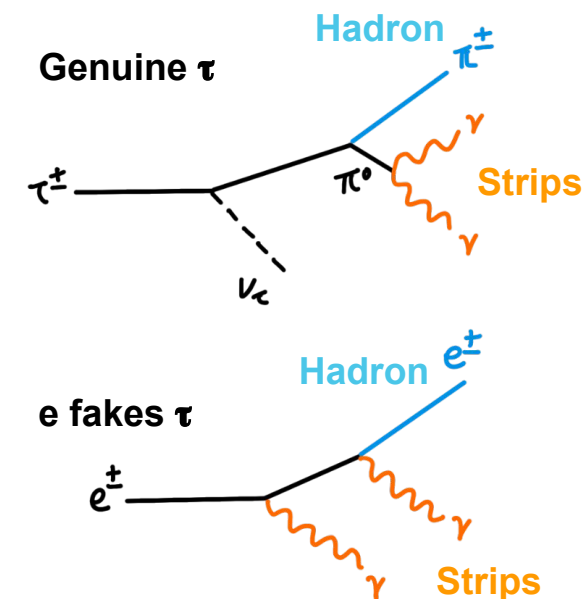
Measurement of Higgs Cross Section In the H→ττ Final State

Doyeong Kim, Kansas State University

Higgs STXS in H→ττ

Higgs Cross Section Measurement

- Cross section of different production modes was measured with good precision using full Run2 data
- **Simplified Template Cross Section (STXS) framework**

  STXS ggH/VBF framework with merging of gen-level bins measured using 137/fb of 13 TeV data
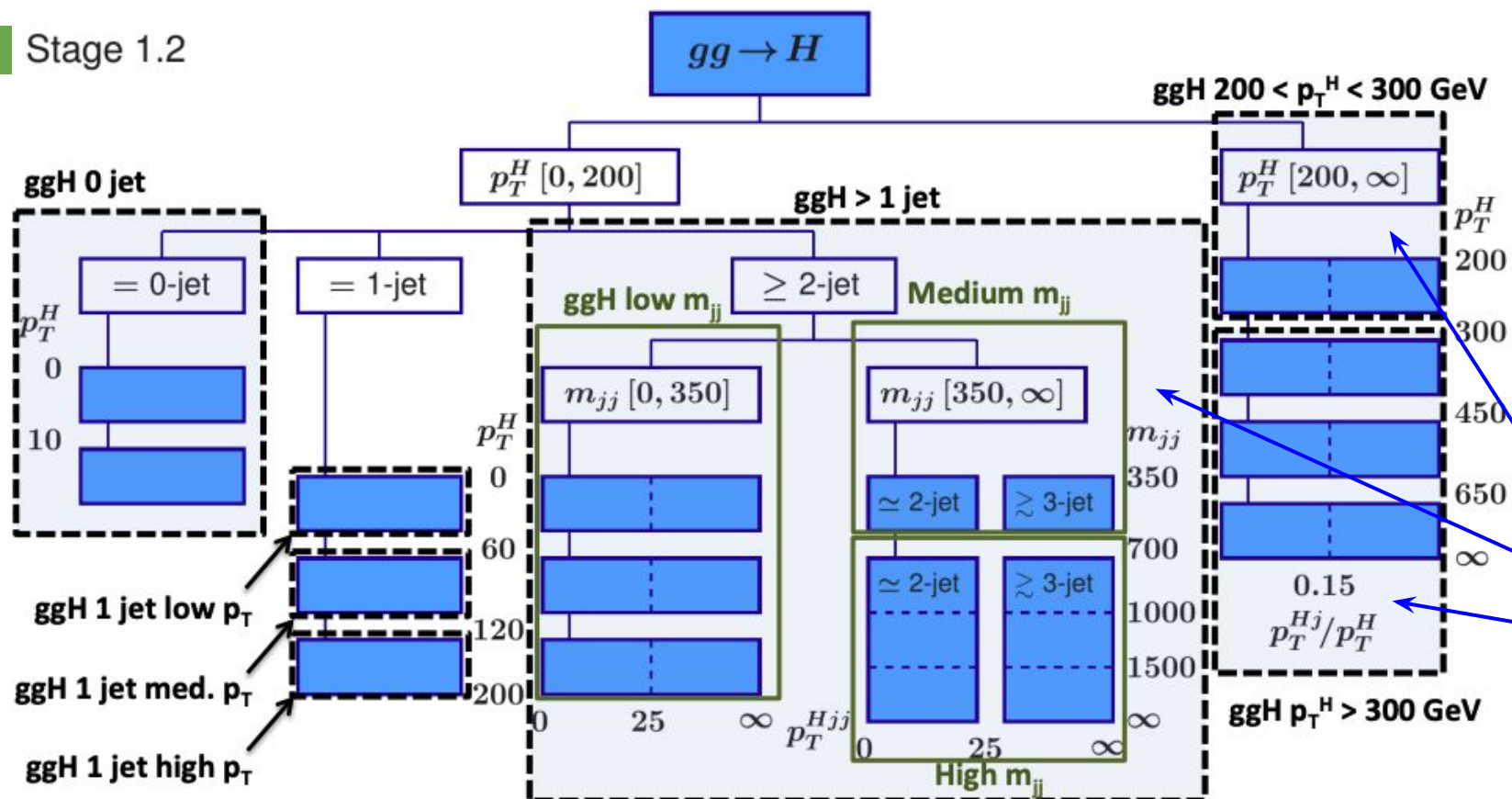

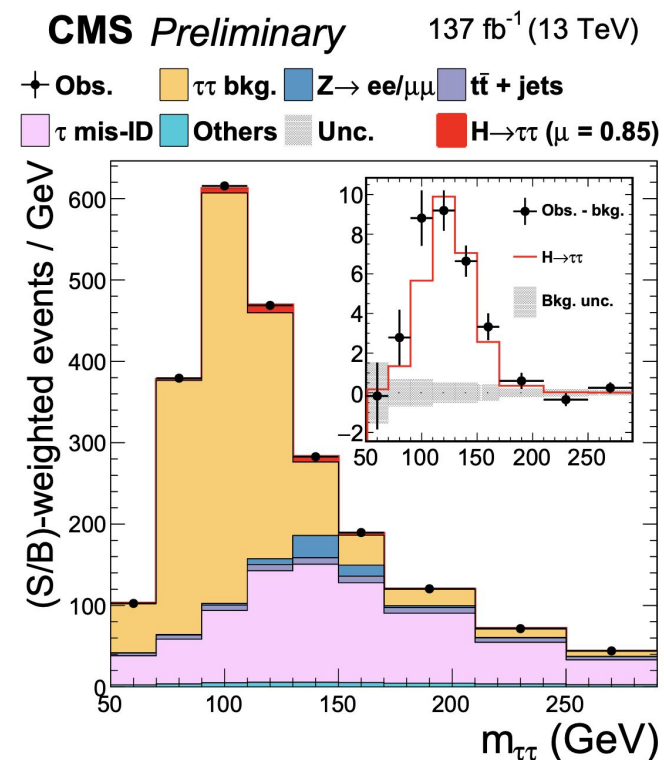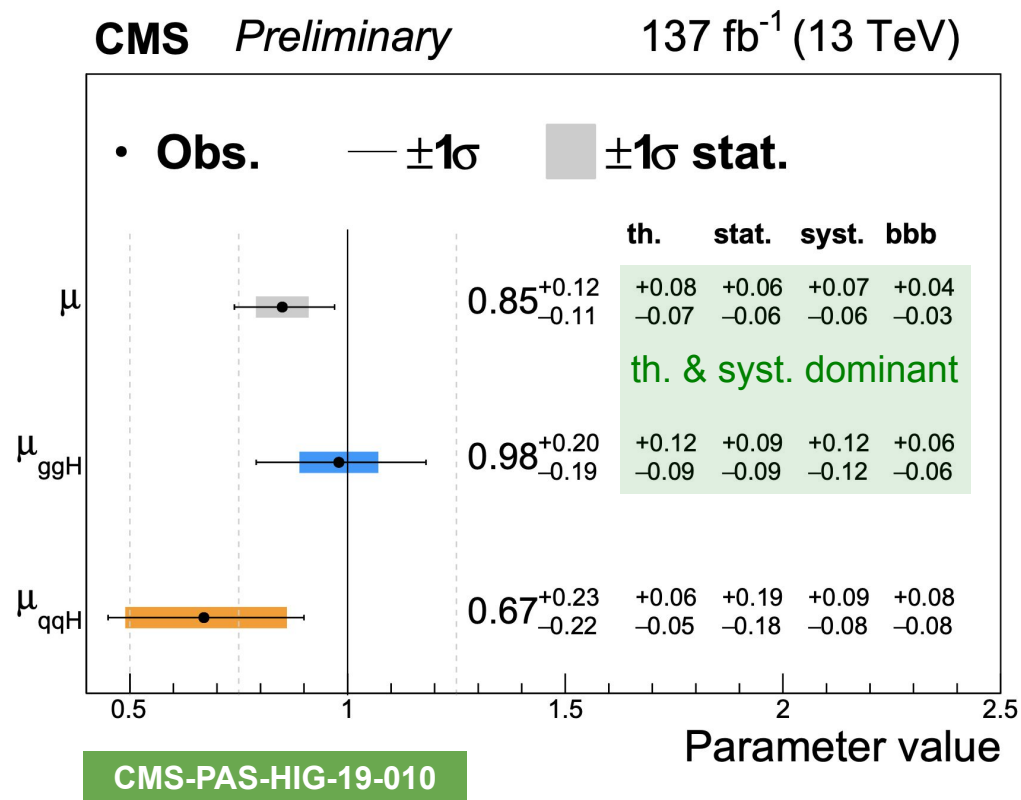H→ττ are competitive high Higgs pT bins or events with jets

Higgs STXS in H→ττ

Analysis Strategy

- Events are categorized into 3 categories to target the different production modes: **1) 0-jet, 2) VBF, 3) Boosted**

- Categories are further split into sub-categories to target specific STXS bins (N_{jets}, Higgs p_T, etc.)

- Perform maximum likelihood fits of 2D discriminants to enhance sensitivity

  - Di-tau mass($m_{\tau\tau}$) vs either m_{jj}, p_T^H, p_T^τ * where $m_{\tau\tau}$ is computed using FastMTT algorithm
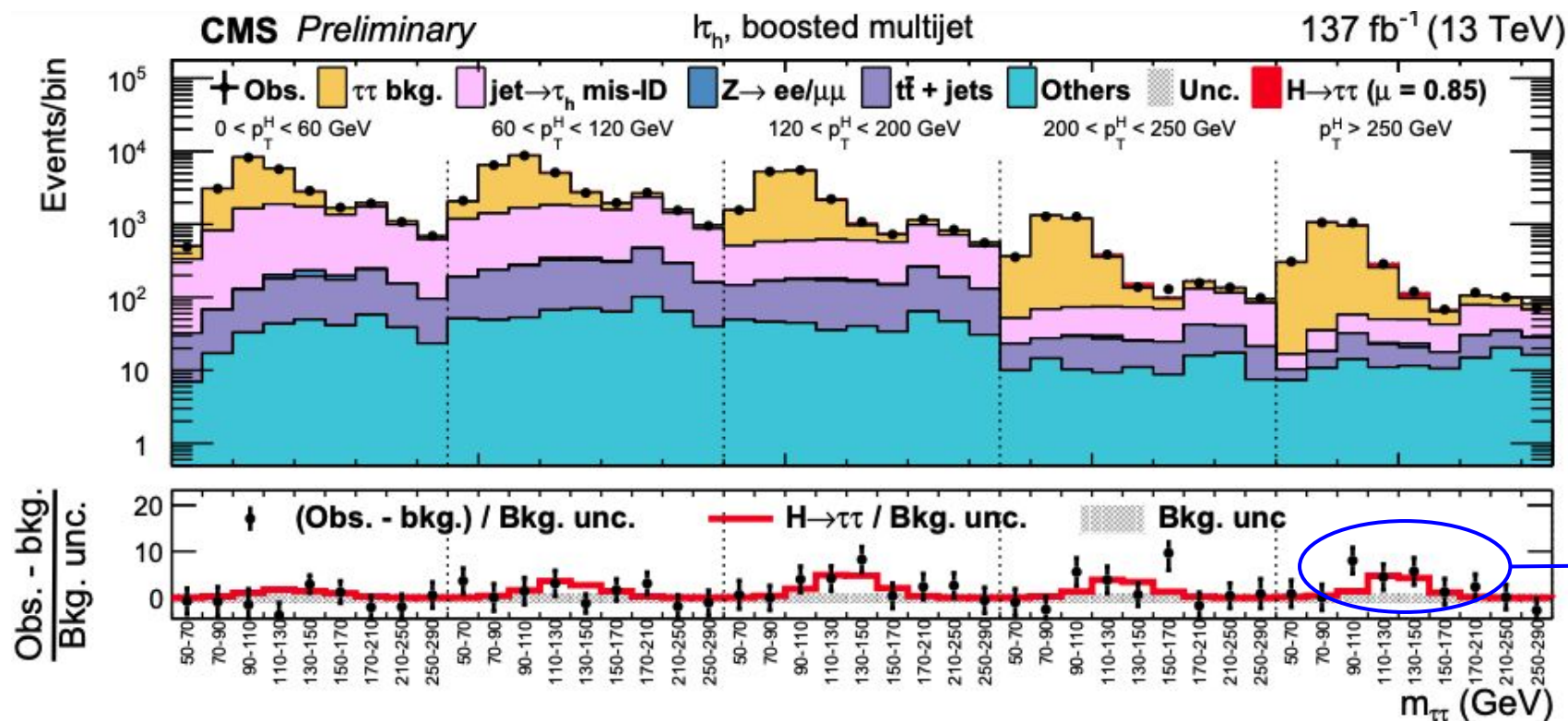
CMS-PAS-HIG-19-010

Significant excess around Higgs mass

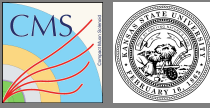Doyeong Kim, Kansas State University

Higgs STXS in H→ττ

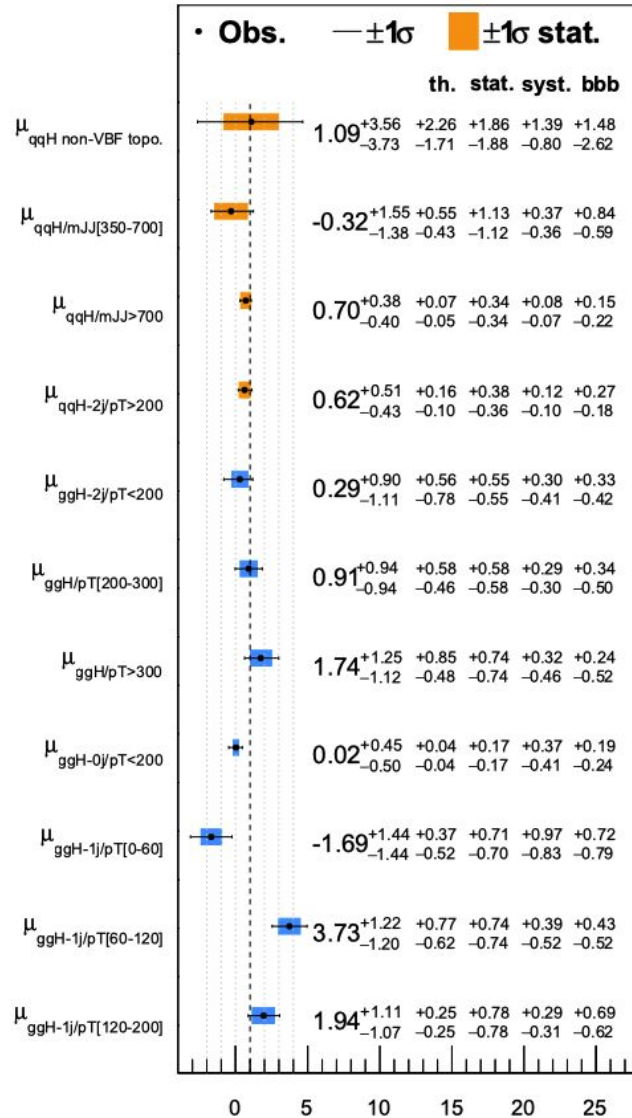# Inclusive Cross Section Results

- The measured signal strengths for the inclusive Higgs, ggH, and qqH relative to SM (left)

- All categories are combined and weighted by S/B (right)

Higgs STXS in H→ττ

STXS Stage1 Cross Section Results

CMS *Preliminary*   Process-based   137 fb⁻¹ (13 TeV)

- The measured value of STXS signal strengths are shown (left)
  - Particularly good sensitivity to high Higgs p_T or VBF-topology

- Scans of the negative log-likelihood (middle, right)
  - The best-fit value observed is ~1σ away from the SM prediction

CMS-PAS-HIG-19-010
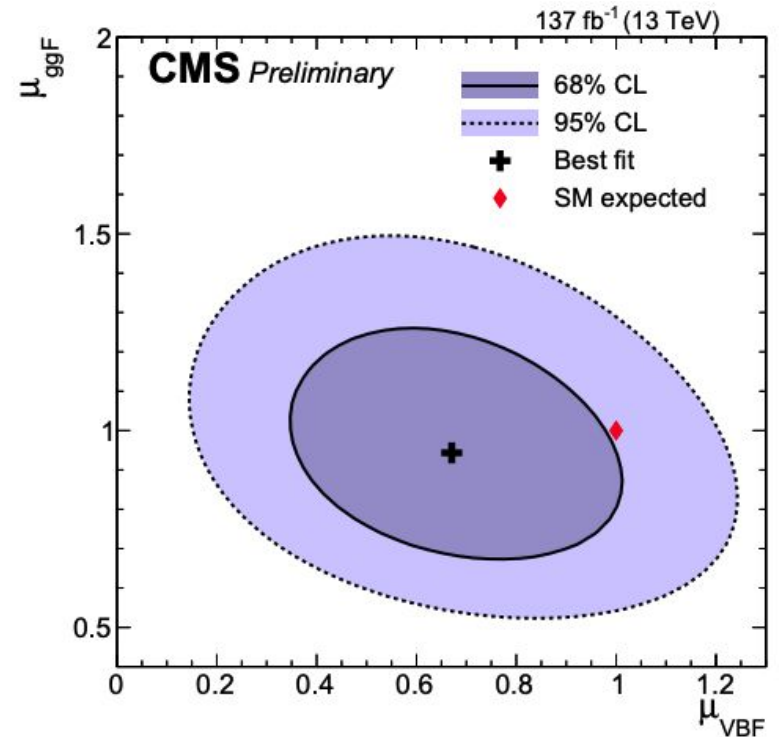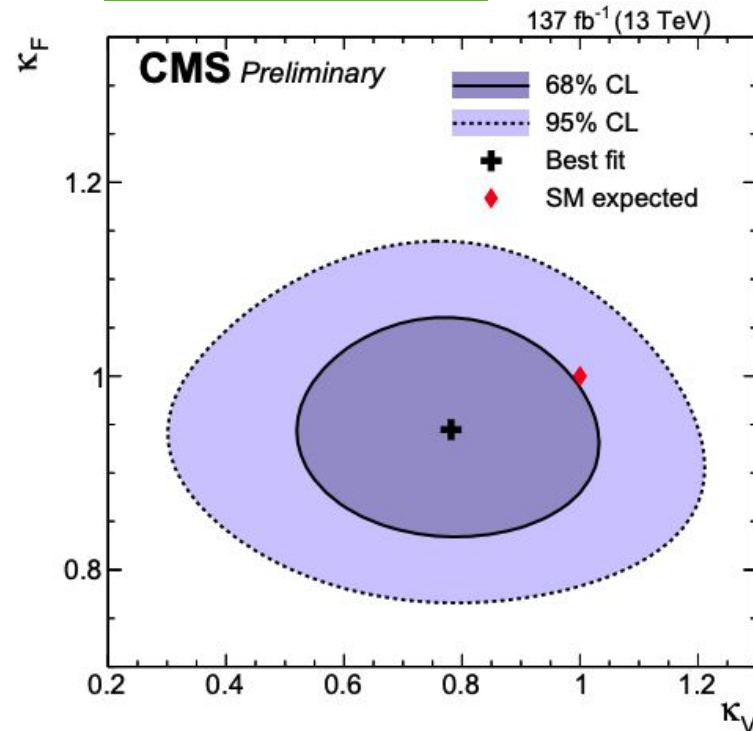
Measurement of
Higgs Differential Distributions
In the H→ττ Final State

Doyeong Kim, Kansas State University

Differential XS in H→ττ   First Measurement of H→ττ Differential Distributions

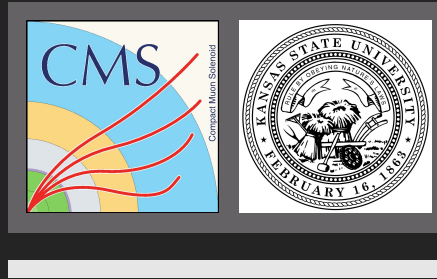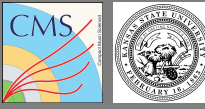- The first-ever inclusive and differential fiducial XS measurement using H→ττ

- The measurements provides a more model independent way to look at Higgs physics in secondary variables than the STXS scheme, but integrates over production modes (ggF, VBF, VH, and ttH productions)

- Higgs differential cross section in

  - **Higgs p_T**
  - **Leading jet p_T** $\rightarrow$ sensitive to the perturbative QCD modelling

  - N_{jets} $\rightarrow$ sensitive to relative contributions of different Higgs boson production mechanisms

- **H→ττ** is particularly sensitive to events with **medium/high Higgs p_T , high N_{jets}, and high jet p_T**

Differential XS in H→ττ

Analysis Strategy

- Fiducial region defined similarly to offline selection for each decay channel

- The analysis is categorized based on p_T^τ (* $e\mu$ left uncategorized)
  - Maintain independence from the 3 different variables
  - S/B increase with tau p_T (suppress jets misidentified to τ_h bkg.)

- Unfolding of measurement is performed together with signal extraction to construct estimator $\boldsymbol{\mu}$

CMS *Preliminary Simulation* 2018 $\mu\tau$

Reco Bins (i) $p_{T;reco}^H$ [GeV]

	[0,45]	[45,80]	[80,120]	[120,200]	[200,350]	[350,450]	[450,∞)
[450,∞)			0.000	0.000	0.000	0.076	0.557
[350,450]	0.000	0.000	0.000	0.000	0.042	0.701	0.436
[200,350]	0.000	0.000	0.037	0.102	0.776	0.222	0.007
[120,200]	0.001	0.017	0.322	0.670	0.176	0.001	-0.000
[80,120]	0.014	0.142	0.362	0.194	0.003	0.000	0.000
[45,80]	0.114	0.391	0.228	0.029	0.001	0.000	0.000
[0,45]	0.872	0.450	0.052	0.004	0.001	0.000	

$p_{T;gen}^H$ [GeV]

Gen Bins (j)

$$\mathcal{L} = \prod_i \mathrm{Poisson}\left(n_i; \sum_j \left[R_{ij}(\boldsymbol{\theta})\mu_j\right] + b_i\right) \cdot \mathcal{C}(\theta_i(\mu))$$

signal strength modifier

→ nuisance constraints

observed events   Reco. Bkg.   Where i runs over reco bins and j runs over gen bins
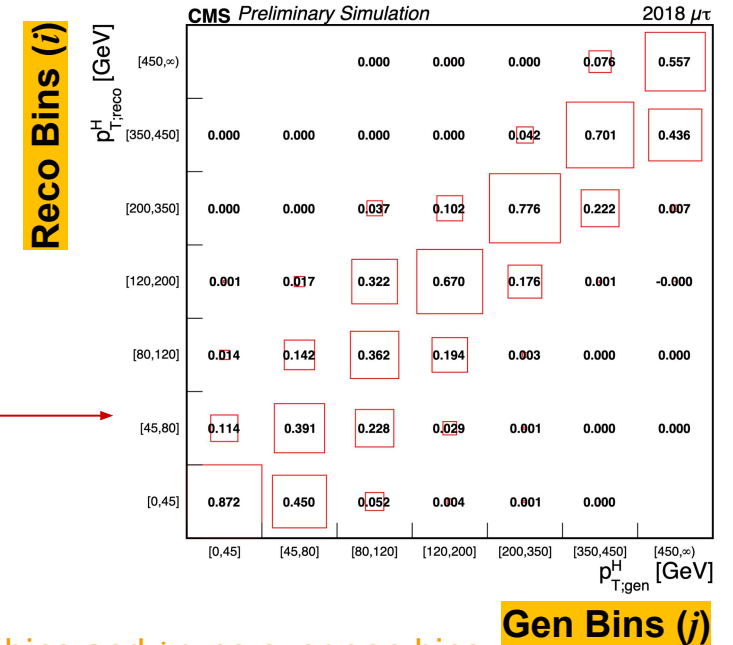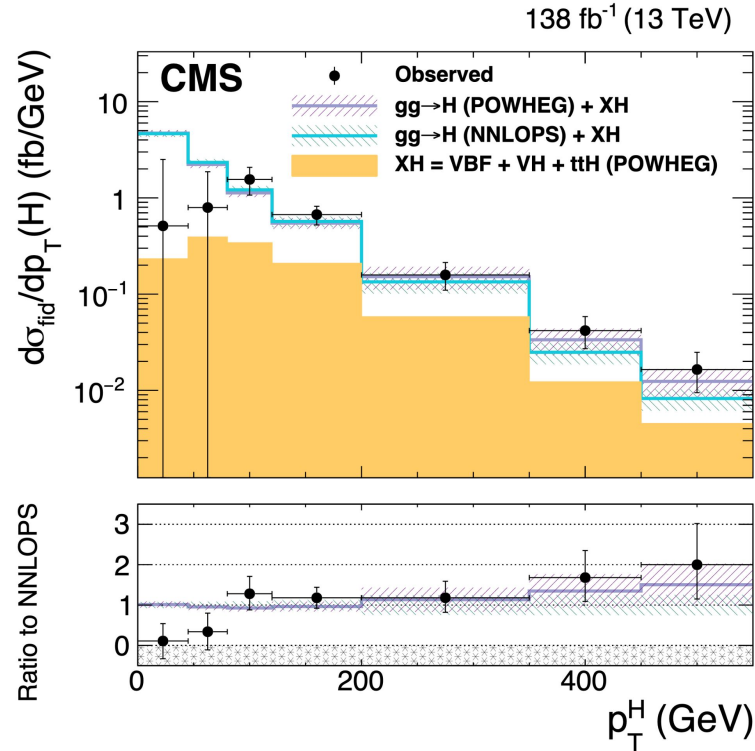
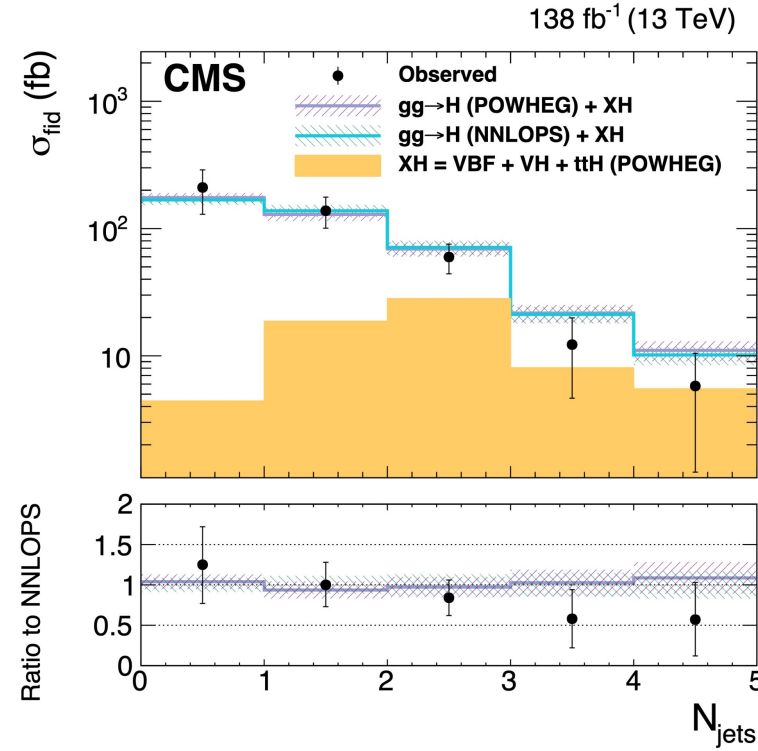- Regularization(multiplying κ to L) is employed to remove statistical fluctuations in the observed distributions

$$\mathcal{K}(\boldsymbol{\mu}) = \prod_{j=1}^{M-2} \exp\left(\frac{-\left[(\mu_{j+1} - \mu_j) - (\mu_j - \mu_{j-1})\right]^2}{2\delta^2}\right)$$

Where M is the number of gen bins
δ is regularization strength

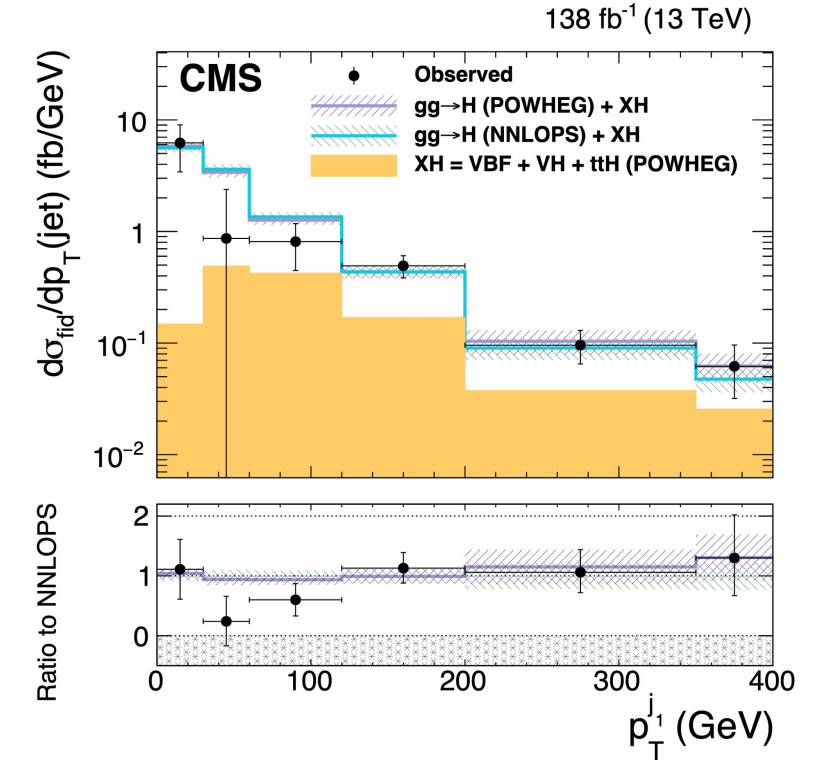# Differential Fiducial XS Results

Differential XS in H→ττ
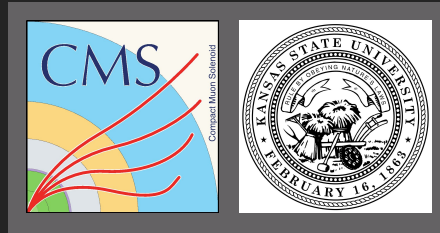
SM p-value: 17%
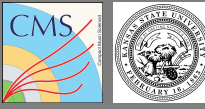
SM p-value: 71%

SM p-value: 45%

- The differential analysis shows good agreement with SM expectation

- Competitive precision w.r.t. other final states at high Higgs p_T, high jet multiplicity

Conclusions

Doyeong Kim, Kansas State University

Conclusions

LHC Run2 opened the door to precision measurements of Higgs cross sections using the H→ττ channel

Two complementary approaches used to study Higgs bosons' properties measuring its cross section

1) The latest results of inclusive cross section and STXS measurement have been presented

   - Inclusive cross section measured: $\mu = 0.85 \, ^{+0.12}_{-0.11}$

2) The first-ever measurement of inclusive and differential fiducial cross sections have been presented

   - Measured value of the fiducial inclusive cross section is 426 ± 102 fb

   - Measured fiducial differential cross sections are particularly precise with respect to other Higgs decay channels for 120 GeV < Higgs p_T < 600 GeV, N_{jets} > 2, and leading jet p_T > 120 GeV
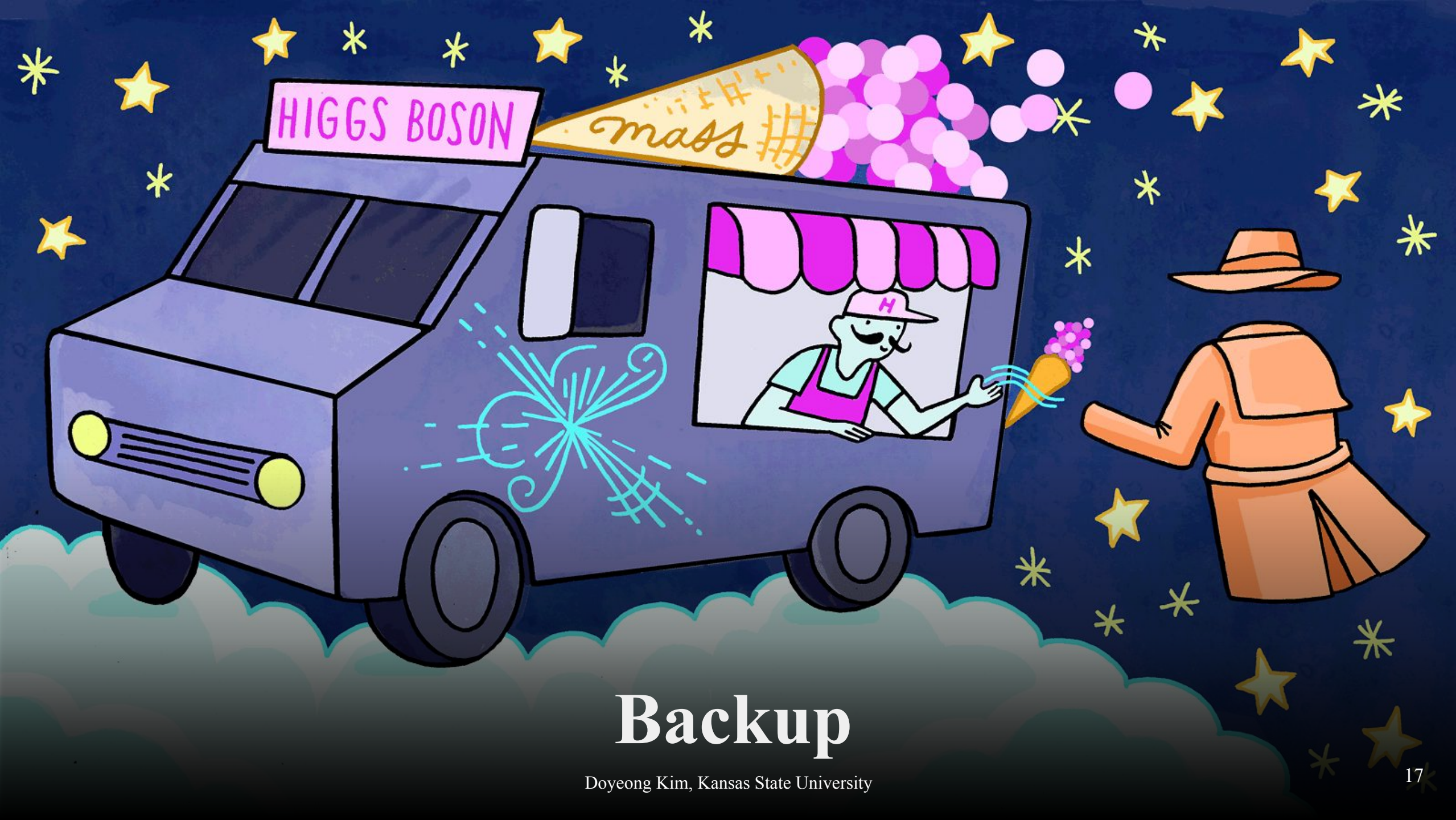
Backup

Doyeong Kim, Kansas State University