Search for a narrow mu+mu- state produced in association with b quark jets

arXiv 1808:01890
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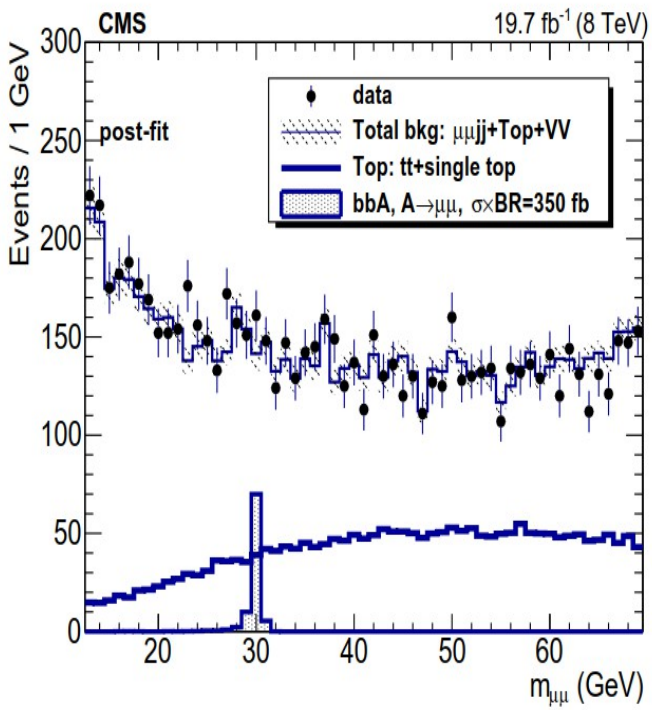
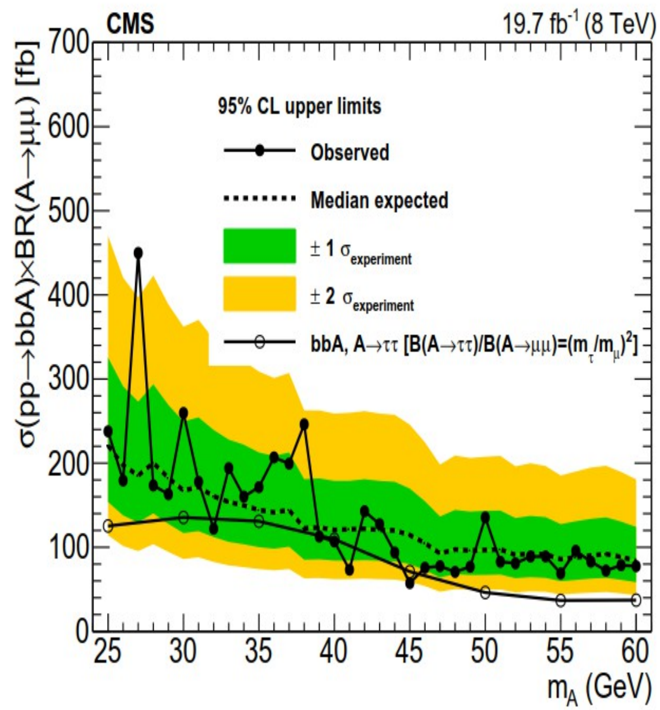
How it was happen

- **A blind analysis based on bbA signal model in 2HDM has been performed using 8 TeV CMS data**
- **events are selected with single muon trigger, 24 GeV** **JHEP11 (2017) 010**
- **no signal observed with optimized selections (pTμ1,2>25, 5 GeV):**





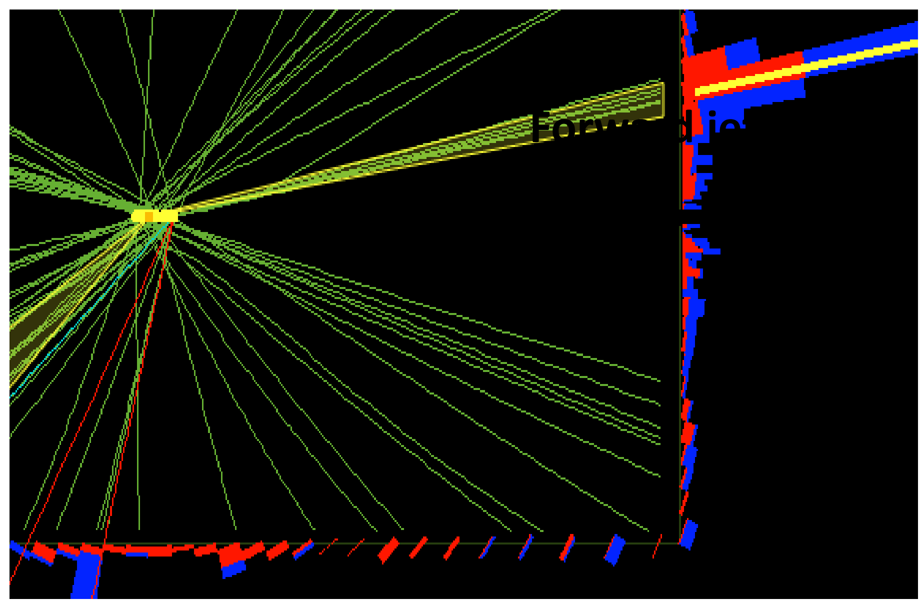
New event selection

- **In the process of performing cross-checks or the bbA analysis at √s=8 TeV with varied kinematic selections, a significant excess in the dimuon mass spectrum was observed in one of these checks with the following selections:**

1st search region

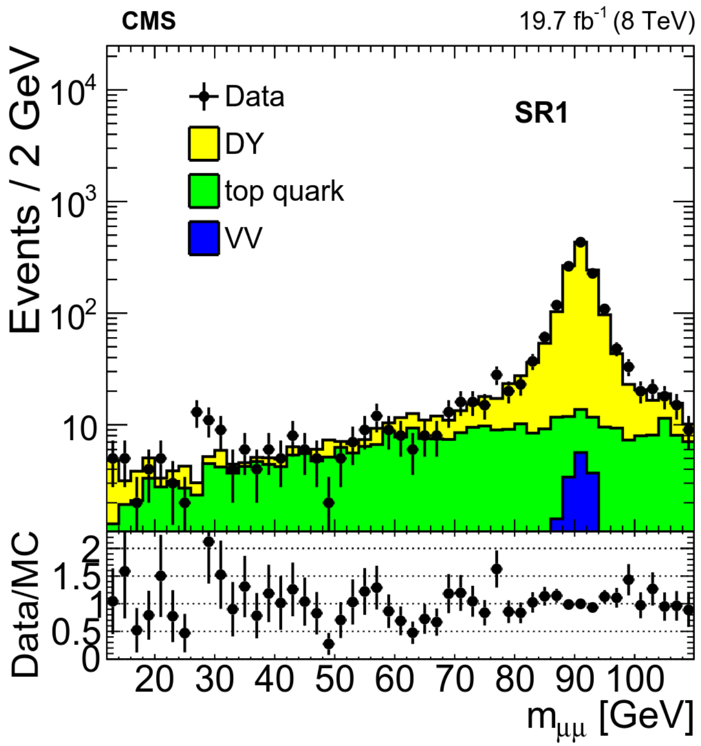
- two opposite–sign muons with $p_T > 25$ GeV, $|\eta| < 2.1$;
- one b–tagged with jet $p_T > 30$ GeV, $|\eta| < 2.4$ and no other jets with $p_T > 30$ GeV, $|\eta| < 2.4$;
- at least one jet with $p_T > 30$ GeV, $2.4 < |\eta| < 4.7$;

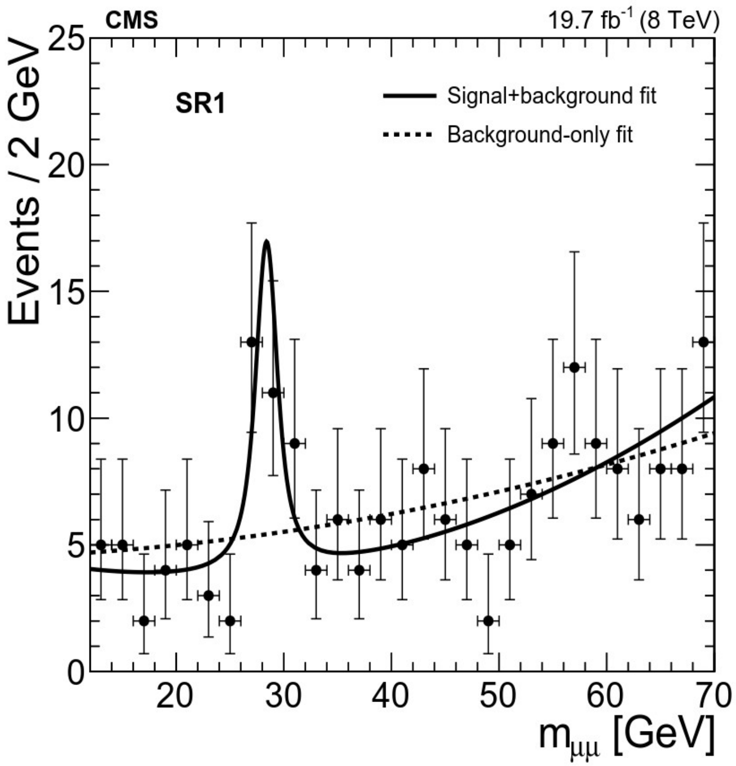
b-tag jet



μ1 **μ2**

1st search region at √s=8 TeV: dimuon mass





- **SM Simulation does not show any "bump" at mμμ ≈ 30 GeV**

1st search region at $\sqrt{s}$=8 TeV

- **A probability of the statistical background fluctuation (a local p-value) was found as 1.5×10-5 (4.2σ) while a significance of this observation was diminished with LEE which was hardly possible to calculate taking into account a choice of all selection criteria.**

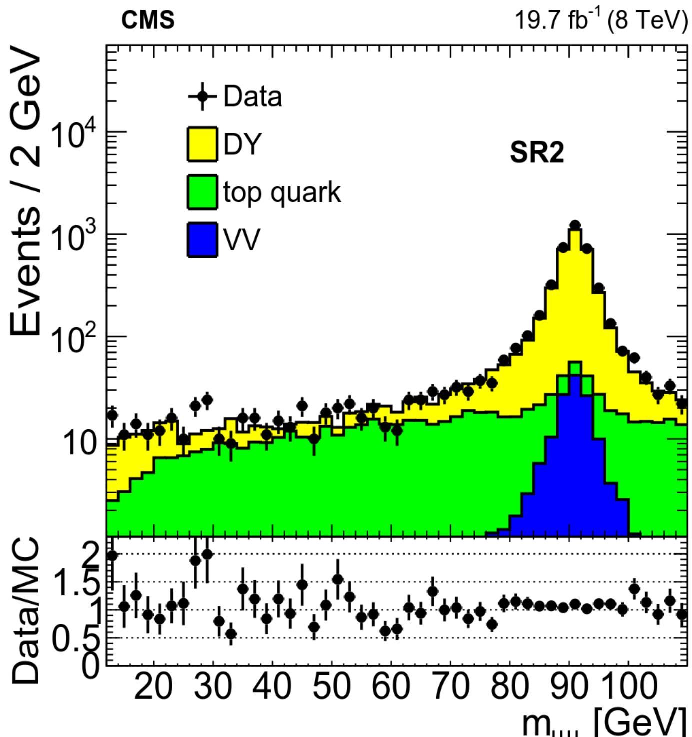
2nd search region

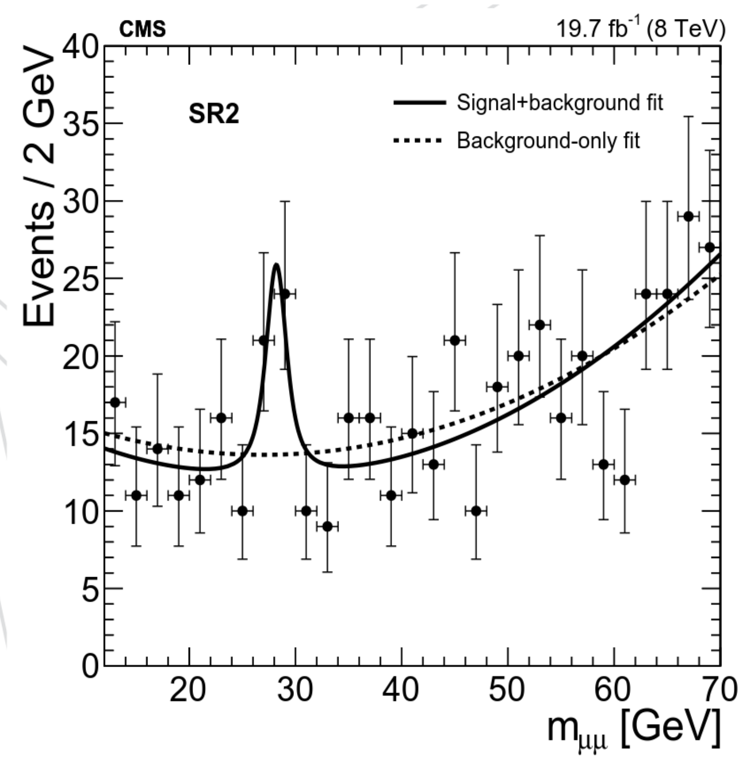
- **In order to get confirmation of the observed enhancement a complementary event sample (2nd search region) with two muons, one central b-jet, one central jet and no forward jets produced at √s=8 TeV pp collisions and two similar event samples produced at √s=13 TeV pp collision were used. SR2 was defined from basic considerations, testing if the production process is dominated by the EWK or strong interactions. In the latter case the second jet may be present not in the forward but rather in the central rapidity region**

2nd search region

- two opposite–sign muons with $p_T > 25\,\text{GeV}$, $|\eta| < 2.1$;
- two jets with $p_T > 30$ GeV, $|\eta| < 2.4$ with at least one b–tagged jet;
- no jets with $p_T > 30$ GeV, $2.4 < |\eta| < 4.7$;
- $p_T^{miss} < 40$ GeV;
- $\Delta\phi(\mu\mu - \text{jj}) > 2.5$.

2nd search region at √s=8 TeV: dimuon mass





- **Simulation does not show a "bump" at $m_{\mu\mu}$ ≈ 30 GeV**

Characterization of the observed dimuon mass spectra

Fitting

- **Unbinned likelihood fit of the dimuon mass distribution was performed using fitted function of the following form:**

$$L(m_X, \Gamma_{\mu\mu}, a_1, a_2) = \frac{(N_S + N_B)^N}{N!} e^{-(N_S+N_B)} \prod_{i=1}^{N} [\frac{N_S}{N_S + N_B} p_i^S(m_X, \Gamma_{\mu\mu}) + \frac{N_B}{N_S + N_B} p_i^B(a_1, a_2)],$$

- **Signal model:**
  - **convolution Breit-Wigner (mX, $\Gamma\mu\mu$) and Gaussian ($\sigma_{\mu\mu}$=0.45 GeV)**
- **Background model: polynomial function**
  - **2nd order for 8 and 13 TeV analyses from F-test**

p-values (Z-scores) and upper limit calculations

- **The statistical significance was evaluated using standard frequentists methods. A profile likelihood ratio statistics is calculated:**

$$q_A \equiv -2 \ln \left[\frac{L(\hat{m}_X, \hat{\Gamma}_{\mu\mu}, \hat{\hat{a}}_1, \hat{\hat{a}}_2)}{L(\hat{m}_X, \hat{\Gamma}_{\mu\mu}, \hat{a}_1, \hat{a}_2)} \right],$$

- **Evaluation of significance (upper limit) is based on q0 (qA)**
- **A standard CMS Higgs Combined Tool is used**

Hypothetical signal parameters and local significances at √s=8 TeV

Event category	SR1 Additional forward jet	SR2 Additional central jet
m_X (GeV)	28.4± 0.6	28.2± 0.7
$\Gamma_{\mu\mu}$ (GeV)	1.9±1.3	1.9±1.1
Local significance (σ)	4.2	2.9

- **combined: mX(8TeV)=28.3±0.4 GeV, Γμμ (8TeV)=1.8±0.8 GeV**
- **the uncertainty of the muon pT scale (≈0.2%) and the dimuon mass resolution uncertainty (≈10%) have a negligible effect on the p values, and the mass and the width measurements**

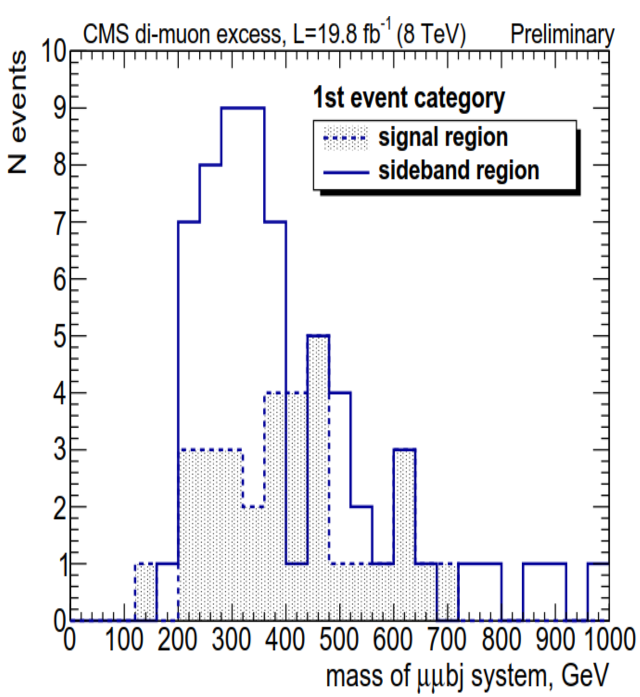
Number of the signal events extracted from the fit

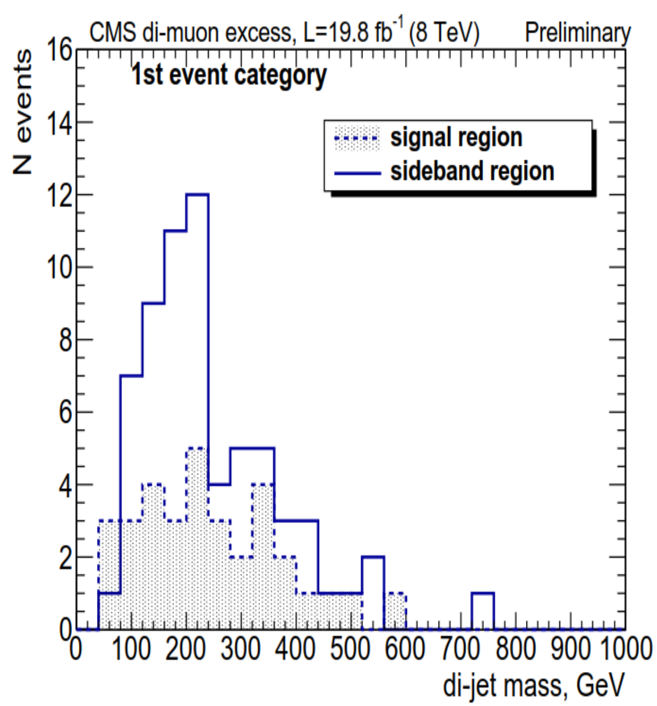
$\sqrt{s}$ (TeV)	8	
Event category	SR1	SR2
N_S	22.0 ± 7.6	22.8 ± 9.5

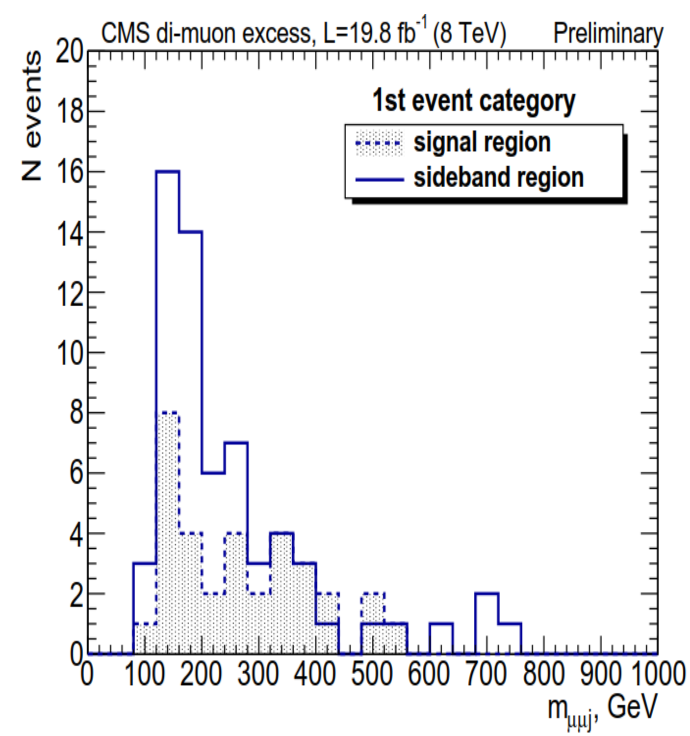
Difference in distributions in the signal and sideband regions for SR1 at 8 TeV

- Signal region:26 < mμμ < 32 GeV
- Sideband region, mμμ in ranges: 12-24 GeV or 34-50 GeV

m(μμbj) **m(bj)** **m(μμj)**







Missing pT for SR1 at 8TeV in signal and sideband regions

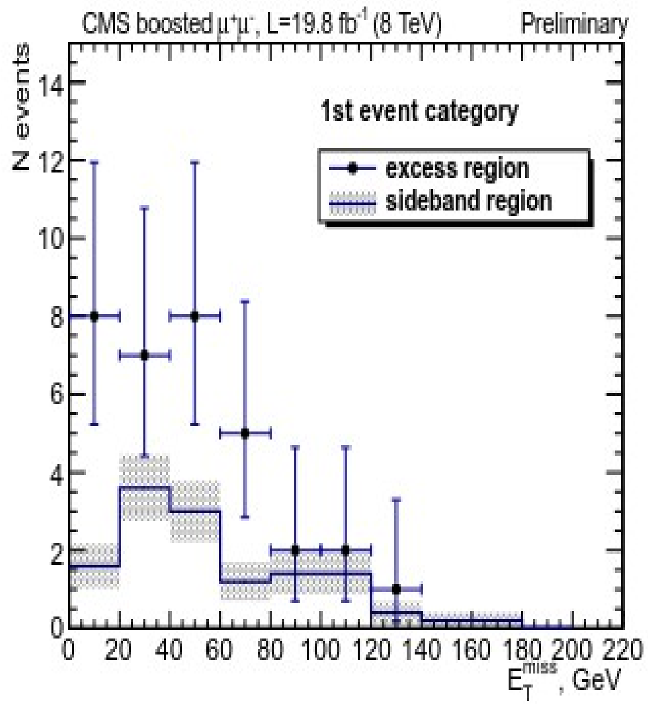
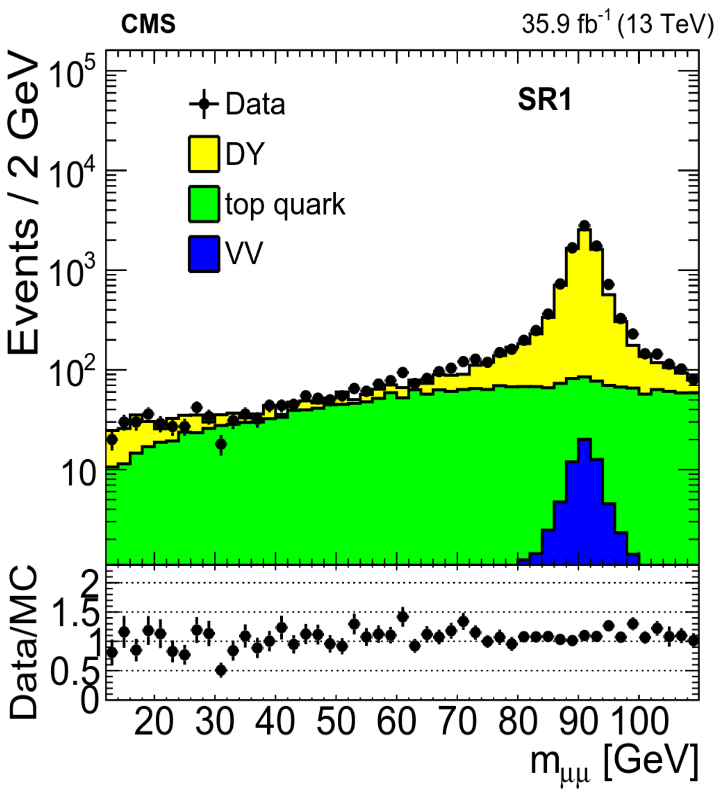
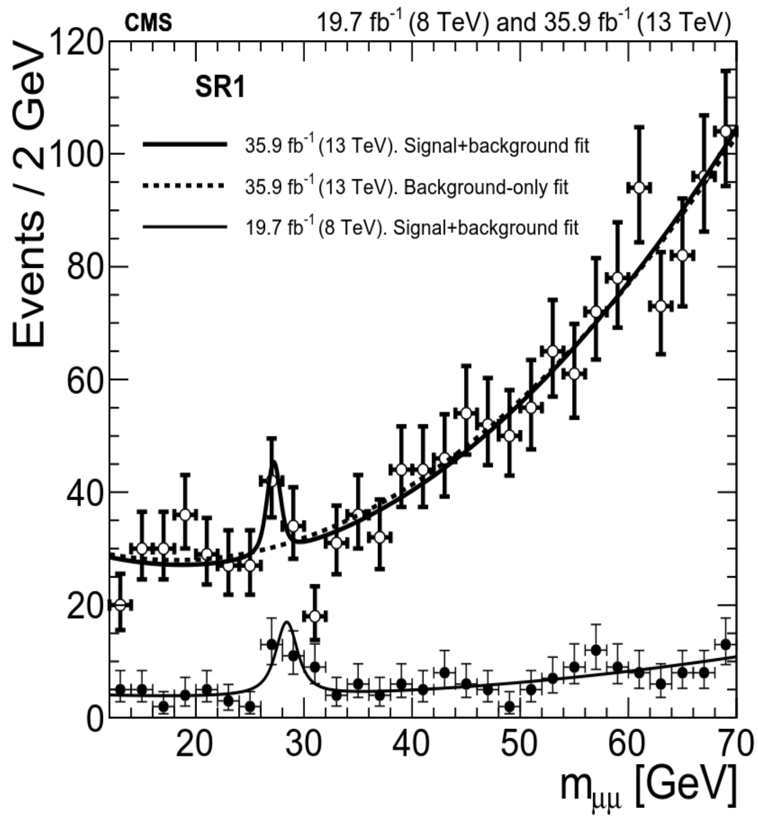


Figure 10: The E_T^{miss} distribution for the first event category in the event excess range of $26 < m_{\mu\mu} < 32$ GeV and the sideband between 12 and 24 GeV or between 34 and 50 GeV. The sideband histograms are normalized to the number of expected background events in the excess region.

Analysis has been repeated with 13 TeV (2016) data using the same search regions as for 8 TeV and the same object IDs, isolation,…

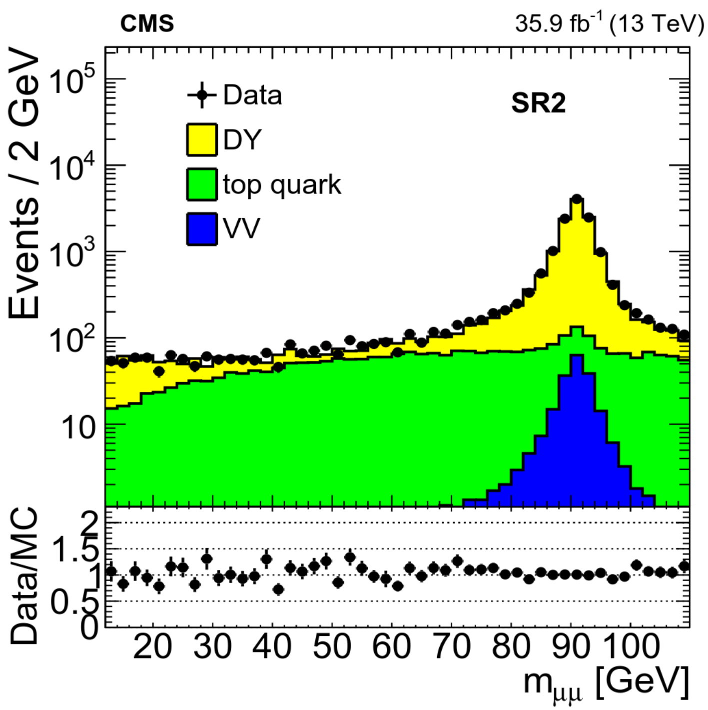
1st search region at √s=13 TeV: dimuon mass

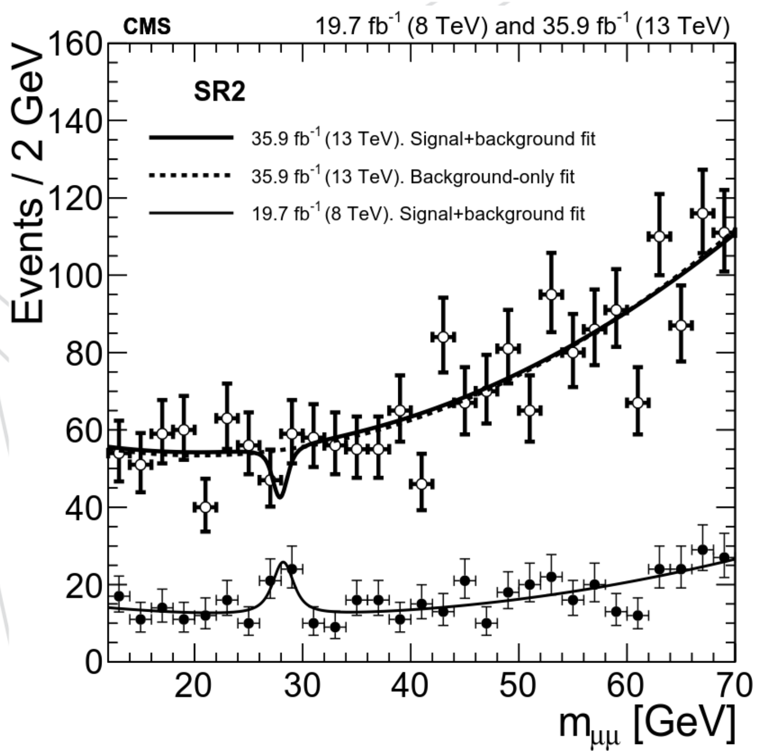




- **A mild excess at √s=13 TeV in 1st search region**

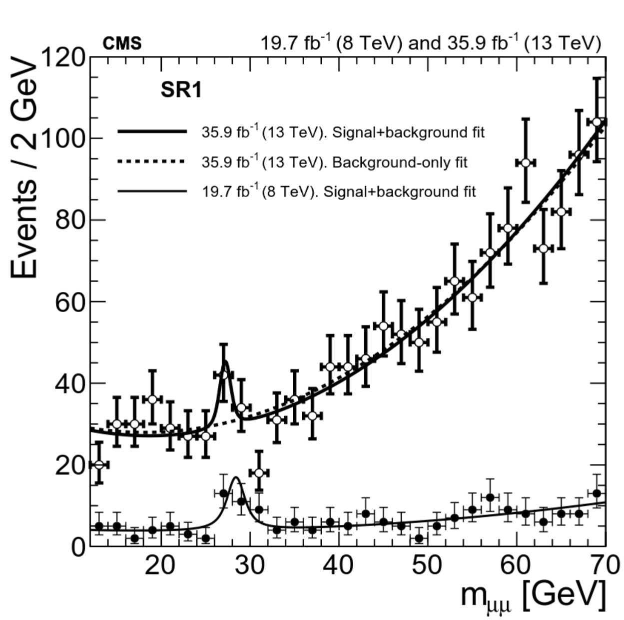
2nd search region at √s=13 TeV: dimuon mass

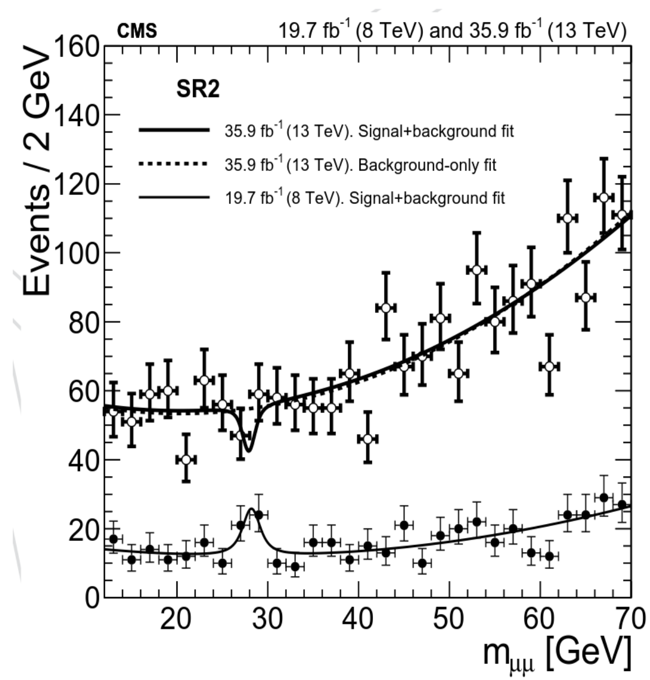




- **Negative yield at √s=13 TeV in 2nd search region**

Fit of dimuon mass at √s=13 TeV





- **A mild excess, 2.0 σ in 1st search region: mX=27.2±0.6 GeV, Γμμ=0.7±1.0 GeV**
  - **mX8TeV=28.3±0.4 GeV**
- **Negative event yiled, 1.4σ in 2nd search region**

Evaluation of fiducial cross-sections and upper limits

- **Fiducial cross-sections and upper limits for both search regions and both √s of pp collisions were evaluated**
- **They were evaluated at the values of mX8TeV=28.3±0.4 GeV, Γμμ8TeV=1.8±0.8 GeV obtained from combined fit of √s=8 TeV pp collision data**
- **The formula for cross-section/upper limit calculations reads:**

$$\sigma_{\text{fid}} = \frac{N_S}{\mathcal{L} \times \varepsilon^{\text{reco}}}$$

where

N_s - the number of events extracted from fit

L - the integrated luminosity,

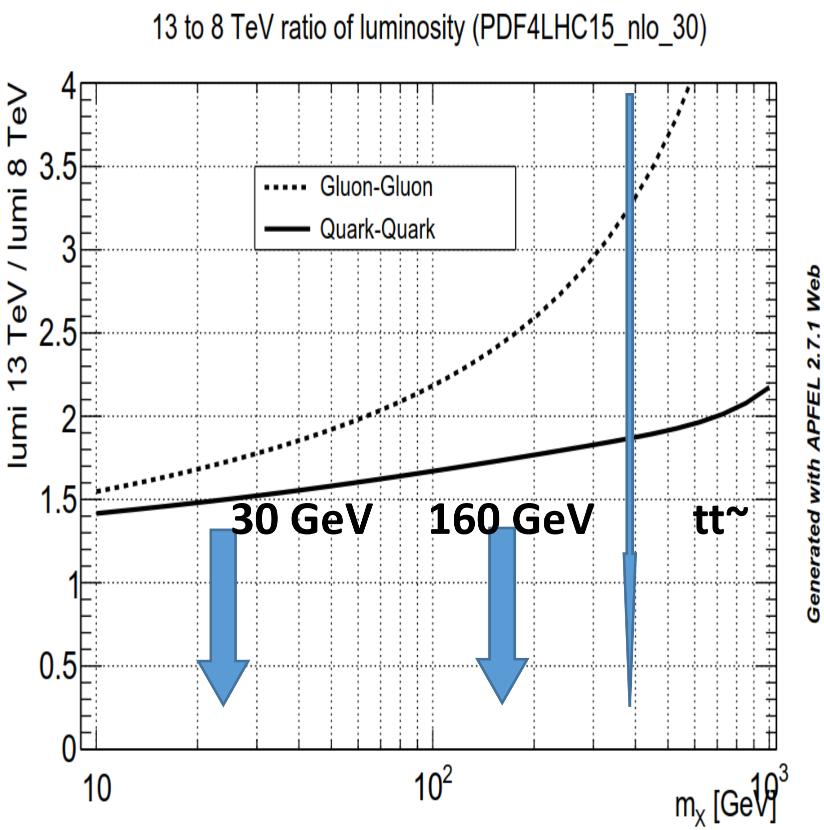
ε^{reco} - the reconstruction efficiency which includes muon trigger, identification and isolation efficiency and b-tagging efficiency

Summary of results in numbers

$\sqrt{s}$ (TeV)	8		13	
Event category	SR1	SR2	SR1	SR2
Local significance (s.d.)	4.2	2.9	2.0	1.4 deficit
N_S	22.0 ± 7.6	22.8 ± 9.5	14.5 ± 9.3	-14.9 ± 10.1
N_S observed upper limit at 95% CL	40.4	44.7	36.9	32.2
N_S expected upper limit at 95% CL	18.3	27.6	27.6	35.6
$\varepsilon^{\text{reco}}$	0.27 ± 0.01		0.28 ± 0.01	
Integrated luminosity, $\mathcal{L}$ (fb^{-1})	19.7 ± 0.5		35.9 ± 0.9	
σ_{fid} (fb)	4.1 ± 1.4	4.2 ± 1.7	1.4 ± 0.9	-1.5 ± 1.0
Observed upper limit at 95% CL (fb)	7.6	8.4	3.7	3.2
Expected upper limit at 95% CL (fb)	3.4	5.2	2.7	3.5

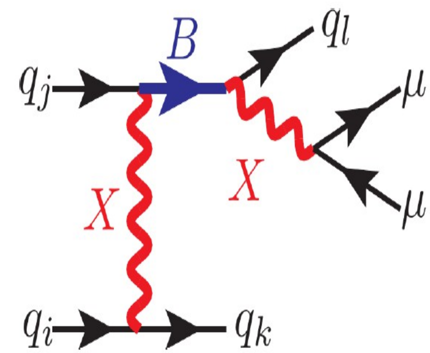
Compatibility of 8 and 13 TeV results

What gain in cross-section we could expect for the hypothetical signal at 13 TeV



some model of the "signal"

(S. Moretti, L. Panizzi)

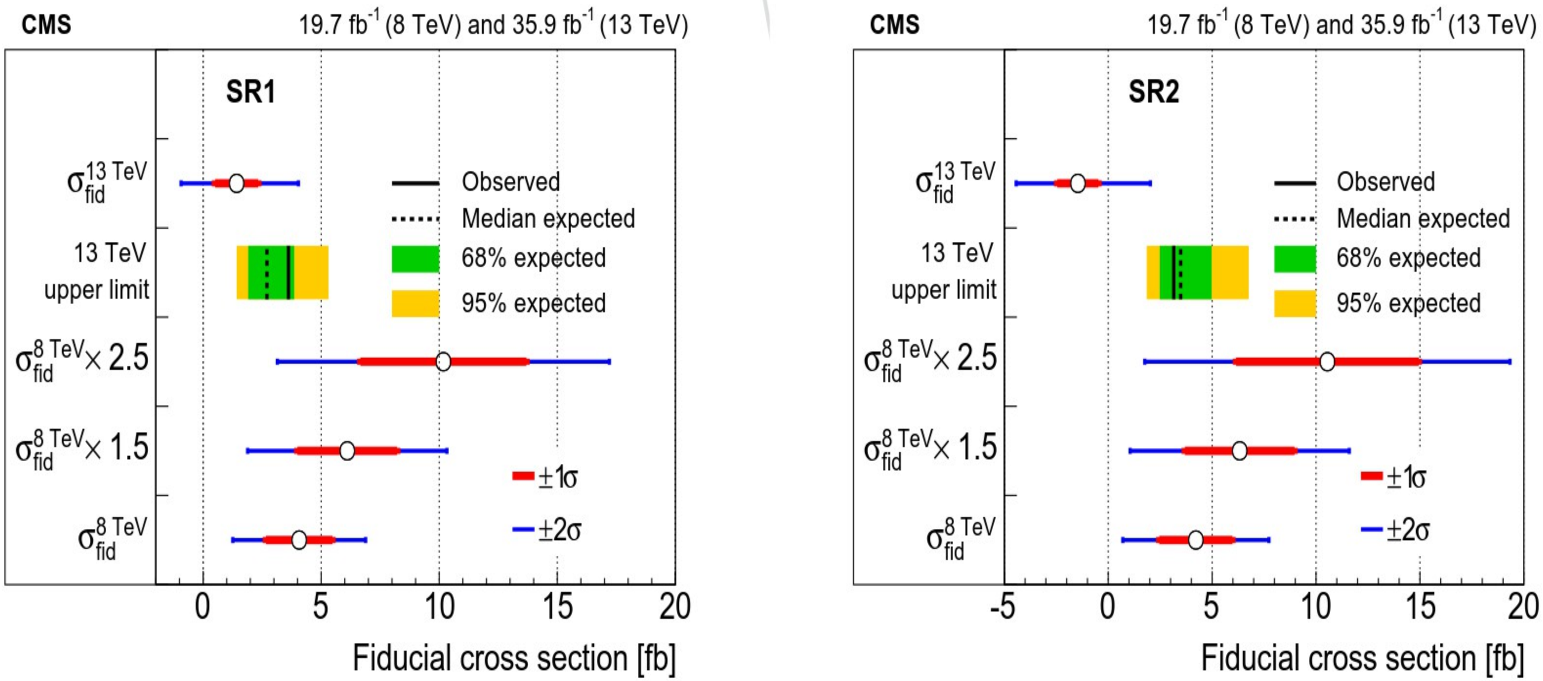


mB ≈ 160 GeV (NWU analysis)

mX ≈ 28 GeV

- **Maximal possible gain is from gg initiated production**
- **Minimal possible gain is from qq initiated production**
  - ***therefore the possible gain could vary between ~ 1.5 and ~ 2.5; tt~ (dominant bkg) increased by 3.3***

Compatibility of 8 and 13 TeV results on one slide



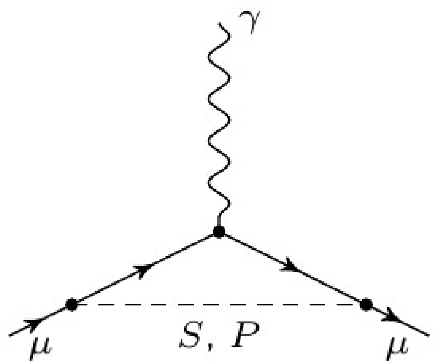
A naïve scaling for predicted cross-sections at 13 TeV does not take into account the possible change in the selection efficiency of the hypothetical signal. We can not exclude that the signal kinematics is disfavored to see it in the 13 TeV data with 8 TeV selections. Experimental conditions are also changed at 13 TeV; for example, a fraction of the pileup jets in the forward region is increased by a factor of ~ 3 leading to the decrease of the forward jet veto efficiency used in SR2

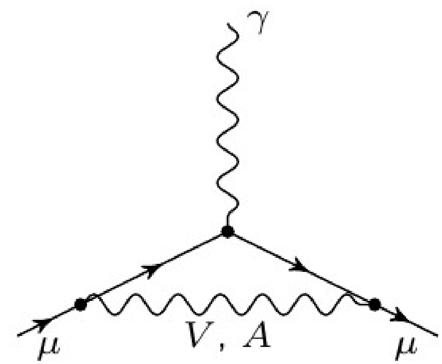
Conclusions

- **We report on the analysis of the $\mu^+\mu^-$ plus b-jet events with an additional jet in the dimuon mass range from 12 to 70 GeV in two mutually exclusive search regions. Analysis uses 19.7 fb^{-1} of pp collision data at $\sqrt{s}$=8 TeV and 35.9 fb^{-1} at $\sqrt{s}$=13 TeV.**
- **An event excess at $\sqrt{s}$=8 TeV was observed in two search regions at the same dimuon mass of ≈ 28 GeV with the local significance of 4.2 and 2.9.**
- **The pp collision data at $\sqrt{s}$=13 TeV show a mild excess of 2.0σ in the 1st search region and the negative event yield, 1.4σ in the 2nd search region**
- **We provide the measurement of the mean mass and width of the event excess at $\sqrt{s}$=8 TeV, and the visible cross-sections and the upper limits on the visible cross-sections for both search regions and both pp collision energies**

[S. I. Godunov, V. A. Novikov, M. I. Vysotsky, E. V. Zhemchugov, arXiv:1808.02431]

$$\delta a_\mu \equiv a_\mu^{\text{exp.}} - a_\mu^{\text{SM}} = (29 \pm 8) \cdot 10^{-10}$$





	S	P	V	A
Leading order δa_μ contribution	$+$	$-$	$+$	$-$

	S	V
Coupling constant	0.041 ± 0.006	0.16 ± 0.02
$\Gamma(X \to \mu^+\mu^-)$	1.8 ± 0.5 MeV	28 ± 8 MeV

Experimental width: 1.8 ± 0.8 GeV. $X \to \tau^+\tau^-$?

In the models with a single extra boson X coupled to $b\bar{b}$ and $\mu^+\mu^-$, $\sigma(pp \to b\bar{b}X(\to \mu^+\mu^-) + \ldots)$ is too high to be consistent with previous CMS searches [arXiv:1707.07283].

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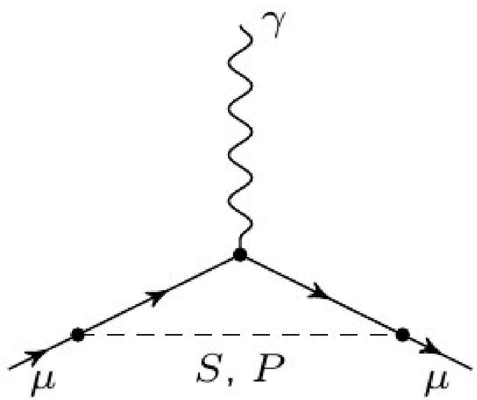

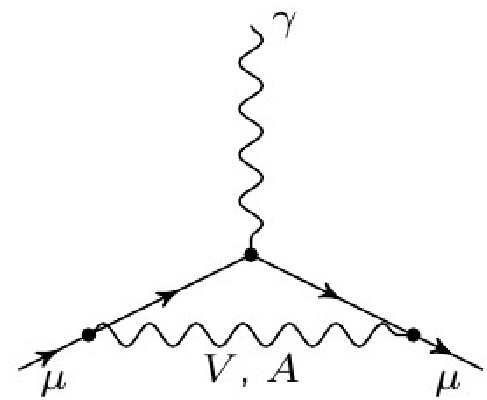

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