The background of the slide is a dark, noisy image of a particle detector, likely CMS, showing a complex network of white and light blue tracks. A specific region in the center is highlighted with a green, semi-transparent rectangular overlay. Decorative elements include a light blue curved shape in the top-left corner and a pink curved shape with small dots in the bottom-right corner.

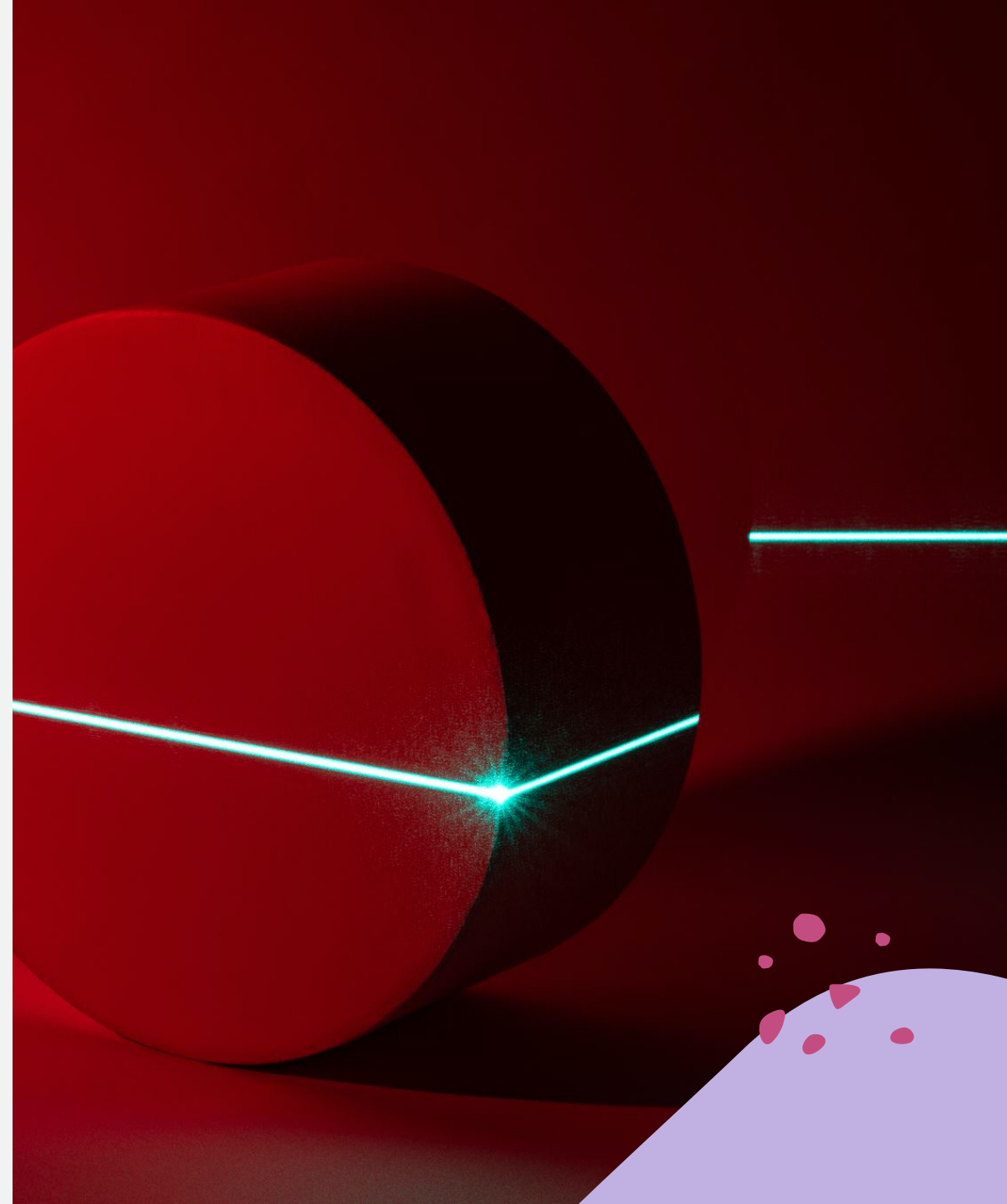
Search for resonances in low-mass dimuon mass spectrum produced in association with b -jets with CMS

Olga Kodolova (on behalf of analysis team)

Introduction

- Discovery of Higgs-boson with mass 125 GeV in 2012 gives the new motivation for extended Higgs sector at LHC.
- A set of models beyond Standard Model predicts light (pseudo) scalar bosons: 2HDM, nMSSM, ...
- An extensive search in ATLAS, CMS, LHCb put some limits to production cross-sections of such particles in the frame of the concrete models.

However, the number of models is countable but the phase-space of the different realizations of nature is infinite. It is impossible to set the absolute exclusion in the ever mass range reachable in the experiment.

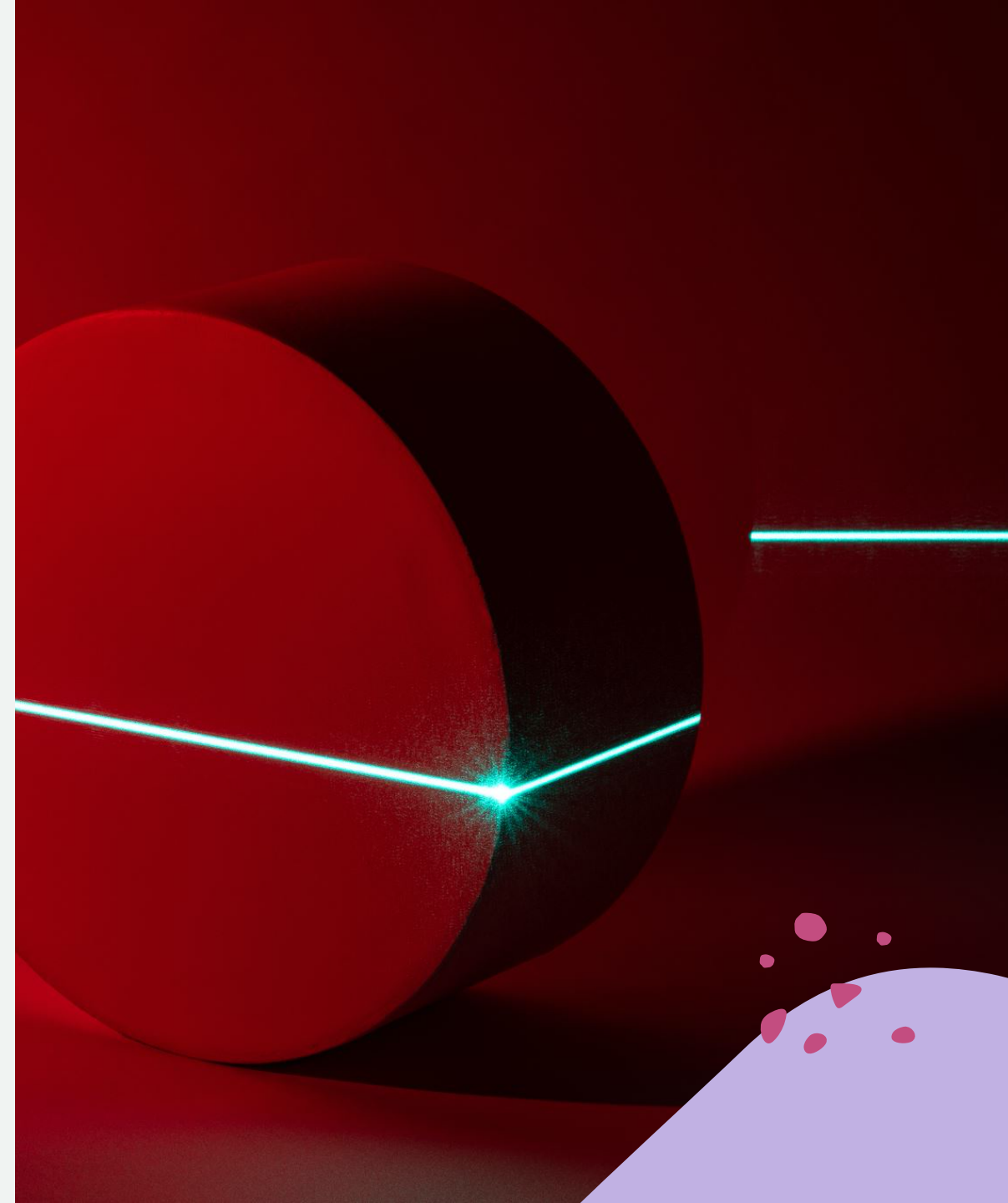


Introduction

While doing the detailed search of dimuon resonance in the mass range 12-70 GeV produced in the association with b-jets

$pp \rightarrow bbA, A \rightarrow \mu^+ \mu^-$ at $\sqrt{s} = 8$ TeV in 2012

an enhancement in the dimuon spectrum near $\text{Mass} = 28$ GeV was observed in events containing a b quark jet in the central pseudorapidity region ($|\eta| \leq 2.4$)



Monte-Carlo background events

8 TeV

13 TeV

Drell-Yan: LO Madgraph with 0,1,2,3, ≥ 4 jets,
parton showering with Pythia 6/8

W+jets: LO Madgraph+Pythia6

tt: Madgraph+Pythia

Single top: powheg+pythia

Diboson production: Madgraph+Pythia

powheg, AMC@NLO + Pythia8

Object and global event selection

Single muon trigger with $p_T > 24$ GeV

Good vertex criteria are switched on

PF and JPT anti- k_T jet algorithms are used with distance parameter $R=0.5(0.4)$ for 8(13) TeV

JetPileUP Identification for jets $|\eta| < 2.5$

B-tagging CSVMVA for 8 TeV with super-Tight working point (0.0005 rejection factor for light-q jets) and for 13 TeV Tight working point (0.001 rejection factor for light-q jets)

Tight global muons are used with Tracker isolation with criteria of vertex ($d_r < 0.2$ cm, $d_Z < 0.5$ cm).

Offline event selection and events categorization in 2012-2017

Note, we do not take into account category with only one jet with $p_T > 30$ GeV and $|\eta| < 4.7$

Although this category is the additional to SR1/2.

Pileup conditions:

8 TeV (2012):

13 TeV (2016):

Event category	Search region 1	Search region 2
Muons	OS, $p_{T1,2} > 25$ GeV, $ \eta < 2.1$	
Dimuon mass	$M_{\mu\mu} > 12$ GeV	
B-tagged jet	$p_T > 30$ GeV. $ \eta < 2.4$	
Other jets	$p_T > 30$ GeV, $2.4 < \eta < 4.7$	$p_T > 30$ GeV. $ \eta < 2.4$
Jet veto	No other jets with $p_T > 30$ GeV. $ \eta < 2.4$	No other jets $p_T > 30$ GeV, $ \eta < 4.7$
p_T^{miss}	-	< 40 GeV
$\Delta\phi(\mu\mu, jj)$	-	> 2.5 rad

Mass spectra at 8 and 13 TeV for SR1/SR2

At 8 and 13 TeV the same search regions (SR1,SR2) are used.

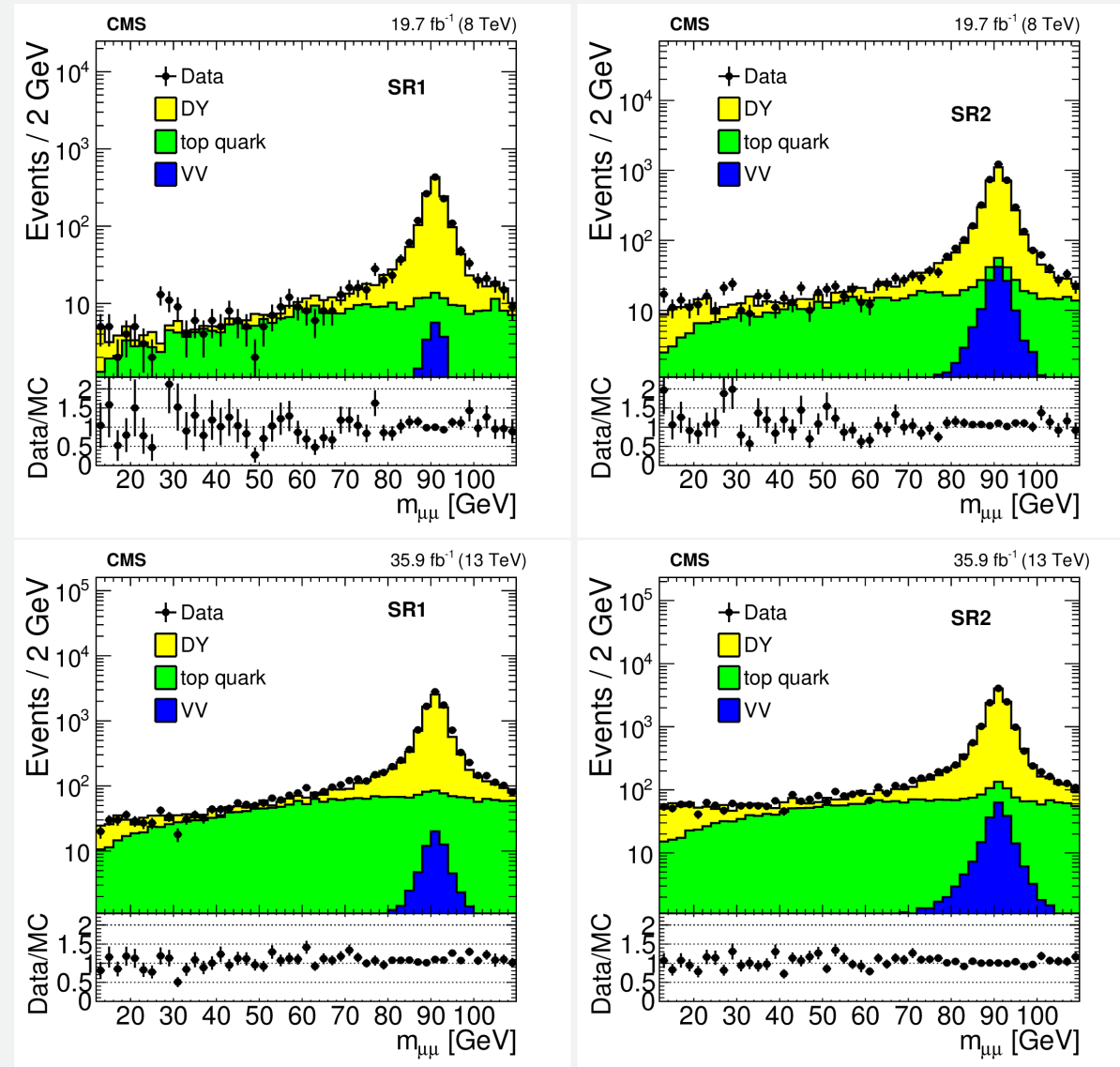
Note:

there is a difference in b-tagging.

8 TeV - super-Tight (lq rejection rate 0.0005)

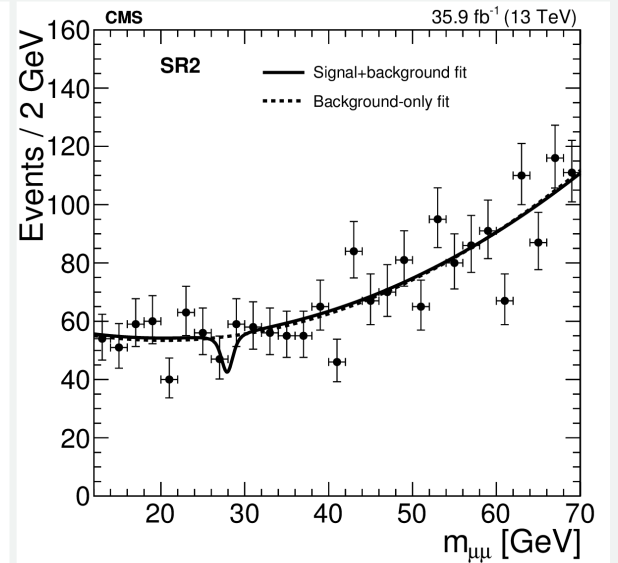
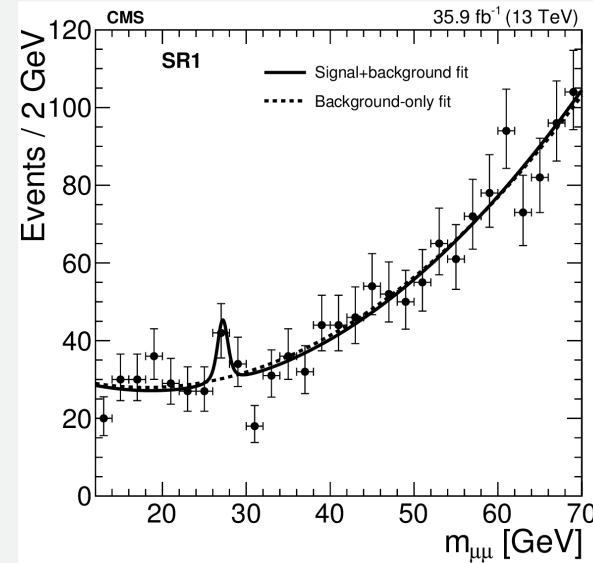
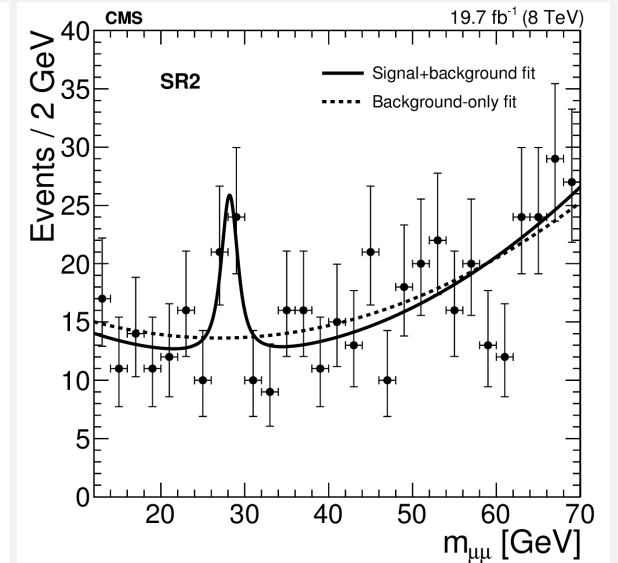
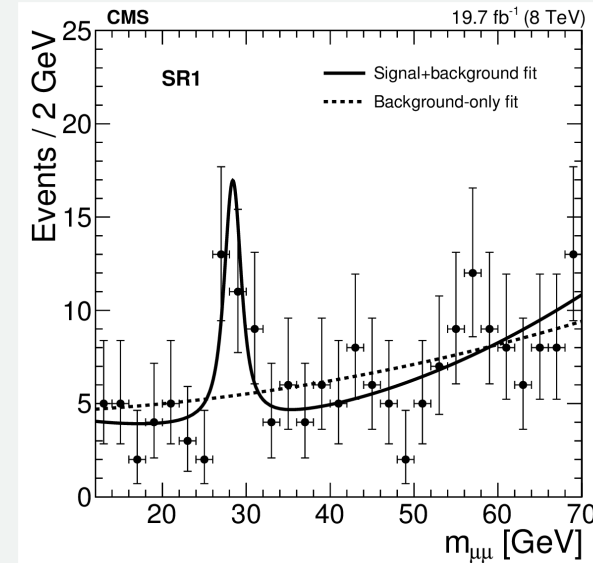
13 TeV - Tight (lq rejection rate 0.001)

tt at 13 TeV increases in 3.5 times w.r.t. 8 TeV

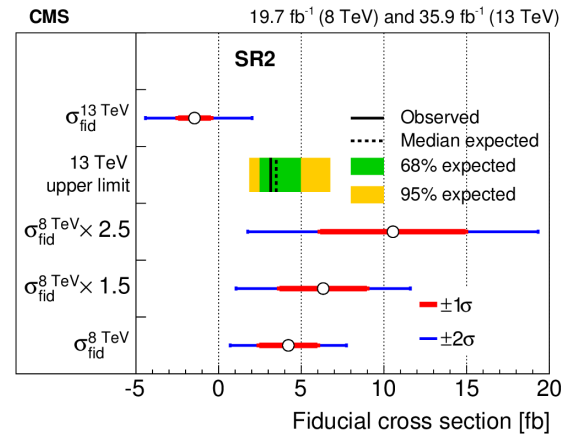
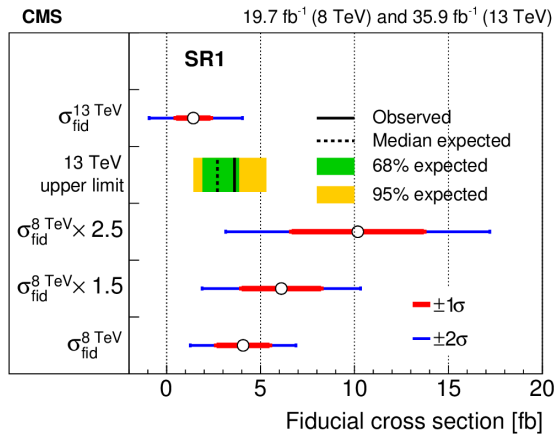


Fit of mass spectra

Unbinned fit is done using polynomial function of the second for background parametrization and Breit-Wigner for signal parametrization.



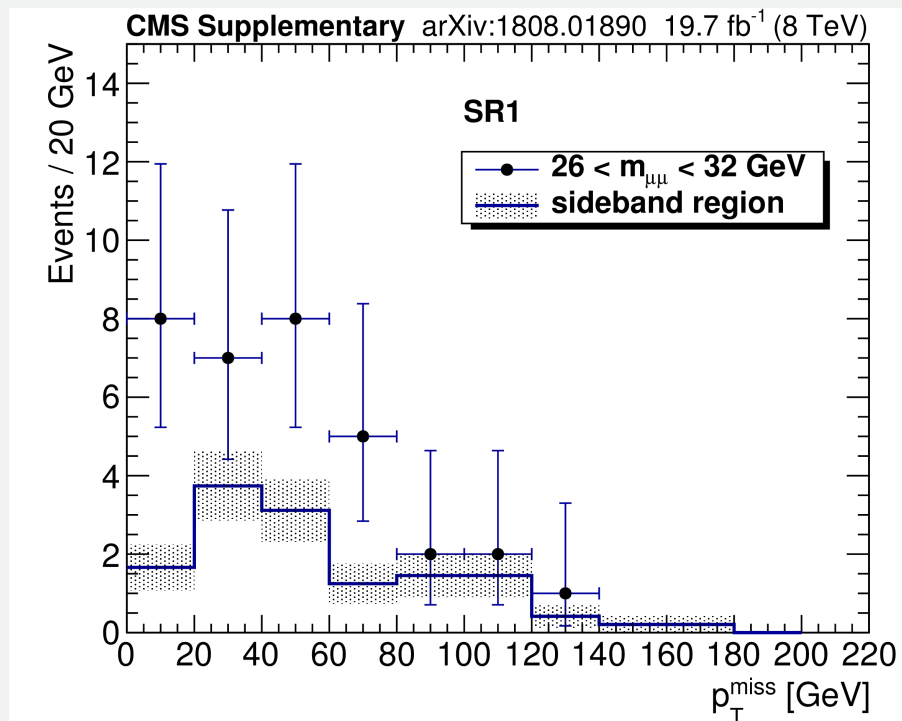
Evaluated cross-sections and limits



Reconstruction efficiency = 0.27

S (TeV)	8		13	
Event category	SR1	SR2	SR1	SR2
Local significance	4.2	2.9	2	-1.4
m_X (GeV)	28.3 \pm 0.4		27.2 \pm 0.6	
$\Gamma_{\mu\mu}$ (GeV)	1.8 \pm 0.8		0.7 \pm 1	
N_S	22 \pm 7.6	22.8 \pm 9.5	14.5 \pm 9.3	-14.9 \pm 10.1
N_S observed upper limit	40.4	44.7	36.9	32.2
N_B observed upper limit	18.3	27.6	27.6	35.6
Int. Lumi	19.7 \pm 0.5		35.9 \pm 0.9	
σ_{fid} (fb)	4.1 \pm 1.4	4.2 \pm 1.7	1.4 \pm 0.9	-1.5 \pm 1.0
Observed upper limit	7.6	8.4	3.7	3.2
Expected upper limit	3.4	5.2	2.7	3.5

Caveats known already at time of paper approval



1. We had the request from CMS to use completely the same cuts for 13 TeV as we did for 8 TeV, but:

At 13 TeV background is increase ~3.5 times due-to increase of $t\bar{t}$ cross-section. We do not know what is increase for our potentially observed process. It may be 1.5 times as for Z-boson

The high mass sideband rises rapidly as function of mass at 13 TeV. NWU team proposed the special cut $p_T^{\mu\mu}/M_{\mu\mu}$ but we could not use it for this paper.

2. The choice of symmetric threshold for p_T^{μ} looks not too natural
3. We put cut for SR2 on p_T^{miss} but SR1 shows that in these events (under the excess) we may have non-zero p_T^{miss}

Full Run II analysis in 2019-2022

We discussed within Higgs POG and had agreed on the analysis procedure:

- optimize the analysis with 2008/2016 data and fix analysis parameters
- use the optimized analysis for 2017-2018 data

If excess exists then calculate significance basing on only 2017/2018 data otherwise calculate upper limits basing on 2017/2018 data.

Optimization strategy

The goal of cuts and categorizations in dimuon excess analysis: suppress $t\bar{t}$ events or Drell-Yan events or both using some general considerations. As we do not know the origin of excess, cuts and categorizations at the same time reveal some features of the excess whatever nature it has.

What we could optimize:

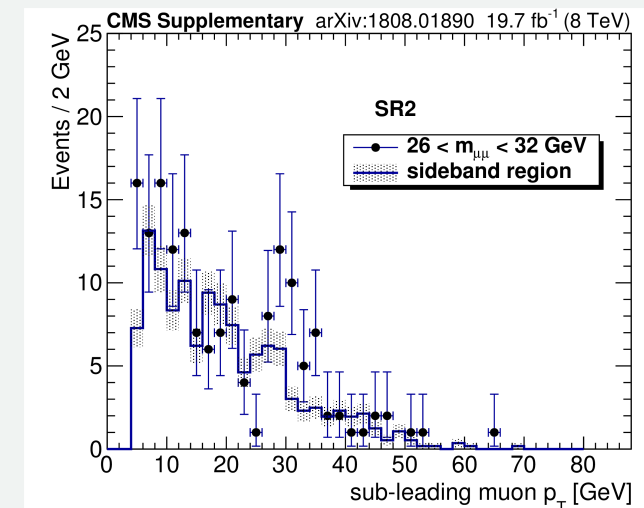
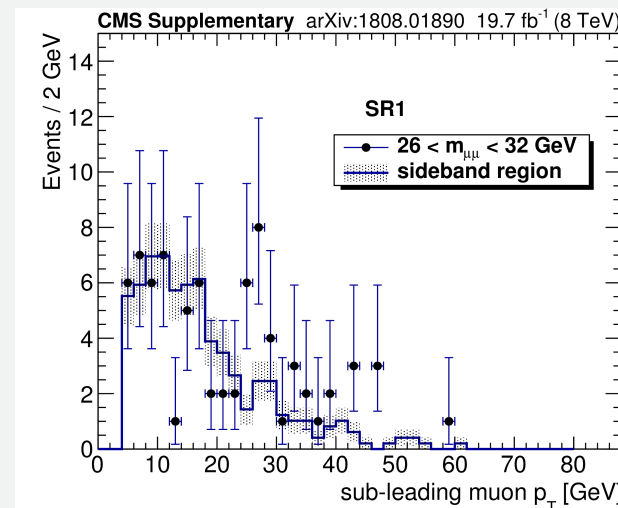
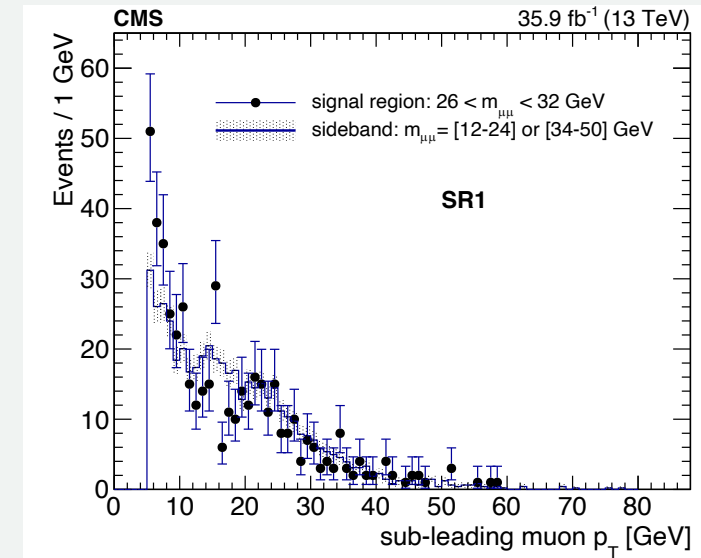
1. Symmetric cut on muon p_T : What is the most optimal cut?
2. The object is boosted: could we use it?
3. Jets: in addition to gluon radiation, due to reconstruction efficiency, jet energy scale, change of jet radii the number of jets with $p_T > 30$ GeV in different η -range may be changed: could we add another jet category?
4. B-tagging - new algorithms appear at market: what is algorithm dependence?
5. Missing p_T : we put this cut against $t\bar{t}$ but it may cut the signal object so as: could we release it?

Muons

p_T cut on the second muon in SR1 in 13 TeV data:
clear difference between sidebands and
signal range.

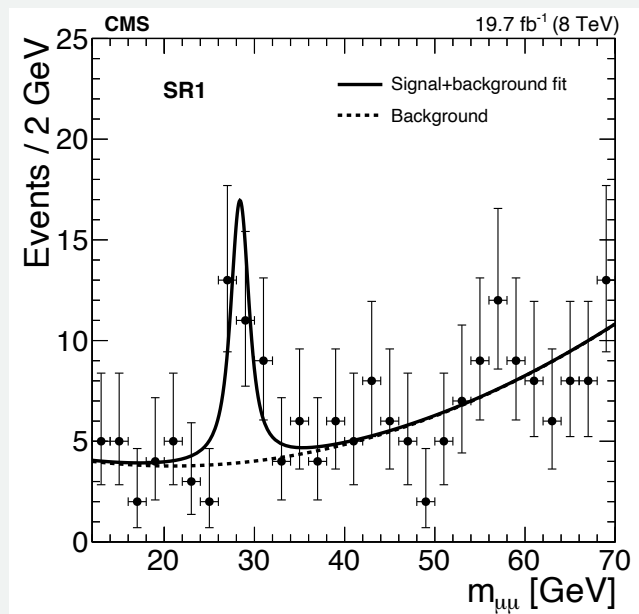
The same feature in p_T spectrum is seen
in 8TeV data both in SR1 and SR2.

Looks like the cut on the second muon can be
optimized. The best choice giving the maximal
significance appeared to be
 $p_{T\mu^{1/2}} = 25, 18 \text{ GeV}$



Boost cut: $p_{T\mu\mu}/M_{\mu\mu}$

No cut

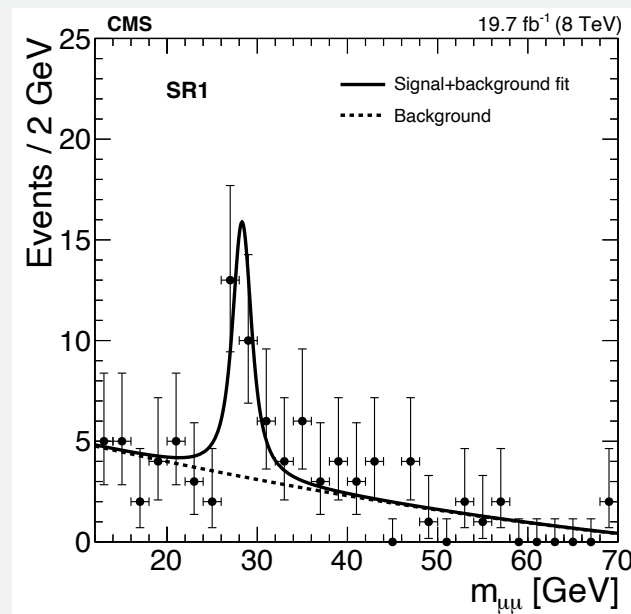


$$N_S^{\text{fit}} = 18.3$$

$$N_B^{\text{fit}} = 11.9$$

$$\text{Local significance} = 4.2$$

$p_{T\mu\mu}/M_{\mu\mu} > 1.7$



$$N_S^{\text{fit}} = 18.3$$

$$N_B^{\text{fit}} = 9.6$$

$$\text{Local significance} = 4.5$$

Symmetric cut $p_{T\mu 1/2} > 25$ GeV

Categorization in the number of jets

In paper:

SR1:

1 bjet in $|\eta| < 2.4$

Central jet veto

≥ 1 jet in $|\eta| > 2.4$

SR2:

1 bjet in $|\eta| < 2.4$

1 jet in $|\eta| < 2.4$

$+\Delta\phi(\mu\mu, jj)$

$+p_T^{\text{miss}} < 40 \text{ GeV}$

+no other jets

New category does not have overlaps neither with SR1 nor with SR2:

1 bjet in $|\eta| < 2.4$

1 jet in $|\eta| < 2.4$

≥ 1 jet in $|\eta| > 2.4$

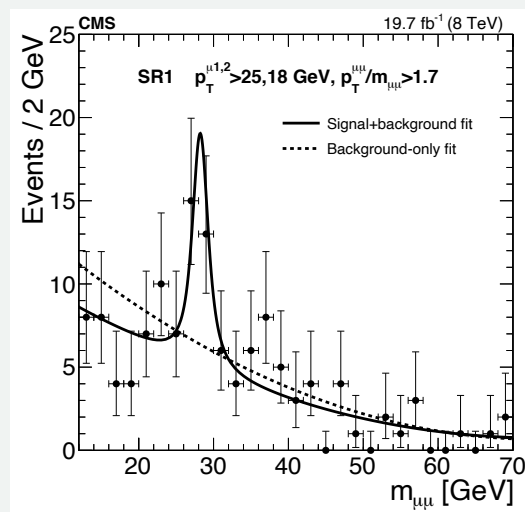
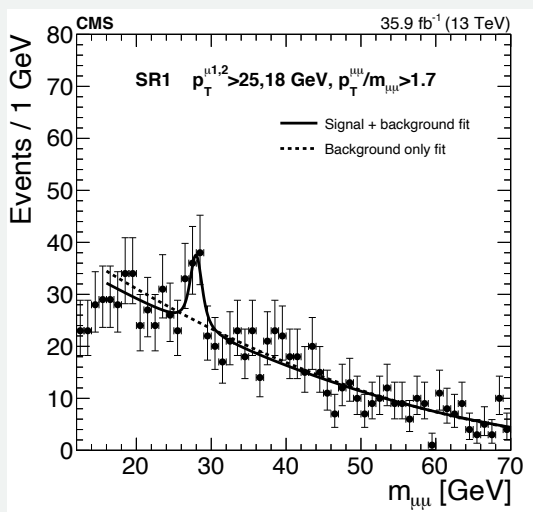
This category is the natural addition to SR1 allowing one more jet on top of CJV.

New Search Region (SR3)

Difference w.r.t. SR1 and SR2:

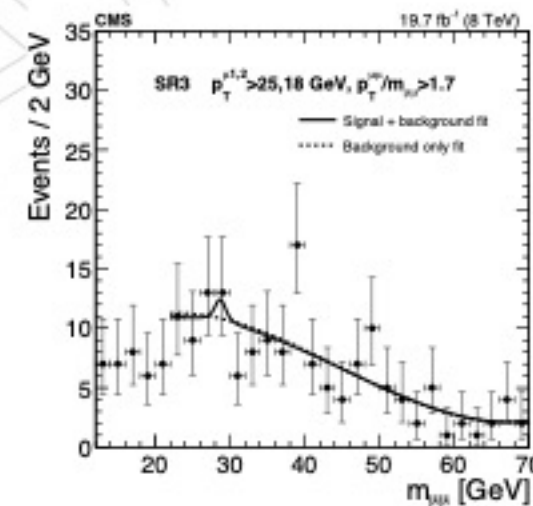
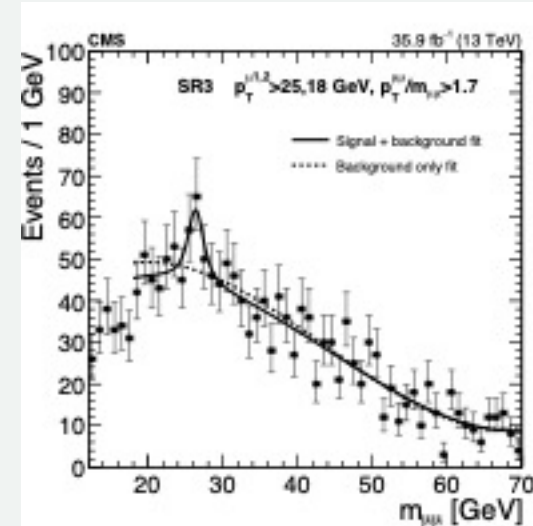
1. It can be considered as SR1 + 1 central jet
2. It can be considered as SR2 + ≥ 1 frw jet+other cuts

SR1/SR3 in 2008/2016



SR1	13 TeV (2016)	8 TeV
N_S	38+-18	26+-10
$M_{\mu\mu}$	28+-0.5	28.2+-0.4
Width	1.4+-1.1	2.1+-1.4
Local sign.	3.0	4.3

Optimized cuts:
 $p_{T\mu 1/2} > 25, 18 \text{ GeV}, p_{T\mu\mu} / M_{\mu\mu} > 1.7$



SR3	13 TeV (2016)	8 TeV
N_S	64+-41	<18(18)
$M_{\mu\mu}$	26.4+-0.6	
Width	2.1+-2.0	
Local sign.	3.0	

Missing p_T or modified SR2

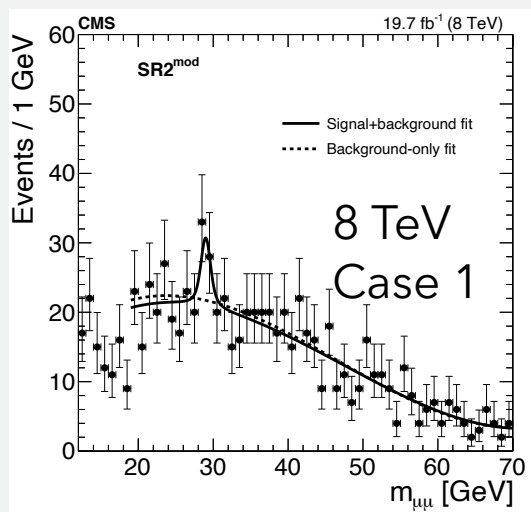
We applied missing p_T cut at SR2 to suppress $t\bar{t}$ background at 8 TeV together with $\Delta\phi(\mu\mu, jj) > 2.5$ cut. However, missing p_T distribution for SR1 reveals that the excess events may have non-zero missing p_T .

For SR2 we request only 2 jets in full eta space (up to 4.7).

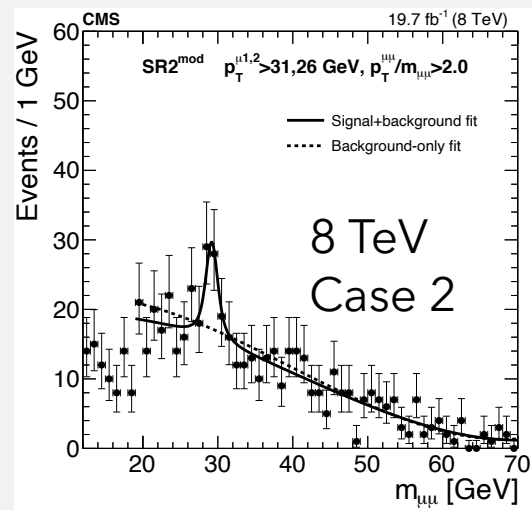
Case 1: drop missing p_T cut and $\Delta\phi(\mu\mu, jj) > 2.5$ cut but keep $p_{T\mu 1/2} > 25$ GeV, add $p_{T\mu\mu}/M_{\mu\mu} > 1.7$

Case 2: drop missing p_T cut and $\Delta\phi(\mu\mu, jj) > 2.5$ cut and optimize $p_{T\mu 1/2}$ and $p_{T\mu\mu}/M_{\mu\mu}$ cuts

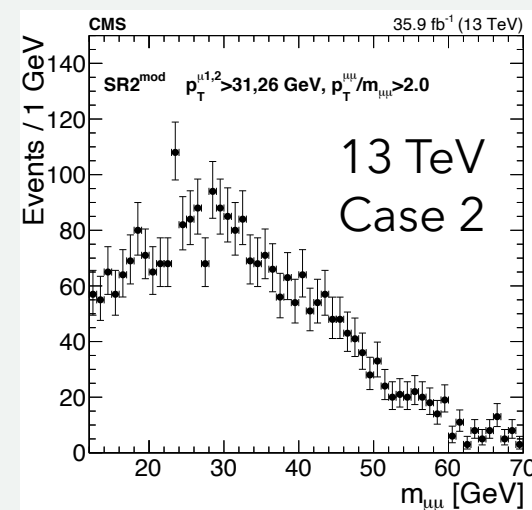
Optimized SR2



Local significance changes
From 3 to 2.1



Local significance changes
From 2.1 to 3.5



Nothing at 13 TeV...
Bg >4 times higher

Difference between 8 and 13 TeV: b-tagging has more soft requirements, pileup increases ~2 times (no PUID in forward region) -> non-zero probability that part of events migrates to SR3.

One more time on categorization : FINAL?

SR1:

$p_{T\mu 1/2} > 25,18 \text{ GeV}$

1 bjet in $|\eta| < 2.4$

Central jet veto

≥ 1 jet in $|\eta| > 2.4$

$p_{T\mu\mu}/M_{\mu\mu} > 1.7$

SR2 modified:

$p_{T\mu 1/2} > 31,25 \text{ GeV}$

1 bjet in $|\eta| < 2.4$

1 jet in $|\eta| < 2.4$

$p_{T\mu\mu}/M_{\mu\mu} > 2$

+no other jets

SR3:

$p_{T\mu 1/2} > 25,18 \text{ GeV}$

1 bjet in $|\eta| < 2.4$

1 jet in $|\eta| < 2.4$

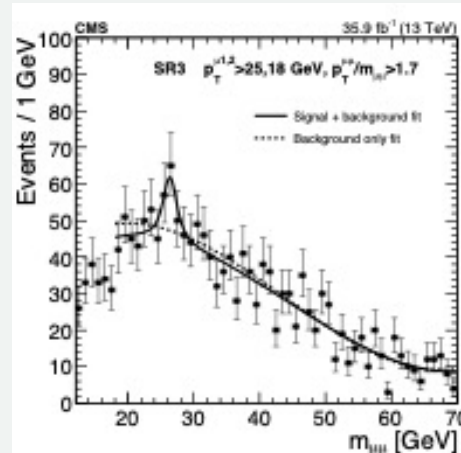
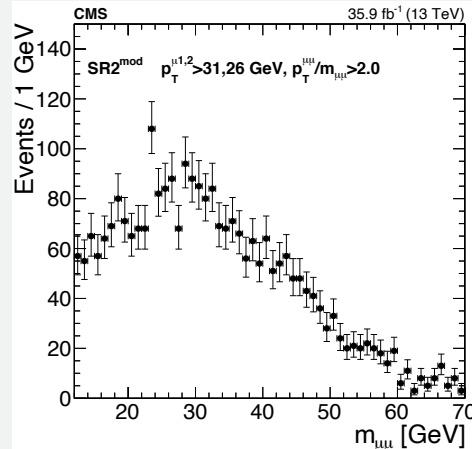
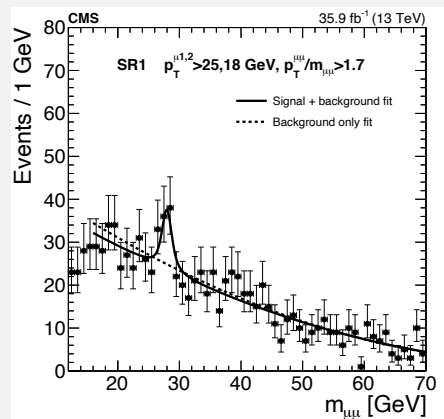
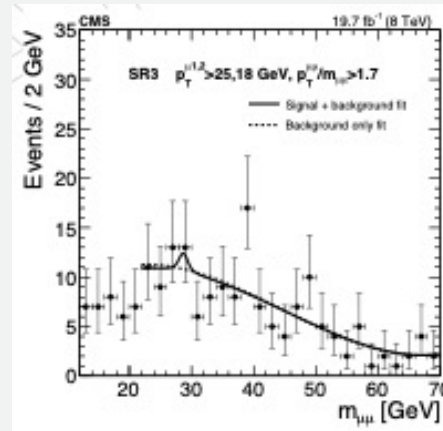
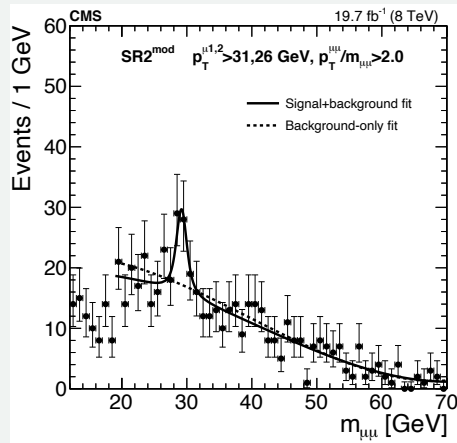
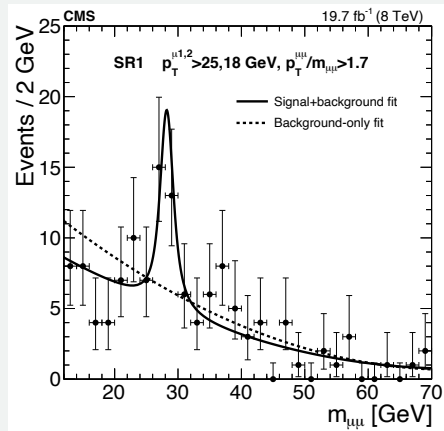
+ ≥ 1 jet in $|\eta| > 2.4$

$p_{T\mu\mu}/M_{\mu\mu} > 1.7$

Difference w.r.t. SR1 and SR2:

1. SR3 can be considered as SR1 + 1 central jet
2. SR3 can be considered as SR2 + ≥ 1 frw jet

SR1+SR2mod+SR3



- Difference w.r.t. SR1 and SR2:
1. SR3 can be considered as SR1 + 1 central jet
 2. SR3 can be considered as SR2 + ≥ 1 frw jet

Note:

Events can migrate in between SR* due to difference in JES
And pileup conditions.

Analysis Note CMS AN-21-0-89

Search for a $\mu^+\mu^- + \text{b-jet}$ event excess at the di-muon mass of 28 GeV in pp collisions at $\sqrt{s} = 13$ TeV using full Run II dataset.

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Summary

- We see the excess of events at $M=28$ GeV in dimuon mass spectrum in SR1, SR2 at 8 TeV with significance 4.2 and 3 correspondingly (paper)
- We see mild excess in SR1 at 13 TeV (2016 year) with the same cuts and categorization (except b-tagging) as used with 8 TeV data (paper)
- We reoptimized cuts and categorization basing on 8 TeV and 13 TeV (2016) year assuming the increase of tt background and pileup.
- We see the dimuon excess at approximately the same mass ~ 28 GeV in dimuon mass spectrum in 2016 data (13 TeV) in SR1 and in the new region SR3. Reoptimized cuts increase the excess at 8 TeV data so as. Nothing is seen in SR2 modified.

According agreement with Higgs conveners we will use these optimized cuts and categorization performing the blind analysis of 2017/2018 data.