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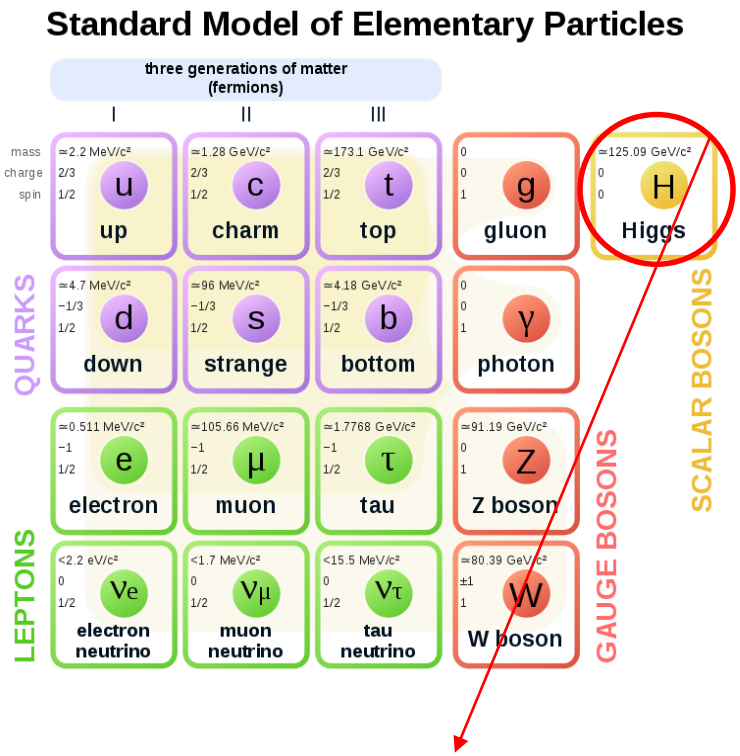
Measurement of Higgs bosons decaying to Tau lepton pairs and Constraints on Anomalous HVV couplings.

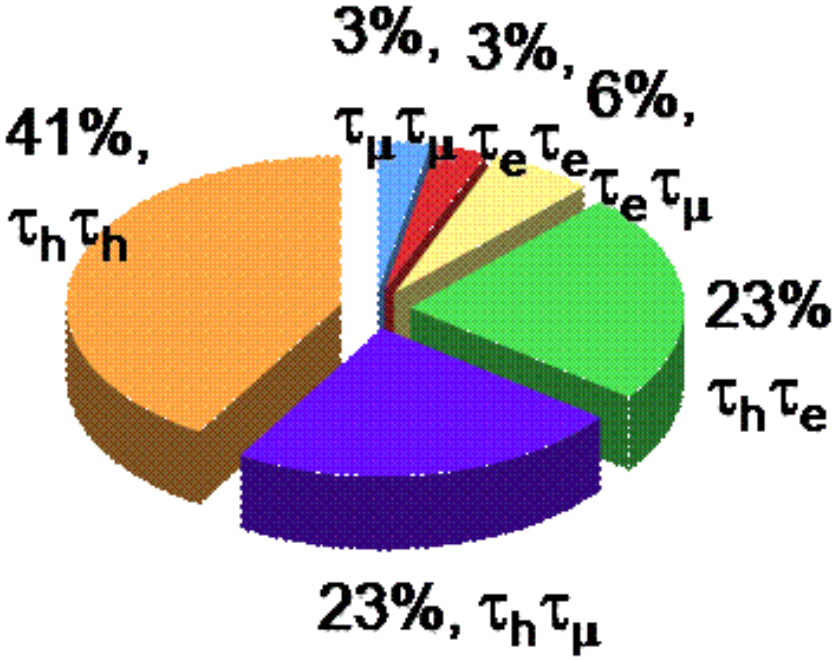
Sam Higginbotham

The Higgs Boson and Taus

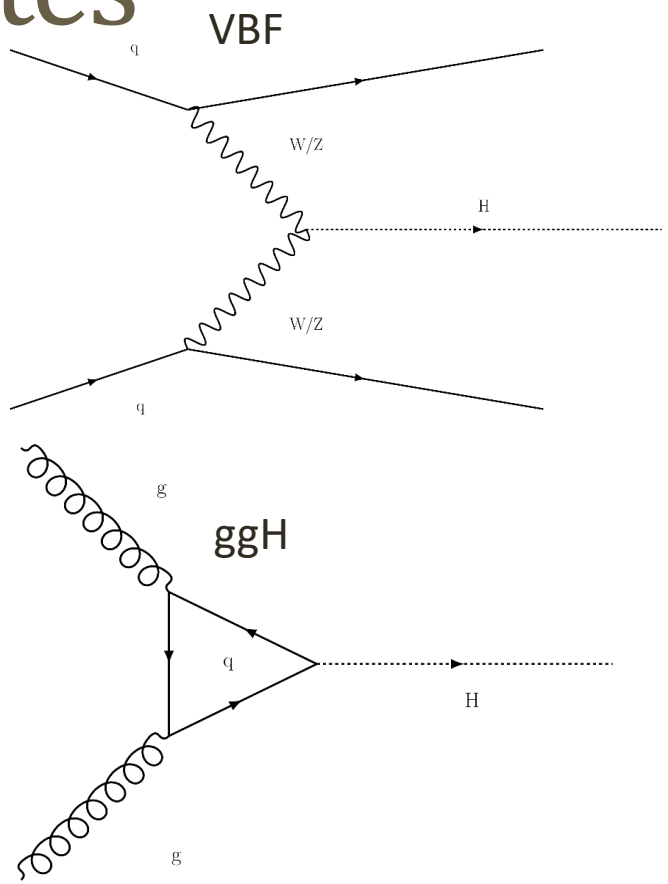


- Use taus to investigate properties of the Higgs:
  - Good Branching Fractions
  - Excellent online selection
  - Higgs couples to mass. Tau is the most massive lepton

- Tau Identification:
  - Tau Decays **hadronically** (τ_h) and **leptonically**
  - Hadron Plus Strips to identify π's in τ_h decays



Signals and Final States



- Production Mechanisms:
  - Vector Boson Fusion (**VBF**)
  - Gluon Gluon Fusion (**ggH**)

- Final States

$$\tau_h\tau_h \ , \ e\tau_h \ , \ \mu\tau_h \ , \ e\mu$$

- Main Backgrounds:
  - QCD background
  - Drell – Yan
  - $t\bar{t}$

- Challenges:
  - Jets faking taus
  - Leptons faking taus

Event Categorization and Fit Model

- 3 Event Categorizations:
  - For a final fit, most categories and channel use a **2D fit** in the limits to extract **significance for the mass of the ττ system**
- **0-jet category** is used to **constrain backgrounds**, VBF and Boosted for signal extraction
  - Shown below is the 0-jet category for each channel

Categorization	$\tau_h\tau_h$	$\mu\tau_h$	$e\tau_h$	$e\mu$
0 - Jet	$m_{\tau\tau}$	m_{vis}:τ_{DM}	m_{vis}:τ_{DM}	m_{vis}:μ_{pt}

  - 0-jet criteria: no jet > 30 GeV, |η| < 4.7, and loose particle flow I.D.

eμ and $\tau_h\tau_h$ **don't resonate sharply around Z** … for $\tau_h\tau_h$ 1D is used for high pt threshold

0jet has **better separation in visible mass**

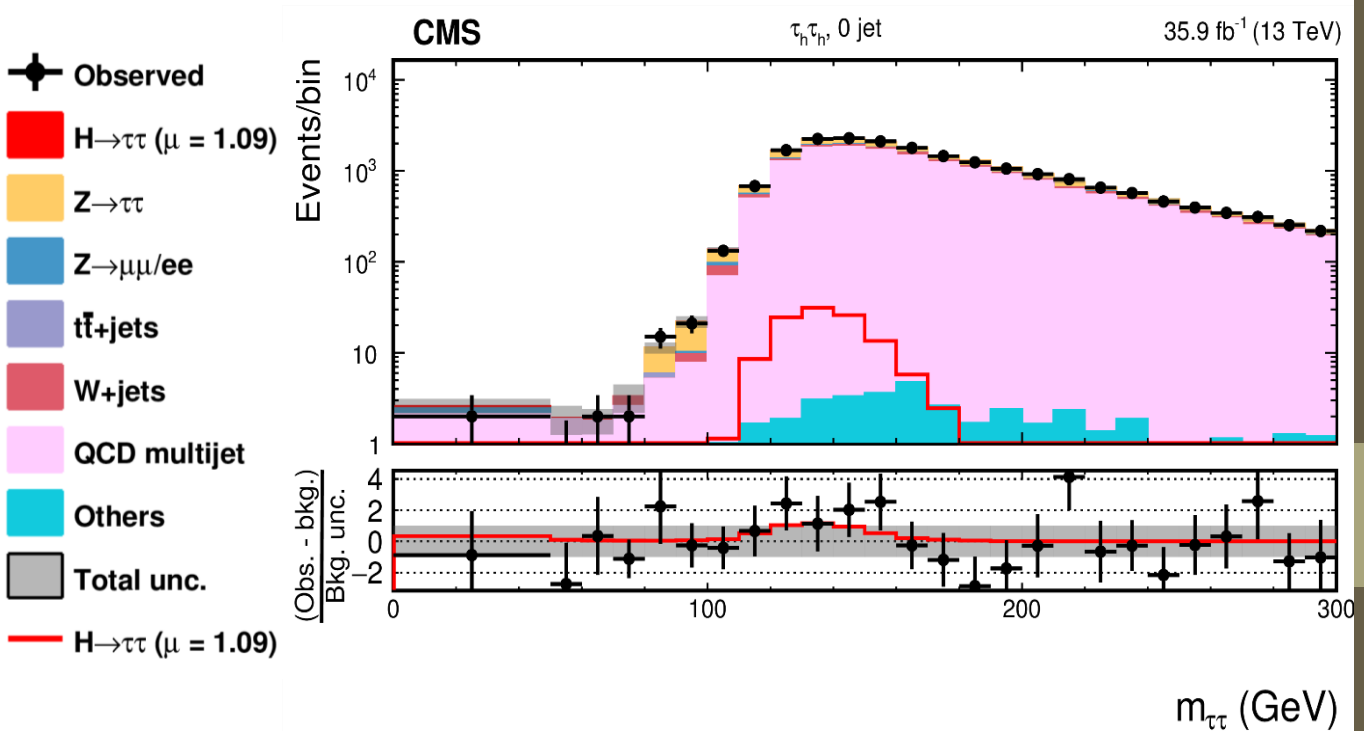
Background Methods

- Several **Control Regions** (CR) are used to measure background for W+Jets, Z+Jets, $t\bar{t}$, and **QCD**

Opposite Sign	QCD Sig	OS Loose
Same Sign	SS Tight	SS Loose
	$\tau_{h:1,2}$ Isolated	$\tau_{h:1}$ anti-Iso $\tau_{h:2}$ anti-Iso

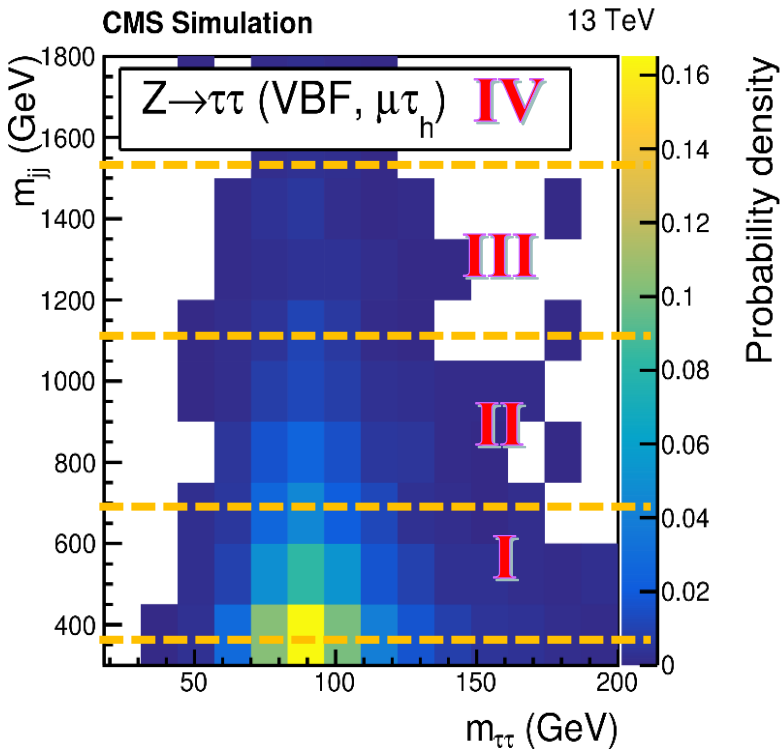
$$\text{QCD} = \text{O.S. Loose Iso.} \times \left(\frac{\text{S.S. Sig. Iso.}}{\text{S.S. Loose Iso.}} \right)$$

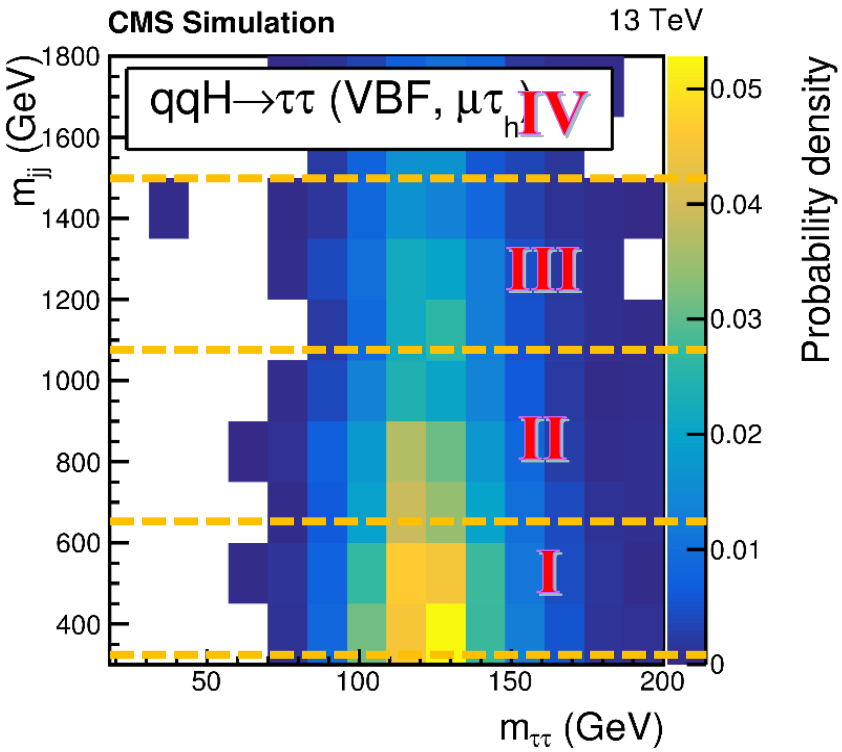
- QCD yield estimated in **sideband region**
- $m_{\tau\tau}$ in the 0 jet category shows QCD dominance



Unrolled Distributions $m_{\tau\tau}$:m_{jj}

- 2D categories are **split** and **unrolled**, VBF category in the $\mu\tau_h$ channel shown
- The Z and Higgs are well **separated** with the Z at 90 GeV and Higgs at 125 GeV





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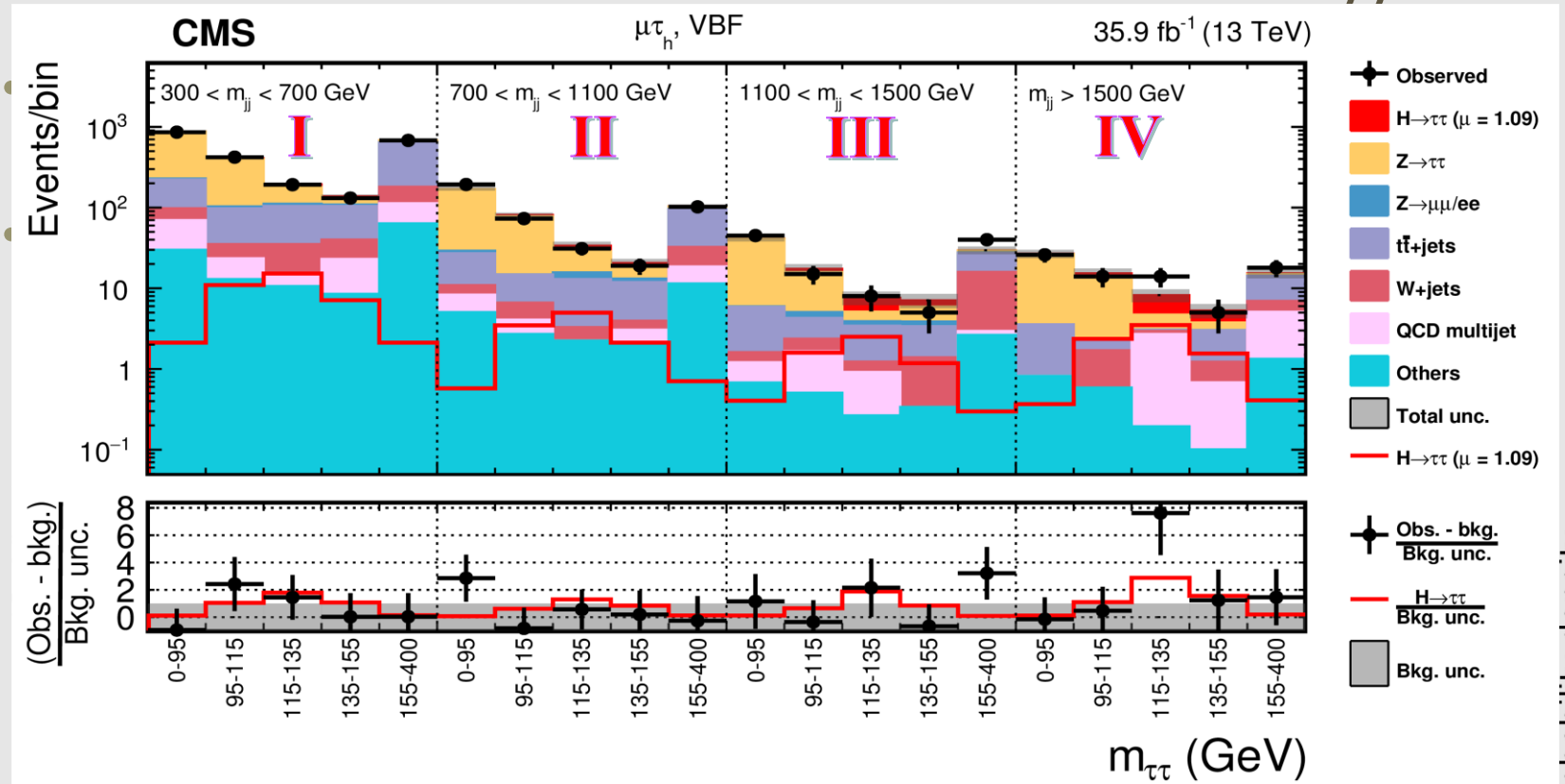
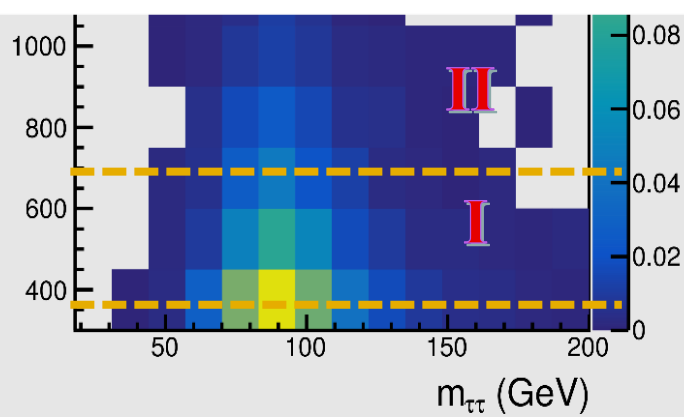
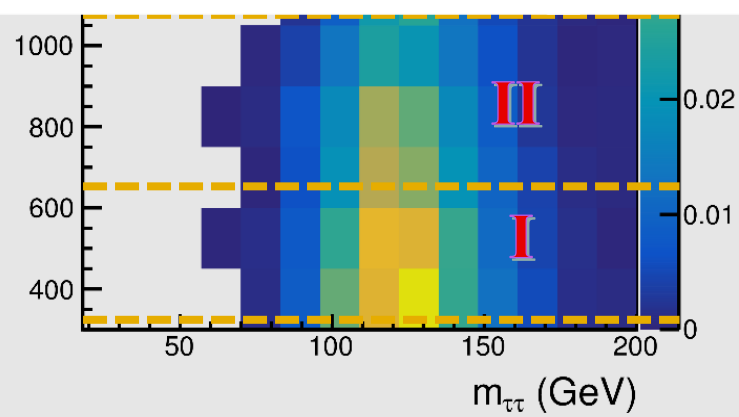
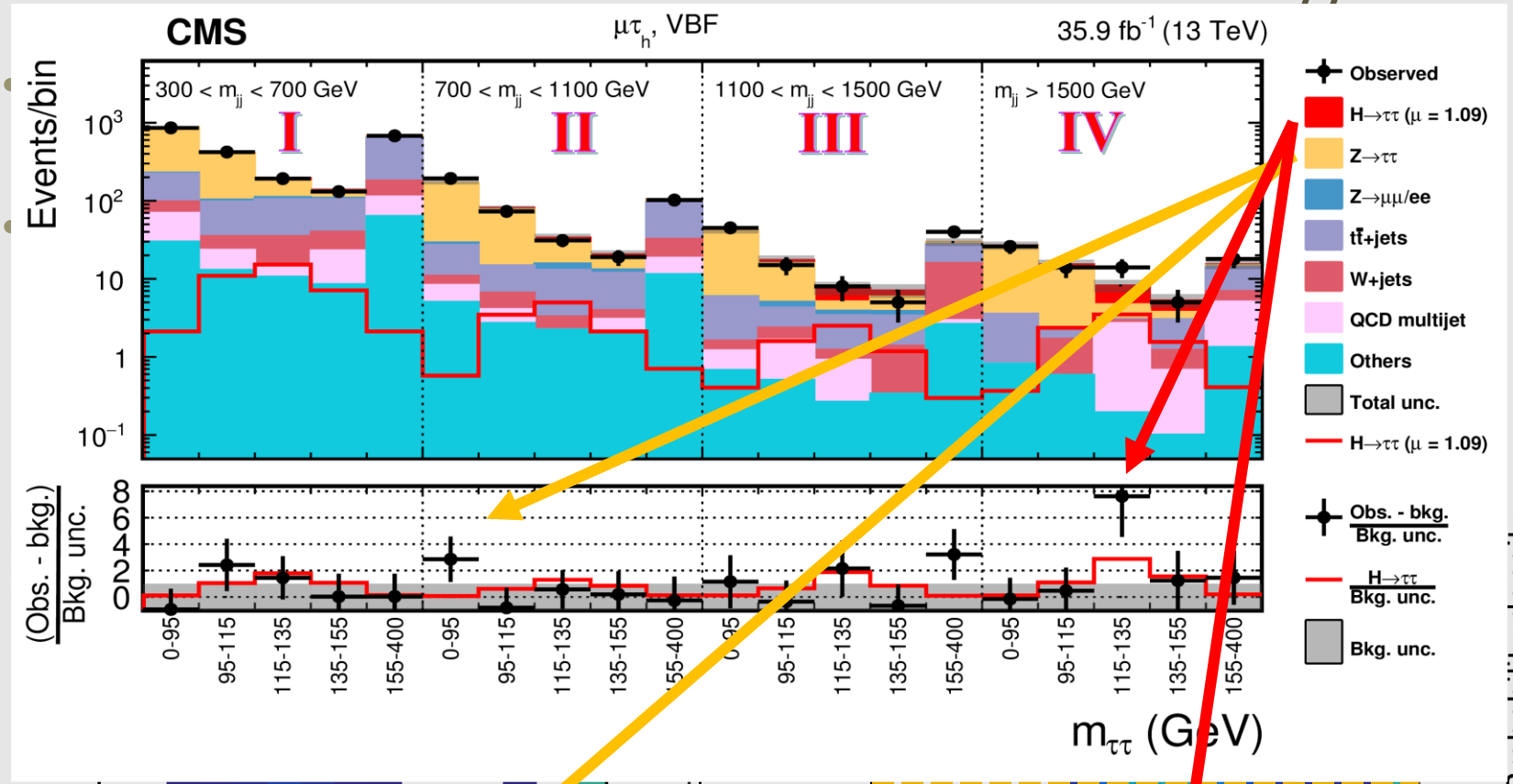


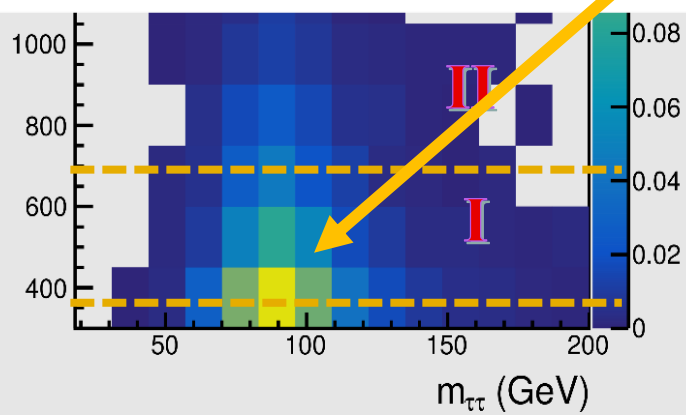


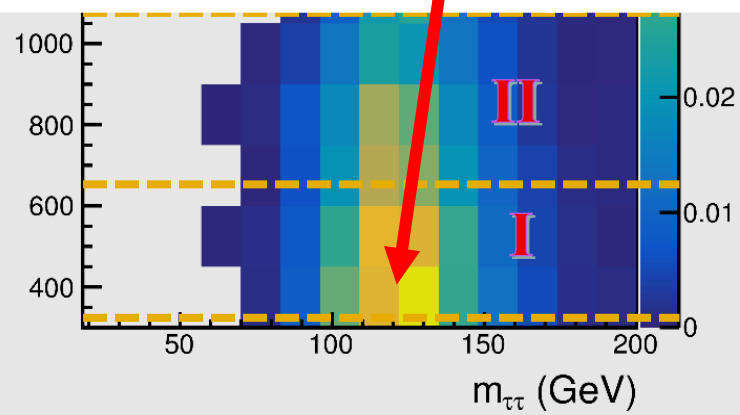


Probability density

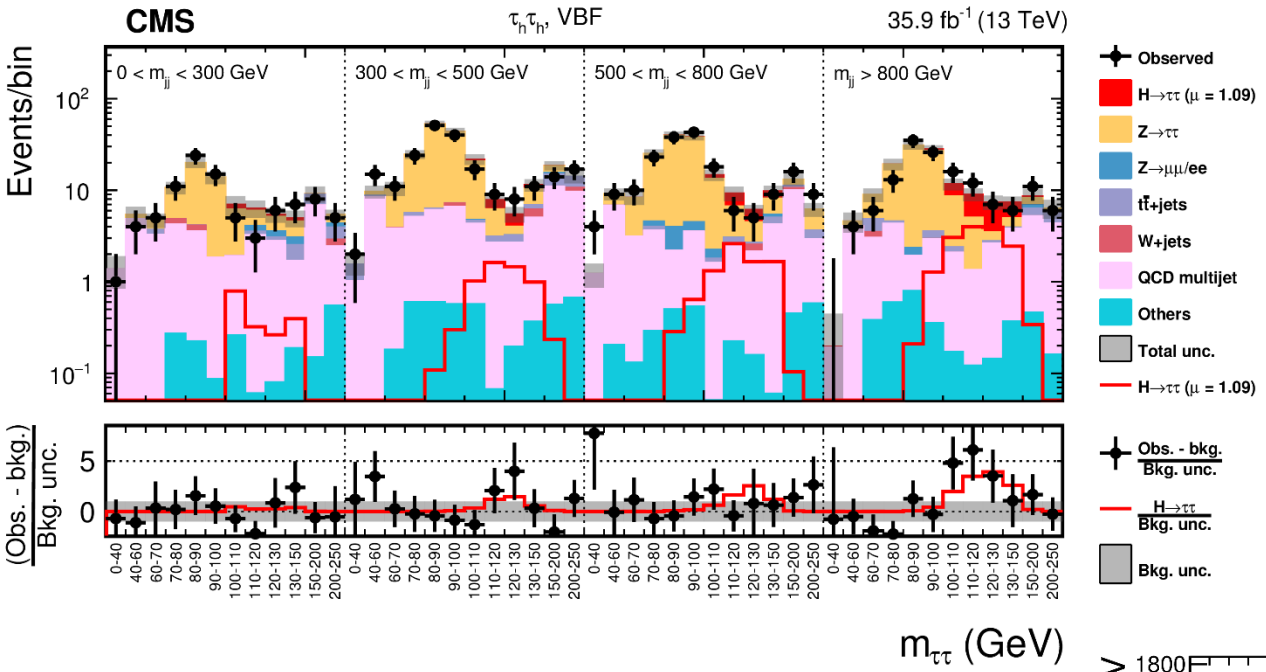
Unrolled Distributions $m_{\tau\tau}$:m_{jj}

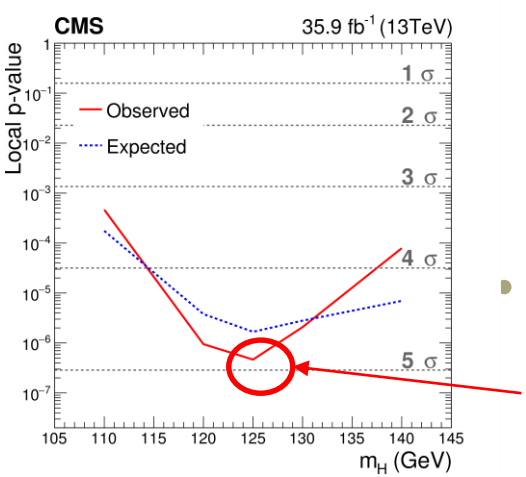




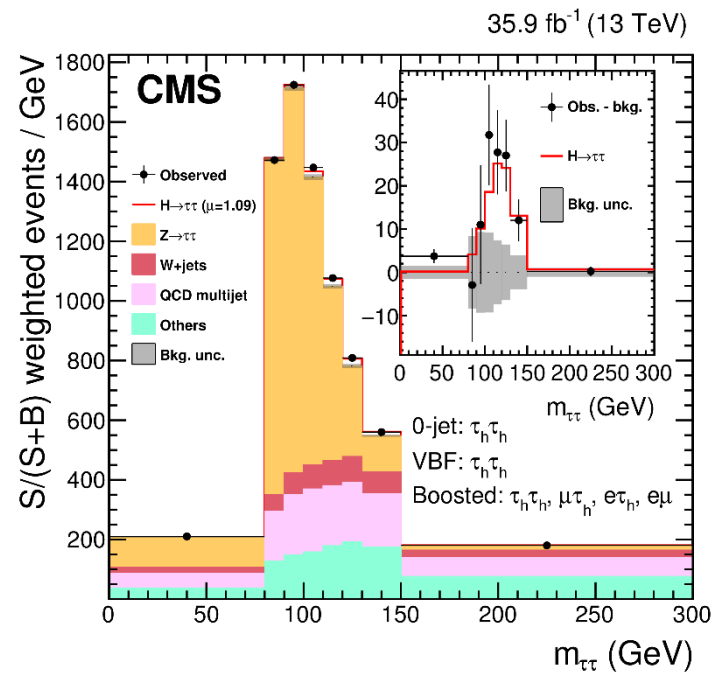


Performance of 2D Fit





- The **S/(S+B) weighted distribution** is shown on the right
- p-value scan shows **5σ** sensitivity



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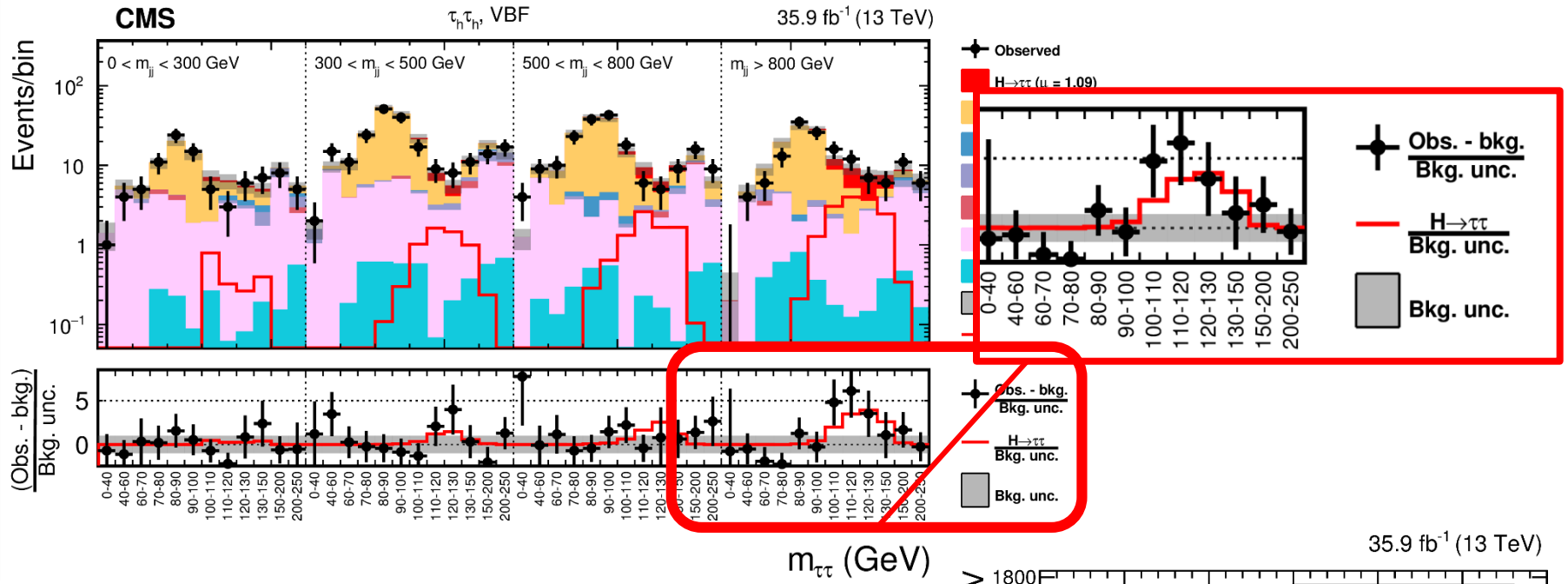

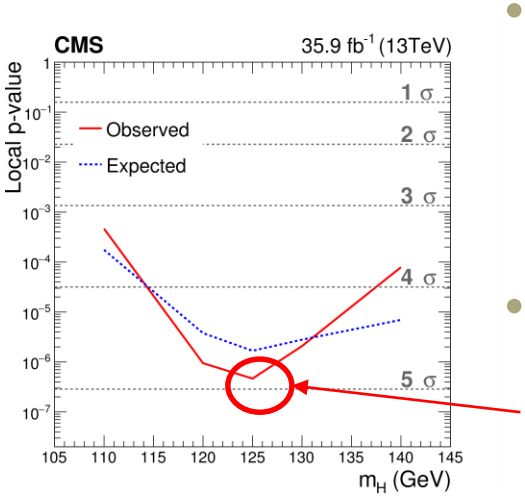

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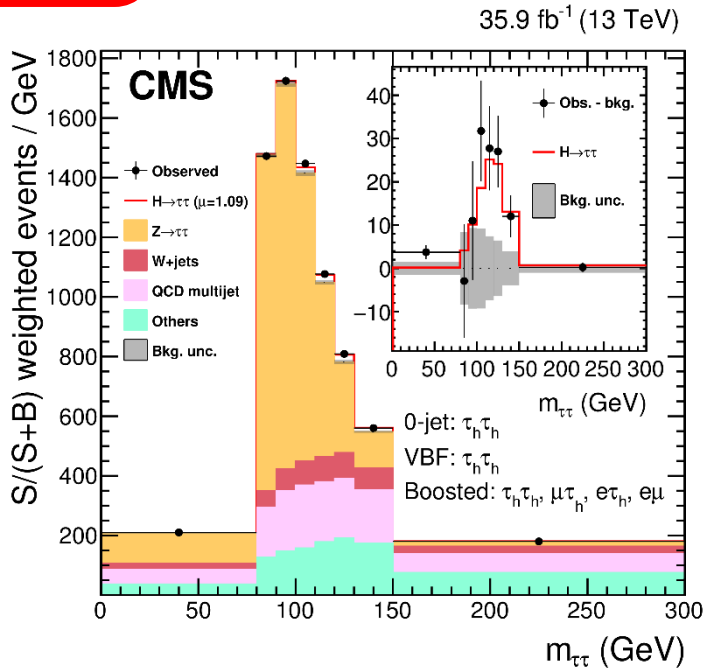
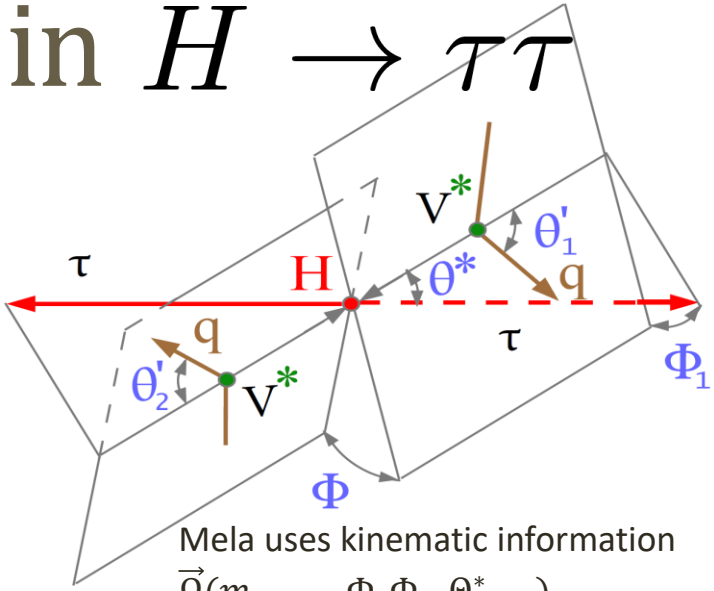
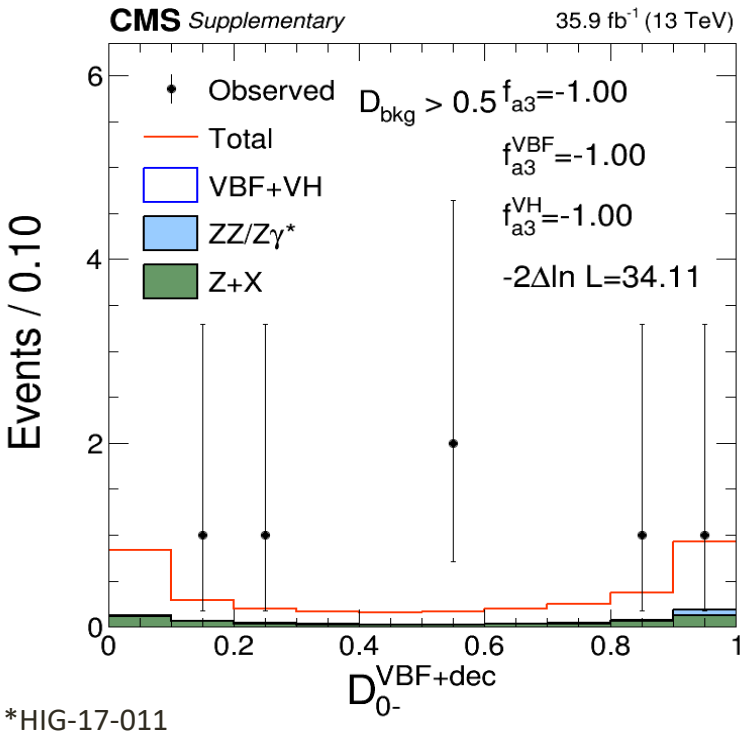


Using MELA in $H \rightarrow \tau\tau$

- Matrix Element Likelihood Analysis (**MELA**) can be used to **constrain couplings** in HVV processes such as Higgs coupling to ZZ, WW, Zγ, γγ, and gg :



Mela uses kinematic information $\vec{\Omega}(m_{Higgs}, \Phi, \Phi_1, \Theta^*, \ldots)$ to build discriminants



*HIG-17-011

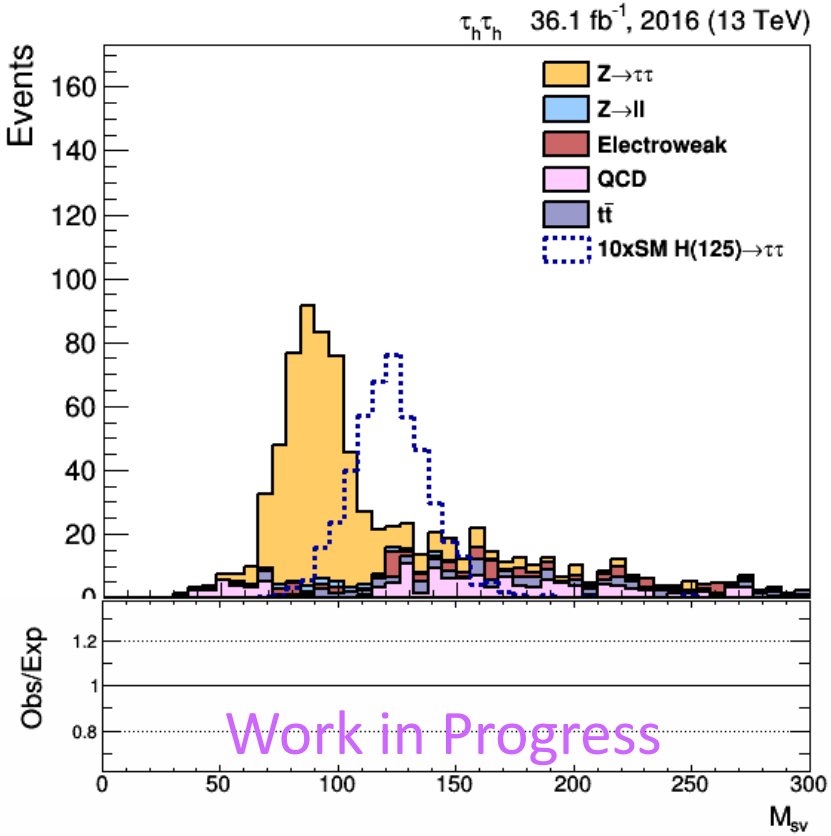
- Build **discriminant** with MELA to make an **optimal observable**

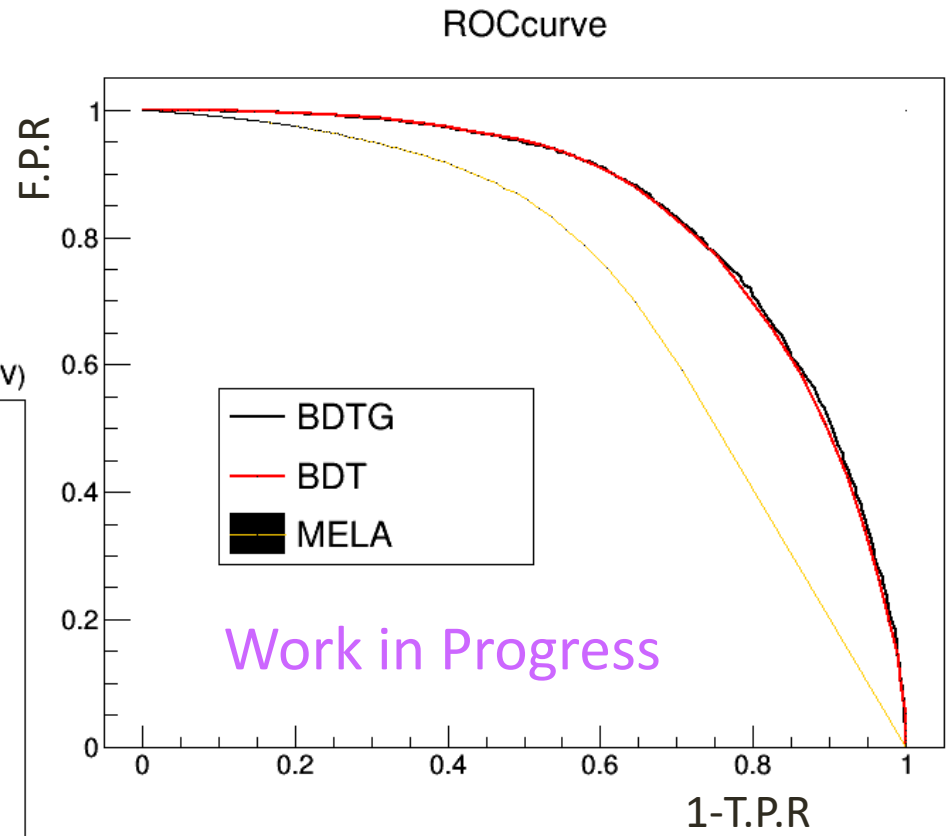
$$D_{0-} = \frac{P_{0-}}{P_{0+} + P_{0-}}$$

- For the future, use discriminant in conjunction with **Machine Learning for 2D or 3D fit**!

Future Studies

- We may use **Machine Learning** and **MELA** in the final 2D or 3D fit.





- R.O.C. Curve with BDTs trained in VBF category
- M_{SV} shown after preliminary BDT cut in Boosted Category

References

- CMS Detector Public Page: Link
- HIG-17-011 Observation of the SM scalar boson decaying to a pair of tau leptons with the CMS experiment at the LHC, CMS PAS HIG-16-043 Link
- Constraints on anomalous Higgs boson couplings using production and decay information in the four-lepton final state, HIG-17-011 Link
- Constraints on anomalous HVV couplings in production of Higgs bosons decaying to tau lepton pairs, CMS CADI HIG-17-034

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Thank you

Backup

Full Event Categorization and Fit Model

- 3 Event Categorizations:
  - For a final fit most categories and channel use a 2D fit in the limits to extract significance for the mass of the ττ system

98% ggH signal, eμ and ττ don't resonate sharply around Z … for ττ 1D is used for high pt threshold

Categorization	ττ	μτ	eτ	eμ
0 - Jet	$m_{\tau\tau}$	m_{vis}:τ_{DM}	m_{vis}:τ_{DM}	m_{vis}:μ_{pt}
Boosted	$m_{\tau\tau}$:$Higgs_{pt}$	$m_{\tau\tau}$:$Higgs_{pt}$	$m_{\tau\tau}$:$Higgs_{pt}$	$m_{\tau\tau}$:$Higgs_{pt}$
VBF	$m_{\tau\tau}$:m_{jj}	$m_{\tau\tau}$:m_{jj}	$m_{\tau\tau}$:m_{jj}	$m_{\tau\tau}$:m_{jj}

0jet has better separation in visible mass. Low DY lepton faking tau in 3-prong DM.

The signal/background of the Higgs increase as a function of HiggsPt.

The signal/background of the Higgs increase as a function of di-jet invariant mass

- $m_{\tau\tau}$ is precisely measured using SV-Fit