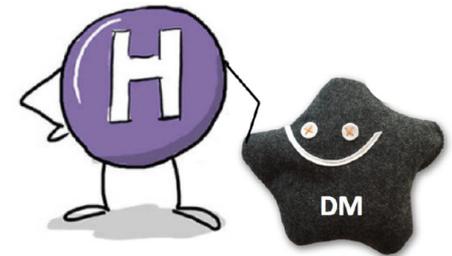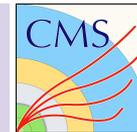# Search for dark matter with mono-Higgs signature

59th Rencontres de Moriond

Electroweak Interactions & Unified Theories

23rd - 30th March, 2025

Shivani Lomte (University of Wisconsin-Madison)
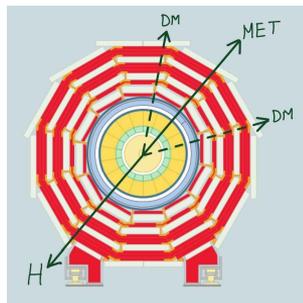on behalf of CMS Collaboration

Introduction

If dark matter (DM) is produced at colliders, we infer its presence from missing energy in transverse plane (p_T^{miss} or MET)
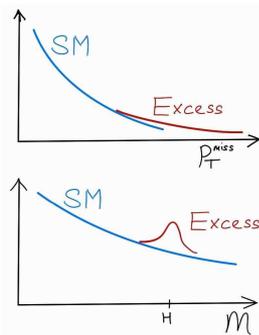
mono-H signature: MET recoiling against Higgs

ISR production highly suppressed. FSR of DM particles or interaction of Higgs with DM via a mediator

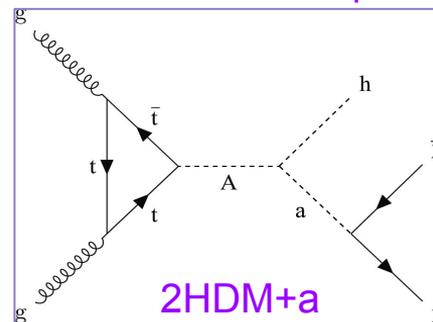Search for excess of events in MET tail and a characteristic bump in visible mass

this search:
MET + H → bb

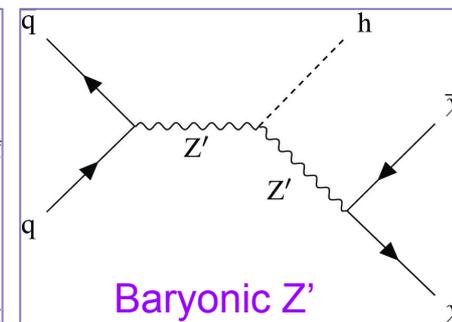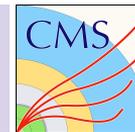Interpretation in benchmark models from ATLAS-CMS DM forum

Simplified models

2HDM+a

Baryonic Z'

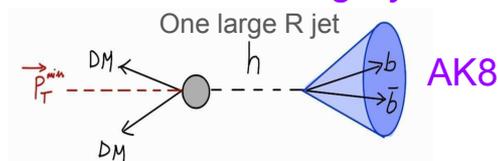Free parameters: M(A), M(a), $\sin\theta$, $\tan\beta$
Fix M(χ)=10 GeV

Free parameters: M(Z') and M(χ)
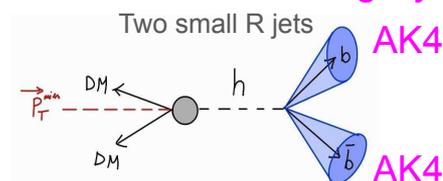Fix g(q)=0.25, g(χ)=1

Analysis Strategy

- ★ Trigger on high MET
- ★ Lepton veto
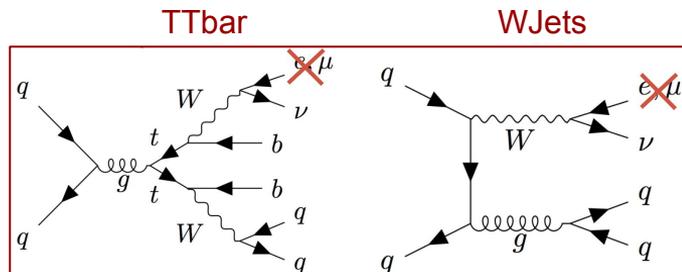- ★ Identify H→b$\bar{b}$ object

Boosted Category

One large R jet

NEW: ParticleNet bb-tagger

Resolved Category

Two small R jets
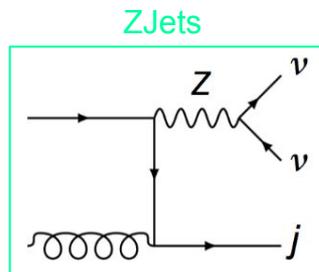

Major Backgrounds: estimated using dedicated control regions based on number of lepton

TTbar   WJets

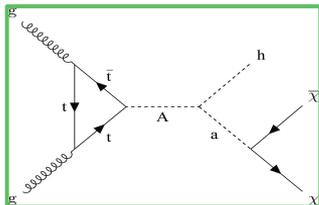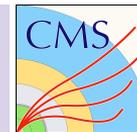Use single lepton control regions
Top(e) and Top(μ) for estimation

ZJets

Use double lepton CRs
Z(ee) and Z($\mu\mu$) ~ Z($\nu\nu$)
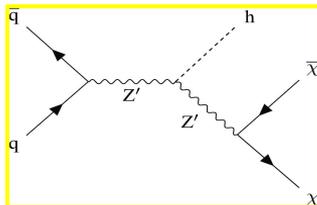

Minor backgrounds are estimated using MC simulation
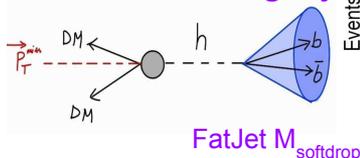Signal is extracted using a simultaneous fit on signal and control regions

3

Results

2HDMa model
fixed parameters:
$m(\chi)$=10 GeV
$\sin\theta$ = 0.35
$\tan\beta$ = 1.0

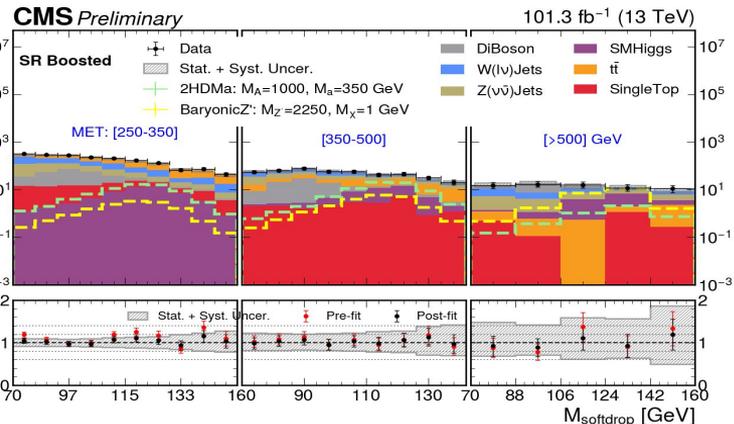**Baryonic Z' model**
fixed parameters:
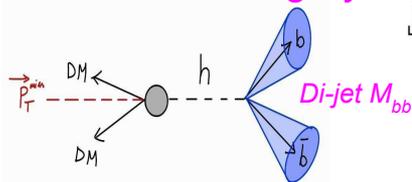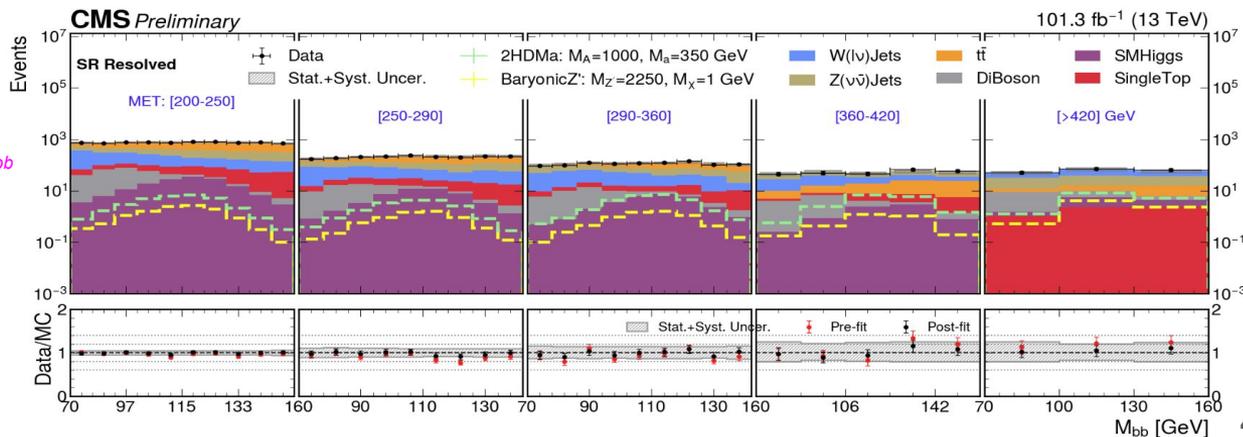g_q = 0.25
g_χ = 1.0

Boosted Category

FatJet $M_{softdrop}$

Main observable is Higgs candidate mass split across MET regions

Resolved Category

Di-jet M_{bb}

No significant excess is observed over SM prediction
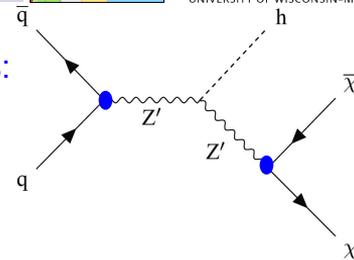
4

Interpretation: limits on Baryonic-Z' model

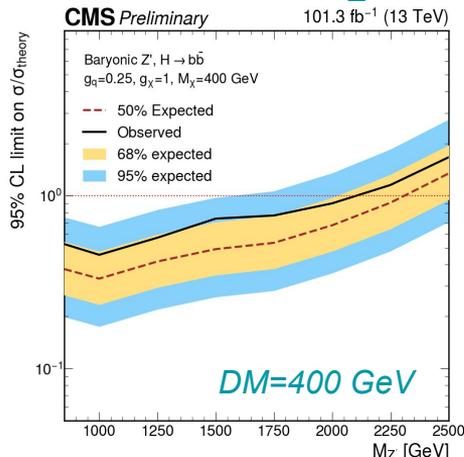Upper limit at 95% CLs using Asymptotic approximation

Fixed parameters:
g_q = 0.25
g_χ = 1.0

1D limit: Fix M_χ to 1, 400 GeV and scan over $M_{Z'}$

DM=1 GeV

DM=400 GeV

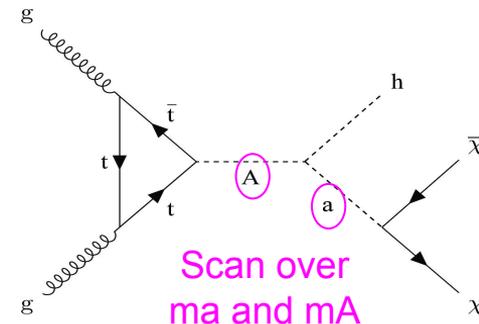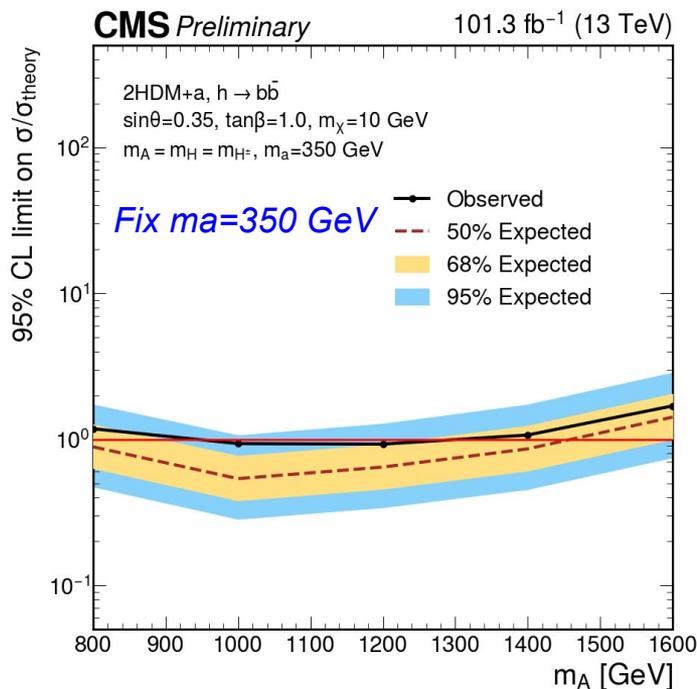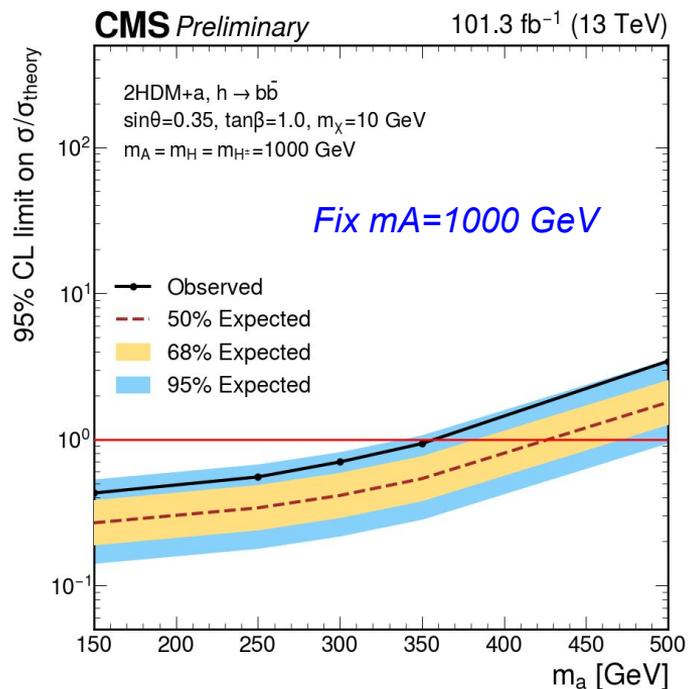Z' masses below the red dotted line are excluded

Observed (Expected) limit: Z' up to 2.20 (2.35) TeV for DM=1 GeV

Exclude DM mass up to 500 GeV for Z'=1.25 TeV

5

Interpretation: limits on 2HDMa model (I)

Limit on pseudoscalar mass

CMS *Preliminary* 101.3 fb⁻¹ (13 TeV)

2HDM+a, h → b̄b
sinθ=0.35, tanβ=1.0, m_χ=10 GeV
m_A = m_H = m_H± =1000 GeV

Fix mA=1000 GeV

- Observed
- 50% Expected
- 68% Expected
- 95% Expected

CMS *Preliminary* 101.3 fb⁻¹ (13 TeV)

2HDM+a, h → b̄b
sinθ=0.35, tanβ=1.0, m_χ=10 GeV
m_A = m_H = m_H± , m_a=350 GeV

Fix ma=350 GeV

- Observed
- 50% Expected
- 68% Expected
- 95% Expected

Scan over
ma and mA

Fixed parameters:
m(χ)=10 GeV
sinθ = 0.35
tanβ = 1.0

Interpretation: limits on 2HDMa model (II)

Limit on sinθ and tanβ parameters

Scan over sinθ and tanβ
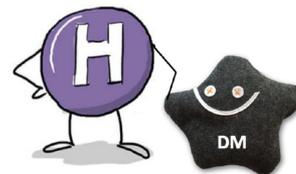
Fixed parameters:
  m(χ)=10 GeV
  mA=600 GeV
  ma=200GeV

Summary and Outlook
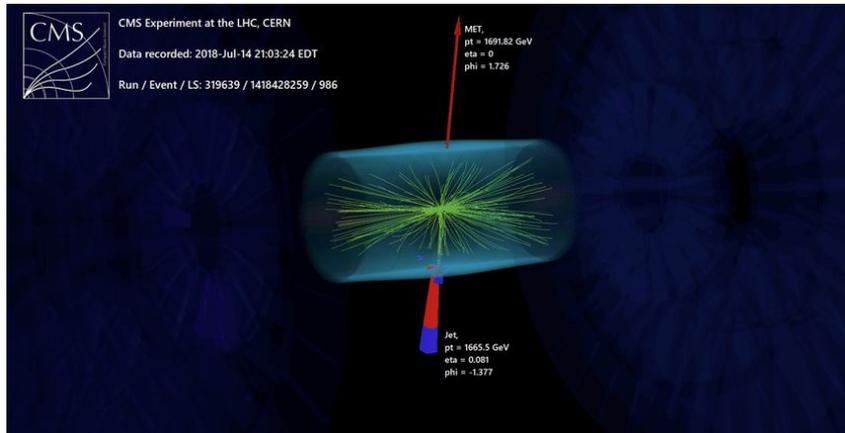
- A CMS search for dark matter with mono-Higgs(bb) signature with 101 fb^{-1} data

- No significant excess is observed over the SM prediction

- Upper limits are set on simplified benchmark models, 2HDMa and Baryonic Z'

- 2016 results are public, combined full Run-2 results will be added to SUS-24-007 paper

Stay tuned for results from Run-3 and mono-Higgs combination (bb + $\tau\tau$ + $\gamma\gamma$) !
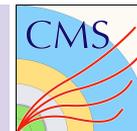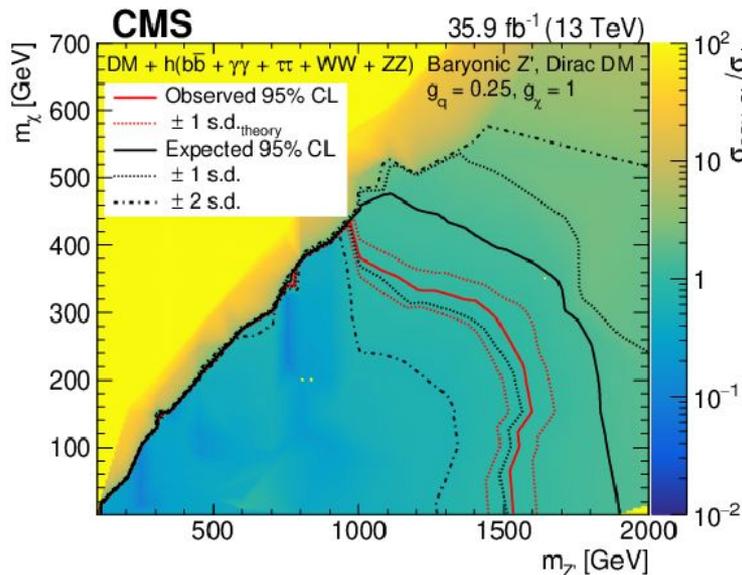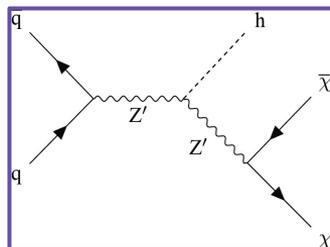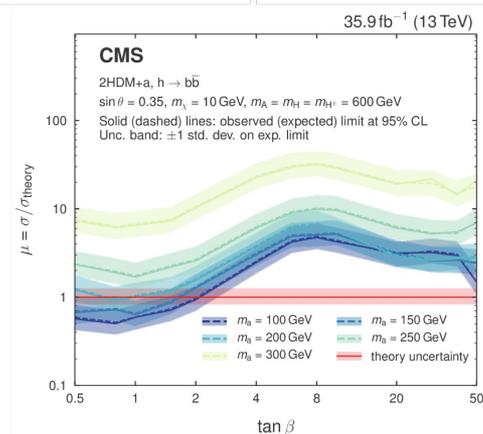
Thank you for your attention

Backup
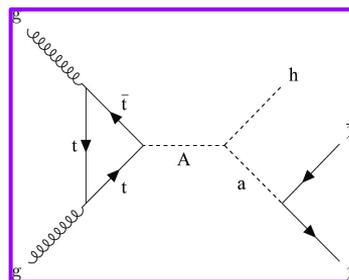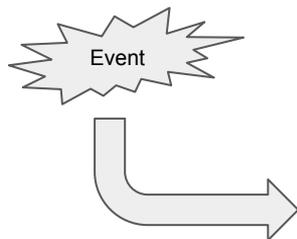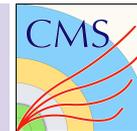
*Eur. Phys. J. C **79**, 280 (2019)*

Baryonic-Z' model

2HDM+a model

Event Selections (SR)

Boosted Category

- 1 AK8 Jet passing ParticleNet bb-tag algorithm
- MET > 250 GeV
- $\Delta\phi$ (MET, AK4/AK8) > 0.4/0.8
- $\Delta\phi$(Tk, PF)MET < 2.0
- $N_{b\text{-jet}}$ = 0, $N_{additional\text{-}jet}$ ≤ 2
- Photon veto, lepton veto

Event

If event fails Boosted selection, then check if passes Resolved selection

Resolved Category

- 2 leading AK4 Jets passing DeepJet b-tag algorithm
  $p_T (b_1) > 50$ GeV, $p_T (b_2) > 30$ GeV
  $p_T (bb) > 100$ GeV & $70 < M(bb) < 160$ GeV
- MET > 200 GeV
- $\Delta\phi$ (MET, AK4/DiJet) > 0.4/1.6
- $\Delta\phi$(Tk, PF)MET < 2.0
- $N_{additional\text{-}jet}$ ≤ 2
- Photon veto, lepton veto

Event Selections (CR)

Boosted Category

Common to SR selections

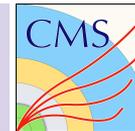**Common Selections:**
- 1 AK8 Jet (non bb-tag)
- Recoil > 250 GeV
- $N_{additional\text{-}jet} \leq 2$
- Photon veto, tau veto

Resolved Category

Common Selections:
- 2 AK4 Jets DeepJet b-tag Medium WP
  $p_T(b_1) > 50$, $p_T(b_2) > 30$ GeV
  $p_T(bb) > 100$ GeV, $70 > M(bb) < 160$ GeV
- Recoil > 200 GeV
- Photon veto, tau veto

Top(μ)
1 Tight Muon
MET > 50 GeV
$N_{b\text{-}jet} = 1$
AK8 Jet (bb-tag)

Z(μμ)
2 Tight OS Muons
$p_T(\mu\mu) > 200$ GeV
$60 < M(\mu\mu) < 120$ GeV
$N_{b\text{-}jet} = 0$

Top(μ)
1 Tight Muon
MET > 50 GeV
$N_{additional\text{-}jet} \geq 1$

Z(μμ)
2 Tight OS Muons
$p_T(\mu\mu) > 200$ GeV
$60 < M(\mu\mu) < 120$ GeV
MET < 100 GeV
$N_{additional\text{-}jet} \leq 2$

Top(e)
1 Tight Electron
MET > 50 GeV
$N_{b\text{-}jet} = 1$
AK8 Jet (bb-tag)

Z(ee)
2 Tight OS Electrons
$p_T(ee) > 200$ GeV
$60 < M(ee) < 120$ GeV
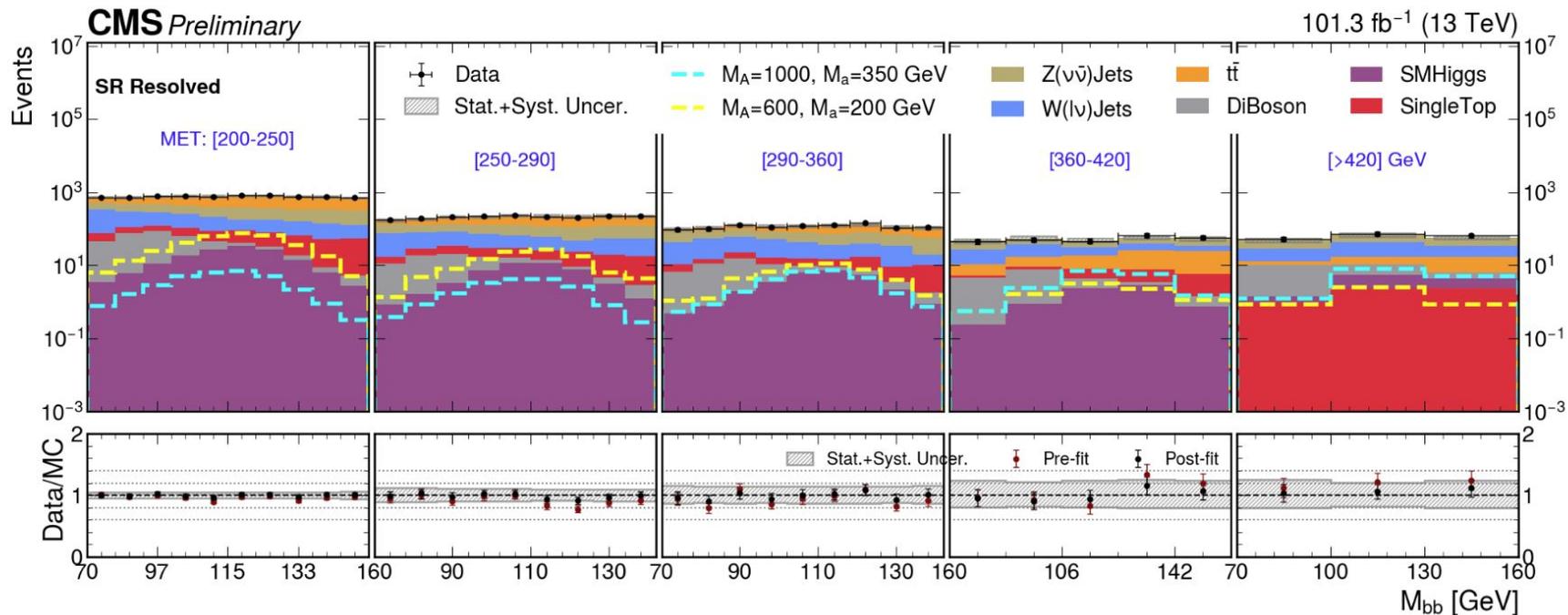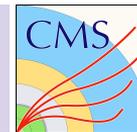$N_{b\text{-}jet} = 0$

Top(e)
1 Tight Electron
MET > 50 GeV
$N_{additional\text{-}jet} \geq 1$

Z(ee)
2 Tight OS Electrons
$p_T(ee) > 200$ GeV
$60 < M(ee) < 120$ GeV
MET < 100 GeV
$N_{additional\text{-}jet} \leq 2$

Recoil: mimic MET in CRs

$$\vec{U} = \vec{p_T^{\text{miss}}} + \vec{p_T}^{ll,l}$$

*OS: Opposite Sign

12

2HDMa signal shapes

Jet multiplicity

SR

Top(μ)CR

Z(μμ)CR
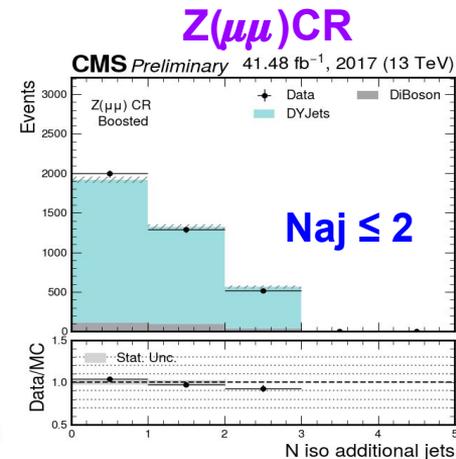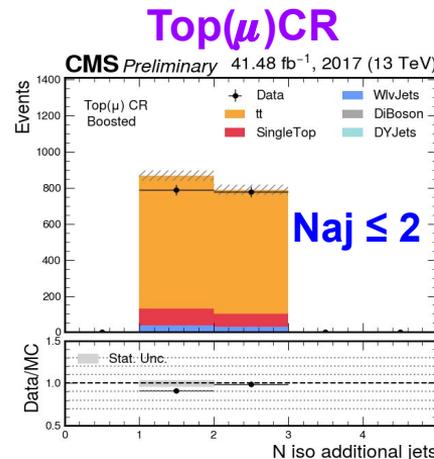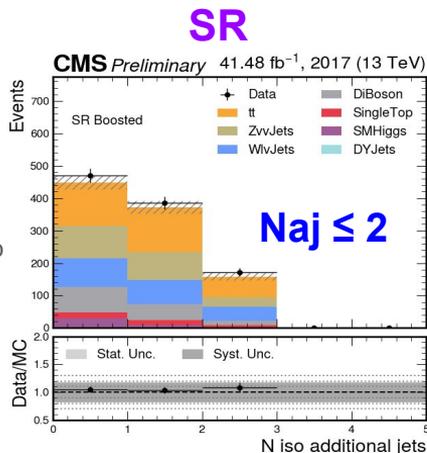
Boosted

iso aj=additional AK4 jets
'away' from FatJet making up
the Higgs candidate.
'away' = dR(FatJet, jet)>0.8

Resolved

aj=additional jets apart from
the AK4 jets making up the
Higgs candidate di-jet.