Search for new physics in lepton(e/μ) + p_T^{miss} final state with full Run 2 dataset recorded by CMS

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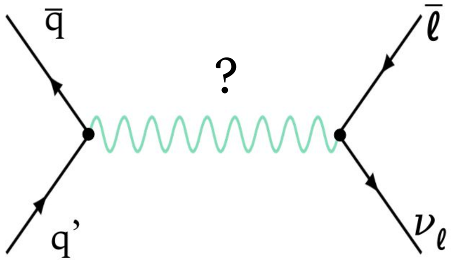
On behalf of the CMS Collaboration

DIS 2021

ℓ (e,μ) + p_T^{miss} final state



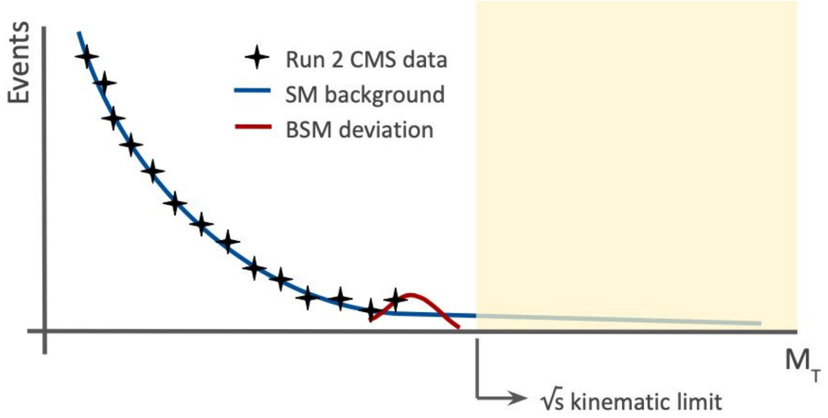
Lepton + p_T^{miss} is one of the most promising channels to search for Physics beyond SM.

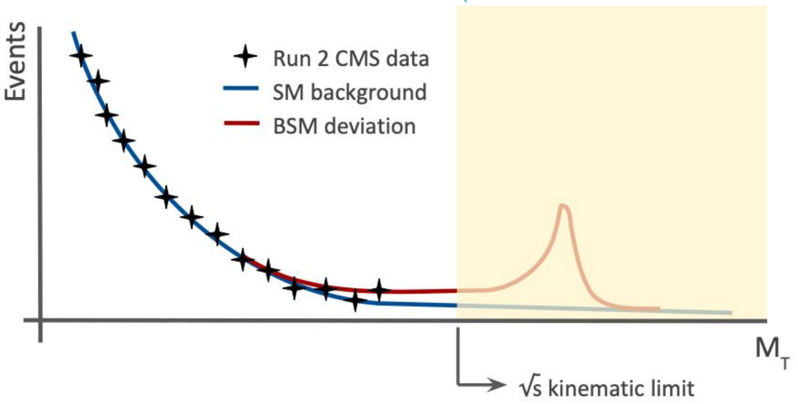
Study based on a binned fit in the **discriminant variable** M_T, in data and background.

$$M_T = \sqrt{2 p_T^{\ell}\ p_T^{miss} (1 - \cos[\Delta\phi(\ell, \vec{p}_T^{miss})])}$$

The search in the lepton+p_T^{miss} channel is performed in different ways:

- ➜ **Model Independent:** can be used to test new physics models as R-parity Violating SuperSymmetry model.
- ➜ **Direct resonance search:** new gauge bosons in the Sequential Standard Model (SSM) and extra dimensions models.
- ➜ **Indirect resonance search:** to constrain the electroweak oblique parameter W.





Data

This analysis has made use of proton-proton collisions from LHC recorded by CMS during the so-called Run 2: years 2016, 2017 and 2018.

Luminosity: amount of collisions produced per unit of area.

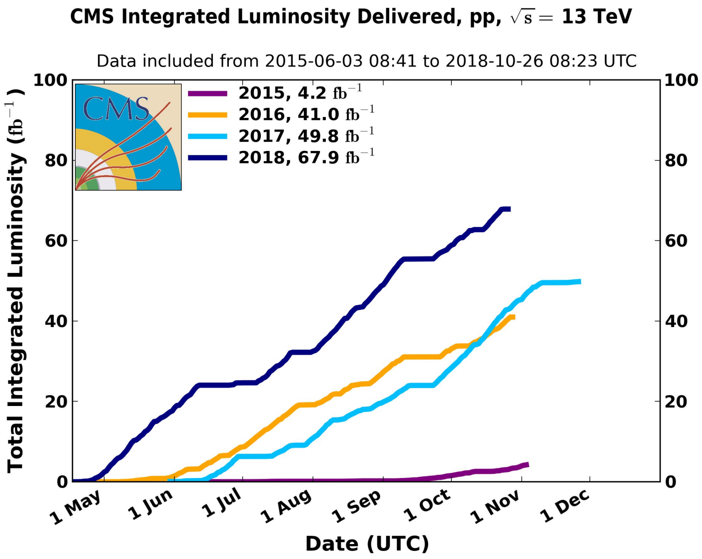
Pileup: number of additional pp interactions in the same or adjacent bunch crossing.

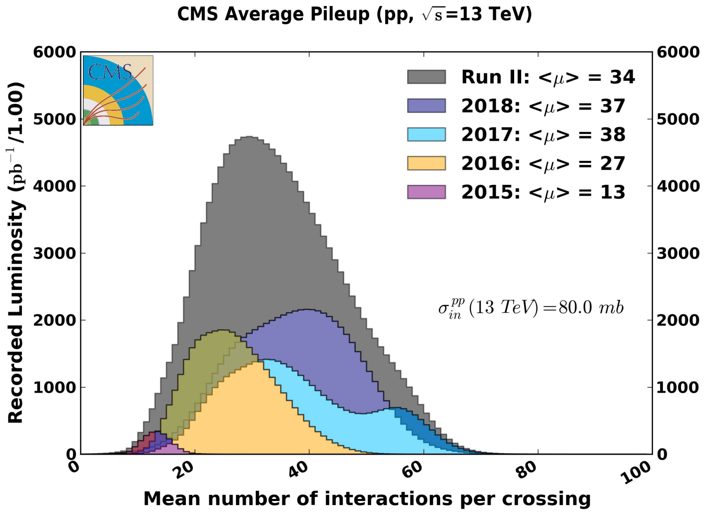
CMS recorded luminosity 2016+2017+2018:

$\mathscr{L}$ = (35.9 + 41.5 + 59.7) fb^{-1} = 137.1 fb^{-1}

CMS Average Pileup 2016, 2017 & 2018:

PU = 27, 38 & 37



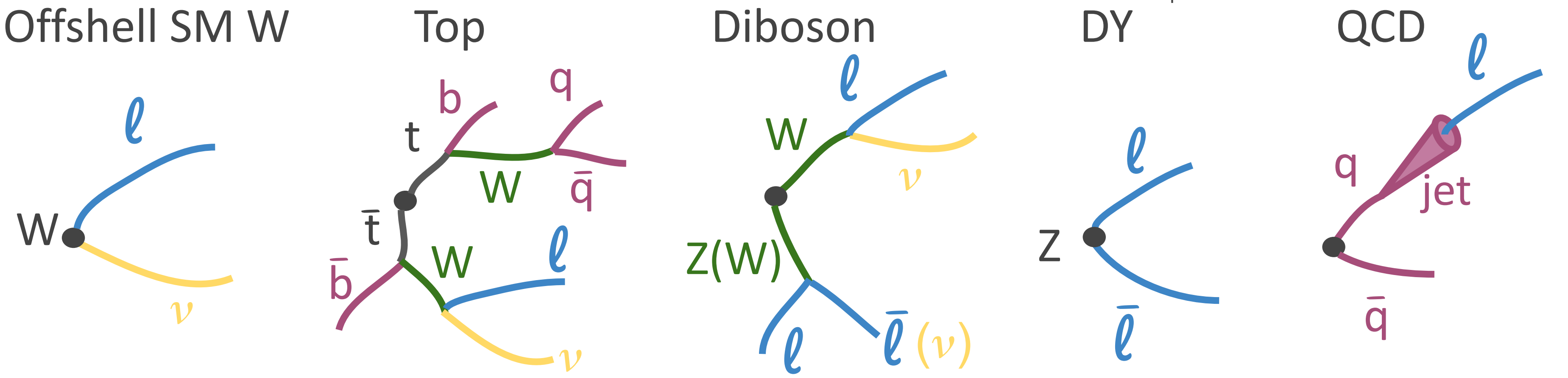


https://twiki.cern.ch/twiki/bin/view/CMSPublic/LumiPublicResults

Background

Background = processes whose final state is the same or can be mistaken as that of the signal (lepton+p_T^{miss}).

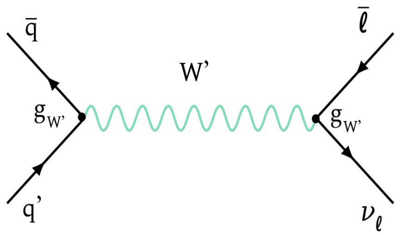
- **W** main and irreducible background:
  - W+jets inclusive low mass (Madgraph MLM)
  - W offshell mass-binned up to ~7 TeV (Pythia ➝ NNLO with K-factor)
  - W HT binned, boosted (MadGraph MLM)
- **Top:** ttbar and single top (PowHeg)
- **Dibosons:** WW (PowHeg), WZ and ZZ (Pythia)
- **DY:** Z to leptons (PowHeg)
- **QCD:**
  - e channel: jet p_T bined (Madgraph)
  - μ channel: p_T bined muon enriched (Pythia)

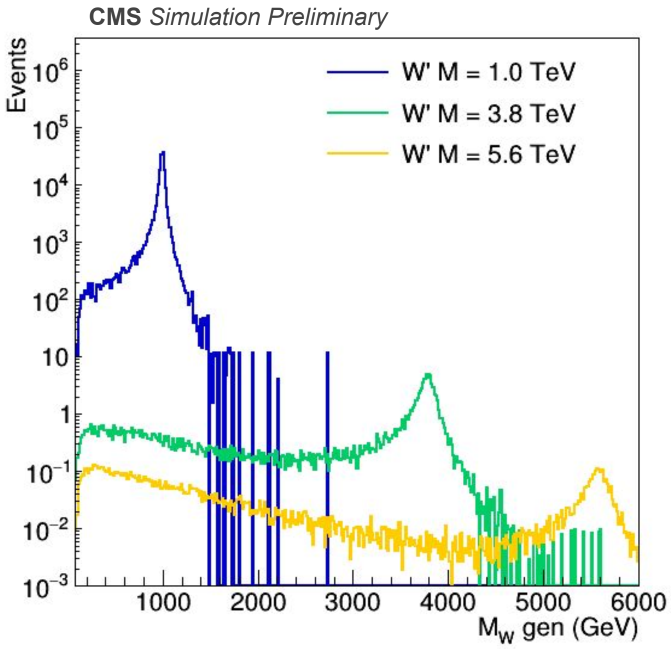


All backgrounds are simulated with MC samples and scaled to Run 2 luminosity using their cross sections.
Top and QCD normalized to data in control region.
Samples corrected by scale factors (SF) taking into account experimental effects from data.

Signal

SSM Wprime signals: SSM W', heavy analogue of the SM W boson assuming equal coupling strength. Narrow resonance decaying leptonically. Generated by PYTHIA 8.2 corrected to QCD NNLO with K-factor as function of W' mass. W' mass from 0.4 to 6.4 TeV.





Selection

Preselection:

- ➜ HLT trigger p_T threshold:
  e channel 175 GeV (2016) 200 GeV (2017 & 2018)
  μ channel 50 GeV
- ➜ Lepton offline p_T threshold & eta:
  e channel p_T > 240 GeV, |η| < 2.5
  μ channel p_T > 53 GeV, |η| < 2.4
- ➜ Veto a second lepton with p_T > 25 GeV and loose ID ➛ DY and diboson rejection

Kinematic cuts: massive resonance production

- ➜ p_T balance $0.4 < p_T^{lepton}/p_T^{miss} < 1.5$
- ➜ Back-to-back: $\Delta\phi(\text{lepton}, p_T^{miss}) > 2.5$

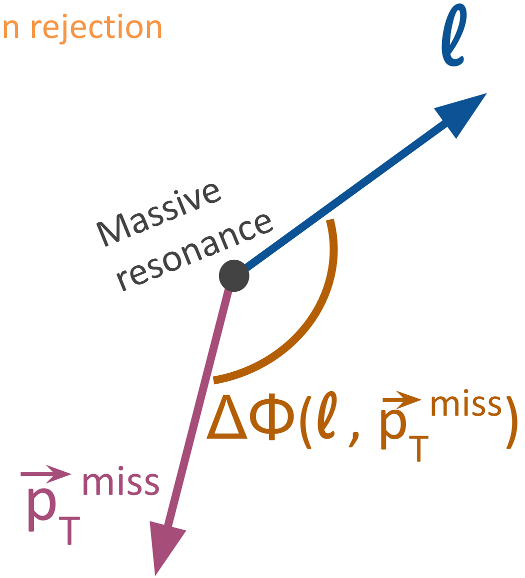
ID quality cuts:

e channel: dedicated high energy electron ID

- ➜ Isolated electron

μ channel: dedicated high p_T muon ID

- ➜ Isolated muon
- ➜ Distance to primary vertex: d_{xy} < 0.02 cm , d_z < 0.5 cm
- ➜ p_T uncertainty: $\Delta p_T > 0.3*p_T$

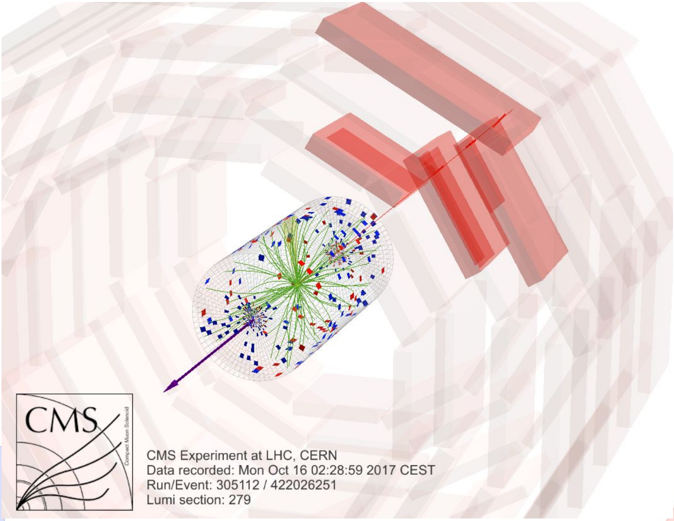


Additional cuts:

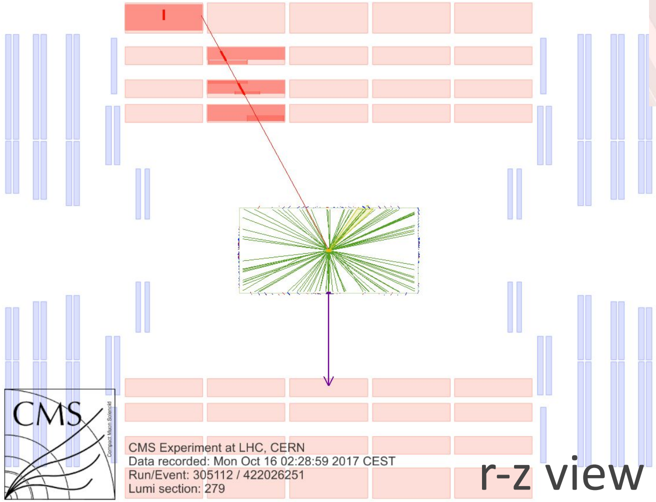
μ channel: reject events with > 6 jets, or leading jet tagged as coming from b-quark ➛ ttbar rejection

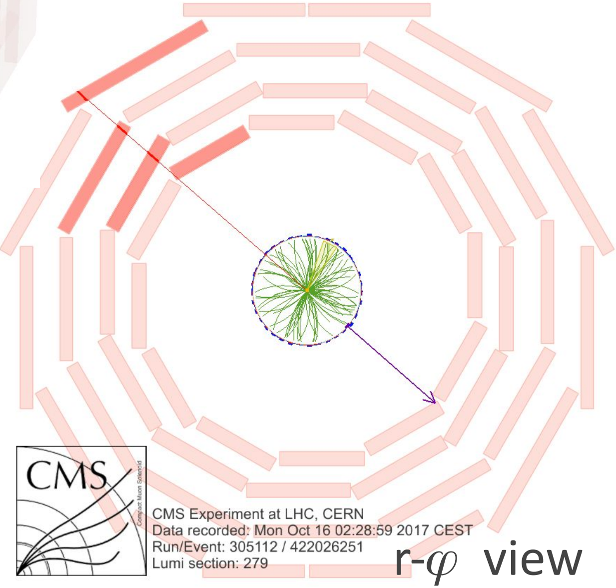
Muon channel highest M_T event (2017)

- ➜ M_T = 2975 GeV
- ➜ p_T^{miss} = 1483 GeV
- ➜ Muon:
  - ➜ p_T = 1491 GeV
  - ➜ η = -0.52
  - ➜ φ = 2.43



Run 2017
run:lumisection:number
305112:279:422026251

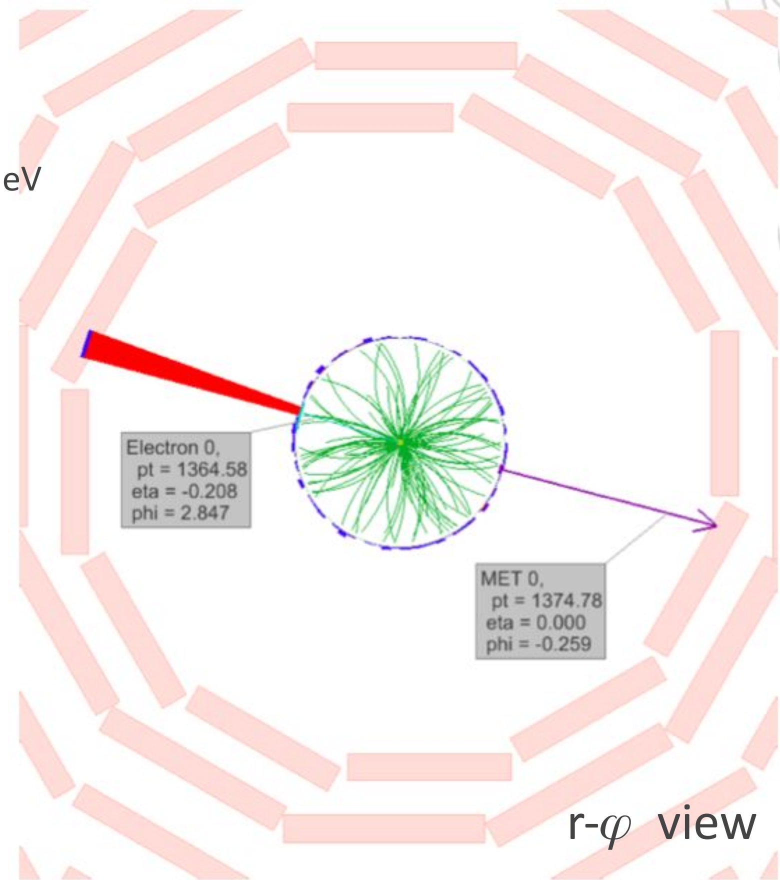


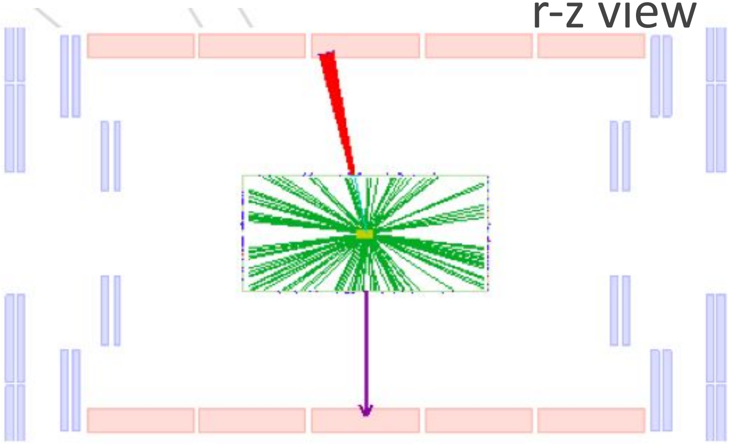


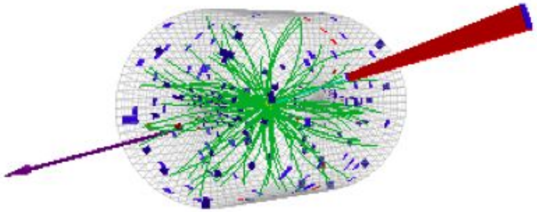
Electron channel highest M_T event (2018)

- ➜ M_T = 2.7 TeV
- ➜ p_T^{miss} = 1375 GeV
- ➜ Electron:
  - ➜ p_T = 1365 GeV
  - ➜ η = -0.21
  - ➜ φ = 2.85

Run 2018
run:lumisection:number
320917:310:508468292







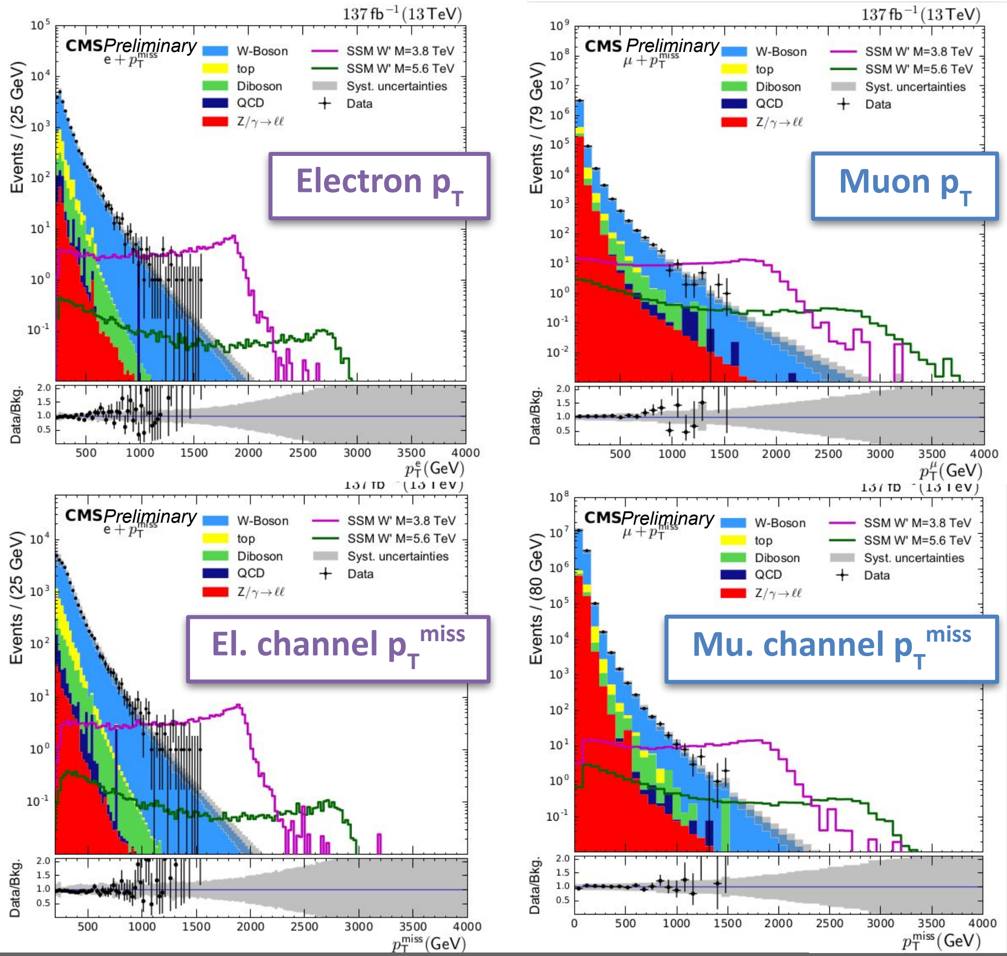
Distributions

Distributions after selection.

Sequential Standard Model (SSM) W' signals with $g = g_{SM}$:

- M = 3.8 TeV
- M = 5.6 TeV

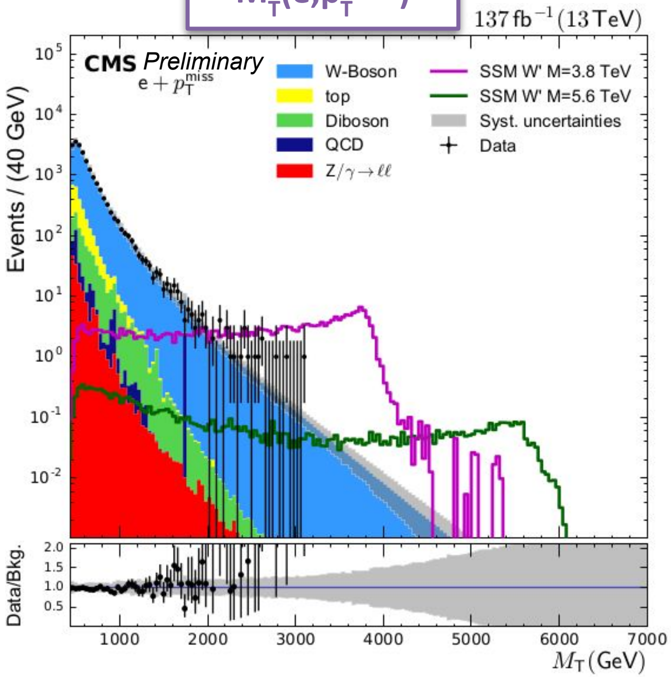
- W-Boson
- top
- Diboson
- QCD
- $Z/\gamma \rightarrow \ell\ell$
- Syst. uncertainties
- Data



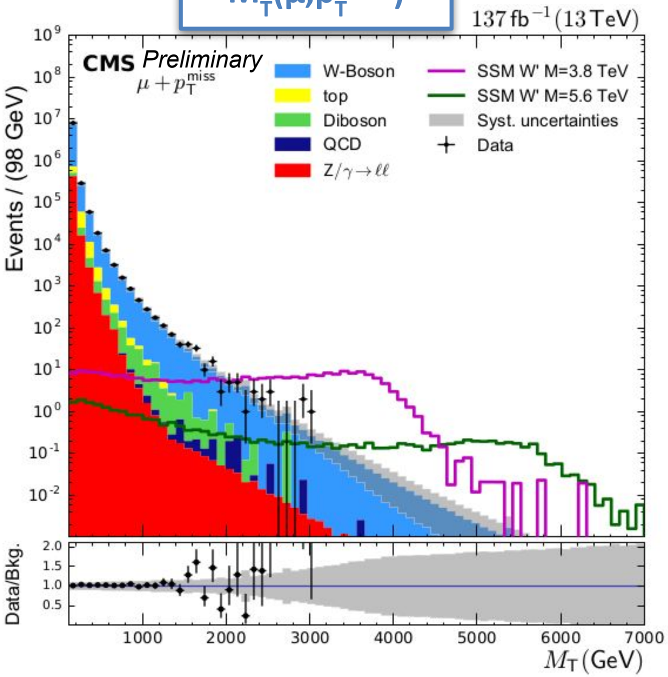
M_T distributions

- ➜ Transverse mass distributions after all selection for full Run 2 data. Discriminant variable.
- ➜ Good agreement between data and SM prediction. No significant deviation.
- ➜ Input for limit setting, statistical analysis with a binned likelihood fit.

$M_T(e,p_T^{miss})$



$M_T(\mu,p_T^{miss})$



Experimental systematic uncertainties - channel specific

Muon channel	
Source	**± Uncertainty value (%)**
Trigger SF	0.5(8) for B(E, p_T >1 TeV)
ID SF	0.4 (B) 2.1 (E)
Muon isolation SF	0.1
Muon p_T resolution	~0 (B) 1 (E)
Muon p_T scale	5-10 p_T shift (p_T > 2 TeV)(E)

Electron channel	
Source	**± Uncertainty value (%)**
Trigger SF	0.5(1.1) for EB (EE)
ID SF	1 - 5 function of el. E_T
Jet energy scale & resolution	2-5
El energy scale and resolution	0.05-0.1(0.1-0.3)EB(EE)
ECAL level-1 prefiring (2017)	20

Orientation: dominant sources

E = endcap
B = barrel

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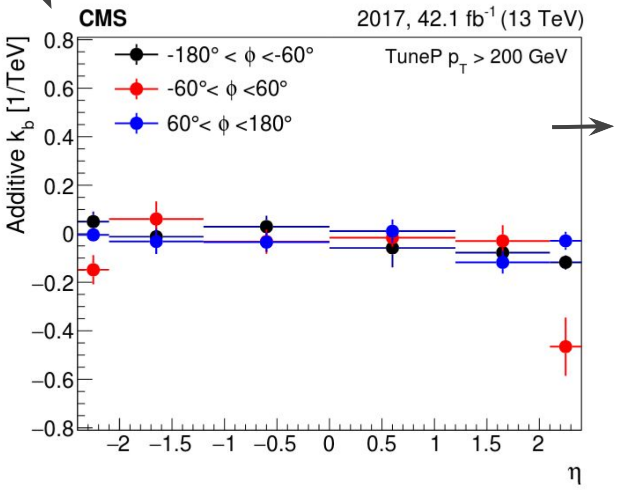
Orange: dominant sources

E = endcap
B = barrel



Muon p_T scale: Generalized Endpoint method calculates a bias due to misalignment as an additive constant $\kappa_b(\eta,\phi)$ to the curvature k = q/p_T, comparing data to MC.

$$1/p_T \leftarrow 1/p_T + \kappa_b(\eta,\phi)$$

Based on this study, statistical treatment is performed to obtain uncertaintainties.

Published in a dedicated paper to high p_T muons: doi:10.1088/1748-0221/15/02/P02027

Systematic uncertainties - global

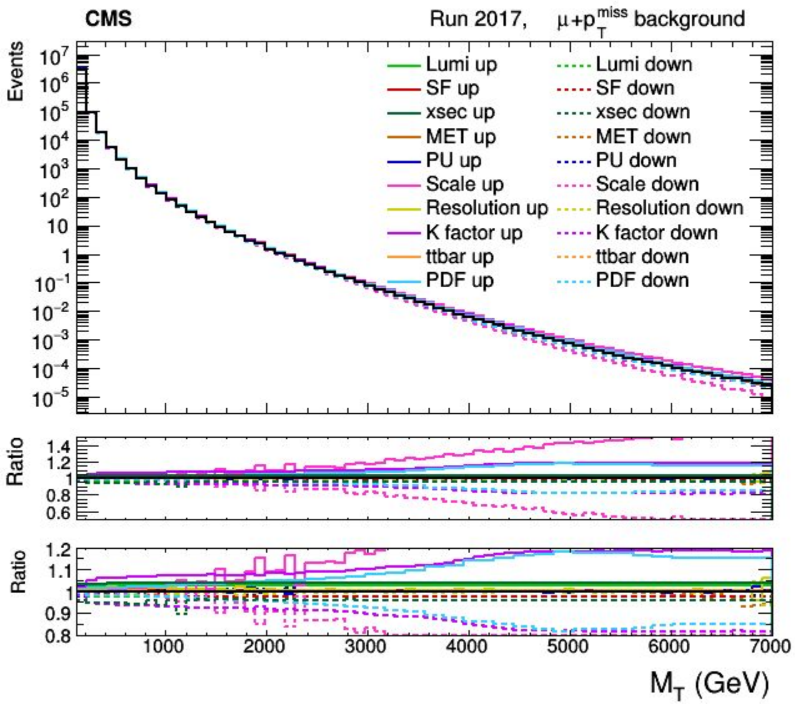
Common sources for both channels:

- ➜ Modelling of the background:
  - ➜ Cross-sections ~ 5 % typically
  - ➜ ttbar CR normalization ~ 5 %
  - ➜ **k-factor:** mass dependent ±(4 - 19)%
  - ➜ **PDFs**: function of M_T ±(3 - 20)%
- ➜ PU reweighting: ± 4.6 % on σ_{MB}
- ➜ Luminosity: ± 2.5%
- ➜ p_T^{miss}: Jet Energy Corrections, propagation lepton p_T uncertainty, jet energy scale and unclustered energy
  - ➘ dominant among the p_T^{miss} sources

Corresponding sources applied to signal samples.

Orange: dominant sources

M_T distribution with the effect of all systematic uncertainty sources being varied +1σ and -1σ.



Statistical Analysis - Limit Setting procedure

➜ Agreement between ATLAS and CMS W' groups, limits are calculated using a Bayesian method.

$$P(theory|data) \propto P(data|theory) \cdot P(theory)$$

➜ Study based on a binned likelihood fit where the observed events are described by a Poisson distribution.

➜ Uncertainties are modeled with log-normal prior distributions. Two approaches are used:

Multi-bin approach

➜ Use information on signal shape

➜ Used for limit on the **SSM** & **split-UED** models

Single-bin approach

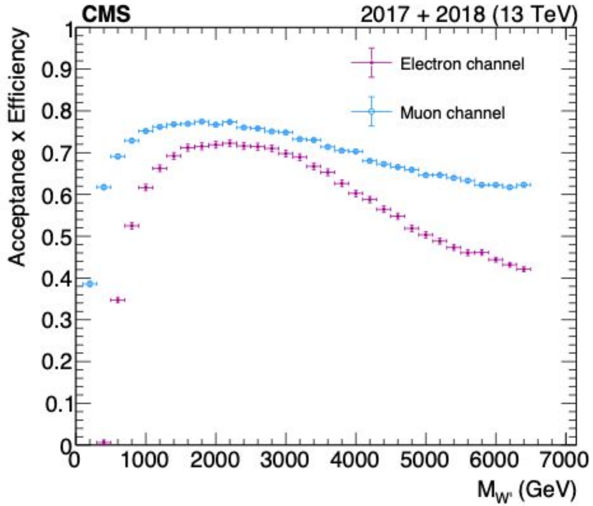
➜ Use information from one single bin

➜ Used to provide **Model-Independent limit**

$A \times \epsilon \times \mathcal{L}$: used to set limit

Signal efficiencies = $M_{W'}$(1.8 TeV) ~ 0.72(e), 0.78(μ)

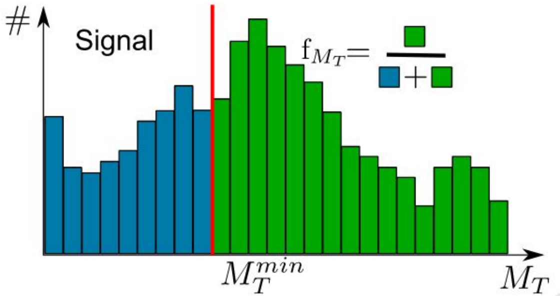
$M_{W'}$(3.8 TeV) ~ 0.63(e). 0.71(μ)



Model independent limit

- ➜ Using a single bin ranging from M_T^{min} to infinity.
- ➜ Limit set on the σ x B and experimental effects (acceptance A x efficiency ε)
- ➜ Can be used to test new physics models having $l+p_T^{miss}$ signature

$$(\sigma \times B \times A \times \epsilon)_{excl} = \frac{(\sigma \times B \times A \times \epsilon)_{MI}(M_T^{min})}{f_{M_T}(M_T^{min})}$$



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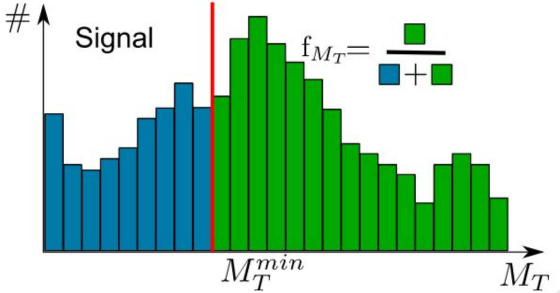

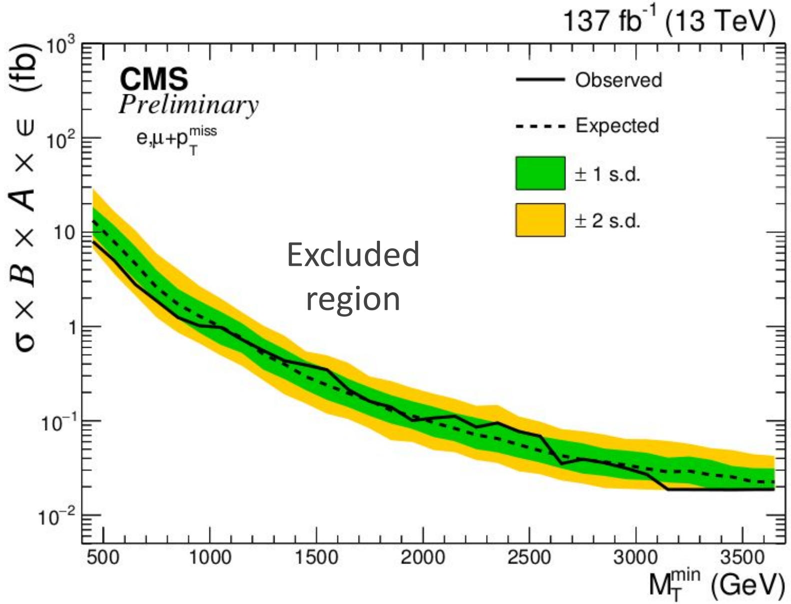

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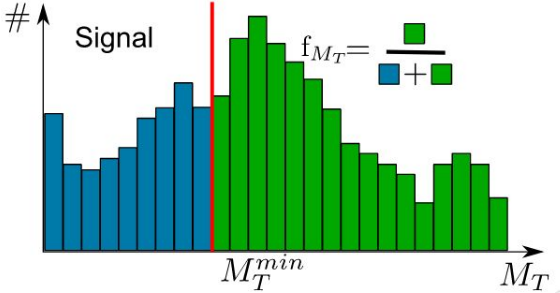
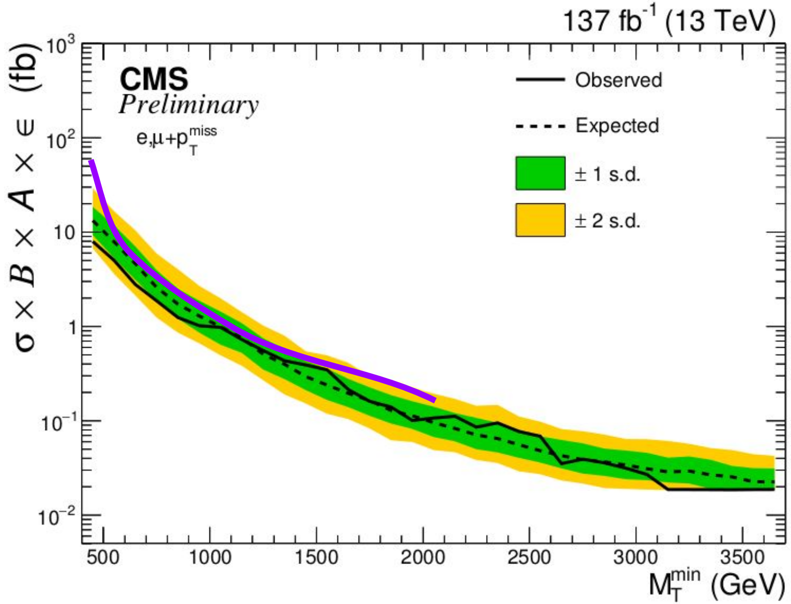


10.1103/PhysRevD.91.092005



Run 1

8 TeV 20 fb^{-1}

Model independent limit

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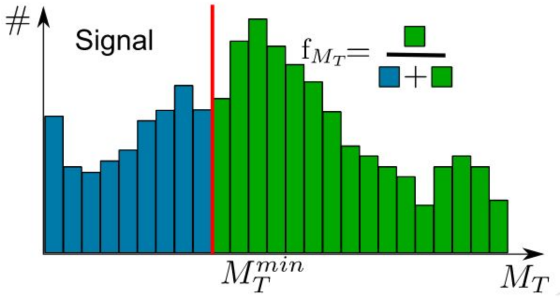
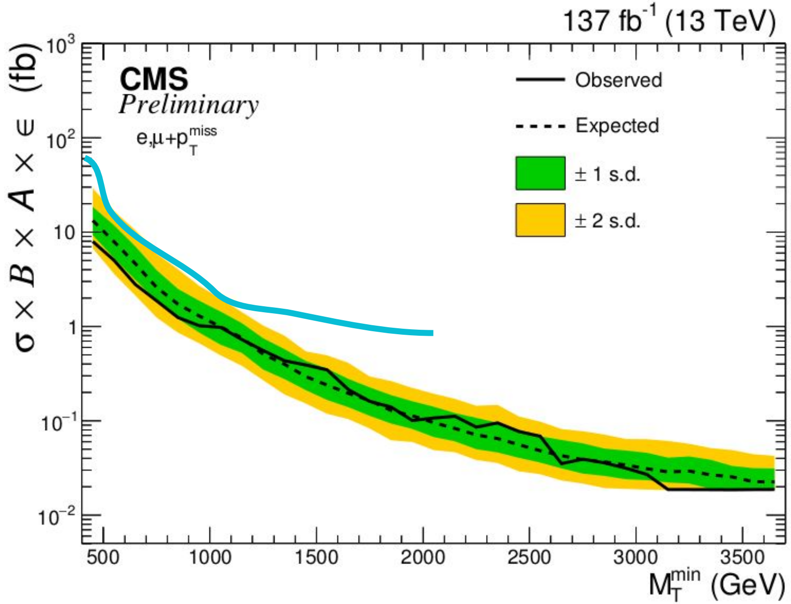


10.1016/j.physletb.2017.04.043



2015

13 TeV 2.3 fb^{-1}

Model independent limit

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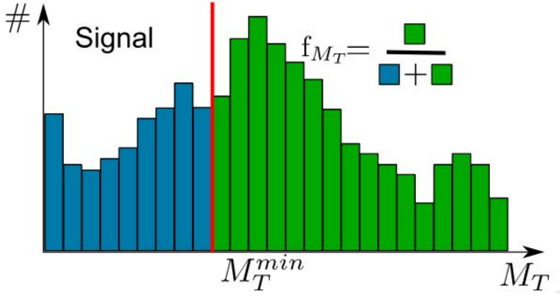
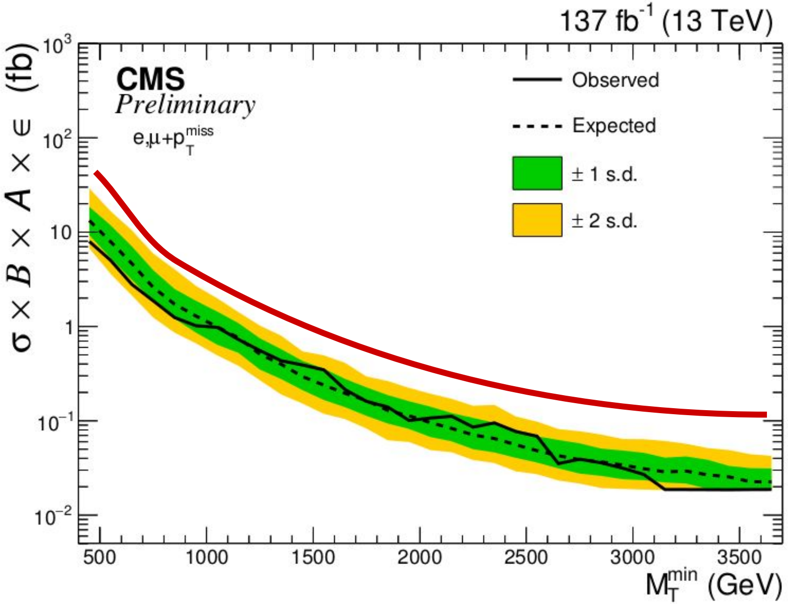


JHEP06(2018)128



2016

13 TeV 36 fb^{-1}

Model independent limit

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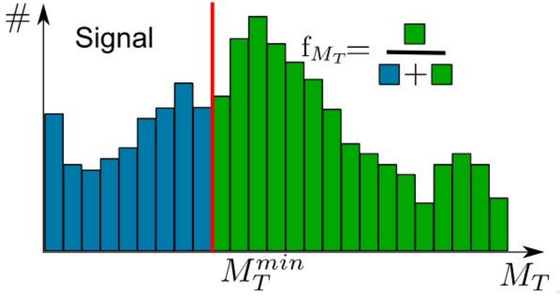

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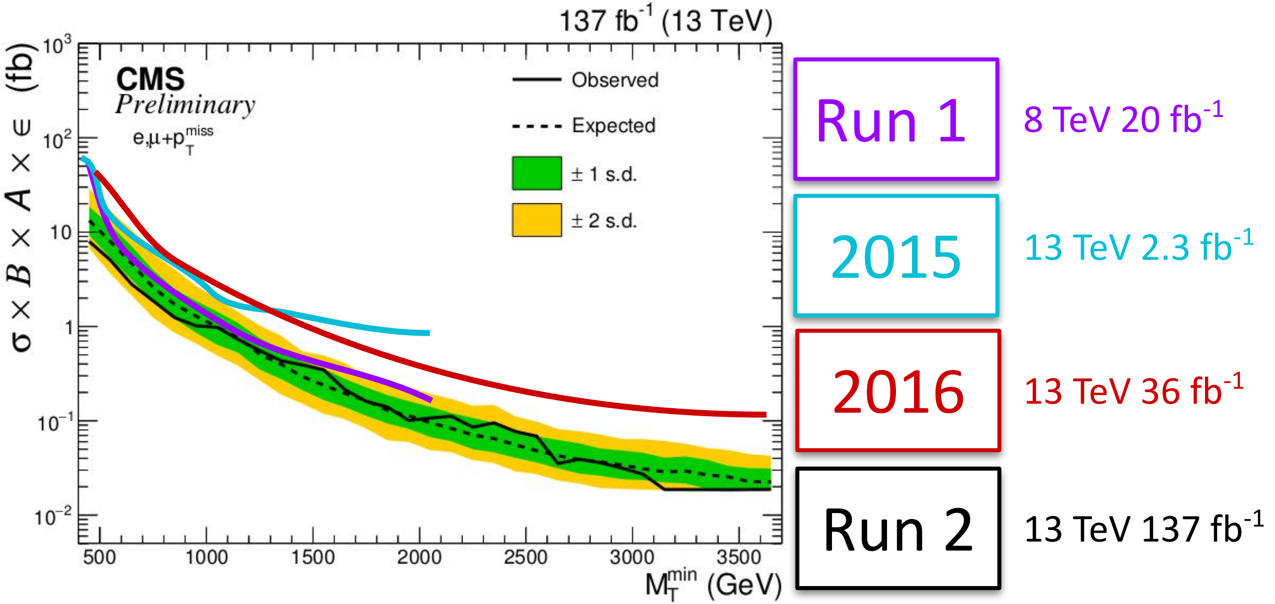
JHEP06(2018)128

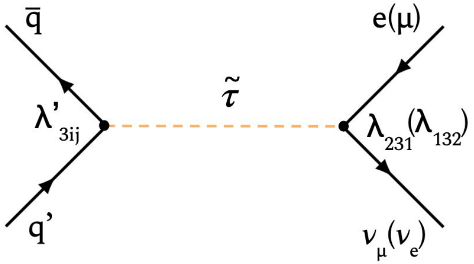


RPV SUSY model

R-parity Violating SuperSymmetry model doi:10.1103/PhysRevD.86.055010

- ➜ By using the model independent limits, bound on the RPV SUSY model can be derived at (λ-$M_{\tilde{\tau}}$) plane.
- ➜ Assuming a SUSY scalar lepton as a mediator with subsequent R-parity and lepton flavor violating decay to a charged lepton and a neutrino. The analysis studies a tau slepton ($\tilde{\tau}$) decays to $e + \nu_\mu$ and to $\mu + \nu_e$.

Decay to $e + \nu_\mu$ given by λ_{231}
Decay to $\mu + \nu_e$ given by λ_{132}



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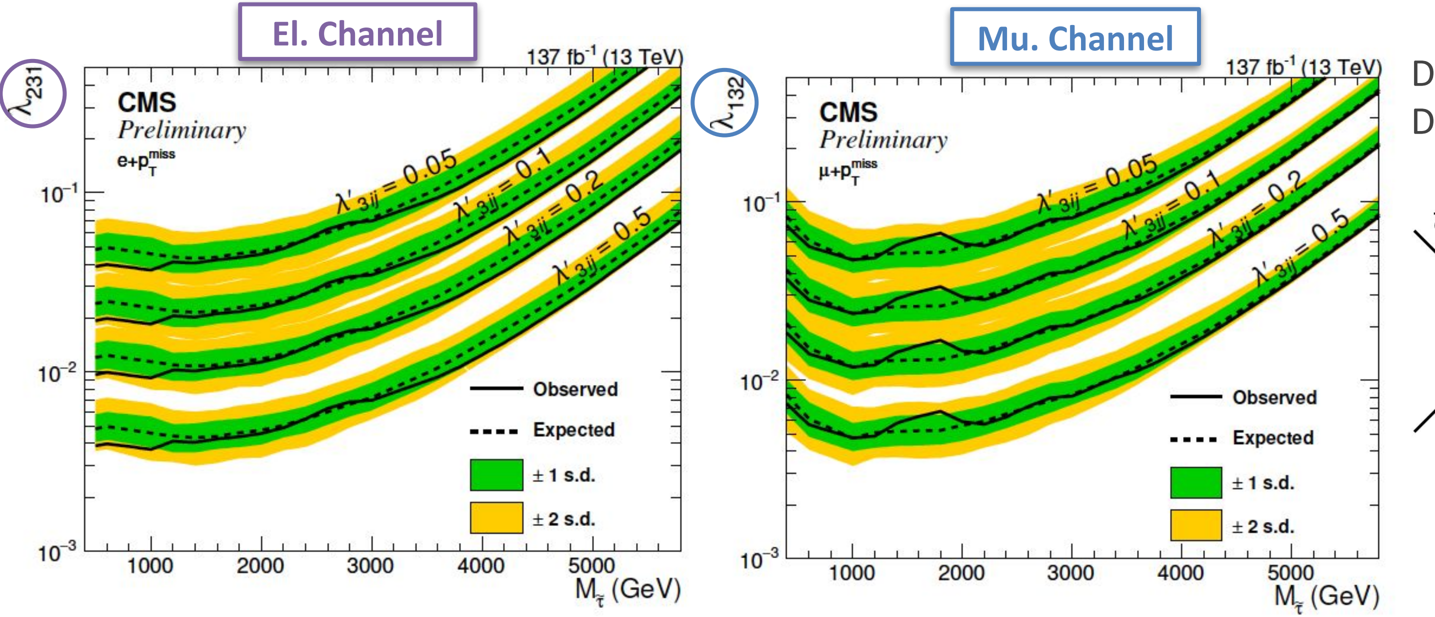
- ➜ If $M_{\tilde{\tau}}$ ~ 1 TeV , λ'_{3ij} = 0.5 : **λ_{231} (λ_{132}) > 3.7 (4.7) x 10^{-3} excluded.**



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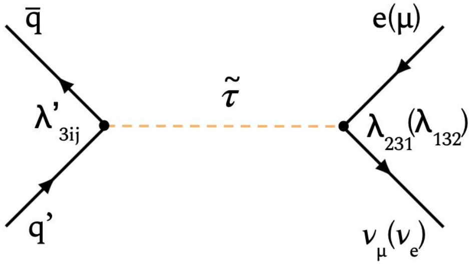
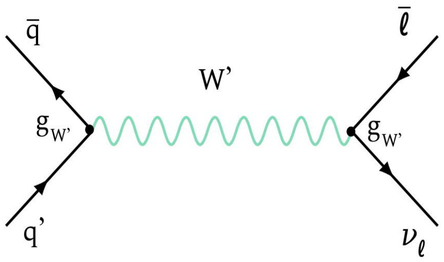


 doi:10.1007/BF01556677

- Statistical analysis with a binned likelihood fit.
- Uncertainties are modeled with log-normal prior distributions.
- SSM W’: heavy analogue of the SM W boson with the equal coupling strength $g_{W'}=g_W$.

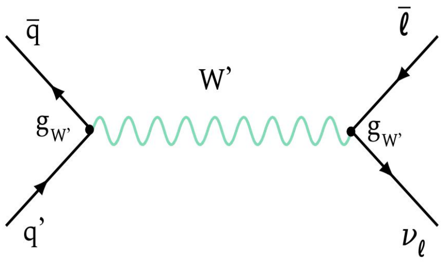


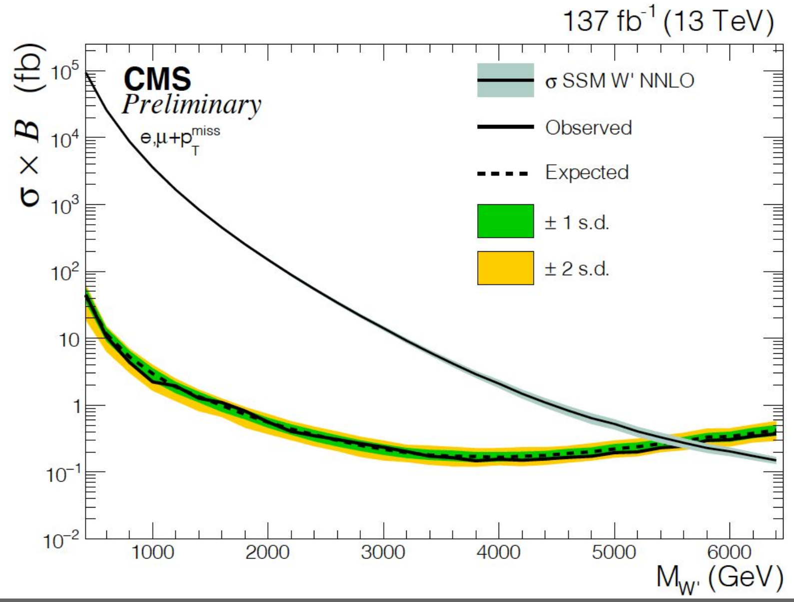
Sequential Standard Model (SSM) W’

doi:10.1007/BF01556677

- ➜ Statistical analysis with a binned likelihood fit.
- ➜ Uncertainties are modeled with log-normal prior distributions.
- ➜ SSM W’: heavy analogue of the SM W boson with the equal coupling strength $g_{W'}=g_W$.
- ➜ Full Run 2 limits on SSM W’ for e+μ combined channel:

$M_{W'}$ > 5.7 (5.6) TeV Obs. (Exp.)





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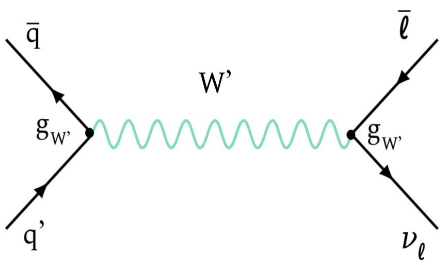
- ➜ Statistical analysis with a binned likelihood fit.
- ➜ Uncertainties are modeled with log-normal prior distributions.
- ➜ SSM W': heavy analogue of the SM W boson with the equal coupling strength $g_{W'}=g_W$.
- ➜ Full Run 2 limits on SSM W' for e+μ combined channel:

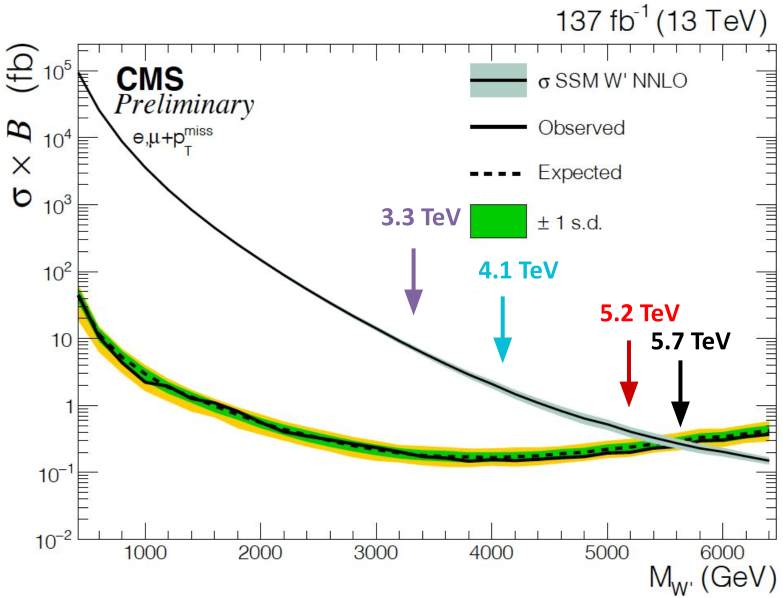


$M_{W'}$ > 5.7 (5.6) TeV Obs. (Exp.)

Previous SSM limits:

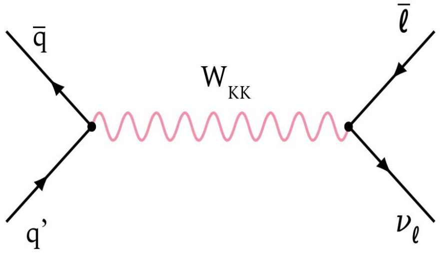
CMS Run 1: $M_{W'}$> 3.3 (3.3) TeV Obs. (Exp.) 10.1103/PhysRevD.91.092005
CMS 2015: $M_{W'}$> 4.1 (4.0) TeV Obs. (Exp.) 10.1016/j.physletb.2017.04.043
CMS 2016: $M_{W'}$> 5.2 (5.2) TeV Obs. (Exp.) JHEP06(2018)128

ATLAS Run 2: $M_{W'}$> 6.0 (5.8) TeV Obs. (Exp.) PhysRevD.100.052013



Split-UED $W_{KK}^{(2)}$

Split-Universal Extra Dimension model doi:10.1007/JHEP04(2010)081



- ➜ Extended space-time with an additional compact 5^{th} dimension of radius R, and a bulk mass parameter of the fermion field, μ.
- ➜ SM particles have a corresponding Kaluza-Klein (KK) partner, $W_{KK}^{(n)}$.
- ➜ Only KK-even modes couple to SM partners.
- ➜ From the SSM W′ limit, bounds for the case n = 2 are set on the split-UED parameter space (1/R, μ).

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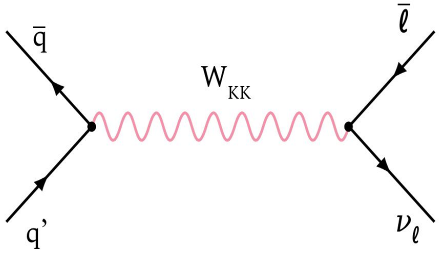

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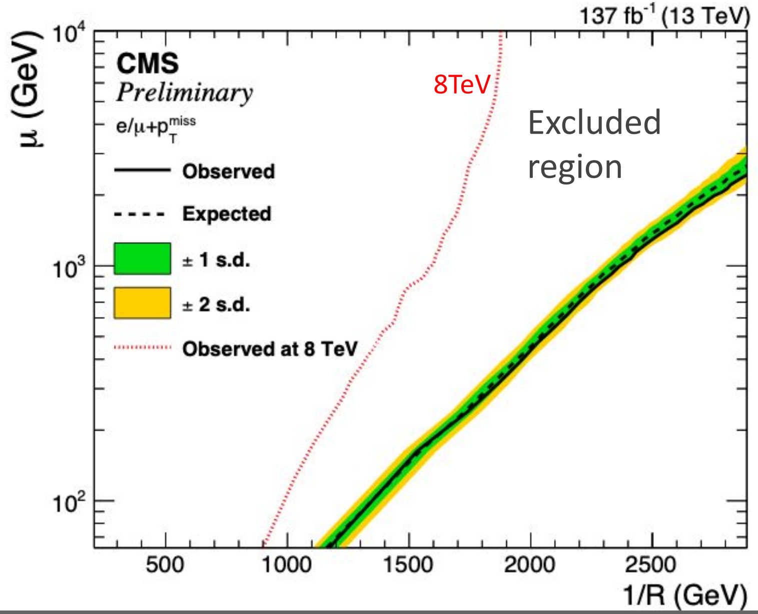
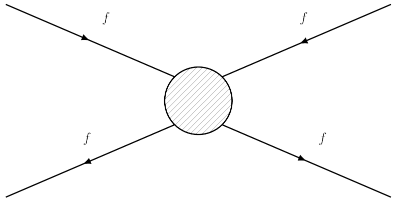


- ➜ Full Run 2 Limits on 1/R for e+μ combined channel : **1/R < 2.8 (2.7) TeV Obs. (Exp.) excluded at μ > 2 TeV.**

W oblique electroweak parameter

doi:10.1016/jphysletb.2017.06.04
10.1016/j.nuclphysb.2004.10.014
arxiv.org/abs/2103.10532

- Universal new physics effects in **4 fermion contact interactions** can be described by the oblique electroweak parameters S, T, W and Y. **W and Y parameters** induce effects that grow with √s.



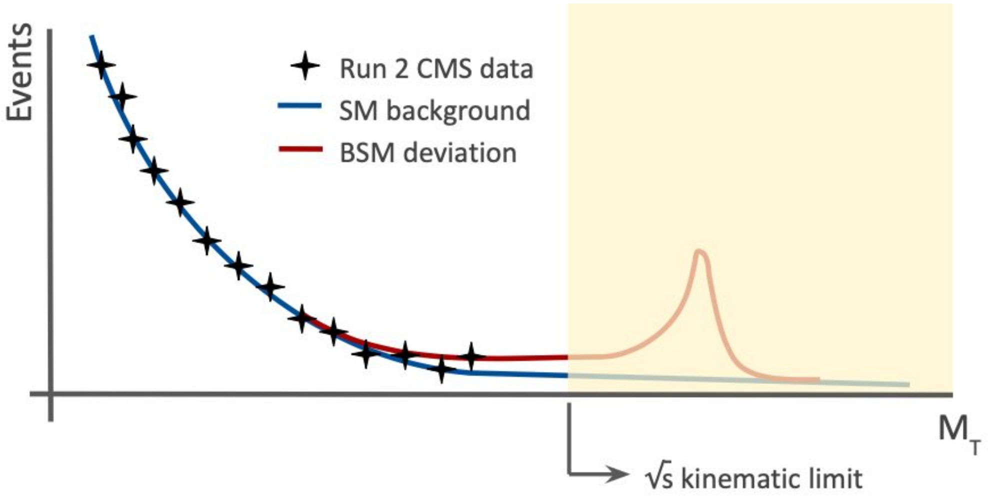
- The effect is that the propagators of the SM electroweak gauge bosons will be modified, and the relative deviations with respect to the SM will be given by the weight :

$$\left|\frac{P_W}{P_W^{(0)}}\right|^2 = \left(1 + \frac{(2t^2-1)W}{1-t^2} + \frac{t^2 Y}{1-t^2} - \frac{W\,(q^2 - m_W^2)}{m_W^2}\right)^2$$

t^2 = tangent squared of SM weak mixing angle ~ 0.3

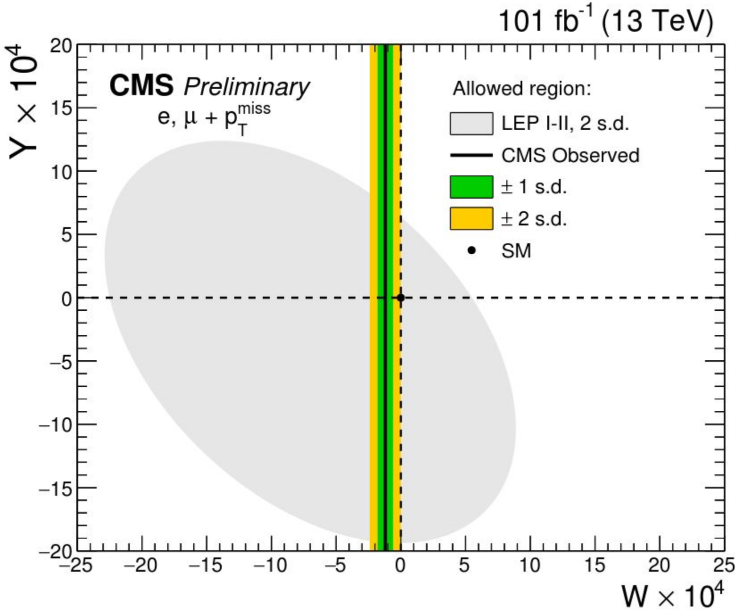
- This weight is applied to the SM background prediction as a function of the W-parameter.

- Fit the W-parameter value to find the one that makes the background best reproduce data by using a binned negative log-likelihood fit.



W oblique electroweak parameter

- ➜ Result of combining 2017 + 2018 data (101 fb^{-1}) for both e and μ channels: **W = $[-12^{+5}_{-6}] \times 10^{-5}$** (± 1 s.d.)
- ➜ Result consistent with SM within 2σ, it reduces a factor ~10 previous bounds from LEP experiments. JHEP02(2016)086
- ➜ First experimental measurement of W oblique electroweak parameter with LHC Run 2 data.



Conclusions

Search for **new physics in lepton(e/μ) + p_T^{miss} final state** by CMS with Run 2 dataset (137.1 fb^{-1}).

No significant deviation from SM expectation is found. We set limits in different ways:

- ➜ Model Independent
  - ➜ R-parity Violating SuperSymmetry model (RPV SUSY), limit on λ-$M_{\tilde{\tau}}$ plane.
- ➜ Direct resonance search:
  - ➜ Sequential Standard Model (SSM), limit on W' mass.
  - ➜ Extra dimensions (split-UED), limit on μ -1/R plane.
- ➜ Indirect resonance search:
  - ➜ Constrain in the electroweak oblique parameter W, first time using LHC data.

These results are published in PAS-EXO-19-17. Coming publication in the last steps of internal review.