ATLAS $H \to \mu\mu$ and Its Impact on CEPC $H \to \mu\mu$

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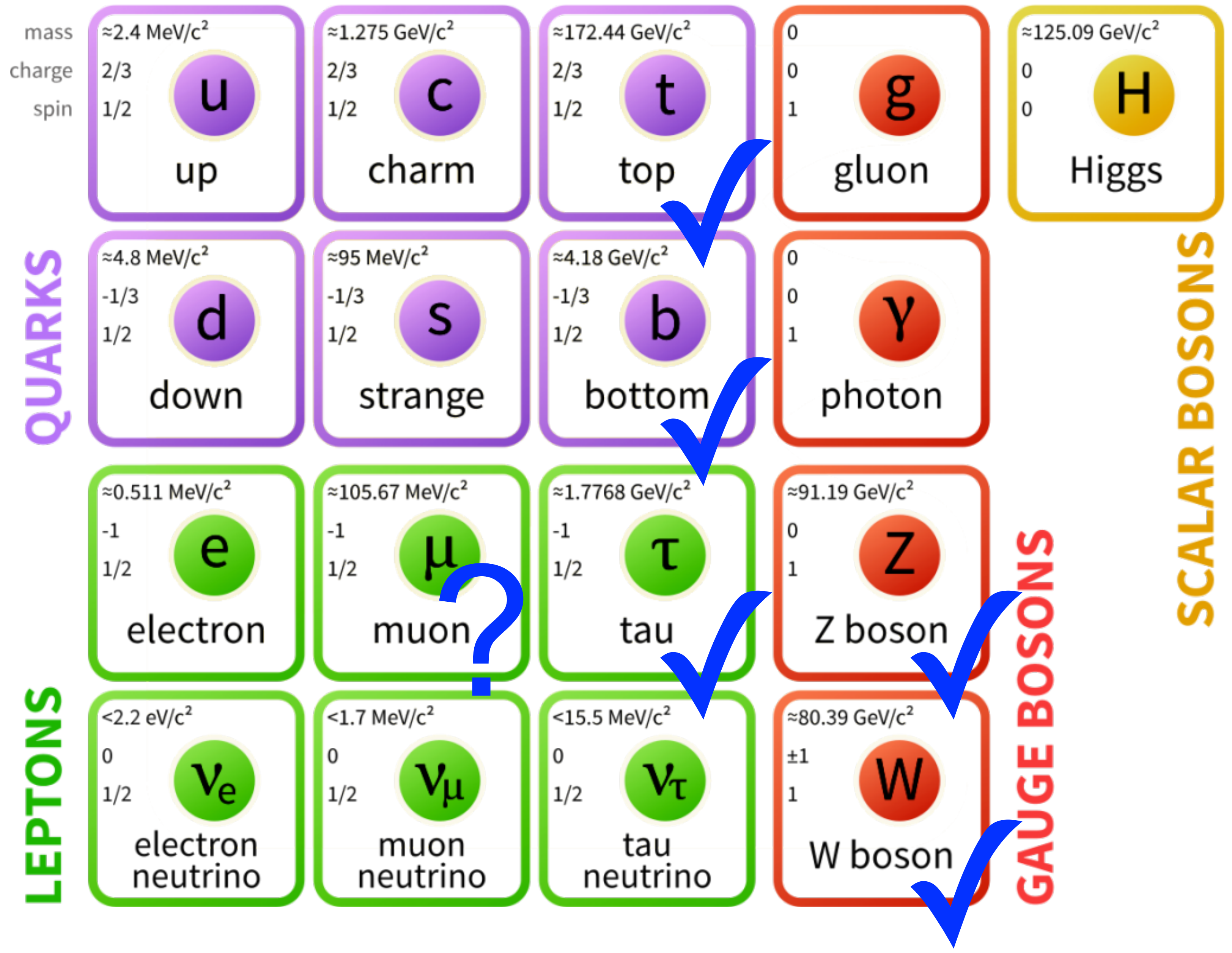
Introduction

- The coupling of Higgs with W/Z boson and third generation charged-fermions have been observed in LHC. JHEP 08 (2016) 045
- The $H \to \mu\mu$ decay is a unique channel to measure Higgs Yukawa coupling to the second generation fermions.
- Full LHC Run2 Data:
  - integrated luminosity is 139 fb^{-1}
  - $\sqrt{s}$ = 13 TeV
- Impact on CEPC $H \to \mu\mu$



$H \to cc$: CEPC or FCC-ee

Analysis Strategy

- Signal: two opposite charged muons
- Background: Drell-Yan (dominant), $t\bar{t}$+single-top, WZ/ZZ
- Based on the different production mode of Higgs , use MVA for event classification
  - ggF: 12 categories
  - VBF: 4 categories
  - VH: 3 categories
  - ttH: 1 category
- Fully data-driven method to estimate background
- Use analytic functions to model Signal and Background

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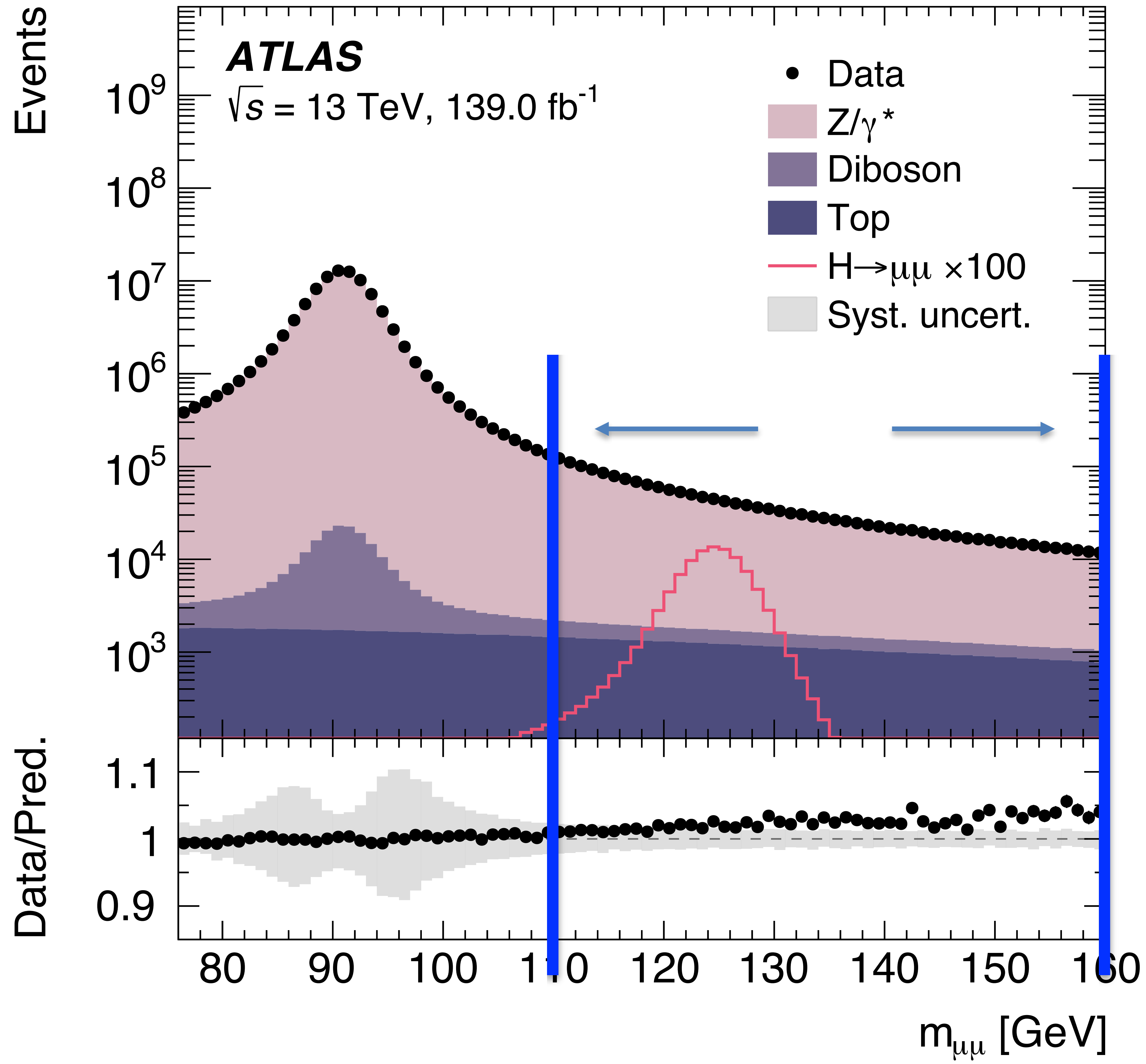

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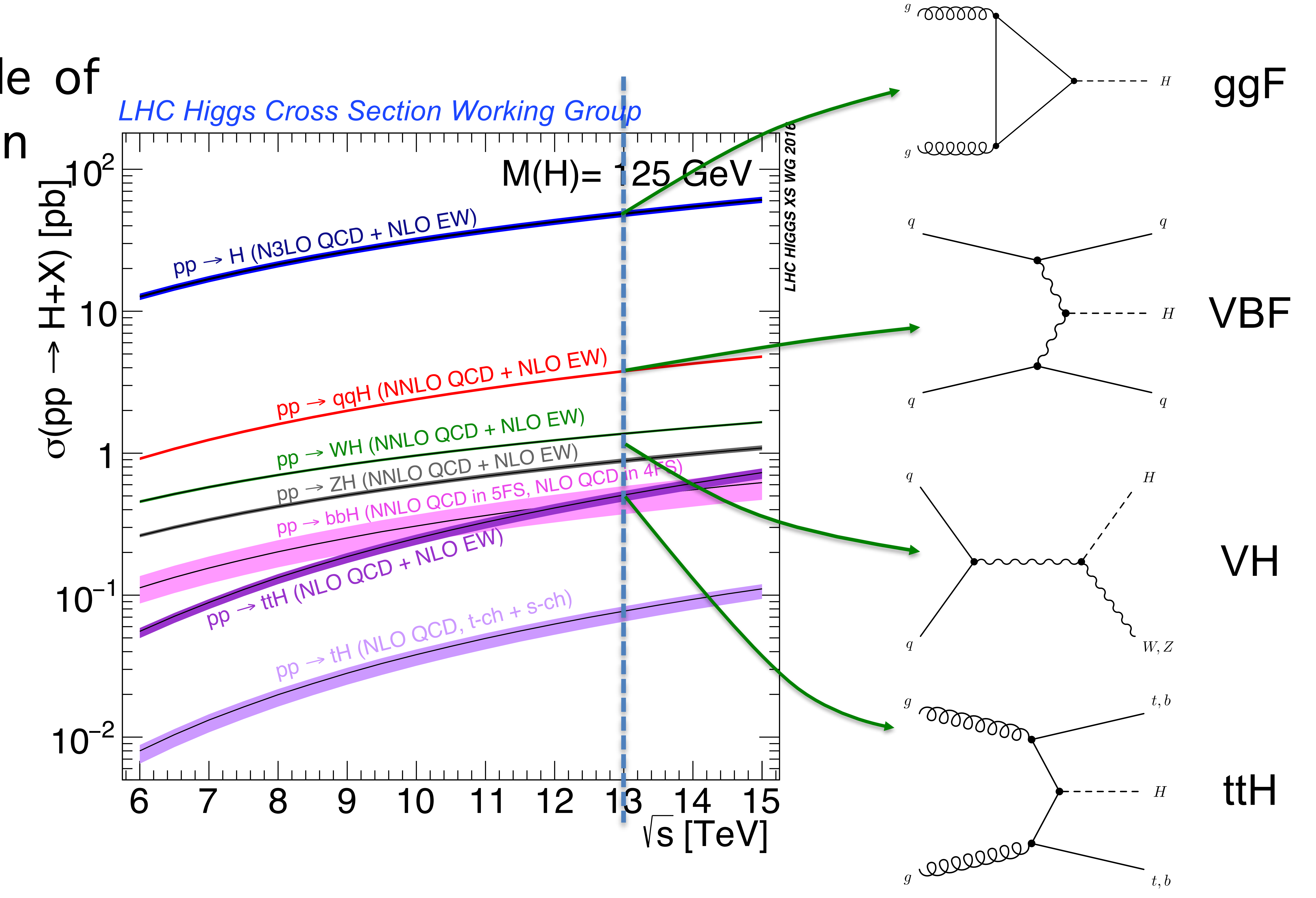
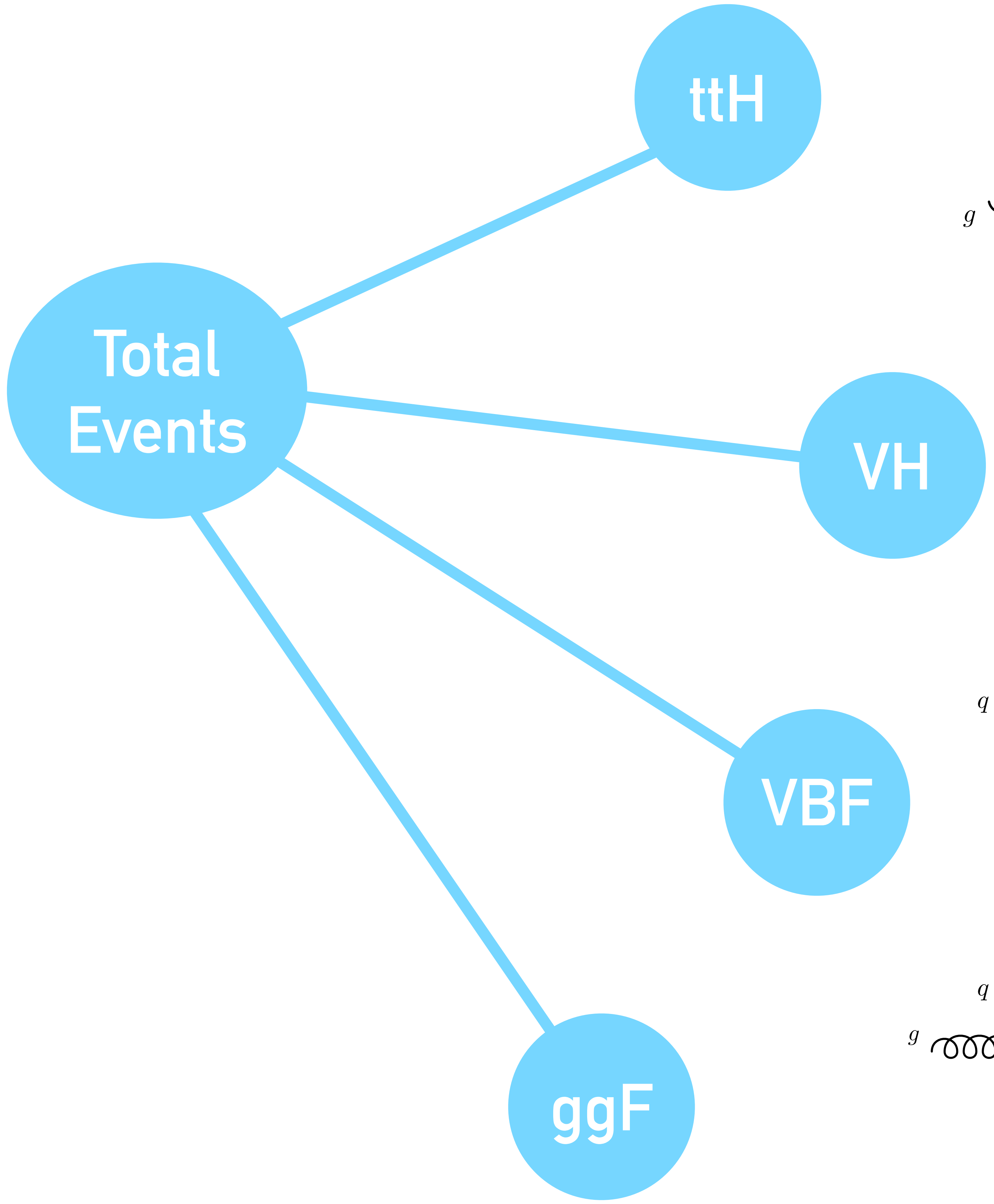
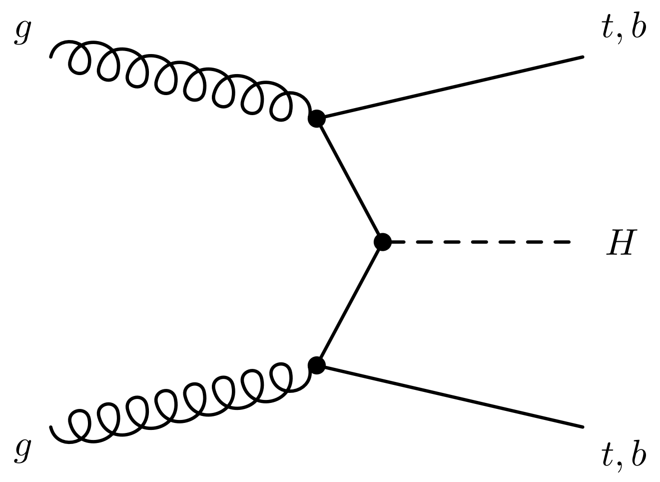


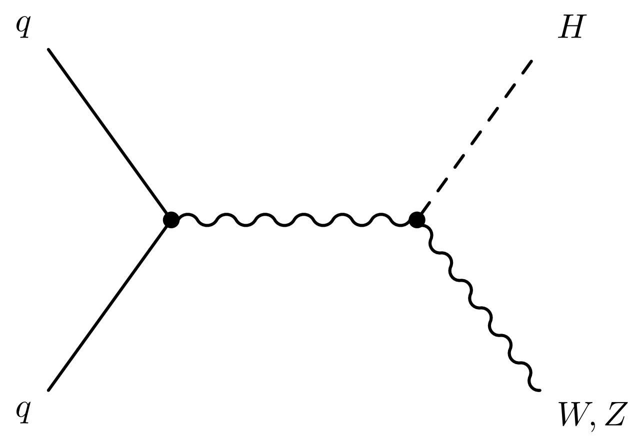
Event Selection

Use different event selection criterial for different production mode

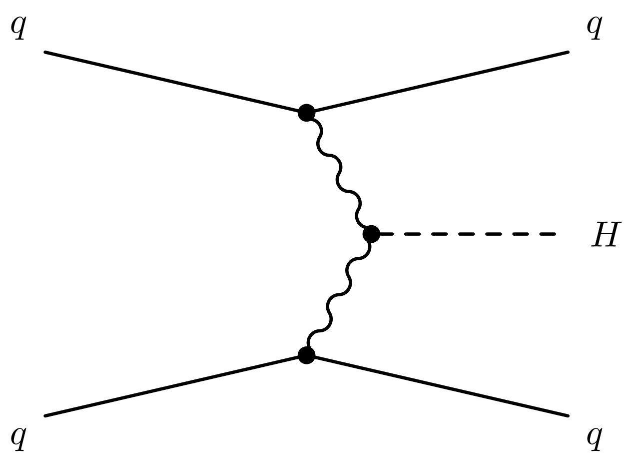




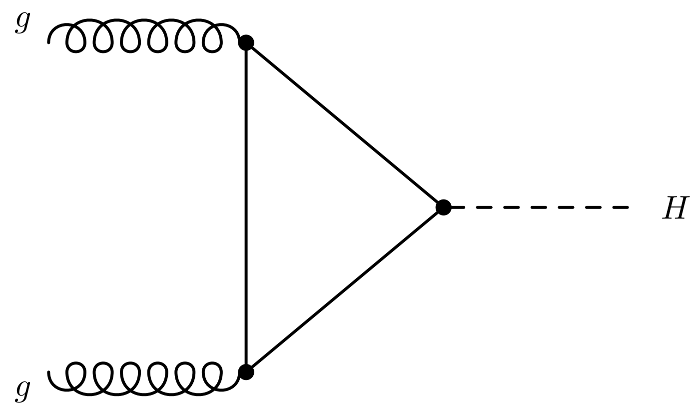
- 3/4 leptons
- At least one b-tagged jet



- 3/4 leptons
- No b-tagged jet



- 2 leptons
- No b-tagged jet



- 2 leptons
- No b-tagged jet

ttH Category

- Use BDT (implemented in XGBoost package) to further suppress backgrounds
- Leading two muons as $H \rightarrow \mu\mu$
- 12 variables are used for the BDT
- Main background is ttZ. Expected signal: 1.2 events

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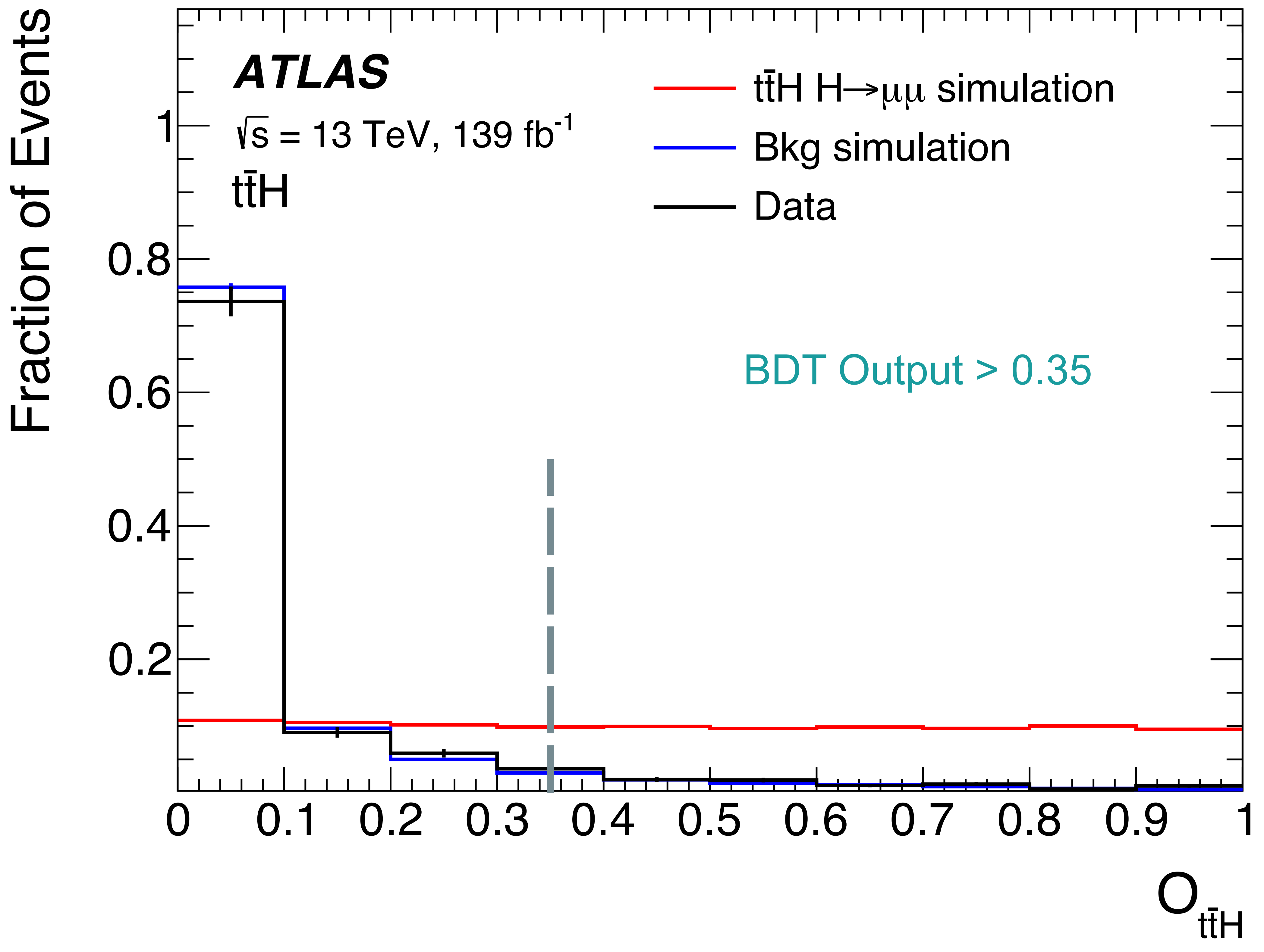
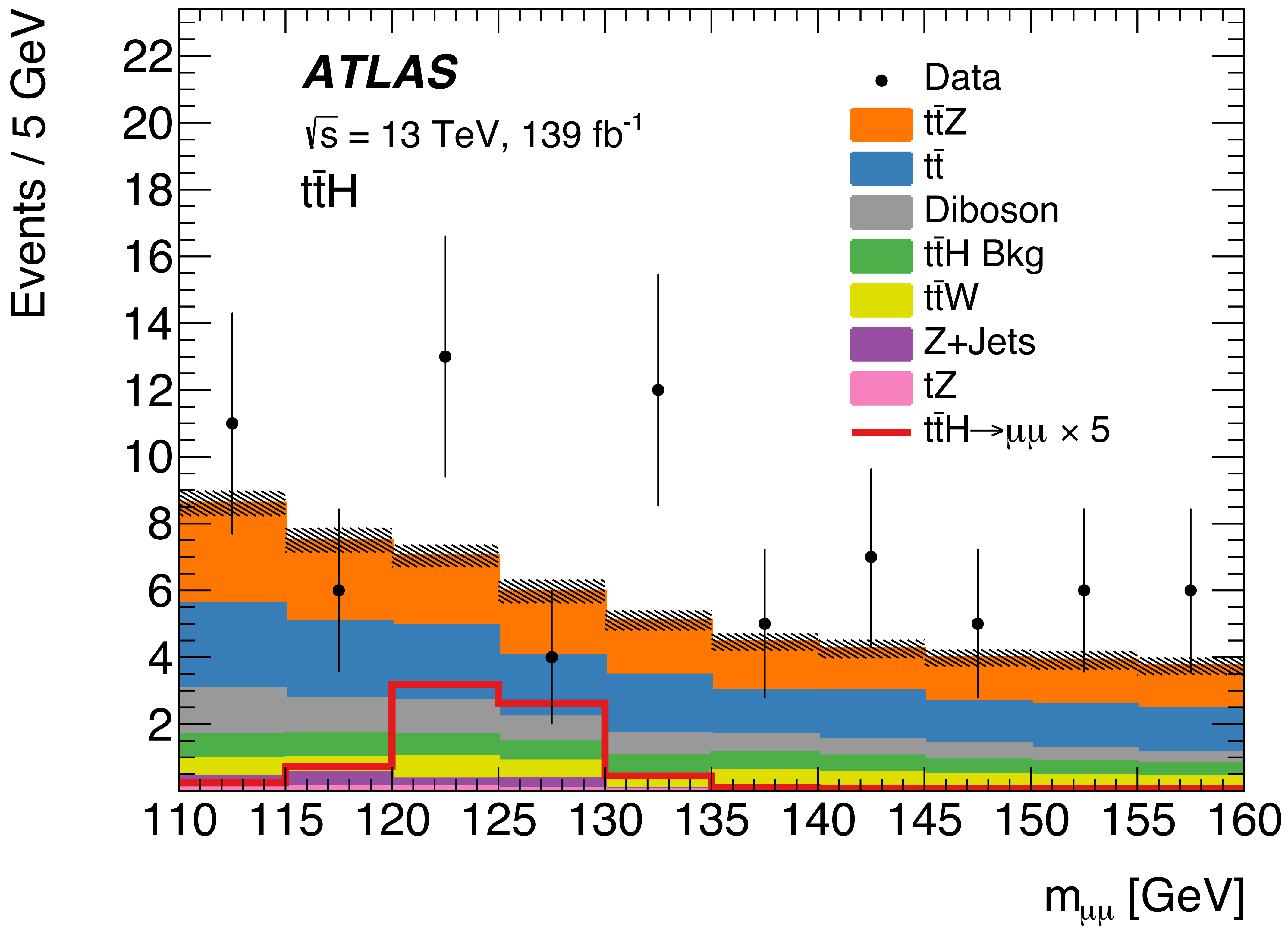


After BDT selection



VH Categories

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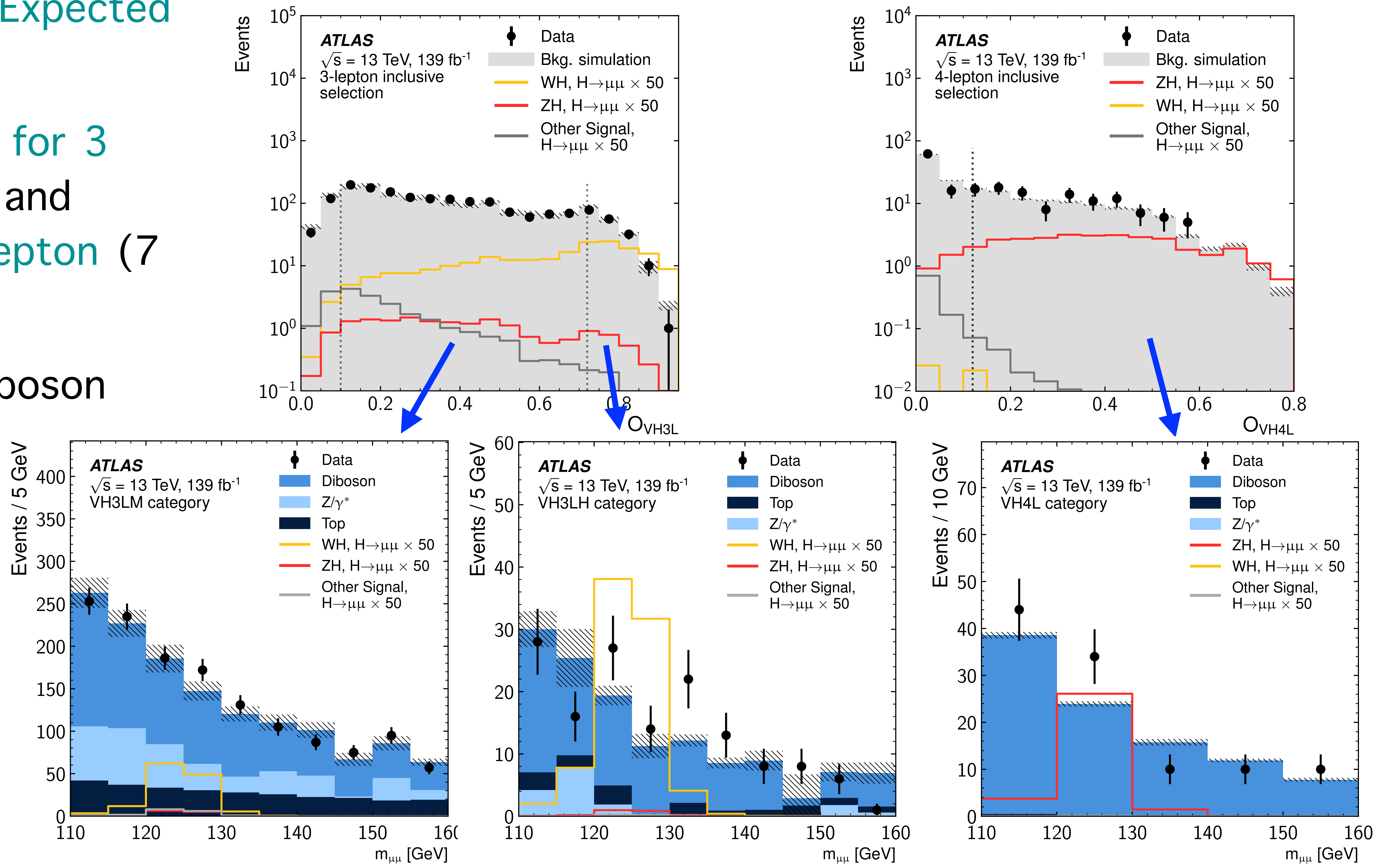
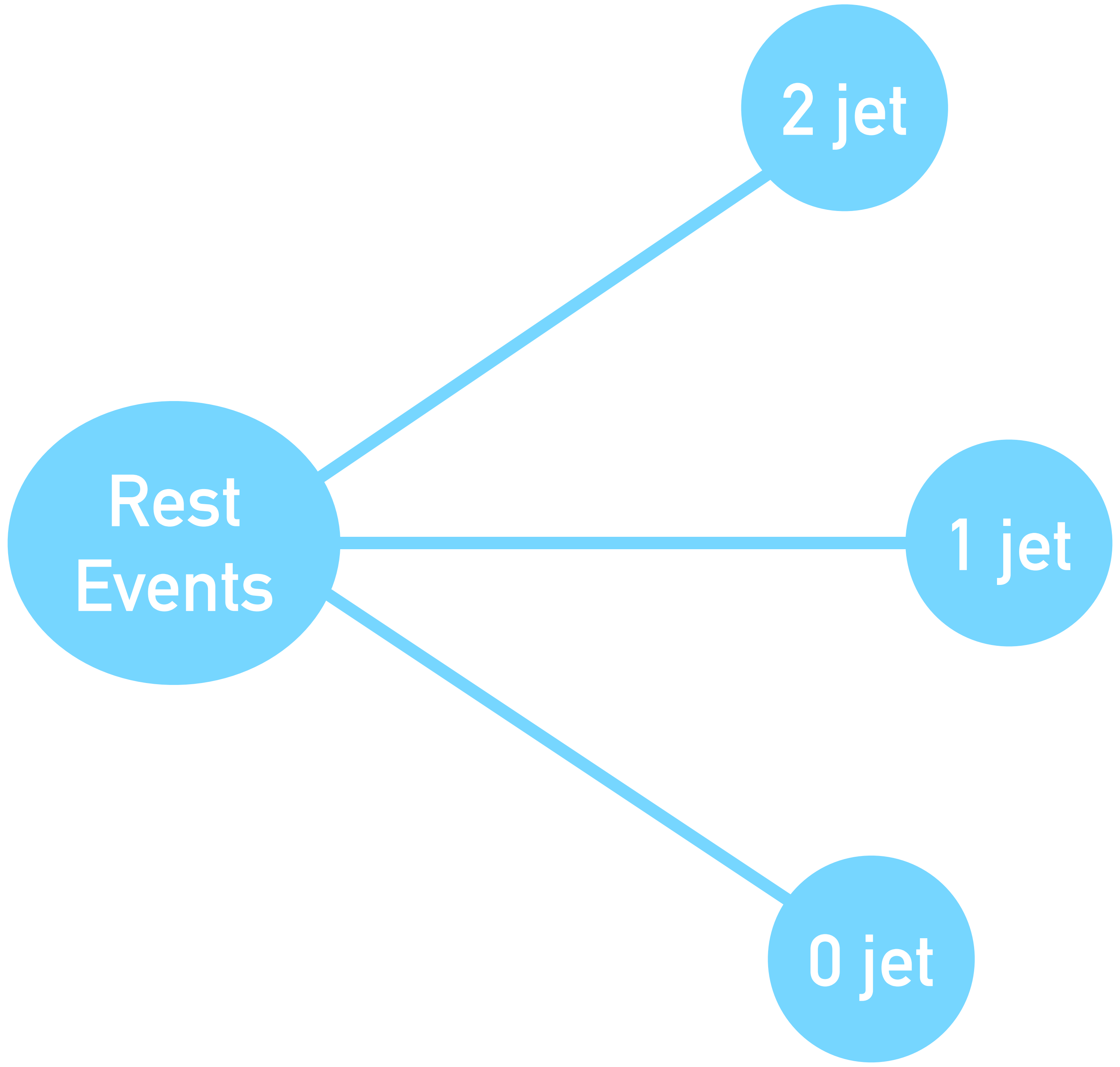
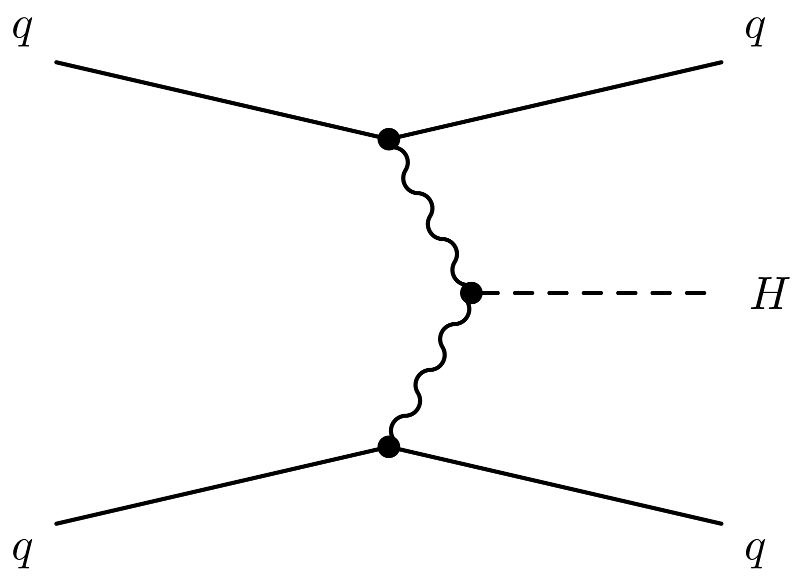
- WH/ZH, $(H \rightarrow \mu\mu)$. Expected signal: 4.7 events
- Two BDTs: one BDT for 3 lepton (8 variables) and another BDT for 4 lepton (7 variables)
- Main background: Diboson



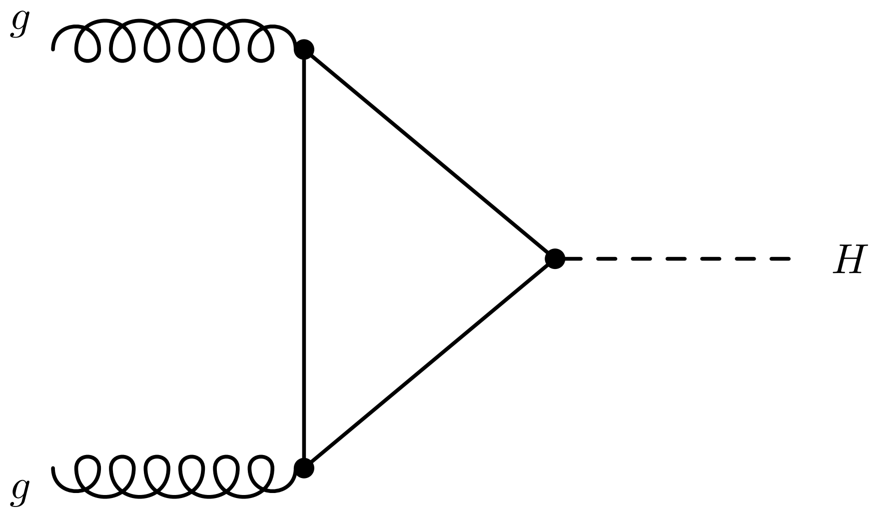
VBF/ggF Categories

[Phys.Lett.B 812 (2021) 135980]





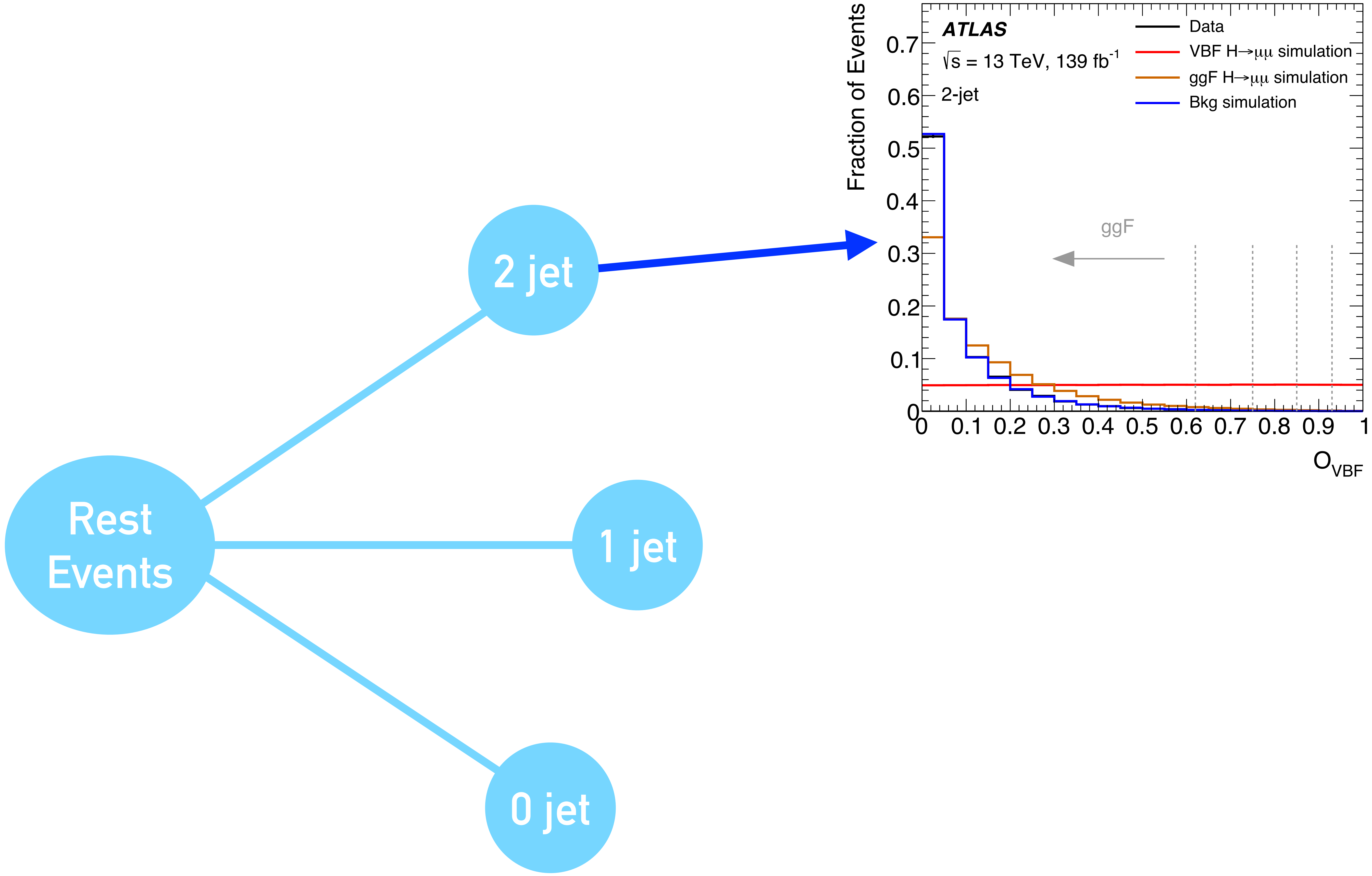
ggF



VBF

2 jet events: events with 2 or more jets

VBF/ggF Categories



[Phys.Lett.B 812 (2021) 135980](https://doi.org/10.1016/j.physletb.2020.135980)

VBF/ggF Categories

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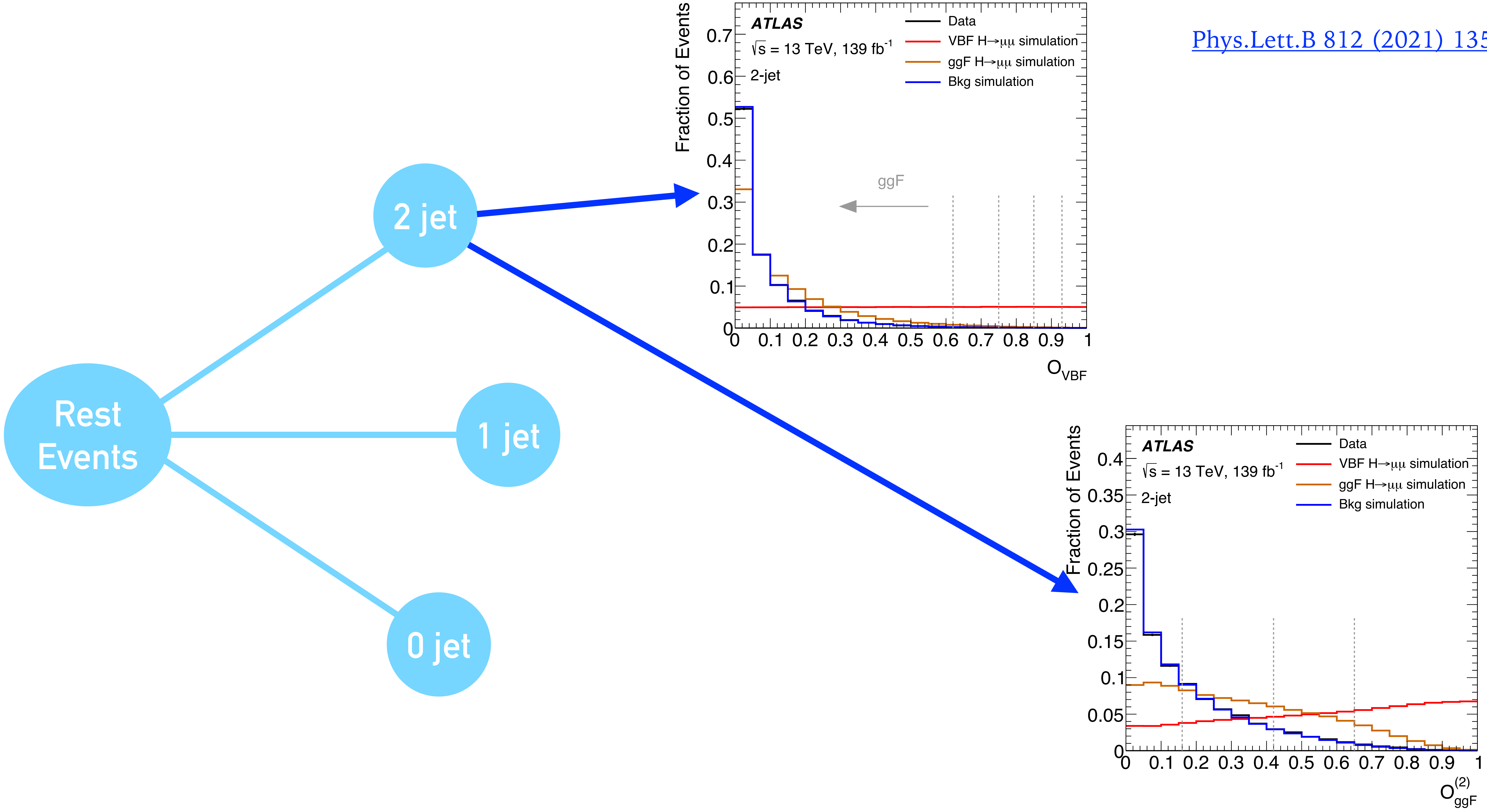

VBF/ggF Categories

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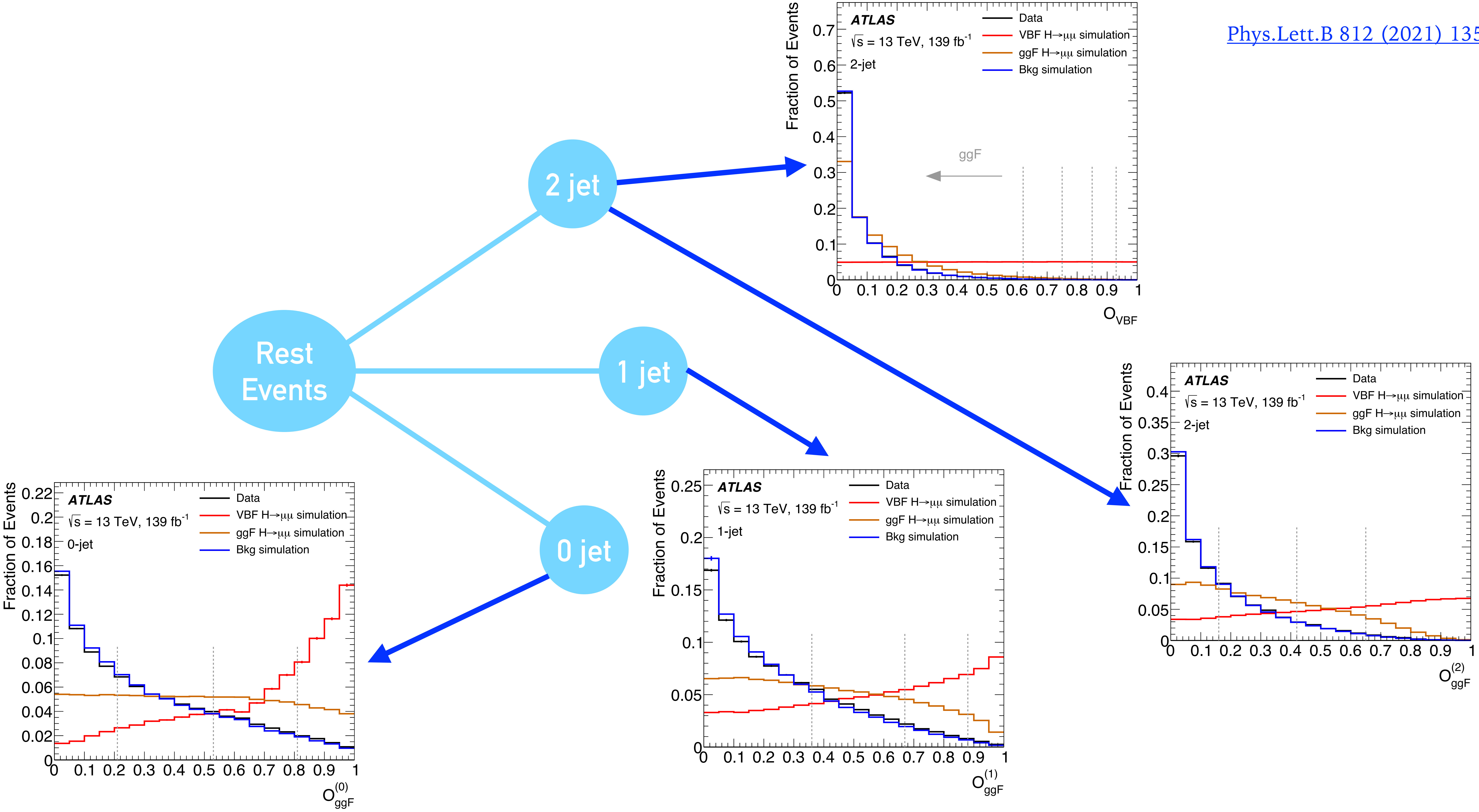

Event Categorization

- 20 categories in total: 4 VBF + 12 ggF + 3 VH + 1 ttH

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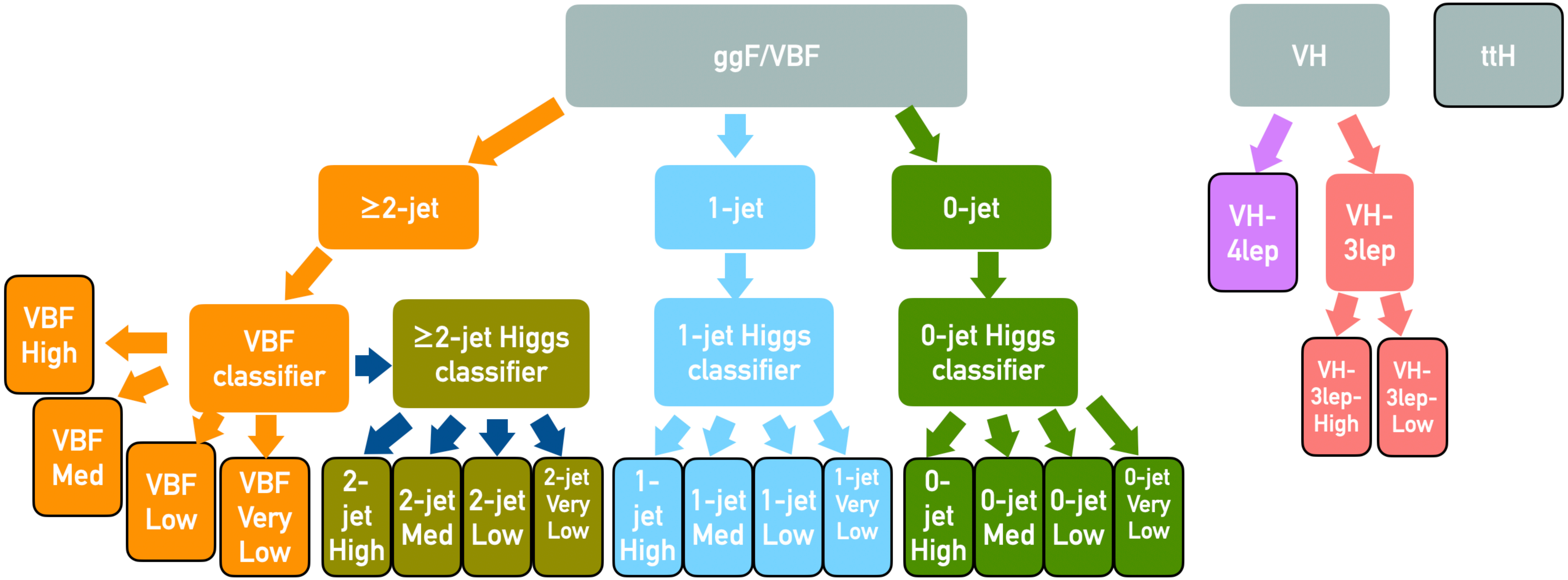

Signal Modeling

- Double-sided Crystal-Ball function is used to model the signal shape, which is described by a Gaussian core of distribution and two asymmetric exponential tails as below:

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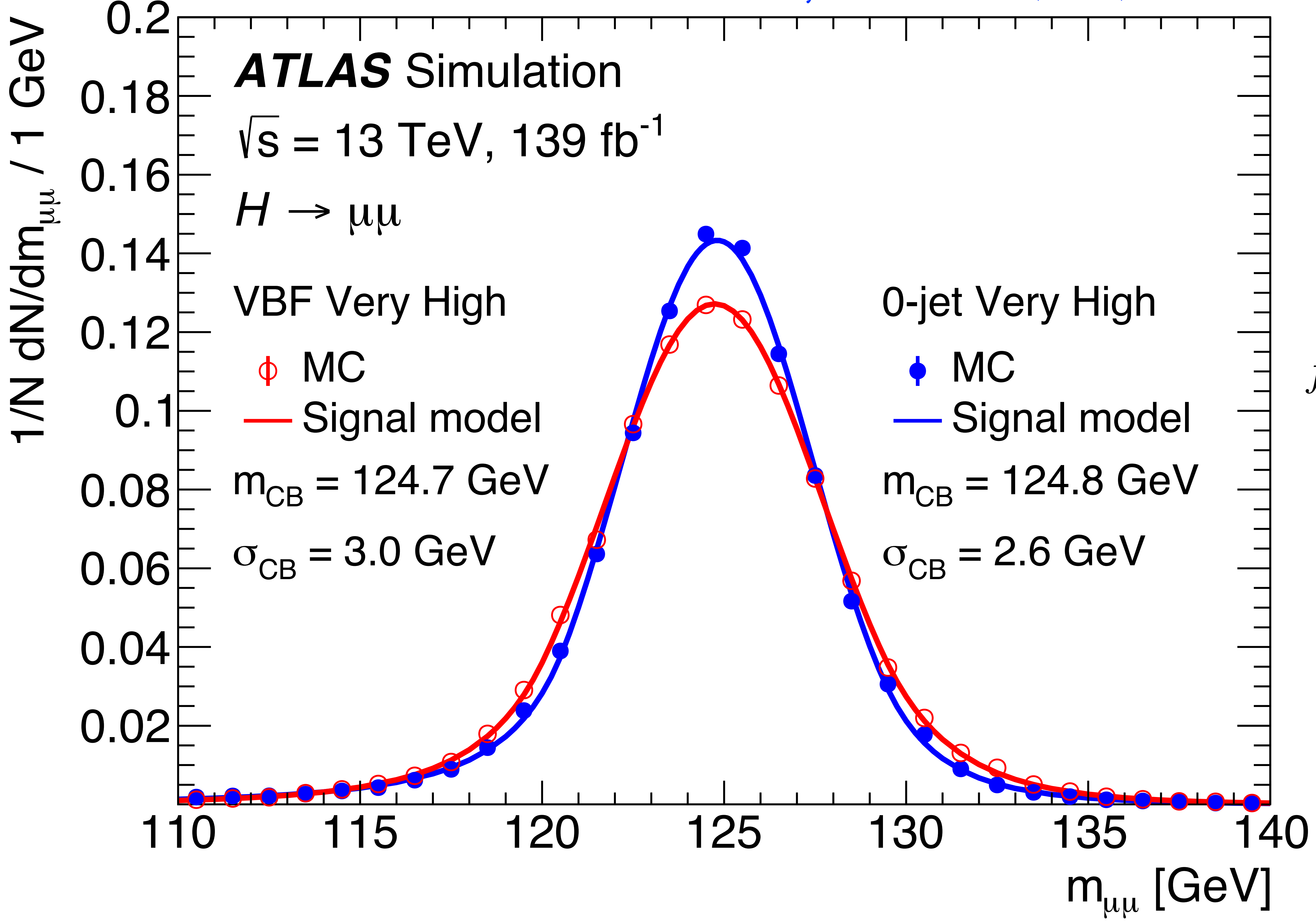

$$
f_{DCB}(m_{\mu\mu}) = \begin{cases}
\exp\left[-\left(\dfrac{m_{\mu\mu}-M_{CB}}{\sigma_{CB}}\right)^2/2\right] & \text{if } \alpha_{low} \le \dfrac{m_{\mu\mu}-M_{CB}}{\sigma_{CB}} \le \alpha_{high} \\
\dfrac{\exp\left[-\alpha_{low}^2/2\right]}{\left[\dfrac{\alpha_{low}}{n_{low}}\left(\dfrac{n_{low}}{\alpha_{low}} - \alpha_{low} + \dfrac{m_{\mu\mu}-M_{CB}}{\sigma_{CB}}\right)\right]^{n_{low}}} & \text{if } \dfrac{m_{\mu\mu}-M_{CB}}{\sigma_{CB}} \le \alpha_{low} \\
\dfrac{\exp\left[-\alpha_{high}^2/2\right]}{\left[\dfrac{\alpha_{high}}{n_{high}}\left(\dfrac{n_{high}}{\alpha_{high}} - \alpha_{high} + \dfrac{m_{\mu\mu}-M_{CB}}{\sigma_{CB}}\right)\right]^{n_{high}}} & \text{if } \dfrac{m_{\mu\mu}-M_{CB}}{\sigma_{CB}} \ge \alpha_{high}
\end{cases}
$$

- M_{CB}: mean value of the DCB function
- σ_{CB}: width of the DCB function
- α_{low}: threshold for the left low-end tail
- α_{high}: threshold for the right low-end tail
- n_{low}: power in the left low-end tail
- n_{high}: power in the right low-end tail

Background Modeling

- Proposed model with two components: [fix] x [floating]
  - Fixed part (physics motivated): LO 2→2 Drell-Yan analytic lineshape
    - $m_{\mu\mu}$ resolution effect included by smearing with Gaussian
- Floating part:

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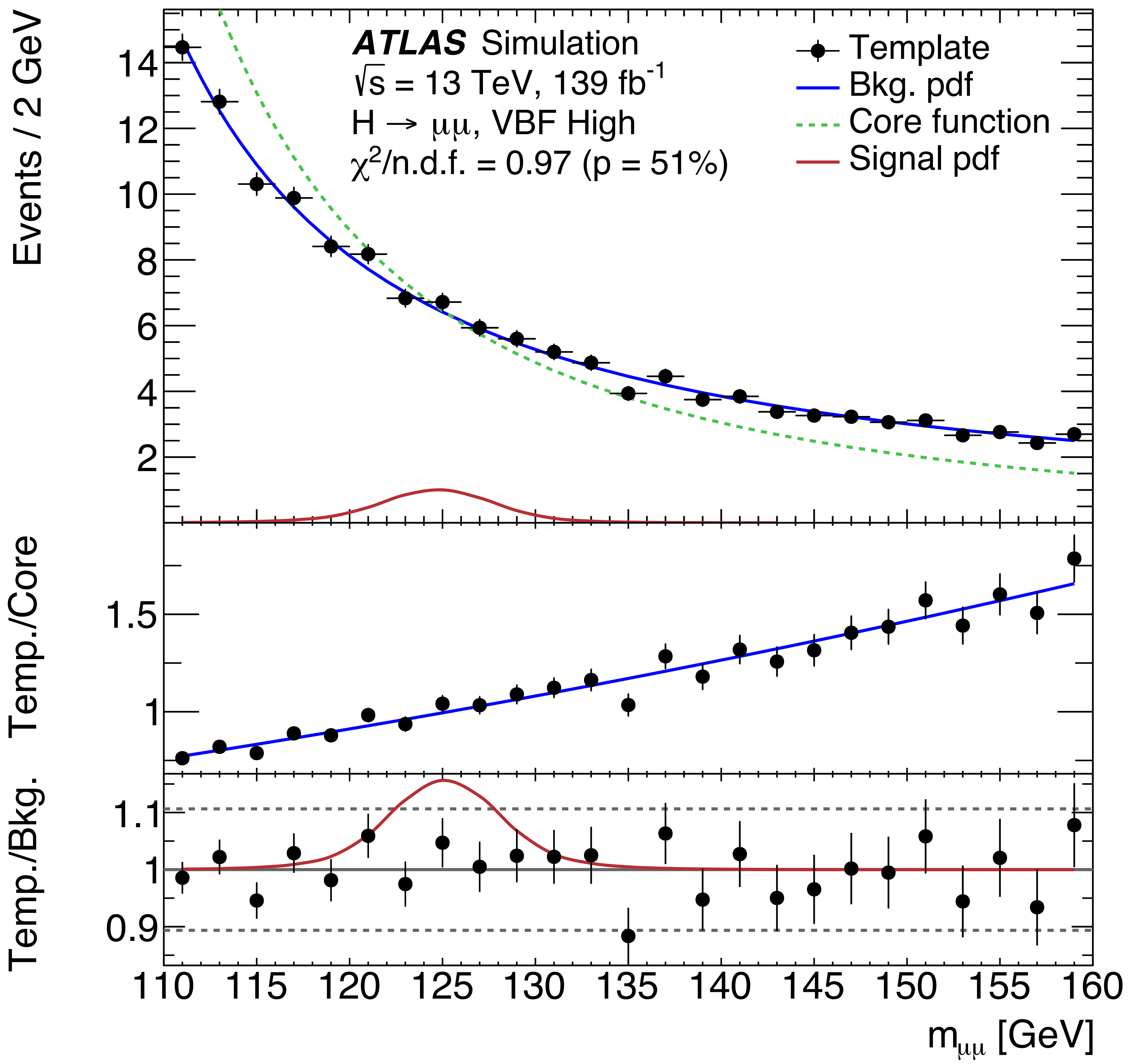
Simultaneously fit with 20 categories to extract signal strength

Category	Empirical Function
VBF Very High	Epoly1
VBF High	Power0
VBF Medium	Power0
VBF Low	Power0
2-jet Very High	Power1
2-jet High	Epoly2
2-jet Medium	Power1
2-jet Low	Epoly3
1-jet Very High	Epoly2
1-jet High	Epoly2
1-jet Medium	Power1
1-jet Low	Power1
0-jet Very High	Power1
0-jet High	Power1
0-jet Medium	Power1
0-jet Low	Epoly3
VH4L	Power1
VH3LH	Epoly2
VH3LM	Epoly3
$t\bar{t}H$	Power0

Function	Expression
PowerN	$m_{\mu\mu}^{(a_0+a_1 m_{\mu\mu}+a_2 m_{\mu\mu}^2+\ldots+a_N m_{\mu\mu}^N)}$
EpolyN	$\exp(a_1 m_{\mu\mu} + a_2 m_{\mu\mu}^2 + \ldots + a_N m_{\mu\mu}^N)$



Statistical Results

- Significance: 2.0σ (1.7σ expected)
- Best fit: μ = 1.2 ± 0.6

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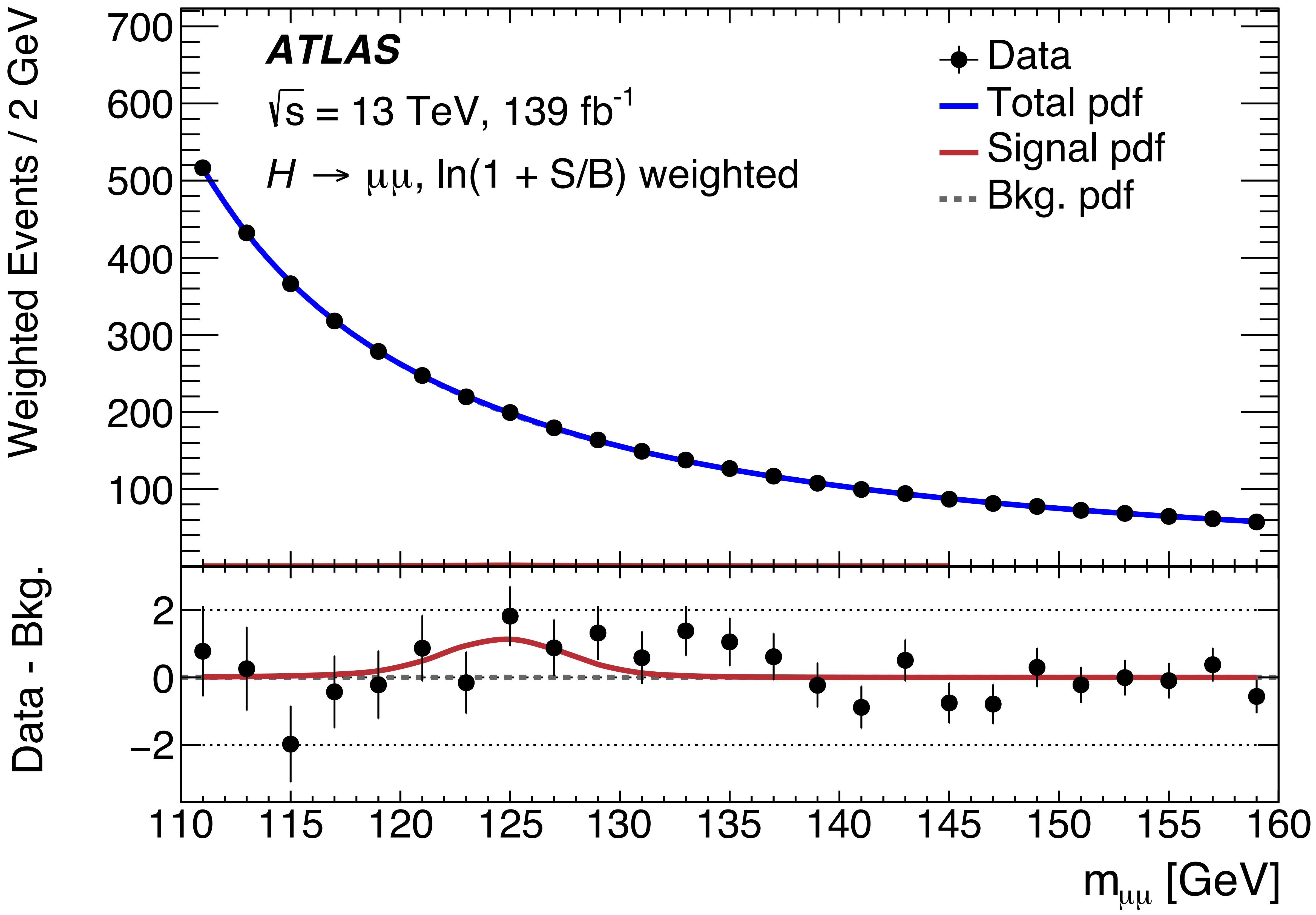

Signal Strength in Different Categories

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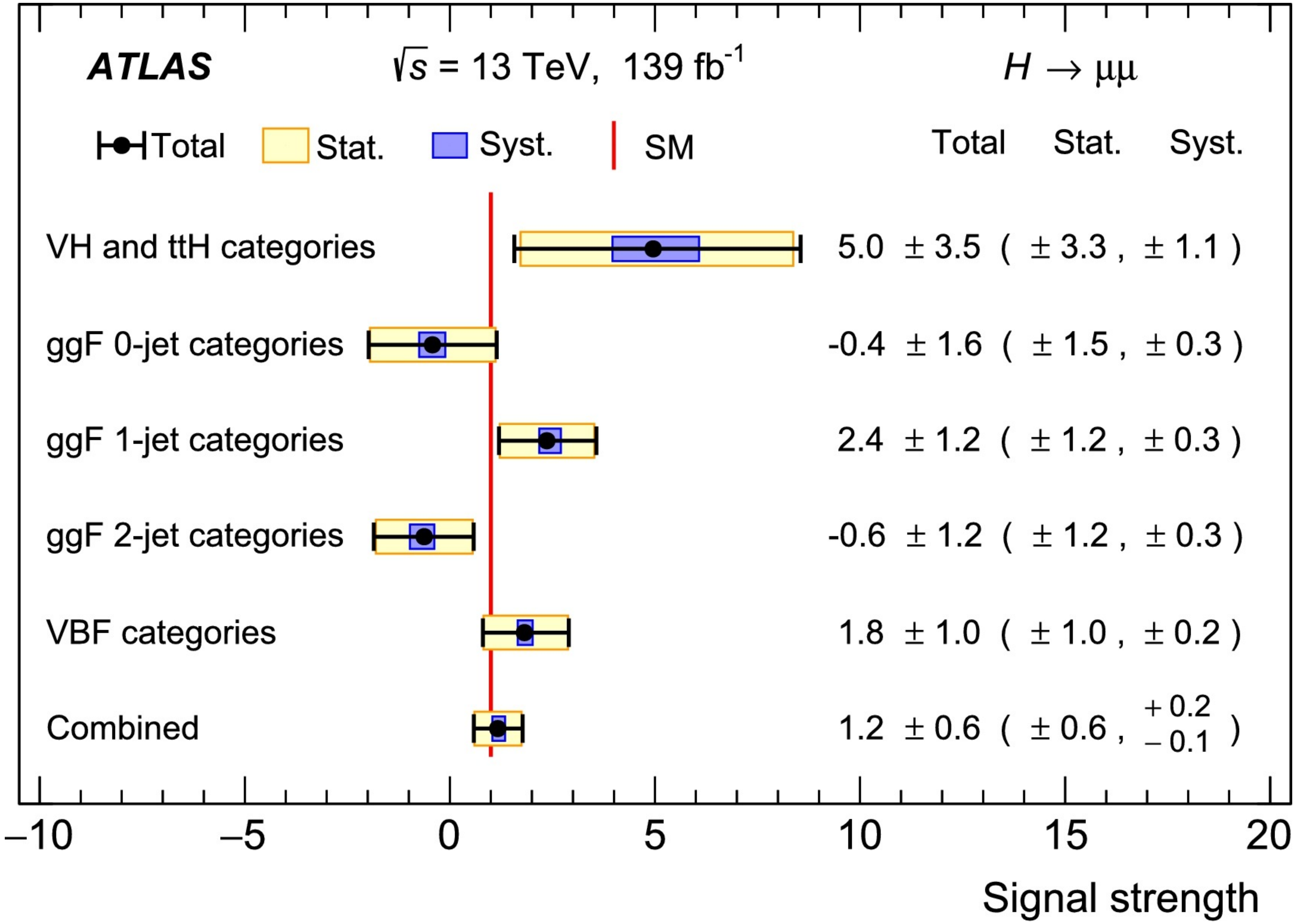
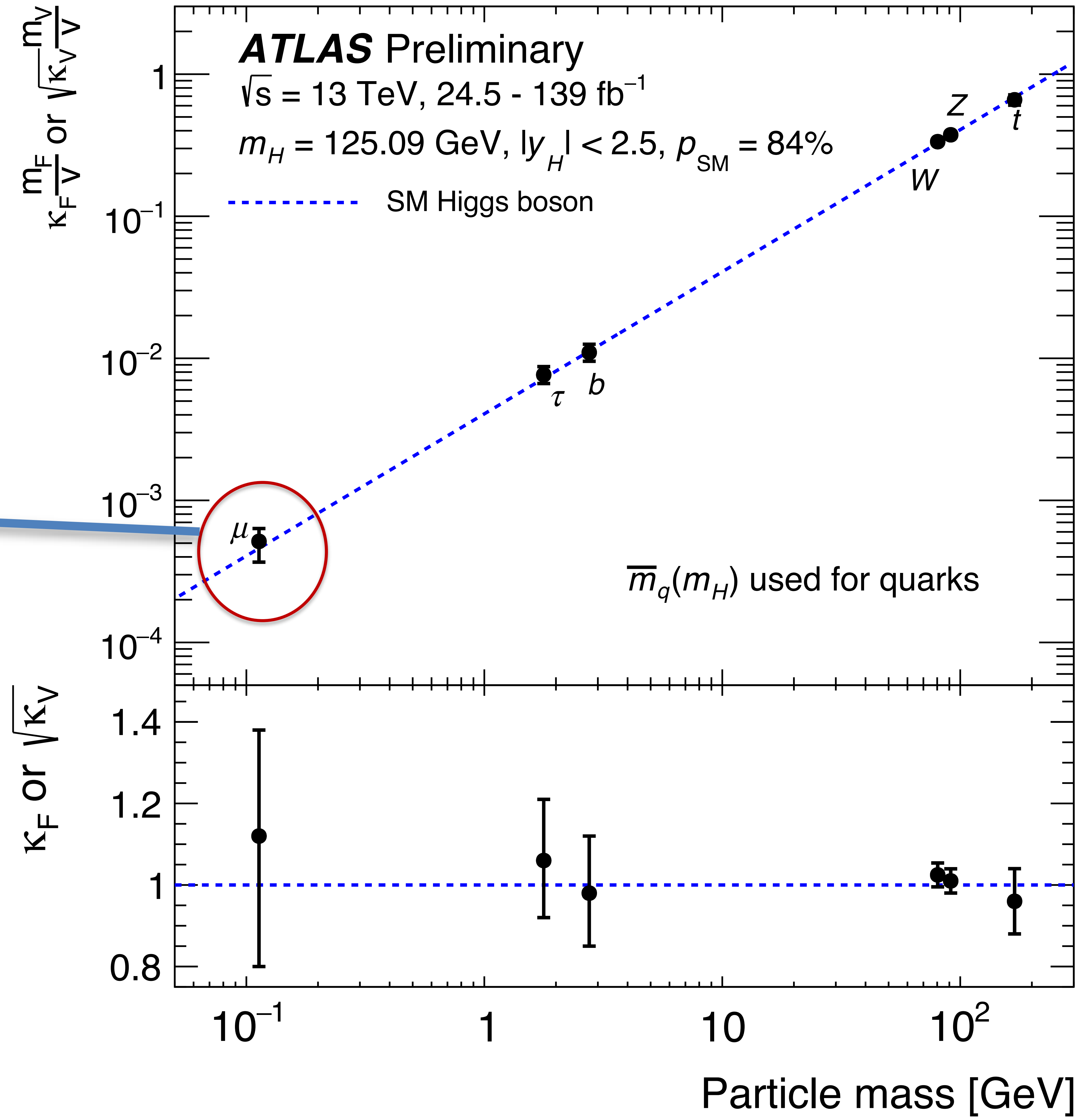


Higgs Coupling

ATLAS-CONF-2020-027



Updated with 139 fb^{-1}

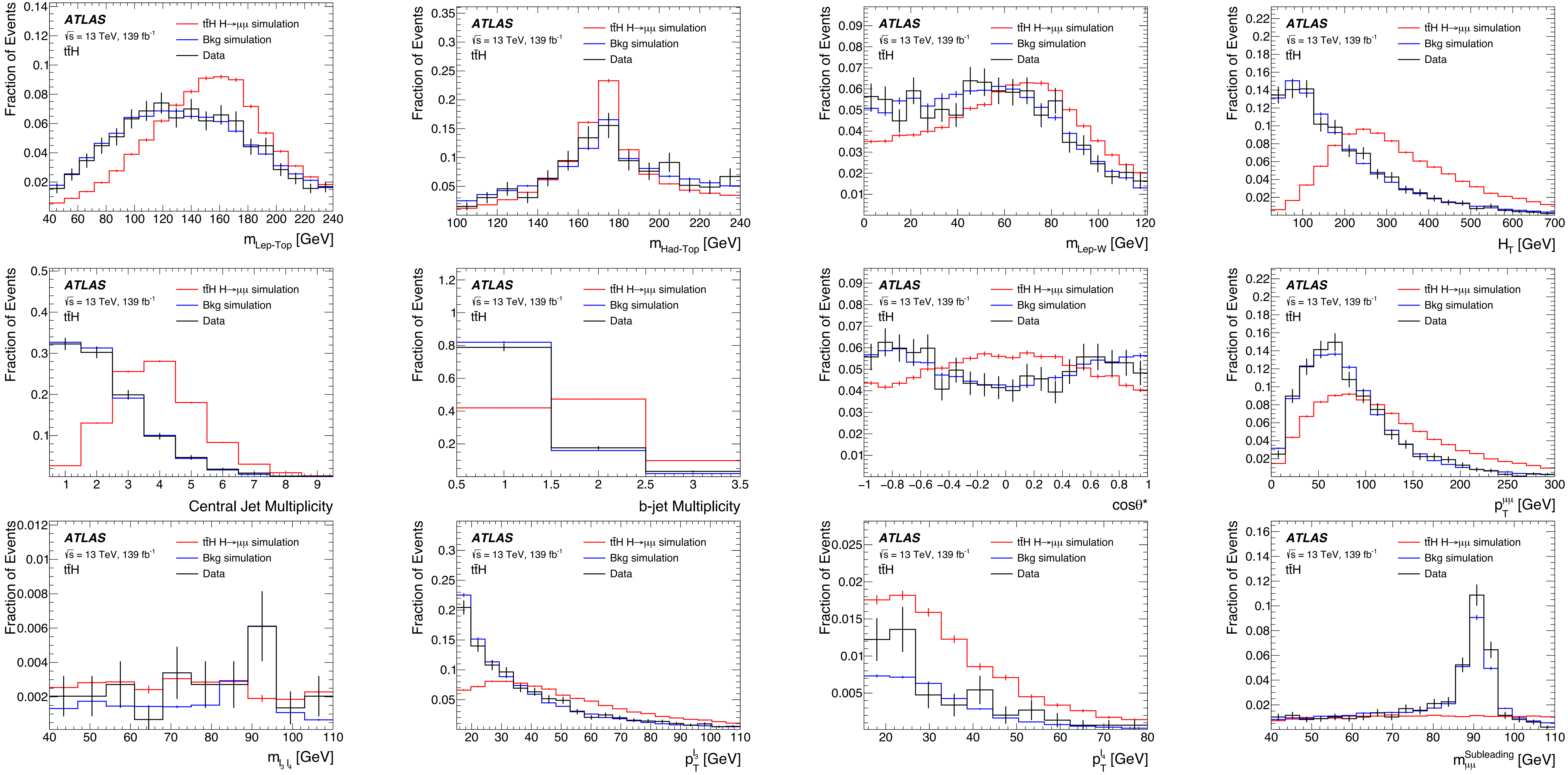
Summary

- $H \to \mu\mu$ is used to probe the Higgs coupling to second generation fermions.
- $H \to \mu\mu$ search with full run2 data. Observed significance: 2σ (1.7σ expected)
- Best-fit combined signal strength: μ = 1.2 ± 0.6
- Outlook in LHC:
  - Need more data to understand the coupling between Higgs and muons
  - LHC Run 3 will start Feb 2022
- Impact on CEPC $H \to \mu\mu$:
  - The background is extremely clean.
  - Develop different event selection criterial based on different production mode.
  - Apply MVA method for event categorization.
  - Use profile likelihood method to estimate significance.

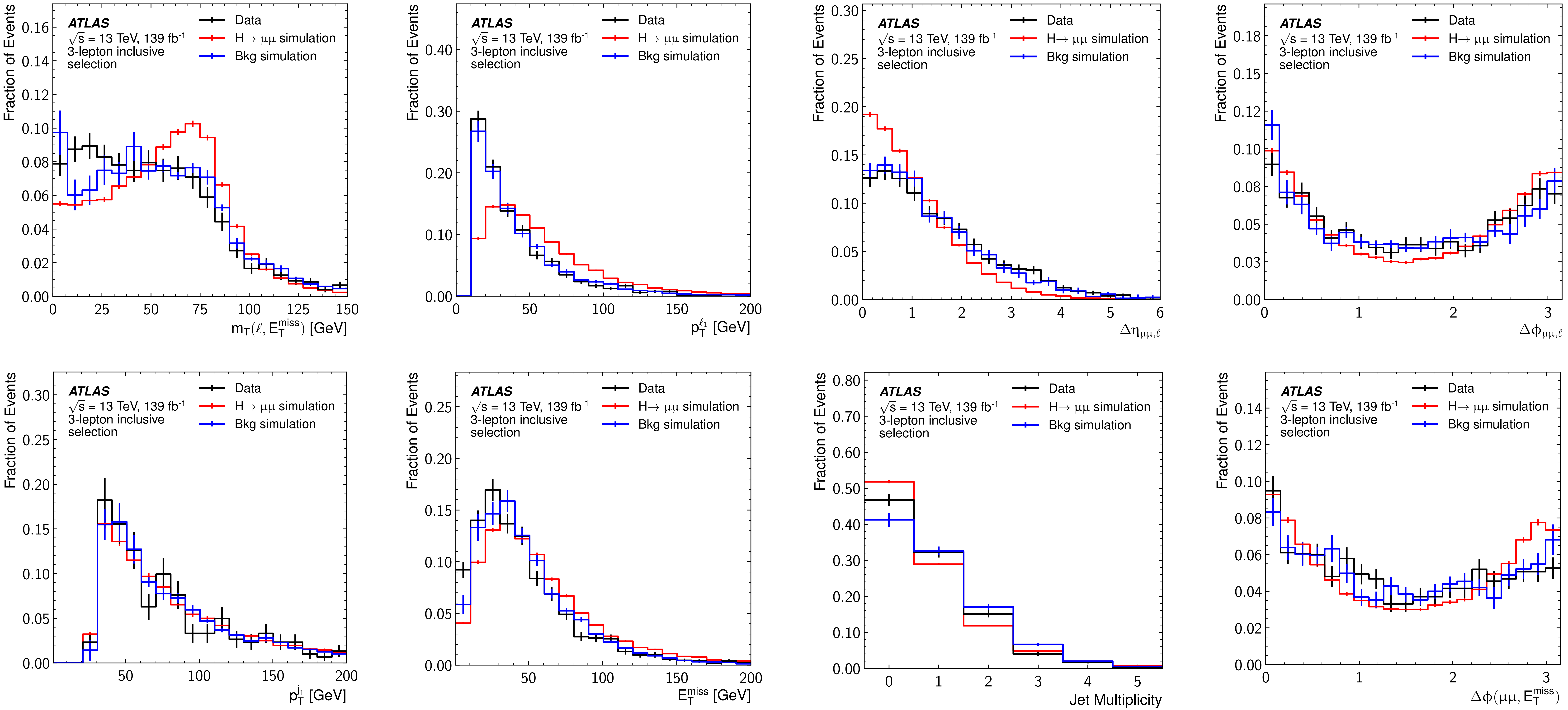
Kunlin Ran' talk: Higgs to dimuon measurement at the CEPC

Backup

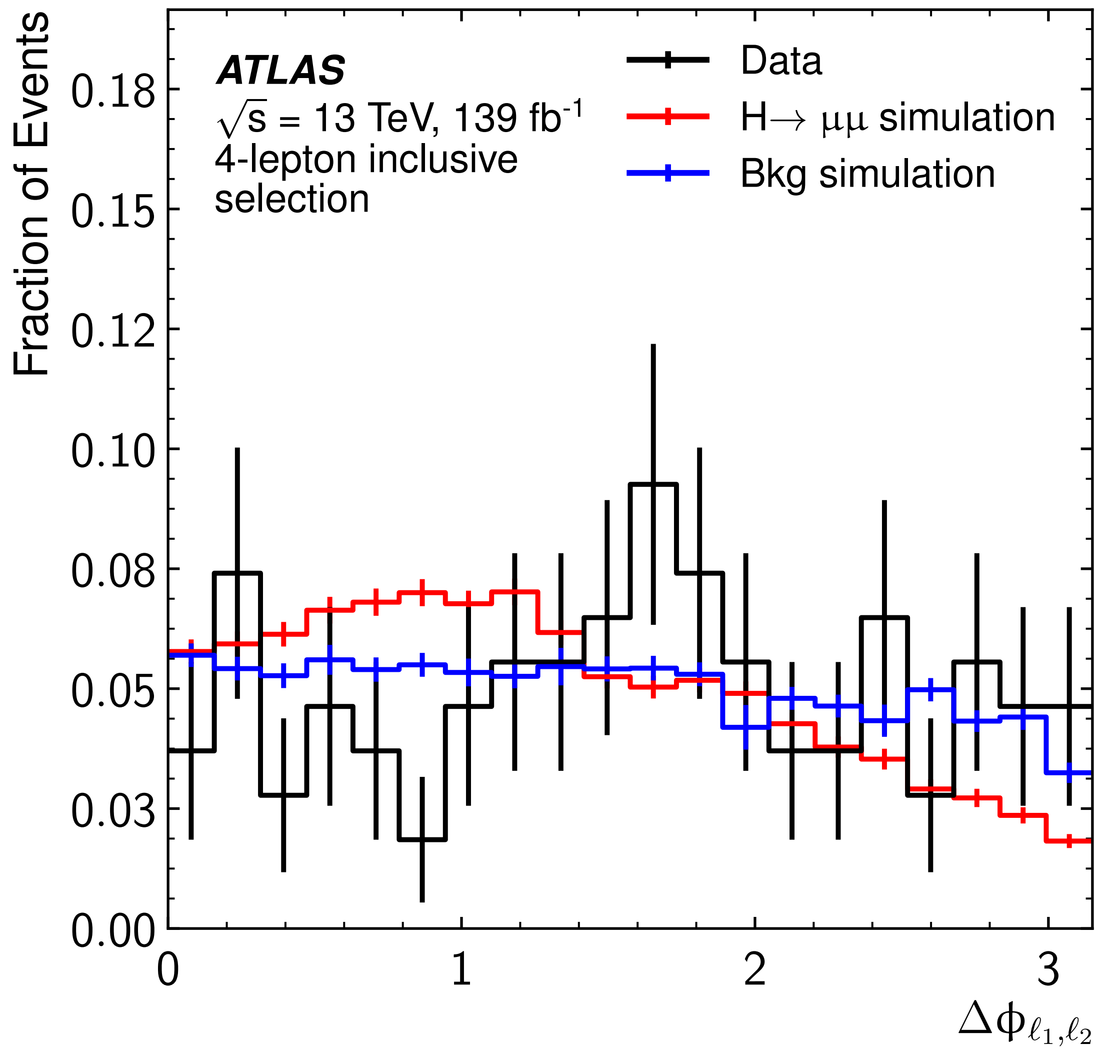
ttH BDT Training Variables

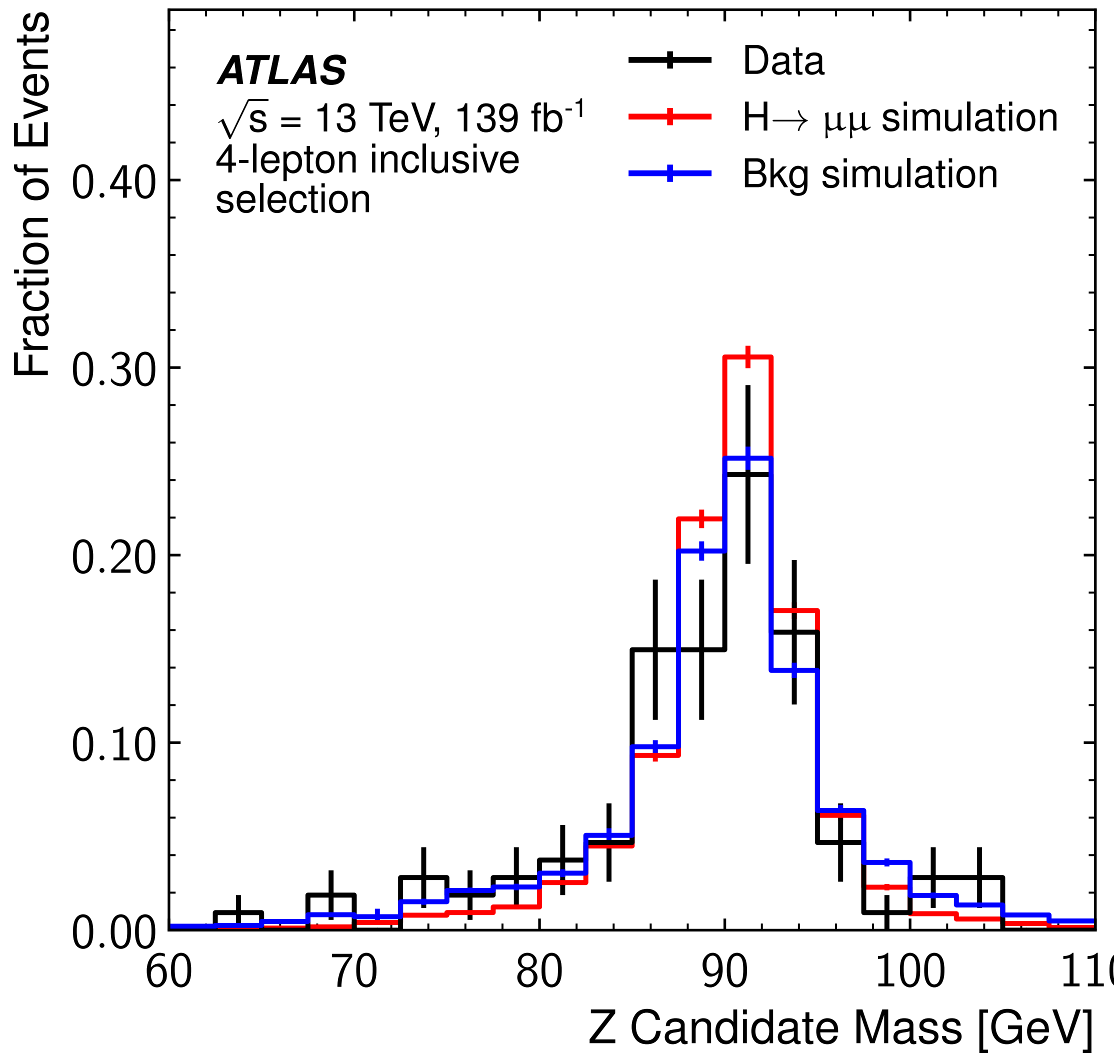


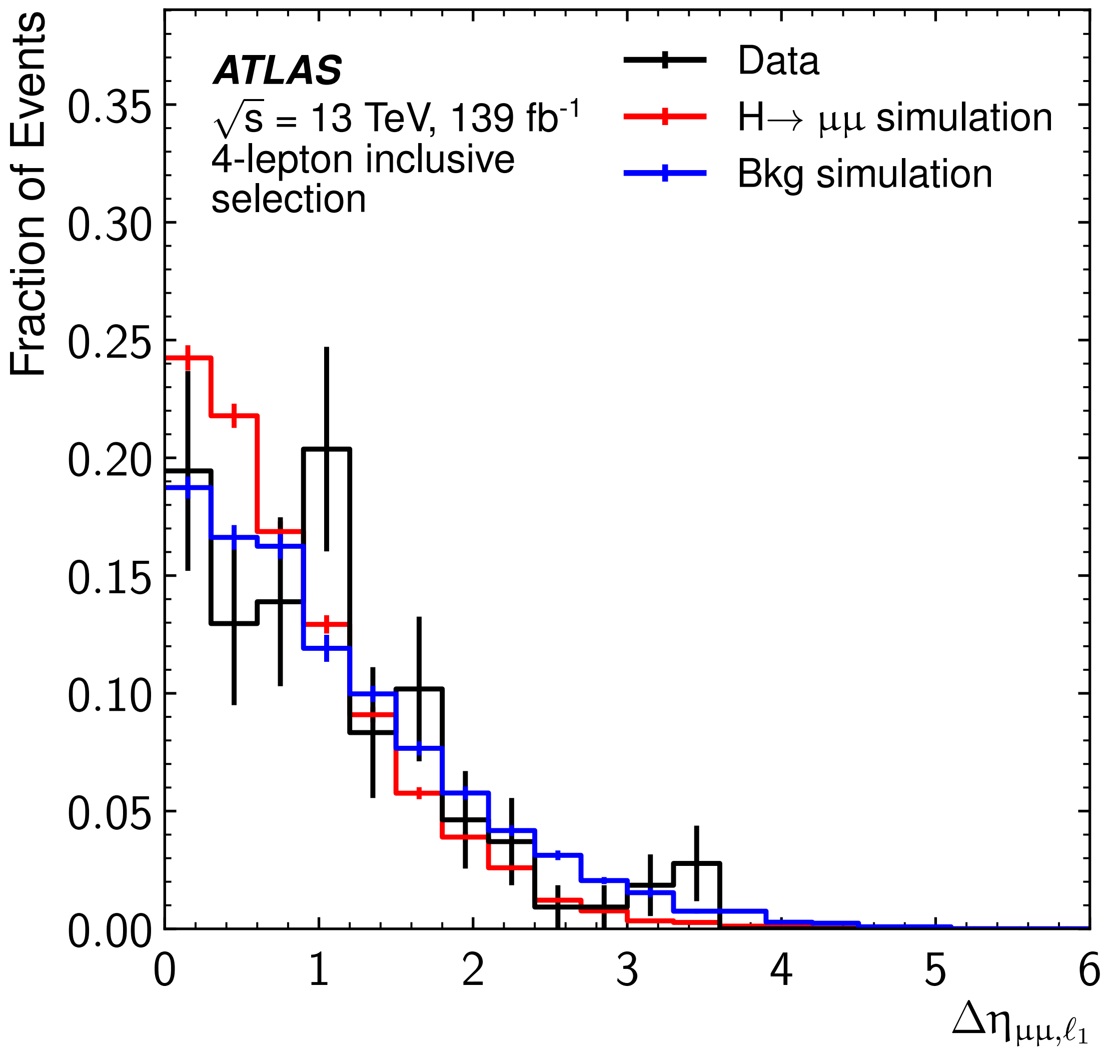
VH 3-lepton BDT Training Variables

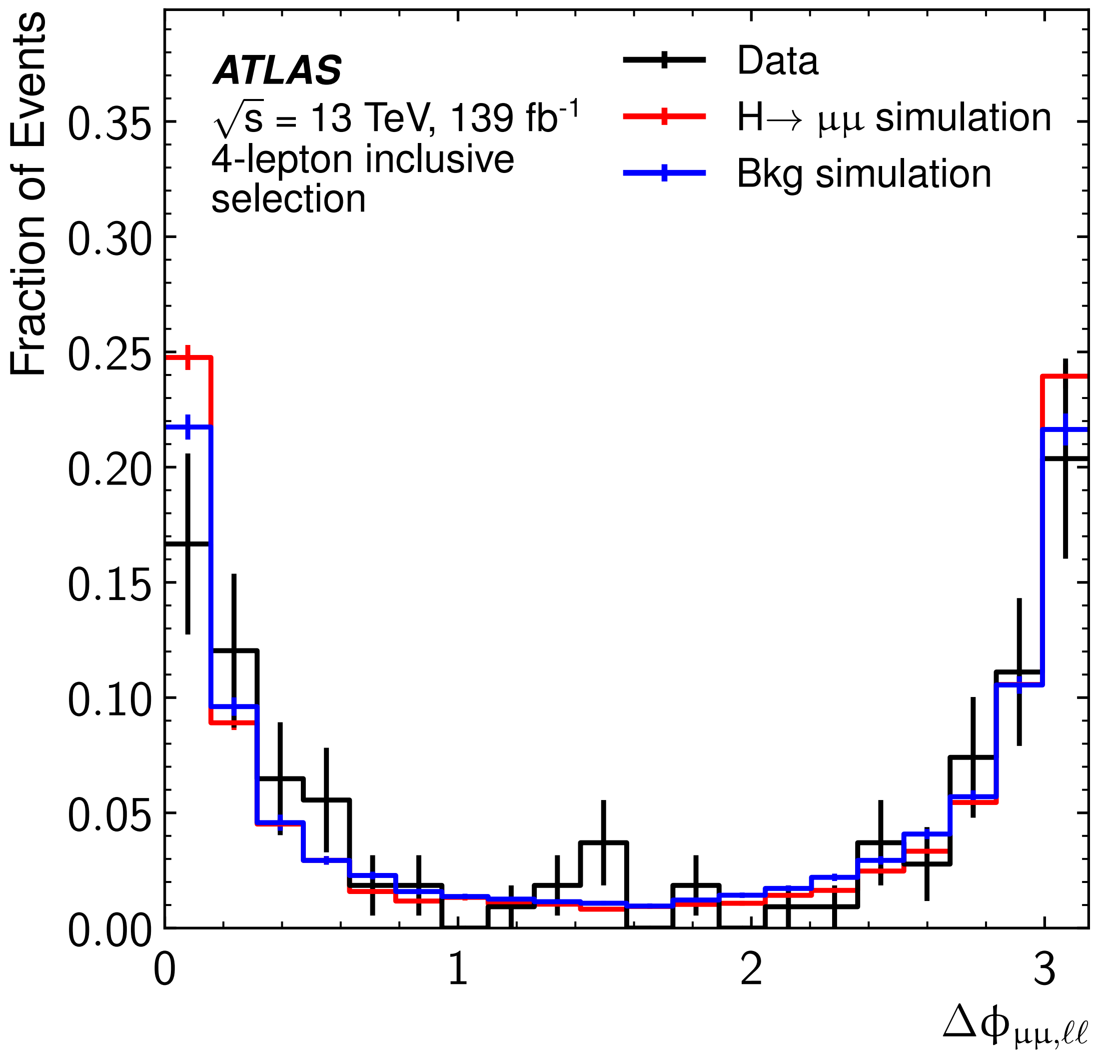


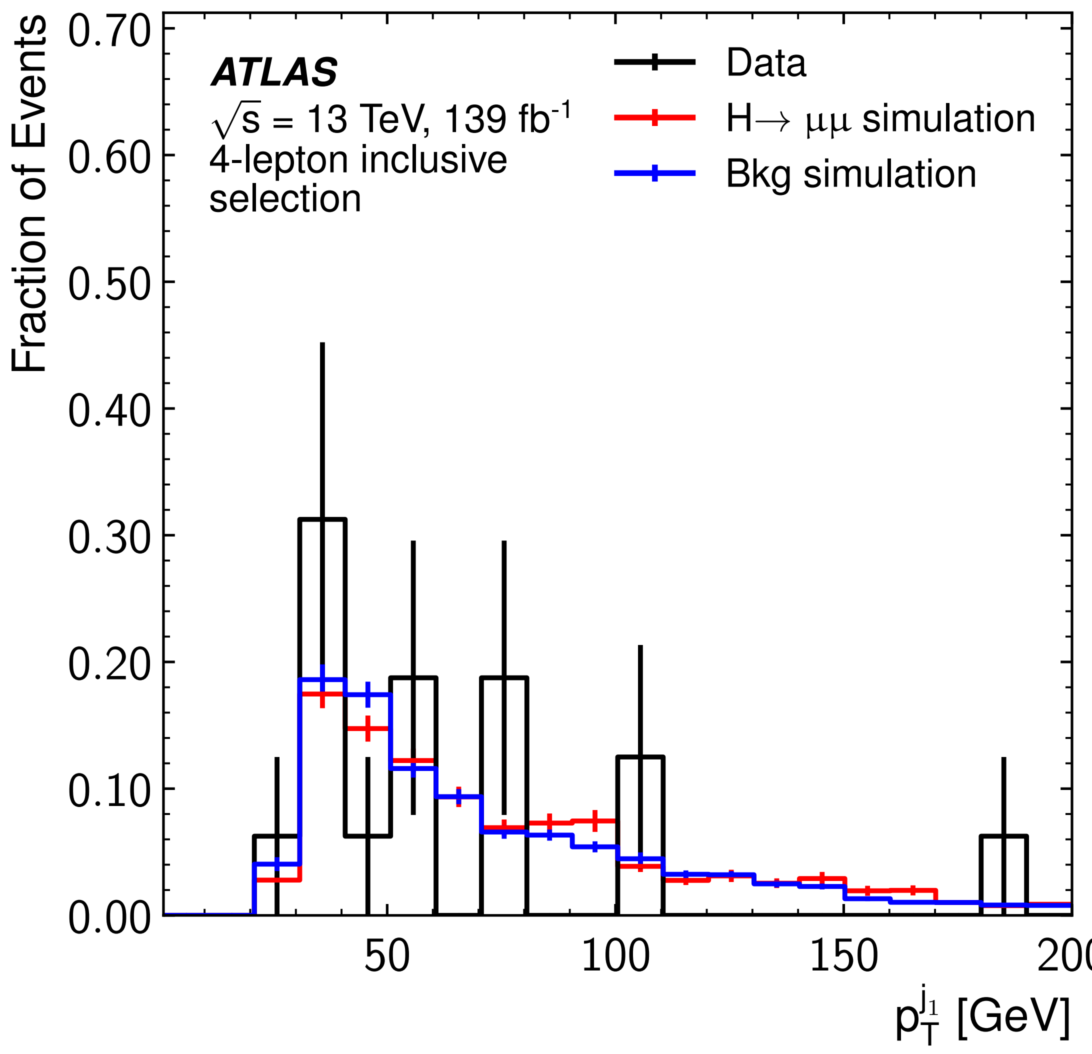
VH 4-lepton BDT Training Variables

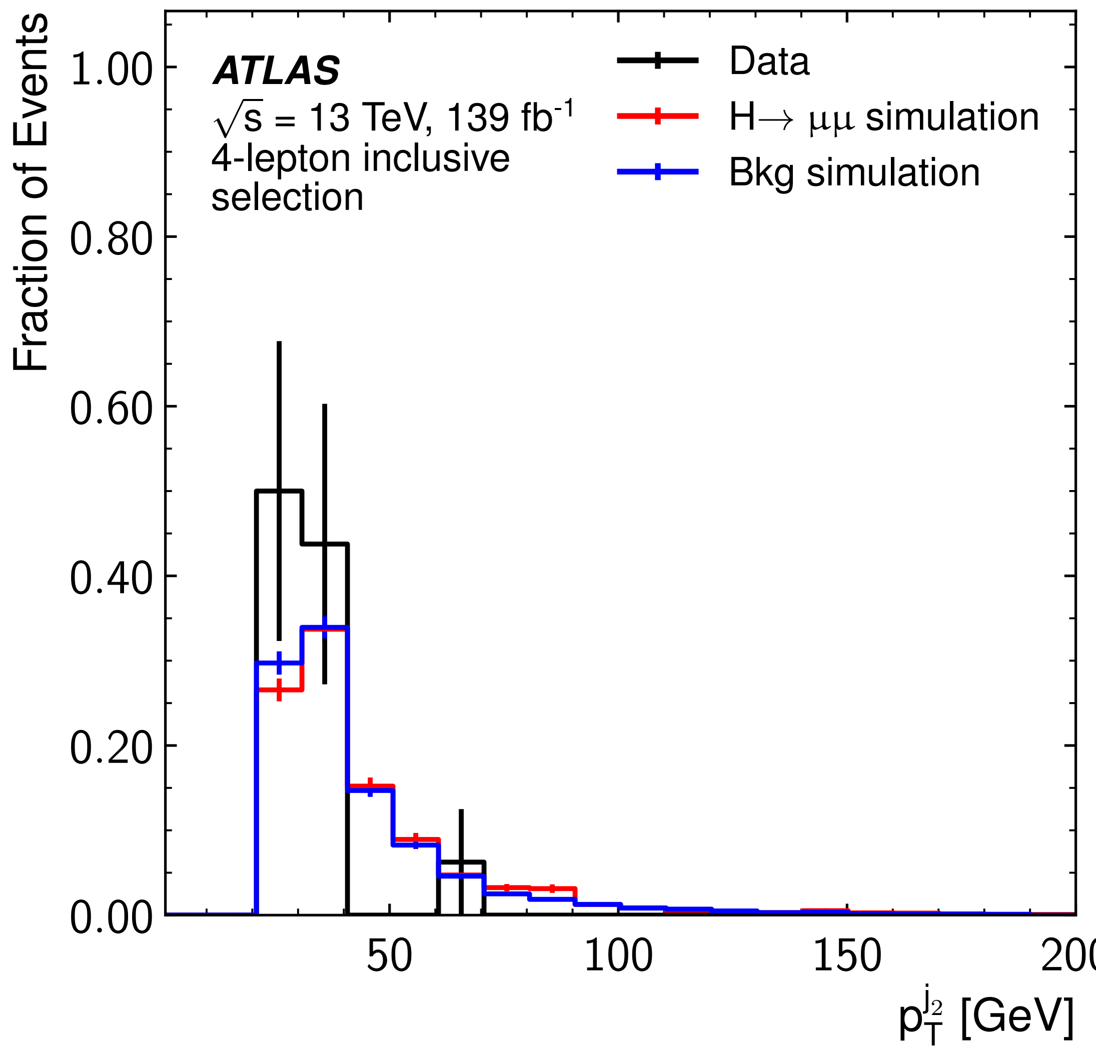


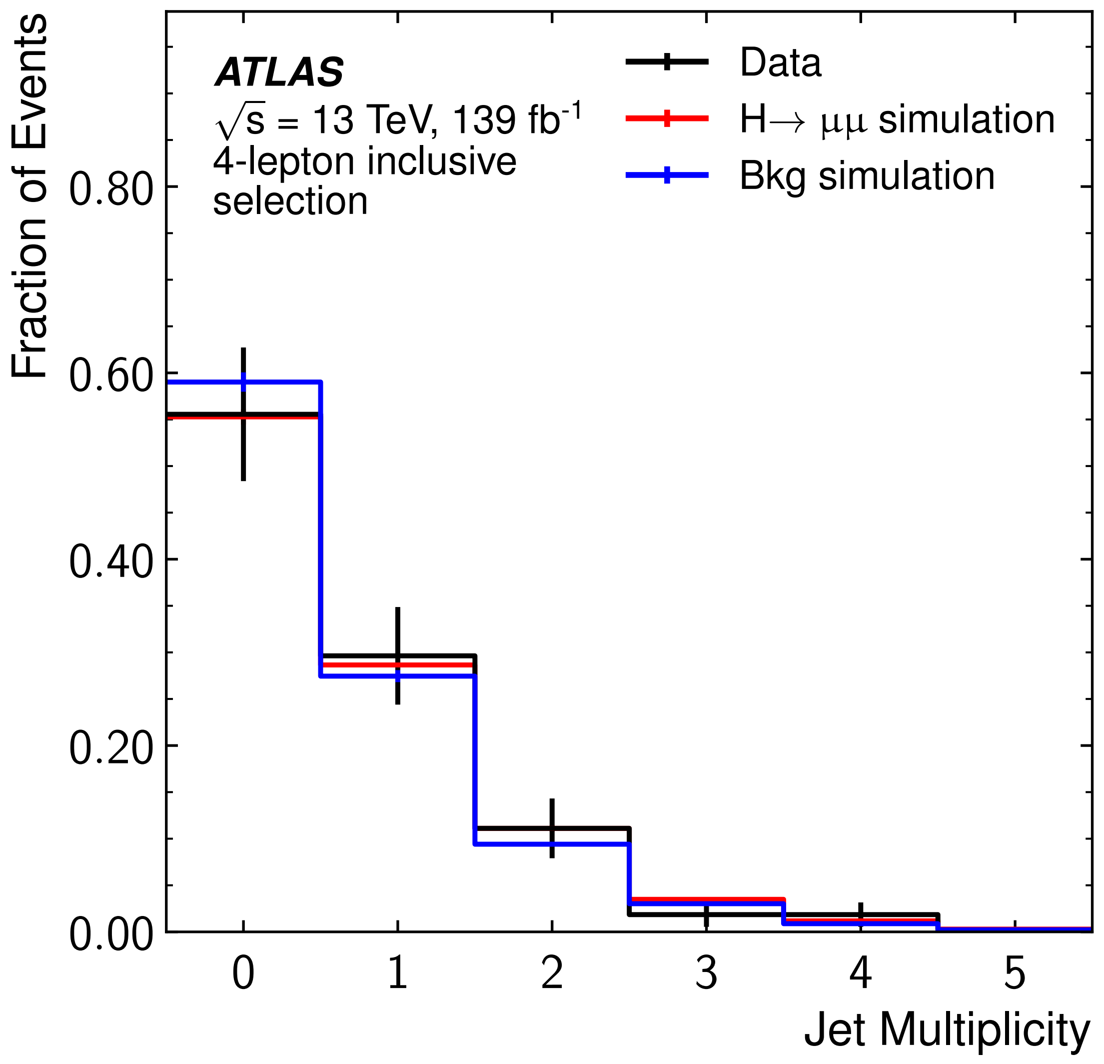






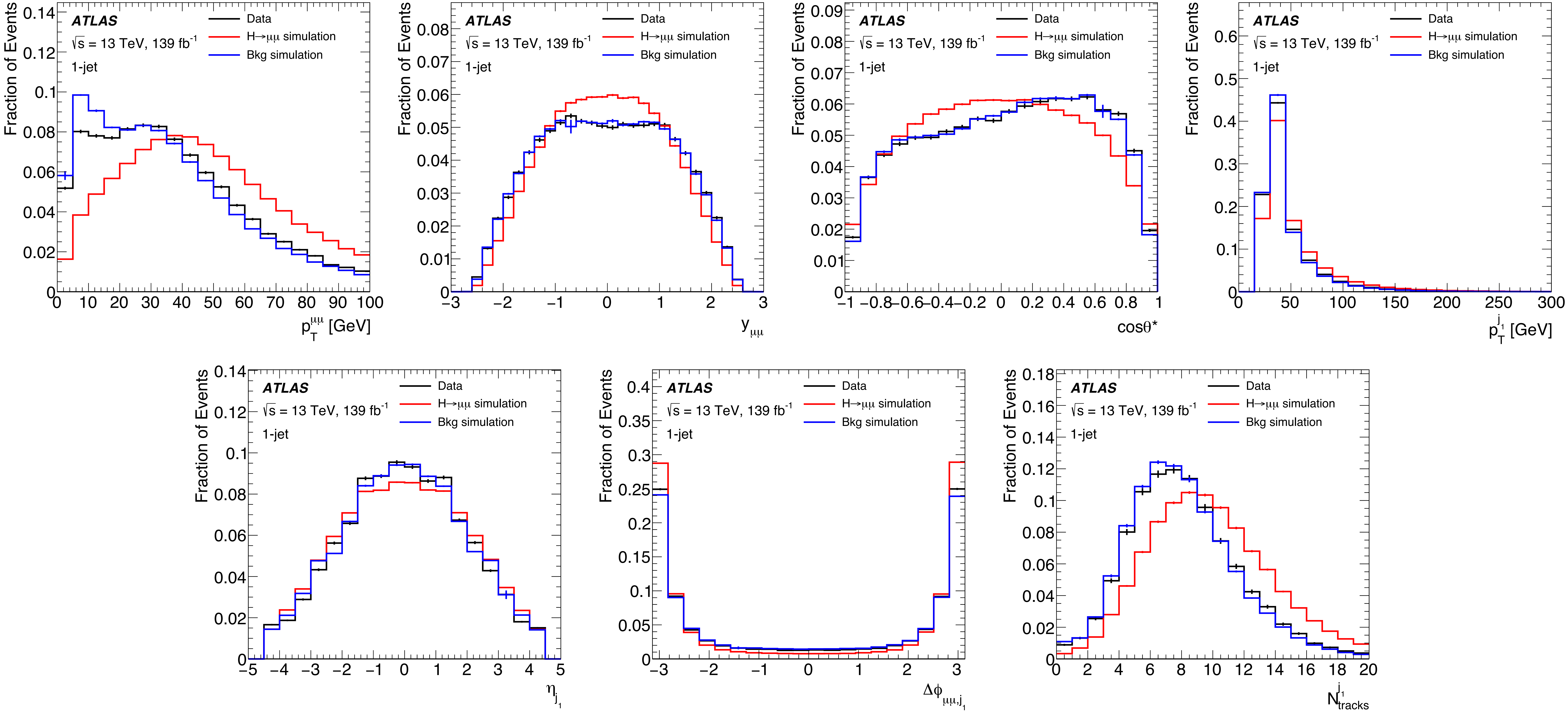




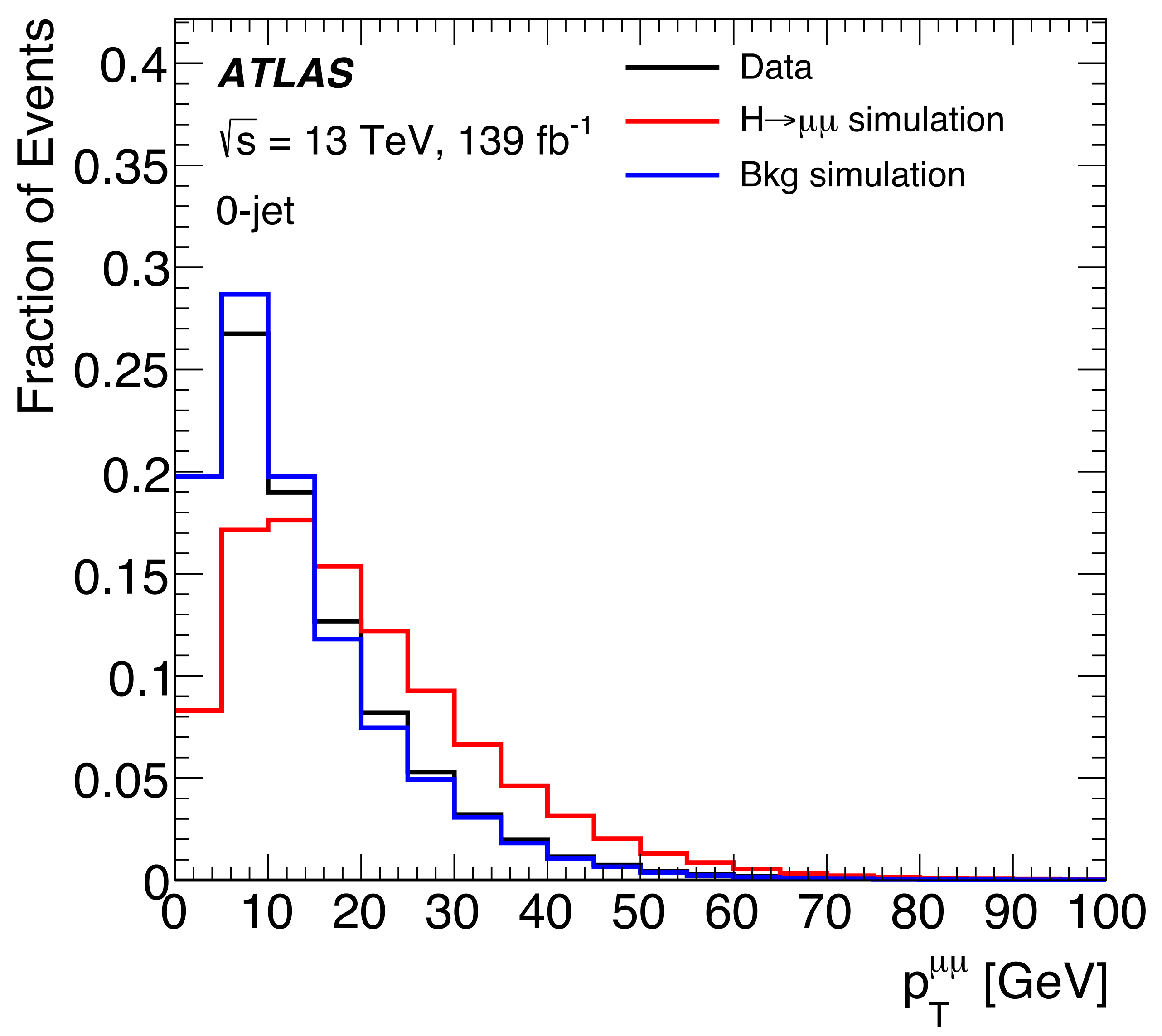


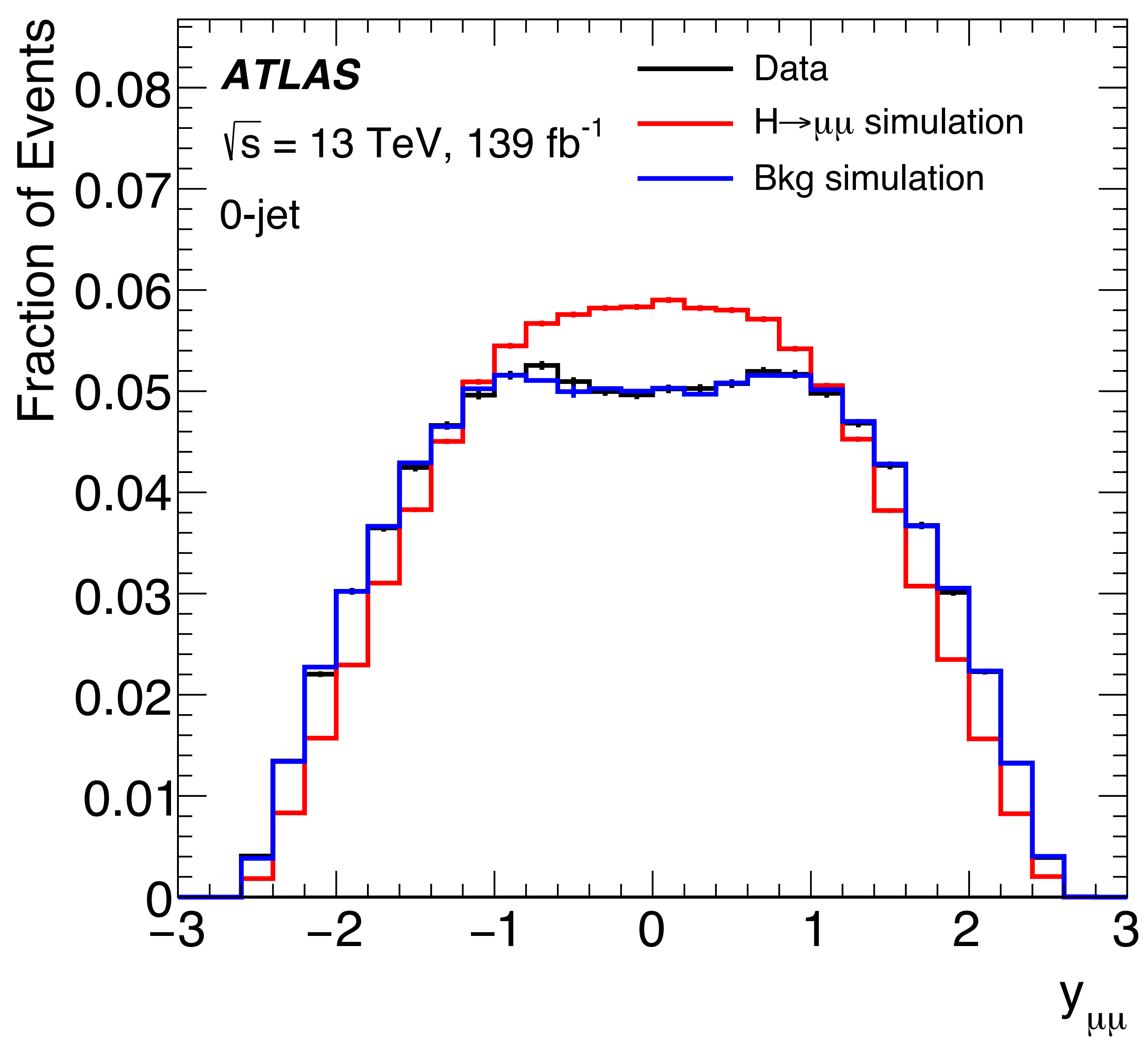
2-jet BDT Training Variables

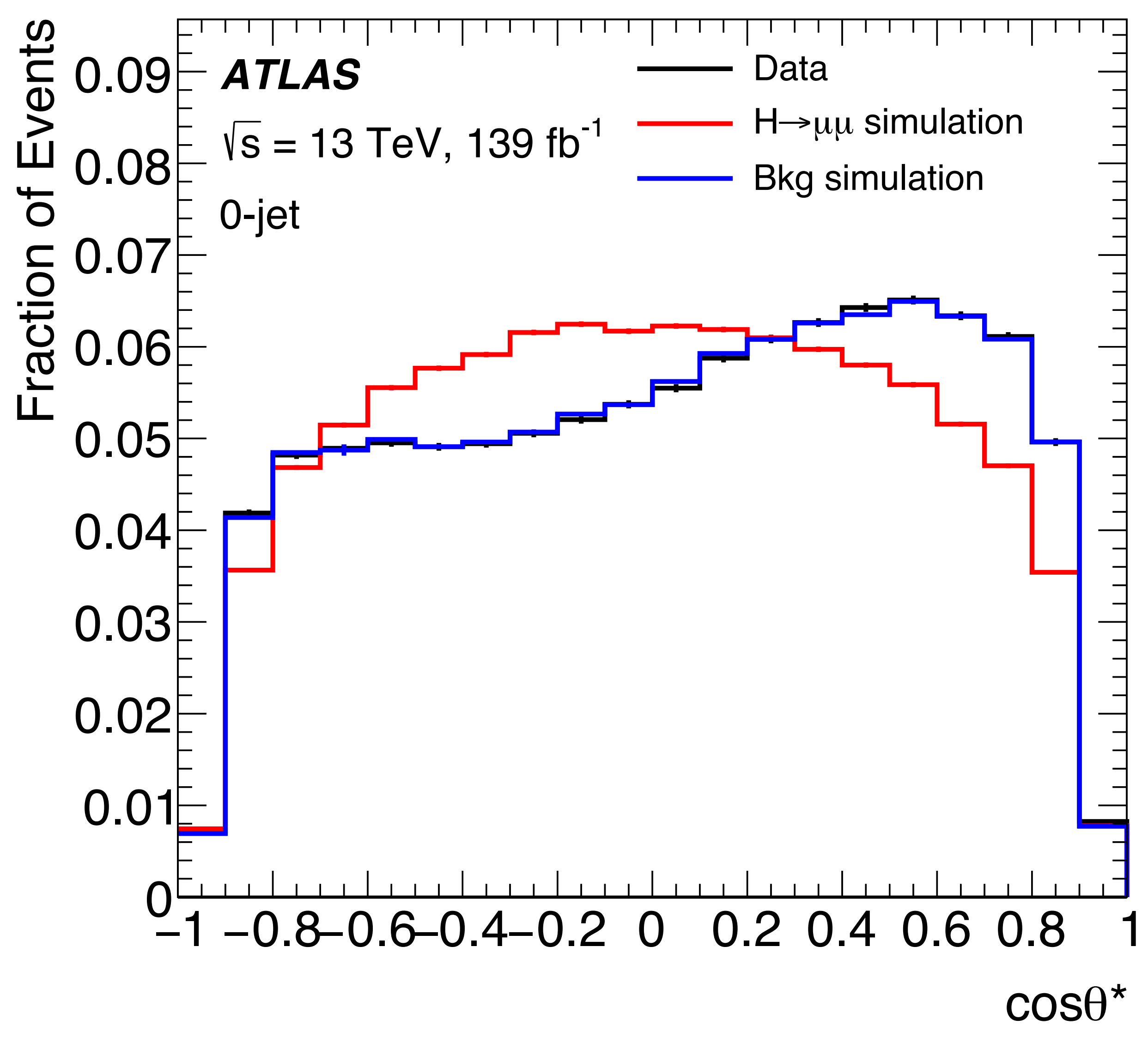
1-jet BDT Training Variables



0-jet BDT Training Variables







Signal plus Background fits with μ = 1.2