Search for associated production of dark matter with a Higgs boson

[Higgs decays to a pair of bottom quarks]

Andrew Askew[2], Raman Khurana[2], Jyothsna Rani Komaragiri[1], **Deepak Kumar**[1], Praveen Chandra Tiwari[1]
Shin-Shan Eiko Yu[3]

[1]Indian Institute of Science, Bangalore, India
[2]Florida State University
[3]National Central University, Taiwan

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Overview

- ☑ Search for Dark matter associated with mono Higgs is one of the dark matter Channel at LHC
- ☑ Mono Higgs + Dark Matter complements to mono-X like searches
- ☑ Looking this search in context of two benchmark models:
  - 2HDM+a Model
  - Z′-Baryonic Model
- ☑ Previous study: EXO-16-050 {for boosted category: using CA15 jet}
- ☑ For today: Looking for events with large MET and low boosted Higgs {resolved category} in 2016 data
- ☑ Plan : Combined resolved + boosted category {2016+2017+2018 data}

Models Overview

Focusing on two Simplified models for this analysis

2HDM+a Model:

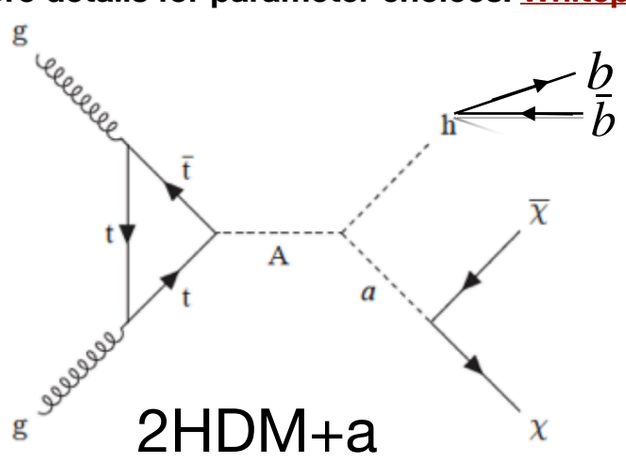
- type-II 2HDM extended by additional light pseudo scalar(**a**)
- Model has 14 parameters

$$\left\{ \begin{array}{c} v,\, M_h,\, M_A,\, M_H,\, M_{H^\pm},\, M_a,\, m_\chi \\ \cos(\beta-\alpha),\, \tan\beta,\, \sin\theta, \\ y_\chi,\, \lambda_3,\, \lambda_{P1},\, \lambda_{P_2} \end{array} \right\}.$$

Free Parameters:

- M_a, $M_A(=M_H=M_{H\pm})$, m_χ, $\sin\theta$, $\tan\beta$
- m_χ=10 is fixed for this analysis

More details for parameter choices: Whitepaper



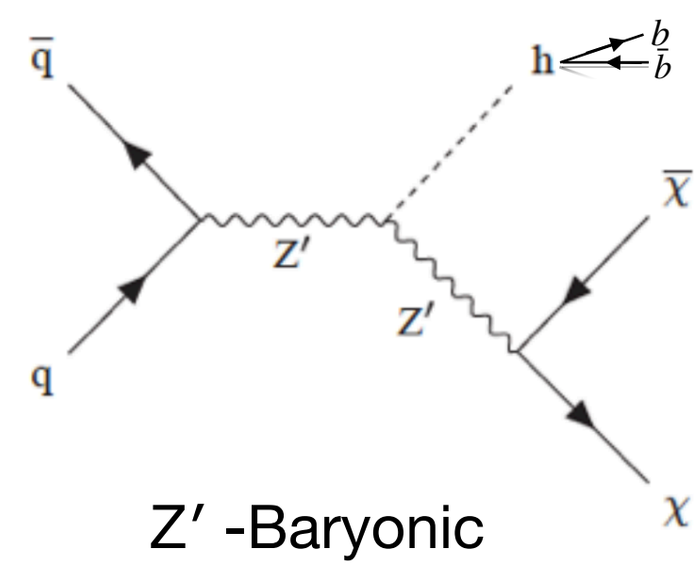
Z′ -Baryonic Model:

- The model is extension of SM by addition of U(1)′ gauge

Parameters:

- $M_{Z'}$, m_χ, g_q, g_x
- [g_q, g_x] are fixed at [0.25, 1] and $g_{hz'z'}/M_{Z'}$ is unity

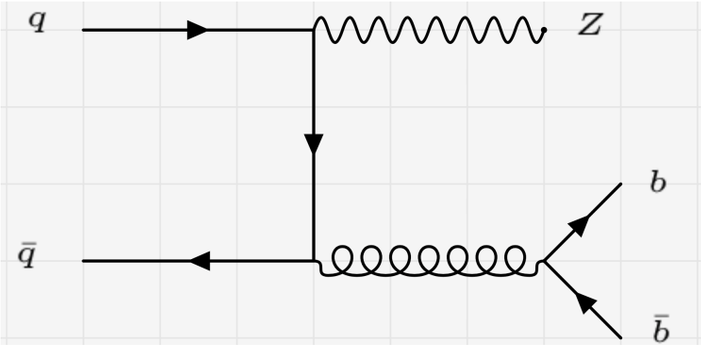
Parameter choices are follow recommendation from : arXiv:1507.00966

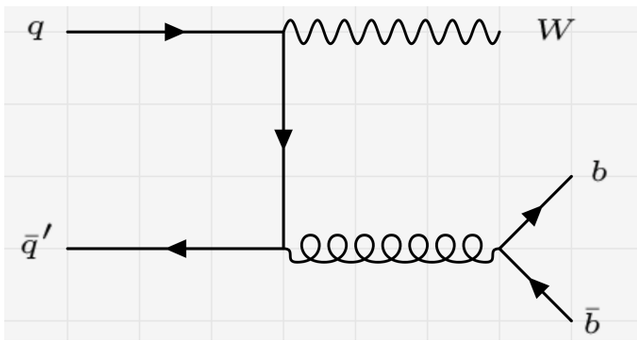


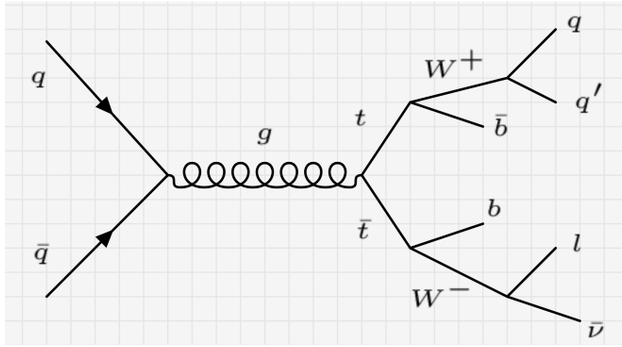
Background Overview

SM process with b quarks and p_T^{miss} can mimic our signal

- Three major backgrounds for this analysis
  - Z+jets: Irreducible background
  - W+jets: Pose background when lepton is lost
  - Top(TT+SingleTop): Pose background when lepton from semi-leptonic TT is lost







- Three minor backgrounds
  - DIBOSON
  - SM H
  - QCD

Triggers and Dataset

- ☑ Using certified events corresponding to 35.5 fb^{-1} from Run2016 [B,C,D,E,F,G,H]
- ☑ MET —> Signal region and Muon control region
- ☑ SingleElectron —> Electron control regions

Dataset	Triggers
MET	PFMET170_*
	HLT_PFMETNoMu90_PFMHTNoMu90_IDTight_v
	HLT_PFMETNoMu100_PFMHTNoMu100_IDTight_v
	HLT_PFMETNoMu110_PFMHTNoMu110_IDTight_v
	HLT_PFMETNoMu120_PFMHTNoMu120_IDTight_v
	HLT_IsoMu24_v, HLT_IsoTkMu24_v
Single Electron	HLT_Ele27_WPLoose_Gsf
	HLT_Ele27_WPTight_Gsf

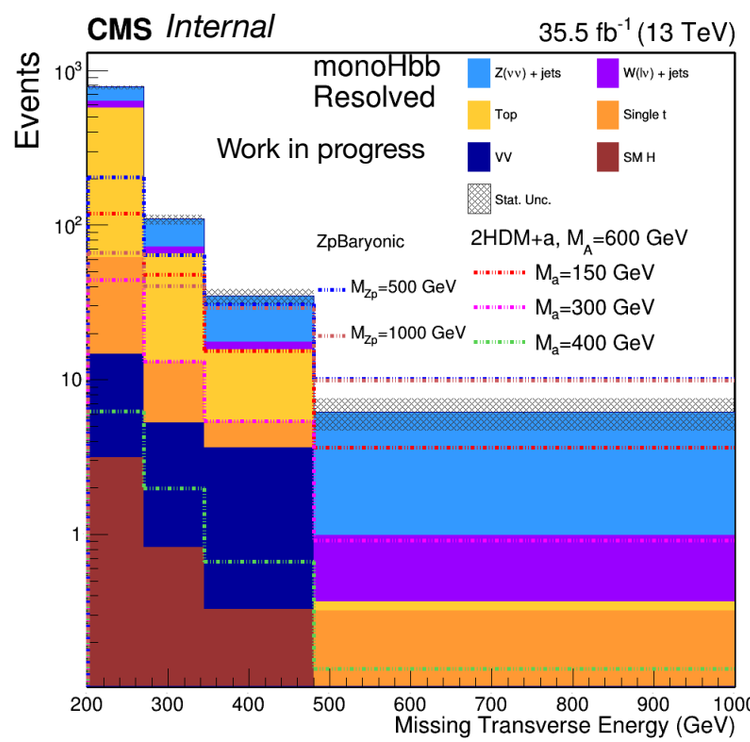
Event selection

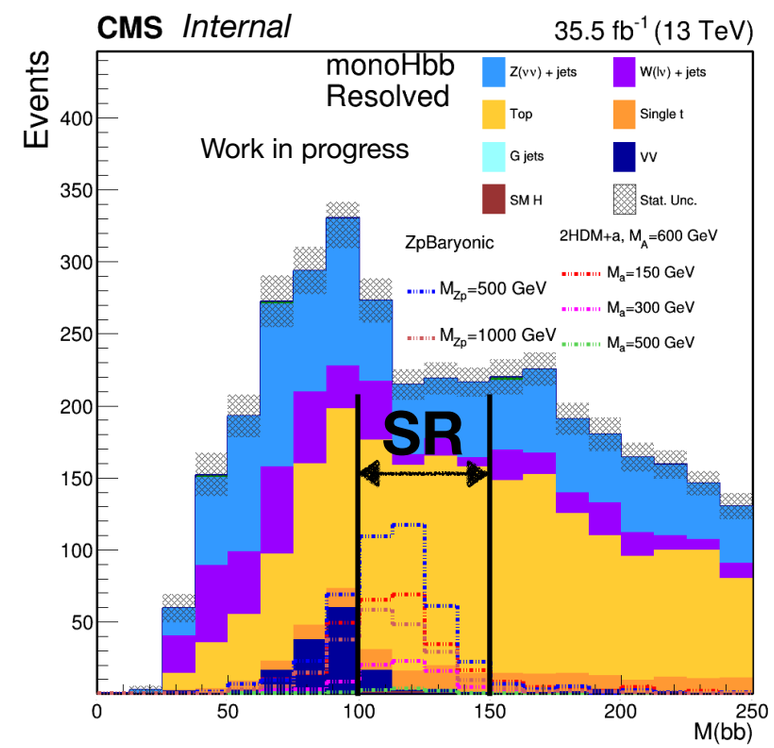
Baseline Selection

- No CA15 fatjet with $p_T > 200$, SDMass [100,150], $|\eta| < 2.4$
- PFMET > 200 GeV (SR) or hadronic recoil > 200 GeV (CR)
- nAK4 jets= 2 or 3
  - ⭐ $p_T > 50$ GeV , $|\eta| < 2.4$ {for leading and subleading jets}
  - ⭐ $p_T > 30$ GeV, $|\eta| < 2.4$ {for additional jet}
- Dijets pair {b tagged using deepCSV MWP} as Higgs candidate with 100 < Mbb < 150 GeV.
- $\Delta\Phi$ (jet, MET) > 0.5
- Lepton veto (SR)

Signal Region

- ☑ Background shape checked in SR (Signal region blinded)
- ☑ MET is shown for SR:
  - ☐ 100 < Mbb < 150 GeV
- ☑ Will apply b jet regression:
  - ☐ To get Higgs mass at correct position
  - ☐ To improve signal efficiency





Signal yield per bin

$p_T^{miss} - bin$			200-270GeV	270-345GeV	345-480GeV	>480GeV
Z+jets			138.54	36.08	15.75	4.98
$t\bar{t}$			507.06	53.21	9.88	0.04
W+jets			55.15	5.23	1.69	0.60
Sigle top			46.99	7.95	1.76	0.24
Diboson			11.59	4.47	3.31	0.0
SM h			3.11	0.81	0.32	0.08
$\sum(SM)$			765.64	107.54	32.50	5.4
Data			–	–	–	–
2HDM+a,	$m_A = 1$TeV,	$m_a = 150$GeV	8.89	7.14	11.53	3.79
Bar. Z′,	$m_{Z'} = .2$TeV,	$m_\chi = 50$GeV	175.25	67.42	34.25	14.28

Major background

Resolved vs Boosted

Resolved Analysis Yield

$p_T^{miss} - bin$			200-270GeV	270-345GeV	345-480GeV	>480GeV
Z+jets			138.54	36.08	15.75	4.98
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Bar. Z′,	$m_{Z'} = .2$TeV,	$m_\chi = 50$GeV	175.25	67.42	34.25	14.28

Boosted Analysis Yield

p_T^{miss}-bin	200-270 GeV	270-350 GeV	350-475 GeV	> 475 GeV
Z+jets	248.9 ± 22.2	97.2 ± 8.5	32.6 ± 3.6	11.1 ± 1.9
$t\bar{t}$	199.2 ± 13.5	52.1 ± 5.2	11.1 ± 2.0	0.7 ± 0.4
W+jets	121.6 ± 21.6	45.0 ± 8.7	8.4 ± 1.9	2.9 ± 0.9
Single top	21.0 ± 4.2	6.1 ± 1.2	0.9 ± 0.2	0.2 ± 0.1
Diboson	16.0 ± 3.1	7.6 ± 1.5	2.4 ± 0.5	1.0 ± 0.2
SM h	12.6 ± 1.4	6.6 ± 0.7	3.3 ± 0.3	1.3 ± 0.1
Σ (SM)	619.3 ± 20.1	214.6 ± 8.1	58.7 ± 3.7	17.2 ± 2.0
Data	619	214	59	21
2HDM+a, $m_A = 1$ TeV, $m_a = 150$ GeV	5.7 ± 0.6	9.8 ± 1.1	18.5 ± 2.1	5.2 ± 0.6
Bar. Z′, $m_{Z'} = 0.2$ TeV, $m_\chi = 50$ GeV	184.2 ± 20.0	118.1 ± 12.8	69.5 ± 7.7	28.9 ± 3.3

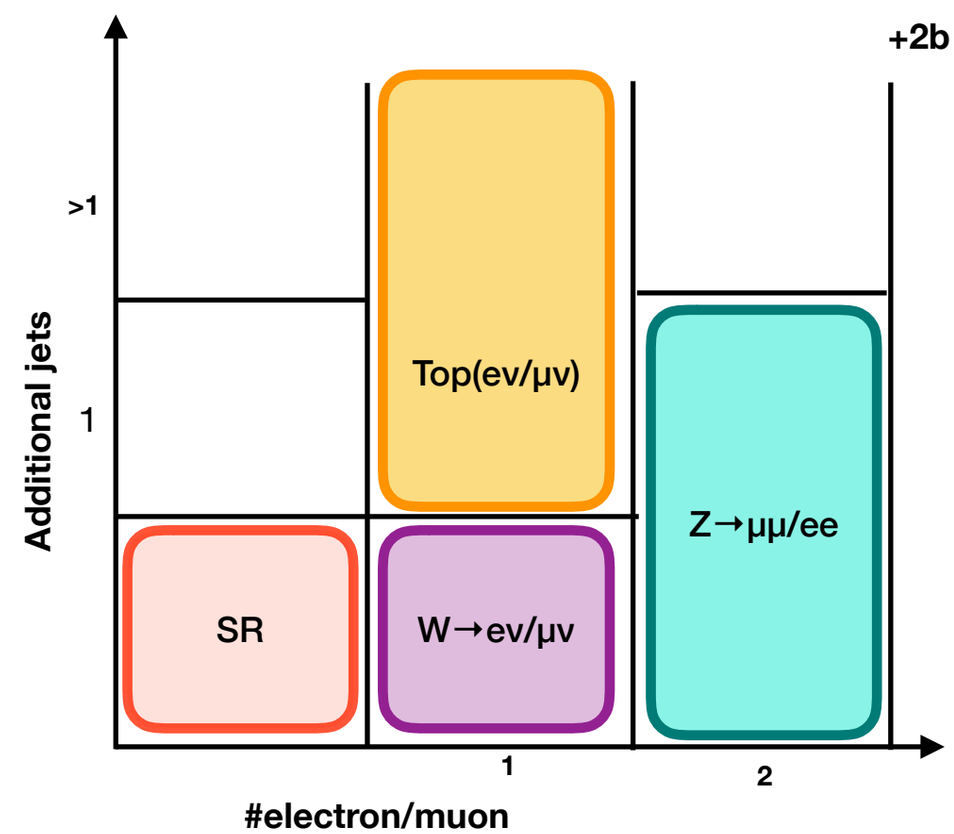
EXO-16-050

Control Regions

To properly model major background for this analysis

- ☑ 6 control regions are defined based on number of leptons, flavour and additional jets.
- ☑ Z(vv)+jets background in SR is modelled using Z(ll)+jets enriched region.
- ☑ W(lv)+jets background(lepton lost) in SR is modelled using high statistics W(lv)+2jets enriched region.
- ☑ TT(semi leptonic) background modelled using W(lv)+jets(>2jets)
- ☑ Hadronic recoil used as proxy for MET in CRs

$$U = -(MET + \sum p_T^{lepton})$$

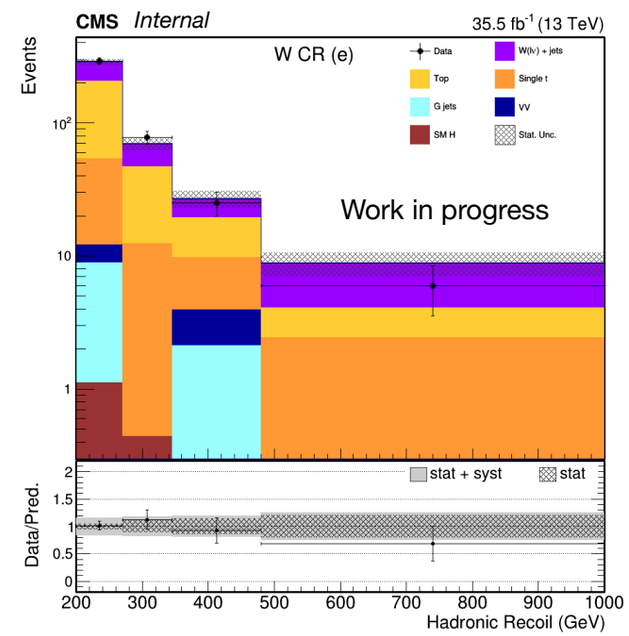


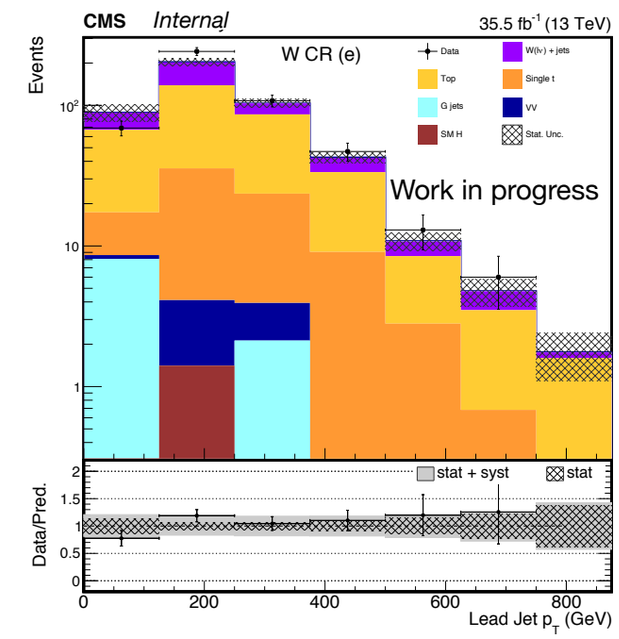
WCR

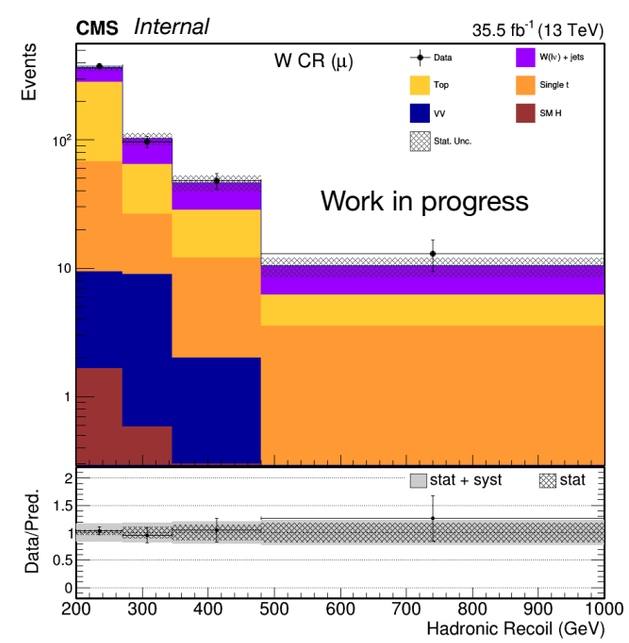
Event Selection

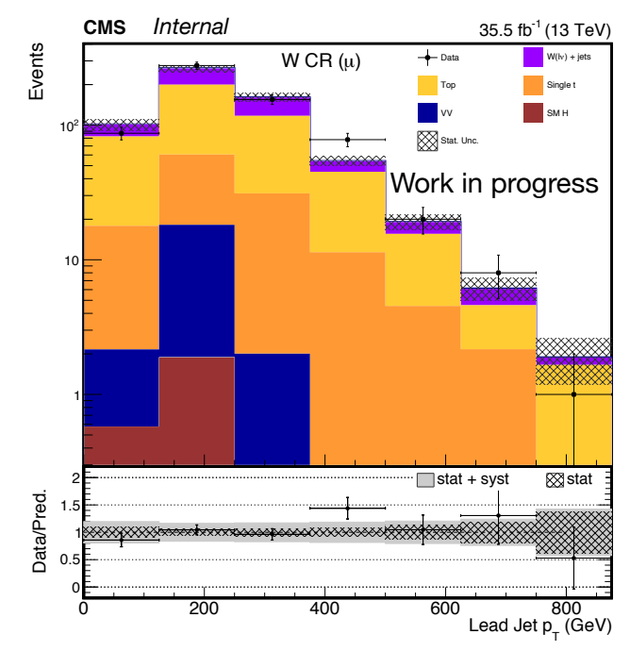
	W→eν	W→μν
#Electron	1	0
#Muon	0	1
Lepton 1	$p_T > 30$	$p_T > 30$
	Tight ID	Tight ID
Lepton 2	veto	veto
Recoil	W Recoil > 200 GeV	
Mass	50 GeV < W Trans Mass < 160 GeV	
Jets	2	
bJets	2	
M(bb)	100 GeV < Mbb < 150 GeV	
CA15Jet	veto	

CR Plots







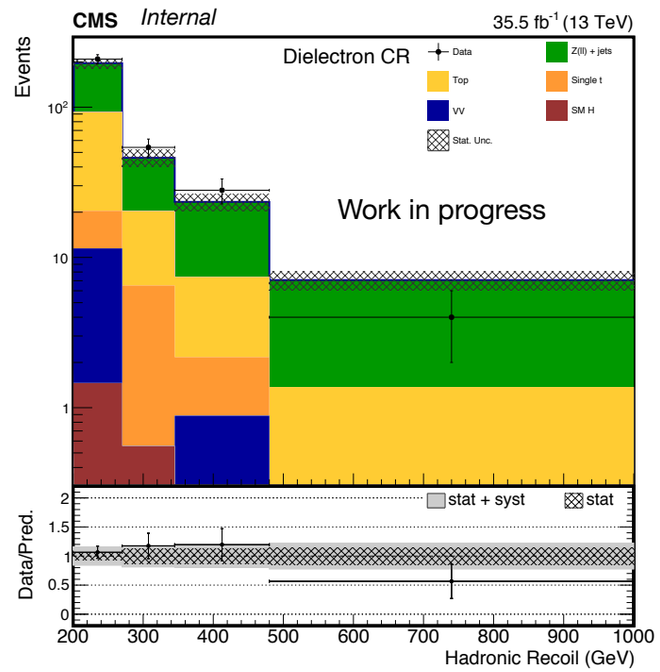


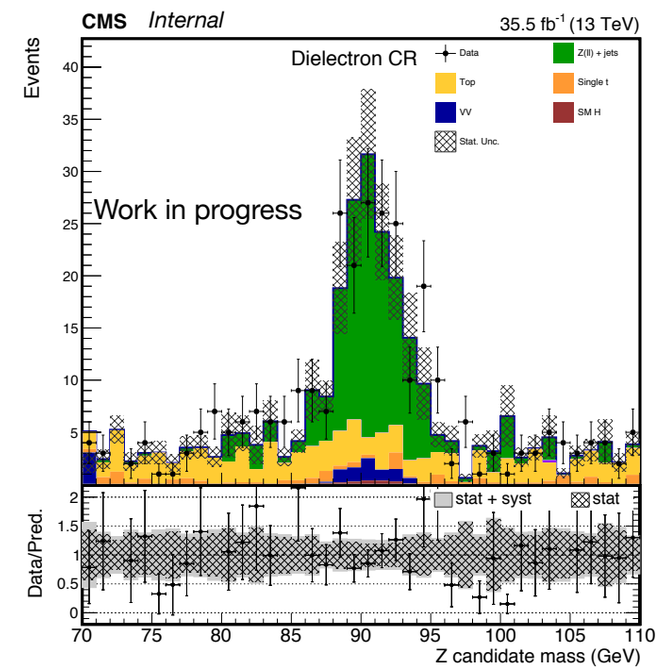
ZCR

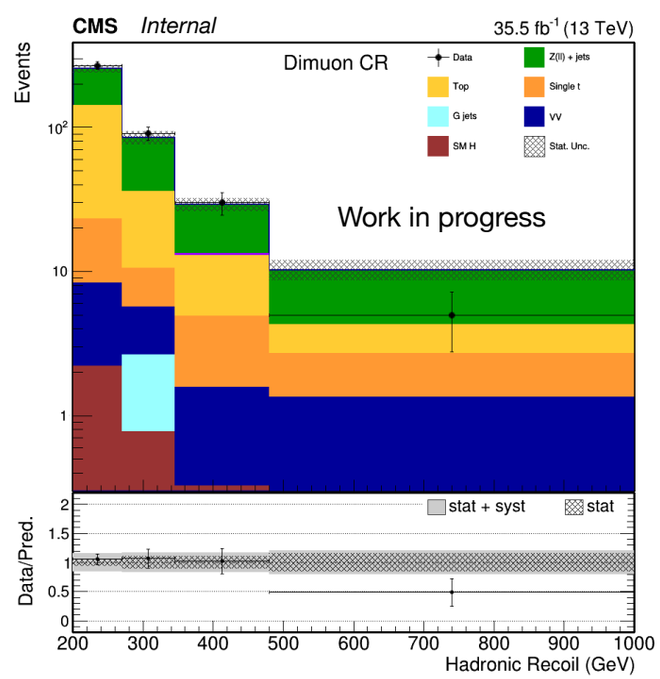
Event Selection

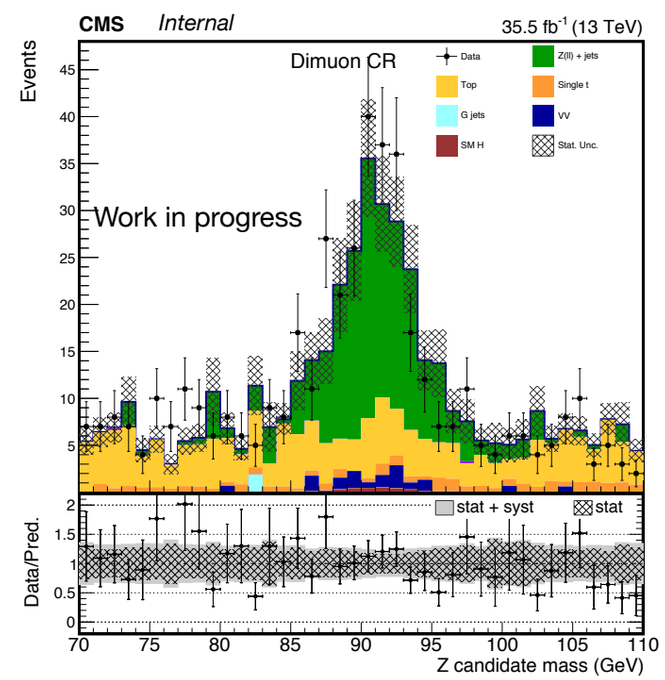
	Z→ee	Z→μμ
#Electron	0	2
#Muon	2	0
Lepton 1	p_T > 30 GeV	p_T > 30
	Tight ID	Tight ID
	Iso < 0.15	
Lepton 2	p_T > 10 GeV	p_T > 10 GeV
	Tight ID	Tight ID
	Iso < 0.15	
Recoil	Z Recoil > 200 GeV	
Mass	70 GeV < Reco Z Mass < 110 GeV	
Jets	2 or 3	
bJets	2	
M(bb)		
CA15Jet	veto	

CR Plots







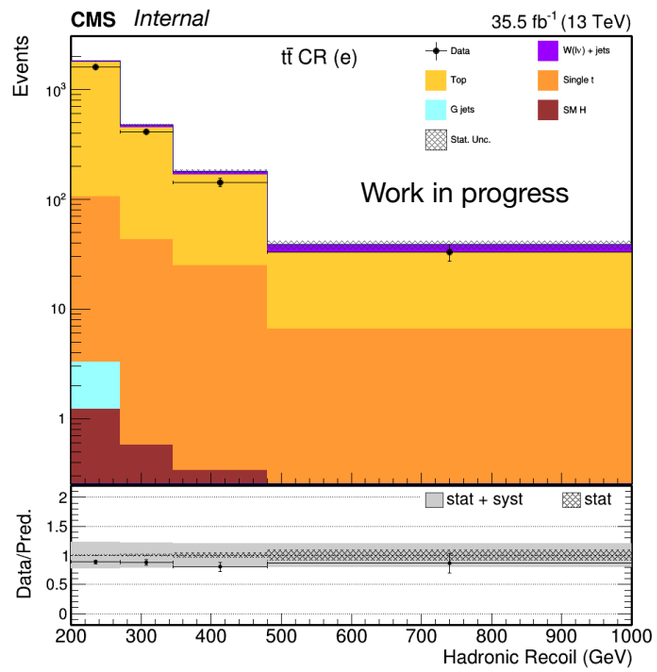


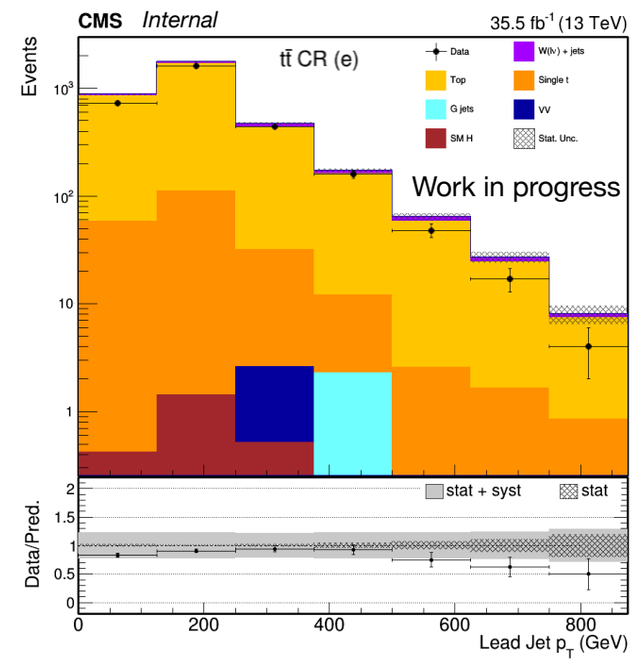
TopCR

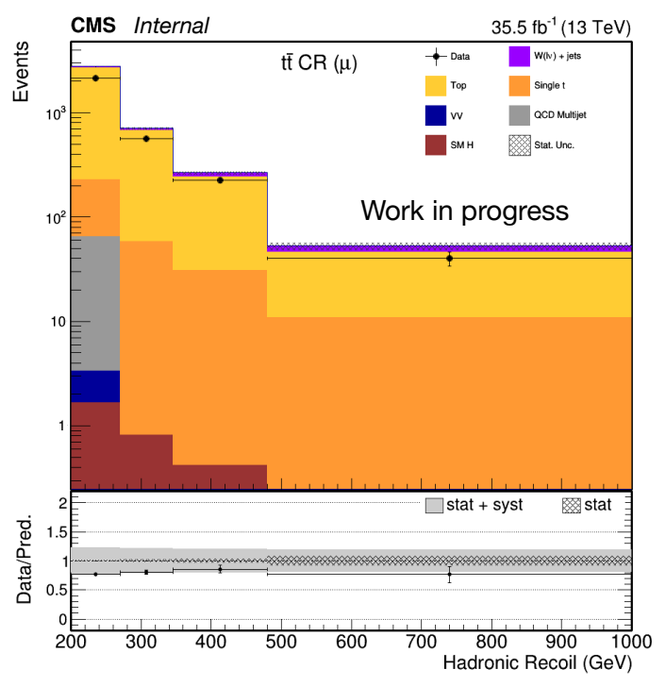
Event Selection

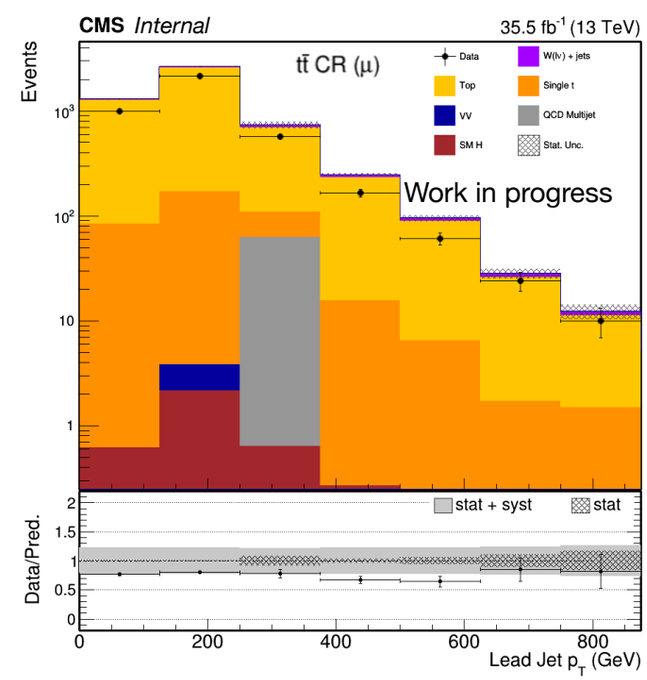
	Top(ev)	Top(μv)
#Electron	1	0
#Muon	0	1
Lepton 1	$p_T > 30$	$p_T > 30$
	Tight ID	Tight ID
Lepton 2	veto	veto
Recoil	W Recoil > 200 GeV	
Mass	50 GeV < W Trans Mass < 160 GeV	
Jets	>2	
bJets	2	
M(bb)	100 GeV < Mbb < 150 GeV	
CA15Jet	veto	

CR Plots





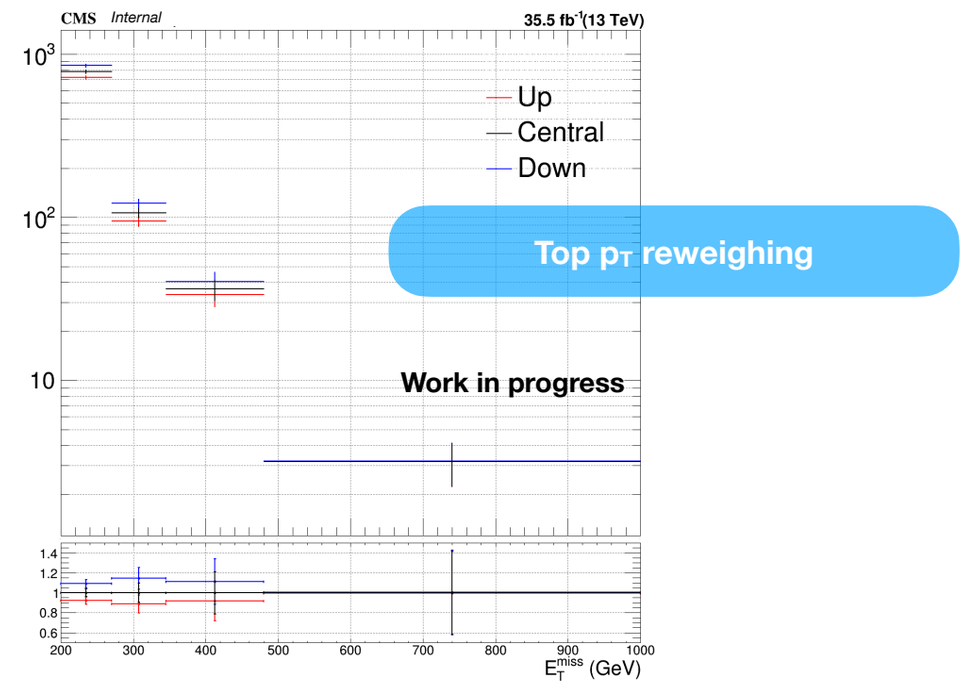


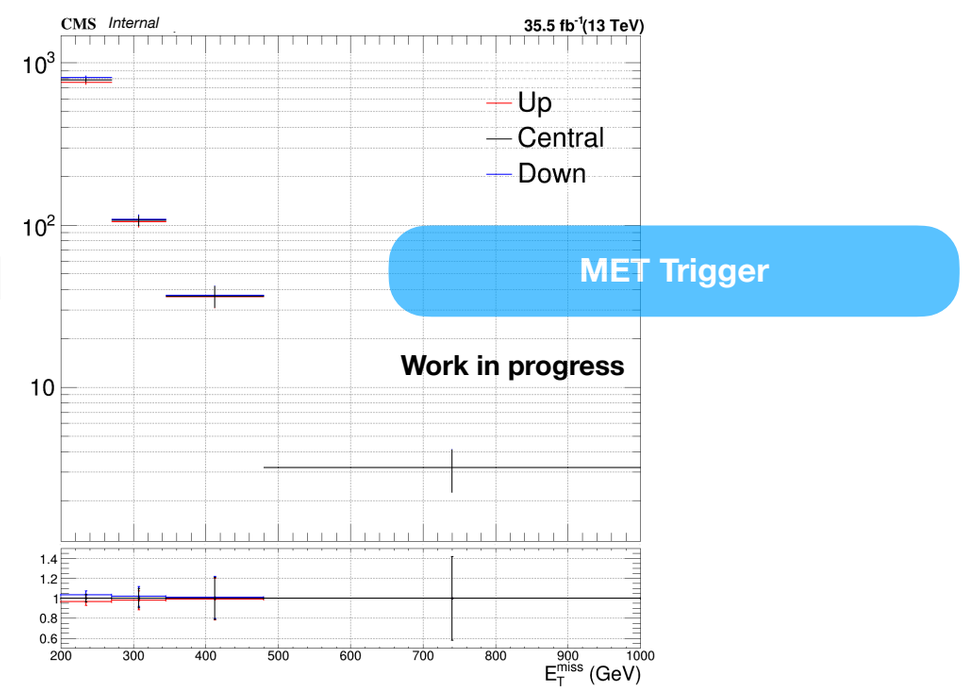


Systematics Uncertainty

Considering following uncertainty to extract the limit.

Source	Uncertainty
Lumi	2.5%
pile up	~0.1-1%
btag	Shape(POG)
Top pT	Shape(50%)
MET trigger	Shape(monoJ)
Electron SF	Shape(POG)
Muon SF	Shape(POG)

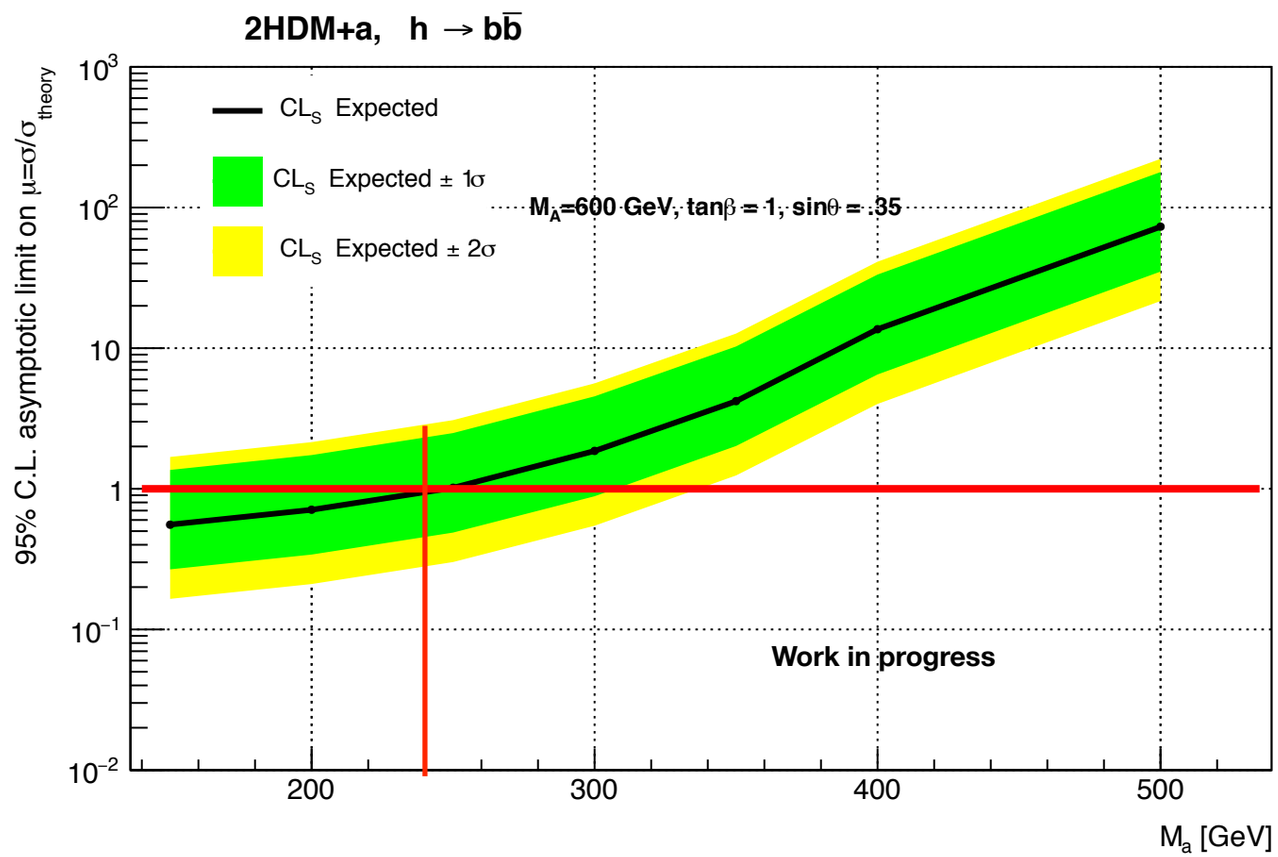




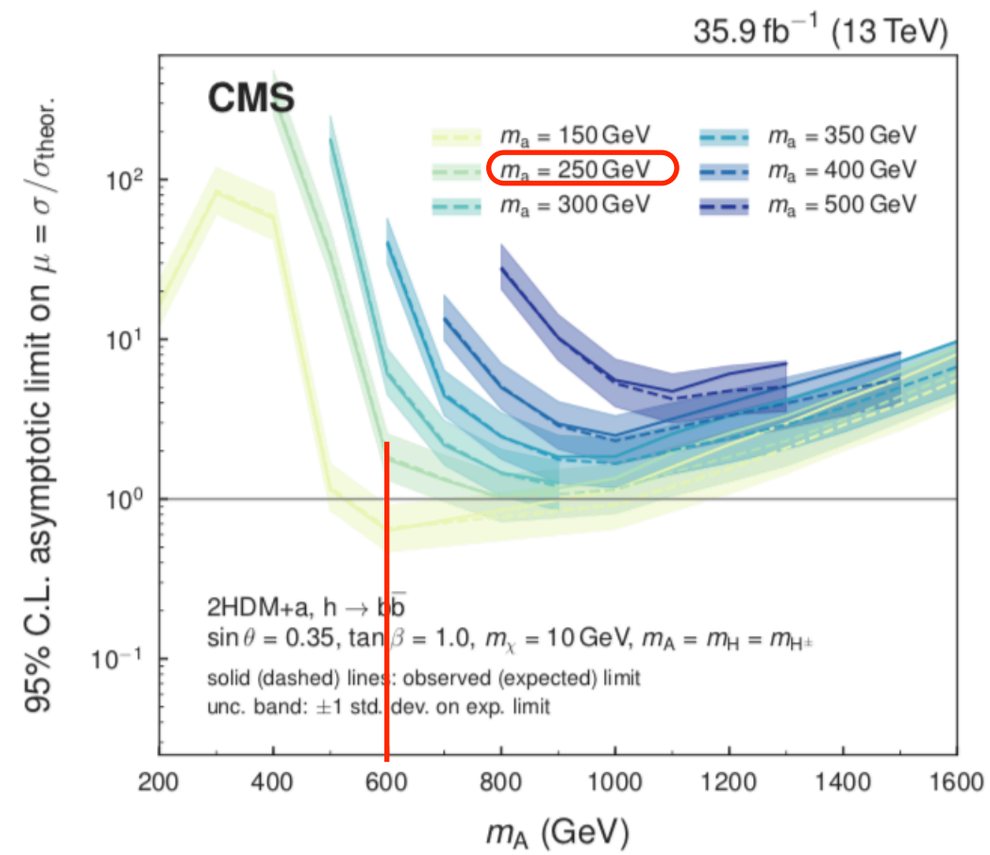
- ☑ Shape variation obtained by applying 50% as up and down systematic.
- ☑ Full difference between the W -> μν and the Z->$\mu^+\mu^-$ trigger turn on is used as systematic uncertainty.

Results: 2HDM+a model

- Reach of resolved category is very similar to boosted category
  - For m_a=250 GeV, m_A=600GeV, tanβ=1, sinθ=0.35
  - m_A scan is in progress



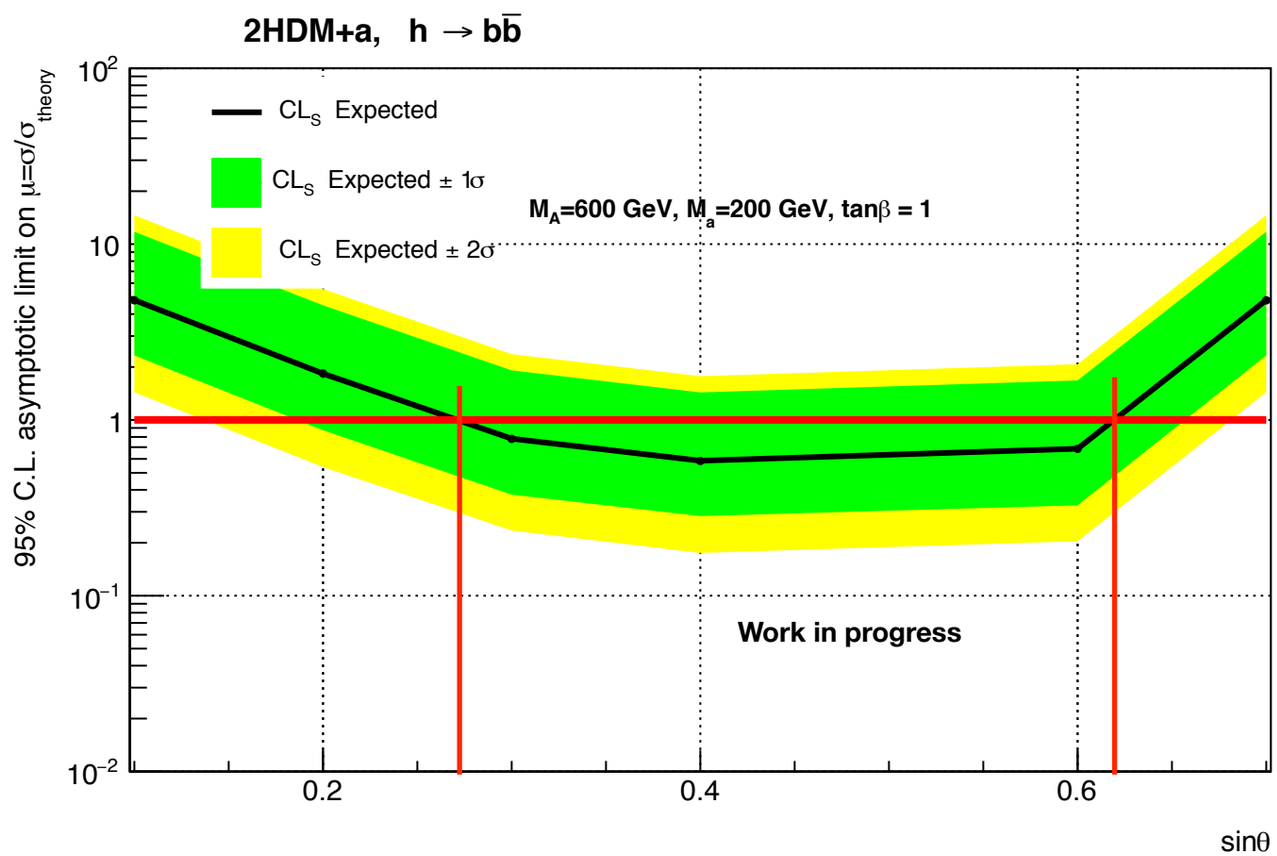
Resolved Category



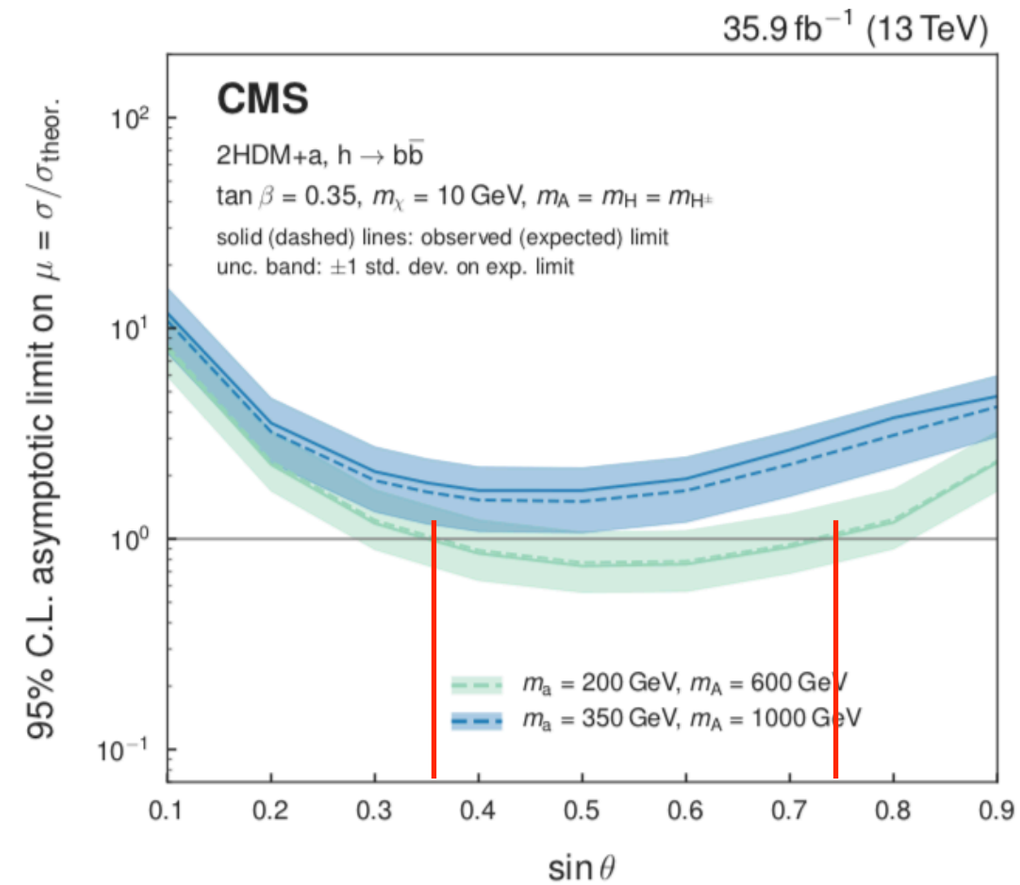
Boosted Category: **EXO-16-050**

Results: 2HDM+a Model

☑ Resolved Analysis may bring improvement at low sinθ



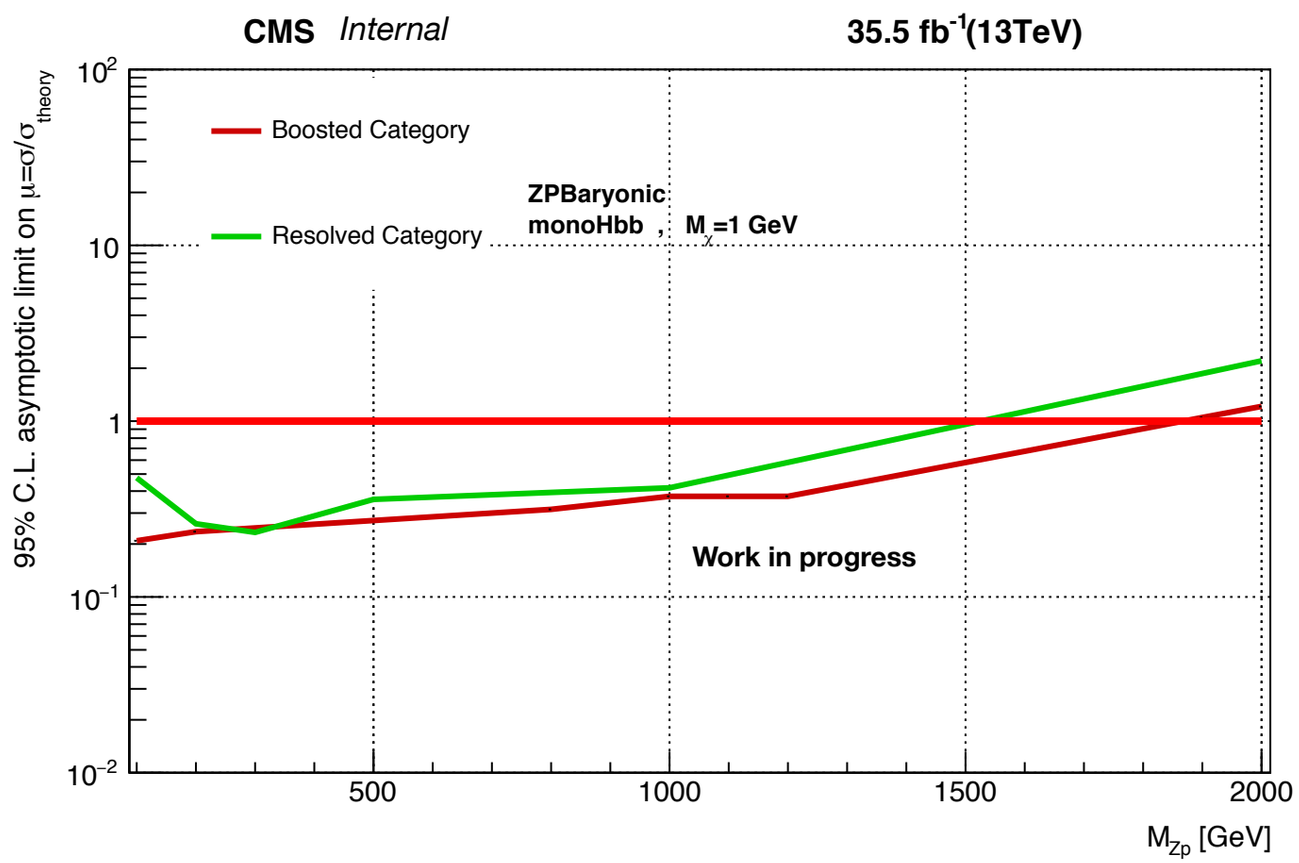
Resolved Category



Boosted Category: **EXO-16-050**

Results: Z′-Baryonic Model

- ☑ Resolved Analysis may bring significant improvement to the Analysis.



Summary

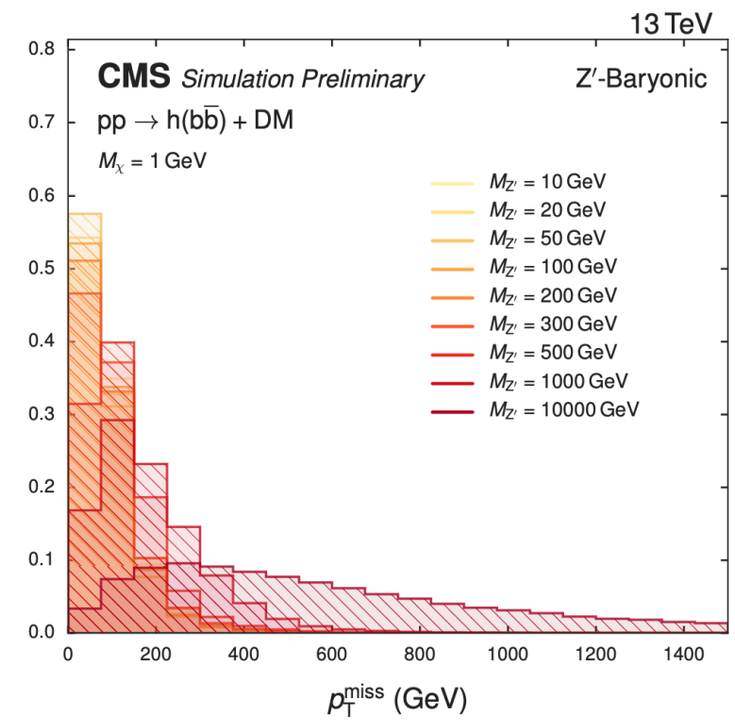
- ☑ Two models are used in this analysis.
- ☑ A search for dark matter in resolved monoH→bb final state is performed.
- ☑ This analysis is completely orthogonal to boosted category, by putting CA15 jet veto
- ☑ Preliminary results shows good potential for the resolved Analysis.

Back-up

Signal samples

Z`-Baryonic	MonoHbb_ZpBaryonic_MZp-*_MChi-*_13TeV-madgraph_MC25ns_LegacyMC
	MZp=[10,50,100,200,300,500,1000,2000]
	2HDMa_gg_sinp_0p*_tanb_*_mXd_10_MH3_*_MH4_*_MH2_*_MHC_*
2HDM+a	MH4=[100,150,200,250,300,350,400,500], MH2=MH3=MHC=[600,700,800,900,1000,1100,1200,1300,1400,1500]
	sinp=[0.1,0.2,0.3,0.35,0.4,0.6,0.7,0.8,0.9] tanb=[1-50]

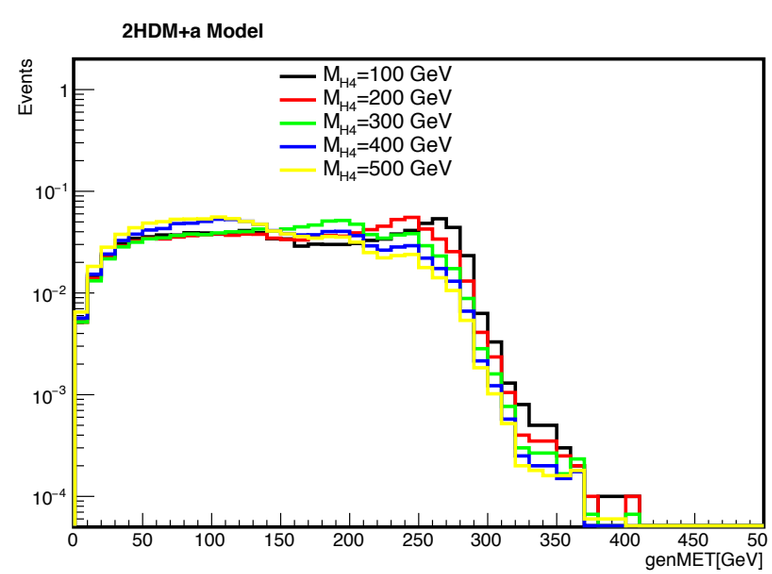
Samples used in EXO-16-050

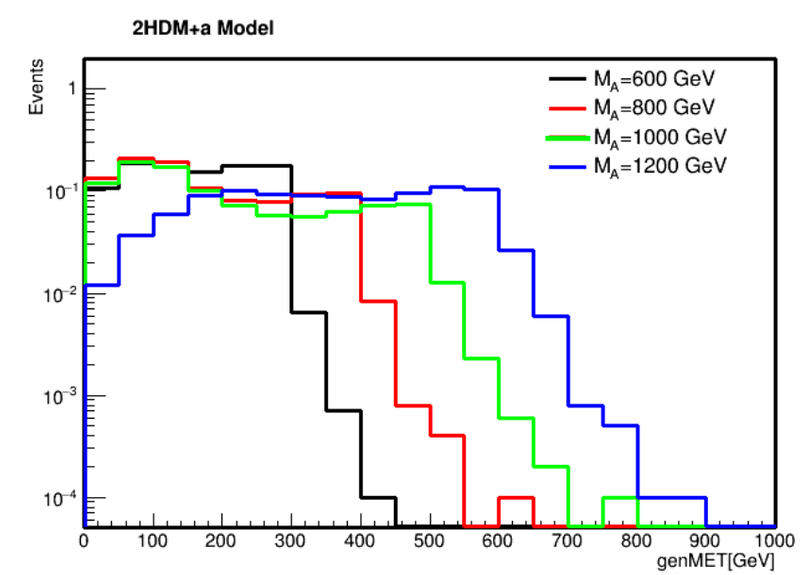


Z′-Baryonic

- ☑ genMET distribution changes when we change mediator masses in the both models
- ☑ genMET definition:

$$genMET = \sum p_T(\chi, \bar{\chi})$$

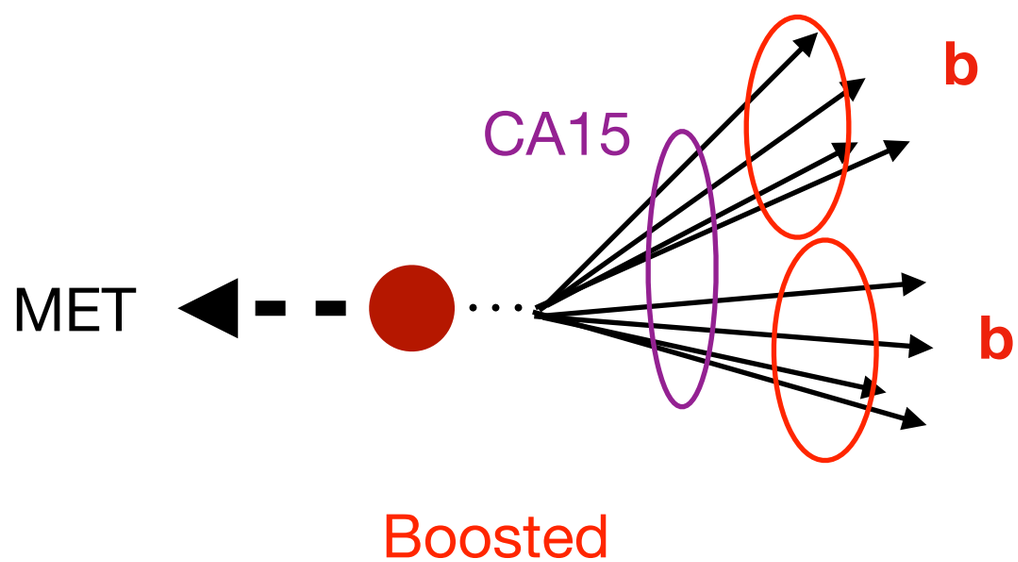




2HDM+a

Motivation

- ☑ All signal events not covered in boosted category(CA15)
- ☑ Aim to catch the signal falling in resolved category



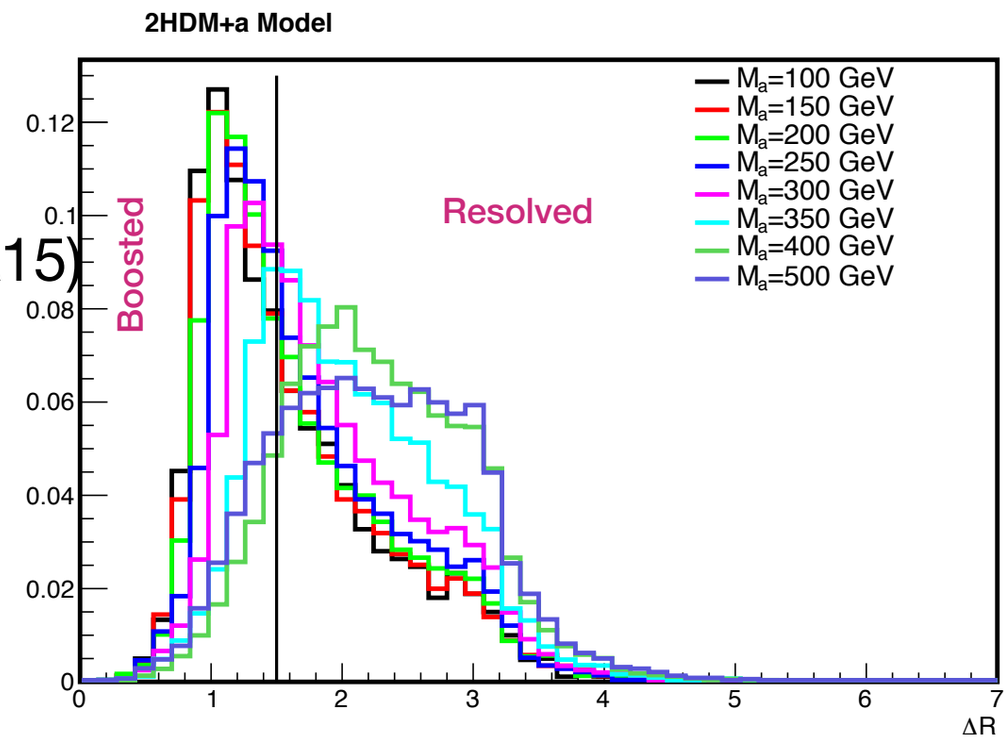
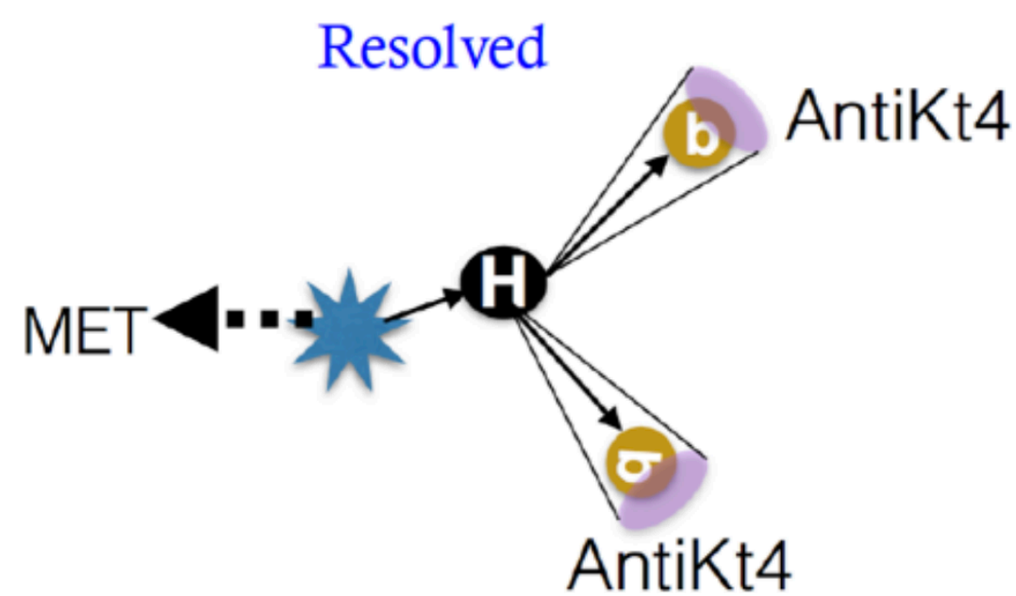


Fig: deltaR between two b jets

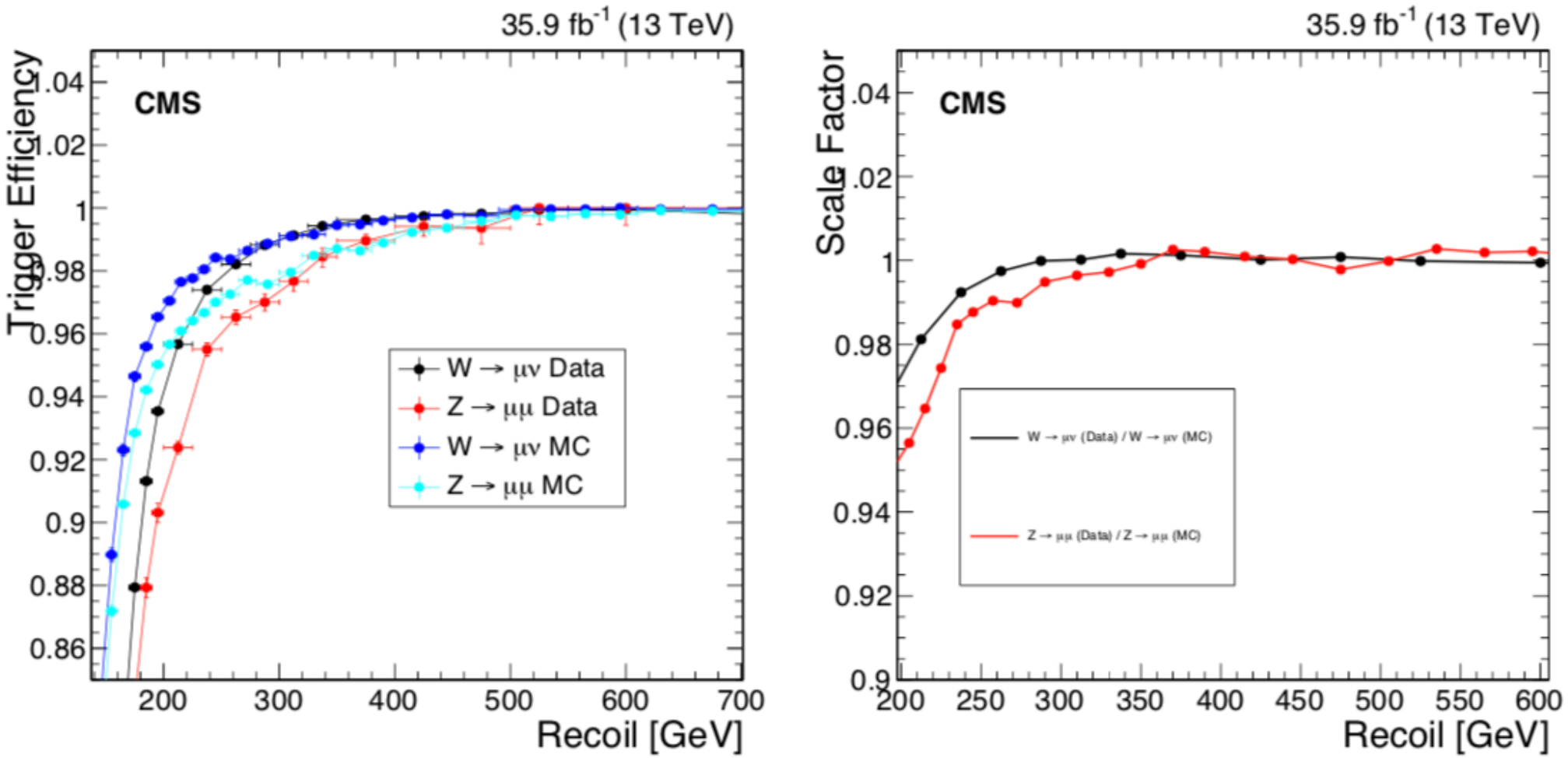


Background Samples

All samples are from the RunSummer16MiniAODv2 campaign

- ☑ **Z(->νν) + Jets**
  - ZJetsToNuNu HT-binned samples
  - HT-100ToInf
- ☑ **W(->lν)+Jets**
  - WJetsToLNu HT-binned samples
  - HT-100ToInf
- ☑ **TT**
  - TT powheg samples
- ☑ **Single TOP**
  - ST_s,channel_4f_leptonDecays
  - ST_t,channel_anEtop_4f_inclusiveDecays
  - ST_t,channel_top_4f_inclusiveDecays
  - ST_tW_anEtop_5f_inclusiveDecays
  - ST_tW_top_5f_inclusiveDecays

- ☑ **Z(->ll) + Jets**
  - DYJetsToLL_M-50 HT binned samples
  - HT-70ToInf
- ☑ **Diboson**
  - ZZ, WZ, WW
- ☑ **QCD Multijets**
  - QCD HT-binned samples
  - HT-500ToInf
- ☑ **SM H**
  - ZH HToBB ZToNuNu, ZH HToBB ZToLL
  - ggZH HToBB ZToNuNu, ggZH HToBB ZToLL
  - WminusH HToBB WToLNu, WplusH HToBB WToLNu



(a) (b)

Figure 6: Comparison on both data and MC between the METNoMu+MHTNoMu trigger efficiency turn on as measured in $W \rightarrow \mu\nu$ and $Z \rightarrow \mu^+\mu^-$ events (left). (Right) Comparison between the data to MC scale factors which show a significant disagreement in the low recoil region; taken from [8].