Search for the Standard Model Higgs Boson Decaying to $\mu^+\mu^-$ in pp Collisions at $\sqrt{s} = 7$ and 8 TeV with the CMS Detector

CMS-PAS-HIG-13-007

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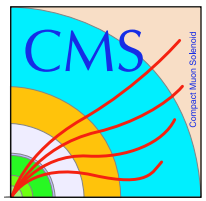


Outline

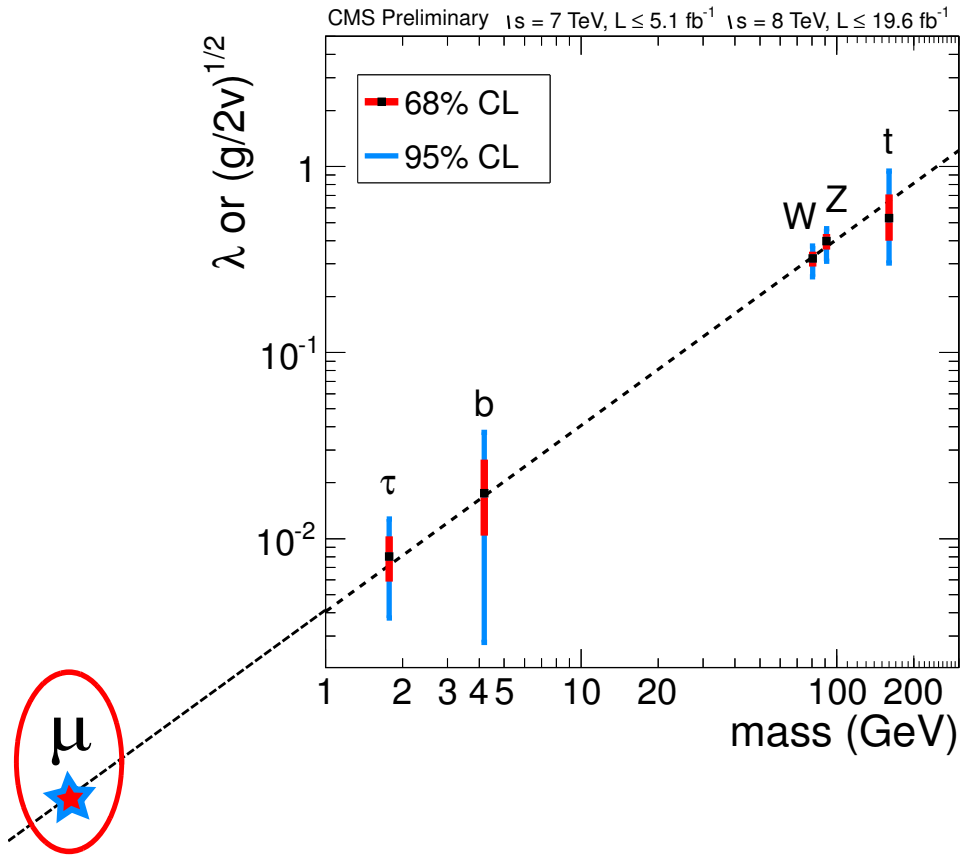
- Motivation
- Outline of the Search
- Results
- Conclusions

Motivation

Why Search for $\mathbf{H \to \mu^+\mu^-}$?

- Smallest Coupling Directly Observable at LHC
- Probe 2nd Generation Fermion Coupling
- Precisely Predicted in SM
- Enhanced in Some New Physics Models CMS-PAS-HIG-12-011
- Very Clean Final State

Narrow Signal Peak on a Smoothly Falling Background



CMS-PAS-HIG-13-005

Search Overview

- Analyze $5.0 \pm 0.1\,\text{fb}^{-1}$ at 7 TeV & $19.7 \pm 0.5\,\text{fb}^{-1}$ at 8 TeV
- Select Events with Single Isolated Muon Trigger
- Require 2 High-p_T Isolated Opposite-Sign Muons
- Divide Events into 2 Categories:
  - 0 or 1-Jet:
    - Large Acceptance for Gluon Fusion (GF) Higgs
  - $\geq$ 2-Jet:
    - Larger S/B for Vector Boson Fusion (VBF) Higgs
- Further Sub-Categorize To Increase Sensitivity
- For each Sub-category, Perform Unbinned Shape Fit
  - Signal Yield & Shape Estimated from MC Corrected to Data
  - Background Yield & Shape Fit to Data

0,1-Jet Sub-Categories

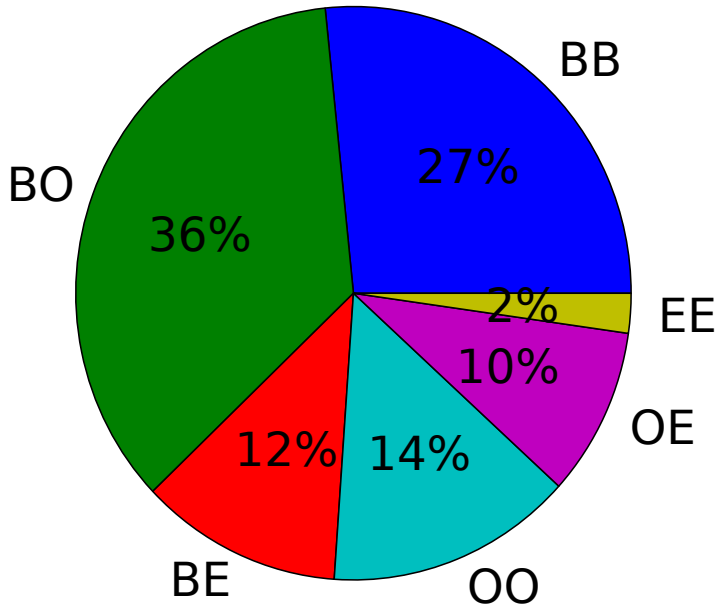
First, Split by $p_T(\mu\mu)$

- 0,1-Jet Tight: $p_T(\mu\mu) \geq 10\,\mathrm{GeV/c}$
- 0,1-Jet Loose: $p_T(\mu\mu) < 10\,\mathrm{GeV/c}$
- Reduced Drell-Yan Background in 0,1-Jet Tight

Sub-categorize by Muon $|\eta|$
Based on p_T Resolution

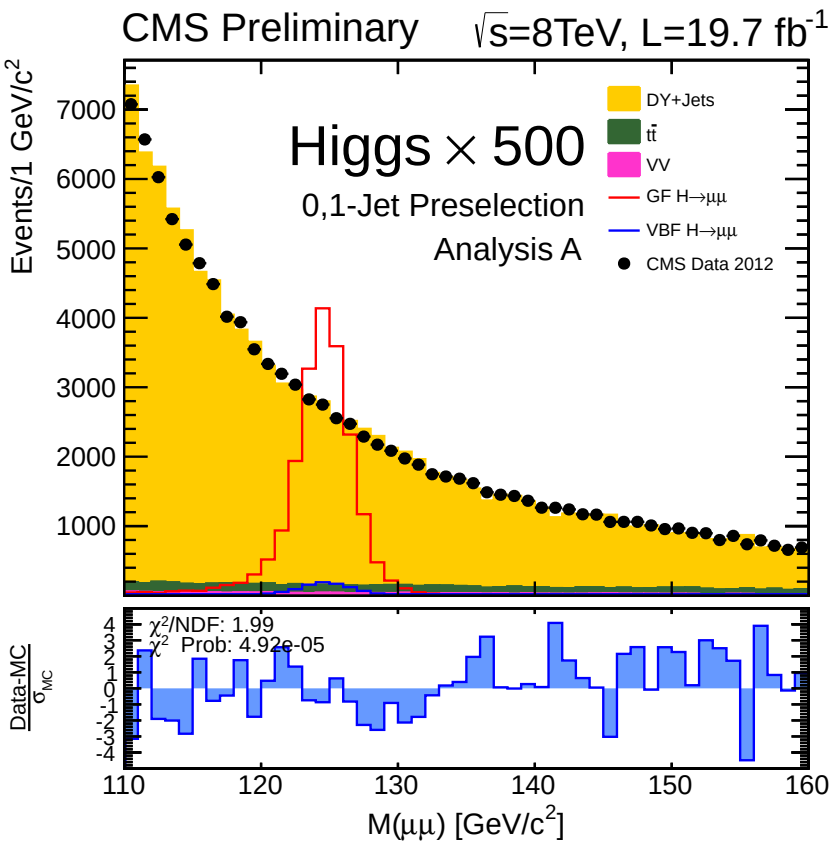
- Barrel: $|\eta| < 0.8$
- Overlap: $0.8 < |\eta| < 1.6$
- Endcap $1.6 < |\eta| < 2.1$
- Central Dimuons Have Better Mass Resolution
- Signal Peak FWHM at $m_H = 125\,\mathrm{GeV/c^2}$: 3.8-5.9 $\mathrm{GeV/c^2}$

Signal Fraction For Various Muon $|\eta|$ Categories

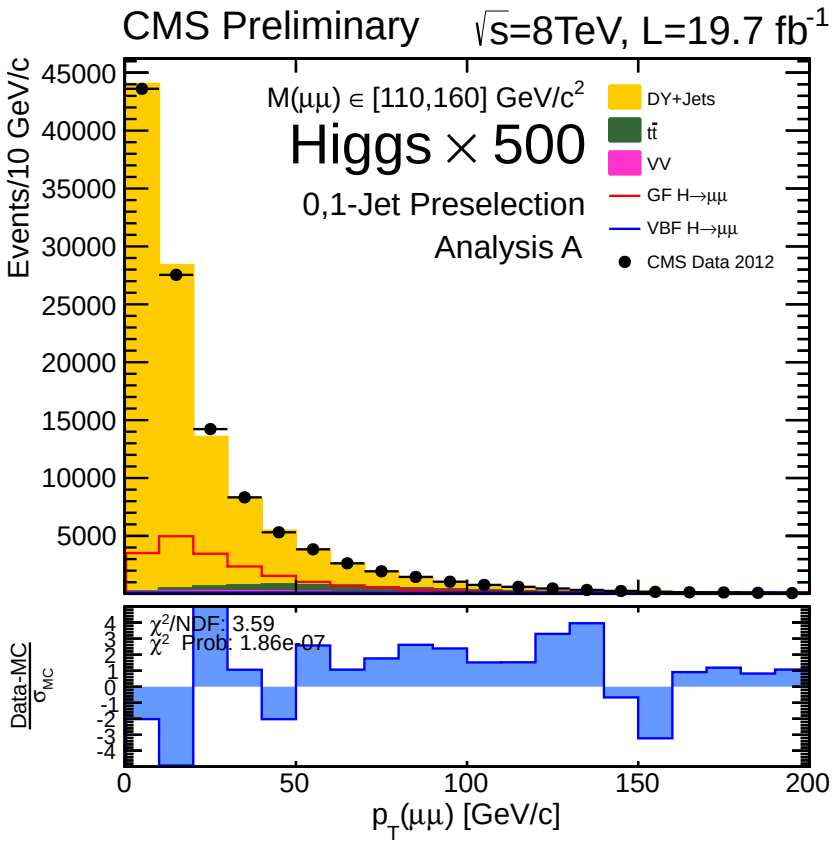


Tight BB & BO Most Powerful 0,1-Jet Categories

0,1-Jet Category Control Plots



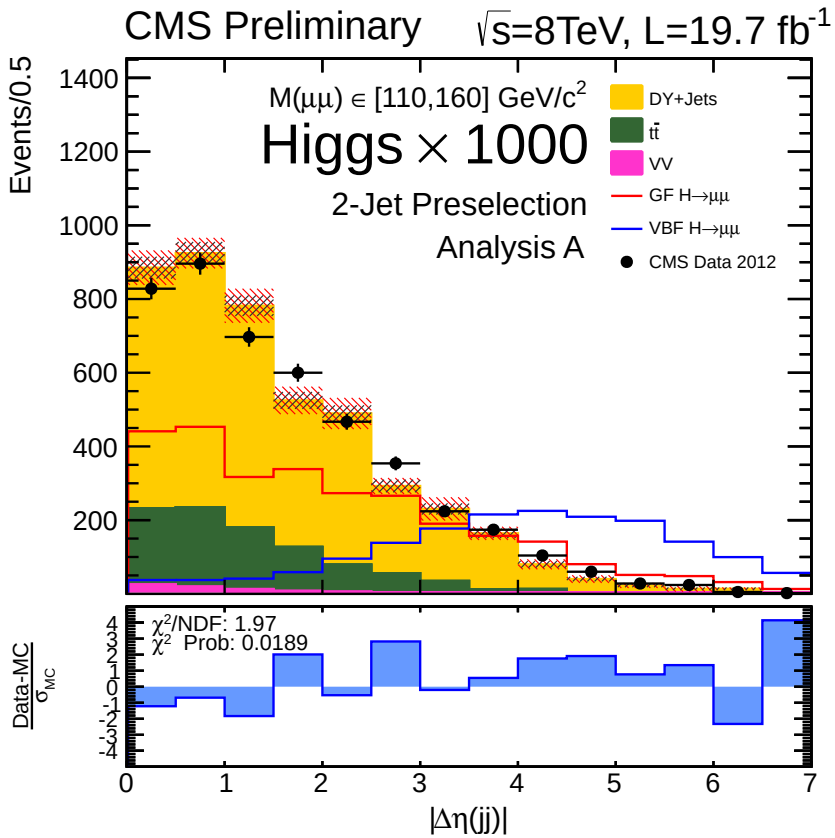
Background Drell-Yan Dominated



GF Higgs Peaks at Higher $p_T(\mu\mu)$

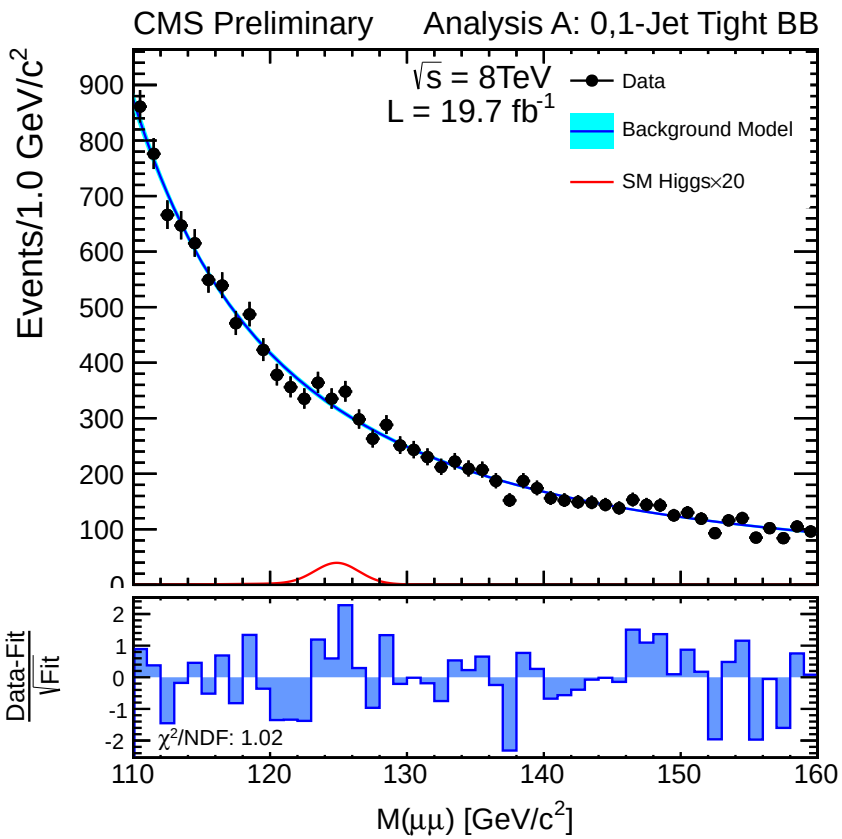
2-Jet Sub-categories

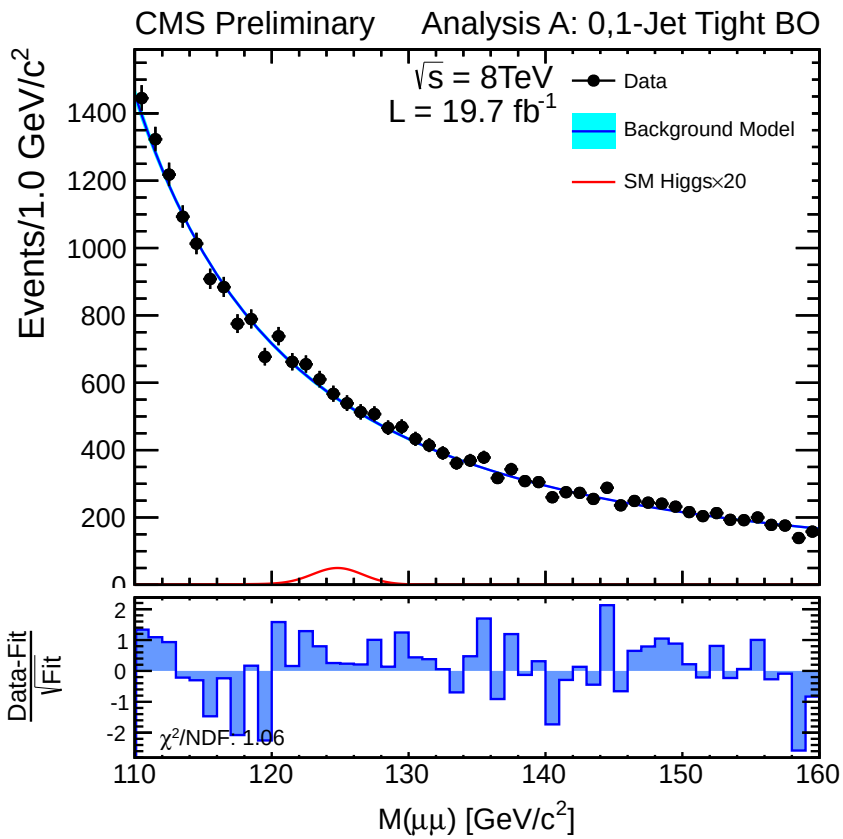
- VBF Higgs Production Mode Enhanced in 2-Jet Category
- VBF Tight Sub-Category:
  - M(jj)$> 650\,\mathrm{GeV/c^2}$
  - $|\Delta\eta(\mathrm{jj})| > 3.5$
- GF Tight Sub-Category:
  - M(jj)$> 250\,\mathrm{GeV/c^2}$
  - $p_T(\mu\mu) > 50\,\mathrm{GeV/c^2}$
- Loose: All Remaining Events



Large Increase in S/B Due to Jet Requirements

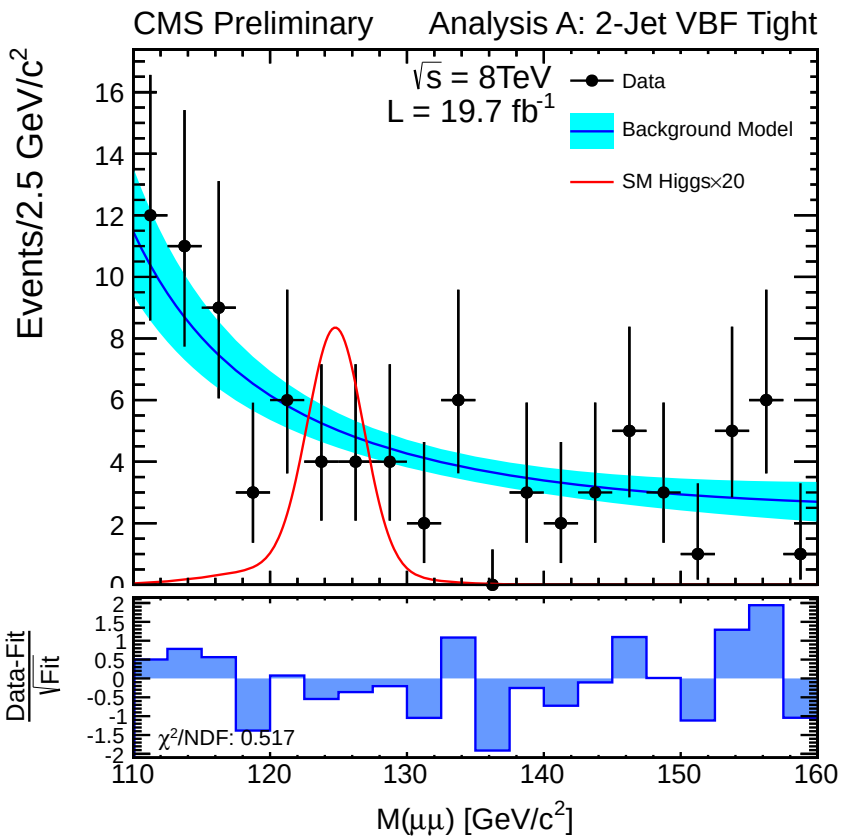
Dimuon Mass Distribution: Example 0,1-Jet Categories

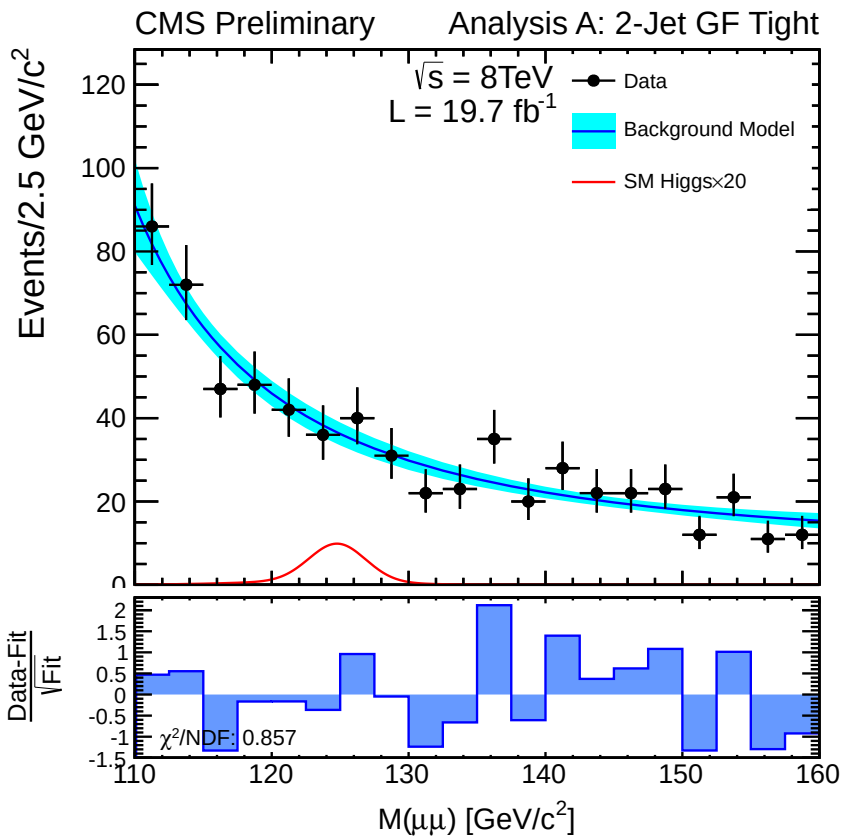




Two Categories with Best Mass Resolution

Dimuon Mass Distribution: Example 2-Jet Categories

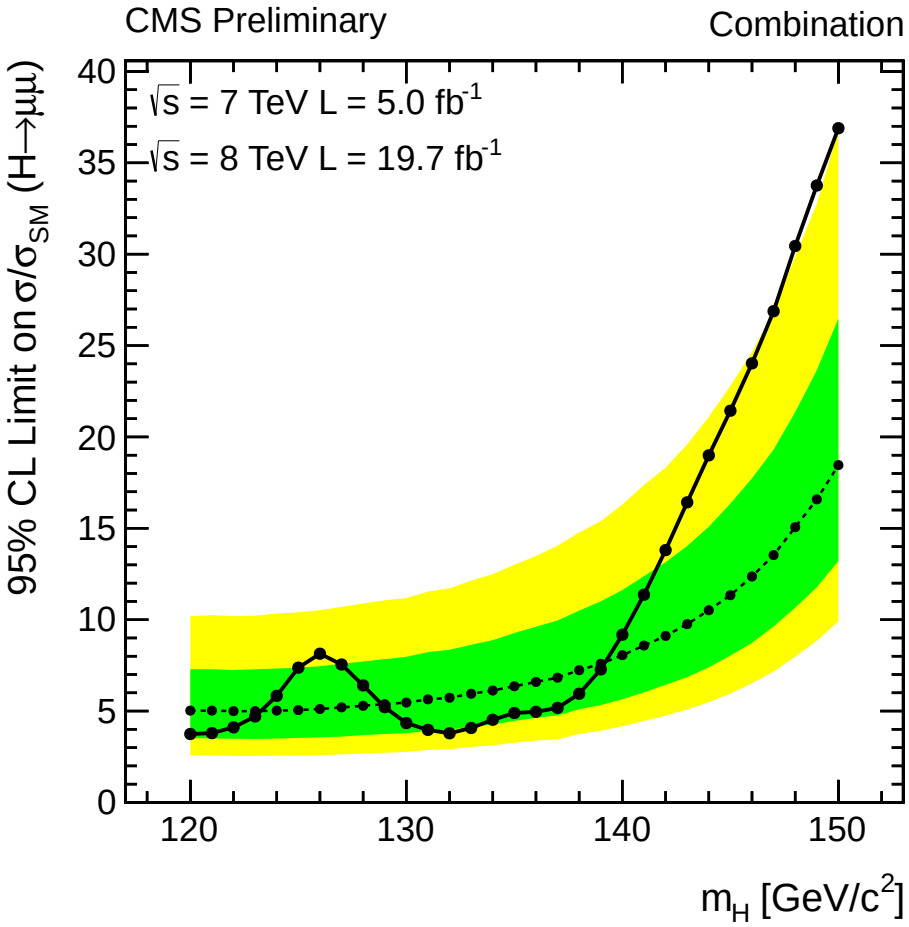




S/B Higher Than 0,1-Jet

Background Statistical Uncertainty Also Higher

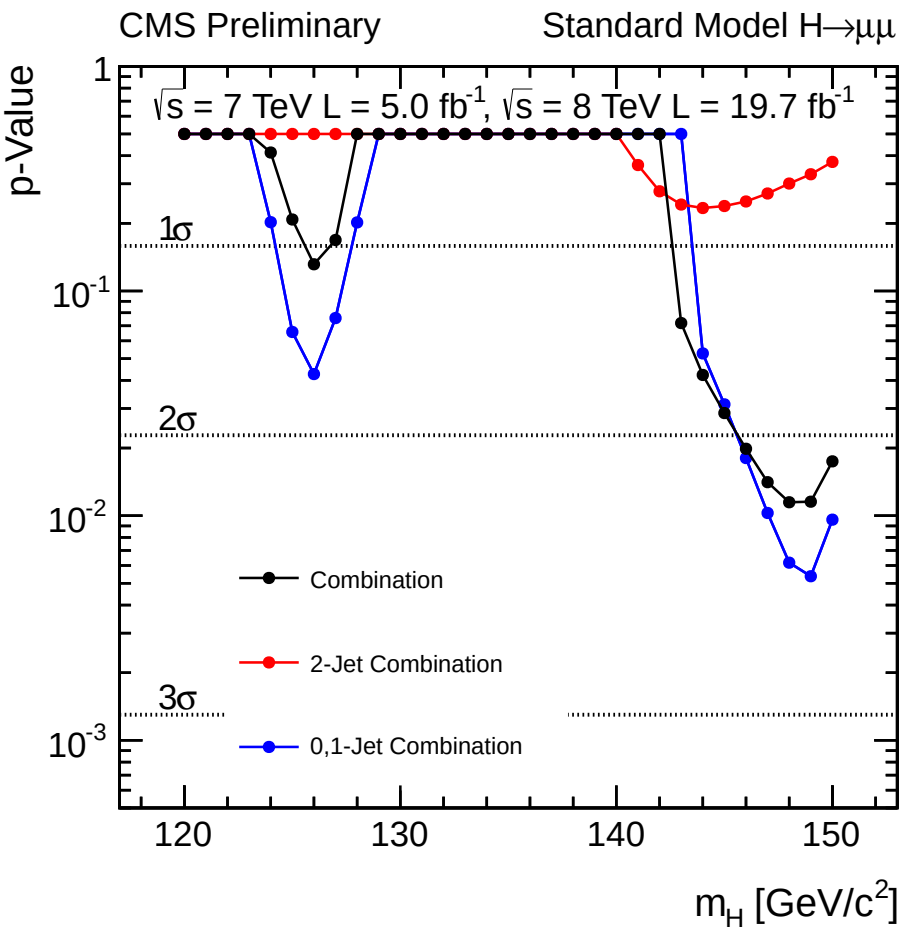
Results: Limits



- 95% CL_s Limit on σ/σ_{SM} for $m_H = 125\,\mathrm{GeV/c^2}$:
  - Expected: $5.1^{+2.3}_{-1.5}\times$SM
  - Observed: $7.4\times$SM
  - Limit at $m_H = 125\,\mathrm{GeV/c^2}$ Confirmed by Independent Analysis
- For Best Estimate CMS Higgs Mass[1], $125.7\,\mathrm{GeV/c^2}$:
  - $\sigma/\sigma_{SM} = 2.9^{+2.8}_{-2.7}$

[1] CMS-PAS-HIG-13-005

Results: Significance



- 1σ Excess Observed Near $125\,\mathrm{GeV/c^2}$
  - Driven by 0,1-Jet Tight BB Category
  - Not Observed in 2-Jet Categories
  - Not Very Significant
- Wide Excess Observed Near $150\,\mathrm{GeV/c^2}$
  - Local Significance: 2.3σ
  - Global Significance: $\mathbf{0.8\sigma}$
  - Not Very Significant

No Significant Excess Found

Conclusions

- Search Performed for Higgs Decays to $\mu^+\mu^-$
- Increase Sensitivity by Categorizing Events According to Production Mode, $p_T(\mu\mu)$, Muon $|\eta|$, and Di-jet Variables
- Most Significant Excess Found $\sim 1\sigma$
- 95% $\mathrm{CL_s}$ Limit on σ/σ_{SM} for $m_H = 125\,\mathrm{GeV/c^2}$:
  - Expected: $5.1^{+2.3}_{-1.5}\times$SM
  - Observed: $7.4\times$SM
  - Limit Confirmed by Independent Analysis
- Best Fit σ/σ_{SM} for $m_H = 125.7\,\mathrm{GeV/c^2}$:
  - $\sigma/\sigma_{SM} = 2.9^{+2.8}_{-2.7}$

Backup

Selection Detail

Muon Selection: 2 Opposite-Sign Isolated Muons, $|\eta| < 2.1$
Leading Muon $p_T > 25\,\mathrm{GeV/c}$, Sub-Leading Muon $p_T > 15\,\mathrm{GeV/c}$

Jet Definition:
Particle-Flow Jets, $p_T > 30\,\mathrm{GeV/c}$, $|\eta| < 4.7$, Anti-κ_T, R=0.5

$p_T^{Miss} \equiv |\vec{p}_T(\mu\mu) + \vec{p}_T(jj)|$

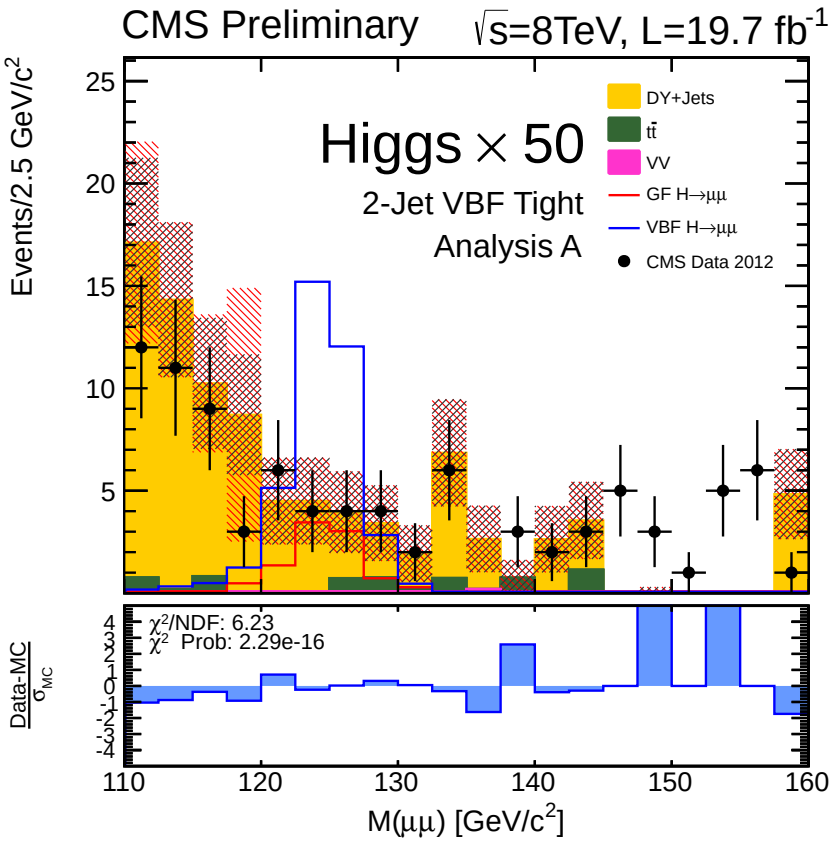
After Muon Selection, All Events Divided into Categories:

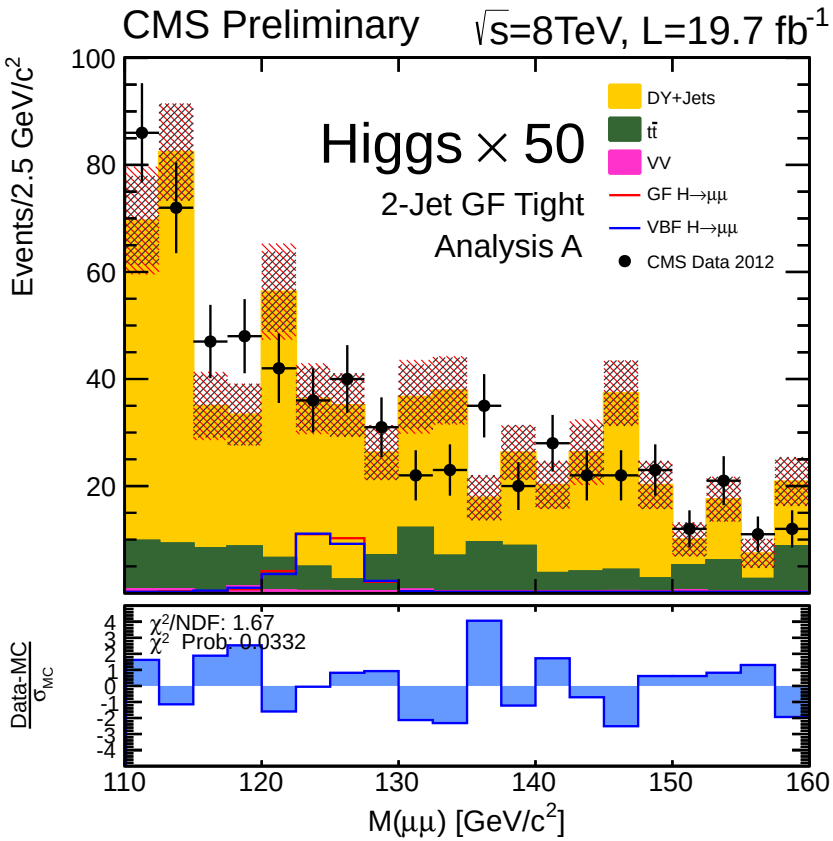
- 2-Jet: Leading Jet $p_T > 40\,\mathrm{GeV/c}$,
  Sub-leading Jet $p_T > 30\,\mathrm{GeV/c}$, $p_T^{Miss} < 40\,\mathrm{GeV/c}$
- 0,1-Jet: All Remaining Muon-Selected Events

Table of Categories

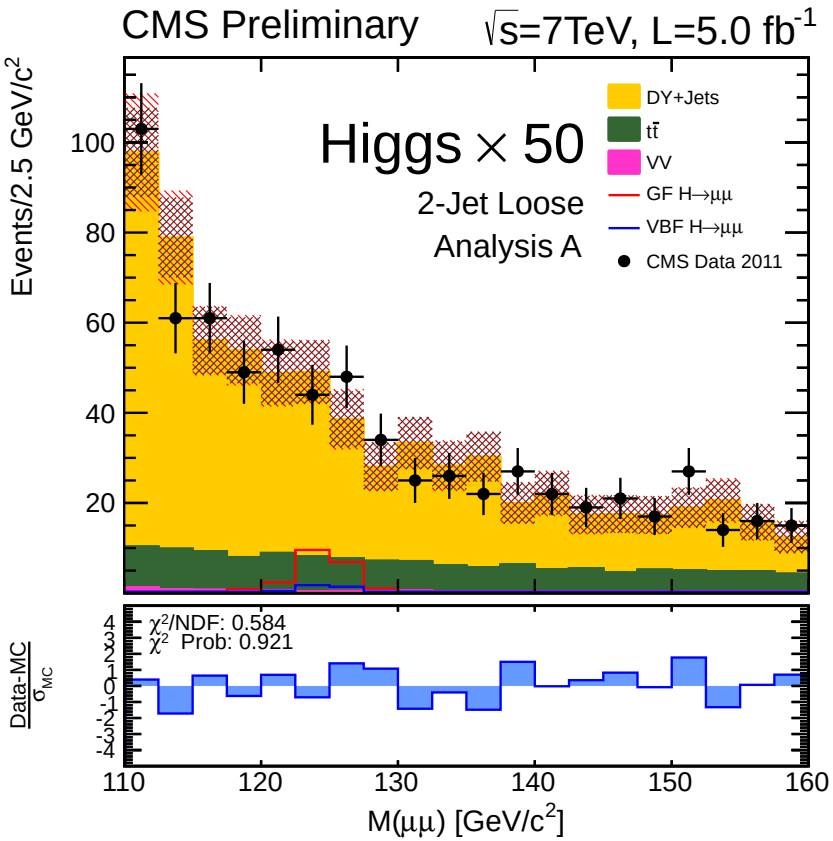
0,1-Jet	**Tight** $p_T(\mu\mu) \geq 10$ GeV/c	**BB** (Barrel-Barrel)
		BO (Barrel-Overlap)
		BE (Barrel-Endcap)
		OO (Overlap-Overlap)
		OE (Overlap-Endcap)
		EE (Endcap-Endcap)
	Loose $p_T(\mu\mu) < 10$ GeV/c	**BB**
		BO
		BE
		OO
		OE
		EE
2-Jet	**VBF Tight** $M(jj) > 650$ GeV/c^2 and $\lvert\Delta\eta(jj)\rvert > 3.5$	
	GF Tight (not VBF Tight selected) $M(jj) > 250$ GeV/c^2 and $p_T(\mu\mu) > 50$ GeV/c	
	Loose (not VBF Tight and not GF Tight selected)	

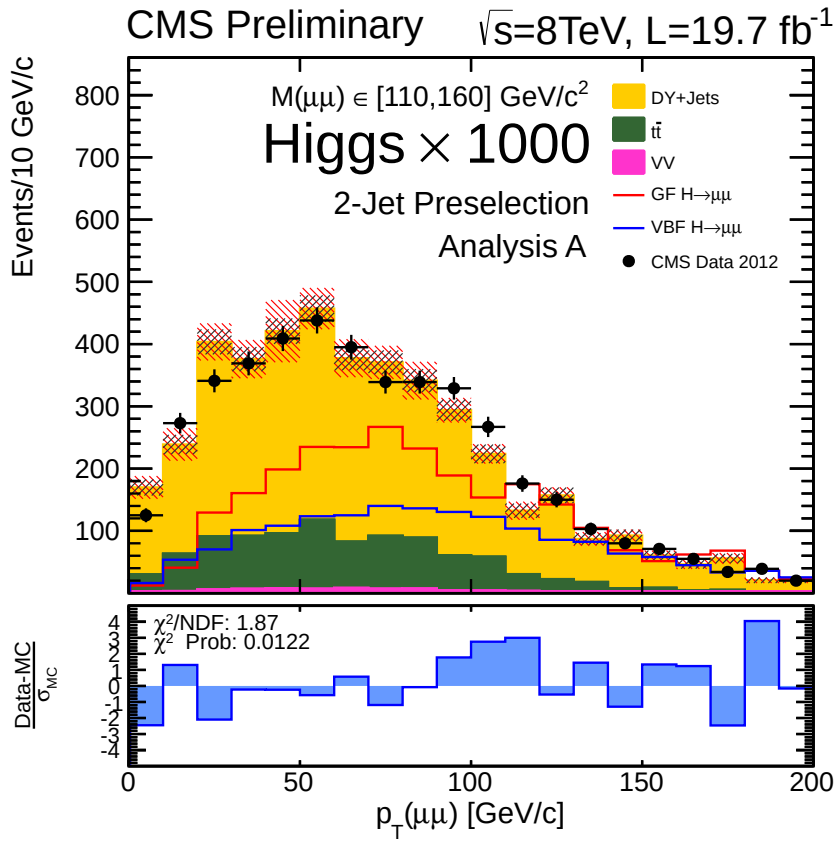
Control Plots: 2-Jet



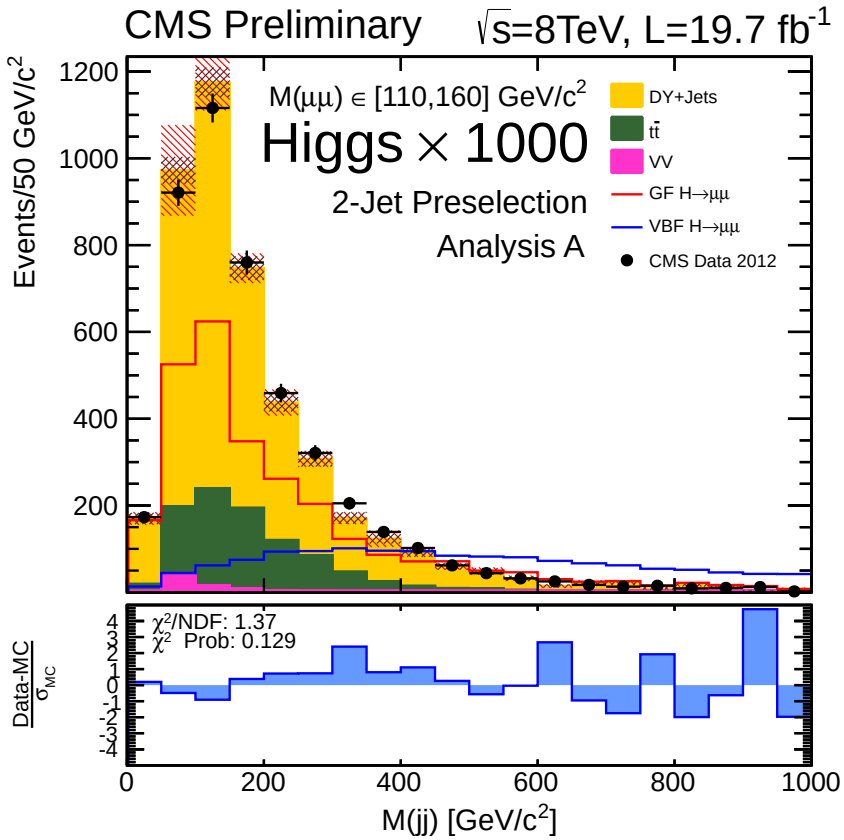


Control Plots: 2-Jet





Control Plots: 2-Jet



Dimuon Mass Shapes

Fit Dimuon Mass from 110-160 $\mathrm{GeV/c^2}$
Signal:

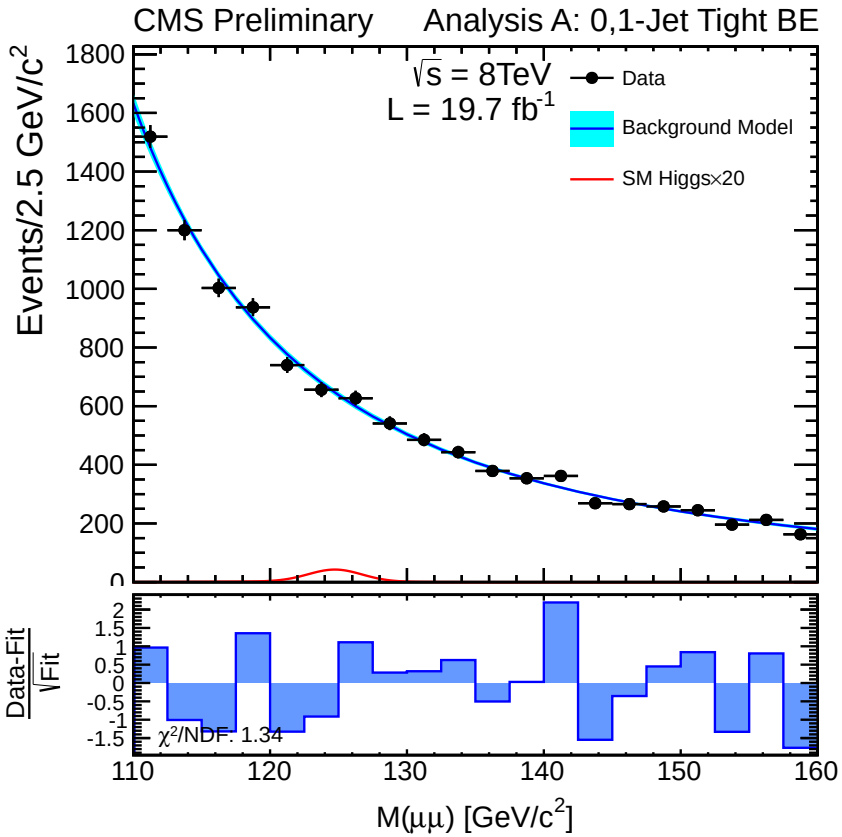
- Modeled by a Sum of 2 Gaussians Fit to MC

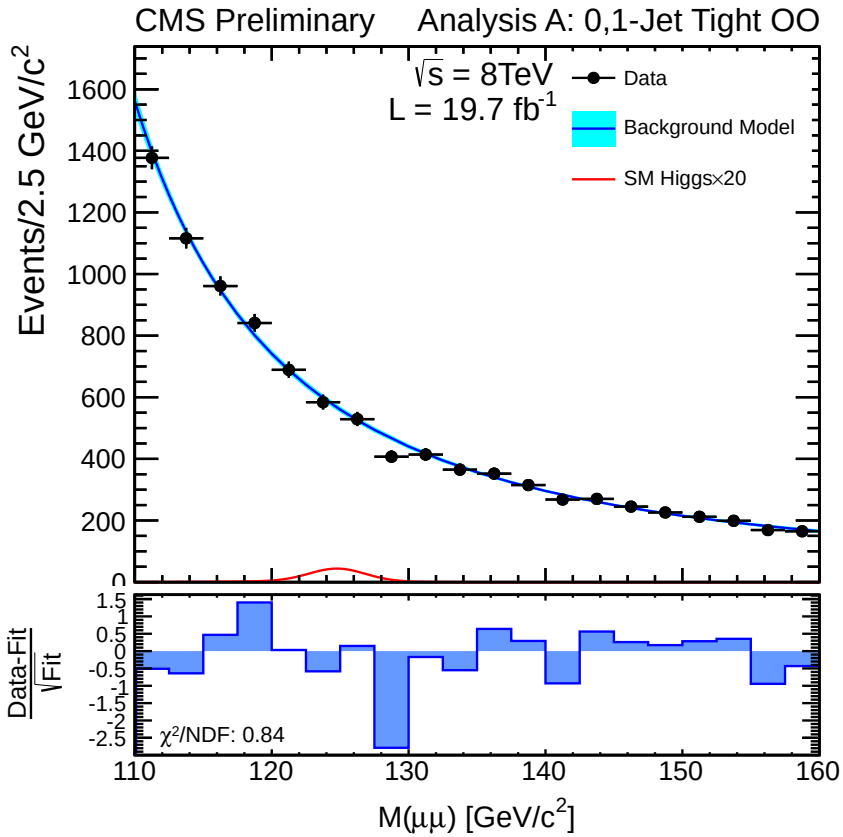
Background:

- Modeled by an Exponential Divided by a Polynomial Fit to Data:

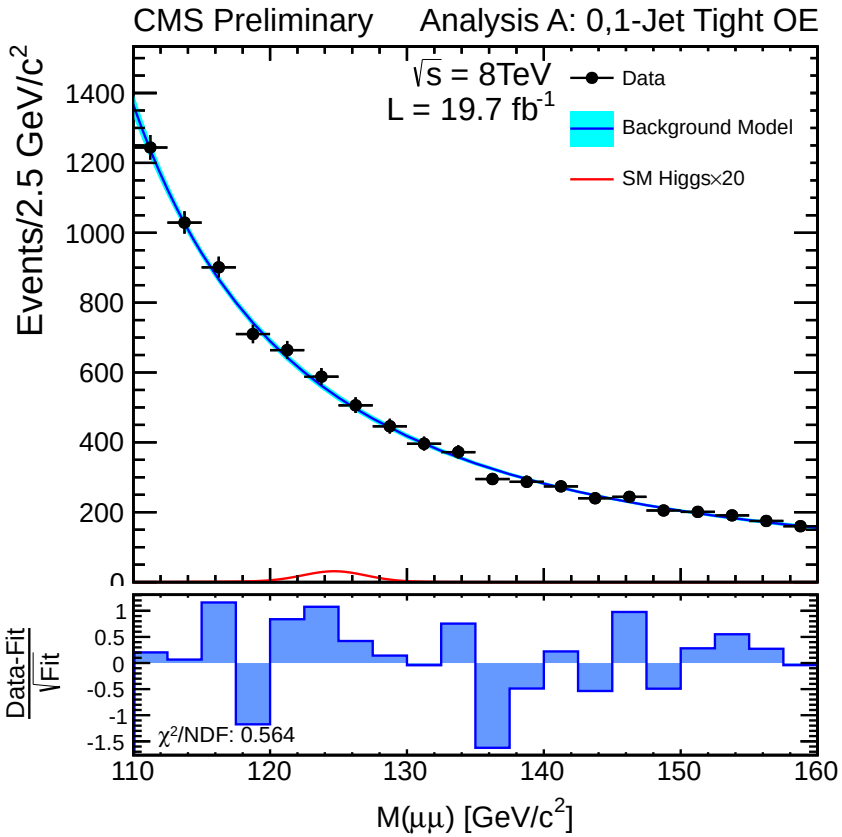
$$\frac{\exp(\mathrm{p_1} \cdot \mathrm{M}(\mu\mu))}{(\mathrm{M}(\mu\mu) - \mathrm{p_2})^2}$$

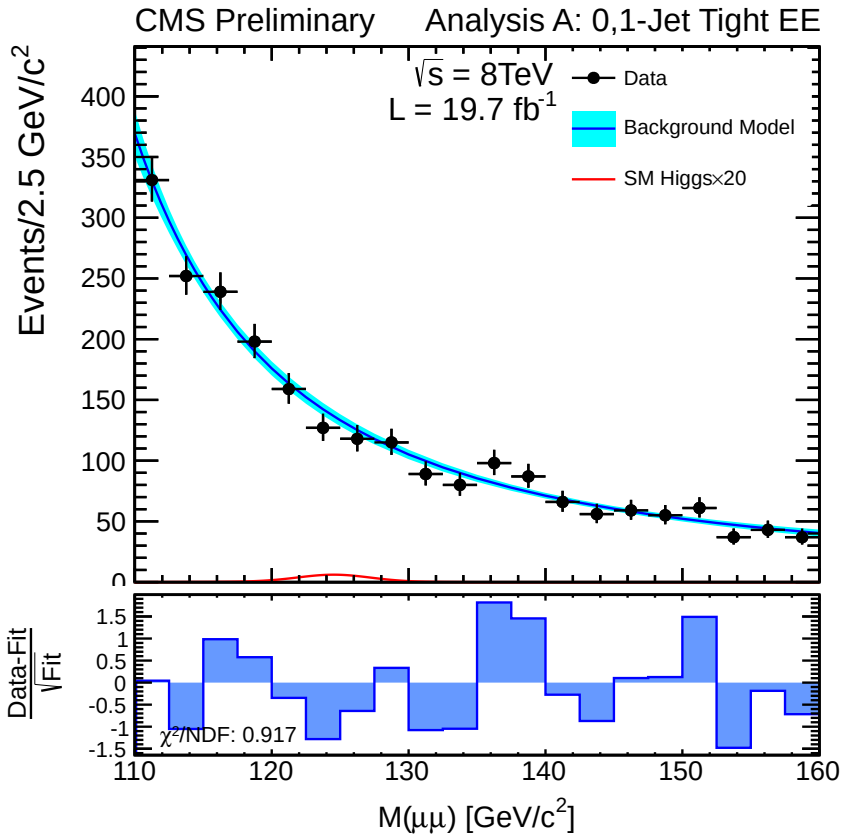
Dimuon Mass Distribution: Example 0,1-Jet Categories



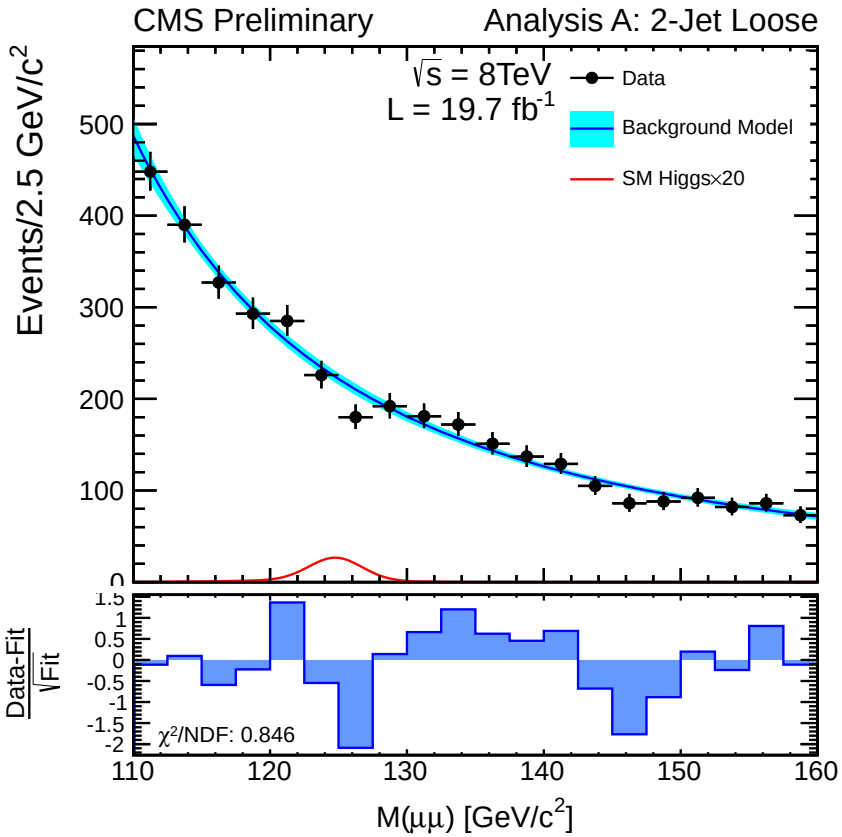


Dimuon Mass Distribution: Example 0,1-Jet Categories

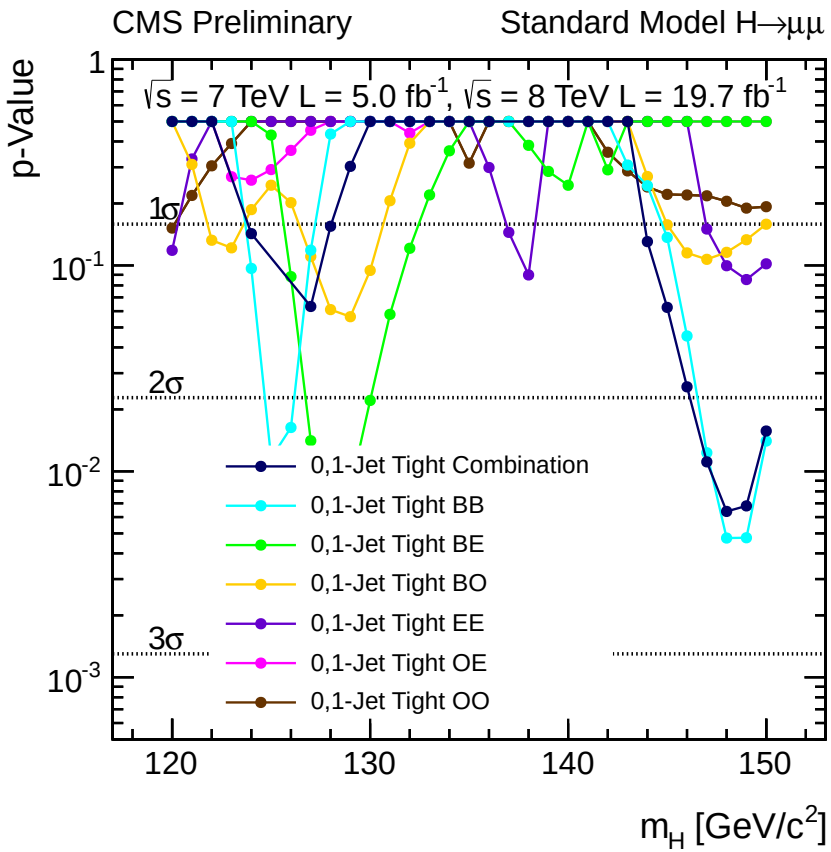


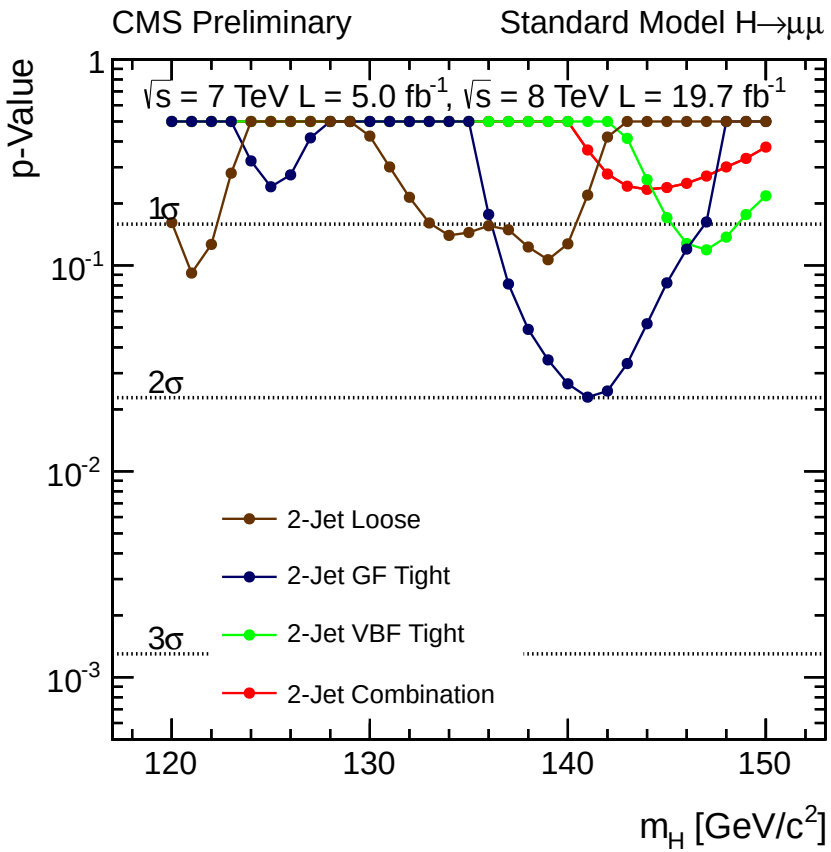


Dimuon Mass Distribution: Example 2-Jet Categories



p-Values Per-Category





Analysis B Selection

Analysis B Performed Only for $m_H = 125\,GeV/c^2$

Muon Selection: 2 Opposite-Sign Isolated Muons

$p_T > 25\,\mathrm{GeV/c}$, $|\eta| < 2.1$

Jet Definition: Jet-Plus-Track Reconstruction, Anti-κ_T, R=0.5

- $p_T > 20\,\mathrm{GeV/c}$, $|\eta| < 2.6$,
- $p_T > 25\,\mathrm{GeV/c}$, $2.6 < |\eta| < 4.7$,

$p_T^{Miss} \equiv |\vec{p}_T(\mu\mu) + \vec{p}_T(jj)|$

After Muon Selection, All Events Divided into Categories:

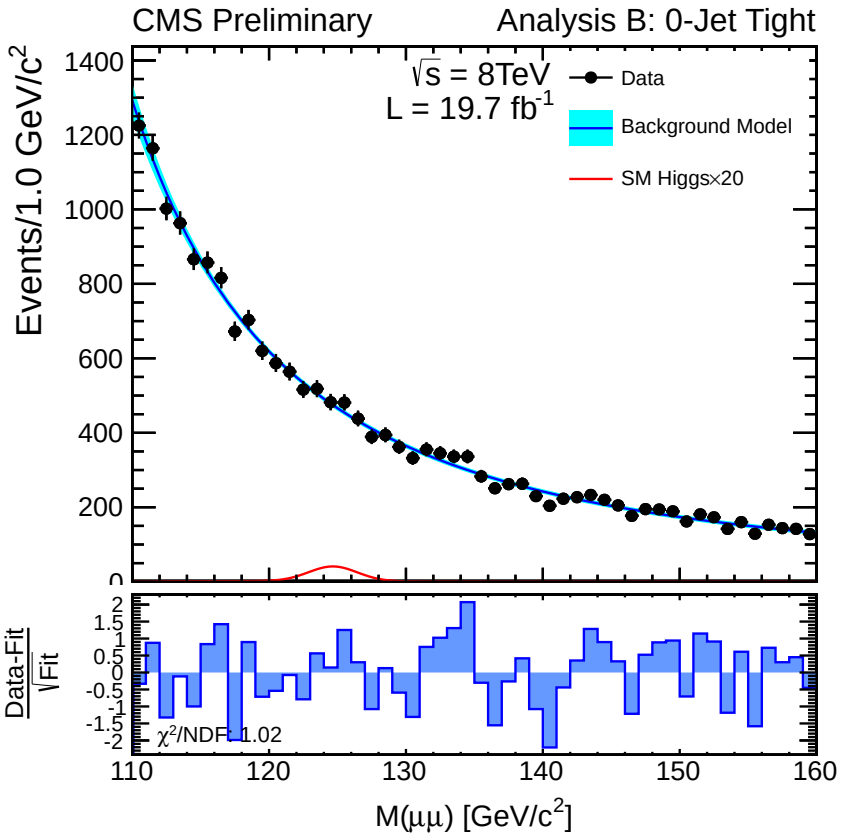
- 0-Jet
- 1-Jet
- $\geq$ 1-Jet

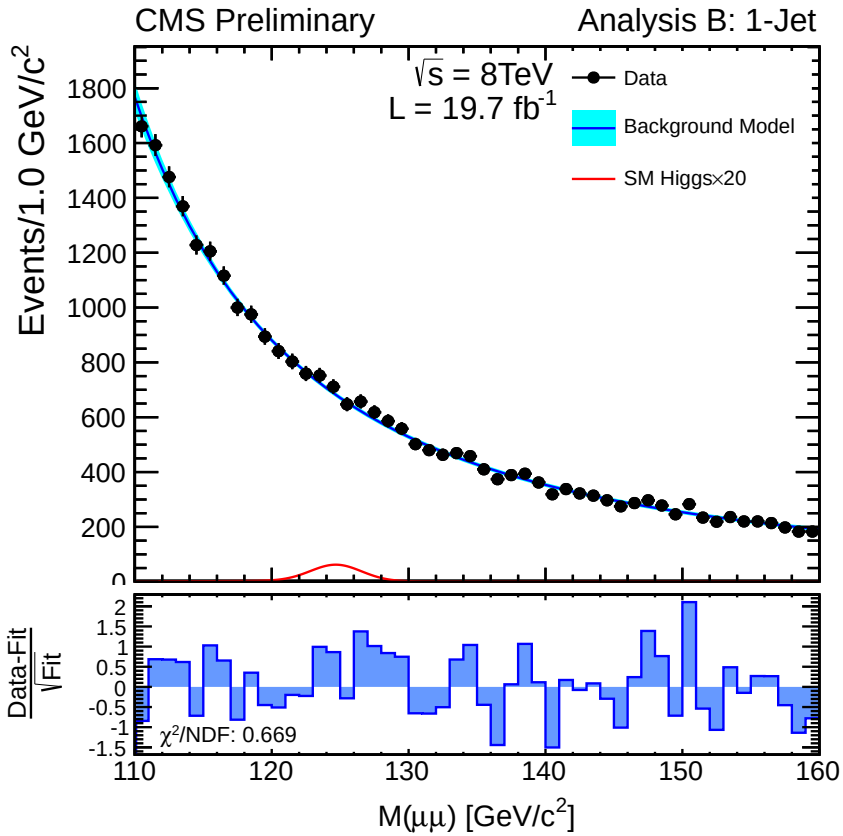
Analysis B Table of Categories

Analysis B Performed Only for $m_H = 125\,GeV/c^2$

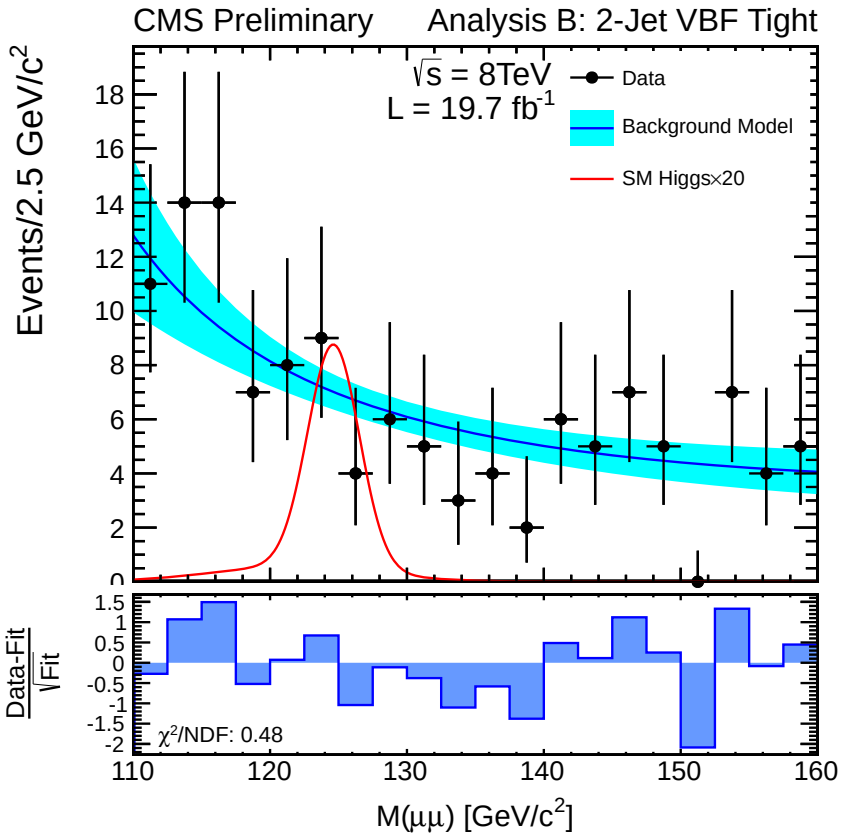
0-Jet	**Tight** ($p_T(\mu\mu) \geq 15\,\mathrm{GeV/c}$)
	Loose ($p_T(\mu\mu) < 15\,\mathrm{GeV/c}$)
1-Jet	no subcategories
2-Jet	**VBF Tight** $M(jj) > 500\,\mathrm{GeV/c^2}$ and $\lvert\Delta\eta(jj)\rvert > 4$, for 7 TeV $\lvert\Delta\eta(jj)\rvert > 3$
	VBF Loose (not VBF Tight selected) $M(jj) > 300\,\mathrm{GeV/c^2}$ and $\lvert\Delta\eta(jj)\rvert > 3$ category used only for $\sqrt{s} = 8$ TeV
	non-VBF (not VBF Tight and not VBF Loose selected)

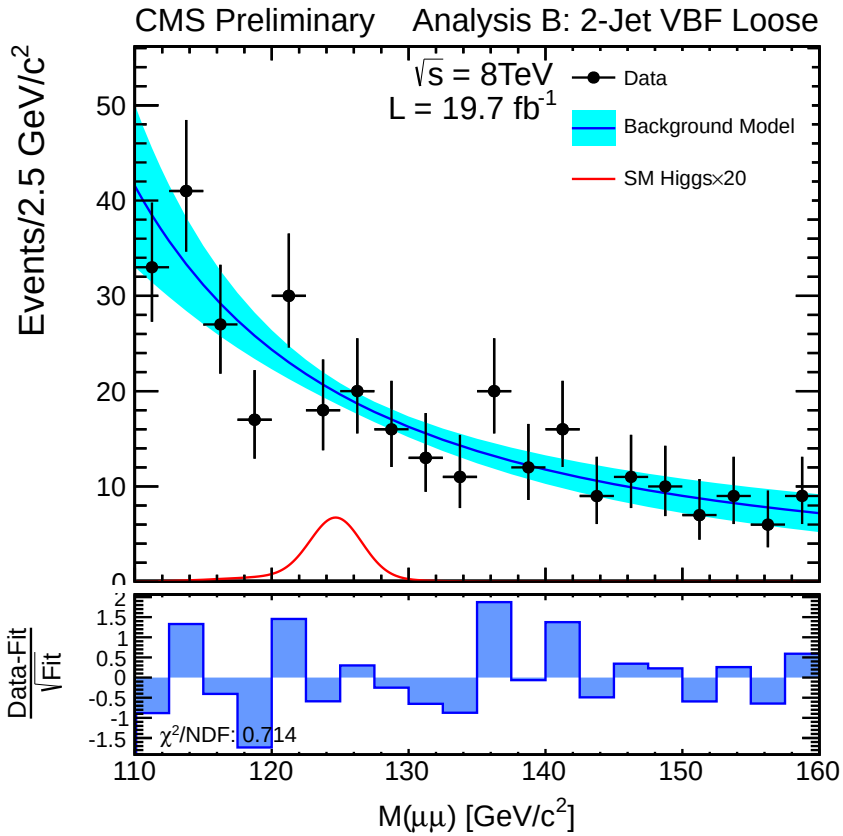
Analysis B Dimuon Mass Distribution: 0-Jet & 1-Jet Categories





Analysis B Dimuon Mass Distribution: Example 2-Jet Categories





$\sqrt{s} = 14$ TeV Projections

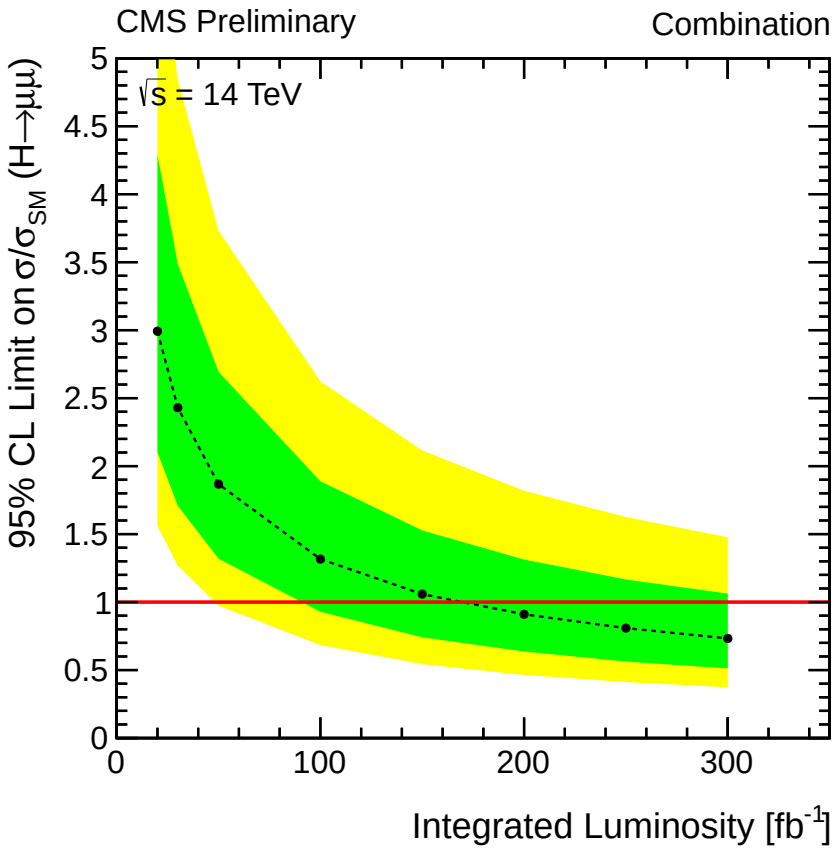
Exclude SM with 175^{+150}_{-75} fb^{-1}

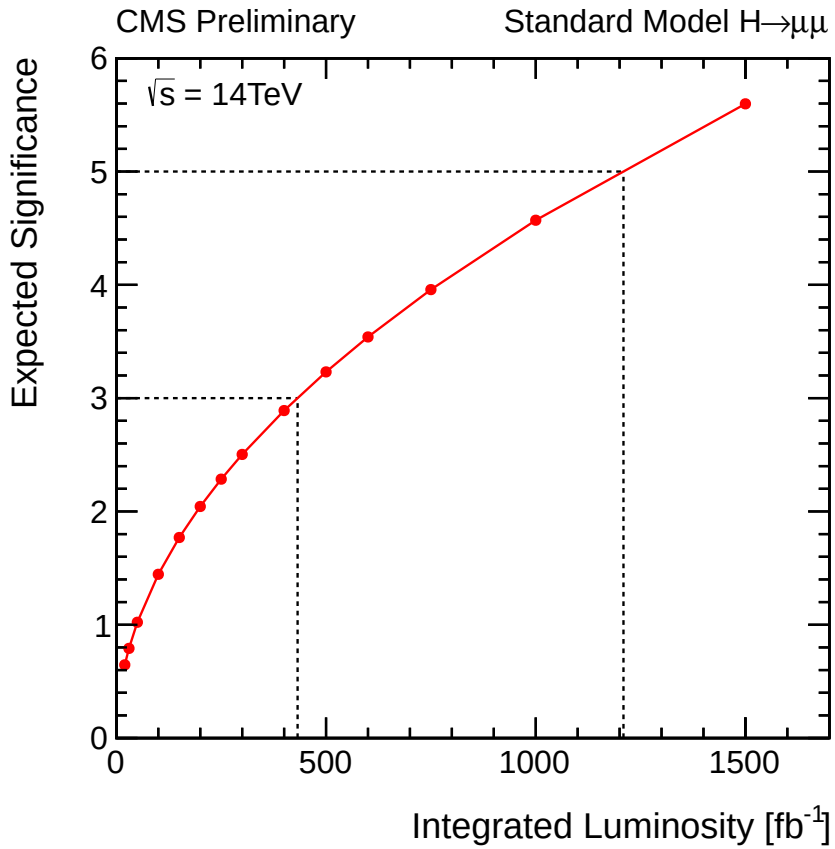
	300 fb^{-1}	3000 fb^{-1}
Significance	2.5σ	7.9σ
Error on σ/σ_{SM} Scenario 1	42%	20%
Error on σ/σ_{SM} Scenario 2	40%	14%
Error on k_μ Scenario 1	23%	8%
Error on k_μ Scenario 2	23%	7.5%

- Scenario 1: All Uncertainties Same as Current Analysis
- Scenario 2: Experimental Uncertainties Scale $1/\sqrt{\mathcal{L}}$, Theoretical Uncertainties Cut in Half

8 TeV Analysis & Samples, with Cross-Sections Rescaled for $\sqrt{s} = 14$ TeV, See: arXiv:1307.7135 [hep-ex]

$\sqrt{s} = 14$ TeV Projections





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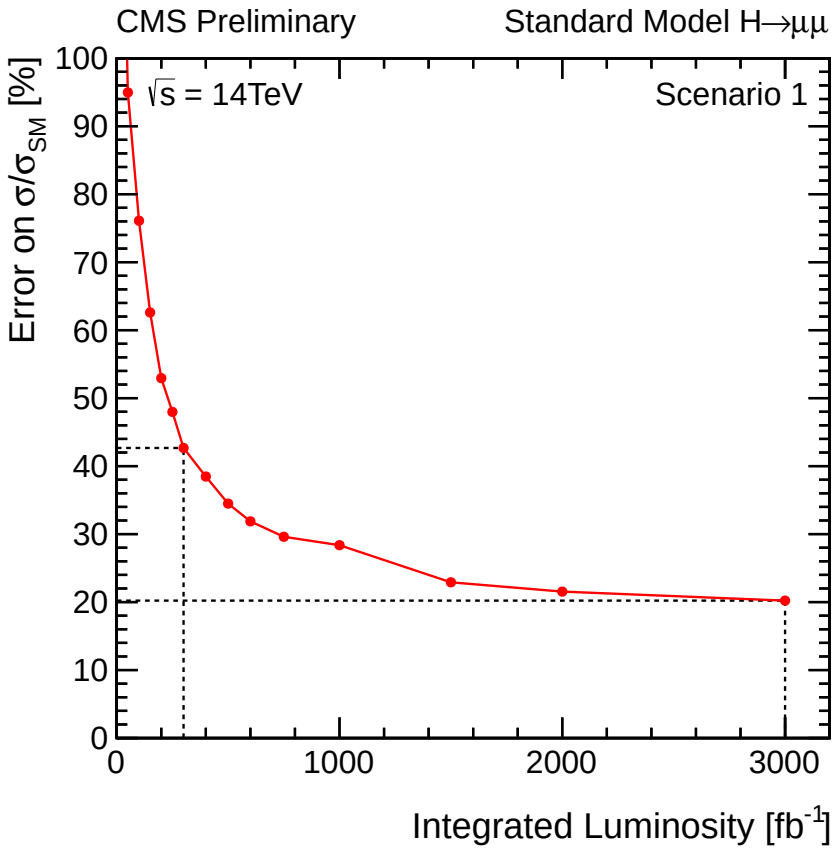
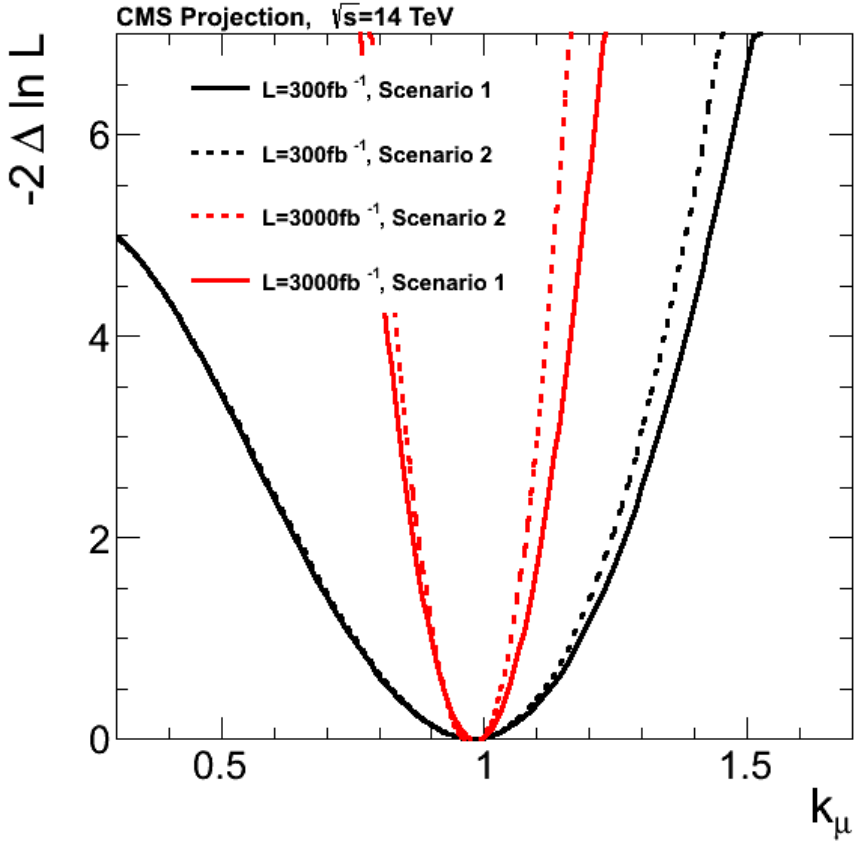
$\sqrt{s} = 14$ TeV Projections





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